Hutchinson

Environmental Sciences Ltd.

Natural Shorelines and their Role in the Protection of Water Quality and Aquatic Habitat

State of the Science Report

Prepared for: County of Haliburton
Job #: J210039

August 18, 2021

1-5 Chancery Lane, Bracebridge ON P1L 2E3 | 705-645-0021
202-501 Krug Street, Kitchener ON N2B 1L3 | 519-576-1711

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www.environmentalsciences.ca

August 18, 2021 HESL Job #: J210039

Mike Rutter
Chief Administrative Officer
County of Haliburton
Box 399 Minden, Ontario
K0M 2K0

Dear Mr. Rutter:

Re: Natural Shorelines and their Role in the Protection of Water Quality and Aquatic Habitat – State of the Science Report

We are pleased to submit the *State of the Science Report* for the *Natural Shorelines and their Role in the Protection of Water Quality and Aquatic Habitat* project. The State of the Science Report addresses the first component of our Shoreline Preservation Review and Consultation. This report summarizes a literature review of current science and Best Management Practices related to shoreline protection. The information contained herein will be used in combination with the jurisdictional review and stakeholder consultation to develop a Shoreline Preservation By-law that balances environmental stewardship and public best interests.

Sincerely,
Per. Hutchinson Environmental Sciences Ltd.

Andrea Smith, Ph.D.
Senior Scientist

Signatures

Report Prepared by:

Brent Parsons, M.Sc.
Senior Aquatic Scientist

Andrea Smith, Ph.D.
Senior Scientist

Neil Hutchinson, Ph.D.
Founder and Senior Scientist

Executive Summary

The County of Haliburton has identified shoreline protection as a key policy area and aims to develop a county-wide Shoreline Preservation By-law. The County hired Hutchinson Environmental Sciences Ltd. (HESL) and J. L. Richards & Associates Ltd. (JLR) to guide the development of the Shoreline Preservation By-law. The State of the Science Report addresses the first component of our Shoreline Preservation Review and Consultation. The information contained herein will be used in combination with the jurisdictional review and stakeholder consultation to develop a Shoreline Preservation By-law that balances environmental stewardship and public best interests.

Shorelines link terrestrial and aquatic ecosystems, acting as a transition zone between land and water. They are biological hotspots and highly productive habitats that provide a myriad of ecological services, including maintenance of water quality, flood protection, and wildlife habitat Shorelines are also attractive locations for human settlement, offering access to lakes and rivers for recreation, nature appreciation, sustenance, cultural traditions, and spirituality. Residential development is often concentrated around shorelines, and most development-related impacts to freshwater habitats occur at the shoreline interface. Natural shoreline vegetation is commonly cleared during development and replaced partially or completely by manicured lawn. Shorelines may also be altered by the addition of docks, boathouses, paths, and seawalls. Shoreline development is increasing in many jurisdictions and has been identified as the main threat to lake health in the United States. If not properly managed, waterfront development can degrade sensitive shoreline habitats, and alter the ecological integrity of adjacent lakes and rivers.

Shoreline buffers can play an important role in protecting lake health. The physical separation they provide between upland human activity and the aquatic environment can aid in mitigating the effects of development and site alteration on water quality, erosion and flood control, and wildlife habitat. However, no single type or size of buffer will perform optimally in all conditions, and determination of buffer characteristics should consider a variety of factors, including the desired function of the buffer, the sensitivity of the adjacent aquatic environment, the intensity of the land use, and site-specific physical features, such as slope, hydrology, and soil type. Characterizing these factors and developing static buffer requirements informed by scientific research over a large landscape, however, is extremely challenging.

The scientific literature on shoreline buffers over the past 30 years has largely focused on watercourses and wetlands, and the impacts of agriculture and forestry. Relatively little research has examined buffer performance in protecting lakes from shoreline development. While this gap in knowledge should be addressed, the existing literature on buffers can still provide useful information that can be applied to the lake context.

Shorelines provide numerous benefits and in general, larger buffers are better at consistently providing a range of protective functions. A 15 m buffer has been found to be the minimum size necessary to maintain physical and chemical functions while 30 m is the minimum necessary to maintain biological functions. Efficient removal of some pollutants (notably sediment) can occur in buffers of 10-20 m width, but other pollutants (such as nutrients) may require buffer widths of 30 m or more for effective attenuation. Water quality improvements generally increase with buffer size (e.g., 10 m removes 65% of sediment from overland runoff while 30 m removes 85% of sediment from overland runoff). Larger buffers are also better at protecting the diversity of aquatic and terrestrial species that rely on shorelines. Semi-aquatic species, such as amphibians and reptiles, can use terrestrial habitat up to 300 m inland from the water's edge. Some

turtle species nest up to 80 m inland. Waterbirds may react to human activity close to their nests, and loons may require several hundred metres between their nests and development.

Site-specific factors and the characteristics of the buffers are important. Low to moderate slopes (<10%) appear to positively influence sediment removal, while steeper slopes have a negative effective on performance. It is challenging determining how site-specific factors should influence buffer size over a large geographic range, but lake classification and lake specific management plans are two potential tools that could be utilized to generalize characteristics of the shoreline and sensitivities of the adjacent waterbody.

Natural vegetation is better able to trap pollutants and stabilize shorelines than manicured lawn due to deeper roots. Furthermore, native vegetation does not require the use of fertilizers, herbicides and pesticides, provides improved habitat for terrestrial and aquatic species, and does not tend to attract nuisance species such as Canada Geese. Maintaining natural shorelines also provides privacy, increases property value, and contributes to the aesthetic quality of the lake environment.

The scientific literature demonstrates that a 30 m buffer generally provides a range of ecological services, and this buffer size is commonly recommended in the peer-reviewed literature focused on shoreline development, aligning with Provincial guidance. While smaller buffers provide some benefits for water quality and aquatic habitat protection, larger buffers provide more ecological services, more completely. Buffers will likely become more important in protecting lake health as climate change effects on freshwater systems continue to intensify. Buffer recommendations are often included in municipal and provincial policies but are seldom enforced, so the theoretical debate of buffer size is outweighed by the reality on the land. To be truly effective, buffer recommendations based on the best available science, and informed by the jurisdictional review and public consultation, will need to be implemented and enforced consistently across the County.

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1. Introduction

Shorelines link terrestrial and aquatic ecosystems, acting as a transition zone between land and water. They are biological hotspots and highly productive habitats that provide a myriad of ecological services, including maintenance of water quality, flood protection, and wildlife habitat (Strayer and Findlay 2010; Kardynal et al. 2011). Shorelines are also attractive locations for human settlement, offering access to lakes and rivers for recreation, nature appreciation, sustenance, cultural traditions, and spirituality. Residential development is often concentrated around shorelines, and most development-related impacts to freshwater habitats (such as alteration of sediment and nutrient inputs, light pollution, and disturbance from boat wakes) occur at the shoreline interface (Hampton et al. 2011). A common development practice in the shoreline environment is the establishment and maintenance of manicured lawn. Manicured, carpet-like green grass lawns are a relatively recent phenomenon that became established during suburbanization after World War II (Steinberg 2007). Shorelines may also be altered by the addition of various structures, such as docks, boathouses, and seawalls, as well as pathways (Taillon and Fox 2004). Shoreline development is increasing in many jurisdictions and has been identified as the main threat to lake health in the United States (Amato et al. 2016). If not properly managed, waterfront development can degrade sensitive shoreline habitats, and alter the ecological integrity of adjacent lakes and rivers (Francis and Schindler 2009; Cole et al. 2018).

Shoreline management should be informed by the best available science to ensure this important habitat is protected. Policies grounded in sound science will ultimately be more defensible, and better able to address environmental challenges effectively and realistically. Scientific knowledge of environmental issues is constantly evolving, and policies should reflect the most up-to-date scientific information and best management practices (BMPs) for successful environmental management.

The County of Haliburton has identified shoreline protection as a key policy area and aims to develop a county-wide Shoreline Preservation By-law. The County hired Hutchinson Environmental Sciences Ltd. (HESL) and J. L. Richards & Associates Ltd. (JLR) to guide the development of the Shoreline Preservation By-law. As part of this process, HESL and JLR are

- conducting an independent State of the Science Report of current science and BMPs related to shoreline protection,
- conducting a jurisdictional review of the approach of other Ontario municipalities to shoreline protection, and
- consulting with stakeholders in the County to gauge public opinion on how shorelines should be protected.

The following State of the Science Report addresses the first component of our Shoreline Preservation Review and Consultation. The literature review summarizes current science on the relationship between shoreline preservation and the protection of water quality, erosion and flood control, and wildlife habitat, and identifies and evaluates BMPs to promote shoreline protection. The focus of the Report is on lake shorelines and the effects of residential development, although some of the science reviewed addresses river, stream and wetland shorelines, and other human land uses, such as agriculture and forestry, where the principles and methods can be applied to the lake environment.

The information contained in the State of the Science Report will be used in combination with the jurisdictional review and stakeholder consultation to develop a Shoreline Preservation By-law that balances environmental stewardship and public best interests. It is anticipated that the By-law will include a variety of recommendations regarding shoreline use, such as buffer sizes, shoreline setbacks, and maximum access path widths. It should be noted that, while the scientific peer-reviewed literature provides the scientific rationale for approaches to shoreline protection, it cannot explicitly address all By-law components because a) the research may either be limited in certain areas or b) the research is not designed to address specific questions related to shoreline management empirically (e.g., how wide of a path can someone have to the shoreline?). Furthermore, while the science can evaluate the role of natural shorelines in protecting water quality and aquatic habitat, it cannot determine what level of protection people desire, or how best to implement and enforce resulting policy. Information gleaned from the jurisdictional review and stakeholder consultation will be used to help inform the development of specific recommendations that cannot be directly addressed by the State of the Science Report.

2. Information Sources

Resource materials and information for the literature review were compiled from a variety of sources. We began our search for relevant scientific information by consulting with experts on shoreline protection. We focussed on experts who were experienced lake managers that a) had a wide exposure to shoreline management from working as consultants for a large range of clients (vs. only government expertise that may be more limited) and which b) had no vested or otherwise interest in Ontario and who could therefore provide truly independent expertise. Six individuals were identified from the North American Lake Management Society[1]'s (NALMS) subject matter expert database:

- Amy Gianotti, Certified Lake Manager and founder of AquaSTEM Consulting,
- Sandy Kubillus, Certified Lake Manager and geologist at Integrated Lakes Management
- Moriya Rufer, Scientist and watershed planner at Houston Engineering Inc.,
- Dr. Ann St. Amand, President and aquatic scientist at Phycotech Inc.,
- Levi Sparks, Certified Lake Manager, aquatic ecologist and water quality scientist at Bandera County River Authority and Groundwater District, and
- Eli Kersh, Certified Lake Manager and aquatic resource consultant at elimnology.

We supplemented resources recommended by these experts with information collected through a desktop search of the peer-reviewed scientific literature. Two online research search engines, Google Scholar and Web of Science™, were used to identify and assemble an initial list of current scientific literature related to shorelines. Search terms included 'shoreline management', 'shoreline naturalization', 'shoreline preservation', 'shoreline protection', 'nearshore', 'riparian', 'aquatic health', 'lake ecology', 'lake health', 'lake management', 'water quality', 'buffer', 'erosion', 'flooding', 'wildlife habitat', and 'best management practices'. The literature review focused on studies published in the last 10 years but did not exclude older studies (1994-2010) generated in our search, since these might still contain relevant information.

[1] https://www.nalms.org/subject-matter-experts/ NALMS is an international society that brings diverse stakeholders together in the interest of lake management: *"Our mission is a simple, but powerful one: to forge partnerships among citizens, scientists and professionals to foster the management and protection of lakes and reservoirs…for today and tomorrow".*

A total of 60 papers were identified through our expert consultation and online search. These publications were then screened by scanning abstracts and narrowed down to studies focused on freshwater temperate systems (46 papers). All relevant literature was then read in full and key information was documented in a spreadsheet (Appendix A). The following sections of the report provide a synthesis and our interpretation of this literature review.

3. Ecological Functions of Shorelines

Shorelines are where land and water meet. The shoreline area can be divided into three distinct zones, which overlap to some degree:

- Upland Zone: the land farthest away from the lake or river, located on higher and drier ground, typically comprised of trees and shrubby vegetation, and often where human dwellings are located;
- Riparian Zone: the land closest to the water, representing a transition from terrestrial to aquatic habitat, which may contain trees, shrubs, grasses, or a mix of vegetation types; and
- Littoral Zone: the aquatic portion, extending from the water's edge to the maximum depth at which sunlight penetrates to the bottom of the water. Vegetation in the littoral zone can include submerged and emergent plants.

