GUIDING SOLUTIONS IN THE
NATURAL ENVIRONMENT

Ecological Buffer Guideline Review

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Disclaimer

This document was produced by Beacon Environmental under the direction of a project Steering Committee comprised of a number of Conservation Authority representatives (as listed above). It should be noted that the opinions and conclusions expressed herein are those of the authors and do not necessarily reflect the individual positions of any of the Steering Committee members, or those of the organizations they represent.

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1. Introduction

The loss and fragmentation of natural habitats in southern Ontario continues to present challenges for planners and ecologists tasked with identifying natural heritage systems that are to be maintained for the long term (as per the Provincial Policy Statement 2005, Policy 2.1.2). Although ecological buffers cannot compensate for habitat scarcity and fragmentation (see **Section 5.1.1**), they have been increasingly recognized as useful planning tools for helping to protect remnant natural heritage features, and their associated functions, from some of the impacts of adjacent land uses in both rural and urbanizing contexts (e.g., Bennett and Molongoy 2006). Buffers can help attenuate sediments and pollutants, screen against human disturbances (such as noise), serve as a habitat transition zones, and contribute to the protection of the given area (e.g., by maintaining microclimate conditions or limiting the spread of invasive species). In the case of forested habitat edges or steep slopes, they can also mitigate potential hazards by providing separation from the potential hazard zone.

> ***The prime purpose of a buffer zone is to insulate areas where biodiversity conservation is the primary objective from potentially damaging external influences, and particularly from those caused by inappropriate forms of land use.***
>
> Bennett and Molongoy 2006
>
> ***A "Buffer" means a zone specifically designed to provide a measure of protection to the natural heritage features and functions, or a transition area between the built form (generally lot line) and the natural feature. The buffer should be planted or allowed to naturalize.***
>
> City of Brampton Official Plan 2006

In southern Ontario, as communities continue to grow, and increasingly recognize the multiple values of their local natural heritage, there is a growing desire to find ways to effectively integrate sustainable natural heritage systems within both urbanizing and rural landscapes. However, there continues to be debate and uncertainty about both the functions that can or should be ascribed to buffers (as described in **Section 2**), as well as appropriate widths for buffers and how best to determine appropriate widths in different contexts.

As natural heritage planning evolves in Ontario, so do the resources and tools for both planners and ecologists to draw on, but specific and quantitative guidance related to buffers continues to be limited in this Province. The Provincial Policy Statement (MMAH 2005) does not specifically address the issue of buffers or define them (see **Section 4**), although they are typically considered as part of the assessment of adjacent lands. The recently updated companion guideline to the Provincial Policy Statement, the Natural Heritage Reference Manual (OMNR 2010), discusses buffers at length, but provides limited guidance in terms of their site-specific implementation[1].

The absence of more specific direction is not surprising given the number and range of factors that need to be considered for appropriate buffer determination (see **Sections 3.5 and 3.6**), however it

[1] The Natural Heritage Reference Manual (OMNR 2010), which is the primary supporting guideline document for implementation of the Provincial Policy Statement (MMAH 2005), defines buffers and asserts their value in mitigating against impacts related to site alteration. and/or development adjacent to natural heritage features throughout the document, but does not recommend minimum widths for any features other than fish habitat (see Table 11-3, p. 106).

leaves the door open to tremendous variability in the way in which buffer requirements are identified and implemented. Typical considerations include: the area and nature of the feature being protected, the nature of the anticipated adjacent land use, the functions which the buffer is expected to perform, and the local biophysical context (e.g., slopes, soils, surface drainage, groundwater conditions and flows). Bringing all these considerations together to generate an appropriate buffer width, or range of widths, requires a good understanding of: (a) the local conditions and sensitivities of the protected feature; (b) the anticipated impacts associated with the change in adjacent land use; and (c) the impacts that a buffer can, and cannot, reasonably be expected to mitigate in that context. To further complicate matters, there are still many gaps in our knowledge regarding how different natural areas, and the species they provide habitat for, respond to changes in adjacent land uses, particularly in an already fragmented landscape. Some responses may be immediate, but others may take years or even decades to manifest themselves (see **Section 5.1.2**). Nonetheless, the Conservation Authorities in southern Ontario have identified a need to develop guidance based on the current science and best practices to ensure that buffer requirements are identified and applied as appropriately and consistently as possible.

In attempt to encourage consistency and provide a relatively high level of protection to natural heritage in the landscape, the provincial Oak Ridges Moraine Conservation Plan (2002), Greenbelt Plan (2005), and Lake Simcoe Protection Plan (2009) all provide prescriptive and specific buffers (as described in **Section 4.1**) – called Vegetation Protection Zones (VPZ) - of at least 30 m on all Key Natural Heritage Features that are to be protected outside of settlement areas (and in some cases within settlement areas). Where VPZs are not prescribed, there is often guidance related to buffers[2], but not specifically to buffer widths.

Conservation Authorities in Ontario are frequently required to confirm or determine appropriate buffer widths for natural areas regulated by them (i.e., wetlands – including wooded wetlands – watercourses, lakeshores, and hazard lands) as part of the permitting process, and in many areas are also asked to comment on natural heritage aspects of development proposals (including appropriate buffers) on behalf of planning authorities, or as part of other stakeholder processes. While some Conservation Authorities in Ontario have developed policies and guidelines related to buffers, they are not consistent among jurisdictions, while others choose to address buffers on a case by case basis.

The purpose of this review was to conduct a critical assessment of the scientific literature on ecological buffers (**Section 3**), provide an overview of the current policy context for buffers in southern Ontario (**Section 4**), and draw on these findings (as discussed in **Section 5**) to develop an evaluation methodology for determining appropriate buffer widths around natural heritage features based on the best available science and in consideration of current practices (**Section 6**).

Throughout the development of this review, the authors were cognizant of the importance that any direction coming out of this review be defensible. Therefore, although this review considers current practices (**Section 4**), the recommendations ultimately developed for the evaluation methodology presented in **Section 6** are largely based on the critical review and synthesis of the current science (**Sections 3 and 5**).

[2] For example, the Lake Simcoe Protection Plan requires that where buffers are required as a result of the application of the Provincial Policy Statement that it shall be "*composed of and maintained as self-sustaining vegetation*".

1.1 Study Scope and Objectives

The objectives of this review were to:

1. Undertake a review of the current scientific and technical literature surrounding ecological buffer guidelines,
2. Undertake a review of the current practices in southern Ontario related to ecological buffers, and
3. Create an evaluation methodology for determining buffers surrounding natural heritage features based on the findings of objective 1 and with consideration for the findings of objective 2.

Originally the intent of the steering committee was that the emphasis of the review should be on case studies and other sources that evaluate the effectiveness of buffers in protecting natural features in both urban and rural settings. However, it was agreed during subsequent discussions with the steering committee (Feb. 1st, 2011) that there are very few known studies of buffer effectiveness in southern Ontario, or elsewhere, and that the review would consequently need to rely more heavily on a critical synthesis of the past and current scientific literature, as well as available technical reports. It was also agreed during subsequent discussions that the primary focus of the guidelines would be on buffer determination for urbanizing contexts, since these are the situations where Conservation Authorities are primarily required to provide buffer recommendations.

Given the prevalent and long-standing use of buffers as a mitigative tool in natural heritage planning, particularly for watercourses and wetlands, it is surprising that there is such a dearth of published short or long-term monitoring studies focussing on buffer effectiveness in relation to their ability to protect core habitats. In part, this is due to the difficulty of correlating cause and effect in such studies (e.g., Underwood 1994).

While monitoring can readily document what is happening within the buffer (e.g., increases in wildlife use or vegetation development for example), and within the core natural area (e.g., shifts in bird species abundance and diversity), only a very carefully designed and well-replicated study with controls may be able to detect if any changes (or lack thereof) in the core habitat are related to the presence (or absence) of a buffer. Often, in real world situations, there are not opportunities to create adequate replicates, or set aside control sites. In addition, monitoring (particularly long-term monitoring) requires both a financial and resource commitment that is beyond the means of most jurisdictions. It also requires individuals who understand the importance of good study design, and are able to make sense of intensive and temporally extensive data, something that is seldom, if ever, undertaken in Ontario for projects under the *Planning Act*.

Although this review refers to, and draws on, literature extending back into the 1980's, there are a number of good review papers that were published up to the early 2000's, therefore the focus of the searches for literature was on more recent scientific and technical articles published since 2000. Literature from prior to (and including) 2000 was gathered and incorporated from previous reviews compiled by members of the study team, and selected additional papers from prior to 2000 that were considered particularly relevant were also added.

This review also specifically focuses on: (a) papers related to ecological buffers as defined in this review (see **Section 2**), and (b) papers that provide numerical buffer recommendations (particularly those based on empirical data collection). Papers that use the term "buffer" but have actually examined the ability of natural or semi-natural areas adjacent to another natural feature to provide habitat (e.g., breeding, foraging, migratory) and/or wildlife corridor functions have generally been excluded. Although qualitative research findings or trends related to buffers have been included, recommended quantitative buffer widths, or ranges, have been highlighted where available so that they that can be used to inform buffer guideline evaluation approaches.

Although a primary focus of the literature review was on research that examines and makes recommendations around effective buffer widths, it was understood that there are many factors that can influence the effectiveness of a buffer apart from its width. Therefore, research on (a) biophysical factors (**Section 3.5**), and (b) buffer design components (**Section 3.6**) that influence buffer effectiveness was also explored and is discussed.

2. Defining Ecological Buffers

2.1 What are Ecological Buffers?

Despite the term being used in the scientific and technical literature since the 1970's, buffers, and specifically ecological buffers, continue to be defined inconsistently and assigned a variety of possible functions (e.g., Martino 2001). It is therefore necessary to clearly describe buffers as they have been defined for this review to frame the scope of the work undertaken and the application of the findings.

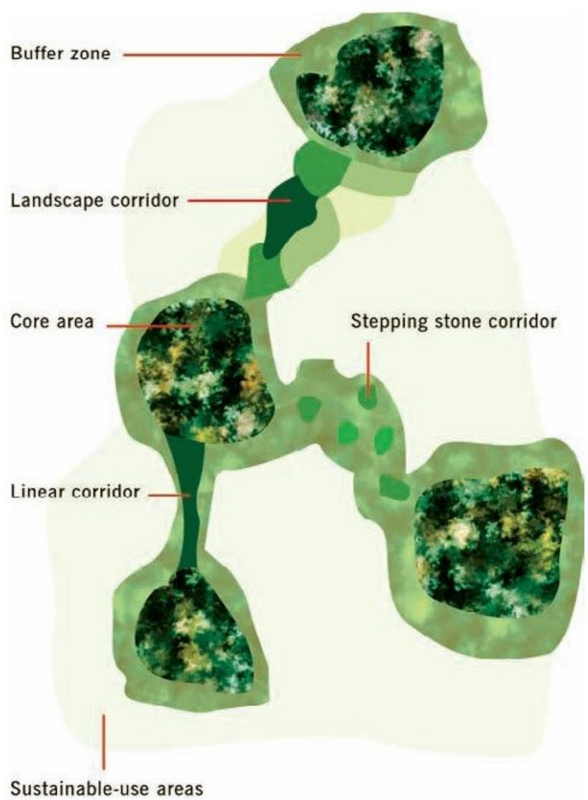

Figure 1. Diagrammatic representation of buffers in the context of a natural heritage network (from Bennett and Mulonguoy 2006).

For this review, buffers are specifically being examined in terms of their ability to protect the natural feature or function of interest, and mitigate the impact of stressors typically arising from the existing or anticipated land use outside the feature or area of function, as described in the Province's recently updated Natural Heritage Reference Manual (OMNR 2010). This guidance document specifies that a buffer should:

- Be between a natural feature and lands subject to development or site alteration;
- Be permanently vegetated (preferably with native species); and
- Protect the natural feature against the impacts of the adjacent land use (rather than provide the functions of the feature itself).

While we generally agree with this description, arguably it overlooks one very important aspect of natural heritage planning. A strictly features-based definition suggests that a feature will encompass the full extent of the critical ecological functions associated with it. However, this is not always the case (e.g., as in the critical role of terrestrial uplands beside wetlands for pond-breeding amphibians, or a turtle nesting area beside a marsh). These areas adjacent to natural heritage features, (that have been identified as important) are incorporated in to the protected area because they are functionally important have been called Critical Function Zones (or CFZs) (Environment Canada 2004) (as illustrated **Figure 2**). Therefore, the somewhat broader definition that speaks to buffers as providing separation from environmentally "sensitive" areas by Norman (1998) is presented here as a more comprehensive and appropriate definition for ecological buffers. This definition assumes that the area being protected includes both the feature that has been identified as significant along with any lands that may be required to protect critical ecological functions of species associated with that feature (i.e., CFZs), prior to determination of any buffer requirements. In this way, the functions of the protected area are clearly distinguished from those of the buffer.

Buffers, as defined for this review, have also been called Protection Zones (as in Environment Canada 2004), or Vegetative Protection Zones (as in the Oak Ridges Moraine Conservation Plan 2002, Greenbelt Plan 2005, and Lake Simcoe Protection Plan 2009) or vegetative filter strips (e.g., Dillaha 1985; Magette *et al.* 1986; Heningsen and Best 2005; Gharabaghi *et al.* 2006). For the purposes of this review, these terms are considered synonymous with "ecological buffers".

> ***Buffer strips are strips of vegetated land composed in many cases of natural ecotonal and upland plant communities which separate development from environmentally sensitive areas and lessen [the] adverse impacts of human disturbance.***
>
> Norman 1998

The term "buffers" is also sometimes confused with terms used to describe other lands outside of protected or designated natural areas, such as setbacks, adjacent lands, and Critical Function Zones. These are each discussed in terms of how they differ from buffers briefly below.

<u>Setbacks</u>: Although often colloquially used as a synonym for buffer, this term is primarily meant to be used as a land use planning term, and more specifically a zoning term, used to describe the minimum required distance between any structure and a specified line (e.g., such as a lot line). Setbacks may include ecological buffers, but are simply distances from a fixed structure or piece of infrastructure, and are not necessarily vegetated.

<u>Adjacent lands</u>: This is another planning term used by municipalities and conservation authorities which, when used in relation to natural heritage features, means (as defined in the

Provincial Policy Statement (MMAH 2005)), "*those lands contiguous to a specific natural heritage feature or area where it is likely that development or site alteration would have a negative impact on the feature or area*". These are typically prescribed at between 50 m and 120 m from the boundary of the protected or designated natural feature[3], and are essentially a trigger for some type of environmental study (typically an Environmental Impact Study (EIS)). Adjacent lands may – and often do - ultimately include buffers, but do not serve the same function. Their function is to ensure that the study area is sufficiently extensive to (a) properly confirm the actual natural area feature boundaries, and (b) assess impacts to the natural area(s) potentially associated with the proposed activities. One of the purposes of the environmental study would be to make recommendations related to an appropriate buffer for the feature, however this width would typically not be equivalent (and would typically be less) than the adjacent lands distance.

Critical Function Zone (CFZ): This term was first formally introduced in the most recent version of *How Much Habitat is Enough?* (Environment Canada 2004) to describe non-wetland areas adjacent to wetlands "*within which biophysical functions or attributes directly related to the wetland of interest occur*". Examples of CFZ include upland grassland nesting habitat for waterfowl, or foraging and overwintering habitat for amphibians that breed in wetlands, as illustrated in **Figure 2**. Notably, the CFZ does not typically include the entire range of habitat used by a given species (e.g., for foraging) but would include the extent of the habitat that is considered critical for that species' survival. Once the CFZ for a given site is identified, then a buffer (or a Protection Zone (PZ)), where appropriate, would be identified around it. Although this term is not ubiquitous in the technical or scientific literature, it is very relevant to this review because it highlights the importance of separating core habitat functions (which should be included in the protected natural area) from protective measures (which should be assumed by the buffer to the greatest extent possible)[4].

Buffers are also sometimes described and studied as features that provide habitat in their own right, such as wildlife corridor functions. While buffers often can and do provide some types of habitat functions, they should not (according to the definition being used here) be identified or designed to provide habitat *per se*, but should be identified and designed to provide protection from the site alteration and/or development in the adjacent lands.

The prime purpose of a buffer zone is to insulate areas where biodiversity conservation is the primary objective from potentially damaging external influences, and particularly from those caused by inappropriate forms of land use.

Bennett and Mulongoy 2006

Buffers should not be treated as extensions of the natural feature.

Natural Heritage Reference Manual (OMNR 2010)

[3] The recently updated Natural Heritage Reference Manual (OMNR 2010) recommends that adjacent lands for all significant natural heritage features be 120 m, with the exception of earth science Areas of Natural and Scientific Interest (50 m) and inland trout lakes on the Canadian shield (300 m).

[4] The current Provincial Policy framework does not explicitly provide for protection of CFZs beyond the actual feature boundaries, although there is some implicit protection through the latest significant wildlife habitat identification criteria, as well as some explicit protection for a few species with regulated habitat listed as provincially threatened or endangered. In the absence of such explicit protection, it is important to identify the extent of habitat required as part of a natural heritage system prior to,and as separate exercise from, determining appropriate buffers for those protected areas.

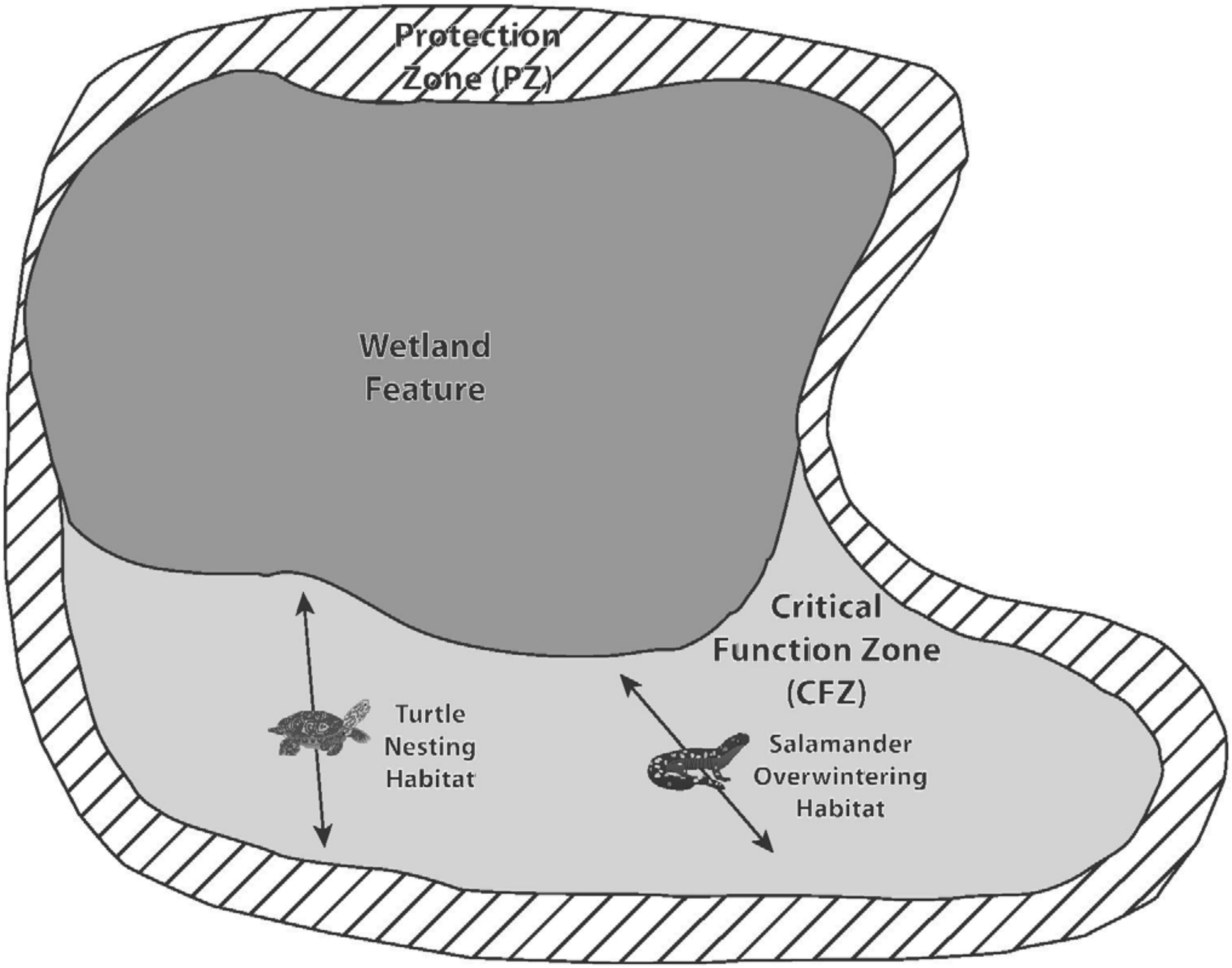

Figure 2. Illustration of distinction between core habitat (a wetland in this case), the Critical Function Zone (CFZ) and the buffer, or Protection Zone (PZ).

In a recent buffer guideline document prepared by the United States Department of Agriculture (Bentrup 2008), buffers (or "conservation buffers" as they are called in the document) are defined as "*strips of vegetation placed in the landscape to influence ecological processes and provide a variety of goods and services to us ... called by many names, including wildlife corridors, greenways, windbreaks, and filter strips* ...". This illustrates the persistent confusion of buffers with other features such as wildlife corridors that should be identified as having important habitat value in their own right.

Additional examples of the range of ways in which the term buffer is used (and misused) can be found in both the scientific and technical literature. A few relevant examples are cited below:

- Guidelines that state key ecological functions of buffers may include providing linkage as a wildlife corridor and contributing to habitat and species diversity (e.g., City of London 2003);

- Scientific papers that examine the use of riparian buffers as wildlife corridors (e.g., Machtans *et al.* 1996);
- Papers that examine the use of riparian habitats by various species in the natural areas adjacent to streams corridors, and call these areas "buffers" (e.g., Spackman *et al.* 1995; Wilk *et al.* 2010; Rundio and Olsen 2007; Machtans *et al.* 1996; Davros *et al.* 2006); and
- Papers that identify Critical Function Zones (CFZ) for amphibians and reptiles (e.g., uplands needed for foraging, overwintering, seasonal migration) but call these areas "buffers" to wetlands (e.g., Veysey *et al.* 2009; Harper *et al.* 2008; Friedenfelds *et al.* 2011; Blank *et al.* 2011; Attum *et al.* 2007).

The term "buffer" is also sometimes used to refer to the 100 m (or sometimes 200 m) distance in from the edge of an upland forest unit from which the "interior" portion of the forest is measured (e.g., Wood *et al.* 2006; Burke and Nol 1998). Although the tool used to conduct this type of analysis using Geographic Information Systems is actually called a "buffer" tool, when applied starting from the outer edge of the unit or functional area inwards it is not identifying a buffer to the feature and/or function in the sense intended by this report, but rather capturing what is generally considered the "edge habitat" of the feature.

Although outside the scope of this review, it is notable that there is a renewed interest in and study of CFZ (as illustrated in **Figure 2**), in part because the miniaturisation of tracking devices and other tools now allow for the spatial distribution and movement of animals to be determined with accuracy. This research will contribute to the evolution of natural heritage planning in Ontario, and elsewhere, and will hopefully help make a clearer distinction between CFZ and buffers to them. The salient point for the purposes of this review is that the CFZ must be identified and incorporated into the "core" protected area prior to the determination of an appropriate buffer (or Protection Zone).

2.2 What Can Buffers Do?

The overall function of a buffer, as described above, is to try insulate a protected natural area from the impacts of adjacent land uses (usually land use changes) so that this area can continue to provide the same, or a comparable range of, ecological goods and services, as it did prior to the change in land use. A summary of specific functions ascribed to buffers is presented in **Table 1.**

> ***Well-designed buffers protect and maintain wetland functions by removing sediments and associated pollutants from surface water runoff, removing, detaining, or detoxifying nutrients and contaminants from upland sources, influencing the temperature and microclimate of a water body, and providing organic matter to the wetland. Buffers also maintain habitat for aquatic, semi-aquatic, and terrestrial wildlife ...***
>
> **Planners Guide to Wetland Buffers for Local Governments (2008)**

Another function sometimes ascribed to buffers, more so by planning authorities than scientific researchers, is to provide opportunities for enhancement or restoration of the core area (e.g., Region of Waterloo 2010). While this may be a laudable objective, this review has not confounded ecological restoration and enhancement with the protection of target functional areas or natural cores. In our view**,** protection and restoration, while complementary, often require different approaches in terms of both planning and implementation, and therefore buffer functions in relation to restoration are not addressed in this review.

Table 1. Overview of Documented Ecological Buffer Functions

FUNCTION CATEGORY	SPECIFIC FUNCTION	SELECTED SOURCES
A. WATER QUANTITY	Attenuation of storm water flows*	Leavitt 1998; Booth 1991; Brown *et al.* 1980; Diana *et al.* 2006
B. WATER QUALITY	Sediment attenuation	Brown *et al.* 1990; Lowrance and Sheridan 2005; Dillaha *et al.* 1986b; Young *et al.* 1980
	Nutrient attenuation / transformation	Bradley *et al.* 2010; Yamada *et al.* 2007; Arango and Tank 2008
	Fecal coliform attenuation	Sullivan *et al.* 2007
	Toxin and heavy metal attenuation / transformation	Thompson *et al.* 2004; Burn 2003; Gay *et al.* 2006; deJong *et al.* 2008
	Water temperature moderation	Leavitt1998
C. SCREENING OF HUMAN DISTURBANCE / CHANGES IN LAND USE	Wind and noise attenuation	Brown *et al.* 1990; Richardson and Miller 1997; Forman 2000
	Light dampening	DeWalle 2010; Kiffney *et al.* 2003
	Screening from physical disturbances (e.g., human activities such as mowing / walking / biking, dumping debris, construction, pets)	Eigenbrod *et al.* 2008; Wenger 1999; Farmer 1991; Cooke 1992; McWilliam *et al.* 2011
D. HAZARD MITIGATION ZONE	Stream bank / slope stabilization	Nilaweera and Nutalaya 1999; Schwarz *et al.* 2010; Tang and Montgomery 2000; Castelle and Johnson 2000
	Mitigate consequences of large branch or tree fall	Schwarz *et al.* 2010; Matheney and Clark 1998
E. CORE HABITAT PROTECTION	Maintaining microclimate conditions (e.g., shade / cooling for fish habitat and forest "interior" species)	Jones *et al.* 1999; Moore *et al.* 2005; Kiffney *et al.* 2003; DeWalle 2010
	Contributing nutrients, large woody debris, and cover (for watercourses, water bodies and wetland areas)	Castelle and Johnson 2000; Steinblums *et al.* 1984
	Maintenance of protected area's biotic integrity: • Limiting spread of invasive species • Providing area for tree roots • Species diversity	• Cutway and Ehrenfeld 2009; Gavier-Pizzaro *et al.* 2010; Vilà and Ibaňez 2011 • Gilman and Partin 2007; Fite and Smiley 2008; Fitzpatrick 2002 • De Luca *et al.* 2004; Diana *et al.* 2006; Palik and Kastendick, 2010; Pollett *et al.* 2010

* This ability is compromised in typical urban settings where sections of streams are channelized and there is a lot more impervious cover (Leavitt 1998). Buffers to water bodies in urban areas have also been shown to have reduced attenuation functions in the face of large and sudden storm events because it is too much water at once (Booth 1991).

Research focussing on buffer functions related to provision of habitat (e.g., wildlife corridor, breeding, foraging) has also been excluded to maintain consistency with the definition of ecological buffers specified here (as described in **Section 1.1**). While buffers, and specifically ecological buffers in the sense described in this review, are intended to protect wildlife habitat, they are not intended to provide habitat in and of their own right (although they often do provide some types of supportive habitat).