Although the upland zone does not directly interact with the lake, its characteristics and activities carried out there influence the waterbody as the gradient of drainage moves downhill, transporting water and any associated pollutants or sediments into the lake. Naturally vegetated shorelines play an important role in protecting water quality, preventing soil erosion, reducing flooding, and providing wildlife habitat for aquatic and terrestrial organisms (Strayer and Findlay 2010, Wehrly et al. 2012). Vegetation in the shore zone traps and filters sediment, nutrients, and other pollutants from surface and subsurface flow, preventing these contaminants from entering waterways where they can cause algal blooms, reduce water clarity and hypolimnetic oxygen, lead to the loss of aquatic habitat, and promote the establishment of invasive species, among other problems (Strayer and Findlay 2010). Plant roots hold soil in place, keeping topsoil from being washed away by rain, currents, and waves. Vegetation litter also shields the ground from the direct impact of rainfall, reducing erosion (France et al. 1998). Vegetation in the littoral zone provides structure, dissipating wave energy which might damage natural shorelines (Borre et al. 2016). Vegetation acts as a barrier to flooding, slowing the movement of water downstream, spreading it over the floodplain, and reducing the magnitude and force of floodwaters (Castelle et al. 1994). Intact upland and riparian vegetation shade the shoreline, reducing overall heating of the lake and providing thermal refuge for aquatic life (Steedman et al. 2001).

Natural shorelines are often referred to as the "Ribbon of Life" because of their disproportionate contribution to supporting biodiversity (OMNR 2000). The exchange of nutrients and organic materials between land and water provides abundant resources for a wide variety of species. For example, inputs of coarse woody debris (including logs, large branches, snags, bark and coarse roots) from riparian trees increases the complexity of littoral zones, providing food and shelter in the nearshore (Czarnecka 2016). Fine particulate organic matter is generated as coarse woody debris breaks down and is a major food source for many aquatic organisms, such as invertebrates, which provide food for fish and birds (Beacon 2012). Vegetation also provides shading to shallow water, moderating water temperatures and making the littoral zone suitable wildlife habitat (Sweeney and Newbold 2014). Aquatic plants (macrophytes) in the littoral zone stabilize sediments, and provide habitat and nutrients for fish, zooplankton, and macroinvertebrates (Hicks and Frost 2011). Ninety percent of all life in lakes, including many fish species, depends on shorelines for breeding, shelter, and foraging (OMNR 2000). Shorelines also provide key habitat for wildlife that rely on both aquatic and terrestrial environments for parts of their life cycle, such as dragonflies, salamanders, frogs, turtles, snakes, mammals, and birds (Semlitsch 1998, Whitaker and Montevecchi 1999, Roth 2005). In addition, shorelines serve as dispersal corridors for many plants and animals, protecting biodiversity by connecting suitable habitat that might otherwise be isolated due to human activity and development (Strayer and Findlay 2010).

4. Threats to Shorelines

Human activity in or near shoreline zones can cause many changes to the ecological structure and function of these areas. Strayer and Finlay (2010) identify the following human impacts to the shoreline:

- Compression and stabilization of soils (e.g., through dredging, filling, and repeated activities),
- Changes to the hydrological regime (e.g., through vegetation removal and hardening of surfaces or drainage management),
- Shortening and simplification (e.g., by straightening natural drainage channels or culverting drainage),
- Hardening the shoreline to protect against erosion (e.g., via seawalls, wooden bulkheads, armouring with riprap),
- Tidying the shore (e.g., removal of woody debris, terrestrial or aquatic vegetation),
- Nearshore dredging, which removes shallow water sediments and vegetation that dissipate wave energy,
- Pollution (e.g., from runoff of sediment, nutrients, and chemical contaminants),
- Disturbance (e.g., trampling of vegetation, boat wakes, artificial lighting),
- Resource extraction (e.g., sand, gravel, plants, fish, and waterfowl),
- Introduction of non-native plant and animal species,
- Increased impervious surfaces (e.g., paved roads, driveways, paths, and buildings).

Climate change is amplifying many of these impacts on shorelines, especially where natural systems have been altered and hardened (Borre et al. 2016). Climate change is expected to have profound effects on freshwater systems, through increased water temperature, and the effects of increased frequency and intensity of both floods and droughts (Abrahams 2008).

Residential or cottage development can result in significant alteration to shorelines through construction (of dwellings, boathouses, docks, boat lifts, and seawalls), installation of septic systems, and landscaping. A study on 12 Kawartha lakes found that cottage development was strongly related to the composition of aquatic plants in the littoral zone (Hicks and Frost 2011). Macrophyte biomass declined with increasing cottage density, and more developed lakes had less diverse aquatic plant assemblages, with a switch from floating leaf and emergent plants on undeveloped lakes to submerged plants on developed lakes (Hicks and Frost 2011). In contrast, a study on the effects of shoreline development to fish in the littoral zone in Pigeon Lake (also in the Kawarthas) found that development had no effect on fish species richness, and that all life stages were most abundant at moderately developed sites (compared with undeveloped and highly developed sites; Taillon and Fox 2004). The authors suggested that the absence of development effects may have been partly related to the abundance of aquatic plant cover at all sites, providing enriched habitat for littoral fish. Furthermore, they suggested that the long history of development on Pigeon Lake, and previous modifications to the shoreline during the Trent-Severn Waterway construction (i.e., flooding, raising of shoreline) may have already eliminated more sensitive fish species (Taillon and Fox 2004).

While poorly managed shoreline development may produce localized impacts, the effects can also be manifested on a larger lake-wide scale, given the strong link between shoreline dynamics and overall lake productivity (Hampton et al. 2011). The cumulative effects of shoreline development, however, have not been well studied (Wehrly et al. 2012). Residential development along lakeshores can cause changes to lake habitat structure and ecosystem function through changes in sediment distribution and stability, nutrient levels, and habitat, which in turn can lead to eutrophication, decreased water quality, and impacts on fish and other organisms (Goforth and Carman 2005, Francis and Schindler 2009).

Shoreline development has been linked to the potential for elevated nutrient inputs (Dillon et al. 1994; Paterson et al. 2006) which, in turn, can cause a host of problems including reduced water clarity, reduced hypolimnetic oxygen and the proliferation of algal blooms. Algal blooms are a common concern because of aesthetic and health concerns associated with algae, namely blue-green algae (or cyanobacteria). The public reporting of algal blooms in Ontario increased significantly from 1994 to 2009 (Winter et al. 2011) which is consistent with worldwide trends. Climate change is a potent catalyst for further expansion of algal blooms (Paerl and Huisman 2008) and therefore the importance of shoreline management and the establishment of best management practices to limit nutrient loading to lakes is more important than ever before.

Goforth and Carman (2005) studied the impact of shoreline development and substrate stability on nearshore ecology in Lake Erie and Lake Michigan. They found that developed sites (modified by erosion control structures and human land use, and mainly comprised of unstable substrate) had lower densities of zooplankton and small shallow water prey fish (based on catch per unit effort – CPUE) compared with natural sites (comprised entirely of highly stable substrate). Densities of benthic macroinvertebrates did not differ by shoreline type but were lower at sites with less substrate stability (i.e., development was not a factor unless it resulted in reduced substate stability). The CPUE of larger nearshore fish, however, showed no difference between shoreline types and substrate stability regimes. The results suggest that physical habitat changes in the littoral zone due to shoreline hardening directly influence invertebrate and prey fish communities. Larger fish species may not have been affected because they are more mobile than their prey. Nonetheless, the long-term cumulative effect of reduced prey availability due to shoreline hardening could be a problem for overall fish productivity in the Great Lakes (Goforth and Carman 2005).

Shoreline hardening was found to affect both macrophyte and fish communities along shorelines in Wisconsin lakes. Shorelines reinforced with riprap had coarser substrates, lower organic content, and cooler water temperatures than natural shorelines. Natural sites had more floating-leaved plants, and larger and more abundant fish populations than the armoured shorelines (Gabriel and Bodensteiner 2011).

The loss or reduction in riparian forest due to shoreline development has been linked to marked declines in habitat and food subsidies (such as coarse woody debris and terrestrial insect prey) to littoral zones, which can have varied effects on lake ecology (Frances and Schindler 2006, 2009, Helmus and Sass 2008). In an experiment on an undeveloped and unfished lake in Wisconsin, Helmus and Sass (2008) removed

70% of coarse woody debris from the littoral zone in one basin physically separated from another reference basin which was left undisturbed. Yellow Perch (*Perca flavescens*), which was the most abundant fish in both basins before the experiment, showed drastic declines in the manipulated basin, compared to no change in the reference basin. In contrast, the macroinvertebrate community had similar composition, diversity and density levels between the two basins. Helmus and Sass (2008) concluded that Yellow Perch likely lost both spawning habitat (leading to reduced reproductive success) and refuge habitat (leading to increased predation by Largemouth Bass, *Micropterus salmoides*) when the coarse woody debris was removed.

Francis and Schindler (2009) examined fish diets along a gradient of shoreline development in north temperate lakes. The contribution of terrestrial insects to diet was negatively correlated with development, comprising up to 100% of fish diet mass in undeveloped lakes compared to an average of 2% in developed. Trout (*Oncorhynchus* spp.) also had an average 50% greater daily energy intake (of which up to 50% was comprised of terrestrial prey) in undeveloped lakes. Terrestrial food sources from intact shorelines thus can play an important role in enriching fish productivity in lakes.

The effects of shoreline development on aquatic habitat were compared in Vermont and Maine, two states with different approaches to regulating lakeshore activity (Merrell et al. 2013). Vermont had no lakeshore zoning, focusing instead on encouraging individual stewardship. Maine had a Mandatory Shoreland Zoning Act, which placed land use restrictions on all land within 76 m of waterbodies. The study examined 234 reference lakeshore sites and 151 unbuffered developed lakeshore sites on 40 lakes in Vermont, and 13 reference lakeshore sites and 36 developed sites on five lakes in Maine, from 2005 to 2008. Development on many of the Vermont lakes included conversion of treed shorelines to lawn, lot leveling, addition of impervious surfaces such as roofs, driveways, patios, and decks close to shore, and seawalls along shorelines. Maine's regulations, meanwhile, required setbacks of at least 30 m from the lakeshore, as well as minimum levels of tree and shrub retention and canopy coverage within the setback.

In Vermont, all littoral habitat components studied differed significantly between developed and reference lakeshore sites, with developed sites having

- less shading, and lower amounts of coarse woody debris, fine and medium woody structure, deciduous leaf litter, periphyton, and dragonfly larval exoskeletons (used as an indicator of suitable habitat for dragonfly emergence), and
- more sand and embedded sediments (smothering habitat for fish and macroinvertebrates).

In contrast, only one parameter (dragonfly larval exoskeletons) showed significant differences between developed and reference sites in Maine (Merrell et al. 2013).

Shoreline development may also threaten the aesthetic value of lakes which attracts people to settle there in the first place. A survey of lakeshore residents on 10 Michigan lakes found that common landscaping practices (such as replacing natural shorelines with lawns, seawalls, beaches, docks and accessory buildings) conflicted with the top reasons residents chose to live or vacation on the lakes, namely the view, interaction with nature, and open spaces (Lemberg and Fraser 2005). Fewer than 5% of residents surveyed considered their properties as being in a natural state, with more than 80% classifying them as having manicured lawn with some shade trees or ornamental shrubs (Lemberg and Fraser 2005).

A 12-year study of Lake Ontario coastal wetlands found a strong relationship between water quality and natural land cover at the watershed scale, indicating that shoreline protection is only one component contributing to overall lake health (Croft-White et al. 2017). Water quality declined in watersheds with more than 6-7% urban coverage but increased in watersheds with more than 10% wetlands and forest cover respectively. .

5. Shoreline Buffers

Shoreline buffers are commonly used to protect lakes and rivers from adjacent human activity. A buffer is a vegetated portion of land that serves as a physical separation between natural features and functions, and development (such as residential development, forestry, agriculture) which may disturb or degrade these features and functions (OMNR 2000, Sweeney and Newbold 2014). A buffer differs from a Critical Function Zone (or Core Habitat), which is the part of a species' habitat critical for its survival, because the buffer is the protection zone which should be applied around this critical habitat (Beacon 2012). In other words, the buffer should not be considered an extension of the natural feature it is meant to protect (OMNR 2000). Similarly, a buffer differs from a setback, which is the minimum distance required between a structure or infrastructure and a natural feature, although a buffer may be included within a setback.

In the shoreline context, buffers are naturally unmowed vegetated land extending along the waterfront, typically in the riparian zone. Buffers may be a combination of trees, shrubs, and herbaceous or grassy vegetation In general, maintenance and restoration of native plants in the shoreline buffer is preferred to use of non-native species, since native species are adapted to local conditions, support local biodiversity, and do not require the use of fertilizers, herbicides, and pesticides, which can degrade water quality (Muskoka Watershed Council 2013). In addition, native vegetation appears better able to trap pollutants in runoff from entering adjacent waterbodies (Zhang et al. 2010) and to stabilize shorelines with its deeper network of roots, compared to lawn. Preservation of natural shorelines also costs less than a manicured lawn and gardens to maintain, provides more privacy along the lakefront, and promotes the aesthetics that attract people to lakeshores (Lemberg and Fraser 2005).

Natural shorelines are also generally avoided by nuisance species like Canada Geese (*Branta canadensis*), which are attracted to open lawns along shorelines, where they can more easily access riparian lands. It is challenging to quantify the impact of waterfowl such as Canada Geese on nutrient loading, because approximately 87% of the phosphorus from goose feces is derived from the lake itself, as food passes quickly through a goose and the process is part of the nutrient cycle, as opposed to a nutrient source (Fleming and Fraser 2001). The impact is magnified beyond the remaining ~13% phosphorus load, however, as phosphorus from feces is more bioavailable for uptake by aquatic plants and algae.

The design of buffer type and width should be determined based on the buffer's desired function, and consideration of site-specific conditions, such as slope, hydrology, soil type, and adjacent land uses (Castelle et al. 1994, McDonnell 2012).

Shoreline buffers can provide numerous benefits including

- Sediment removal and erosion control,

- Removal of excess nutrients (mainly phosphorus and nitrogen) and other pollutants (including pathogens, pesticides, and heavy metals),
- Moderation of stormwater runoff,
- Moderation of water temperature,
- Maintenance of habitat diversity and protection of core habitat (e.g., as a source of habitat and food subsidies to the littoral zone),
- Reduction of human impact (by acting as a screen or barrier between human activity and wildlife; Beacon 2012; McDonnell 2012).

Numerous studies have been conducted over the last 30 years on buffer effectiveness. Most of the research has focused on riparian buffers along watercourses or wetlands, and their role in buffering agricultural and forestry impacts. In comparison, relatively few studies have examined the application of buffers to lake ecosystems and lakeshore development (Owens et al. 2021). Research has also been uneven in its focus on different buffer functions. For example, Beacon (2012) identified gaps in research on the role of buffers in mitigating storm flows and intercepting toxins and pathogens. More recently, Stutter et al. (2019) highlighted the lack of research on the capture and retention of soluble phosphorus and nitrogen in subsurface flows through buffers, and on the role of buffer design and management on protecting terrestrial and aquatic wildlife habitat. In addition, research has demonstrated wide variability in buffer effectiveness, partly because of variation in conditions among sites, but also because standardized approaches to measuring buffer performance are lacking (Beacon 2012).

Although much of the research on shoreline buffers has not directly focused on lakeshore environments and waterfront residential development, the findings from other studies are still broadly applicable to lake systems. Different types of land uses (e.g., agriculture, forestry, urban development) may produce similar disturbance patterns along the shoreline through widespread clearing of vegetation. Buffers are expected to function in similar ways across different aquatic systems, although the scale of their influence may vary (Beacon 2012). For example, the equivalent sized buffer along a small stream compared with a large lake may differ in its effectiveness. Nonetheless, while gaps remain in our knowledge of buffer performance in the lakeshore context, the following review provides a general overview of their potential in such systems.

5.1 Case Studies

Castelle et al. (1994) conducted a review of the literature on buffer effectiveness around streams and wetlands. Smaller buffers were generally adequate when they were in good condition (i.e., comprised of dense native vegetation and undisturbed soils), surrounded by low intensity land uses (such as park land or low density development), and when the stream or wetland had low functional value (e.g., the feature was highly disturbed or dominated by non-native vegetation). The size of the buffer needed to be increased, however, if buffer condition was poor, if adjacent land uses intensified, and if the feature to be protected was of higher ecological value (Castelle et al. 1994). Buffers less than 5-10 m were typically found to be insufficient for protecting the natural physical, chemical, and biological characteristics of adjacent aquatic features. A minimum 15-30 m buffer was recommended, with the lower end of the range identified as the minimum size necessary to maintain physical and chemical functions, and the upper end of the range identified as the minimum necessary to maintain biological functions (Figure 1).

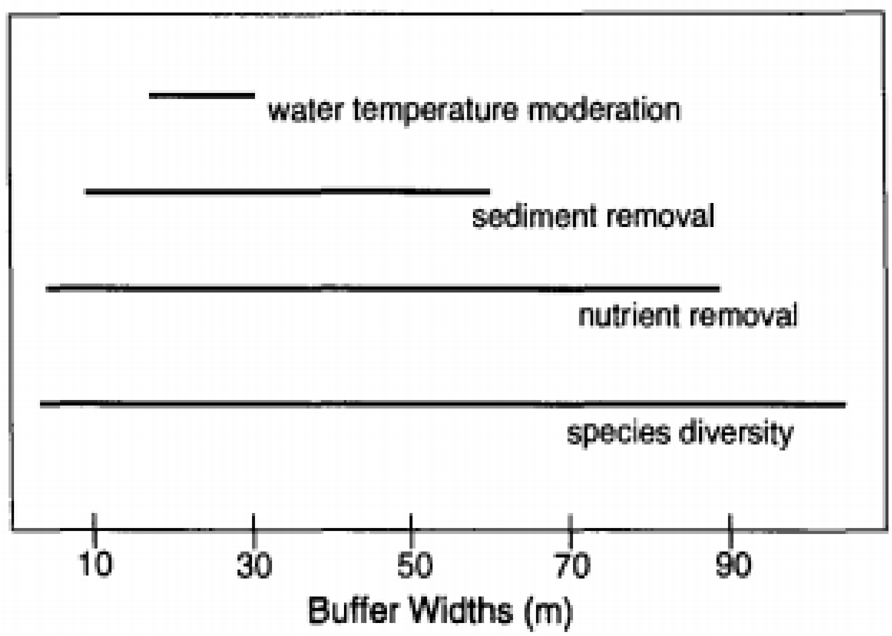

Figure 1. Range of buffer widths necessary to protect specific ecological functions in streams and wetlands (from Castelle et al. 1994).

5.1.1 Removal of sediment and pollutants

Buffers reduced phosphorus and total suspended solids (TSS) in stormwater runoff from residential development in Maine (Woodard and Rock 1995). Buffer effectiveness was evaluated for different slopes (2.3-12%) and ground cover (sparse to moderate cover, seeded or not seeded lawn) and compared to a control site which had a moderate slope (5.7%) and was forested and undeveloped. Ground cover had a greater influence on buffer function than slope. At all sites, a 15 m buffer reduced phosphorus concentrations to within the control range. TSS was also reduced but to a lesser degree. Buffers in which the ground was stabilized with underbrush and a layer of decomposing forest litter were most effective at removing pollutants, while buffers containing exposed soil contributed TSS to overland flow. Woodard and Rock (1995) concluded that a 15 m buffer should be sufficient for trapping phosphorus and TSS at sites with low to moderate slopes (<12%), sufficient ground cover, a stable soil matrix, and minimal channelization.

Phosphorus is generally considered the limiting nutrient for the growth of aquatic plants and algae in freshwater environments because reducing nitrogen inputs favors nitrogen-fixing cyanobacteria and nitrogen fixation is generally sufficient to allow for increased plant and algae biomass in proportion to phosphorus (Schindler et al. 2008). However, other scientists argue that nitrogen-deficient growth occurs at specific total nitrogen : total phosphorus ratios (e.g., <20; Guildford and Hecy, 2000) so nitrogen was considered during the literature review. A 2005 review of riparian buffers by the U.S. Environmental Protection Agency found that their effectiveness at nitrogen removal was highly variable (Mayer et al. 2005). Narrow buffers (1-15 m) sometimes removed up to 96% of nitrogen loads, but in other cases, they contributed nitrogen. Wider buffers (>50 m) were more consistent in removing nitrogen, ranging from 58 to 100% effective. Nitrogen removal from surface flows was generally inefficient (average 33% effective), compared to subsurface removal, which was typically high (average 90% effective) and appeared unrelated to buffer width. Nitrogen is an essential nutrient for plant growth and reproduction, and plants absorb it from the soil through their roots, explaining why subsurface removal is superior. Furthermore, water movement below the surface tends to be slower than surface flow, creating more time for plants to take up the nutrient. A variety of vegetation types (grass, grass/forest, forest, forest/wetland, wetland) had similar removal abilities for subsurface flow. Mayer et al. (2005) generated a linear regression model to estimate buffer thresholds for nitrogen removal. They found that overall, a 3 m buffer was predicted to have a 50% removal effectiveness, vs. 75% for a 28 m buffer, and 90% for a 112 m buffer. Mayer et al. (2005) concluded that soil type, watershed hydrology, and subsurface biogeochemistry may be more important than vegetation type or buffer width in determining nitrogen removal capabilities in riparian buffers, because these factors influence microbial denitrification and plant uptake of the nutrient.

Zhang et al. (2010) conducted a review of the effects of buffer width, slope, soil type, and vegetation type on the capacity of buffers to reduce non-point source pollution. Of the pollutants examined, buffer width influenced the removal of pesticides the most (explaining 60% of the total variance in removal efficiency), followed by nitrogen (44%), sediment (37%) and phosphorus (35%). Buffer capacity to remove sediment showed a greater influence of width at smaller buffer sizes than larger ones. For example, increasing buffer width from 5 to 10 m would improve function by 8-9%, while increasing buffer width beyond 20 m would accrue no additional gain for sediment removal. Buffer slope had a positive relationship with sediment removal efficiency for slopes less than 10%, but a negative effect on steeper slopes. Soil drainage type (i.e., well, moderately or poorly drained) had no influence on buffer function.

Zhang et al. (2010) found that vegetation type affected the removal efficacy of all pollutant types except pesticides. Grass buffers and treed buffers removed more sediment than buffers with a mix of grass and trees. Treed buffers performed better at removing phosphorus and nitrogen than those with either a mix or just grass. The type of grass buffer (e.g., native grasses vs. cultivated lawn) was not specified in the literature review. However, Zhang et al. (2010) reported on a study by Abu-Zreig et al. (2004) which found that riparian buffers comprised of native grasses were more effective at phosphorus removal than ones made up of perennial ryegrass and red fescue adjacent to cropland in southern Ontario. As with sediment, greater gains in removal efficiency were seen with buffer width increases in smaller (5 to 10 m) than larger (20 to 30 m) buffers, with no change for treed buffers in their ability to remove nutrients (100%) beyond 20 m. Zhang et al. (2010) concluded that a 30 m buffer with low to moderate slopes would remove at least 85% of the pollutants tracked in the study.

Table 1. Predicted pollutant removal efficiency of buffers (from Zhang et al. 2010).

		Predicted removal efficacy, %			
	Buffer width =	5 m	10 m	20 m	30 m
Sediment	(a) Slope = 5%; mixed grass and trees	67	76	78	78
	(b) Slope = 5%; grass/trees only	82	91	93	93
	(c) Slope = 10%; mixed grass and trees	77	86	88	88
	(d) Slope = 10%; grass/trees only	92	100†	100	100
	(e) Slope = 15%; mixed grass and trees	58	67	68	68
	(f) Slope = 15%; grass/trees only	73	81	83	83
Nitrogen	(a) Mixed grass and trees/grass only	49	71	91	98
	(b) Trees only	63	85	100	100
Phosphorus	(a) Mixed grass and trees/grass only	51	69	97	100
	(b) Trees only	80	98	100	100
Pesticide		62	83	92	93

† If predicted values exceed 100, the value of 100 was assigned instead.