Notably, the main functional categories for buffers identified in **Table 1** have been used as the main sub-headings for each of the following sections discussing the scientific and technical literature related to vegetated buffers for (a) watercourses and water bodies, (b) wetlands, and (c) upland woodlands and forests.

3. Literature Review

Section 3 summarizes the findings of the literature review conducted on ecological buffers. Although there are several ways these findings could have been organized, this review organizes them according to broad habitat types, as follows:

- Buffers to watercourses and water bodies (**Section 3.1**)
- Buffers to wetlands (**Section 3.2**)
- Buffers to upland woodlands / forests (**Section 3.3**)
- Buffers to meadows and other specialized habitats (**Section 3.4**)

Buffer types and design were identified as a particular area of interest at the outset, and are discussed, to the extent possible based on the review in **Section 3.5** in relation to all habitat types.

This format was selected because: (a) different habitats tend to interact with adjacent land uses in fundamentally different ways due to their different hydrologic dynamics and vegetative structures, and (b) buffer research – and application – tends to be focussed around distinct habitat types. Notably, the available science only speaks to buffers to watercourses and wetlands, and to some limited extent (*via* extrapolation from edge effect science) woodlands, forests and meadows. Therefore, not all natural heritage feature categories identified in the Provincial Policy Statement are addressed through this review. In particular, no information on buffers to valleys was available for consideration. In addition, buffers to somewhat specialized habitats that occur in southern Ontario (e.g., alvars, cliffs, shrub thickets) are not specifically addressed because of the absence of any scientific or technical literature regarding buffers to them.

There are also a number of concepts and themes related to buffers that emerge from the literature that apply to various habitat types. These are discussed in **Section 3.5** and **Section 5**.

The focus of the literature search was on obtaining relevant peer-reviewed, scientific journal articles, however technical articles (referred to as "grey literature") were also screened and included where deemed appropriate. As mentioned in **Section 1.1**, the literature searches were also focussed on papers and documents published after 2000[5] in recognition of the fact that there are several fairly comprehensive literature reviews that examine the literature up until that date (and in some cases

[5] The literature review component of this project was completed in June 2011and therefore documents considered include those published that month or before, with the exception of a very few articles incorporated as part of document review and finalization.

beyond), including work undertaken by members of Beacon's study team (e.g., Henshaw and Leadbeater 1999), whose findings have been incorporated into this review. Over the course of the literature searches for buffer papers, more than 3,000 articles were screened from natural sciences databases, and more than 250 were reviewed in detail.

This review is intended to inform decision making in southern Ontario, therefore papers selected for detailed review were generally studies with at least some empirical data collected in temperate habitats in eastern North America, although papers from other places were also included where they were considered relevant or able to shed light on specific topics of interest.

3.1 Buffers to Watercourses and Water Bodies

There are two categories of buffers to watercourses and water bodies that will be considered in this section, as follows:

1. Buffers to watercourses and water bodies (e.g., lakes, permanent ponds); and
2. Buffers to the bands of vegetation, or lands, immediately adjacent to watercourses and water bodies, generally described as riparian areas[6].

The difference between these two is illustrated in **Figure 3**. This figure labels buffers to watercourses as the "Aquatic Protection Zone" (Category 1 above), and buffers to riparian areas as the "Terrestrial Protection Zone" (Category 2 above) to distinguish them. This figure also illustrates the "Critical Function Zone" which can provide critical habitat functions for a wide range of species that are adapted to breed and/or forage in vegetated areas immediately adjacent to watercourses or water bodies. Depending on a variety of local conditions and factors, a terrestrial protection zone may not be feasible or appropriate.

Valleylands are also a distinct natural heritage feature under the Provincial Policy Statement (2005) related to watercourses insofar as they are defined as: "*a natural area that occurs in a valley or other landform depression that has water flowing through or standing for some period of time*". However, the boundaries and extent of valleylands are not identified consistently among conservation authorities, or among municipalities, and although valleys typically contain riparian areas, riparian areas and valleylands are not synonymous. Furthermore, no scientific or technical research using the term "valleylands", particularly in relation to buffers, was uncovered as part of this study and therefore it has not been considered further in this literature review.

Riparian areas have also been fairly well-documented as movement corridors for various species of wildlife. However the focus of this review was on research that evaluates the functions of buffers to either watercourses or water bodies themselves, or to their riparian areas, not on the intrinsic habitat values of either of these features.

As discussed in **Section 2**, this review assumes that the full extent of the Critical Function Zone associated with the feature has already been identified (and protected) prior to any consideration of appropriate buffer width and/or design. However, the extent of these zones for watercourses and

[6] For the purposes of this review we intend riparian areas to be defined as per the definition provided by Biology Online – "An area of land directly influenced by water. An ecosystem that is transitional between land and water ecosystems. Riparian areas usually have visible vegetative or physical characteristics reflecting the influence of water. River sides, lake borders, and marshes are typical riparian areas".

water bodies continues to be debated, and their determination can be particularly challenging for both lake shores and watercourses, which tend to be dynamic, both temporally and geographically. Pond edges and lakeshores are known to fluctuate seasonally, as well as between years, depending on the weather, but generally within a relatively limited range (e.g., no more than a few feet). However watercourses, depending on their biophysical and land use setting, can move within their meander belt, and also change substantially from headwater drainage features to higher order streams in the landscape. While it is beyond the scope of this review to explore all these issues, it is important to recognize that while there is some consensus around the idea that maintenance of some type of vegetated riparian zone is required for a watercourse or water body to maintain its full range of ecological functions, there continues to be a lack of consensus about how to define this zone[7],[8].

As natural heritage planning in southern Ontario evolves, there is a growing interest in and need to better define the full extent of the Critical Function Zone associated with watercourses and water bodies, as well as the Critical Function Zone associated with riparian lands, and then considering the appropriateness of buffering these areas, and what widths and types of buffers are most suitable. Unfortunately, the available science and technical research are not yet substantial or refined enough to address all of these issues.

As is evident in the following sub-sections, the two categories of buffers described above are rarely distinguished in the scientific or technical literature, which generally refers to the entire zone adjacent to the watercourse or water body as a “Riparian Buffer”, as shown in **Figure 4**, irrespective of the intrinsic ecological and habitat functions that zone may have unto itself. Most of the research on ecological buffers that has accumulated since the 1980’s has focussed on the buffer functions of riparian vegetation. The bulk of this scientific and technical research has focussed on the water quality functions of vegetated buffers to permanent watercourses (e.g., rivers, creeks and streams) in an agricultural or forestry setting (e.g., Steinblums *et al.* 1984; Welsh 1991; Durst and Ferguson 2000; OMNR 2000) (as illustrated in **Figure 4**), and responses of wildlife lakeshore development (e.g., Traut and Hostetler 2003; 2004). Some research has also examined the water quality and quantity functions of riparian buffers in the context of urbanization (e.g., Woodard and Rock 1995; Schueler 2000; Matteo *et al.* 2006). There are also a number of papers that have examined the habitat functions of riparian areas adjacent to watercourses (e.g., Croonquist and Brooks 1993; Spackman and Hughes 1995; Hennings and Edge 2003; Pearson and Manuwal 2001; Perkins and Hunter 2006; Ficetola *et al.* 2008; Wilk *et al.* 2010; Marczak *et al.* 2010), but no researchers consider the potential need for a buffer to these habitats with the exception of Semlitsch and Bodie (2003) who generically recommend a 50 m buffer to watercourse riparian habitat for stream breeding amphibians.

[7] Conservation Authorities regulate lands typically associated with riparian areas (e.g., lands adjacent to watercourses including meander belts, floodplains, wetlands and hazard lands)). However this regulated area may or may not encompass all the vegetation adjacent to a watercourse. Debate about defining the extent of the “riparian area” continues.
[8] The Rouge North Management Plan (Schollen & Company 2001), Chapter 4, defines the riparian areas broadly as bankfull channel width + meander belt width + vegetation community maintenance areas.

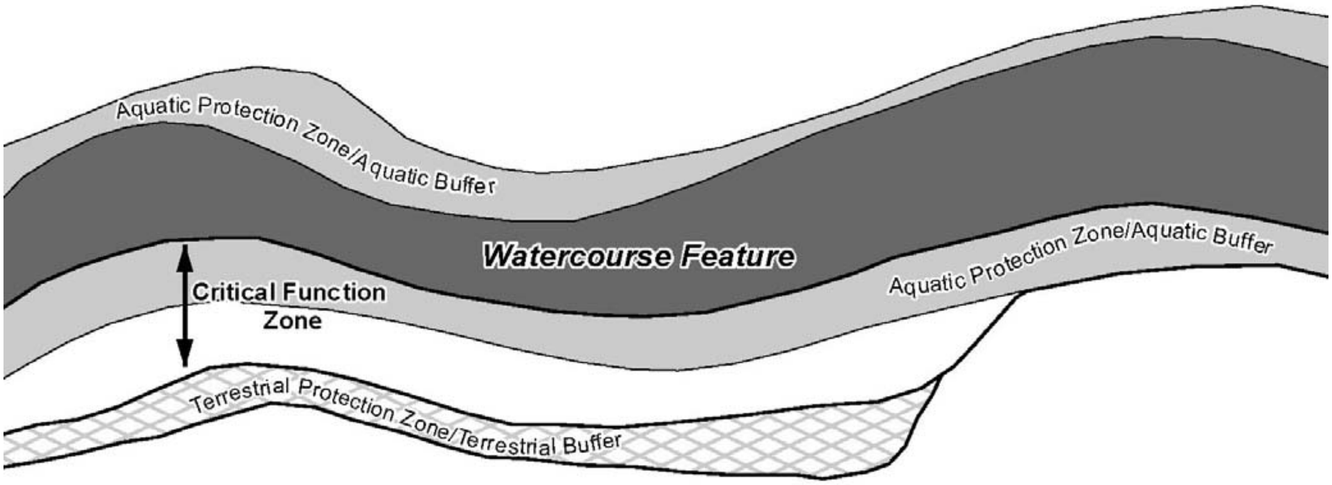

Figure 3. Illustration of distinction between the Aquatic Protection Zone (or buffer to the watercourse) and the Terrestrial Protection Zone (i.e., buffer to the riparian area).

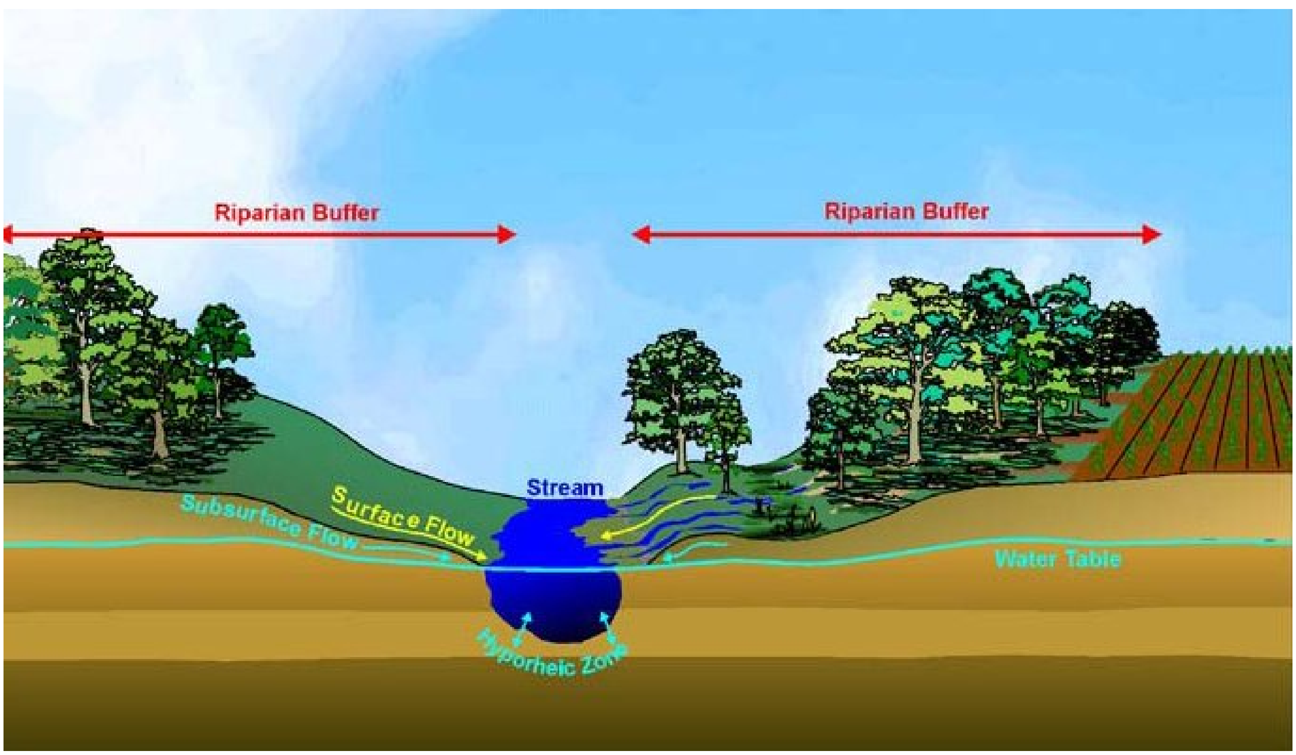

Figure 4. Diagram of a riparian buffer in an agricultural context (from Mayer *et al.* 2006).

The current literature on this topic is summarized in the following sub-sections, and focuses on research that evaluates the effectiveness of vegetated buffers in protecting water quantity, water quality and habitat functions associated with watercourses and stream corridors. In this section we refer to these as “riparian buffers”, as they are referred to in the literature, and intend for this term to generally encompass the vegetated areas immediately adjacent to the given watercourse or water body, although it is understood that in some cases this includes the floodplain and/or meander belt area. Although most research cited has been conducted on watercourses, the relevance of this literature to other water bodies (such as ponds and lakeshores) is discussed.

3.1.1 Water Quantity Functions

The literature that focuses on the functions of vegetated buffers in relation to water quantity is limited. Many researchers recognize that one of the key factors affecting buffer effectiveness is the local hydrologic regime (e.g., Mayer *et al.* 2006; Lee *et al.* 2003; Woodard and Rock 1995; Norton and Fisher 2000; Castelle and Johnson 2000) and that a given buffer’s ability to attenuate storm flows will be dependent on the amount and frequency of overland flows, as well as the catchment area, local topography, soil type, and other factors such as impervious surfaces and land use in the given watershed.

- In their study of the effectiveness of forested riparian buffers in mitigating the effects of urbanization on watercourses in the Piedmont region of Maryland and the Puget Sound region of Washington, Blaha *et al.* (2002) found that buffers of 30 m to more than 100 m helped mitigate water levels during storm flows, but only in watersheds where levels of imperviousness were low to moderate (i.e., 20% to 45%). This suggests that in watersheds where levels of imperviousness are high, storm flows are too great for vegetated buffers to be able to mitigate them, which is consistent with conclusions reached by some other researchers (e.g., Leavitt 1998).

- Diana *et al.* (2006) also linked the presence of 100 m riparian buffers in a predominantly agricultural watershed in Michigan to more stable stream flows, although the effects of different riparian buffer widths was not examined.

- In their technical paper on riparian buffers in agricultural contexts, Fisher and Fischenich (2000) state that riparian buffers promote floodplain storage due to backwater effects, interception of overland flow, and reduction in travel times (thereby reducing peak flows), and conclude that buffer widths ranging from 20 m to 150 m can be effective at providing this function. However, this recommendation is not based on any empirical evidence from the literature that buffers can in fact perform this function, and is instead, as they acknowledge, drawn from anecdotal information.

Empirical studies specifically examining the function of riparian buffers in relation to storm water flows in rural or urban settings are lacking, although there appears to be landscape-level support for this function.

3.1.2 Water Quality Functions

There are many papers spanning the last three decades that have examined the ability of different widths of vegetative buffers to attenuate the overland flows of nutrients into watercourses (primarily phosphorus and nitrogen). Although for the vast majority of the research, running watercourses (i.e., streams, creeks and rivers) have been the focal natural heritage features, the findings and principles with respect to buffer effectiveness are equally applicable to standing water bodies such as ponds and lakes. Rather than itemize all these papers, the following is a summary of the key findings and trends from several relatively current review papers, supplemented with findings from a few additional sources. These findings are summarized in **Table 2** and the following text. Notably, most of these studies are over relatively short periods of time (i.e., one to two years). Considerations related to buffer effectiveness related to water quality over time are discussed in **Section 3.5**.

Vegetated buffers shown to be able to attenuate nutrients and sediment, as well as contaminants, range from 2 m in width to over 100 m, and results are highly variable between and even within studies (e.g., Leavitt 1998; Osborne and Kovacic 1993; Peterjohn and Correll 1984; Lowrance *et al.* 1997; Lowrance *et al.* 2002). While buffers in the 2 m to 9 m range have been shown to attenuate some sediment and phosphorus, buffers in the 9 m to 30 m range tend to demonstrate more consistent and complete attenuation, and many authors agree that, in general, effective water quality functions are best performed by buffers in the 30 m width range (e.g., Dillaha *et al.* 1985; Dillaha *et al.* 1986; Dillaha 1989; Magette *et al.* 1986; Environmental Law Institute 2008; Wenger 1999).

The documented variability is thought to be due, in part, to different site conditions (as discussed in **Section 3.5**), but also, in part, due to inconsistent study designs and measures of “effective” attenuation or water quality. Some of the more recent reviews (e.g., Adamus 2007) have criticized some of the water quality research related to buffers for its lack of use of systematic standards, and have pointed out the importance of other watershed-scale factors in watercourse conditions and dynamics. Nonetheless, despite unanswered questions about appropriate buffer widths and inconsistencies in study designs, the functions of vegetated buffers with respect to water quality remain undisputed.

Recent model-based research by Diebel *et al.* (2009) maintains that even though some sources of phosphorus and sedimentation cannot be attenuated by stream buffers, in most watersheds a large proportion of these pollutants can be. Key variables that can affect buffer effectiveness include soil texture, slope, vegetation cover, presence of carbon in the soil (i.e., organic matter), and, most critically, the nature (i.e., concentration and frequency) of inputs. In some cases different responses may also be attributable to differences in broader landscape contexts (i.e., proportion of impermeable surface in a given watershed, subwatershed or catchment area). As emphasized in the OMAFRA best practices book on riparian buffers in agricultural settings, although vegetated buffers can contribute to improving and maintaining water quality, buffers alone cannot protect water quality (OMAFRA 2004), and need to be accompanied by other best practices and mitigative measures on the site, and in the watershed, as a whole.

<u>Nutrient Attenuation or Transformation</u>

A relatively recent and thorough meta-analysis of papers examining the ability of vegetated buffers adjacent to watercourses or water bodies to attenuate nitrogen from surface water flows, primarily in an agricultural context (Mayer *et al.* 2007) found that while the majority (i.e., close to 50%) of the nitrogen tended to be removed within the first 25 m, buffers with greater widths (i.e.,26 m to 50 m, and over 50 m) had increasing nitrogen removal effectiveness (i.e., 70% for the 26 m to 50 m buffers and 85% for buffers greater than 50 m). Other documented trends were that nitrogen transported via subsurface flows was better attenuated than nitrogen transported via surface flows (i.e., ~40% versus 75%), and buffers comprised of forested wetlands were the most effective at nitrogen attenuation, followed by buffers comprised of mixed woody and herbaceous vegetation. This latter finding speaks to the value in having a combination of woody and herbaceous vegetation, as well as the value of wetlands in buffers, where one of the desired functions is to help ensure protection and maintenance of water quality.

Most of the research on riparian buffers has been conducted in an agricultural setting, and most authors note that soil type and soil condition are primary factors in buffer effectiveness, and that both slope and local hydrologic dynamics are also important considerations (see **Section 3.5** for more discussion on these factors). Some notable trends that emerge from the scientific and technical literature related to water quality buffer functions include the following (from Wilson and Imhof 1998; Environmental Law Institute 2008; Wenger 1999; Hawes and Smith 2005):

- Phosphorus carried in surface runoff is better attenuated in narrower buffers (e.g., 10 m or less) than nitrogen carried in surface runoff;
- Phosphorus carried in surface runoff is better attenuated in grassed than forested buffers; and
- Nitrogen carried in surface runoff is better attenuated in grassed than forested buffers, while nitrogen carried in subsurface runoff is better attenuated in forested than grassed buffers.

The trend in the literature that subsurface denitrification is more effective in forested buffers may be explained by recent evidence found by Gift *et al.* (2010) that the presence of both organic matter and deep rooted vegetation improve this buffer function.

In an attempt to verify the ability of riparian buffers to attenuate groundwater nitrates in an agricultural context, Yamada *et al.* (2008) studied ground water quality in a stream adjacent to a 25 m buffer planted with a mix of woody and herbaceous vegetation. They found significant declines in nitrate concentrations within two years of buffer establishment as compared to the non-buffered control area, confirming the ability of vegetated buffers to attenuate nitrogen from subsurface groundwater flows, at least in some contexts.

This research, cumulatively, strongly supports the position that vegetated buffers are able to attenuate both nitrogen and phosphorus from both surface and subsurface (e.g., shallow groundwater) flows, and emphasizes the importance of having buffers with a combination of herbaceous and woody vegetation in order to effectively achieve this function. The additional value of having wetlands in buffers, as documented by Mayer *et al.* (2007), to enhance water quality functions speaks to the intrinsic contribution that these features can make to water quality at both a site-specific and watershed scale. Although in the context of southern Ontario most wetlands are protected as significant natural heritage features in their own right, the literature points to the potential value in maintaining unprotected wetlands adjacent to watercourses or water bodies as part of the buffer for enhancing the water quality functions of this protective feature in the landscape.

Attenuation or Transformation of Other Contaminants

A few research papers have also examined the ability of riparian buffers to remove contaminants such as fecal coliform and toxins such as herbicides and pesticides.

- The 2008 Environmental Law Institute review cites research (Coyne *et al.* 1995) that demonstrated the ability of a 9 m buffer to remove some (34 % to74 %) of the fecal coliform in agricultural runoff.
- Sullivan *et al.* (2007) found buffers of 1 m to 3 m were able to attenuate more than 99% of the fecal coliform on loamy soils.
- Gay *et al.* (2006) documented 10 m wide and 100 m long forested buffers to a stream as being able to attenuate atrazine (a herbicide) from spray on adjacent agricultural lands, but not so effectively during periods of heavy rainfall, underscoring the reduced water quality function of vegetated buffers under periods of intense surface water flows.

Although no research papers were found that specifically document the ability of riparian buffers to attenuate heavy metals, this function is assumed to apply to riparian buffers as it has been documented for wetland buffers (Sheldon *et al.* 2005). It can also be safely assumed that if a vegetated buffer can attenuate contaminants other than nutrients (such as fecal coliform, herbicides, and heavy metals) and prevent them from entering a water course or wetland, a vegetated buffer can perform the same function adjacent to a pond or lake. However, this function has only been tested for a very limited number of contaminants in a limited number of circumstances, and should not be generalized without this caveat.

Stream Temperature Moderation

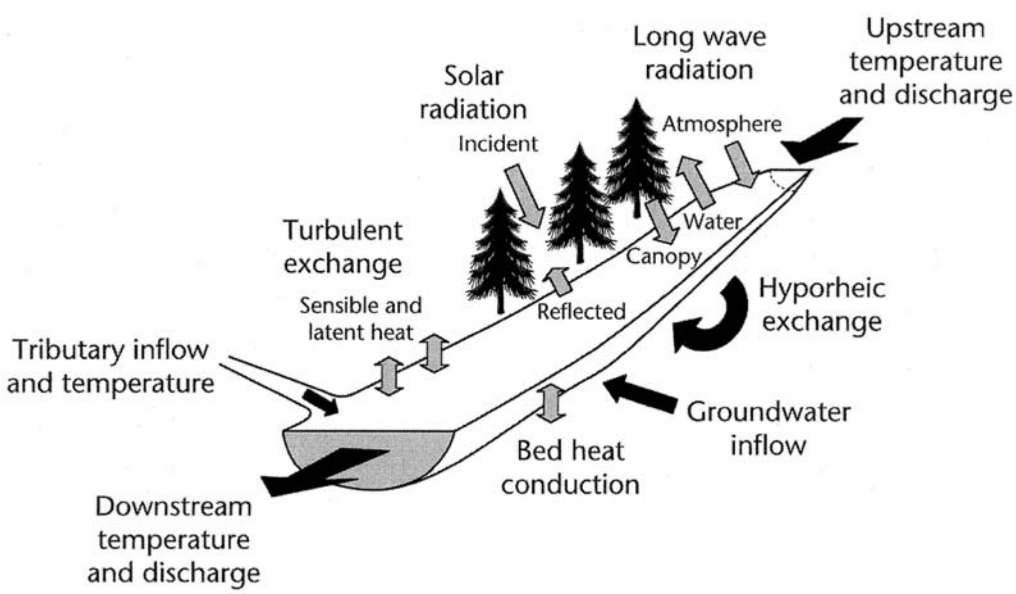

Figure 5. Illustration of abiotic influences on watercourses that can influence water temperature (from Moore *et al.* 2005).

Buffers are also typically ascribed with the ability to moderate stream temperatures (e.g., Durst and Ferguson 2000). This capacity has been shown to vary with the stream width, height of buffer vegetation canopy, and influence of upstream land uses and conditions on overall stream temperature. As shown in **Figure 5**, there are a number of inputs and factors at both the site-specific scale and from upstream that can affect stream temperature. The presence of a buffer providing canopy to all or part of the stream section is only one such factor. As Castelle and Johnson (2000) point out, the extent to which a vegetated buffer can provide stream temperature moderation will depend on the site's geographic location (i.e., latitude, longitude, elevation), local climactic conditions, the stream channel conditions (i.e., width, depth, velocity, extent of groundwater inputs versus surface water inputs and nature of surface water inputs), and the extent of riparian or topographic shading (i.e., canopy cover).

- In their review of the influences of timber harvesting adjacent to watercourses, Moore *et al.* (2005) found that the presence or absence of a buffer was not consistently related to recovery times for stream temperatures after timber harvesting, although where surface water (rather than ground water) is the primary source for the watercourse, they found that buffers with woody vegetation could protect against summer increases in stream temperatures.

- Similarly, Blann *et al.* (2002) found that shrubby and forested buffers did have the capacity to moderate stream temperatures, but that other factors (such as upstream inputs, stream width) were also key variables.

- A recent publication by DeWalle (2010) modelling riparian buffer provision of stream shade found buffers of 12 m were sufficient for moderating stream temperature in mid-latitudes (for both E-W and N-S streams) for streams up to 6 m wide, as long as the buffer was sufficiently tall (~ 30 m) and dense.

- Both Kiffney *et al.* (2003) and Clinton (2011) found that in studies comparing 10 m and 30 m forested buffers adjacent to streams retained following timber harvest with unbuffered stream reaches, higher stream temperatures were linked with unbuffered stream segments in both summer and winter.

- Castelle and Johnson (2000) cite research primarily from forestry studies where buffers left standing were treed. Several studies conclude forested buffer strips of at least 30 m were found to provide the same level of shading as the original forest, and were able to maintain stream temperatures within 1°C their former average temperatures, while other studies reported than forested buffers of 12 to 15 m were able to protect most small streams from significant temperature changes.

As described above, current research suggests that forested buffers between 10 m and 30 m in width can help maintain cooler stream temperatures for watercourses that are relatively narrow and whose primary water sources are from surface rather than ground water. While this benefit may also extend to small ponds, it would only extend a limited amount, or perhaps not at all, to wider watercourses and larger water bodies such as lakes. Furthermore, while there seems to be a link between the presence of forested buffers and moderation of stream temperatures, it is difficult given all the variables that play in to stream temperature (as shown in **Figure 4**) to prescribe generic buffer widths for all situations without consideration for stream flows, width, height and density of the buffer vegetation, local climate and stream channel conditions.