Beacon (2012) conducted a critical synthesis of the scientific and technical literature on buffers, scanning more than 3000 studies, and reviewing 250 in detail. Average buffer sizes of 10 to 40 m for watercourses and 15 to 80 m for wetlands were widely documented to attenuate sediments and other pollutants. Sediment and phosphorus were typically well attenuated by narrower buffers than was nitrogen. Buffers 2-9 m captured some sediment and phosphorus, but larger buffers (9-30 m) were generally more consistent in their performance and were able to achieve full attenuation. In comparison, studies on nitrogen removal recommended widths of 15 to more than 40 m. Grass (or herbaceous) buffers were better able to capture phosphorus and nitrogen in surface runoff than forested buffers, but forested buffers trapped more subsurface nitrogen than grassed buffers, likely because they had high levels of organic matter and deep-rooted vegetation, promoting denitrification and plant uptake. Types of grass buffers reviewed included ones comprised of Reed Canary Grass (*Phalaris arundinacea*) an invasive species, and Switchgrass (*Panicum virgatum)*, a native plant. Overall, a 30 m buffer was recommended to achieve multiple water quality benefits (Beacon 2012).

The ability of riparian buffers to intercept subsurface nitrogen is strongly influenced by subsurface water flux (or the amount of water flowing through the buffer below the surface). A review of 30 studies of buffer function along watercourses found that the median removal efficiency of 89% for subsurface nitrate was not related to buffer width or vegetation type (grass vs. trees) but was inversely related to subsurface water flux (Sweeney and Newbold 2014). Under equivalent rates of water flux (>50 l/m/day) buffers less than 40 m wide had a median removal efficiency of 55%, compared to 89% for buffers greater than 40 m (Sweeney and Newbold 2014). Under average water flux conditions, 30 m and 100 m buffers were predicted to remove 48% and 90% of subsurface nitrogen respectively. Given the variation in efficiency across sites, Sweeney and Newbold (2014) recommended at least 30 m wide buffers for effective nitrogen removal at the watershed scale, and indicated that removal efficiency was likely to continue to increase above 30 m.

Sweeney and Newbold (2014) also reviewed sediment removal by watercourse buffers. Up to 65% of sediment from overland flows could be captured in 10 m buffers, increasing to 85% in 30 m buffers. Larger particle sizes of sediments (such as sand) typically settle out of flow within a few metres, but wider buffers are needed to effectively trap finer silts and clays that can impair water quality.

The capacity of riparian buffers to remove sediment was further assessed in a meta-analysis of more than 90 studies (Ramesh et al. 2021), which examined the role of a suite of factors including buffer width, length, and area, as well as vegetation type, area ratio (upland contributing area to buffer area), sediment loads, and flow rates. Overall, buffers had an average removal efficiency of 75%. Buffers comprised of grass only or a mix of grass and woody vegetation (trees and/or shrubs) were better than woody vegetation buffers at sediment removal (Figure 2; although data were limited for some of these types). The literature review did not provide details on the type of grass buffers (e.g., native grasses vs. cultivated lawn), other than indicating that they could include grasses, stiff grass hedges, and herbaceous crops. Buffer widths in the 10 to 20 m range were most effective at trapping sediment (Figure 3).

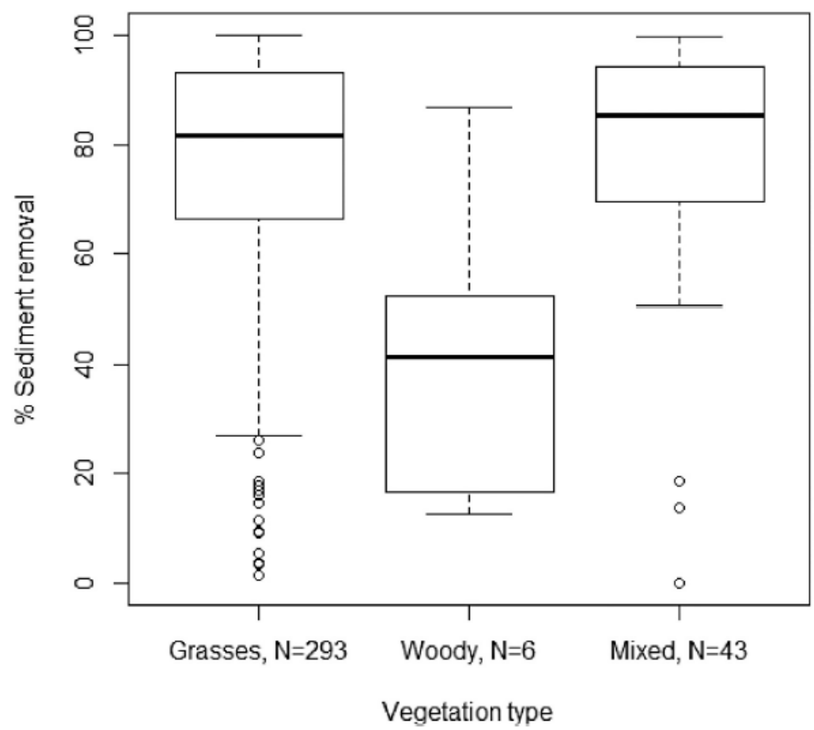

Figure 2. Boxplot of sediment removal in different types of buffers (from Ramesh et al. 2021). The lower and upper boundaries indicate the 25th and 75th percentiles, respectively. The bold line within the box indicates the median. The bars above and below the box represent the 90th and 10th percentile of sediment reduction, respectively.

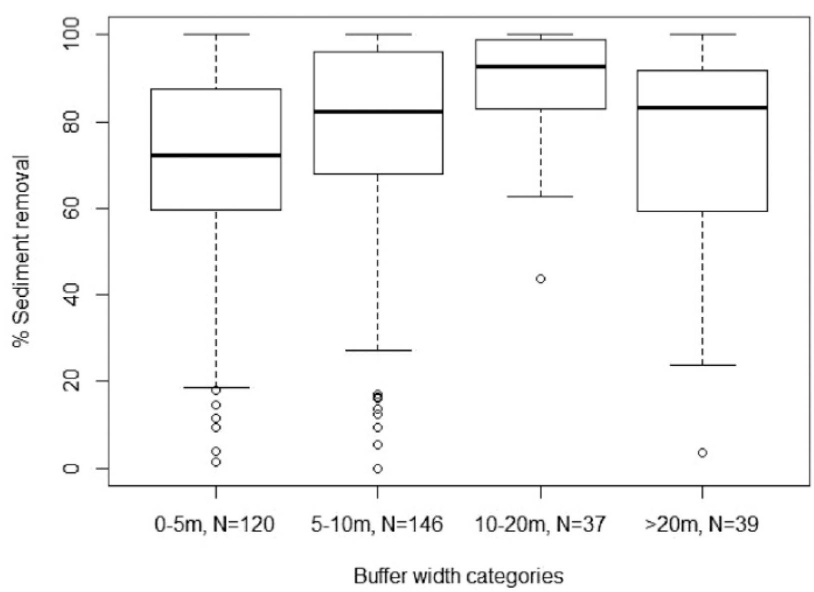

Figure 3. Boxplot of sediment removal for different buffer widths (from Ramesh et al. 2021).

In contrast, riparian forest buffers did not appear to improve benthic community structure in a study of lakes in New York state (Owens et al. 2021). The benthic macroinvertebrate community composition of buffered and unbuffered lakes with a mix of land uses (including agriculture, forestry, and residential development) were compared as an indicator of water quality. No difference was found in the biotic index of water quality among lakes, suggesting that a forested buffer would not trap pollutants from entering the lake through inlet streams or stormwater runoff drains (Owens et al. 2021) or that effects in water quality were too small to influence benthic community structure. In addition, lakes in the study area likely were experiencing the legacy effects of historical agricultural activity in their watersheds, through internal loading of nutrients, which could interfere with any changes resulting from treed buffers. Furthermore, invasive alien species (including Zebra Mussels, *Dreissena polymorpha*) were present in all study lakes, which may have confounded results by homogenizing macroinvertebrate communities (Owens et al. 2021). The findings of this study emphasize that buffers, on their own, cannot address all factors contributing to lake health, and that broader landscape level effects, as well as historical influences, should be considered.

5.1.2 Maintenance of habitat diversity and protection of core habitat

Characteristics of buffers designed to protect wildlife habitat will vary depending on the species of interest. Semi-aquatic organisms, like frogs, salamanders, snakes, and turtles may need significant areas of terrestrial habitat adjacent to their aquatic habitat for feeding, shelter, nesting and overwintering. For example, a literature review of the habitat requirements of six salamander species in the northeastern United States found that adults used upland habitat on average 125 m from the edge of wetlands, while juveniles were up to 70 m from shorelines (Semlitsch 1998). A review of the habitat requirements of 65 amphibian and turtle species (which included species found in Ontario) documented core terrestrial habitat ranging from 159 to 290 m from the aquatic edge for amphibians and 127 to 289 m for reptiles (Semlitsch and Bodie 2003). To adequately protect both the aquatic and terrestrial core habitat of these species from human disturbance, Semlitsch and Bodie (2003) recommended at least a 30 to 60 m aquatic buffer (which would be encompassed by protection of core terrestrial habitat) and a 50 m buffer terrestrial buffer beyond the core terrestrial portion (Figure 4). In Ontario, the mean distance to water of freshwater turtle nests ranges from 33.5 m and 35.7 m (for Spotted Turtle, *Clemmys guttata* and Northern Map Turtle, *Graptemys geographica* respectively), 51.8 m (for Snapping Turtle, *Chelydra serpentina*), and 71.2 m and 77.8 m (for Blanding's Turtle, *Emydoidea blandingii* and Painted Turtle, *Chrysemys picta* respectively; Steen et al. 2012).

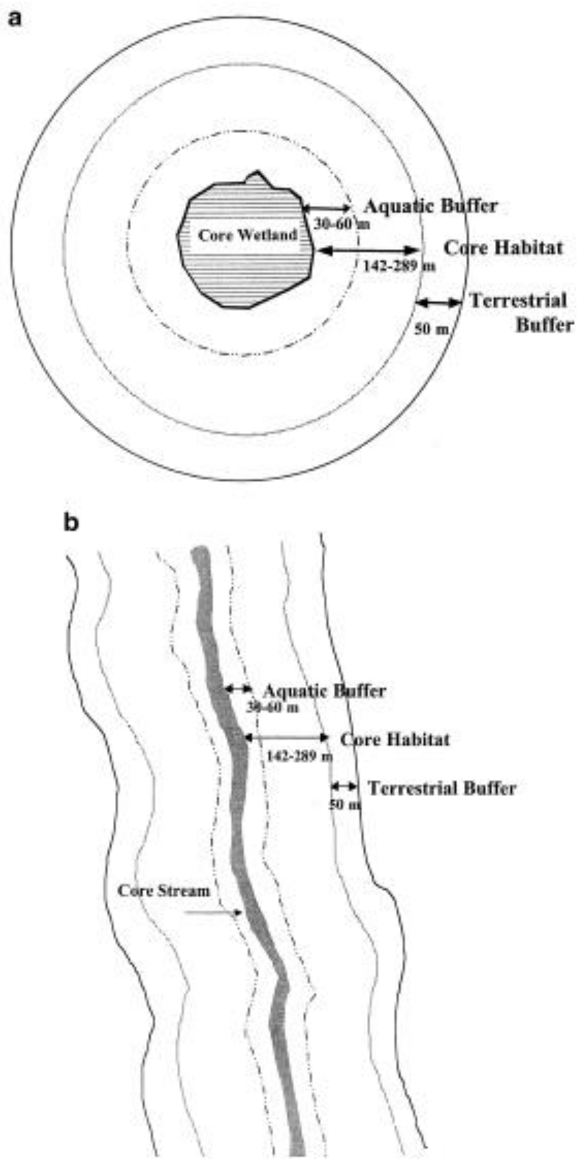

Figure 4. Proposed zones of protection for amphibians and reptiles using (a) wetlands and (b) streams (from Semlitsch and Bodie 2003).

Numerous wildlife studies have examined the minimum distance at which species are disturbed by human activity. While this research is not directly focused on buffer effectiveness, it can be useful for identifying minimum buffer size to protect wildlife habitat from human disturbance (Beacon 2012). Sensitivities vary widely among species and depending on the type and intensity of disturbance. Beacon (2012) reported a study by Rodgers and Smith (1997) which found that waterbirds were flushed from their nests by noise within 14-24 m and were more sensitive to pedestrians (requiring up to 34 m distance) than cars (up to 24 m distance). In general, minimum buffers of 15-100 m were recommended for waterbird species (Beacon 2012).