3.1.3 Screening of Human Disturbances or Changes in Land Use

Vegetated buffers, particularly buffers vegetated with shrubby or woody vegetation, can screen impacts associated with anthropogenic activities in adjacent lands. The ability of buffers to mitigate against direct human disturbances has been primarily explored in the literature on vegetated buffers to wetlands, rather than for buffers to water courses and water bodies. However, many of these impacts are potential issues for vegetation and wildlife associated with watercourses, just as they are for vegetation and wildlife associated with wetlands. Documented impacts include:

- noise (largely related to road traffic, but also to other anthropogenic sources); and
- physical disturbances related to human presence, including:
    - Trampling and dumping;
    - The introduction and spread of invasive plant species;
    - Wildlife disturbed by recreational activities (i.e., walking / hiking, biking or boating near and around natural areas) (discussed below);
    - Wildlife disturbed by the presence of housing and associated human activities.

The only area of research related to the potential for riparian buffers to mitigate any of these impacts that was found during this review relates to wildlife disturbance by recreational activities, and is discussed below. A summary of the current literature on how vegetated buffers may mitigate the other impacts listed above to wetlands is provided in **Section 3.2.3**, and can generally be considered to apply equally to watercourses and water bodies such as ponds, particularly relatively narrow or small ones. However, the extent to which vegetated buffers may mitigate these impacts for larger water bodies will likely decrease as the size of the feature itself increases.

Notably, no technical or scientific literature was found that examined the potential functions or appropriate widths for buffers to riparian areas in terms of screening the intrinsic habitat functions of those zones.

Preventing Disturbances Related to Recreational Activities

One of the potential functions of riparian buffers is to mitigate against disturbances related to human activities that directly disrupt the species that reside in the watercourse or water body either permanently or temporarily. Although not focused on the effectiveness of buffers, there is a body of literature that has examined the minimum distances at which wildlife – and particularly waterbirds – are disturbed by human activities. These responses have been labelled “flight initiation distances (FID)” for birds or “alert behaviour” for various wildlife species (e.g., Traut and Hostetler 2003). These researchers measure the minimum distances at which wildlife either demonstrate alert signals or behaviours, or are basically scared away by human presence (e.g., walking cycling, boating). Although these distances cannot be directly translated into appropriate buffer distances, they do provide information on the ranges of sensitivities of different species, and have been used by some authors as the basis for buffer recommendations. Examples of such papers identified through this review are cited below.

- Rodgers and Smith (1997) found waterbirds were flushed[9] by noise within 14 to 24 m from their nests, with wider buffers required from walkers (up to 34 m) than cars passing by (up to 24 m).

- Josselyn *et al.* (1989) (as cited in Adamus 2007) found some bird species to be disturbed by humans approaching from as far as 53 m (175 ft), although many species of waterbirds appeared to become habituated to human presence over time.

- Sheldon *et al.* (2005) reported studies that found unscreened human activities and noises were disruptive to water birds at 15 to 50 m, but that nesting herons required at least a 100 m buffer from human disturbances.

- A relevant study cited by Castelle *et al.* (1992) is one by Josselyn *et al.* (1989) that found most human activities causing disturbance to waterbirds in the San Francisco Bay ranged between 15 and 53 m, however more comprehensive research by Cooke (1992) found a wider range of flushing distances documented for flocks of waterfowl in natural areas in urban settings, and concluded that buffer widths of 61 to 91 m beyond wetlands are more likely to support wetland-dependent wildlife, with the large end of the range recommended for higher intensity land uses.

- Rodgers and Schwickert's (2002; 2003) research on flushing distances of waterbird and raptor species in response to personal watercraft and outboard-powered boats on the Florida coast found responses were highly variable and had mean ranges of 20 m to 172 m depending on the species. Based on their results they recommend buffer zone distances ranging between 100 and 365 m for different water birds and raptors for this particular recreational activity.

These studies include high levels of variability among and even within species responses, and so careful consideration for species-specific sensitivities as well as the nature of the recreational activity and site context should all factor into buffer determination in such cases.

3.1.4 Hazard Mitigation Zone Functions

Lands adjacent to watercourses and other water bodies are generally understood to be and accepted as hazard lands where some type of setback and/or additional precautions are required due to the proximity to water and in many cases the presence of floodplains or steep / erosion prone slopes. The dynamic nature of natural watercourses and lakeshores is also considered in the identification of natural hazard lands.

A discussion on the nature and assessment of hazard lands is outside the scope of this review[10]. As with Critical Function Zones, it is assumed that the extent of the critical hazard or erosion-prone area

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[9] One of the concepts that has emerged from the buffer-related research on water birds is that of "flight initiation distance" (FID) or the distance at which animals flee the approach of an assumed predator. This has also been called the "flushing" distance. Research by Blumstein *et al.*, (2003) concluded that distinct FIDs can be associated with different species, although there is tremendous variability in these distances, and that these FIDs can be used as a conservative guideline for setting buffer widths for this group of species.

[10] An overview of natural hazards and current provincial guidance on assessment of such features and areas is available in the "Understanding Natural Hazards" guide published by the Ontario Ministry of Natural Resources in 2001 and available on-line at http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@water/documents/document/mnr_e002317.pdf

has been (or will be) identified prior to any determination of buffer requirements. However, consideration of natural hazards is relevant to the discussion of buffers in so far as (a) maintaining or re-establishing vegetation cover in some types of natural hazard lands can help stabilize soils and prevent erosion, and (b) vegetated buffers adjacent to identified hazard lands may screen these areas from unwanted human intrusion (although a fence is likely just as or more effective in performing this function, as described in McWilliam *et al.* 2011 for upland woodlands). The ability of a buffer to effectively achieve this type of screening will depend on a variety of factors including the area and nature of the feature being buffered, the vegetative structure of the buffer and its aspect (e.g., is it on a slope), and the wildlife that use the feature and their sensitivities.

There has been surprisingly little empirical research on the ability of different widths and types of vegetated buffers to stabilize steep slopes and/or contribute to erosion control in flood prone lands, despite the fact that rapid revegetation of such areas following disturbances is a routine recommendation and practice in most jurisdictions. Nilaweera and Nutlaya (1999) and Schwarz *et al.* (2010) both assess (and confirm) the ability of roots of woody species to stabilize slopes from a structural perspective, but do not consider variables such as soils or slope *per se*.

The ability of vegetative buffers to stabilize stream banks, which in turn protects the quality of water in stream as well as some of the intrinsic functions of the riparian zone, is discussed concisely by Castelle and Johnson (2000). In their technical report they cite research linking stream bank stabilization to vegetation root density and show that stabilization effectiveness increases dramatically with increases of root densities of up to 2 mm/mm^3 of soil, and then tapers off. Schwarz *et al.* (2010) and Nilaweera and Nutalaya (1999) demonstrate that the larger lateral roots of trees play a significant role in the stabilisation of steep slopes. Although there are relatively few studies that actually test this function *in situ*, it seems to be generally accepted and understood to vary with nature of slope and soils. In a model-based study that makes this assumption, Tang and Montgomery (2000) found that the prescribed 10 m to 25 m riparian buffers failed to capture most of the erosion prone areas in watersheds of Washington State, and that buffers in the order of 100 m were required to do so. Notably, these would be measured from the aquatic habitat, and not from the riparian habitat.

The Environmental Law Institute cites four papers that recommend specified riparian buffer widths (or ranges) to support bank stabilization (i.e., Fisher and Fischenich 2000 – 10 m to 20 m, Corbett and Lynch 1985 – 20 m to 30 m, and Spence *et al.* 1996 – more than 52 m). However the first two are based on professional opinion rather than empirical data collection, while the latter is a technical study specifically focused on protecting salmonid habitat. Use of reviews such as this requires careful consideration of the original work or erroneous conclusions can be drawn. More research specifically focussed on different widths of buffers with different vegetative structures on different slopes and soil types is needed to provide better guidance.

3.1.5 Core Habitat Protection Functions

Although no research was uncovered that examined the effectiveness of buffers to riparian areas from a habitat perspective, there have been a number of studies that have linked the presence of forested or naturalized riparian buffers along stream corridors in watersheds with good to high levels of watercourse biotic integrity, as measured by benthic assessments and/or fish population assessments. Some examples are cited below.

- In their study of the effectiveness of forested riparian buffers in mitigating the effects of urbanization on watercourses in the Piedmont region of Maryland and the Puget Sound region of Washington, Blaha *et al.* (2002) found that reaches with relatively wide (i.e., more than 100 m on each side), continuous and forested buffers were linked with good or high levels of biotic integrity (as measured by benthic invertebrate scores) within all subwatersheds with up to 20% levels of impervious surfaces, and most subwatersheds with up to 45% impervious surfaces. Although this research supports the value of forested buffers in urban areas, it also speaks to the importance of broader landscape planning.

- Jones III *et al.* (1999) in their study of 12 stream segments downstream of watersheds with at least 95% forest cover found that the length of non-forested riparian area was much more significant than riparian buffer width in influencing fish assemblages, again pointing to the importance of landscape scale planning.

- Diana *et al.* (2006) in their study of 48 stream reaches in the Huron and Raisin River basins in southeastern Michigan found the presence of 100 m riparian buffers (forested and wetland) had a strong positive relationship with in-stream habitat.

- Roberts and Prince (2010), in their watershed-scale study of Chesapeake Bay, found non-vegetated lands contributed more significantly to nitrogen and phosphorus loading in watercourses than vegetated lands, but interestingly also found that small amounts of nitrogen loading were also linked to the presence of coniferous forests in the lands adjacent to watercourses. They also found land use to have a much more significant effect on nitrogen and phosphorus loadings at the watershed scale than the size of vegetated buffers.

While forested buffers can contribute to stream health at the site-specific and watershed scales, it is also apparent that forested buffers can only do so much with respect to protection and maintenance of both water and habitat quality, particularly in watersheds that are highly urbanized.

The inherent dynamism of natural watercourses and the fact that they are a continually moving natural heritage feature (unlike wetlands or woodlands), makes assessing the site-specific effectiveness of buffers to these features a literally moving target. This challenge is reflected in the research where direct links between the presence or absence of a buffer in a given reach and positive biotic health indices are not always present. Some examples from the literature are cited below.

- In a study of stream reaches in Alaska comparing reaches that were clearcut, buffered and left natural, fish community responses in those reaches were variable and were more closely tied with the season and presence of large woody debris (Murphy *et al.* 1986).

- Barton *et al.* (1985) examined relationships between riparian land use and suitability of southern Ontario streams for trout, and found that the primary environmental variable distinguishing trout streams was water temperature, although water temperature, concentration of fine particulate matter, and variability of discharge were all inversely related to the extent of upstream banks covered by forest. Notably, 56% of the variation in weekly maximum temperature could be explained by the fraction of riparian bank forested within 2.5 km upstream.

- A study of stream salamanders in North Carolina by Willson and Dorcas (2003) that found no correlation between buffer width or level of disturbance and salamander abundance, but significant inverse correlation with levels of habitat disturbance in the broader watershed.

- A study of macroinvertebrate richness in relation to riparian buffer treatments (i.e., fencing of buffer areas and coppicing of buffer trees) in Wye, U.K. had inconclusive results that were difficult to assess due to the lack of pre-treatment data. The fact that the buffer widths were restricted to between one and three metres may also help explain the equivocal results (Clews and Ormerod 2010).

- Both Rios and Bailey (2006) and Teels *et al.* (2006) found that while the presence of forested riparian buffers in an agricultural context were linked to some site-specific positive biotic indicators (e.g., good diversity levels of benthics), such trends were not evident at the watershed scale.

These studies underscore two important and related points for riparian systems: (1) that forest cover and land uses upstream tend to have a significant impact downstream, so that the benefits of buffers cannot simply be assessed on site-specific scale, and (2) depending on the upstream conditions, even substantial site-specific buffers may not be enough to compensate for broader, landscape-level habitat loss and degradation.

An interesting paper by Baker *et al.* (2006) looked at different methods for assessing riparian buffer effectiveness related to nutrient interception, and found that watershed-scale and near-stream land cover were so strongly correlated that results of studies based on fixed-distance metrics (e.g., land cover within 100 m from a mapped watercourse) were confounded, highlighting the importance of placing the results of some of the studies cited above into a watershed, flow-based context. A case in point is a watershed-scale study by Goetz *et al.* (2003) that found positive correlations between stream health and the presence of forested riparian buffers within 100 ft (30.5 m) of the watercourse, but acknowledged that this finding was confounded with the elevated levels of overall forested habitat (and reduced impervious surfaces) in those areas, making the case for the value of the buffer in and of itself equivocal.

This relationship between the landscape-level condition and the site-specific condition is a pattern that repeats itself in many aspects of natural heritage. In some cases, it is the landscape-level that dominates the equation. Simply put, no buffer width can mitigate for effects that are driven by landscape-scale changes such as significant loss of forest cover and replacement with impervious surfaces across the watershed.

Notably, no landscape-level studies looking at the functions of buffers to ponds or lakes at the watershed scale were uncovered as part of this review.

Contributions of Structure and Nutrients

Although vegetated buffers to watercourses and water bodies are often recommended because of their ability to attenuate excess nutrients from storm runoff, buffers themselves can also be important sources of nutrients for watercourses and water bodies. Vegetated buffers to watercourses, particularly buffers comprised of shrubs and trees, support aquatic habitat by providing large woody debris, which is known to be important for stream hydrologic dynamics and fish habitat (Durst and Ferguson 2000). Several interesting studies in the northern and northwestern U.S. cited in Castelle and Johnson (2000) found that most of the woody debris sources came from within 30 m of the stream bank, although distances differed depending on the channel types and the influence of slope was not considered. Vegetated buffers also contribute particulate organic matter to streams and other watercourses, which is a primary source of nutrients for aquatic organisms. Castelle and Johnson (2000), in their review of a limited number of forestry papers on this topic from the 1970's, 1980's and 1990's, found that forested buffer strips of at least 30 m along streams left intact after deforestation activities were generally reported as effective at maintaining pre-logging aquatic species diversity. In their review paper, Fischer and Fischenich (2000) concluded that buffers in the range of 3 m to 10 m were the primary source of leaves, twigs and branches falling into the stream. These findings all speak to the role that riparian buffers can play in directly contributing to the sustainability of healthy aquatic systems. Although this function may not be as pronounced on a large lake, it is likely that a comparable habitat support function is provided for many ponds.

Riparian Habitat Protection

It is widely recognized that riparian zones tend to be hotspots of biological diversity, and that they protect fish habitat by maintaining shade, reducing sedimentation, and contributing structure and nutrients, as described above. However, there are very few papers that specifically address the potential value of a buffer to a riparian area of critical habitat, and no papers were found that assess them empirically. Those identified through our research are cited below:

- Crawford and Semlitsch (2007), in their study of stream salamanders, found critical habitat zones (or CFZs) of 27 to 43 m from the watercourse were sufficient for most Appalachian salamanders (including species that occur in Ontario), and recommend an additional 50 m buffer to protect against edge effects. Notably, while the recommended CFZ is based on distances for foraging documented in the literature, the 50 m buffer zone appears to be a generic recommendation based on professional judgement rather than evidence from empirical studies.

- Muenz *et al.* (2006) found that, in an agricultural setting, buffered riparian areas had higher percentages of sensitive invertebrate groups, and that in-stream larval salamanders were more abundant at the buffered locations, although overall amphibian abundance in the riparian area itself was no different between the buffered and unbuffered sites. Specific buffer widths are not assessed.

Despite the numerous papers, and continued research, on the value of riparian habitat for various species as either critical habitat (i.e., for breeding, foraging, overwintering) (e.g. Pollett *et al.* 2010), a movement corridor (e.g., Spackman and Hughes 1995, Wenger and Fowler 2000, Hennings and Edge 2003), or serving other supportive habitat needs, there continue to be very few papers assessing the potential value of buffers to these habitats in river valleys or floodplains.

Table 2. Summary of quantitative recommendations from key papers and reviews related to effective buffer widths along watercourses*.

MEASURED BUFFER FUNCTION(S)	FOCAL SPECIES OR GUILD	REC. BUFFER SINGLE VALUE (metres)	REC. BUFFER RANGE (metres)	SOURCE	COMMENTS
A. WATER QUANTITY					
storm water attenuation	NA		20 to 150	Fischer and Fischenich 2000	Drawn from anecdotal evidence.
storm water attenuation	NA	35	20 to 55	Johnson and Ryba 1992	
B. WATER QUALITY					
contaminant attenuation (various)	NA	50		Environmental Law Institute 2003	Selected generalized median based on a synthesis of numerous studies.
detrital input	NA		3 to 10	Fischer and Fischenich 2000	Drawn from a literature review in an agricultural context.
fecal coliform attenuation	NA	55	30 to 90	Johnson and Ryba 1992	
fecal coliform attenuation	NA		1 to 3	Sullivan *et al.* 2007	On loamy soils small buffers very effective for fecal coliform attenuation.
nitrogen attenuation	NA		20 to >40	Buffler 2005	Numbers synthesized from literature review of +120 sources.
nitrogen attenuation	NA	50		Mayer *et al.* 2007	Results based on meta-analysis of other studies. Buffers of +50 m were more consistent than those less than 25 m.
nitrogen attenuation	NA		15 to 30	Wenger 1999	Buffer width needs vary with soil condition, slope, local hydrology.
nutrient attenuation	NA	25		Environmental Law Institute 2003	Selected based on a survey of numerous studies.
nutrient attenuation	NA		> 30	Hickey and Doran 2004	Based on a review - most papers showing significant nutrient removals for buffers of more than 30 m.
nutrient attenuation	NA	20	5 to 48	Ryba and Johnson 1992 (as cited in Leavitt 1998)	
nutrient attenuation	NA		1 to 60	Wilson and Imhof 1998	Includes data from 24 studies between 1977 and 1993
nutrient attenuation - subsurface nitrogen	NA		10 to 50	Osborne and Kovacic 1993	Subsurface nitrogen is better attenuated in forested (73-100%) than grassed buffers (10-60%).
nutrient attenuation - subsurface nitrogen	NA	27		Osborne and Kovacic 1993	Subsurface nitrogen is better attenuated in forested (73-100%) than grassed buffers (10-60%).
nutrient attenuation - surface nitrogen	NA		9 to 27	Osborne and Kovacic 1993	Surface nitrogen is better attenuated in grassed than forested buffers.
nutrient attenuation - surface nitrogen	NA		30 to 50	Osborne and Kovacic 1993	Surface nitrogen is better attenuated in grassed than forested buffers.
nutrient attenuation - surface phosphorus	NA		16 to 50	Osborne and Kovacic 1993	Surface phosphorus attenuated in narrower buffers than surface nitrogen.
nutrient attenuation - surface phosphorus	NA		5 to 27	Osborne and Kovacic 1993	Surface phosphorus better attenuated in grassed than forested buffers.

MEASURED BUFFER FUNCTION(S)	FOCAL SPECIES OR GUILD	REC. BUFFER SINGLE VALUE (metres)	REC. BUFFER RANGE (metres)	SOURCE	COMMENTS
pathogen attenuation	NA		3 to >6	Buffler 2005	Numbers synthesized from literature review of +120 sources.
pesticide attenuation	NA	>9		Buffler 2005	Pesticide particulates associated with sediment. Numbers synthesized from a literature review of +120 scientific and technical sources.
phosphorus attenuation	NA	>20		Buffler 2005	Numbers synthesized from a literature review of +120 scientific and technical sources.
phosphorus attenuation	NA		9 to 30	Lowrance *et al.* 2002	Some phosphorus attenuated in 5 - 9 m buffers but more effective in 9 - 30 m.
phosphorus attenuation	NA		21 to 27	Young *et al.* 1980	67% to 88% removal
sediment attenuation	NA		5 to 30	Castelle and Johnson 2000	
sediment and nutrient attenuation	NA	16.3		Lee *et al.* 2003	Most effective buffer combined switchgrass and shrubs.
sediment and phosphorus attenuation	NA		9 to 30	Wenger 1999	Buffers as narrow as 5 m have been shown to be effective in the short term but are thought to be come easily saturated and buffers of at least 9 m but closer to 30 m are recommended.
sediment attenuation	NA		3 to >10	Buffler 2005	Numbers synthesized from a literature review of +120 scientific and technical sources.
sediment attenuation	NA		2.5 to 20	Gharabaghi *et al.* 2006	Most sediments attenuated within first 5 m (but no study of effectiveness over multiple years)
sediment attenuation	NA	48	2 to 110	Johnson and Ryba 1992	
sediment attenuation	NA	35		Paterson *et al.* 1980	
sediment attenuation	NA	19		Peterjohn and Correll 1984 (as cited in Osborne and Kovacic 1993)	
sediment attenuation	NA		3 to 122	Wilson 1967	Range reflects test on different soil types: sand most effective at 3 m, silt at 15.2 m and clay at 122 m.
sediment attenuation	NA	24.4		Young *et al.* 1980	92% sediment removal rate from feedlot through vegetated buffer strip - 2 years of testing
various pollutants attenuated	NA	10		Castelle and Johnson 2000	Included screening for heavy metals.
various pollutants attenuated	NA	90		Dickey and Vanderholm 1981	
various pollutants attenuated	NA		5 to 30	Fischer and Fischenich 2000	Drawn from a literature review in an agricultural context.
various pollutants attenuated	NA	30.5		Schueler 2000	One of few studies in urban context.
various pollutants attenuated	NA	36		Young *et al.* 1980	
various pollutants attenuated	NA	30		Zhang *et al.* 2010	Average recommendation based on meta-analysis of over 70 studies.

MEASURED BUFFER FUNCTION(S)	FOCAL SPECIES OR GUILD	REC. BUFFER SINGLE VALUE (metres)	REC. BUFFER RANGE (metres)	SOURCE	COMMENTS
C. SCREENING OF HUMAN DISTURBANCE / CHANGES IN LAND USE ***(no studies making specific buffer width recommendations found, see Table 3)***					
D. HABITAT TRANSITION / HAZARD MITIGATION ZONE ***(only one quantitative making specific buffer width recommendation found)***					
bank stabilization	NA	50		Environmental Law Institute 2003	Based on a survey of only two studies, including one that was itself a technical report and not based on empirical data.
E. CORE HABITAT PROTECTION					
Contributions of large woody debris and particulate organic matter	Aquatic organisms		10 to 40	Castelle and Johnson 2000	For large woody debris 40 – 60% of input was found to come from first 10 m, and 30 m tended to capture 100% of the contributions. For particulate organic matter (POM), 60 – 85% came from the first 15 m, and vegetated buffers of up to 40 m were needed for 100% of the potential POM contributions.
protection of core wildlife habitat	Various		15 to 30	Castelle *et al.* 1994	Note slightly narrower and significantly wider buffers may be required depending on site-specific conditions / circumstances.
protection of core wildlife habitat	herpeto-fauna	50		Crawford and Semlitsch 2007	Note the buffer may also provide some critical foraging habitat.
protection of core wildlife habitat	Various	100		Environmental Law Institute 2003	Selected based on a survey of numerous studies recommending buffers ranging from 4 to 1600 m, with 75% extending up to 100 m.
protection of core wildlife habitat	NA	50	10 to 200	Johnson and Ryba 1992	
protection of core wildlife habitat	NA		6 to 123	Norman 1998	From review of five selected forestry review papers.
protection of core wildlife habitat	herpeto-fauna		5 to 23	Pollett *et al.* 2010	Only test limited range of buffer widths and cite other papers recommending 46 m minimum buffers.
protection of core wildlife habitat	herpeto-fauna	50		Semlitsch and Bodie 2003	Recommend a 50 m terrestrial buffer in addition to a 172 - 349 m core habitat protection zone along the watercourse.
protection of core wildlife habitat	Various		10 to 30	Wenger 1999	Note this is strictly for protection of the aquatic habitat in the watercourse terrestrial habitat requires min of 100 m.
shade production	NA	30		Castelle and Johnson 2000	~85% effectiveness at ~30 m for a number of different streams.
stream temperature moderation	NA	30		Environmental Law Institute 2003	Selected based on a survey of numerous studies.
stream temperature moderation	NA	28	15 to 50	Johnson and Ryba 1992	
stream temperature moderation	NA	12		DeWalle 2010	Works for streams up to 6 m wide at mid-latitudes with relatively dense forested buffers of at least 30 m tall.

*** Although the papers cited have focused on the functions of vegetated buffers to watercourses, and primarily streams and creeks, many of these same functions could be attributed to buffers to standing bodies of water as well (such as ponds and lakes), although the effectiveness of a number of these functions may be altered (and likely reduced) for larger water features.**

3.1.6 Overview of Riparian Buffer Papers

It is now well-established and accepted in the scientific and technical literature that maintenance of some natural vegetation along watercourses can mitigate against some of the impacts related to land use changes on watercourses. Although much less well-researched, presumably these same concepts can be applied to standing water bodies and lakeshores, although as noted in **Table 2** above it is assumed that many of the functions associated with riparian buffers will be reduced or diluted for wider watercourses (e.g., rivers as opposed to streams and creeks, and large lakes as opposed to ponds). Water quality functions such as the ability of buffers to attenuate sediment, nutrients, and toxins, have been studied the most extensively (as illustrated by the number of papers under this category in **Table 2**), but the ability of buffers to both provide habitat (e.g., contribution of organic matter, woody debris) and protect aquatic habitats (e.g., provide shade, stabilize slopes) has been examined as well (e.g., Castelle and Johnson 2000; Osborne and Kovacic 1993; Wilson and Imhof 1998, Wenger 1999; Norman 1998; Blaha *et al.* 2002; Quinn *et al.* 2004; Anbumozhi *et al.* 2005; Mayer *et al.* 2006; Zhang *et al.* 2010).

A further limitation of the research on ecological buffers that has accumulated since the 1980's is that it has focussed on the buffer functions of riparian vegetation associated with permanent watercourses (e.g., rivers, creeks and streams) in an agricultural or forestry setting (e.g., Steinblums *et al.* 1984; Welsh 1991; Durst and Ferguson 2000; OMNR 2000) (as illustrated in **Figure 4**). Research that has examined the water quality and quantity functions of riparian buffers in the context of urbanization (e.g., Woodard and Rock 1995; Schueler 2000; Matteo *et al.* 2006) is available but not extensive.

Nonetheless, there is a sufficient body of research regarding the effectiveness of riparian buffers to be able to draw out some quantitative trends and gather some rough guidance, as provided below. Notably, while we have critically selected papers for our review, and for inclusion in **Table 2**, that we feel are based on reasonably accurate and objective study, not all papers listed in **Table 2** can be weighted equally (e.g., some of them are recommendations drawn from reviews of multiple or in some cases over a hundred papers), therefore the numbers should be understood to be approximations based on the current science rather than definitive.

A. WATER QUANTITY FUNCTIONS: Empirical evidence is insufficient to draw any conclusions.

B. WATER QUALITY FUNCTIONS: Average ranges between 10 m and 40 m, with an average single recommendation of about 30 m, but note that sediment and phosphorus can generally be well-attenuated in narrower buffers than nitrogen, that sediment alone can generally be well-attenuated in buffers that are less than 10 m, and that a combination of herbaceous and woody vegetation is most effective for overall nutrient attenuation.

C. SCREENING OF HUMAN DISTURBANCE / CHANGES IN LAND USE: No empirically based buffer recommendations were found. Research on "Flight Initiation Distances" for waterbirds (as described in **Section 2.3.3**) recommends minimum buffers ranging between about 15 m and 100 m from nesting sites, depending on the species of waterbird and the nature of the human impact triggering the response – these have a narrow application. Additional screening functions related to abiotic impacts can be performed in lower ranges (i.e., 15 m to 50 m) as described under the section on wetland buffers.

D. HAZARD MITIGATION ZONE**:** As discussed in the review, the study of assessing and defining hazard areas is a science unto itself, and for the purposes of this review the focus is on the ability of a vegetated buffer – either to the watercourse or to the riparian area – to help mitigate this hazard. Unfortunately, although a few studies speak to this function and document the ability of roots to improve slope stability, none assess the effectiveness of different buffer widths from this perspective. The 50 m recommendation in the Environmental Law Institute (2003) review is based more on water quality than slope stabilization considerations.

E. CORE AQUATIC HABITAT PROTECTION: Average ranges between 10 m and 75 m, with an average single recommendation of about 50 m. Note that papers were screened to try and exclude recommendations that incorporated Critical Function Zones in their buffer recommendations, and that in most cases there was significant variability in recommended buffer widths both between and even within different taxonomic groups. Notably, insufficient data currently exists to draw even preliminary conclusions related to appropriate buffers (or protection zones) for riparian habitats.

While the approximate averages are useful to gain an overview perspective, it is important to recognize the wide variability in recommended widths for buffers in different contexts, and the need to consider site-specific factors as well as some aspects of landscape context in riparian buffer determination. These factors are discussed in **Section 3.5**.

Despite the years of research and numbers of papers on the effectiveness of riparian buffers with respect to water quality functions, there remain relatively few papers that specifically assess riparian buffer effectiveness in terms of aquatic habitat protection functions, and even fewer that consider terrestrial buffers to riparian habitats that serve as CFZs for aquatic organisms. As natural heritage planning in southern Ontario evolves, there is a growing interest and need in examining and assessing the potential functions of buffers to riparian areas, from both a water quantity and quality, as well as a habitat protection perspective. Unfortunately, empirical studies assessing buffers to the so-called “Riparian Buffer” (as shown in **Figure 4**) were not located.

3.2 Buffers to Wetlands

After watercourses, wetlands are the next best-studied habitat type with respect to buffers. Vegetated buffers to wetlands intended to protect wetlands from the impacts of adjacent land uses (typically agriculture or urbanization) have been under discussion in the scientific and technical literature since the mid-1990’s (e.g., Norman 1998; Woodard and Rock 1995). In southern Ontario, much of this discussion was precipitated by new legislation and policies passed in the early 1990’s protecting wetlands south of the Canadian Shield.

As with riparian buffers, there continues to be confusion between the functions of lands adjacent to wetlands in terms of their inherent habitat functions (i.e., CFZs) as opposed to their buffering functions (i.e., PZs), as illustrated in **Figure 2**. In this review, the focus is on the identification of appropriate buffers to wetland habitats and wetland functions, and the working assumption is that the full extent of the actual habitat has or will be identified prior to application of a buffer, even when that function extends to the upland environment. Although this assumption may seem straightforward, the consideration of lands outside the protected feature itself in terms of their role in providing critical habitat functions to the species that reside within the feature is often overlooked. While wetland buffers will almost inevitably provide some incidental habitat functions, their primary purpose should be the protection of the core wetland and any associated habitat that has been identified as required or important for supporting associated wetland functions deemed to be significant and identified for protection.

3.2.1 Water Quantity Functions

Changes to surface and groundwater dynamics associated with development and urbanization that have the most potential to impact the water balance of wetlands include: (1) increased storm water runoff (due to an increase in impervious surface area, compaction of soils, and the loss of vegetation that once intercepted rainfall), (2) decreased groundwater recharge (and resulting reduction in infiltration due to an increase in impervious surface area and compaction of soils) and (3) flow constrictions (i.e., by the construction of roads, bridges, pipelines or other structures across individual wetlands, or upstream or downstream of them) (Carter 1996). However, the ability of buffers to mitigate some of these water quantity impacts at the site-specific, or even the landscape scale, has not been well-studied.

Brown *et al.* (1990) drew on a combination of local data and literature sources to generate estimated buffer width recommendations for minimizing groundwater drawdown caused by urbanization adjacent to different types of wetlands in Florida, and came up with quite a large range (i.e., 6 m to 168 m). Notably, they include no empirical data to support the idea that a site-specific buffer would necessarily be able to mitigate such an impact.

Angier *et al.* (2005) in their research on hydrology of a first-order riparian zone and stream in a mid-Atlantic coastal plain in Maryland, emphasize the importance of groundwater seepage and discharge in terms of its influence on the effectiveness of a forested buffer in an agricultural land use context. This highlights that groundwater is a potential issue that needs to be considered with when making buffer determinations.

Although changes in adjacent land uses are known to have potential impacts to surface and groundwater flows to wetlands, these impacts are usually difficult to quantify, and currently too variable and poorly understood to extrapolate any types of generalized buffer requirements. Depending on the underlying geologic and surficial soils conditions, wetlands may be impacted by changes in land use at the watershed or even broader scale, and therefore site-specific buffers would be unlikely to provide measurable benefits in this regard. There will be exceptions, but typically buffers are not used to mitigate the effects of impacts to groundwater flows, although they may be used to try and moderate surface flows. They may also be used as a physical space within which to install measures to mitigate against site-specific losses to, for example, infiltration.

Buffers to wetlands may help mitigate storm flows to wetlands in urban or urbanizing areas when those buffers are provided in place of additional impervious surfaces, but in rural landscapes wetlands surrounded by natural grasslands may actually receive more runoff volume than those surrounded by tilled soil (Adamus 2007). As with riparian buffers, the ability of site-specific buffers to mitigate for landscape-scale land use changes appears to be limited.

3.2.2 Water Quality Functions

Well-established functions of buffers to wetlands include: protecting wetland water quality by attenuating sediments (and associated contaminants), attenuating and transforming nutrients and other contaminants (through plant uptake or biological conversion in wetland soils), and helping to maintain cooler water temperatures by providing shade (Sheldon *et al.* 2005). Evidence supporting these functions is discussed below. Notably, sediments and nutrients are often researched and discussed together because nutrients are often transported *via* sediment-laden water, and phosphorus is typically bound to sediments.

Sediment and Nutrient Attenuation / Transformation

Although wetlands themselves are thought to be sinks for contaminants on a watershed scale, the use of vegetated buffers to mitigate this impact recognizes the ecological value of wetlands, and the potential degradation of that value in the face of the numerous impacts associated with both agricultural activities and urbanization in adjacent lands. Examples of research findings are cited below, and additional findings are provided in **Table 3**:

- Woodard and Rock (1995) found buffers of 15 m on wetlands in a new residential development were adequate to attenuate most sediment and phosphorus from storm water runoff, and that buffers stabilized with an underbrush and a layer of decomposing forest litter were most effective, even on sites with slopes of up to 12%.

- Norman (1998), in his review concludes that in urban areas buffers of 30.5 to 91.5 m are required for adequate removal of sediment, recommending 50 m buffers to wetlands as a suitable minimum.

- The review by Sheldon *et al.* (2005) documents buffers between 2 m and 122 m as being effective at sediment control, with the mean being 38 m and the highest value (i.e., 122 m) being for clay soils. The same review documents buffers of between 3.8 m and 260 m (with the latter being an outlier) as being able to effectively remove nutrients from surface waters, with a mean of 40 m. Generally, buffers in the lower range (i.e., 6 m to 12 m) have lower rates of removal (e.g., around 50%) while those in the higher range (i.e., 20 m to 85 m) showed higher removal rates (e.g., 70% to 99%). Effective nutrient removal was found to require a wider range of buffer widths, but was generally achieved between 5 and 40 m.

As with riparian buffers, there is significant variability in the range of buffer widths documented as being effective at attenuating sediments and nutrients, as well as other contaminants. This variation in performance speaks to both that lack of consistent measures of "effectiveness" and the actual variability in effectiveness of different buffer widths depending on the site conditions. For example, if 99% removal is the established objective, then a buffer width of 85 m might be required. However, if 60% is deemed "acceptable", then a buffer of 12 m might be reasonable. Important site variables – such as slope, soil type, nature of vegetation in the buffer, local hydrologic regime – will also have a significant influence (as discussed in **Section 3.5**). For example, Sullivan *et al.* (2007) report narrow buffers of 1 to 3 m capable of assimilating as much coliform bacteria as buffers of up to 25 m, and attributes this finding largely to the combination of a gentle slope and loamy soils in the buffer.

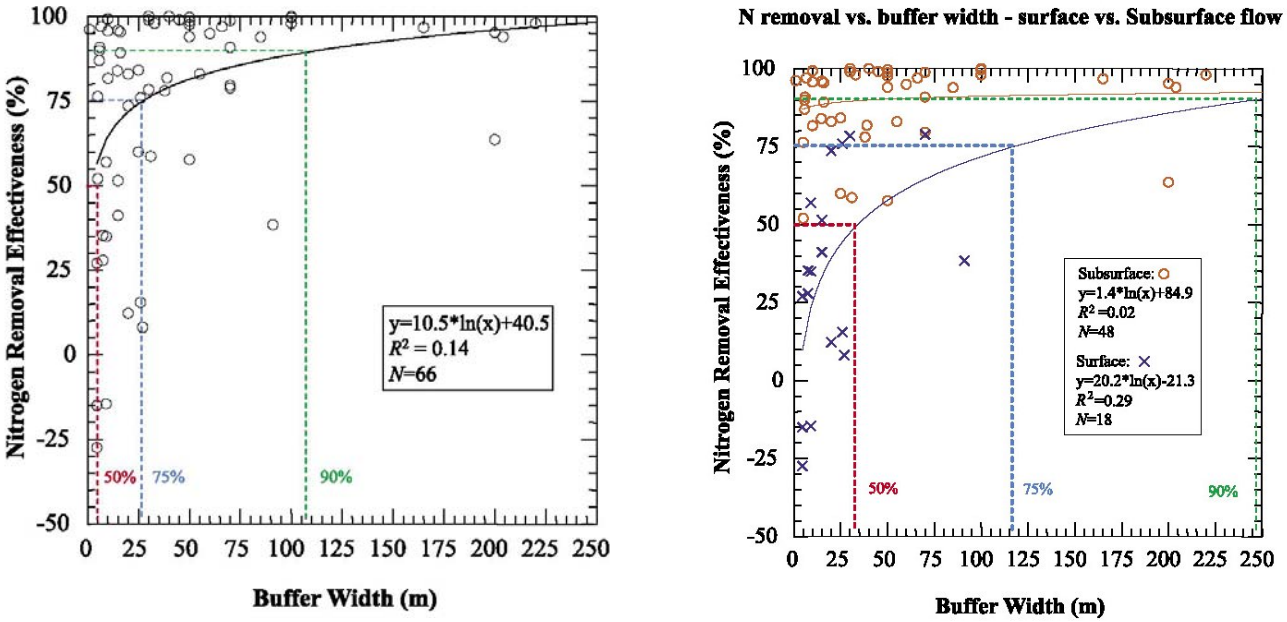


Figure 6. Graphs illustrating the relationship between buffer widths and nitrogen removal effectiveness for surface (both) and subsurface (left) flows (from Mayer *et al.* 2006).

Notably, when it comes to attenuation of sediments (and other contaminants) studies have shown that the relationship between buffer width and attenuation is not linear, and that beyond a certain threshold wider is not necessarily significantly better when it comes to water quality considerations. As discussed in Sheldon *et al.* (2005), a number of studies have found that most attenuation occurs within the first 30 to 40 m, with only limited increases with greater widths (see **Figure 5**). As a result, setting an efficacy target for sediment or nutrient removal at 90% versus 75% can result in significantly different buffer widths being recommended. As shown in **Figure 6**, a 50 m buffer would provide 80% sediment removal for most buffers captured in this review, but a buffer of at least 150 m would be required to increase that effectiveness to over 90%.

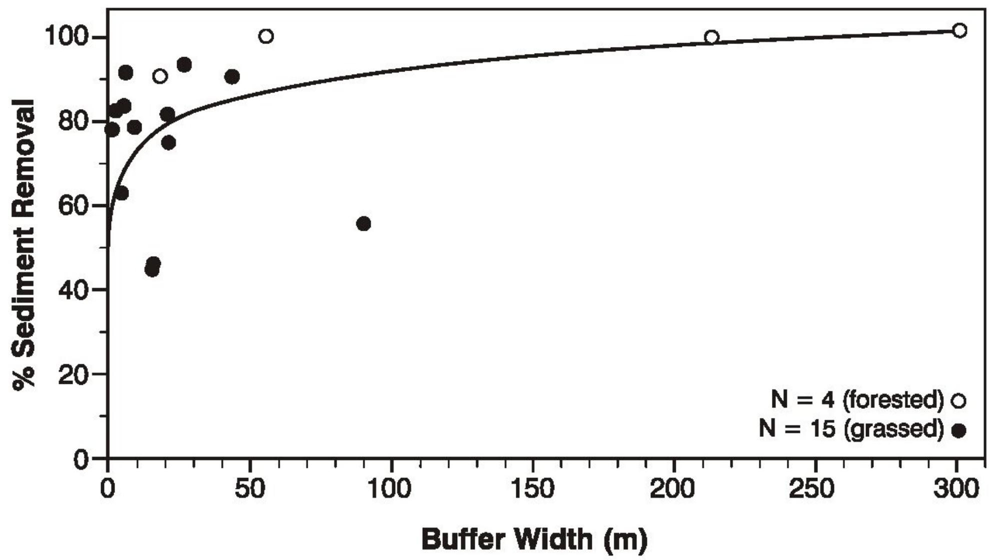


Figure 7. Illustration of non-linear relationship between buffer width and sediment removal effectiveness (from Sheldon *et al.* 2005).

Other Contaminant Attenuation or Transformation

Although the ability of vegetated buffers to remove toxins and pathogens is discussed by researchers (e.g., heavy metals, fecal coliform, pesticides, herbicides), surprisingly few papers actually test this function for wetland buffers. Hypothesized mechanisms include adsorption to attenuated sediments, uptake by vegetation, and degradation through soil biochemical processes.

- Four studies (cited in Sheldon *et al.* 2005) indicate pesticides and fecal coliform concentrations in receiving waters can be reduced by vegetated buffers in the range of 4 m to 35 m.
- Although their study was not focused on buffer efficacy, Thompson *et al.* (2004) found that forested buffers of 30 m to 60 m significantly mitigated effects of glyphosate herbicide spray from adjacent agricultural lands on wetlands, and amphibians within them. Notably, it is not known if narrower buffers would have been equally effective as narrower buffers were not tested.
- Recent research by Passeport *et al.* (2010) in an artificial wetland and a forest plot suggests that buffers can play a role in reducing the levels of pesticides to watercourses in largely agricultural watersheds, but no buffer widths are tested.

As pointed out by Sheldon *et al.* (2005), this is a significant gap in the scientific literature on wetland buffers.

3.2.3 Screening of Direct Human Disturbances

One of the primary functions of buffers is to mitigate against disturbances related to human activities that directly disrupt the species that reside in the wetland either permanently or temporarily. These are distinguished from the indirect effects related to broader landscape level land use changes (such as widespread timber harvest, conversion of lands to agricultural uses or urbanization) that result in the runoff of sediments, nutrients and other contaminants, as well as overall changes in hydrologic flows, addressed in **Section 3.2.1** and **Section 3.2.2** above.

The ability of wetland buffers to mitigate against direct human disturbances has been explored in the literature for the following topics, each discussed below:

- noise (largely related to road traffic, but also to other anthropogenic sources); and
- physical disturbances related to human presence, including:
    - Trampling and dumping within the wetland;
    - The introduction and spread of invasive plant species;
    - Wildlife disturbed by recreational activities (i.e., walking / hiking, biking or boating near and around natural areas);
    - Wildlife disturbed by the presence of housing and associated human activities.

Additional potential stressors to wetland habitats include intrusion of natural or artificial light (particularly to forested wetland edges) (e.g., Kiffney *et al.* 2004), dust (e.g., Farmer 1991), or domestic pets (e.g., Metsers *et al.* 2010). However, research conducted for this review found no papers that specifically address the ability of buffers to mitigate these impacts to wetlands, or even research that examines the extent to which these stressors can extend into a wetland from the edge. The review by Sheldon *et al.* (2005) supports this identified gap and reports no research on the specific impacts of domestic pets specifically on wetland plants, or the ability of wetland buffers to mitigate against such impacts, although they do cite research providing evidence of how domestic cats and dogs can disturb and harm wetland wildlife. Some research on the extent to which these impacts extend into forested edges is presented in **Section 3.3** under the discussion of edge effects to forests.

Noise Abatement

Noise from anthropogenic sources is known to disrupt many species of wildlife, and recent research has shown that noise (in this case from busy road traffic) can have a negative impact on the reproductive success of some species (in this case, Great Tits), presumably because it masks mating signals and calls (Halfwerk *et al.* 2011). Similarly, Eigenbrod *et al.* (2008) found that frog diversity was lower in areas with busier roads. Although responses varied significantly among species, and forest cover was also a crucial factor, Eigenbrod *et al.* (2008) found that landscapes with low traffic densities within 500 m of amphibian breeding ponds were consistently linked with greater levels of diversity. One likely explanation for this is the disruption of mating signals and calls by road traffic. Research by Bee and Swanson (2007) found that Gray Treefrog females showed latent responses and decreases in orientation towards target signals in the presence of frog choruses and busy road noises. This research supports the need for a buffer and/or some type of noise barrier around wetlands providing habitat for these species, particularly during the breeding season.

Along forest roads through Vermont, the density and reproductive success of Ovenbirds (*Seiurus aurocapillus*), known as forest-interior birds was lower at road edges (0 m to 150 m) than in forest interior (150 m to 300 m) areas (Ortega and Capen 1999). That study could not identify the cause, but habitat quality metrics, independent of vegetation structure were implicated.

Dense coniferous vegetation has been shown to attenuate noise. Castelle *et al.* (1992) cites a study that found evergreen buffers of 6 m were able to abate the noise of busy streets by four to six decibels (Harris 1985). However most of this attenuation occurs at high and low frequencies, while most traffic noise peaks in the 1000 to 2000 Hz spectrum (Duerksen *et al.* 1996). In addition, the effectiveness of vegetation in attenuating traffic noise diminishes with distance. This ability could potentially be improved with use of wider screens or combining vegetative screens with other measures (e.g., soil berms). The role of buffer design in enhancing the effectiveness of a buffer in abating noise (and other intrusions or encroachments), is discussed in **Section 3.6.3**.

Shisler *et al.* (1987) found noise and other impacts were documented at 15 m to 30 m in from wetland edges from low-intensity land uses, and at 30 m to 50 m in from wetland edges for higher intensity residential, commercial or industrial land uses. In these contexts, the most effective noise barriers were buffers with dense shrubs and steep slopes, supporting the idea that vegetation in combination with design measures can be an effective approach.

In their review, Sheldon *et al.* (2005) cite research that found 32 m of dense forest was required to filter sounds from commercial land uses, but found little other research that specifically studies the ability of different wetland buffers (or vegetative buffers combined with other design elements) to attenuate noise entering a wetland.

<u>Protecting Wetlands from Trampling, Dumping and Recreational Activities</u>

Although buffer width is only part of what contributes to a buffer's effectiveness, it would appear that for direct human disturbances (such as trampling, dumping and recreational impacts), wider buffers can contribute to wetland protection. Cooke (1992) in an analysis of wetland buffers in King and Snohomish counties in Washington State found that wider buffers (in this case of more than 15 m) were more effective at preventing direct human disturbances from encroaching into protected wetlands. Most buffers of less than 15 m (95%) were consistently linked with more noise, physical disturbance of foraging and nesting areas in the protected wetlands, and dumping of refuse and yard waste in to the protected wetlands. However, only 35% of buffers greater than 15 m were linked with such impacts, and were also associated with fewer changes in wetland water quality and quantity. Based on this analysis they recommended wetland buffers designed to mitigate against direct human impacts be 16 m to 61 m wide.

The nature and intensity of the adjacent land uses can also play a role how well a wetland buffer can prevent encroachments into the wetland. Castelle *et al.* (1992) cite a study by Shisler *et al.* (1987) in which 100 wetland sites were assessed in terms of buffer width and direct human disturbances to wetlands (e.g., dumping of garbage and fill, vegetation damage and removal, trampling). They found that the intensity of adjacent land uses accounted for much of the variation, and recommended wetlands in lower intensity land uses (i.e., agriculture, low density residential, passive recreation) have buffers of 15 m to 30 m from wetlands, while wetlands within high density residential, commercial or industrial have buffers of at least 30 m.

Other research is available on the impacts of trails, but is focussed on the impacts of trails within natural areas, and not adjacent to or within the buffers to natural areas, and is not included here.

Additional research on wildlife responses to recreation on water bodies, as well as hiking, is discussed in the section under riparian buffers (**Section 3.1.3**).

Preventing Spread of Invasive Plant Species

Little research was found on the ability of wetland (or any habitat) buffers to limit the spread of invasive plant species. The available research is summarized below:

- Cutway and Ehernfeld (2009) examined invasive plant spread into 17 forested wetlands in an urban context in New Jersey and found that wetlands in industrial areas were much less invaded than those in residential areas. The authors do not attribute this to greater human use or encroachment, or to the presence of more invasive garden plants, in the residential areas (wetlands in both had trails and comparable levels of apparent use, as well as comparable composition of landscaping plants), but rather different edge management. The residential areas typically had mown lawn well-shaded by trees backing onto the wetland providing no real barrier to invasive species spread, while the industrial areas typically had parking lots or buildings backing onto unmaintained wetland edges of dense herbaceous, shrub and vine vegetation. They also observed more deer in the residential areas and considered this another possible vector for propagule spread.

- Houlahan *et al.* (2006) studied relationships between plant communities in more than 50 wetlands in southeastern Ontario and found the strongest positive relationships with forest cover at 250 to 300 m from the wetland edge. They concluded this distance was linked to the ability of adjacent forests in this zone to both provide native sources of propagules and provide a barrier against invasive species. However, this finding does not necessarily imply that a buffer of 250 to 300 m is required to prevent the spread of invasive species into a wetland.

Some additional research on invasive plants and edge effects in forested habitat is discussed in **Section 3.3**.

Preventing Disturbances Related to the Presence of Housing

Wetlands in urbanizing areas, as well as rural areas with exurban development, are impacted by construction and post-construction activities (e.g., debris placement, encroachment) require buffers to protect some species against noise and disturbances from direct human presence and activities. However, there is surprisingly no peer reviewed scientific or published technical research on the ability of vegetated buffers to mitigate these kinds of disturbances at the site scale. A recent paper found that explored buffer functioning in relation to wetland birds from the landscape scale is described below.

- Smith and Chow-Fraser (2010) looked at obligate marsh-nesting birds in 20 coastal marshes in southern Ontario and found bird richness and abundance was significantly higher in rural landscapes than urban landscapes, Their results in relation to the presence or absence of vegetated buffers were inconclusive, although their classification of "buffered" habitats was very loose (i.e., presence of at least 20% forested area within 500 m of the wetland). This work does however link more concentrated development and reduced marsh bird abundance and diversity.

Other research that has examined riparian buffer functions at the watershed scale is presented in **Section 3.1.5**. At the site scale, additional research that relates to buffers and housing impacts falls into the category of "edge effects" research. This research focuses on the responses of species (primarily birds) to residential housing developments in lands adjacent to protected natural areas, as well as documented impacts in natural areas related to the presence of housing developments, and is discussed in **Section 3.3** which looks at buffers in relation to forests and woodlands

Other Considerations Related to Wetland Buffers

While a number of wetland species have been shown to be sensitive to direct anthropogenic disturbances, it would be incorrect to assume that all wetland wildlife require naturalized buffers to prevent disruption of their activities. Some examples are cited below:

- In a study by Attum *et al.* (2008) the Common Northern Watersnake and Midland Painted Turtle were shown to prefer larger wetlands within a few hundred metres of other wetlands, but their distribution was not affected by proximity to roads or the extent of adjacent forest.

- In their study of wildlife responses to mined versus natural peat bogs in New Brunswick, Bonifait and Villard (2010) found that songbird abundance was not reduced in peat bogs surrounded by areas disturbed by mining and left intact with some adjacent buffer (300 m to 500 m), while odonate abundance was much higher in bogs surrounded by natural habitat This is consistent with findings by Bried and Ervin (2006) that odonates require relatively wide buffer zones around wetlands to maintain natural levels of abundance and diversity.

- Traut and Hostetler (2003, 2004) observed that many waterbirds along urban lakes in central Florida appear to favour developed shorelines for a variety of behavioural patterns seemingly linked to their preference for open areas versus tall, emergent vegetation.

An additional, and important, consideration is that wetland buffers in and of themselves cannot solve broader natural heritage planning problems. DeLuca *et al.* (2004) did not look at buffer widths *per se* but tested impacts of adjacent land use and found marsh bird community in Chesapeake Bay integrity declined significantly when urban/suburban development within 500 m and 1000 m of the marsh exceeded 14% and 25% respectively. This speaks to the potential value of buffers in habitat protection, and also highlights the importance of the landscape, and provides evidence that buffers cannot replace appropriate landscape-level planning.

Well-designed buffers must be employed in combination with comprehensive land use planning that maintains a landscape containing relatively large, intact habitat areas in order to further conservation goals.

Planners Guide to Wetland Buffers for Local Governments (2008)

3.2.4 Protection of Core Habitat

There has been a considerable amount of new literature relating to protected areas adjacent to wetlands over the last decade. However, much of this literature, both scientific and technical, does not clearly distinguish between areas of critical habitat (CFZs) and protective buffers (or PZs) to this habitat. This causes confusion because the current literature shows a continued focus on the wetland itself as the “core” habitat, and the adjacent upland areas as “buffers” even though the science is increasingly demonstrating that these areas are equally important for the immediate and long-term persistence of a number of wetland-dependent species (as shown in **Figure 2**).

For the purposes of this review studies focussing on areas adjacent to wetlands that provide critical habitat for wetland dependent species are not being considered with respect to buffer determination because these areas constitute core habitat themselves (or Critical Function Zones) and should not be confused with buffers which are intended to protect that habitat by mitigating against the impacts of adjacent land uses. This review focuses on those papers that specifically speak to buffers rather than CFZs alone, and includes some papers and reviews where the two concepts have been blended and cannot be separated.

Additional confusion is created when the literature fails to distinguish between habitat that is critical to survival (i.e., foraging, overwintering) and that which was part of a linear movement or dispersal of a particular individual or series of individuals (i.e., migration) (e.g., Veysey *et al.* 2009; Baldwin *et al.* 2006; Milam and Melvin 2001; Semlitsch 2008). In part this confusion exists because it is not easy for empirical studies to distinguish movement for foraging or to overwintering sites from broader migration movements. Some of this may be resolved as the ability to track certain species over time improves.

In most of the literature examining upland habitats associated with wetlands, actual buffers to the identified critical function or habitat zones are not discussed. For example, the *Planner’s Guide to Wetland Buffers for Local Governments* (Environmental Law Institute 2008) is based on a review of local ordinances as well as hundreds of scientific papers and supporting analyses. Their review of literature on CFZs for wildlife concluded that 30 to 91 m areas were required for wildlife (with some studies recommending larger widths), but provide no separate recommendation for a buffer distinct from this CFZ. The few exceptions identified through our research are cited below:

- Semlitsch and Bodie (2003) discuss “biologically relevant core habitats” surrounding wetlands for various herpetofauna in a North American context, and are one of the few to distinguish between a critical terrestrial habitat zone adjacent to wetlands (and watercourses), and a separate buffer to this terrestrial habitat to protect it. Based on data for 19 frog, 13 salamander, five snake and 28 turtle species they recommend a general critical habitat zone of 142 to 289 m followed by a 50 m terrestrial buffer.