A study on the effects of lakeshore development on the Common Loon (*Gavia immer*) in New York State found that breeding success was affected by proximity to development (Spilman et al. 2014). Successful nests were on average 442 m away (range 41-1500 m) from human settlement, while unsuccessful nests were closer, on average 342 m away (range 2-1223 m).

Buffer vegetation type can influence the composition of adjacent aquatic invertebrate communities. Forested buffers were associated with greater stream shading, increased gravel content, and faster flow velocities, as well as more larvae in the sensitive insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), compared with unbuffered reaches dominated by grass and herbaceous vegetation (Sargac et al. 2021).

5.2 Summary of Buffer Recommendations

Buffers are often intended to achieve multiple benefits, including water quality protection, provision of wildlife habitat, and aesthetics. Their design will thus involve balancing a variety of factors to optimize their performance and determining what level of performance is desired. For example, if 95% removal of a pollutant is the goal, the buffer width required will likely be larger than if 50% removal is the goal (Beacon 2012). In addition, consideration of site-specific features affecting buffer effectiveness is necessary, as well as the type, intensity, and configuration of adjacent land uses (Beacon 2012).

The following table summarizes characteristics of effective shoreline buffers documented in the scientific literature.

Table 2. Summary of characteristics of effective shoreline buffers.

Function	Recommended Buffer Width	Type of Aquatic Feature	Comments	Source
Water quantity, water quality, water temperature, core habitat protection, barrier to human disturbance	15-30 m	Watercourse and wetlands	• Lower end of range minimum sufficient for protection of chemical and physical components of aquatic systems • Upper end of range minimum sufficient for protection of biological components of aquatic systems	Castelle et al. 1994
Water quality	15 m	Lake	• Reduced phosphorus and TSS at sites with <12% slopes, sufficient ground cover, stable soil matrix, and minimal channelization	Woodard and Rock 1995
Core habitat protection	192-339 m	Watercourse and wetlands	• Calculated as 50 m terrestrial buffer beyond terrestrial core habitat for amphibians and turtles	Semlitsch and Bodie 2003
Water quality	>50 m • 3 m: 50% effective	Watercourse and wetlands	• 58-100% effective at nitrogen removal • Surface removal 33% average removal efficiency	Mayer et al. 2005

	• 28 m: 75% effective • 112 m: 90% effective		• Subsurface removal 90% average removal efficiency	
Water quality	20-30 m	Watercourse	• Up to 85% of pollutants (sediments, nutrients, pesticides) removed at 30 m • Buffer slope positively associated with sediment removal for <10% slopes • Grass buffer and treed buffer removed more sediment than grass/tree mix • Treed buffer removed more phosphorus and nitrogen than grass/tree mix or just grass buffer	Zhang et al. 2010
Water quantity (e.g., attenuation of storm flows)	20-150 m	Watercourse	• Empirical data lacking, based mainly on anecdotal evidence • Influenced by factors such as local hydrologic regime, catchment area, topography, soil type, impervious cover, and land use in the watershed	Beacon et al. 2012
Water quality	1-122 m		• Sediment and phosphorus can generally be well	

	• Average range between 10-40 m • Average single recommendation of ~30 m		attenuated in narrower buffers than nitrogen • Combination of herbaceous and woody vegetation most effective for overall nutrient attenuation • Most attenuation is documented within the first 30-40 m	
Barrier to human disturbance or changes in land use	15-100 m		• Empirical data lacking • Range based on flight initiation distance research on waterbirds, distance depends on species and type of human impact	
Core habitat protection	10-75 m • Average single recommendation 50 m		• For large woody debris, 40-60% of input occurs within 10 m of shore; 30 m tends to capture 100% of contribution • For particulate organic matter, 60-85% of input occurs within 15 m of shore; 40 m needed for 100% of contribution	
Water quality	15-80 m	Wetlands	• Sediment and phosphorus can generally be well	

	• 30 m recommended for multiple water quality benefits		attenuated in narrower buffers than nitrogen • Combination of herbaceous and woody vegetation most effective for overall nutrient attenuation	Beacon et al. 2012
Hazard mitigation zone (e.g., stabilize steep slopes)	10-50 m		• Empirical data lacking • Influenced by slope, condition, and height of trees (if present), composition of vegetation	
Core habitat protection	15-300+ m • Average range 45-110 m		• Depends on focal species and land use context • Buffers often conflated with critical function zones (or core habitat)	
Water quality	10-30 m	Watercourse	• 10 m removes 65% of sediment from overland flow • 30 m removes 85% of sediment from overland flow	Sweeney and Newbold 2014
Temperature regulation	20-30 m		• Buffer ≥ 20 m maintains water temperature within 2ºC of that within fully forested watershed • Buffer ≥ 30 m maintains water temperature the	

			same as within fully forested watershed	
Core habitat protection	30+ m		• Coarse woody debris input equivalent to natural levels if buffer width equal to height of mature streamside trees (~30 m) • Diversity and abundance of macroinvertebrate and fish communities, and the condition of instream habitat remain similar to within fully forested watershed with $\geq$ 30 m	
Water quality	10-20 m	Not specified	• 75% sediment removal efficiency • Grass or grass/woody mix remove more sediment than woody vegetation only	Ramesh et al. 2021

5.3 Provincial Guidance

Preservation of a naturally vegetated shoreline buffer has long been recognized as a best management practice to minimize the impacts of development on adjacent waterbodies and watercourses. The Provincial Policy Statement (PPS; 2020), under the Planning Act, identifies significant natural heritage features that must be protected from development and site alteration. While the PPS does not set out specific requirements to establish buffers around significant natural heritage features, buffers are often used by planning authorities as a protective measure and a means to allow development while still protecting the feature of interest. The Natural Heritage Reference Manual, which provides guidance on natural heritage policies under the PPS, recommends minimum distances of naturally vegetated buffers adjacent to fish habitat to protect it from development and site alteration (OMNR 2010; Table 3). These buffer recommendations are based primarily on research by Castelle et al. (1994) and Environment Canada (2004). The Manual indicates that planning authorities may apply larger buffers if additional sensitivities are identified, such as a highly stressed aquatic feature, the presence of aquatic species at risk, or the need to enhance ecological function (e.g., bank stabilization, pollutant removal, wildlife habitat; OMNR 2010). The Manual acknowledges that buffer recommendations may evolve as more research is generated on the impacts of development on natural heritage features and functions (OMNR 2010).

Table 3. Minimum recommended buffer sizes to protect fish habitat (from OMNR 2010).

Type of Fish Habitat	Minimum Recommended Buffer
Warmwater streams	30 m or 15 m if it can be demonstrated that there will be no negative impact on the natural feature and its ecological functions
Coolwater streams	30 m or 20 m if no negative impact on the natural feature and its ecological functions
Coldwater streams and inland waterbodies on the Precambrian Shield[2]	30 m

The Province's Lake Capacity Assessment Handbook provides guidance on controlling phosphorus entering lakes through management of shoreline development (Government of Ontario 2010). The Handbook encourages the maintenance and restoration of natural shoreline vegetation as one way to reduce phosphorus loading to lakes (in addition to minimizing amount of exposed soil, reducing fertilizer use, and maintaining properly functioning septic systems). No overall buffer size is recommended in the Handbook, but for lakes on the Precambrian Shield, where soils are typically thin, and fractured bedrock common, a minimum 30 m setback or no development zone from waterbodies is recommended. In general, as large a setback as possible is recommended (Government of Ontario 2010). A 30 m buffer is also recommended for stream environments by Environment Canada in "How Much Habitat is Enough?" (2013).

[2] *The Precambrian Shield (also known as the Canadian Shield)* is a geologic region extending across central and northern Ontario (including Haliburton County) which is characterized by thin soil and exposed bedrock.

Buffers are referred to as vegetation protection zones in provincial land use plans (the Greenbelt Plan, the Lake Simcoe Protection Plan, the Niagara Escarpment Plan, and the Oak Ridges Moraine Conservation Plan). These zones, comprised of naturally self-sustaining vegetation, are to be established and maintained around key natural heritage features and key hydrologic features outside of settlement or urban areas. Development and site alteration are generally prohibited within vegetation protection zones, with some exceptions (e.g., for conservation and flood or erosion control, and low intensity recreational use). Vegetation protection zones must be of sufficient width to protect key natural heritage features and key hydrologic features and their ecological functions. Buffer width is to be determined on a site-specific basis in the Niagara Escarpment Plan (Government of Ontario 2017a). In the Greenbelt Plan and the Oak Ridges Moraine Plan, buffers of at least 30 m are required adjacent to wetlands, fish habitat, kettle lakes, and the meander belt of permanent and intermittent streams (Government of Ontario 2017b,c). The Lake Simcoe Protection Plan designates minimum vegetation protection zones of 30 m from the Lake Simcoe shoreline in shoreline built-up areas (or wider if deemed appropriate through a natural heritage evaluation) and 100 m for the remaining Lake Simcoe shoreline outside existing settlement areas (Government of Ontario 2009). Structures are only permitted within these shoreline vegetation protection zones if (i) no other alternative location exists and the area affected within the vegetation protection zone is minimized, (ii) the ecological functions of the zone are maintained, and (iii) pervious materials and designs are used as much as possible (Government of Ontario 2009).

The Province of Ontario has produced fact sheets for the public on best management practices to preserve and restore natural shorelines. These resources encourage various approaches to protecting natural shorelines, through maintenance of natural vegetation, minimizing human activity, allowing degraded sites to re-naturalize, planting native species and removing non-native vegetation (Government of Ontario 2000, Government of Ontario and DFO 2000).

6. Other Considerations

6.1 Variable Width Approach

The scientific literature indicates that buffer effectiveness depends on a combination of buffer characteristics, site-specific conditions, surrounding land uses, and the desired function(s) of the buffer. Applying a single buffer width across a variety of situations, therefore, may not adequately account for this variation (Castelle et al. 1994). Furthermore, using a fixed-width approach may lead to the minimum recommended buffer width becoming the standard width adopted in all situations, regardless of situations where a larger buffer might be more appropriate (Beacon 2012), or conversely, where a smaller buffer may achieve the desired protection.

Numerous researchers thus advocate a more flexible approach in delineating buffer size, that is informed not only by the general science on buffer function, but also on local and landscape contexts (Castelle et al. 1994, Beacon 2012, Stutter et al. 2021). Yet, the fixed-width approach to buffers is typically used by planning authorities because it requires less technical knowledge of existing conditions and the underlying science on buffers, is more easily enforced, provides more regulatory certainty, and is less expensive and time-consuming than the alternative variable-width approach (Castelle et al. 1994, Beacon 2012).

Beacon (2012) describes a detailed buffer determination process that combines general scientific knowledge on buffer effectiveness with consideration of site-specific factors. The process begins with the identification of a 'Base Buffer Width', which is the lowest range of buffer widths identified in the literature as providing a specific buffer function (in other words, the range of buffer widths with the greatest risk of not achieving the desired function; Table 4). The next step is to increase the buffer width, as necessary, based on site-specific biophysical and land use considerations (such as hydrologic dynamics, slopes, buffer vegetation composition, and soils) and sensitivity of the natural heritage feature to be protected, to generate a 'Preliminary Buffer Width'. This 'Preliminary Buffer Width' may then be further adjusted depending on site-specific constraints or opportunities (Beacon 2012).

Table 4. Risk-based guidelines for buffer width determination (from Beacon 2012).