- Powell *et al.* (2010) recommend a 75 m forested buffer to protected wetlands for Rusty Blackbirds in a context of timber harvested areas in Maine (but acknowledge this zone may also serve some critical habitat functions for the bird such as foraging).

Although the above two studies recommend buffers to wetlands including consideration for CFZs, they do not actually empirically test the ability of their suggested buffers to protect the focal species of their studies from disturbances. While buffer recommendations from a broad range of studies is listed in **Table 3**, none of those related to wildlife are based on direct empirical assessments of buffer effectiveness.

Table 3. Summary of key quantitative findings related to buffers for wetlands.

MEASURED BUFFER FUNCTION(S)	SPECIES: Focal species or guild	Rec. Buffer: single value (m)	Rec. Buffer: range (m)	Source	Comments
A. WATER QUANTITY ***(no studies making specific buffer width recommendations found)***					
B. WATER QUALITY					
herbicide attenuation	amphibians		30 - 60	Thompson *et al.* 2004	Note this range of buffer widths was the only one tested.
nitrogen attenuation	NA		30 - 52	Environmental Law Institute 2008	Nitrogen retention requires larger buffers than phosphorus.
nutrient attenuation	various		6 - 168	Brown *et al.* 1990	Includes Critical Function Zone for wildlife.
nutrient attenuation	NA	30	19 - 88	Castelle *et al.* 1992	
nutrient attenuation	NA	40	3.8 - 260	Sheldon *et al.* 2005	Range and mean of effective buffer widths cited (see Table 5-2); note 260 m is an outlier and some of these studies are on watercourses not wetlands *per se.*
nutrient attenuation	NA		10 - 90	Skagen *et al.* 2008	Identified range based on review of literature.
sediment and phosphorus attenuation	NA	9		Environmental Law Institute 2008	Sediment and nutrient retention capacity closely linked to soil conditions.
sediment and phosphorus attenuation	NA		15 - 22	Woodard and Rock 1991	Found steeper slopes (i.e., 12%) required wider buffers.
sediment and phosphorus attenuation	NA	15		Woodard and Rock 1995	The effect of slope examined but results are inconclusive.
sediment attenuation	NA	6		Hook 2003	Found 6 m buffers to attenuate more than 0% of sediments regardless of slope (0-20%) or grassed buffer type.
sediment attenuation	NA	50	30.5 - 91.5	Norman 1998	50 m is recommended as the required baseline / minimum.
sediment attenuation	NA		10 - 60	Skagen *et al.* 2008	Identified range based on review of literature.
sediment attenuation	various		23 - 114	Brown *et al.* 1990	
sediment attenuation	NA	38	2 - 122	Sheldon *et al.* 2005	Range and mean of effective buffer widths cited; note some of these studies are on watercourses.

MEASURED BUFFER FUNCTION(S)	SPECIES: Focal species or guild	Rec. Buffer: single value (m)	Rec. Buffer: range (m)	Source	Comments
C. SCREENING OF HUMAN DISTURBANCE / CHANGE IN LAND USE					
physical barrier to human disturbance	NA		15 - 46	Castelle *et al.* 1992	For encroachments and refuse dumping.
physical barrier to human disturbance	NA	16	16 - 61	Cooke 1992	Buffers of between 16 and 61 m were much less affected by severe disturbance after residential developments were constructed, compared to those less than 15 m.
D. HABITAT TRANSITION / HAZARD MITIGATION ZONE ***(no studies making specific buffer width recommendations found)***					
E. CORE HABITAT PROTECTION ***(includes recommendations from reviews only based on findings from papers as those cited above)***					
protection from adjacent deforestation	Plants	15		Palik and Kastendick 2010	Found 15 m forested buffer temporarily protected vegetation associated with seasonal wetlands, but study limited to one year and one buffer width.
protection from adjacent deforestation	Rusty Blackbird	75		Powell *et al.* 2010	Includes critical habitat.
protection from direct and indirect human disturbances	various		98 - 223	Brown *et al.* 1990	Includes critical habitat for wildlife and noise buffer.
protection from direct and indirect human disturbances	various		61 - 91	Castelle *et al.* 1992	These are recommended minimums.
protection from direct and indirect human disturbances	herpetofauna	400		Eigenbrod *et al.* 2008	Recommend a 100 m Critical Function Zone around wetlands plus a 400 m buffer between this zone and busy roads, but the effectiveness of this buffer was not tested.
protection from direct and indirect human disturbances	various		30 - 305	Environmental Law Institute 2008	Highly variable depending on species and habitat characteristics. Includes critical habitat for wildlife.
protection from direct and indirect human disturbances	birds (waterbirds)		100 - 200	Erwin 1989	Recommendation based on flushing distances for several seabirds (Least and Royal Terms, and Common Terns).
protection from direct and indirect human disturbances	birds (waterbirds)		14 - 34	Rodgers and Smith 1997	Flushing distance greater from walkers than cars passing by; greater for nesting birds that perching/foraging birds.

MEASURED BUFFER FUNCTION(S)	SPECIES: Focal species or guild	Rec. Buffer: single value (m)	Rec. Buffer: range (m)	Source	Comments
protection from direct and indirect human disturbances	herpetofauna	50		Semlitsch and Bodie 2003	Recommend a 50 m terrestrial buffer in addition to a 172 - 349 m core habitat protection zone around the wetland.
Various	various		61 - 91	Castelle *et al.* 1992	These are recommended minimums.
Various	various		15 - 30	Castelle *et al.* 1994	Note slightly narrower and significantly wider buffers may be required depending on site-specific conditions / circumstances.
Various	NA		8 - 23	Sheldon *et al.* 2005	For wetlands with minimal habitat functions and low-intensity adjacent land use.
Various	NA		15 - 46	Sheldon *et al.* 2005	For wetlands with moderate habitat functions and moderate or high-intensity adjacent land uses.
Various	NA		46 - 92	Sheldon *et al.* 2005	For wetlands with high habitat functions, regardless of the intensity of the adjacent land uses.

3.2.5 Overview of Wetland Buffer Review Papers

While many studies provide recommended widths for single or multiple buffer functions regarding protection of wetland habitats (as shown in **Table 3**), there is a significant amount of variability even in mean width recommendations (a shown in **Figure 7**). As with riparian buffers, buffers for wetland water quality functions generally have narrower ranges than buffers for habitat functions, although there are some cases where relatively wide buffer widths are recommended for water quality alone.

As for the wildlife habitat functions, many of the papers looking at wetland buffers for habitat functions confound the protective buffer with the Critical Function Zone adjacent to the wetland, rather than considering the effectiveness of a buffer to that zone (as in **Figure 7**). Furthermore, the few papers that make recommendations specific to a protective zone do not actually empirically test or assess these buffers in terms of their ability to protect the wetland or its wildlife from the stressors outside its boundaries, and so these recommendations should be viewed cautiously. Nonetheless, there is a sufficient body of literature to provide a good starting point for making preliminary recommendations with respect to both buffer widths and key factors that need to be considered in buffer determination.

Although the technical literature points out the desire for simplified, prescriptive buffers (e.g., Wenger 1999), there seems to be broad consensus in the scientific literature that because of the number of site-specific variables that require consideration it is impossible to recommend a single width buffer that will be appropriate for most sites (e.g., Castelle and Johnson 1994, Sheldon *et al.* 2005, Adamus 2007). In addition to site-specific biophysical factors (i.e., soils, slopes, local hydrology), Adamus (2007) asserts that buffer widths must be determined with consideration for:

- Adjacent land use activities;
- The amount and configuration of development in the adjacent lands and landscape;
- The structure and type of vegetation in the buffer; and
- The particular species the buffer is being designed to protect.

In order to address this range of variables but still provide concrete guidance, some review papers identify ranges instead of single variable buffer widths, and others provide distinct recommendations for buffers to account for different desired functions and/or existing and anticipated conditions, as cited below:

- In their study of wetlands in East Central Florida, Brown *et al.* (1990) generate the following means and ranges for all wetland types:
  - 24 m to 137 m (range 6 m to 168 m) to minimize groundwater drawdown;
  - 23 m to 114 m (range 23 m to 114 m) to control sedimentation; and
  - 98 m to 182 m (range 98 m to 223 m) to support wetland dependent wildlife habitat needs (i.e., including the CFZ).

- Castelle *et al.* (1994) recommended minimums from 15 m to 30 m for both water quality and habitat functions, recognizing slightly narrower or significantly wider buffers may be required depending on site specific conditions.

- The Environmental Law Institute (2003) recommended minimum protection zones of 25 to 50 m for wetlands for water quality functions.

- Sheldon *et al.* (2005) develop three recommended buffer ranges that require a valuation of wetland functions and proposed adjacent land uses, as follows:
  - buffers between 8 and 23 m for wetlands with minimal habitat functions and low-intensity adjacent land uses;
  - buffers between 15 and 46 m for wetlands with moderate habitat functions and moderate or high-intensity adjacent land uses; and
  - buffers between 46 and 92 m (or more) for wetlands high habitat functions, regardless of the intensity of the adjacent land uses.

Notably, none of these recommendations or papers considered the possibility of reducing vegetative buffer widths if combined with other design elements to support buffer functions, which is another potential factor that can have significant impacts on a buffer width recommendation. Such considerations are discussed in **Section 3.6**.

For water quality, most studies recommend minimum wetland buffers in the range of 30 m. As Adamus (2007) points out, recommended buffers that are wider are usually based on (a) the authors' opinion rather than actual data, (b) studies not subject to peer review, (c) studies of runoff from cattle feedlots (expected to require wider buffers due to the concentrations of nutrients), and (d) studies where an unusually wide buffer was needed to achieve a high level of nutrient or sediment attenuation (e.g., more than 90%).

In some reviews (e.g., Environmental Law Institute 2003; Sheldon *et al.* 2005), wider minimum buffers are ascribed in relation to wildlife habitat protection functions, but that these include values derived from papers that have assessed the CFZ adjacent to the wetlands rather than the width required to protect this habitat. That is not to say that some species and guilds of wildlife may not require relatively large buffers under some circumstances. However, in some cases as long as core habitat needs for breeding, foraging and migration are met, an additional buffer may not provide significant additional benefits. Again, key considerations such as the size of the core habitat and the overall landscape context, as well as the level of sensitivity of the focal species to disturbance, need to be considered. More research in this area, particularly in terms of well-designed long term monitoring to test the effectiveness of different sized buffers in supporting habitat use by wetland-dependent species, is needed to provide more specific direction for buffers intended to protect core wetland habitats. As it stands, the preliminary quantitative guidance (as provided in **Table 3** and the text above) that can be gleaned from the available science can be summarized as follows:

A. WATER QUANTITY FUNCTIONS: The empirical evidence is insufficient. Brown *et al.* (1990), one of the few papers to make buffer recommendations for water quantity functions (and specifically to minimize groundwater drawdown in relation to changes in adjacent land uses), suggests between 24 m and 137 m may be effective, with appropriate widths being dependent on soils and local hydrologic dynamics.

B. WATER QUALITY FUNCTIONS: Average ranges between 15 m and 80 m, with an average single recommendation of about 30 m for multiple water quality benefits, noting that sediment and phosphorus can generally be well-attenuated in narrower buffers than nitrogen and that a combination of herbaceous and woody vegetation can be most effective for overall nutrient attenuation.

C. SCREENING OF HUMAN DISTURBANCE / CHANGES IN LAND USE: Minimum buffers ranging between about 15 m and 50 m, based on limited data.

D. HAZARD MITIGATION ZONE: No available empirical data looking at this function for wetland buffers on a site-specific basis. However, key considerations would include slope, height and condition of trees (if any) on feature edges, and vegetative composition of the buffer itself. Based on the literature reviewed and these considerations, a reasonable range could be from 10 m to 50 m.

E. CORE HABITAT PROTECTION: Recommended minimum buffers range from about 15 m to over 300 m. Averages range from about 45 m to 110 m, but must be considered with caution because: (a) the actual numbers vary significantly depending on the focal species and land use context, and (b) while we screened papers to try and exclude recommendations that identified Critical Function Zones (CFZs) instead of buffers, we have included several reviews where recommendations for buffer widths include both CFZs and buffers to those CFZs where the two could not be separated. Furthermore, the ranges and averages do not reflect the significant variability in recommended buffer widths both even within different taxonomic groups considered, or the many species and taxonomic groups not considered.

As with riparian buffers, while the approximate averages are useful to gain an overview perspective, it is important to recognize the wide variability in recommended widths for buffers in different contexts, and the need to consider site-specific factors (e.g., local hydrologic dynamics, soils, slopes, wetland types and size), species and functions which the buffer is expected to protect, as well as land use context in wetland buffer determination. These factors are discussed in **Section 3.5**.

Despite the growing body of available research that has been conducted on the effectiveness of wetland buffers, there continues to be confusion between CFZ and buffer functions, which confounds the determination of appropriate buffer widths. Nonetheless, the research conducted to date strongly supports the ability of vegetated buffers to provide a number of important functions in terms of protecting wetlands' water quality and habitat functions, and potentially even mitigating some water quantity stressors.

3.3 Buffers to Upland Woodlands and Forests

The term "buffer" (or "vegetative filter strips") first started to be used in an ecological context in the literature in the 1970's, but really became more widely used in the 1980's, primarily in the context of riparian buffers to streams in an agricultural setting or forestry setting (as described in **Section 3.1**). Although there are quite a few papers that look at the functions of forested buffers to watercourses, typically in the context of timber harvest (e.g., Steinblums *et al.* 1984; Jones *et al.* 1999; Moore *et al.* 2005; Perkins and Hunter 2006; Palik and Kastendick 2010), these are considered in **Section 3.1** because the feature being buffered is a watercourse (not a woodland or forest).

The other notable group of papers looking at forested buffers that have been excluded from this section are those that have used the term "buffer" but are actually looking at the inherent habitat functions of the buffer to the watercourse (e.g., for breeding, foraging or migration) (e.g., Machtans *et al.* 1996; Pearson and Mauwal 2001; Perkins and Hunter 2006). The focus of this section is on studies that examine the abilities of vegetated lands adjacent to woodlands and forests to mitigate against the impacts coming from the matrix.

This review uncovered no papers that actually examine the functions of different widths and / or types of buffers to woodlands or forested areas. The research on "edge effects" has been used as a surrogate source of information. Given the increasing interest in and use of buffers around forested areas in urban and urbanizing settings, it is surprising that there is so little empirical research that has been conducted on the actual ability of such buffers to mitigate against various stressors. There are, however, a number of papers that speak to the edge effects of various disturbances to woodlands or forests from the agricultural or urban matrix. These have been included to inform the discussion of buffers in this review.

The values and ranges presented for edge effects cannot be directly extrapolated to provide recommended buffer widths because they reflect findings on the distance(s) in from the forest edge at which the effect of a given stressor can be detected, rather than how far beyond the feature edge a vegetated buffer is needed to effectively mitigate that stressor. Nonetheless, the extent of various edge effects can provide information on the impacts which a buffer would be expected to try and mitigate. Furthermore, it is expected that a large enough vegetated buffer, and particularly one containing some trees and large shrubs, would have the ability to reduce or potentially even eliminate the intrusion by many of the stressors identified.

Murcia (1995) in her review defines three types of edge effects, as follows:

(1) abiotic effects (i.e., changes in the environmental conditions as a result of the structurally dissimilar matrix) – ranging from 15 to 50 m
For example changes in light, air temperature and moisture, soil temperature and moisture, penetration of chemical compounds such as herbicides or pesticides

(2) direct biological effects (i.e., changes in the abundance and distribution of species caused by changes in physical conditions) – ranging from 15 to 150 m
For example, tree density, species composition, species abundance (e.g., Wood *et al.* 2006) seedling regeneration, plant mortality

(3) indirect biological effects (i.e., changes in species interactions related to the difference in physical conditions) – ranging from 10 to 600 m
For example, predation, brood parasitism, competition, herbivory, seed dispersal and plant propagation.

Reviews by Murcia (1995) and others (e.g., Henshaw and Leadbeater 1999; Ewers and Didham 2006; Environment Canada 2004; Batary and Baldi 2004; Environmental Law Institute 2003) have shown a wide range in documented edge effects, and generally support a generally accepted rule of thumb that forest edge effects generally drop off and forest "interior" conditions (e.g., cooler, moister) begin at approximately 100 m in from the forest edge.

Findings from the "edge effects" research, and other research related to upland woodland or forest buffers is discussed in **Sections 3.3.1 to 3.3.4**, and presented in **Table 4** below.

3.3.1 Water Quantity and Quality Functions

Although there are many papers that have examined the ability of riparian forested buffers along watercourses to improve water quality (see **Section 3.1.2**) and a few that have looked at water quantity (see **Section 3.1.1**), no scientific or technical papers were identified through this review that specifically studied the ability of an upland forest buffer to protect or mitigate impacts to water quality or quantity elsewhere on or off site. Several landscape scale studies have, however, looked at relationships between the extent of forest cover and/or forested riparian buffers in the landscape and water quality in a given watershed and found there to be positive correlations. This research is discussed in **Section 5.1**.

3.3.2 Edge Effects of Human Disturbances / Changes in Land Use

No research that directly tested the effectiveness of buffers in protecting upland woods from human disturbances was found as part of the work undertaken for this review. However, there is some research on documented responses of plants and wildlife to impacts along the forest or woodland edge that can inform the discussion of buffers, as summarized in **Table 4**. These include direct disturbances, such as physical encroachments and noise from adjacent back yards, as well as disturbances related to human recreational activities in adjacent lands. While the documented edge effects cannot be directly extrapolated to buffer widths, they can provide some idea of the ranges of sensitivities of different plants and wildlife species.

While the literature review of edge effects provided here is not comprehensive, representative papers that cover off documented edge effects for most stressors studied have been included. Documented edge effects to the following stressors are discussed in this section:

- Noise (from vehicular traffic, as well as people);
- Toxins (e.g., drift of herbicide / pesticide / fungicide sprays from adjacent lands);
- Disturbance associated with recreational activities (e.g., hiking, biking); and
- Disturbance associated with permanent human presence (e.g., housing, pets, invasive plants).

<u>Noise</u>

Most edge effect papers related to noise focus on noise from road traffic. A few papers speak to the edge effects of road traffic on forest-dwelling birds and document responses ranging from 30 m to 5 km into forest edges (Reijnen *et al.* 1997; Houlahan and Findlay 2003; Eigenbrod *et al.* 2008; Forman and Deblinger 2000; Benitez-Lopez 2010) as summarized in **Table 4**.

Notably, not all road traffic has been shown to have a negative impact on wildlife. King and DeGraaf (2007) and Forman *et al.* (2002) both detected little to no effect of low traffic roads (both maintained and not) on forest breeding birds, indicating that the road itself is not the source of impact for forest birds, but rather the level and frequency of noise associated with it. Forman (2000) found that impacts to forest birds were generally not detected until levels of road traffic reach 10,000 vehicles per day, and that edge effects tended to increase with increasing levels of traffic.

In a unique study that tried to isolate the effects of persistent anthropogenic noise on forest birds, Bayne *et al.* (2008) studied the responses of boreal forest bird density and occupancy within (a) 100 m to 300 m and (b) 400 m to 700 m from compressor stations and found that a number of species did have a negative response (i.e., reduced density and reduced occupancy) due to the presence of persistent anthropogenic noise even in a fully forested context.

Notably, it was forest area-sensitive bird species that were primarily being affected by the presence of noise in the papers cited above. However, noise would not be an issue in many fragmented forests in urban contexts where these species no longer occur because the local and landscape levels of forest cover are inadequate to sustain them, and perhaps, levels of disturbance are too high.

Disturbance Associated with Recreational Activities

Studies documenting responses of plants and wildlife to human recreational activities both within and adjacent to forested areas also report a very wide range of distances at which direct effects or wildlife responses were detected.

- In a comprehensive review of raptor responses to human disturbances and mitigation approaches, Richardson and Miller (1997) report flushing distances ranging from 17 m (e.g., Merlin) to 990 m (e.g., Bald Eagle), and put forward associated buffer recommendations ranging from 50 m (for Merlin) and 1600 m (for Golden Eagle). However, these buffers are not actually tested for effectiveness in this study or any of those cited.

- Taylor and Knight (2003) document most deer, antelope and bison "flushing" in response to hiking and mountain biking within 100 m to 390 m of park trails in forested areas, although notably these responses were within rather than adjacent to a natural area.

- Hamberg *et al.* (2008) found that the effects of human trampling from informal trail formation along the forest edge of boreal forests extended up to 50 m in from the edge.

The range in distances illustrates how edge effects can vary depending on the focal species, nature of recreational activity, and nature of the forested habitat itself. Furthermore, buffers can only mitigate against recreational activities along the feature edge, and may prevent or minimize unwanted access to a given woodland or forest. But obviously the impacts related to recreation within the feature itself must be managed using other tools and mechanisms.

Disturbance Associated with Human Presence

Physical disturbances associated with human presence studied in the literature include those related to the presence of houses or development, roads and pets. Those identified through this review are cited below.

- Friesen *et al.* (1995), in one of the first papers to study the impacts of residential development on forest birds, found that in relatively small forests ranging from 3 ha to 50 ha, woodlots with no adjacent residential development had the most diverse and abundant neotropical migrant bird communities irrespective of patch size, and that diversity levels dropped off most sharply for sites with what they classified as high levels of residential adjacent homes (i.e., more than 25). While the paper recommended the need for buffers, it did not suggest any specific widths or parameters for them.

- Based on their synthesis from other studies, Ries *et al.* (2004) recorded average responses to various human disturbances adjacent to forested areas as extending up to 50 m for plants, up to 100 m for invertebrates, and between 50 to 200 m for birds, although examples where responses were recorded deeper into the forest were recorded for all groups.

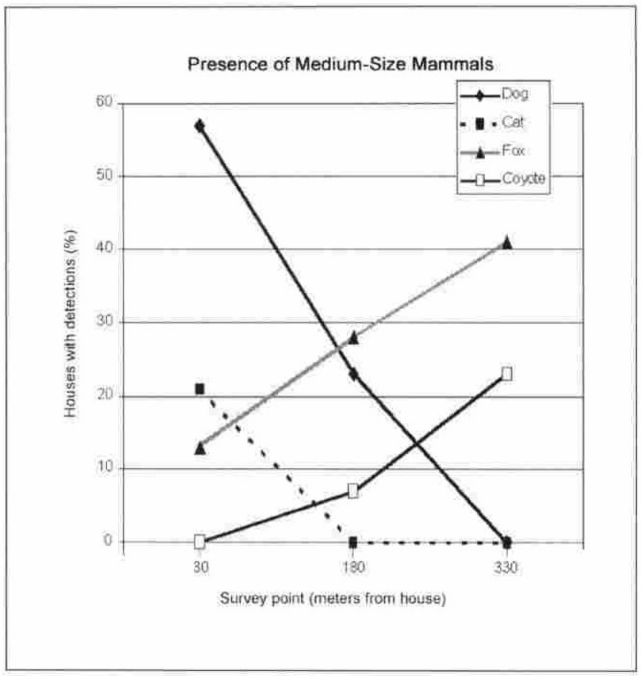
- In their recent study of over 180 areas adjacent to 40 different publicly owned forests in southern Ontario, McWilliam *et al.* (2010) documented encroachments in 99% of areas within 20 m of the forest edge, with the most obvious and severe encroachments recorded within the first 10 m. A follow-up paper expanding on this research and looking at over 400 publicly owned forests adjacent to residential lots found most encroachments occurred within the first 16 m to 20 m.

- Odell *et al.* (2003) and Odell and Knight (2001) documented the impacts of residential sprawl in the mountainous shrublands of Pitkin County, Colorado and found that almost all species of shrubland birds sensitive to human activity showed significant declines in abundance 30 m from the houses, but increased at survey points at 180 m and 330 m from the houses.

Direct encroachments or impacts along the edges of forested areas related to vegetation seem to be restricted to the first 10 to 50 m, or less (see the section below on invasive species), but impacts to wildlife can extend much further in to the forest.

Many edge effect papers related to roads focus on the responses of birds to noise from road traffic. However, a few papers speak to the edge effects of road traffic on vernal pool / forest dwelling amphibians (Reijnen *et al.* 1997; Houlahan and Findlay 2003; Eigenbrod *et al.* 2008) as summarized in **Table 4**. Houlahan and Findlay (2003) documented significant drops in amphibian species diversity and abundances within 200 m of busy roads, and recommend that such roads be kept at least this distance from some wetlands and forest in a given planning jurisdiction if amphibian populations are to be maintained. However, as discussed above, edge effect values cannot simply be translated into buffer recommendations.

A few papers were found that examined the extent of impacts into forested or shrubland areas by domestic cats and dogs. Research by Metsers *et al.* (2010) on home ranges of domestic cats in urban and rural areas found they extended up to 1.2 km and 2.4 km respectively, suggesting that buffer zones to exclude them from natural areas would need to be very wide, unless combined with other measures such as fences.



In their study in mountainous shrublands, O'dell *et al.* (2003) documented an inverse relationship between the abundance of cats and dogs around homes in rural areas and the presence of wild fox and coyote. This relationship, shown in **Figure 8**, illustrates how cats were not documented much beyond 180 m from their homes but dogs strayed further (more than 330 m).

Figure 8. Relative abundance of domestic pets versus medium-sized mammals in relation to residential housing within natural areas (from O'dell *et al.* 2003).

3.3.3 Hazard Mitigation Zones

Although not related to mitigating edge effects *per se*, an additional potential function of buffers to woodlands and forests (as discussed by the steering committee) is to provide a setback from potential hazards related to tree fall. This review did not uncover any scientific or technical research on this function, nor do there appear to be any examples in current natural heritage planning in Ontario (or elsewhere) where this logic has been explicitly used to justify buffers to wooded areas. However, the importance of retaining dead wood and snags within woodlands to support their ecological functioning is recognised, and when these forest elements, as well as trees that are in decline occur along a feature edge that is relatively close to a potential target, they can present a potential risk.

Trees, as well as branches, in woodlands and forests occasionally fall as a result of natural processes (e.g., age, decay) as well as storm events. When changes in land uses create new or exposed forest edges, opportunities for tree fall to occur outside the defined feature boundaries (typically the tree driplines) are created, and present potential risks if immediately adjacent lands include structures and active human uses.

While there is some logic in ascribing hazard mitigation to buffers, managing risk related to hazard is typically more of a management and safety issue rather than an ecological function. Based on this function, a buffer to a woodland or forest should extend the maximum distance at which a tree along the feature edge might fall wherever there are immediately adjacent uses (e.g., a house, a yard) or activities (e.g., a trail) that would put property or persons at immediate risk. Using this same logic, the entire rationale for the buffer could be removed by simply removing all potential hazard trees along the feature edge. This practical aspect of buffer management has been recognized by jurisdictions in the United States where regulations explicitly allow for removal of hazard trees within ecological buffer zones (e.g., Sammamish, Washington; Seattle, Washington). It is also common practice among some municipalities in southern Ontario to require removal of identified hazard trees along edges of natural areas that will be abutting developments or public open spaces.

While it is acknowledged that tree fall may be a consideration in woodland or forest buffer determination, it is not recommended that this function be the primary determinant for buffer width because it can be so readily addressed through management. In many cases, hazard trees along the feature edge could be removed without necessarily having a negative impact on the overall ecological values for which a given woodland or forest is protected. Nonetheless, where areas of “potential tree fall” overlap with other more strictly habitat-based buffer width requirements, there may be opportunities to remove this potential risk, and maintain the ecological values associated with these trees. Snag management within protected forests is common (for example, in many conservation areas within the GTA), and there is no reason why such management should not be extended to urban forest systems where it can be accommodated. Alternate management solutions that could be considered include partial removal of hazard trees, snag creation in “safe areas” (i.e., those where there are no potential anthropogenic targets), or selective expansion of buffer widths where snags along the feature edge occur in unusually high densities. A buffer extended to capture both the largest trees that might be able to grow, and that are located right at the edge of the forest, would likely result in a wider buffer than what otherwise would be required or could be justified. Therefore, it is recommended that tree fall be a secondary consideration in woodland or forest buffer determination, and that the buffer to accommodate this potential risk be satisfied to the extent that the recommended width is designed to support other more strictly ecological or hydrologic buffer functions (as presented in **Table 1**).