Natural Heritage Feature Category	Buffer Function Category	< 5 m	5 – 10 m	11 – 20 m	21 – 30 m	31 – 40 m	41 – 50 m	51 – 60 m	61 – 70 m	71 – 80 m	81 – 90 m	91 – 100 m	101 – 110 m	111 – 120 m	> 120 m
WATERCOURSES and WATER BODIES															
	A. Water Quantity	data indicate that this is not mitigated by site specific buffer													
	B. Water Quality	HIGH	HIGH	MODERATE	MODERATE	LOW	LOW	LOW	LOW	LOW	LOW				
	C. Screening of Human Disturbance / Changes in Land Use	HIGH	HIGH	MODERATE	MODERATE	LOW	LOW	LOW							
	D. Hazard Mitigation Zone	should be based on consideration of hazards, but may overlap with buffers													
	E. Core Habitat Protection		HIGH	HIGH	MODERATE	MODERATE	MODERATE	MODERATE	LOW	LOW	LOW	LOW	LOW	LOW	LOW
WETLANDS															
	A. Water Quantity	data indicate that this is not mitigated by site specific buffer													
	B. Water Quality	HIGH	HIGH	MODERATE	MODERATE	MODERATE	MODERATE	LOW	LOW	LOW	LOW				
	C. Screening of Human Disturbance / Changes in Land Use	HIGH	HIGH	MODERATE	MODERATE	LOW	LOW								
	D. Hazard Mitigation Zone	should be based on consideration of hazards, but may overlap with buffers													
	E. Core Habitat Protection		HIGH	HIGH	MODERATE	MODERATE	MODERATE	MODERATE	LOW	LOW	LOW	LOW	LOW	LOW	LOW

Key: Risk of Not Achieving the Desired Buffer Function
HIGH
MODERATE
LOW

HESL (2014) assessed existing site evaluation guidelines for waterfront development used by conservation authorities in eastern Ontario, which included consideration of buffer determination. The review examined the site evaluation guidelines recommended in the "Rideau Lakes Basin Carrying Capacities and Proposed Shoreland Development Policies" (the 'Rideau Lakes Study", Michalski and Usher, 1992). Biophysical site characteristics were examined by Michalski and Usher (1992) to determine shoreline setbacks via a scoring system. The authors acknowledged that the approach "*has not been developed on the basis of reams of data collected in a rigorous and scientific fashion; rather, it represents the results of our experience in applying and implementing development setbacks in a wide range of biophysical landscapes across Ontario for a variety of environmental protection and resource management purposes*." Several references were cited by Michalski and Usher (1992) to support the attributes of individual site characteristics and the subsequent development scores identified. HESL (2014) determined that the Rideau Lakes study was thorough and provided an abundance of information at both the regional and site-specific scales allowing for development of effective policy aimed at reducing the impacts of shoreline development on water quality. Review of site evaluation guidelines included an update to the site-specific biophysical criteria , which are presented in **Error! Reference source not found.** and **Error! Reference source not found.**.

Table 5. Updated biophysical criteria for shoreline setbacks.

Site Characteristic	Criteria			Score
Soil Depth	**Depth (cm)**			
	>150			0
	100-150			2
	75-100			4
	50-75			6
	25-50			8
	<25			10
Soil Texture	**Type**	**Percolation Rate**	**Phosphorus Retention Capability**	
	Coarse sand and gravel	Excessively rapid	Low	10
	Silty clay and clay	Low to impermeable	High	7
	Well-graded sands	Permeable to moderate	Low to medium	5
	Silty sand, clayey sand, silt and fine sand	Moderate to low	Medium to high	3
	Sandy loam	Moderate to low	Medium to high	3
	Loam	Permeable to moderate	Medium to high	0
Soil Analysis	If native soil between tile field and lake is > 1m deep, <1% $CaCO_3$ and >1% Iron/Aluminum			-10
Slope	**Slope Class**			
	0%-13%			0
	13%-20%			8
	20%-25%			10
	>25%			12
Vegetation	**Vegetation Cover Type**			
	Undisturbed woodlands, old fields, and meadows			0
	Disturbed woodlands, old fields, and meadows			3
	Close-seeded legumes (clover, alfalfa) and rotation meadows			5
	Row crops			7
	Fallow fields and base bedrock outcrops			10

Once criteria have been evaluated and scored based on biophysical characteristics (Table 5), the results are used to determine the shoreline buffer width as presented as “horizontal setback distance” by Michalski and Usher in the Rideau Lakes Study.

Table 6. Biophysical site scores and recommended shoreline buffer.

Total Score	Recommended Depth of Shoreline Buffer (m)
36-40	90
31-35	80
26-30	70
21-25	60
16-20	50
11-15	40
≤10	30

Consideration of site-specific information and determination of individual shoreline buffer sizes is challenging to complete on a large scale. It is also challenging to characterize general conditions that influence buffer effectiveness at a large watershed or County scale because of the variability in site conditions and characteristics of adjacent waterbodies. Nonetheless, the variable width approaches described highlight the importance of considering site-specific factors in determining suitable buffer widths.

6.2 Lake Classification

The primary purpose of lake classification is to group lakes with similar characteristics or management needs so that appropriate management tools (e.g., buffer sizes) can be applied to protect desired attributes from the impacts of shoreline development. The complexity of the classification approaches and information requirements can vary considerably from the use of complex models to more simple qualitative approaches.

Lake classification is an effective management tool because it is not a “one size fits all approach” and individual characteristics of the lake, watershed, existing development, and social factors can be accounted for across a large area. Classification allows for planning decisions or the scaling of BMPs to be determined objectively even if the initial selection of classification criteria is subjective. Importantly, classification schemes can be tailored depending on information and resource availability, which is especially important when attempting to classify a large number of lakes over large spatial scales, with variable data availability and often limited resources, as is the case in Ontario.

A challenge in completing the classification scheme is determining appropriate classification criteria. Criteria could include physical and biological lake characteristics (e.g., depth, flushing rate, shoreline irregularity, fishery, natural heritage features, past occurrences of algal blooms, invasive species, trends in concentrations of nutrients or other pollutants), “responsiveness” to phosphorus calculated using the Lakeshore Capacity Model, social factors (e.g., existing development and development pressure, distance to urban centres), and watershed characteristics (e.g., existing land use, soil conditions). The selection of classification criteria is dependent on several factors, including the information and resources that are available, the scale at which the classification is applied, and the intent of the classification (i.e., which attributes are being managed) and the available accepted management tools (e.g., minimum development standards, limits to amount and type of development, BMPs, etc.).

6.3 Lake Specific Management

Individual lake plans that address shoreline development can also be completed. The primary advantage of lake-specific approaches to managing shoreline development is that local concerns and/or lake-specific issues can be addressed, which may not be possible with a provincial or local government approach designed to accommodate more general jurisdiction-wide issues. Disadvantages of this approach can include difficulty in reaching consensus on issues, and resource requirements (technical and financial support). Resource requirements can be substantial to conduct required studies, develop development standards to address concerns and implement the recommendations into planning.

7. Summary/Conclusion

Shoreline buffers can play an important role in protecting lake health. The physical separation they provide between upland human activity and the aquatic environment can aid in mitigating the effects of development and site alteration on water quality, erosion and flood control, and wildlife habitat. However, no single type or size of buffer will perform optimally in all conditions, and determination of buffer characteristics should consider a variety of factors, including the desired function of the buffer, the sensitivity of the adjacent aquatic environment, the intensity of the land use, and site-specific physical features, such as slope, hydrology, and soil type. Characterizing these factors and developing static buffer requirements informed by scientific research over a large landscape is, however, extremely challenging.

The scientific literature on shoreline buffers over the past 30 years has largely focused on watercourses and wetlands, and the impacts of agriculture and forestry. Relatively little research has examined buffer performance in protecting lakes from shoreline development. While this gap in knowledge should be addressed, the existing literature on buffers can still provide useful information that can be applied to the lake context.

Shorelines provide numerous benefits and in general, larger buffers are better at consistently providing a range of protective functions. Castelle et al. (1994) noted that a 15 m buffer is the minimum size necessary to maintain physical and chemical functions while 30 m is the minimum necessary to maintain biological functions. Efficient removal of pollutants (notably sediment) can occur in buffers of 10-20 m width, but other pollutants (such as nutrients) may require buffer widths of 30 m or more for effective attenuation. Water quality improvements generally increase with buffer size (e.g., 10 m removes 65% of sediment from overland runoff while 30 m removes 85% of sediment from overland runoff; Sweeney and Newbold 2014). Larger buffers are also better at protecting the diversity of aquatic and terrestrial species that rely on shorelines. Semi-aquatic species, such as amphibians and reptiles, can use terrestrial habitat up to 300 m inland from the water's edge. Some turtle species nest up to 80 m inland. Waterbirds may react to human activity close to their nests, and loons may require several hundred metres between their nests and development.

Site specific factors and the characteristics of the buffers are important. Low to moderate slopes (<10%) appear to positively influence sediment removal, while steeper slopes have a negative effective on performance. It is challenging determining how site-specific factors should influence buffer size over a large geographic range, but lake classification and lake specific management plans are two potential tools that could be utilized to generalize characteristics of the shoreline and sensitivities of the adjacent waterbody.

Natural vegetation is better able to trap pollutants and stabilize shorelines than manicured lawn due to deeper roots. Furthermore, native vegetation does not require the use of fertilizers, herbicides and pesticides, provides improved habitat for terrestrial and aquatic species, and does not attract nuisance species such as Canada Geese, which can add to the nutrient loading to a lake. Maintaining natural shorelines also provides privacy, increases property value, and contributes to the aesthetic quality of the

The scientific literature demonstrates that a 30 m buffer generally provides a range of ecological services, and this buffer size is commonly recommended in the peer-reviewed literature focused on shoreline development, aligning with Provincial guidance. While smaller buffers provide some benefits for water quality and aquatic habitat protection, larger buffers provide more ecological services, more completely. Buffers will likely become more important in protecting lake health as climate change effects on freshwater systems continue to intensify. Buffer recommendations are often included in municipal and provincial policies but are seldom enforced, so the theoretical debate of buffer size is outweighed by the reality on the land. To be truly effective, buffer recommendations based on the best available science, and informed by the jurisdictional review and public consultation, will need to be implemented and enforced consistently across the County.

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Appendix A. Literature Review Summary

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Title	Authors	Year	Source	Focus	Findings
Wetland and stream buffer size requirements - a review	A. J. Castelle, A. W. Johnson, C. Conolly	1994	Journal of Environmental Quality 23: 878-882	buffers: water quality	•3-200 m found effective depending on site, 15 m met most conditions (chemical and physical), but larger needed to cover biological functions (30 m+) •smaller buffer size adequate when in good condition (dense native vegetation, undisturbed soils), low functional value of wetland or stream (highly disutrbed, dominated by non-native plants), and low-impact adjacent land uses (e.g., parkland, low density residences) •larger buffer size needed when buffers in poor condition, with intense land uses adjacent, and higher value water feature
Control of residential stormwater by natural buffer strips	S. E. Woodard, C. A. Rock	1995	Lake and Reservoir Management 11(1): 37-45	buffers: water quality	•evaluated buffer ability to remove phosphorus and suspended solids from residential stormwater under different slopes (1-5% slope vs 10-15%) •inputs from either subdivision or condominium complex •found that residential runoff relatively high in P and suspended solids, especially during the construction phase •buffer effectiveness highly variable, but generally 15 m natural buffer effective in reducing P concentrations to background values observed at control site •ground cover had greater impact on removal ability than slope
Spatial relationships among boreal riparian trees, litterfall and soil erosion potential with reference to buffer strip management and coldwater fisheries	R. F. France, R. Peters, L. McCabe	1998	Annales Botanici Fennici 35: 1-9	buffers:erosion control	•litter cover protects ground from raindrop impact, thereby reducing soil erosion •found litter production in boreal riparian buffer strips (0-20 m from shorelines) lower than in adjacent upland forest (20 to 50 m upslope), due to presence of smaller trees, dominance of coniferous species, and bare exposed bedrock in foreshore •suggests riparian zones in these northwestern ON lakes have less potential to buffer receiving waters from watershed clearcutting then previously thought
Biological delineation of terrestrial buffer zones for pond-breeding salamanders	R. D. Semlitsch	1998	Conservation Biology 12(5): 1113-1119	buffers: wildlife habitat	•lack of clear understanding on extent of terrestrial habitat needed by wetland species, especially semi-aquatic organisms like salamanders •salamanders found average 125 m (adults) and 70 m (juveniles) from edge of aquatic habitats •assuming buffer zone encompasses 95% of population, would need to extend 164 m from wetland's edge into terrestrial habitat for salamander species studied
Breeding bird assemblages inhabiting riparian buffer strips in Newfoundland, Canada	D. M. Whitaker, W. A. Montevecchi	1999	Journal of Wildlife Management 63(1): 167-179	buffers: wildlife habitat	•compared breeding bird assemblages in undisturbed shoreline habitats vs. those in 20-50 m wide riparian buffer strips in boreal forests subject to timber harvesing in Newfoundland •total abundance higher in buffer strips due to presence of species associated with clearcut edge habitats and greater abundance of ubiquitous species •riparian buffer strips supported diverse avian assemblage including many riparian and woodland species •interior forest species were rare even in widest buffers (40-50 m)
Elevated numbers of flying insects and insectivorous birds in riparian buffer strips	D. M. Whitaker, A. L. Carrol, W. A. Montevecchi	2000	Canadian Journal of Zoology 78(5): 740-747	buffers: wildlife habitat	•compared abundance of flying insects along undisturbed lakeshores and riparian buffer strips in clearcuts in boreal Newfoundland forest •significantly more insects captured in buffers likely because they act as windbreaks, collecting airborne insects blown in from adjacent clearcuts and lakes •found concurrent increased abundance of insectivorous birds in buffers vs. undisturbed shorelines, possibly due to increased prey availability

Littoral water temperature response to experimental shoreline logging around small boreal forest lakes	R. J. Steedman, R. S. Kusherneriuk, R. L. France	2001	Canadian Journal of Fisheries and Aquatic Sciences 58: 1638-1647	littoral water temperature	•shoreline logging did not significantly increase average littoral water temperatures in two small boreal forest lakes in northwester Ontario •however, clearcut shorelines had maximum littoral water temperatures 1-2 C greater and increases of 0.3-0.6 C in average diurnal temperature range during early summer compared with undisturbed shorelines or shorelines with 30 m buffer •increased temperatures due to daytime heating
Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles	R. D. Semlitsch, J. R. Bodie	2003	Conservation Biology 17(5): 1219-1228	buffers: wildlife habitat	•reviewed terrestrial habitat requirements of 19 frog, 13 salamander, 5 snake and 28 turtle species •core terrestrial habitat for amphibians ranged from 159-290 m •core terrestrial habitat for reptiles ranged from 127-289 m
Urban lakes and waterbirds: effects of development on avian behavior	A. H. Traut, M. E. Hostetler	2003	Waterbirds 26(3): 290-302	wildlife habitat	•studied waterbirds along developed and undeveloped shorelines on 4 partially developed urban lakes in Florida •found that many species appeared to favour developed shorelines for a variety of behaviours (e.g., foraging, resting, tending young) •alert/fleeing behaviour observed less frequently along developed shoreline suggesting habituation to localized human disturbance •suggest that undeveloped shoreline may serve as important refuge for birds more sensitive to human disturbance or developed habitat •dense stands of tall emergent vegetation along undeveloped shoreline may limit waterbird behaviour
Quantitative review of riparian buffer width guidelines from Canada and the United States	P. Lee, C. Smyth, S. Boutin	2004	Journal of Environmental Management 70: 165-180	buffers	•reviewed guidelines for retention of treed riparian buffers after timber harvest •mean buffer widths ranged from 15-29 m •Boreal region had widest buffers, southeastern region had narrowest •common modifiers of guidelines were waterbody type and size, shoreline slope, and presence of fish •jurisdictions without modifiers for slope or fish applied wider baseline buffers vs. jursidications with these modifiers •buffer widths were generally protective for aquatic biota and habitats but generally less than recommended size for terrestrial biota
The influence of residential and cottage development on littoral zone fish communities in a mesotrophic north temperate lake	D. Taillon, M. G. Fox	2004	Environmental Biology of Fishes 71: 275-285	wildlife habitat	•examined sites along development gradient (undeveloped, moderately developed and high development) and habitat types •all fish life stages most abundant in moderately development sites •habitat had greater effect than development on fish abundance •absence of effects may be due to shallow sites, extensive macrophyte coverage throughout, and ongoing and previous disturbance due to Trent-Severn waterway (flooding, raised shorelines) •artificial structures may offset natural habitat that is lost •shoreline modification that does not reduce abundance of nearshore macrophytes or complexity of habitat does not appear to adversely affect fish diversity

Nearshore community characteristics related to shoreline properties in the Great Lakes	R. R. Goforth, S. M. Carman	2005	Journal of Great Lakes Research 31 (Supp1): 113-128	wildlife habitat	•benthic macroinvertebrate densities did not differ between shoreline types, but generally lower at nearshore sites with less stable substrates •shallow water prey fish CPUE and zooplankton densities generally lower for nearshore areas adjacent to developed mid-bluff shorelines and sites with less stable substrates •larger fish CPUE seemed unaffected by local shoreline and substrate properties in nearshore
The residential lakeshore access allocation problem: minimizing barrier effects on shoreline habitat buffers	D. S. Lemberg, R. Fraser	2005	Environmental Modeling and Assessment 10: 265-276	buffers	•lower impact landscaping with native species, retaining natural cover except for access paths, becoming more popular along lakeshore developments •provides lower costs to developers, more privacy to homeowner, and preservation of lakeshore aesthetics drawing people to the lakes in the first place •developed mathematical model to select shared access to lakeshore environment from lakeshore homes while protecting shoreline habitat
Riparian Buffer Width, Vegetative Cover, and Nitrogen Removal Effectiveness: A Review of Current Science and Regulations	P. M. Mayer, S. K. Reynolds, Jr., T. J. Canfield, M. D. McCuthchen	2005	U.S. Environmental Protection Agency	buffers: water quality	•found nitrogen removal effectiveness varied widely among riparian zones studied, but overall average 74% effectiveness •subsurface removal of N often high (90% average effectiveness), but did not appear related to buffer width •surface removal of N partly related to buffer width and was generally inefficient (33% average effectiveness) •some narrow buffers (1-15 m) removed significant proportions of N (up to 96% effectiveness), but narrow buffers sometimes contributed to N loads in riparian zones also •wider buffers (>50 m) more consistently removed significant portions of N (e.g., 58-100% effectiveness) •various vegetation types(grass, grass/forest, forest, forest/wetland, wetland) were equally effective at removing N in subsurface but not in surface flow •calculated that 3 m buffer predicted to have 50% removal effectiveness vs. 28 m (75%) vs. 112 m (90%) •findings suggest that soil type, watershed hydrology and subsurface biogeochemistry may be more important factors affecting N removal than vegetation type or buffer width
Buffer zone applications in snake ecology: a case study using Cottonmouths (*Agkistrodon piscivorus*)	E. D. Roth	2005	Copeia 2005(2): 399-402	buffers: wildlife habitat	•radio-telemetry study of riparian snakes •found 83% observation within 10 m of stream, but gravid females found up to 94 m from shoreline •highlight importance of terrestrial areas adjacent to wetlands and riparian habitat as critical to persistence of riparian taxa
Degradation of littoral habitats by residential development: woody debris in lakes of the Pacific Northwest and Midwest, United States	T. B. Francis, D. E. Schindler	2006	Ambio 35(6): 274-280	coarse woody debris	•residential development had a strong negative effect on CWD and riparian forest characteristics •strong positive correlation between riparian forest density and littoral CWD abundance
Stopover habitat along the shoreline of northern Lake Huron, Michigan: emergent aquatic insects as a food resource for spring migrating landbirds	R. J. Smith, F. R. Moore, C. A. May	2007	Auk 124(1): 107-121	wildlife habitat	•found higher arthropod biomass estimates at shoreline vs. inland habitats in spring •suggests more arthropod prey (insects and spiders) available for warblers at shoreline habitats (<0.4 km of shoreline) than inland (>0.4 km) • during spring migration

Climate change and lakeshore conservation: a model and review of management techniques	C. Abrahams	2008	Hydrobiology 613: 33-43	climate change	•climate change has broad effects on freshwater systems including -increased water temperatures -increased sedimentation and pollution, including greater nutrient levels, entering systems -changes to hydrology (especially through more winter runoff and less snowmelt in spring) •increased seasonal variability in precipitation, river flows, evapotransporation due to more intense and frequent flooding and droughts
The significance of littoral and shoreline habitat integrity to the conservation of lacustrine damselflies (Odonata)	R. G. Butler, P. G. deMaynadier	2008	Journal of Insect Conservation 12: 23-36	wildlife habitat	•diversity and composition of damselfly assemblages related to abundance and richness of littoral zone macrophytes, extent of riparian disturbance, benthic substrate granularity, and lake productivity •protection of littoral and shoreline habitat integrity (espcially emergent and floating macrophytes) critical to conservation of lacustrine biodiversity
The rapid effects of a whole-lake reduction of coarse woody debris on fish and benthic macroinvertebrates	Helmus, M. R. and G. G. Sass	2008	Freshwater Biology 53: 1423-1433	coarse woody debris	•whole-lake experiment removed ~70% littoral CWD in one basin and retained 100% CWD in other basin •Yellow perch most abundant fish prior to experiment, declined to very low densities in treatment basin after manipulation •no evidence of effects on macroinvertebrates
Shoreline urbanization reduces terrestrial insect subsidies to fishes in North American lakes	Francis, T. B. and D. E. Schnidler	2009	Oikos 118(12): 1872-1882	terrestrial insect subsidies	•quantified effects of lakeshore urbanization on terrestrial insect subsidies to fish •found negative correlation between subsidies and shoreline development •terrestrial inscets made up 100% of fish diet mass in undeveloped lakes vs 2% in developed lakes •trout in undeveloped lakes had average 50% greater daily energy intake (up to 50% comprised of terrestrial prey)
Multiscale relationships between Great lakes nearshore fish communities and anthropogenic shoreline factors	R. R. Goforth, S. M. Carman	2009	Journal of Great Lakes Research 35: 215-223	wildlife habitat	•relationship between nearshore ecology and shoreline processes poorly understood •compared fish community between intact vs. modified shorelines •found some shallow water and nearshore fish community measures influenced by adjacent shoreline features, and several measures related to urban-residential land uses and shore structure of updrift shoreline areas, suggesting cumulative human influence operating over larger spatial scales •conclude that multi-scale management strategies needed for shorelines that address both local and cumulative, larger-scale environmental impacts to local nearshore biota
Ecology of freshwater shore zones	D. L. Strayer, S. E. G. Findlay	2010	Aquatic Sciences 72: 127-163	shore zone ecology	•shore zones among most productive and most threatened habitats in the world •shore zones are complexes of habitats with high biodiversity •shore zones dissipate large amounts of physical energy, can receive and process high volumes of autochtonous and allochthonous organic matter, and undergo intensive nutrient cycling •the ecological character of shore zones influenced by physical energy, geologic or anthropogenic structure, hydrologic regime, nutrient inputs, biota, and climate

A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution	X. Zhang, Z. Liu, M. Zhang, R. A. Dahlgren, M. Eitzel	2010	Journal of Environmental Quality 39: 76-84	buffers: water quality	•quantified role of buffer width, slope, soil type and vegetation type on pollutant removal efficacy •buffer width alone explains 37% (sediment), 60% (pesticides), 44% (nitrogen), and 35% (phosphorus) of total variance in removal efficacy •buffer slope was positively associated with sediment removal efficacy when slope $\leq$ 10% and negatively when slope $\geq$ 10% •buffers made of trees had higher N and P removal efficacy vs. those made of grasses or grasses and trees •soil drainage type did not have significant effect on efficacy •conclude that 30 m buffer under favourable slope conditions removes >85% of all the studied pollutants
Impacts of riprap on wetland shorelines, Upper Winnebago Pool Lakes, Wisconsin	A. O. Gabriel, L. R. Bodensteiner	2011	Wetlands 32: 105-117	shoreline hardening	•compared riprapped to natural sites •armoured shorelines had coarser, more compacted substrates with lower organic content; cooler temperatures with higher dissolved oxygen; and greater water clarity •natural sites had more abundant floating-leaved plants, more abundant and larger fish
Disproportionate importance of nearshore habitat for the food web of a deep oligotrophic lake	S. E. Hampton, S. C. Fradkin, P. R. Leavitt, E. E. Rosenberger	2011	Marine and Freshwater Research 62: 350-358	wildlife habitat	•shallow nearshore disproportionately important as feeding and breeding habitat for fish in large deep oligotrophic lakes •found salmonid predators derived >50% carbon from nearshore waters, even though this zone only made up 2.5% total lake volume in Washington State lake
Shifts in aquatic macrophyte abundance and community composition in cottage developed lakes of the Canadian Shield	A. L. Hicks, P. C. Frost	2011	Aquatic Botany 94: 9-16	macrophyte community	•examined 12 lakes across cottage development gradient vs. macrophyte communities at 0.5 and 1.5 m depths •macrophyte biomass declined with increasing cottage density and more developed lakes had less diversity and species richness at shallower (0.5 m) depth •cottage development strongly correlated with community species composition
Avian responses to experimental harvest in southern boreal mixedwood shoreline forests: implications for riparian buffer management	K.J. Kardynal, J. L. Morissette, S. L, Van Wilgenburg, E. M. Bayne, K. A. Hobson	2011	Canadian Journal of Forestry Research 41: 2375-2388	wildlife habitat	•compared responses of riparian and upland-nesting birds to 3 levels of forest harvesting near shorelines of boreal wetlands (0-50%, 50-75%, 75-100% clearing within 100 m of water) •upland-nesting species showed greatest declines in abundance of interior forest nesting species with the highest harvest levels •shrub-nesting and generalist species increased in abundance •riparian birds showed little response to harvest •suggests retention of small buffers may not be an effective management strategy for conservation of birds occupying shoreline forests
Ecological Buffer Guideline Review	Beacon Environmental Ltd.	2012		buffers	•buffers protect water quantity, water quality, core habitat, screen human disturbance/changes to land use, serve as hazard mitigation zone •recommended buffer width depends on function, site-specific factors and wider landscape context •research mainly in agricultural context and on watercourses •generally 10-100 m range recommended
Naturally Vegetated Shoreline Buffers - An overview of the benefits and the science	J. McDonnell, MNR	2012		buffers	•30 m common width in Ontario but no science supporting one-size-fits-all approach