If a buffer that is beyond a width that can be justified based on other ecological or hydrologic considerations is determined to be required to accommodate the potential risk of tree fall, then this requirement should be addressed independently as a hazard setback. This is comparable to the approach to slope erosion hazards. While a vegetated buffer in a riparian zone will likely provide some slope stabilization and erosion control, the determination of the slope hazard setback is a separate exercise based on topographic and geotechnical considerations, rather than the buffering functions of the riparian area *per se*.

3.3.4 Edge Effects and Core Habitat Protection

No research that directly tested the effectiveness of buffers in protecting upland woods from anthropogenically driven changes in the surrounding landscape was found as part of the work undertaken for this review. However, there is some research on documented responses of plants and wildlife to impacts along the forest or woodland edge that can inform the discussion of buffers, as summarized in **Table 4**. These include disturbances such as changes in microclimate along the forest edges (e.g., temperature, light), drift of chemicals applied to adjacent lands, and the spread of invasive plant species from gardens or as a result of physical disturbances. While the documented edge effects cannot be directly extrapolated to buffer widths, they can provide some idea of the ranges of sensitivities of different plant and wildlife groups.

Bird nest predation in forests is another impact to wildlife that has been identified as an edge effect and linked to the nature and extent of changes in adjacent land uses (to both agriculture and residential or other types of development). While examples of this literature have been considered in the context of this review (e.g., Tewksbury *et al.* 2006; Smith 2004; Sinclair *et al.* 2005), ultimately this body of research was determined to be of very limited use in helping inform buffer determination for upland or lowland forests. Research like that of Thorington and Bowman (2004) found predation rates significantly higher adjacent to higher density housing, but found no relationship between levels of predation and distance of nest from the forest edge. Perhaps in the future, research testing the ability of forested buffers to mitigate the impacts of nest predation could be of value.

A final category of buffer functions identified is the maintenance of biotic integrity of the feature itself, in this case provision of additional rooting area for trees along the edges of the feature as it matures and evolves over time, as well as potential accommodation for standing snags within the feature that may present a hazard (see discussion **Section 3.3.3** above).

Microclimate Changes Along Forest Edges

The ability of a vegetated buffer to protect forested habitats from microclimate changes (e.g., temperature, humidity, wind, soil moisture) particularly around the edges, has been discussed in the literature but never empirically tested. In a somewhat unique study of 22 mature upland forest fragments in rural and urban south central Ontario, Burke and Nol (1998) found that microclimate changes (i.e., increases in light intensity and reductions in soil moisture) were evident and extended up to 20 m from the edge, irrespective of forest fragment size. It follows that a buffer that includes a vegetative structure similar to that of the feature being protected would be able to mitigate this impact.

Several papers examining abiotic edge effects in various parts of the United States were cited in the Environmental Law Institute (2003), as follows:

- Brothers and Spingarn (1992; as cited in Environmental Law Institute 2003) found microclimactic differences were limited to the first 8 m in forest fragments.
- Matlack (1993; as cited in Environmental Law Institute 2003) detected differences in light, air temperature, litter moisture and humidity extending up to 50 m from the forest edge.
- Chen *et al.* (1995; as cited in Environmental Law Institute 2003) found solar radiation gradients extended from 15 m to 60 m into upland old-growth forest, while humidity and wind speed gradients extended as far as 240 m.

Light is another stressor that is mentioned regularly in the literature on wetland impacts, but whose isolated effects have hardly been studied for upland forests. In two papers in northern British Columbia (Kiffney *et al.* 2003; Kiffney *et al.* 2004), solar input to watercourses is compared between riparian areas where trees have been clearcut as compared to areas with 10 m and 30 m buffers. In both studies the 30 m buffers provided the most effective protection to the watercourse in terms of maintaining levels of shade and associated insect populations.

It is logical to assume that a forested buffer would be able to mitigate many of the microclimactic impacts described above, however the appropriate buffer width would depend on the vegetative structure of the buffer itself (including the density of the vegetation), as well as its aspect in relation to the feature, and the position of the protected feature itself in terms of exposure to changing climactic conditions. The size and overall age of the feature itself are additional considerations in identifying an appropriate buffer for mitigation of microclimate impacts along feature edges.

Exposure to Toxins Along Forest Edges

Pesticide and herbicide drift have been examined by a few researchers in terms of the extent to which they can extend from adjacent agricultural lands into forested habitats, and in some cases this data has been used to suggest appropriate buffer widths to mitigate against this impact (even though the actual effectiveness of these buffers was not tested empirically):

- Burn (2003) acknowledged the potential use of buffers to protect lowland and upland wildlife habitat from pesticide drift in agricultural settings, but did not test or suggest any specific buffer widths for this function.

- Boutin and Jobin (1998) recorded herbicide drift from adjacent agricultural fields extending from 6 to 9 m into woodlands, and cited other studies that document herbicide drift in the same range (i.e., 5 to 10 m).

- Gove *et al.* (2007) found the effects of herbicides on woodland ground covers extended at between 4 m and 9 m in from the forest edge from adjacent agricultural landscapes.

- De Jong *et al.* (2008) found the effects of pesticides, herbicides and fungicides extended more than 18 m into the forest edge from the adjacent agricultural setting.

Buffer recommendations, where made, in these studies generally correspond to the extent of the documented edge effect. While this does not seem an unreasonable approach with respect to this direct and readily measurable impact, factors to consider in determining an appropriate buffer width include vegetative structure of the buffer itself (including the density of the vegetation), as well the position of the protected feature itself in terms of exposure to changing climactic conditions, and particularly wind.

Spread of Invasive Species

Invasive species are a serious issue in natural areas in an urban or urbanizing context, but can also threaten ecosystems in rural and agricultural contexts (Duguay *et al.* 2007; Gavier-Pizzaro *et al.* 2010). A couple of studies identified through this review that examined the extent to which invasive species penetrated the edges of forested habitats are cited below.

- The review by Adamus (2007) cites a few papers that indicate invasive plant spread into forested edges may be limited to 3 m, but that they can extend 21 to 60 m into the forest.

- McDonald and Urban (2006) found that in studies of 66 forest edge segments in an agricultural context that invasive species only altered the forest community species composition significantly within the first 5 m of the forest edge, and seemed to be restricted by a combination of seed dispersal and suitable edaphic factors.

- A recent review by Vilà and Ibáñes (2011) focusing on 17 empirical studies (not all in forests) confirmed that invasive species tend to be more abundant along patch edges than in the "interior" habitat, and that documented invasions ranged from 10 m to 225 m with a mean of 80.53 m ±20.53 m. They noted that the landscape matrix is very influential.

This limited research suggests that invasive species tend not to spread too far into forest edges. However, in urban and even rural settings, invasive species can be – and are - introduced via other routes such as internal pathways.

Additional Rooting Area

An additional ecological reason for buffers to woodlands or forests identified through this review is to provide additional area for tree roots.

Although no peer reviewed science that examines the extent of trees' "critical root zones" was uncovered as part of this review, there are a number of technical studies in arboricultural publications that provide general guidance about appropriate tree protection zones for individual trees that can be considered to inform buffer considerations related to this function.

Current practices in Ontario, and elsewhere, measure the critical tree protection zone from the base of the trunk to the external tree drip line. This is based on the assumption that the roots within this zone are the most critical to the survival of the given tree. However there is evidence to suggest that this area may not be adequate for some species, particularly for larger deciduous trees. Furthermore, it could be argued that the buffer should provide some rooting area for the trees (and shrubs) along the woodland or forest edge as they mature in order to continue to sustain the feature into the future.

While there is a lack, once again, of scientific research on this topic area, there are a few published and unpublished technical papers (e.g., Fitzpatrick 2002, Matheny and Clark 1998) looking at appropriate distances for root zone protection. For example, in an unpublished literature review and a limited field assessment conducted for a woodlot beside an agricultural field in Vaughan in 2004 (B. Henshaw, pers. comm. 2011), tree roots were generally found to extend far beyond the drip line and more rigorous tree protection areas were considered to be between 1.5 and 3 X the dripline radius, depending on soil types, moisture regime and tree species involved.

Generally, soil type (moisture regime and texture), tree size/age/condition and tree species are considered the most critical factors in determining a root protection zone (Matheny and Clark 1998). Other factors may include proposed land use change, slope, and changes in hydrologic regime.

Given that assessing the actual extent of active tree roots is typically not feasible as part of a typical study, arborists have developed several methods of determining optimal tree root protection zones. These go beyond the "critical" zone within the dripline and include distances determined based on the diameter of the tree trunk (Abbey 1998, Fite and Smiley 2008, Despot and Gerhold 2003). Examples of approaches include: the critical root zone (i.e., dripline) plus 46 additional cm of radius for every 2.54 cm of dbh beyond 75 cm or the critical root zone (i.e., dripline) plus 1.5 times the dripline radius.

Table 4. Summary of edge effects related to various stressors in agricultural and urban matrices around woodlands and forests.

Stressor	Context	Focal Guild / Species	Impact Zone	Source
A & B. WATER QUANTITY AND WATER QUALITY *(no papers found on edge effects and these functions)*				
C. DIRECT EDGE EFFECTS FROM HUMAN DISTURBANCES / CHANGE IN LAND USE				
deforestation (agriculture)	agricultural	birds (Cavity-nesting)	up to 400 m	Deng and Guo 2005
deforestation (clearcut)	natural	birds - ground nesters	up to 100 m (in this zone recruitment was lower than survival)	Manolis *et al.* 2002
human activity (hiking, mountain biking)	natural	large mammals - Mule Deer, Bison, Pronghorn Antelope	found 70% probability of flushing at 100 - 390 m from activity on trails	Taylor and Knight 2003
human activity (noise, visual of humans)	various	birds - raptors	range in flushing distances of 17 - 990 m; buffers recommended range from 50 - 1600 m (includes forested wetlands)	Richardson and Miller 2007
human activity (noise, visual of humans)	urban	birds - common urban adapted species	8 - 18 m for alert and flight distances	Fernández-Juricic *et al.* 2001
human activity (noise, visual of humans)	natural	birds - forest species	4 - 36 m for alert and flight distances	Fernández-Juricic *et al.* 2004
human disturbance (trampling)	urban	NA	up to 50 m on average (review paper)	Hamberg *et al.* 2008
human disturbance (trampling)	natural	soil microbes	up to 50 m (in boreal forest)	Malmivaara *et al.* 2008
human disturbance (waste disposal, landscaping, construction)	urban	NA	observed at 99% of sites within 20 m of forest edge, with most severe impacts within 10 m	McWilliam *et al.* 2010
human disturbance (waste disposal, landscaping, construction)	urban	NA	most encroachments within 16m to 20 m from forest edge	McWilliam *et al.* 2011
noise (industrial)	natural	birds	up to 700 m (in boreal forest)	Bayne *et al.* 2008
road salt	urban / suburban	woody plants	within ~ 10 m of the road	Forman and Deblinger 2000
road traffic noise	rural	amphibian species diversity and abundance	effects strongest at 200 m, but detected at 2000 - 3000 m (in forested wetlands)	Houlahan and Findlay 2003

Stressor	Context	Focal Guild / Species	Impact Zone	Source
road traffic noise	rural	amphibian abundance	recommendation for a 100 m forested Critical Function Zone around wetlands plus a 400 m buffer between the wetland and busy roads (in forested wetlands)	Eigenbrod *et al.* 2008
road traffic noise	urban / suburban	birds - forest-interior species	~ 650 m	Forman and Deblinger 2000
road traffic noise	natural	birds	disturbance distances documented between 30 and 2800 m; 1000 m (on each side of road) recommended	Reijnen *et al.* 1997
roads	natural	birds - forest-interior (Ovenbird)	~ 50 m; disturbance linked to rarely used, unpaved roads	Ortega and Capen 1999
roads and other infrastructure	various	birds	up to 1 km (in forests and open meadows)	Benitez-Lopez *et al.* 2010
roads and other infrastructure	various	mammals	up to 5 km (in forests and open meadows)	Benitez-Lopez *et al.* 2010
D. HABITAT TRANSITION / HAZARD MITIGATION ***(this function not related to edge effects; no papers cited)***				
E. INDIRECT EDGE EFFECTS ON CORE HABITAT PROTECTION				
herbicides	rural	NA	6 - 9 m	Boutin and Jobin 1998
herbicides	agricultural	plants (forest herbs)	up to 4 m	Gover *et al.* 2007
herbicides, pesticides, fungicides	agricultural	plants, fungi, caterpillars	up to 18 m on average (includes forested wetlands)	de Jong *et al.* 2008
invasive plants	various	NA	10 - 225 (80.5 m mean), from 17 papers	Vilà and Ibáñes 2011
invasive plants	urban / suburban	NA	10 - 120 m from the road	Forman and Deblinger 2000
invasive plants	rural	NA	up to 5 m	McDonald and Urban 2006
invasive plants	urban	NA	presence of 10 m mown grassed strips in front of fenced buffer reduced invasions by yard escapes	McWilliam *et al.* 2011
microclimate changes	rural-urban	plants	up to 20 m (in mature forests)	Burke and Nol 1998
various	various	plants	up to 50 m on average (review paper)	Ries *et al.* 2004
various	various	invertebrates	up to 100 m on average (review paper)	Ries *et al.* 2004
various	various	birds	up to 50 to 200 m on average (review paper)	Ries *et al.* 2004

Given that a large tree in the context of southern Ontario would typically be in the range of 80 to 140 cm DBH, in practice this would result in an additional zone beyond the dripline of between about 2.5 and 11.5 m.

Studies on distances required for truly effective tree protection zones as part of buffers to woodlots and forested areas is another area where empirical, peer-reviewed research is sorely lacking and badly needed to advance our understanding or tree and woodlot / forest protection, particularly in urbanizing contexts. However, based on current practices protection of "additional rooting area" buffers to mature woodlots, or woodlots expected to mature, in the range of 3 to 12 m could be justified.

3.3.5 Overview of Buffers to Woodland / Forest Habitats

In his discussion of forest edge effects on forest plants and birds, Friesen (1998) identifies buffers to forests as a fundamental planning approach needed to mitigate impacts in urban contexts, but acknowledged the buffer widths required for this mitigation had yet to be studied. This remains true in 2012. There is, however, literature on edge effects as well as consideration for additional rooting area and tree fall that can be used to help inform consideration of woodland and forest buffers. While it must be treated with caution, the edge effects research provides some preliminary direction for buffer considerations as well as ranges for appropriate buffer widths.

A. WATER QUANTITY FUNCTIONS: No empirical or technical evidence is available to support this function for upland woodland or forest buffers.

B. WATER QUALITY FUNCTIONS: No empirical or technical evidence is available to support this function for upland woodland or forest buffers.

C. SCREENING OF HUMAN DISTURBANCE / CHANGES IN LAND USE: Most readily measurable effects of immediate human disturbance (e.g., trampling, dumping of waste, yard extensions, spray or road salts) are documented as occurring within the first 10 m to 20 m of the forest edge, but can extend up to 50 m. Responses of wildlife species to human-related disturbances in adjacent lands have been documented to be limited within the first few metres for some species in some situations, but have also been documented as extending into the wooded feature dozens and hundreds of metres. Based on this edge effect an appropriate buffer for the direct disturbances may be in the range of 10 m to 20 m, additional buffer width for screening impacts of human disturbances for wildlife would need to consider the species or guilds being targeted for protection, the land use context, the vegetative structure of the buffer, and possibly the natural heritage system context in which the given feature is located.

D. HAZARD MITIGATION ZONE: This would be equivalent to the height of the tallest trees along the feature edge in cases where they may fall and pose a potential risk to property or persons. However it is recommended that where this exceeds the buffer width that has been identified based on other criteria that this setback be identified separately as a risk management zone, or that management be undertaken to minimize or remove the potential risk.

E. CORE HABITAT PROTECTION: Zones to provide additional rooting area for large trees along the edges of wooded features may range from 3 to 12 m, while edge effects range from a few to about 100 m on average for abiotic and biotic impacts that are indirectly related to anthropogenic activities.

As with riparian and wetland buffers, it is important to consider site-specific factors (e.g., local hydrologic dynamics, soils, slopes, woodland / forest type and size), species and functions which the buffer is expected to protect, as well as land use context as part of buffer determination.

Recent work by McWilliam *et al.* (2011) in more than 400 plots in woodlands adjacent to residential rear yards found that the bulk of encroachments occurred within the first 16 to 20 m. On the other end of the spectrum, a review paper by the Environmental Law Institute (2003) found that documented edge effects ranged from 8 m to 5 km, with 75% of studies reporting effects at 230 m or less.

The Environmental Law Institute (2003) uses their findings as the basis for recommending generalized buffers of 230 to 300 m from habitat edges, however the largest documented effects were related to responses of birds and mammals, and it is questionable to what extent these longer distance effects are actually site-specific “edge effects” rather than responses to changes in the extent and nature of habitat in the broader landscape (e.g., fragmentation). This is an important distinction, because pointing to edge effects as the causative factor suggests that simply placing a larger buffer on the given feature can mitigate the observed impacts, whereas if overall habitat fragmentation and loss is the driver of the documented responses, then buffers can do very little and the solution lies in increasing overall habitat coverage and connectivity. Here, as elsewhere, it is important not to confuse the function of buffers with habitat restoration that may be desired and required to restore certain ecosystem functions (e.g., habitat for area-sensitive species).

3.4 Buffers to Meadows and Other Specialized Habitats

No scientific research or reports were found that explore the potential value of buffers to meadow or grassland habitats, or other specialized habitats (e.g., snake or bat hibernacula).

However, several edge effect papers that consider the potential value of buffers to meadow or grassland habitats and species were found. These are cited below:

- One of the oldest papers documenting a negative response of grassland birds to traffic noise was by van der Zande *et al.* (1980) in the Netherlands where they documented responses at up to 1,800 m near busy highways.

- More recently, Forman and Deblinger (2000) found possible edge effects of high traffic roads (i.e., noise) on open country or grassland bird species (e.g., Eastern Meadowlark and Bobolink) extending at least several hundred metres from the road. Subsequent research by Forman *et al.* (2002) found no significant responses to low traffic roads (i.e., 3-8,000 vehicles/day), but observed increasing responses with increasing traffic loads and noise, with the furthest extending up to 1,200 m (i.e., reduced presence and breeding for traffic levels of more than 30,000 vehicles/day).

- Research by Miller *et al.* (2001) found two species of grassland birds (i.e., Vesper Sparrow and Western Meadowlark) were flushed by people walking on and off-trail, both with dogs on and off leash, at ranges of 9 to 38 m. It is unclear if this response was stimulated by noise or mere physical presence, or both.

- Reijnen *et al.* (1997) and related research cited by them in this paper, reported disturbances of road traffic extending from 30 to 3,150 m from the road edge for various grassland species with means of 190 m for 10,000 vehicles/day roads and 560 m for 50,000 vehicles/day roads and ascribed the effect to noise.

- In the one paper exploring buffers for grassland birds, Fernandez-Juricic *et al.* (2005) studied the flight initiation distances (i.e., the distance at which the presence of some disturbance triggered flight) of five grassland birds in Argentina and documented distances of ~ 20 m to 100 m, but then used these to estimate required buffers using six different methods. These methods yielded extremely variable results, with recommendations ranging from about 20 m to about 33,000 m for the species most intolerant to human disturbance. Many of these models appear to fail to distinguish between the identification of habitat requirements and appropriate protective buffers.

- Bollinger and Gavin (2004) found Bobolinks avoided nesting within 25 m to 100 m of forest edges, as well as near roads, but did not avoid nesting near forest edges adjacent to old fields or pastures, suggesting the presence of vehicular traffic and related noise was being avoided, rather than the proximity to forest edge.

Although the research cited above cannot be directly translated into appropriate buffer widths for grassland species, these studies, and some others focussing on grassland birds (e.g., Patten *et al.* 2006) provide support for the idea that some area-sensitive grassland species, just like area-sensitive forest species, could benefit from some type of screening and/or buffer from human disturbances, and particularly noise, especially in a context where the extent of their core habitat is limited.

3.5 Biophysical Factors Affecting Buffer Effectiveness

Although this review has, for largely pragmatic reasons, focused on the available science related to recommended buffer widths to protect different habitat types and perform different functions, it is understood that the efficacy of a buffer is not simply a function of its width, even though width is often the most important controllable variable. Hydrologic dynamics, topography and slope, soil type and conditions, and vegetative structure of the buffer and are all recognized as very important factors influencing buffer efficacy (e.g., Ducros and Joyce, 2003: Polyakov *et al.*, 2005; Buffler, 2005; Hawes and Smith, 2005; Johnson and Buffler, 2008). While these factors are sometimes taken into consideration in determination of buffer widths, there are few research papers that actually evaluate buffer effectiveness in relation to these specific parameters. Some of the research related to these topics identified through this review is summarized below.

In a recent meta-analysis by Zhang *et al.* (2010) of more than 70 riparian buffer studies in a primarily agricultural context they found that buffer width alone explained between 35 and 60% of the total variance in removal efficacy for sediment, pesticides, nitrogen, and phosphorus. Slope and buffer vegetation composition were equally important factors, but interestingly soil drainage type did not show a significant effect on pollutant removal efficacy. This kind of research illustrates the importance of considerations beyond width.

3.5.1 The Influence of Hydrologic Dynamics

A key factor that should not be overlooked in buffer design is the on-site hydrology. Dillaha *et al.* (1986a) in their assessment of 33 buffers in agricultural settings note that accumulation of surface runoff in natural drainage ways often bypassed the buffers, making it impossible for them to perform the nutrient and sediment attenuation functions for which they were designed. Several other researchers also note that the intensity of rainfall or storm events also tends to be negatively correlated with the ability of a buffer to attenuate sediments, nutrients and other contaminants (e.g., Lee *et al.* 2003; Woodard and Rock 1995). Closely related to this is the size of the contributing runoff area and the runoff velocity, which also impact buffers' rates of pollutant retention.

Sheldon *et al.* (2005) conclude from their review of wetland buffers the way water enters a buffer influences its ability to attenuate sediments, nutrients and other substances. For example, sheet flow is more readily intercepted than channels or rivulets. In their review of riparian buffers, Castelle and Johnson (2000) find that the flow regime (i.e., extent, volume, frequency and duration of flooding) comes up as a key factor affecting buffer functions. Adamus (2007) asserts that flow pattern "*is perhaps the most important factor influencing buffer effectiveness*", at least for wetlands and watercourses, and acknowledges this is closely linked to soil type and slope.

A study that highlights how site-specific hydrologic factors can result in very different buffer responses was completed by Norton and Fisher (2000). Although not specifically a "buffer" study, examination of nutrient dynamics in two coastal plain basins in Chesapeake Bay in the U.S. showed two very different responses to nutrient attenuation. In one basin, forested areas both within and adjacent to the riparian areas were sources and sinks of nitrogen and phosphorus in the local streams, while in the other basin forest had no significant effect on stream nitrogen or phosphorus levels. The lack of effect in the latter basin was attributed to local biophysical differences (i.e., finer-textured soils, higher riparian slopes) that created less opportunity for surface water attenuation and more overland storm flow.

As pointed out by Leavitt (1998) and Herson-Jones *et al.* (1995), this can be a significant issue in urban and urbanizing settings where there is much more impervious surface, and surface water is often piped or directed to culverts, leading to storm events that result in relatively sudden and intense overland flows which do not provide much opportunity for buffers to wetlands or watercourses to attenuate nutrients, sediments or other substances. This is shown empirically by Arango and Tank (2008) who found no significant differences in levels of nitrogen between buffered and unbuffered streams in Michigan, and attributed this to the extent of tile drainage in the headwater streams, and the overriding influence of land use changes.

Another aspect to local hydrology to consider in relation to buffers is the contributing area ratio. Adamus (2007) states that: "*[n]ot all buffer studies have found the ratio of buffer area to contributing area to be a good predictor of buffer effectiveness, but [some] authors of those that have suggested the vegetated buffer acreage should be at least 15% of the acreage of its contributing area, especially the part of the contributing area that is capable of generating polluted runoff*". Although this value is likely not appropriate for all settings, it conveys the concept that wetland and riparian buffer widths should be adjusted in relation to the size and expected volume from their contributing areas.

The presence (or absence) of groundwater that manifests itself on the surface (e.g., seepage areas, springs) also has the ability to significantly influence stream flow, and transport of nitrates and other such pollutants (Angier, *et al.* 2005), but is another aspect to buffers that is typically overlooked. As

Angier *et al.* (2005) describe: "*The shallow subsurface is under the influence of riparian vegetation, and often includes organic-rich soil and reducing conditions, all of which present a high potential for [nitrogen] removal. Although these organic rich soils are often characterized as poorly-drained, extensive biological (and hydrological) activity in the riparian corridor tends to generate a network of macropores. These macropores create preferential flowpaths through the soil, and may increase infiltration and exfiltration within the riparian zone. Macropores are typically considered in terms of enhancing infiltration (recharge) into the subsurface, yet they can also serve as foci for discharging groundwater (which has been less thoroughly examined). This can lead to heterogeneous, asymmetric groundwater contributions to the surface, and have significant effects on the overall denitrification potential of the ecosystem.*"

For riparian buffers, the location of the stream in the watershed, and the order of stream also have an influence on buffer effectiveness (presumably because the gradient affects both ground and surface water flows). Anbumozhi *et al.*, (2005) found forested riparian buffers in the headwaters were significantly more effective at nutrient, sediment and pesticide retention than those further downstream. As Fisher *et al.* (2000) state, "*[t]he spatial placement of buffer strips within a watershed can have profound effects on water quality. Although buffer strips are important along all river and stream reaches, those in headwater streams (i.e., those adjacent to first, second, and third order systems) often have much greater influences on overall water quality within a watershed than those buffers occurring in downstream reaches*."

3.5.2 The Influence of Slope

As stated by Adamus (2007), vegetated buffers tend to be more effective (at least with respect to water quality) on relatively flat or mildly sloping terrain because this allows more time for surface water to move down through the roots and effectively be filtered. However, other factors, such as soil type and the structure of surface vegetation, are also recognized as important influences.

Although slope has long been recognized as a factor in determination of appropriate buffer widths, relatively few studies specifically examine the influence of slope in relation to buffer effectiveness. Slope has primarily been evaluated in terms of how it alters storm water, sediment and nutrient attenuation. However, results are unclear because it is difficult to separate the influence of slope from other related factors such as the buffer's vegetative structure and the soil type. Some examples of findings and recommendations from the literature are cited below:

- Leavitt (1998) points out that steep slopes beside water features require much greater buffers because of the increased risk of landslide and cites Portland, Oregon's floodplain models that recommend 5 m buffers for streams with 20 – 40 ha drainage areas, but increase that to a 15 m buffer if the slope exceeds 25%, and 15 m buffers for streams with more than 40 ha drainage areas, increasing to a 60 m buffer if the slope exceeds 25%.

- Woodard and Rock (1995) found that buffers on slopes of up to 12% were still able to effectively attenuate sediments and phosphorus from residential storm water as long as they were vegetated with established ground covers and shrubs as well as a layer of forest litter, although in their earlier research (1991) they document these steeper slopes as needing wider buffers (i.e., closer to 23 m as opposed to 15 m) to achieve the same level of effectiveness.

- Schueler (1987) asserts that vegetative filter strips cannot function as intended with respect to sediment and nutrient attenuation if they are on slopes of more than 15% and function best on slopes of 5%.