Assessing local and landscape patterns of residential shoreline development in Michigan lakes	K. E. Wehrly, J. E. Breck, L. Wang, L. Szabo-Kraft	2012	Lake and Reservoir Management 28: 158-169	coarse woody debris	•evaluated relationships between residential development intensity and littoral zone habitat and disturbance characteristics in 332 Michigan lakes $\geq$ 4 ha •residential development had strong negative effects on woody debris •lakes with greater cumulative residential development had greater littoral zone impacts at local scales •larger lakes had greater impacts in littoral zone
Terrestrial habitat requirements of nesting freshwater turtles	D. A. Steen, J. P. Gibbs, K. A. Buhlmann, J. L. Carr, B. W. Compton, J. D. Congdon, J. S. Doody, J. C. Godwin, K. L. Holcomb, D. R. Jackson, F. J. Janzen, G. Johnson, M. T. Jones, J. T. Lamer, T. A. Langen, M. V. Plummer, J. W. Rowe, R. A. Saumure, J. K. Tucker, D. S. Wilson	2012	Biological Conservation 150: 121-128	wildlife habitat	•reviewed records of >8000 nests and gravid female records for 31 species in Canada and the US •distancing encompassing 95% of nests varied among species •in Ontario mean distances from water for nests were 33.5 m (Spotted Turtle), 35.7 m (Northern Map Turtle), 51.8 (Snapping Turtle), 71.2 m (Blanding's Turtle), and 77.8 m (Painted Turtle)
Determining if Maine's Mandatory Shoreland Zoning Act Standards are Effective at Protecting Aquatic Habitat	K. Merrell, J. Deeds, M. Mitchell, R. Bouchard	2013	Vermont Department of Environmental Conservation and Maine Department of Environmental Protection	buffers	•compared lakeshore development in Vermont and Maine to compare different approaches to lakeshore development standards in 2 states •Maine's Mandatory Shoreland Zoning Act requires land use controls for all land within 76 m of ponds; Vermont has no standards and relies on individual stewardship of lakeshores •studied 234 reference lakeshore sites and 151 unbuffered developed lakeshore sites on 40 lakes in Vermont vs. 13 reference lakeshore sites and 36 developed sites on 5 lakes in Maine •found MSZA effective tool for mitigating effects of shoreland development: only 1 parameter (# odonata exuviae), had statistical differences between developed and undeveloped reference sites in Maine vs. all parameters for Vermont developed and undeveloped reference sites
Assessment of Municipal Site Evaluation Guidelines for Waterfront Development in Eastern Ontario's Lake Country	HESL	2014		buffers	•shoreline development linked to potential for elevated nutrient inputs, which can lead to host of problems including reduced water clarity, reduced hypolimnetic oxygen, proliferation of algal blooms •slope and soil characteristics influence potential for phosphorus from shoreline development migrating to lake •shoreline buffers are BMP for mitigating P enrichment •slopes >25% too steep to act as shoreline buffers •slopes up to 13% can effectively attenuate sediments and P if vegetation well established and forest litter present, but steeper slopes require wider buffer widths •vegetation plantings in buffer should focus on native, tolerant species with deep-rooting potential

The effects of lakeshore development on Common Loon (*Gavia immer*) productivity in the Adirondack Park, New York, USA	C. A. Spilman, N. Schoch, W. F. Porter, M. J. Glennon	2014	Waterbirds 37(sp1): 94-101	wildlife habitat	•mean distance from nest site to nearest point of development was greater for successful vs. failed nests •presence of nesting pairs significantly related to increased shoreline length and decreased level of development •Loon chick hatching success significantly related to development density on small but not large lakes •amount of development not as important to nesting Loons as placement: clustering of development allows buffer for nesting areas
Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: a literature review	B. W. Sweeney, J. D. Newbold	2014	Journal of the American Water Resources Association 50(3): 560-584	buffers: water quality/wildlife habitat	•wider buffers with more vegetation have greater capacity to intercept, sequester, degrade and process pollutants •grass buffer can adequately trap sediment and other contaminants, but more effective performance across greater number of functions achieved with forest buffer •focus on nitrogen and sediment removal •subsurface nitrate removal varied inversely with subsurface water flux, with wider buffers removing greater nitrogen under same water flux levels (89% for buffers >40 m vs. 55% median removal efficiency for buffers <40 m) •effective N removal at watershed scale likely requires buffers at least 30 m wide, with performance increasing above 30 m •10 m buffers trapped 65% sediment vs ~85% in 30 m buffers (mostly fine silts and clays make up difference) •protection for macroinvertebrates increases with presence of trees in buffer
The challenge of motivated cognition in promoting lake health among shoreline property owners: biased estimation of personal environmental impact	M.S. Amato, B. R. Shaw, E. Olson, N. Turyk, K. Genskow, C. F. Moore	2016	Lake and Reservoir Management 32(4): 386-391	perception of shoreline development	•property owners viewed own shoreline development as less harmful than it was judged by others •findings highlight barrier to outreach efforts to enlist property owner cooperation in mitigating habitat degradation from shoreline development
At the forefront of shoreline management	L. Borre, R. L. Smyth, E. A. Howe	2016	Lakeline Summer 2016: 8-13	effects of climate change on shorelines and lakes	•changing hydrology and water levels impact shorelines and lakes through erosion and sediment loading (flooding), and loss of wetland connectivity,exposure of aquatic vegetation in littoral zone (drought)
Coarse woody debris in temperate littoral zones: implications for biodiversity, food webs and lake management	M. Czarnecka	2016	Hydrobiologia 767: 13-25	coarse woody debris	•coarse woody debris provides stable habitat for many species in littoral zone of lakes with forested shorelines •creates spatial complexity in nearshore that promotes abundance, diversity and productivity of littoral biota •shoreline development reduces and modifies CWD entering lakes, resulting in (i) loss of fish spawning and refuge habitat, (ii) loss of food and habitat for benthic detritivores
A shoreline divided: Twelve-year water quality and land cover trends in Lake Ontario coastal wetlands	M. V. Croft-White, M. Cvetkovic, D. Rokitnicki-Wojcik, J. D. Midwood, G. P. Grabas	2017	Journal of Great Lakes Research 43: 1005-1015	water quality	•significant relationships between land cover and water quality index score at all scales (500, 1000, 2000 m wetland buffers, a quaternary watershed) but strongest at watershed scale

Inadequacy of best management practices for restoring eutrophic lakes in the United States: guidance for policy and practice	R. A. Osgood	2017	Inland Waters DOI 10.1080/20442041.2017.1368881	eutrophication	•examined effectiveness of watershed BMPs to restore eutrophic lakes •BMPs for P removal fall short of % required to restore lakes (generally require >80% external P reduction) but most BMPs provide 50% reduction (under ideal conditions) and <25% (in practice) •literature review found buffers remove 30-45% of upstream total P, but this results in no significant difference between P inputs and outputs •BMPs may be sufficient in small watersheds (<10x lake surface area), where external and internal P loading rates modest, or where incremental water quality improvement the goal, rather than restoration •in most cases effective P inactivation methods needed to mitigate internal P loading and intercept dissolved P in inflowing waters
A method for assessing shoreline stability of Alpine Lake, West Virginia	C. Rando, L. Hopkinson, M. O'Neal, J. Fillhart	2017	Journal of Contemporary Water Research & Eduction 160: 85-99	shoreline stability	•developed rapid stability assessment tool for lake shoreline based on measures of bank height, bank angle, erosion, armouring, wind and wave action, unconsolidated materials, protection measures, vegetation, and accretion •compared assessment results to observed erosion rates
Assessing LakeSmart, a community-based lake protection program	F. R. Cole, A. Junker, C. R. Bevier, M. Shannon, S. Sarkar, P. J. Nyhus	2018	Journal of Environmental Studies and Sciences 8: 264-280	water quality, BMPs	•participants in LakeSmart program more likely to recognize threat of declining water quality, adopt or enhance existing lake-friendly landscaping bmps, and help foster strong sense of community than non-participants
Current insights into the effectiveness of riparian management, attainment of multiple benefits, and potential technical enhancements	M. Stutter, B. Kronvang, D. Ó hUallacháin, J. Rozemeijer	2019	Journal of Environmental Quality 48: 236-247	buffers: water quality, wildlife habitat	•gaps in knowledge on capture and retention of soluble P and N in subsurface flows through buffers, impact of buffer design and management on terrestrial and aquatic habitats and species; effect of saturated buffers on greenhouse gas emissions •agricultural context
Effects of forested buffers on benthic macroinvertebrate indicators of water quality in the Western Finger Lakes, New York	M. C. Owens, C. J. Williams, J. M. Haynes	2021	Inland Waters 11(1): 78-88	buffers: macroinvertebrate indicators of water quality	•few studies examine effectiveness of buffers in reducing pollutant runoff to lakes (most focus on rivers and streams) •compared macroinvertebrate community composition between oligo-mesotrophic lakes with reforested watersheds (including shoreline buffer strips) and unprotected meso-eutrophic lakes with mix of land uses (mixed, forested, agricultural, developed) •found no difference in biotic index of water quality between lakes •subwatershed land use generally did not correlate with biotic indices of water quality within lakes •suggests nearshore forest buffers do not have significant impacts on benthic macroinvertebrate communities and their biotic indicators of water quality, instead these communities are likely infleunced by within-lake habitat conditions and legacy effects of agricultural land

A secondary assessment of sediment trapping effectiveness by vegetated buffers	R. Ramesh, L. Kalin, M. Hantush, A. Chaudhary	2021	Ecological Engineering 159: 106094	buffers: water quality	•meta-analysis to explore sediment removal capacity of riparian buffers (>90 studies) •assessed role of buffer width, length, area; vegetation characteristics; residence time and roughness (above-ground obstacles to runoff and sediment flow); area ratio (upland contributing area: buffer area); sediment loads; inflow and outflow volumes, flow rates •overall mean sediment removal efficiency 75% and median removal 82% •grass and mixed grass-woody vegetation buffers had higher efficiency than woody vegetation only buffers (but data limited on mixed and woody-only buffers) •buffer width influences efficiency, with 10-20 m buffer better able to trap sediment than smaller or larger width categories •could not identify any critical slope influencing effectiveness of sediment reduction by buffer •developed model describing relationship between buffer sediment removal efficiency, water inflow/outflow volume, and roughness, explaining 50% of variation •findings emphasize importance of considering flow parameters in buffer design
Forested riparian buffers change the taxonomic and functional composition of stream invertebrate communities in agricultural catchments	J. Sargac, R. K. Johnson, F. J. Burdon, A. Truchy, G. Rîşnoveanu, P. Goethals, B. G. McKie	2021	Water 13: 1028	buffers: wildlife habitat	•assessed how different riparian vegetation types influence stream invertebrate communities in agricultural landscapes •forested riparian buffers had greater shading, increased gravel content in stream substrates, and faster flow velocities •detected changes in invertebrate taxonomic composition in response to buffer presence: increase in sensitive Ephemeroptera, Plecoptera, Trichoptera taxa, increase in species with preference for gravel substrates and aerial active dispersal as adults