- Wenger (1999) acknowledges slope is a key factor in the ability of a given buffer to attenuate nutrients and sediments, and suggests that 2 feet (0.61 m) be added for every 1% increase in slope to the "base" buffer width.

- Norman (1998) in his review concludes that filter strip performance is best at 5% or less, and hardly effective at attenuating runoff on slopes of more than 15%.

- Philips (1989) also emphasizes the importance of slope and points out that on slopes greater than 5% sheet flow starts to become channelized.

- In their review of riparian buffers, Castelle and Johnson (2000) cite research that recommends an additional 0.6 m for each 1% slope to a maximum of 50 m for 70% slopes (Haussman and Pruett 1978) and 6 m of each 5% slope increase (Clark 1977) beside watercourses. In an earlier review of wetland buffers, Castelle *et al.* (1992) conclude that buffers with dense vegetative cover on slopes less than 15% are most effective for water quality functions.

- Hook (2003) in his comparison of sediment attenuation for grassed buffer types between 1 and 6 m at 0 to 20% slope found that as long as buffers were at least 6 m wide there was no appreciable different in sediment attenuation irrespective of slope. Buffers of 1 or 2 m did have somewhat lower attenuation as slope increased (from 96% to 91%).

- Rules of thumb for adjusting buffer widths in relation to slope from a range of technical and policy sources in North America are synthesized by Adamus (2007), and summarized below, although none have been derived from empirical studies:
  - Increases in 0.3 m to 0.9 m (1 to 3 ft) for every degree increase in slope;
  - Increase in 3 m (10 ft) for every degree increase in slope;
  - Increases in 0.6 to 1.5 m (2 to 5 ft) for every percent increase in slope; and
  - 50% increase in the recommended buffer for slopes greater than 30%.

Generally, although buffer effectiveness in attenuating sediments, nutrients and other substances is considered reduced on steeper slopes, it is also recognized that this loss in effectiveness can be compensated for to some extent by increasing buffer width, and possibly by introducing more vegetative structure to the buffer (e.g., fallen logs) that slows the flows of water. For example, Broderson (1973, as cited in Sheldon *et al.* 2005), found that adequately sized buffers (in this case, 61 m) were able to effectively control sediment in entering Washington wetlands even on steep slopes.

3.5.3 Vegetative Composition of Buffers

The review of wetland buffers by Sheldon *et al.* (2005) ties a buffer's ability to remove sediment and other contaminants to the ability of the vegetation and roots to mechanically remove these elements from the water column, as well as the presence of large woody debris to slow and interrupt flows (among other factors). However, few papers actually test the ability of different vegetation types to effect buffer functions.

Hook (2003) tested the ability of three grass-like vegetation types (i.e., sedge wetland, rush, bunchgrass upland), and found the more dense wetland vegetation types (i.e., sedge and rush) to be more effective at sediment attenuation than the upland bunchgrasses at very narrow buffer widths (i.e., 1 or 2 m) but comparably adequate at 6 m buffer widths.

A number of papers compare the ability of grassed versus forested buffers to attenuate nutrients and sediments (e.g., Brown *et al.* 1990 and others as cited in Wenger, 1999; Wilson and Imhof, 1998; ELI, 2008). The available data indicate that grassed buffers are generally more effective at attenuating surface phosphorus and nitrates, but forested buffers are more effective at attenuating sub-surface nitrogen (Wilson and Imhof 1998).

- Lee *et al.* (2003) found that buffers comprised on switchgrass (*Panicum virgatum*) and shrubs were 20% more effective at attenuating soluble nutrients than buffers comprised of switchgrass alone. However, the buffers with woody vegetation were also twice as wide as those without (i.e., 7 m versus 15 m) and so it is unclear to what extent the results are due to the width versus the vegetation structure of the buffer.

- In another interesting, but inconclusive, paper, Lowrance and Sheridan (2005) compare the buffer effectiveness of a grassed strip (8 m) adjacent to a forested strip that has been (a) left untouched, (b) thinned, or (c) clearcut. Although they found the combination of grass and forest to be a more effective buffer than grass alone, because of the lack of replication no other conclusions could be drawn. More studies are needed to develop a better understanding of how the vegetative composition / structure of buffers affects their effectiveness.

- Knight *et al.* (2010) compared the effectiveness for water quality functions of naturally forested buffers versus naturally forested buffers with an additional grassed filter buffer in an agricultural setting, and found the combination to be more effective, but did not isolate for the fact that these buffers were also significantly wider (i.e., 20 m to 40 m versus 10 m to 30 m).

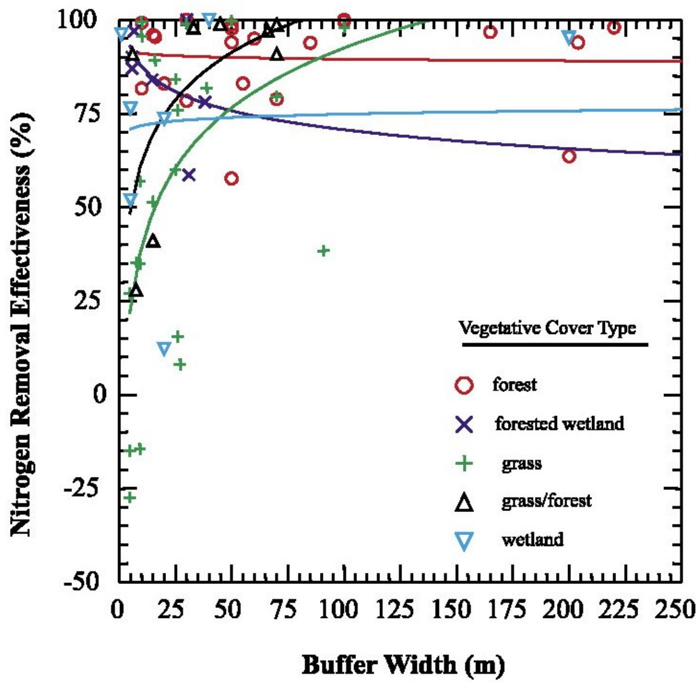


Figure 9. Illustration of the relative effectiveness of buffers with different vegetative composition from reviewed papers (from Mayer *et al.* 2006).

One interesting relationship, identified by Adamus (2007), is that wooded wetland or riparian buffers dominated by nitrogen-fixing plants such as alders tend to be sources of nitrate (rather than sinks) in the associated water bodies, at least at certain times of the year and can therefore hamper buffer “effectiveness” in this regard.

Noise and light, it might be assumed, are better attenuated by forested (at least coniferous) than grassed buffers, but no studies were found to substantiate this hypothesis.

No research appears to have been undertaken on whether or not native vegetation may be more effective than non-native vegetation in terms of providing water quality benefits, but the answer is likely more closely tied to root structure of the different plants and their relative capacity for uptake of various substances, rather than their status as native or not. Some researchers have, however, suggested that buffers be vegetated with primarily native species because of the habitat value (e.g., improved ability to protect the core habitat by pre-empting the introduction or spread of exotic and/or invasive plants) (e.g., Wenger 1999; Environmental Law Institute 2003).

In terms of providing wildlife habitat related benefits to wetlands, the preferred species composition is really dependent on the local wildlife composition and desired buffer functions. Adamus (2007) describes how it is better to have buffers that are dominated by trees and shrubs because they provide more of a visual / noise screen and physical barrier for human intrusion, as well as cover and shade.

3.5.4 Soil Type

The soil type, and its infiltration capacity, is one of the fundamental characteristics influencing a buffer's ability to attenuate water, and thereby remove sediment and other contaminants. As a result, buffers with somewhat coarse soil types tend to be more effective than those with fine textured soils, although overly coarse soils in which water infiltrates very rapidly also only allow for limited attenuation of nutrients, sediments and other contaminants in the water column (Adamus 2007). Therefore moderately coarse soils with some organic content are expected to be the best at supporting buffer effectiveness, although research in this area is generally lacking.

- In one of the oldest buffer studies, the potential for soil type to influence buffer effectiveness is clearly demonstrated. Wilson (1967) evaluated the different sediment removal capacities of different soil types and finds significant differences with sand capturing the largest amount of sediment in 3 m wide buffers, silt in 15.2 m wide buffers and clay in 122 m wide buffers.

- Polyakov *et al.* (2005) point out in their review of buffer effectiveness in agricultural contexts that nutrient and pollutant removal is highly dependent on the hydraulic characteristics of the underlying soil, as the soils may direct, impede or retard the movement of runoff through the buffer. Soil characteristics, along with slope, will also dictate the nature of water flow in both the horizontal and vertical directions.

- In the review by Mayer *et al.* (2006) they conclude that wetland buffers on soils with limited organic matter tend to have less capacity to remove nitrogen, and other researchers have also documented reductions in water quality functions with soils that are lacking organic matter (e.g., Woodard and Rock 1995). Gift *et al.* (2010) found that soils with organic matter and deep rooted plants were consistently more effective at nitrogen removal from subsurface water flows.

- One recent study (Bradley *et al.* 2011) explored the influence of earthworms and plant litter on the ability of a riparian buffer in an agricultural context to improve denitrification, but were unable to link the reduced nitrate concentrations in the buffer soils to the presence of worms or leaf litter.

Key considerations include soil type, structure, depth, presence of organic matter, and soil water storage capacity and conductivity.

3.6 Buffer Design Considerations

In addition to biophysical considerations, there has been some (albeit limited) discussion in the literature about different kinds of buffers in terms of their vegetative structure, as well as different buffer zones in terms of vegetative structure, function and width. Although some researchers have compared the effectiveness of grassed versus forested buffers for some functions (e.g., nutrient attenuation, as described in **Section 3.5**), no research was uncovered in which the effectiveness of the various buffer zonation was empirically tested. Some concepts are, nonetheless, put forward here for consideration. Although there are a number of design mechanisms (such as fences or berms) that are recommended and used in practice to enhance or support the effectiveness of vegetative buffers, these are also virtually unstudied in the scientific literature, but are presented for consideration as part of this review because of their potential applied value.

3.6.1 Buffer Vegetative Structure

Several studies speak to the greater effectiveness of buffers comprised of dense shrubs or treed vegetation to contribute water quality functions (e.g., see Osbourne and Kovacic 1993). Although some researchers concluded the data trends were too sparse and inconsistent to draw firm conclusions (e.g., Sheldon *et al.* 2005; Adamus 2007), a recent meta-analysis by Zhang *et al.* (2010) found that forested buffers were consistently more effective at attenuating pollutants from agricultural run-off than grassed buffers. Based on their study of phosphorus retention in a multi-species (i.e., switchgrass, brome-alfalfa mix and treed) buffer, Tomer *et al.* (2007) suggest that buffer efficacy could hypothetically be improved by placing higher water use plants where runoff is expected to accumulate. Currently, research in this area is lacking.

Another consideration in buffer design is that relatively narrow bands of forested buffers left along otherwise open areas (e.g., along watercourses, hedgerows) can be susceptible to blow down. In their review, Sheldon *et al.* (2005) cite research by Pollock and Kennard (1998) that concludes that newly created riparian forest buffers should be no less than 23 to 35 m wide to withstand the effects of wind. This implies that treed buffers should be either adjacent to an existing treed natural area being protected, or wide enough to stand alone without presenting a potential hazard. Another study in California by Reid and Hilton (2001; as cited in Adamus, 2007) found 30 m wide forested swath were inadequate to prevent blowdown. Obviously local climactic conditions, as well as the topography and soils-rooting systems of the particular site will be factors.

Although no studies were found to test this hypothesis, a few authors suggest that having a buffer comprised of a dense "wall" of vegetation to reduce the penetration of undesirable agents from the matrix, particularly in an urban setting, would be beneficial to the protection of habitat functions (e.g., Marzluff and Ewing 2001; Cutway and Ehrenfeld 2009).

3.6.2 Zoned Buffers

Several researchers, based on their experience, have developed recommendations around multi-zoned buffers. In some cases the zoned approach is in recognition of the fact that in practice buffers are often places where some types of activities and uses are permitted (e.g., low-impact trails, storm water management ponds), and therefore there needs to be a distinction between a portion where such activities are permitted, and a portion where they are not. In other cases the zones are intended to reflect the different types of habitat requirements identified for the target wildlife guild or species as well as a buffer to that habitat (e.g., Calhoun *et al.* 2005; Semlitsch and Bodie 2003). Notably, these "buffer zones" include critical habitat which, for the intent and purposes of this review, are considered to be an extension of the core habitat area. Some examples are provided below.

Welsh (1991) was one of the first researchers to suggest a three-zone approach for riparian buffers and was focussed on water quality functions adjacent to primarily agricultural lands (as shown in **Figure 8**). Zone 1, immediately adjacent to the stream, consists of riparian shrubs and trees and should be at least 4 m wide. Zone 2 extends upslope, can be periodically harvested vegetation, and should be 6 to 30 m, with wider zones for larger streams. Zone 3 is a vegetated filter strip between the cultivated crop land (or other land use) and should be "wide enough" to control concentrated erosion flow. It should also be established first. This zoned approach is discussed in a number of technical reports (e.g., Fisher and Fischenich 2000) but no well-designed empirical studies have been conducted to test the proposed design's effectiveness.

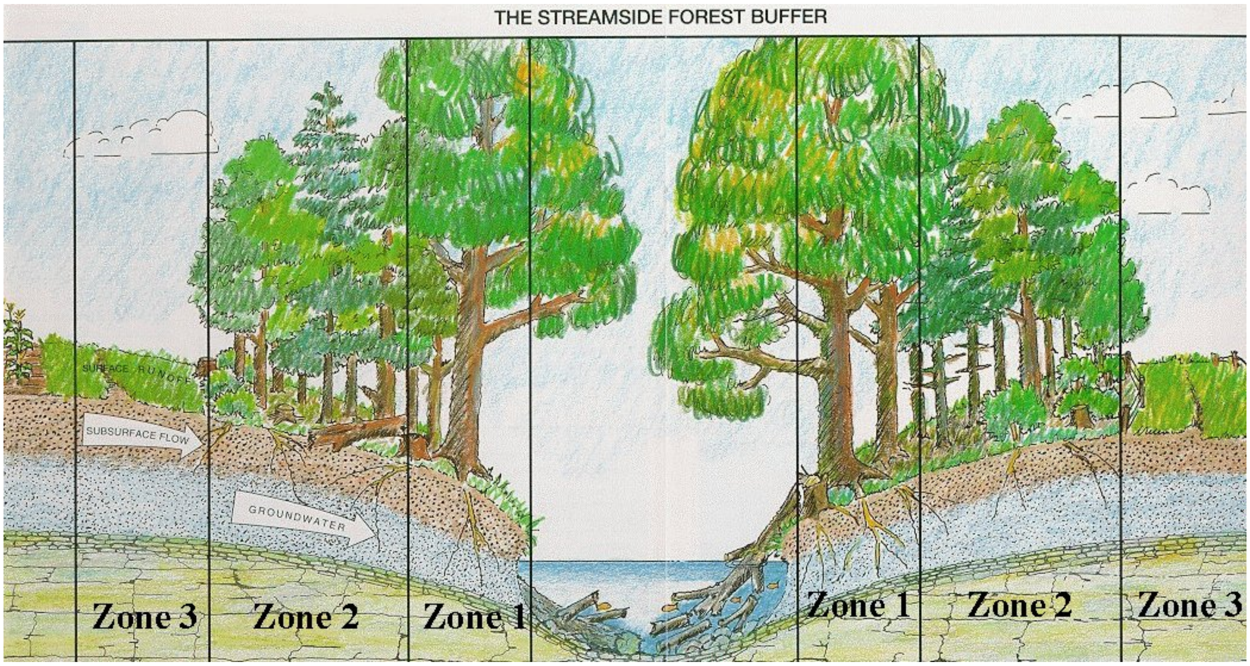


Figure 10. The three-zoned riparian buffer approach as fist described by Welsh (1991) and illustrated here in Fisher and Fischenich (2000).

Calhoun *et al.* (2005) recommend three zones around wetlands for the effective protection of pool-breeding amphibians in an urbanizing setting: (1) the pool depression, (2) the pool envelope (i.e., specified as land within 30 m of the pool), and (c) a combination of critical terrestrial habitat and buffer specified as 30 – 230 m from the pool. They further recommend no development or disturbances in the first two zones and less than 25% of the third zone be developed. However, neither (2) the envelope nor (3) the critical terrestrial habitat are buffers *per se* (as defined for this review, see **Section 2**) because each zone has a specific and important habitat function related to the amphibian life cycle (i.e., zone 2 is upland staging habitat for juvenile amphibians and zone 3 is at least in part for post-breeding foraging, hibernation and migrating).

Semlitsch and Bodie (2003) recommend a slightly different system of buffer zones for the effective protection of wetland or stream-breeding amphibians in an urbanizing setting that consists of: (1) a 142 to 289 m core habitat zone around the wetland, or on both sides of the stream (including a 30 to 60 m immediate "buffer" to the aquatic habitat), followed by a (2) 50 m terrestrial buffer, with the explicit function being the protection of the core habitat from edge effects. Although they readily acknowledge that protection of this extent of habitat will not be feasible in all settings, they assert that these numbers represent a realistic range based on the empirical data collected for amphibians in eastern North America.

Duerksen *et al.* (1996) also speak to the concept of zoned buffers, but more so in the context of having two zones to protect natural areas from anthropogenic physical disturbances. The first zone, closer to the protected feature, would be managed to restrict permitted uses to relatively low impact activities (such as hiking or cycling), while another zone around this would permit low density development but exclude high density development and busy roads. Although research on the impacts of even "low-impact" recreational activities shows that they can have more of an impact on wildlife than originally thought, the concept of using zoned buffers to create different management zones with different levels of permitted uses remains one worthy of consideration. As described in **Section 4**, some municipalities are beginning to use this type of approach for buffer implementation.

Recent research by McWilliam *et al.* (2011) on encroachments from residential back yards into adjacent upland protected woodlands has provided very relevant data with respect buffer design, even though the paper does empirically test buffer effectiveness. They looked at ten different boundary treatments between the back yard and the adjacent natural area (e.g., nothing, property demarcation posts and plantings on shrubs and trees, ungated fences, gated fences, grassed strips) and found that while no treatment completely stopped encroachments, mown grass strips combined with ungated fences consistently formed the most effective barrier against encroachments. These data support the presence of an actual fence rather than a "living fence" when trying to protect woodlands from impacts associated with residential back yards.

3.6.3 Other Design Elements to Enhance Buffer Effectiveness

A variety of design and engineering tools and options are considered and implemented in practice to try and either complement or enhance the functions of vegetated buffers. These include fences (ranging from cedar rail to chain link to solid noise barriers), earth berms, use of crossings, bioengineering (such as brush mattresses and coir logs), infiltration galleries and linear storm water management features. Notably, these elements are also recommended and implemented for other reasons than helping to protect natural features and their related functions.

The only scientific research identified through this review related to this topic was on fences, which appear to provide relatively effective protection for natural areas in urban or urbanizing settings. Ikuta and Blumstein (2003), in their unique research testing the ability of fencing (1.8 m high) to limit human encroachment into, and disturbance of, a protected natural area, found that the fence was effective. McWilliam *et al.* (2011) in their study on encroachments into protected woodlands also found fencing (irrespective of height) combined with grassed buffer strips to be the most effective means of limiting encroachments from adjacent back yards. As Baines and Andrew (2003) report, fences can, however, sometimes have unexpected negative ecological effects. In their study of the use of fencing to keep deer out of grouse (ptarmigan) habitat in the Scottish Highlands, they found consistently high levels of grouse mortality related to collisions with exclosure fences, even with more visible types of fencing. Accommodating movement of local wildlife needs to be considered as well.

OMAFRA's (2004) publication on riparian buffer effectiveness mentions a number of design options that can support buffers and contribute to best practices on agricultural lands. These include use of fencing to keep livestock out of riparian areas combined with controlled access crossing points over watercourses, and the use of coir logs and brush mattresses to help with slope stabilization and vegetation establishment in restored riparian areas.

Both scientific and technical literature is lacking on the effectiveness of these measures in relation to their ability to support or supplement desired buffer functions in terms of water quality, screening from physical human, or core habitat protection. However, given the increasing pressure on the remaining lands within southern Ontario's urban areas, research testing whether or not such tools could allow for narrower buffers without sacrificing effectiveness would be very valuable. Even in the absence of such science, it is incumbent upon planners to ensure that once the buffer's protective requirements are established and widths determined, that intrinsic design elements consider opportunities to enhance the adjacent natural areas (e.g., through native plantings).

4. Policy and Current Practices Review

Despite the widely recognized value of buffers, as a result of all the variables to consider, and the gaps in our knowledge, buffer determination has become one of the most challenging and controversial aspects of natural heritage planning in southern Ontario. Although no cross-jurisdictional analyses have been done to assess buffer application across southern Ontario for different natural heritage features and in different land use contexts, there is general agreement among professionals who are required to accept, reject or comment on recommended buffer widths that the approach taken is far from consistent between or within jurisdictions.

The original terms of this review required a summary of best practices for buffer guidelines in southern Ontario. However, there are very few documented studies that monitor and measure buffer effectiveness in Ontario, particularly in terms of its ability to maintain the natural heritage attributes of a given feature in an urbanizing context. In general, there is limited post-construction monitoring of natural areas following changes in land use (except where it has been required under a federal or provincial act), and no documented monitoring that has been specifically designed to assess buffer effectiveness in an urbanizing context - particularly not over an extended period of time - was uncovered as part of this review. Furthermore, habitat fragmentation is a relatively new phenomenon to which species are still adapting, and to which species respond differentially (e.g., Ewers and Didham 2006; Jacquemyn *et al.* 2003; Keyghobadi *et al.* 2005), making assessing ecological buffer effectiveness very challenging.

Therefore instead of reviewing documented best practices, this section summarizes current policies and practices from:

1. existing provincial policies and acts;
2. selected conservation authorities in southern Ontario;
3. selected municipalities in southern Ontario; and,
4. some recent reviews from the United States.

4.1 Provincial Policy and Legislation

This section provides an overview of current provincial policies and legislation related to buffers, as summarized in **Table 5**. The information has been entirely drawn from a review of the relevant policy and legislative documents. Key policy direction from each relevant piece of legislation / policy is summarized below.

The Provincial Policy Statement (2005) provides no direct guidance related to ecological buffers, but does provide some indirect guidance through its primary supporting document, the Natural Heritage Reference Manual (OMNR 2010).

> ***The [Provincial Policy Statement] identifies significant features that should be protected, but it does not specifically require or address the delineation or protection of buffers. Notwithstanding this, it has become standard practice of many planning agencies to require buffers adjacent to certain features.***
>
> **Natural Heritage Reference Manual (OMNR 2010)**

The Natural Heritage Reference Manual (in Section 13.5.4.2) further states that: "*The physical separation of development from natural feature boundaries using vegetated protection areas or vegetation protection zones is one of the most widely used mechanisms for softening or reducing (i.e., buffering) the impacts of land use changes on adjacent natural features*." While the document asserts that buffers can contribute substantially to the protection of wetlands, woodlands, valleylands and other natural features, it shies away from any specific recommendations because appropriate widths for buffers can vary depending on the sensitivity and functions of the features and proposed adjacent land uses. Benefits (or functions) associated with buffers in the Manual include: reduction of encroachment, reduction of light and noise, space for tree fall, protection of root zones, enhancement of woodland interior, allowance for hunting habitats of dogs and cats, location for trails, and attenuation of runoff.

In addition to some text related to buffers throughout the Natural Heritage Reference Manual (OMNR 2010) and a short annotated bibliography, the only specific numerical guidance provided is consistent with the Ontario Ministry of Agriculture and Food and Rural Affairs' guidelines for vegetated buffers along streams in an agricultural context, as follows:

- Warm water streams: 30 m or 15 m;
- Cool water streams: 30 m or 20 m; and
- Coldwater streams: 30 m.

These guidelines have been adopted by many conservation authorities and are being adopted by a growing number of municipalities in southern Ontario (see **Sections 4.2 and 4.3**).

The Oak Ridges Moraine Conservation Plan (2002), Greenbelt Plan (2005) and Lake Simcoe Protection Plan (2009) all call buffers to natural heritage features vegetation protection zones (VPZs) (as defined in the adjacent text box) and require VPZs of at least 30 m on all significant (or key) natural heritage features outside the settlement or urban areas. The Lake Simcoe Protection Plan (2009) policies further state that these areas be comprised of self-sustaining vegetation.

> ***Vegetation protection zone***
>
> ***A vegetated buffer area surrounding a key natural heritage feature or key hydrologic feature ... The width of the vegetation protection zone ... is to be of sufficient size to protect the feature and its functions from the impacts of the proposed change and associated activities that will occur before, during, and after, construction, and where possible, restore or enhance the feature and/or its function.***
>
> **Greenbelt Plan (MMAH 2004)**

VPZs in the settlement or urban areas are typically determined through Environmental Impact Studies on a case by case basis and must be in conformity with the policies of the local planning authority. Generally, low intensity recreational uses are permitted in the VPZ but not storm water management facilities (although aspects of them, such as outfalls, may be permitted within the VPZ).

The Niagara Escarpment Plan (last updated in 2005) does not include any minimum buffer requirements, but includes a number of policies related to buffers and setbacks (see **Table 5**).

The *Conservation Authorities Act* (2006) includes neither prescribed minimum buffers nor prescribed minimum setbacks from natural features.

Table 5. Summary of provincial policies or legislation related to buffers (outside Settlement Areas).

Legislation / Policy	Jurisdiction	Trigger for Study	Buffer Requirements
Planning Act (1990) / Provincial Policy Statement (2005)	Ontario	No specified trigger distance for environmental studies.	No prescribed buffers or minimum setbacks. <u>PPS, Section 2.1.6</u> *Development and site alteration not permitted on adjacent lands to the natural heritage features and areas...unless the ecological function of the adjacent lands has been evaluated and it has been demonstrated that there will be no negative impacts....* *Adjacent lands – contiguous to a specific natural heritage feature or area where development or site alteration is likely to have a negative impact on the feature or area. The extent of the adjacent lands may be recommended by the Province or based on municipal approaches...*
Greenbelt Act / Greenbelt Plan (2005)	Greater Golden Horseshoe and Bruce Peninsula	Natural Heritage Evaluation and hydrological evaluation are required for development or site alteration within 120 m of a key natural heritage feature (KNHF) or a key hydrologic feature (KHF).	<u>Within NHS:</u> Key Natural Heritage Features (e.g., Significant habitat of endangered and threatened species; Fish habitat; Significant Woodlands, Wetlands; Significant Wildlife habitat, sand barrens, savannahs, prairie, and alvars) all require a 30 m minimum Vegetation Protection Zone (i.e., buffer) <u>Outside of NHS:</u> Wetlands, seepage areas, springs, permanent and intermittent streams, fish habitat, lakes and significant woodlands (as defined and identified by local Official Plans) require a 30 m minimum Vegetation Protection Zone (i.e., buffer)
Oak Ridges Moraine Conservation Act and Oak Ridges Moraine Conservation Plan (ORMCP) (2002)	Oak Ridges Moraine, Southern Ontario	Natural Heritage Evaluation required for development or site alteration within the minimum area of influence of a key natural heritage feature – generally 120 m.	Wetlands (greater than 2 ha), fish habitat, significant valleylands (stable top of slope), significant woodlands (greater than 4ha in Countryside and Settlement, greater than 0.5 ha in Natural Core and Natural Linkage), permanent and intermittent streams, seepage areas and require a 30 m minimum Vegetation Protection Zone (i.e., buffer).
Lake Simcoe Protection Act and Lake Simcoe Protection Plan	Lake Simcoe Watershed	Outside the Greenbelt or ORMCP, development or site alteration within 120 m of a KNHF or KHF requires	Wetlands and significant woodlands / significant valleylands / natural areas abutting Lake Simcoe outside of Greenbelt or ORMCP require a 30 m minimum Vegetation Protection Zone (i.e., buffer).

Legislation / Policy	Jurisdiction	Trigger for Study	Buffer Requirements
(LSPP) (2009)		a Natural Heritage Evaluation.	Vegetation Protection Zones, to be composed of and maintained as natural self-sustaining vegetation.
Niagara Escarpment Planning and Development Act / Niagara Escarpment Plan (2005)	Niagara Escarpment	None	No minimum buffers are specified, however there are a number of policies around buffers and setbacks, as follows. <u>Section 2.5 New Development Affecting Steep Slopes and Ravines</u> The implementing authority will establish a minimum development setback from the brow or crest and toes of a slope or ravine and no disturbance of grades or vegetation below crest and above the toe shall occur. An engineering report shall be prepared if stability of slope is in question. <u>Section 2.6 New Development Affecting Water Resources</u> Water Quality: No sewage system is permitted closer than 30 m from: the high water mark of any lake; the top of a stream bank or ravine or the edge of any wetland (except where this can't be achieved on an existing lot of record). A setback (i.e., buffer from) for other development will be established from each side of a stream, river bed, lakeshore or wetland necessary to maintain existing water quality. The width of this buffer shall be determined by the implementing authority in consultation with the appropriate agency and shall consider: soil type, type and amount of vegetation cover, slope, and fish and wildlife. Wetlands: A development setback from the wetland area is required and is to be maintained or established as a natural vegetation buffer. <u>Section 2.14 Areas of Natural and Scientific Interest</u> Setbacks are to be established by the implementing authority with the MNR.

4.2 Selected Conservation Authority Policies and Practices

This section provides an overview of current conservation authority practices related to implementation of buffers. The information has been drawn from a combination of policy document review and discussion with various conservation authority staff. The review includes a cross-section of conservation authorities from southern and eastern Ontario, and includes all members of the Steering Committee for this project.

It is important to distinguish between natural areas that are regulated by the conservation authority[11] for which it can require buffers as a permit condition, and those for which it provides plan review and recommendations but where the given municipality is the planning authority.

Key findings and themes that emerged from the review of 11 different conservation authorities include the following:

- Four of the 11 conservation authorities surveyed currently have specific minimum buffer width guidelines included in their policies.
    - The minimum buffers recommended by Credit Valley Conservation (CVC) range from 10 m (for hazards, significant woodlands and non-significant protected wetlands) and 30 m (for provincially significant wetlands and from the bankfull flow of watercourses).
    - Conservation Halton (CH) requires (except where permitted under policies 3.4 to 3.53) the following setbacks (which they apply as minimum buffers):
        - 7.5 m for minor watercourse systems and 15 m for major watercourse systems from the greater of the stable top of bank, Regional storm floodplain or meander belt;
        - 15 m from non-provincially significant wetlands and wetlands less than 2 ha, and
        - 30 m from provincially significant wetlands and wetlands greater than 2 ha.
    - Toronto Region Conservation Authority (TRCA) recommends 10 m to top of bank and is in the process of updating these guidelines from 1994.
    - Ottonabee Region Conservation Authority (ORCA)'s new 2012 policies specify a minimum 30 m development setback for new development adjacent to Provincially Significant Wetlands.

- In all jurisdictions with Greenbelt Plan Areas, policies for buffers are consistent with the Plan and require 30 m vegetation protection zones on protected features as per the Plan.

- Most conservation authorities focus on getting agreement on buffers to watercourses and significant wetlands[12], while several provide input related to buffers for other features (e.g., woodlands, Environmentally Sensitive Areas and significant wildlife habitat) in accordance with municipal Memorandums of Understanding.

[11] These include wetlands, watercourses and shorelines as well as hazard lands, but depending on the conservation authority may not include the same types or sizes of wetlands.

[12] While most Conservation Authorities consider Provincially Significant Wetlands as "significant", others define "significant wetlands" more broadly (e.g., Conservation Halton includes all wetlands of at least 2 ha whether provincially significant or not).

- Nine of the 11 conservation authorities surveyed seek buffers of 15 m on warm watercourses, 30 m on cool or cold watercourses and 30 m on (provincially) significant wetlands.

- Some conservation authorities are planning to update their policies and are considering including minimum buffer guidelines, while others would prefer to have input to and rely on provincial and municipal direction. Although a number of conservation authorities (i.e., four of the 11 surveyed) have tried to keep storm water management ponds outside of ecological buffers, with the shift towards Low Impact Development (LID) approaches to storm water management, the integration of LID in buffers will likely be increasingly considered and permitted.

- Several conservation authorities surveyed allow “low impact” trails in buffers, but encourage their location towards the buffer exterior.

- While several conservation authorities are participating in some long-term monitoring studies, to the best of our knowledge there are currently no studies underway that involve Ontario’s conservation authorities that have been specifically designed to assess buffer effectiveness[13].

- Challenges identified in buffer implementation include:
  - implementation of buffers in urban areas much more challenging than in rural areas;
  - very difficult to get 30 m buffers on provincially significant wetlands for proposed single family dwellings on existing lots of record;
  - difficult to implement desired buffers if the local planning authority is not supportive and if there are no supporting policies in their Official Plans;
  - no policies for off-site compensation where desired buffers cannot be achieved on-site.

4.3 Selected Southern Ontario Municipal Policies and Practices

This section provides a sampling of some municipal policies and practices related to the implementation of buffers. The information has been drawn from a combination of policy document review and correspondences with various municipal staff. A number of municipalities from upper or single tier and lower tier municipalities in southern Ontario were contacted, and efforts were focused on jurisdictions known to have more progressive buffer policies.

Key findings and themes that emerged from the review of four upper or single tier municipalities and three lower tier municipalities include the following:

- A number of progressive municipalities (i.e., three of the seven reviewed) are increasingly moving towards requirements for minimum buffers to natural areas in their planning policies. Such buffers are generally 10 m, but in some cases are up to 30 m, even for

[13] Monitoring buffer effectiveness requires careful experimental design (including statistical design, controls and sufficient replication), a long-term commitment, and the support of both the local planning authority and the private landowner(s). Information from such studies would be very helpful in informing planning.

some features outside of areas falling under the provincial Greenbelt where 30 m minimum Vegetation Protection Zones are required on all significant natural features.

- One upper tier municipality encourages all lower tier municipality to have the local conservation authority peer review all Environmental Impact Studies with respect to buffers and other ecological requirements.
- While some municipalities are trying to keep trails and/or storm water management facilities outside of buffers, most find this challenging, especially in urban or urbanizing areas where land use pressures are more intense.

- Key challenges to buffer implementation include:
    - Lack of clear, specific and practical guidance in the technical or scientific literature on appropriate buffer widths;
    - The absence of buffers in areas with older zoning by-laws;
    - The difficulty in implementing buffer guidance provided from subwatershed studies at the site-specific scale;
    - Persistent challenges to buffer policies and requirements by proponents of development; and
    - Balancing buffer requirements with the many other land use needs, particularly in urban settings.

Some additional and somewhat older sources of Ontario municipal buffer recommendations identified through our review include the following:

- Region of York riparian forest buffer standards (Draft) (Silvecon 2000):
    - 30 m buffer comprised of a 5 m no management zone beside the watercourse or wetland plus 25 m where only selective cutting is permitted. Also, 20 m of buffer are added for every 15% increase in slope (e.g., 16 – 30% slopes require a 50 m buffer).

- City of London Guideline for Ecological Buffers and Development Setbacks (2004):
    - Woodlands: 10 m beyond the dripline;
    - Wetlands: 30 m for water quality benefits; ratio of 3:1 of upland to wetland habitat for protection of small wetlands;
    - Watercourses – permanent: 30 m from high water mark, or 30 m + 0.5 m per 1% slope;
    - Watercourses – intermittent: 15 m from high water mark, or 15 m + 0.5 m per 1% slope; and
    - Valleylands / Ravines: 10 m from top of bank.

Although not explicitly adopted by any Ontario municipalities, the guidelines provided through the Carolinian Canada Committee (2003) in their Draft Guidelines for Environmental Impact Statements are often used as a reference point by progressive municipalities in southern Ontario, and are therefore worth citing. Their generic buffer guidelines, based on best available science at the time, are as follows:

- Woodlands: 10 m from dripline;
- Wetlands: 30 m for water quality; ratio of 3:1 of upland to wetland for small wetlands;

- Watercourses: 30 m from high water mark; 50 m for cold water streams, + 0.5 m per 1% slope; and,
- Wildlife: 100 m (which incorporates a CFZ).

Another guideline of note is the one published by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA 2004) on best practices for riparian buffer strips in agricultural settings. This guideline recommends minimum riparian buffers to watercourses of 15 m to 30 m depending on the stream classification (i.e., warm, cool or cold water). This guideline is widely accepted and sometimes used as a reference for municipalities, even in urban settings.

Finally, the Rouge North Management Plan (Schollen & Company 2001) recommends "vegetation maintenance areas" of 30 m to 53 m wide adjacent to the bankfull channel and meander belt widths of the watercourse.

4.4 Selected Policies and Recommendations from Other Jurisdictions

A comprehensive review of recommended buffer widths outside of Ontario was outside the scope of this report, however a few examples from the technical literature from the U.S. are provided for reference below.

- Castelle *et al.* (1992) summarize adopted wetland buffer standards from 50 states, counties and cities in the U.S. and found requirements ranged from zero up to 91 m, with the bulk of the jurisdictions requiring buffers in the range of 7 m to 30 m. Some of these have likely been updated.

- Chase *et al.* (1995) in their Guidebook for New Hampshire Municipalities, the Vermont Agency of Natural Resources (2001), and the Massachusetts Buffer Manual (2003) all recommend 100 ft (30 m) minimum buffers for wetlands and watercourses under most conditions.

- Wenger and Fowler (2003) in their guideline for developing a comprehensive buffer ordinance for Georgia support the 30 m minimum for riparian buffers in agricultural landscapes, but also recommend an exemption for small parcel owners because of the economic impact relative to their land holdings.

- Adamus (2007)[14] summarizes the following standards for wetland buffers in the State of Washington:
    - AGRICULTURAL LAND USES: 6 m to 12 m herbaceous filter strips recommended adjacent to agricultural land uses;
    - TIMBER HARVEST AREAS:
        - forested buffers of 30 m on average (range of 15 m to 61 m), around bogs larger than 2 ha and non-forested wetlands with more than 0.2 ha of standing water; and

[14] Notably, no required minimum buffer widths are specified for forested wetlands in Washington at the time of the review by Adamus (2007), although he does indicate these features are sensitive to changes in microclimate conditions as a result of the removal of surrounding wooded areas.

  - 15 m average, or buffers in the range of 8 to 61 m, around bogs smaller than 2 ha and non-forested wetlands.

- The Partners for Wildlife Program of the U. S. Fish and Wildlife Services has promoted a buffer program since 1994 that recommends riparian buffers of about 30 m (but as wide as 50 – 90 m where slopes exceed 4%) comprised of a diversity of short grasses, mid-grasses and mixed forbs (Skagen *et al.* 2008). Notably this includes reviews of some papers that incorporate CFZs into their buffer recommendations.

In their review of 60 provincial, territorial and state guidelines for forested riparian buffer retention in the context of timber harvesting in the U.S. and Canada, Lee *et al.* (2004) found that mean buffer widths varied from 15 to 29 m, which is consistent with the recommendations cited above.

5. Discussion: Key Concepts, Data Gaps and Summary of Findings

5.1 Key Concepts and Issues

5.1.1 The Importance of Big Picture Planning: Buffers Alone are Insufficient

Ecological buffers are primarily intended to protect, and sometimes to enhance, the functions of a natural area or function to which they are applied. However, buffers in and of themselves cannot protect a feature from broader landscape scale effects that relate to the distribution, presence and productivity of many species, and thereby reduce or remove an individual natural area's ability to support certain species.

In southern Ontario, and many other parts of the world, habitat loss and the ongoing fragmentation of remaining habitats continues to be the primary cause of species decline and loss. In addition, manipulation and engineering of hydrologic systems continues to test the resilience of remnant habitats and of the species that depend upon them. While a buffer may be able to protect a natural area from stressors associated with adjacent land uses, and may even be able to increase the effective area of a feature marginally, it cannot compensate for larger scale changes in the landscape that affect the amounts and extent of available habitat, as well as its condition.

There is increasing agreement that the amount of habitat on the landscape is the key driver for many species. The scale of that "landscape" is less than clear and is probably not a constant. There is therefore a very real limit to which the effectiveness of buffers can be extended in the face of landscape level land use changes. For example, no amount of buffer will protect area-sensitive forest breeding birds from fragmentation effects if there is an inadequate level of overall forest cover in the given landscape (e.g., Donnelly and Marzluff 1994, Donnelly and Marzluff 2006). This is not because buffers are unable to mitigate stressors, such as light or noise, but because the buffer itself cannot compensate for the overall reduction or loss of forested habitat.

Another example is that of buffers to wetlands with breeding habitat for amphibians and reptiles. It has been become increasingly clear over the past decade that simply placing a buffer on a wetland cannot necessarily be expected to fully conserve amphibian populations, and that portions of the uplands associated with these wetlands are of critical importance to the amphibians' life cycle and need to be protected in the same way as the wetlands themselves (e.g., Calhoun *et al.* 2005, Semlitsch 2007). Beyond these critical habitat areas, or Critical Function Zones (as per Environment Canada 2004), there is also a recognized need for protection some types of natural corridors that allow for broader movement in the landscape to maintain amphibian populations in the long term (Houlahan and Findlay 2003; Bauer *et al.* 2010; Roe and Georges 2007, Price *et al.* 2004; Ficetola *et al.* 2008). These requirements should be addressed prior to any consideration of buffers.

Water quality functions are also significantly influenced by broader land use changes and dynamics. For example, in their study of 73 wetlands in southeastern Ontario, Houlahan and Findlay (2004) found negative correlations between water nitrogen and phosphorus levels, sediment phosphorus levels, and forest cover at between 2,250 and 4,000 m from the wetland edge. This again suggests the limitations of what buffers alone can achieve.

[The] results suggest that maintenance or protection of reach and riparian buffers alone will not sufficiently protect stream function and structure from catchment-wide impacts.

Stephenson and Morin 2009

Buffer width is usually not sufficient to counteract the influence of land-use changes and storm water management facilities within the wetland's contributing basin.

Sheldon *et al.* 2005

The overriding importance of landscape scale land cover, particularly in headwater areas has also been demonstrated for aquatic habitats. Roy *et al.* (2007) studied the influence of forested riparian buffers and land cover at various scales on fish communities. They found that fish assemblage variables (e.g., endemic richness and abundance) were most strongly associated with riparian cover in the overall catchment, and not with 30 m buffers on stream reaches. Stephenson and Morin (2009) similarly found in their study of aquatic biomass and community structure at various spatial scales, that the most metrics were explained at the catchment scale (rather than the reach or riparian scale).

This research all indicates that the primary consideration in effective natural heritage planning needs to be identification and protection of the full range of core habitats required to support the indigenous species, as well as, where appropriate, levels of connectivity between them. Appropriate management of the local hydrology at the watershed scale is critical to this exercise. Buffers then need to be applied to these protected areas as tool to help sustain these areas in the face of changes in the adjacent land uses.

Buffers, in and of themselves, also cannot compensate or mitigate for broader changes in hydrologic and/or hydrogeologic regimes caused by changes in the landscape. Buffers may be able to attenuate storm water flows under some conditions and slow the process of evapotranspiration from adjacent waterbodies, particularly if they are relatively shallow and small, but are limited in their ability to maintain hydroperiod, which is typically more affected by land use changes in watersheds surrounding wetlands (Sheldon *et al.* 2005; Stephenson and Morin 2009; Leavitt 1998; Roberts and Price 2010).

Buffers, if applied and designed appropriately, have the ability to reduce the gradient of impact on a given feature at the site scale, and if applied consistently along a contiguous feature (e.g., a riparian corridor) can also result in cumulative benefits (i.e., to aquatic habitats). However, buffers are only one of multiple tools available to land use planners and ecologists to try and sustain natural heritage features and their functions. At the broader scale, initiatives such as implementing connected Natural Heritage Systems are intended to ensure that sufficient natural cover is retained in the first place.

Parkyn *et al.* (2003) studied 23 riparian buffers planted with woody species along streams in New Zealand and assessed them between two and 24 years after planting. They conclude that site-specific riparian buffers alone in agricultural settings are not enough to adequately protect or restore stream water quality or aquatic habitat conditions, although they may become more effective over extended periods of time (e.g., 25 to 50 years) once they provide fuller canopy closure. They note that broader scale landscape planning that starts systematic planting from the headwaters and works its way down may also be more effective.

It is important to recognise the limitations of what buffers can achieve in a changing landscape. Nonetheless, as highlighted in this review in both urban and rural settings, protective buffers can be of value in minimizing direct and indirect effects on watercourses, wetlands and woodlands (e.g., Friesen 1998; Ehrenfeld 2004; Flanagan and Richardson 2010).

5.1.2 Buffers over Time

Buffers, like the core natural areas they are meant to protect, tend not to be static features but rather dynamic vegetated areas that change over time. As a result, their functions can also change in relation to shifts in the core habitat. However little research has been done that examines this temporal aspect.

The bulk of the research on buffers over time addresses their degradation in relation to human, or other, uses:

- In their study of 21 wetland buffers in Washington State, Cooke (1992) (in Castelle *et al.* 1992) found 86% of them (i.e., 18 of 21) had measurably reduced buffer zones within eight years of establishment, primarily adjacent to residential developments, because of the extent of the encroachments observed. This was particularly evident for buffers of 7 m or less, but also to a lesser extent for those of up to 15 m.

- Similarly, Dillaha *et al.* (1986a) assessed vegetated buffer strips in 33 farms in Virginia and found 36% were partially or completely ineffective due to degradation by livestock. Cooke (1992) noted a similar trend in buffers around wetlands in residential areas where buffers,, and particularly buffers up to 15 m, were significantly affected by human trampling and activities over time.

- Booth (1991) also notes that in an urban setting a buffer’s ability to attenuate sediment is substantially reduced by degradation. Obviously, any functions which a buffer may have that relies on vegetation are eroded when the vegetation and soil associated with that buffer is trampled, compacted and otherwise disturbed.

Some other studies (e.g., Wenger, 1999; Woodard and Rock, 1995) have suggested that buffer effectiveness with respect to nutrient, sediment and/or contaminant attenuation may decrease over time as a result of repeated exposure to storm water flows and the gradual “saturation” of the buffer. This has been demonstrated in work by Dillaha (as cited in Sheldon *et al.* 2005) that found less than 10% of grass filter strips were effective at sediment and nutrient removal after three to five years. Woodard and Rock (1991) also note this same phenomenon in the backyards of newly constructed homes adjacent to wetlands where the “sediment front” advanced slightly with each storm and slightly wider buffers were required as time elapsed.

However, a recently published long-term study of buffer water quality functions over time by Newbold *et al.* (2010) found that in an agricultural setting a 36 m to 40 m riparian buffer comprised mainly of planted trees was able to maintain effective nitrogen and sediment attenuation functions for a period of ten years (following an initial five year period of buffer establishment). Although the study was at a single location, and was not replicated within that location, the authors studied the progress of buffer establishment, surface and groundwater nitrates and phosphorus, and sediments annually, in some detail, and for a longer period of time than any other published buffer study. Interestingly, while Newbold *et al.* (2010) found that surface and groundwater nitrates were attenuated by the buffer (as compared to the unbuffered reference site) fairly consistently over a ten year period, and levels of sediments were also significantly lower in the buffered site, net phosphorus was <u>not</u> different. It is suggested that this is because although the buffer removed some of the subsurface phosphorus through sediment attenuation, it was not enough to compensate for increased phosphorus in the stream from groundwater flows.

There has also been some consideration of, but very limited research on, changes related to the evolution of the buffer itself over time. Murcia (1995) hypothesizes that buffers to wooded or forested systems may play an important role for a newly created edge, but less of a role over time as that edge “hardens”. In cases where a newly planted buffer is being installed around a watercourse or wetland, time can be beneficial insofar as the establishment and growth of herbaceous and woody vegetation can help improve water quality. For example, Vellidis *et al.* (2003) documented significant improvements in wetland water quality from a 38 m buffer over a nine year period, while Yamada *et al.* (2008) documented improvements in groundwater quality within three years of planting a 25 m buffer along a stream in an agricultural setting. A thesis (Orzetti 2005, as cited in Okay 2007) reported that restored forested riparian buffers in the northwestern U.S. begin to show effectiveness after about five years and are hypothesized to increase in effectiveness for 30 to 40 years or longer as the trees mature. Clearly monitoring programs designed over a few years are not going to detect these kinds of changes.

Another temporal consideration, but one that is rarely considered, is that of differential functionality in different seasons. In temperate climates, wetland buffers have, for example, been shown to (not surprisingly) have much lower surface nitrate retention the winter than the summer (Mayer *et al.* 2006).

More research would be helpful on the temporal aspect of buffers, and this facet should not be ignored even though it adds another dimension and complication to the already complex science and practice of buffers.

5.1.3 Buffers and Climate Change

The effects of climate change in southern Ontario are expected to be much less severe than elsewhere on the planet, but these changes are anticipated to affect ecosystems. Indeed some evidence of climate change response has already been documented in Ontario and elsewhere (e.g., 2degreesC 2007; Crick 2004; Niven *et al.* 2009). Although there are many models and predictions, current data suggests that over the next 40 or so years there will be an average mean temperature increase of 2.5 to 3°C as well as an increase in overall annual precipitation, by perhaps 10%, with some likelihood of more frequent extreme weather events (e.g., droughts, flooding, ice storms) (e.g., Wilby *et al.* 2010). The extent to which these will affect natural systems is unclear. In some cases (e.g., storm frequency) only a few additional events, are forecast.

Most flora and fauna in temperate systems are already well-adapted to a wide range of climactic conditions. It is anticipated that species that may be vulnerable to shifts associated with climate change will be those lacking phenotypic adaptability, with limited dispersal ability, with specialized habitat needs, and/or with relatively narrow geographic ranges (e.g., Davis *et al.* 2005; Honnay *et al.* 2002).

Resilience in ecological systems is the amount of disturbance that a system can absorb without changing stability domains. Adaptive capacity is described as system robustness to changes in resilience.

Gunderson 2000

One of the most commonly suggested proactive responses to mitigating impacts to such species is the enlargement of existing natural areas through buffers (e.g., Beir and Brost 2010; Galatowitsch *et al.* 2009; Hannah 2008; Christensen 2008; Spring *et al.* 2010; Wilby *et al.* 2010; Environmental Law Institute 2008). The theory is that a more buffered habitat will be more resilient in the face of the anticipated climactic stressors. However, it remains unclear how climate change will affect southern Ontario habitats and endemic species, or if additional buffers around protected areas in and of themselves will actually be able to mitigate any of the anticipated landscape scale changes because of their unpredictable timing and intensity. For example, as pointed out by Leavitt (1998), in urban watersheds – particularly those with relatively high percentages of impermeable surfaces and channelized waterbodies – riparian buffers can reduce water temperatures but may not be able to attenuate peak flows or filter sediments / nutrients because they are largely bypassed in large storm events. More empirical research and testing of the ability of buffers in providing the various benefits often ascribed to it is required (Wilby *et al.* 2010).

In a review by Noss (2001) considering possible adaptations and mitigation of forested ecosystems to climate change, he identifies buffer zones around nature reserves as having the potential to accommodate for population shifts. However he also points out that in order for this strategy to be effective the buffer zones must be extensive (unspecified extent), there must be ongoing monitoring to document the nature and extent of species shifts, and land managers must be prepared to adjust boundaries.

As is clear from the discussion above, in discussions on climate change, the buffer area is really being viewed as an extension to the CFZ rather than a protective barrier around the feature or function.

5.2 Key Data Gaps

For all habitat types, the primary data gap in relation to buffers in the lack of short, medium or long-term studies on the actual effectiveness of buffers to achieve the functions associated with them (i.e., water quality and habitat functions). No scientific or technical studies specifically designed to test buffer effectiveness were found as part of our literature search. Given the very high value of otherwise developable lands in southern Ontario, there is a real need for a better scientific basis for buffer determination. Well-designed and well-replicated buffer effectiveness studies for various habitat types are sorely needed to inform this determination. The design of these studies must be such that cause and effect can be linked or at least strongly inferred; otherwise they will not be able to inform the discussion: controls, pre-buffer monitoring and statistical soundness all become critical.

This primary data gap is not easily overcome, and it is recognized that these types of studies are challenging in so far as they require: very careful experimental design, some form of replication, some type of control, relatively long-term data collection, and agreement by the planning jurisdiction and the landowner(s) to allow for collection of data. BACI (Before-After-Control-Impact) monitoring designs have been hailed by some as a potential experimental solution to the need for "control" sites when in reality there is not one (e.g., Conquest 2000). However, there are a number of limitations to the reliability of results from such studies (e.g., Underwood 1994), some of which may be overcome by modified BACI designs. The fact that this approach does not seem to have been adopted in any of the current scientific literature suggests that these limitations may not be so readily overcome. Although the idea of establishing separate plots within the same site as both the "control" and the test (or "impact") site is appealing because it provides a solution to the absence of actual "control", further testing of the application of the BACI design is required to determine if the results produced are sufficiently robust.

A secondary gap is that there are very few buffer studies addressing upland forests or woodlots. While there has been a fair amount of research examining edge effects from changes in land uses on wooded natural areas, and specific impacts from the matrix, there have been very few studies that examine the effectiveness of different widths and types of buffers in mitigating stressors and their effects. This makes it very difficult to recommend appropriate buffers to forested areas based on the science.

A tertiary gap is for buffers around wetlands and riparian areas. There is a need for studies that examine different widths and designs of buffers (e.g., grassed *versus* shrubs *versus* forested) in terms of their water quality protective functions over a period of one full year, and ideally multiple years. Important questions to examine are whether these functions are seasonal, and whether or not they diminish over time. Effectiveness also needs to be measured in a more systematic way against established water quality standards. In their relatively recent review, Skagen *et al.* (2008) emphasize the need for "real-world" studies with adequate replicates and controls, as well as sample sizes that include comparisons of pre- and post-treatment data. This same suggestion would apply to any forthcoming woodland buffer studies.

A fourth key gap that was identified is the general lack of science specific to valley features, as well as a lack of a generally accepted definition for what such features encompass. While in Ontario bankfull stream channel boundaries are generally acknowledged as requiring a buffer to support water quality functions, riparian features are generally considered to be the buffer to the watercourse and therefore not in need of any buffer themselves. To some extent, this can be addressed by acknowledging any critical habitat functions provided by the riparian area and thereby recognizing it as a feature in its own right, which in turn requires a terrestrial habitat buffer (e.g., as shown in **Figure 3**). However, science that explicitly considers and studies the potential functions of buffers to riparian areas would also be helpful.

Not surprisingly, there is also very little information on how buffer widths should be adjusted (if at all) in relation to habitat area. Although some of the studies of edge effects (e.g., Murcia 1995) have been used to inform the minimum area of forested habitat required to support species classified as purportedly needing forest “interior” conditions, there has been little published research on how buffers of different widths (and structures) could mitigate edge effects, and to what extent the buffer’s ability to mitigate these effects changes in relation to relative core habitat size.

Additional specific areas of note related to buffers where there is a lack of research and understanding include the:

- Ability of buffers to intercept toxins (such as heavy metals) and pathogens (such as fecal coliform); and
- Benefits, if any, of buffers when applied to open meadow and grassland habitats from a wildlife habitat protection perspective.

Finally, no studies were located that have empirically tested the potential value of management or buffer design measures that might provide comparable mitigative benefits as a wider buffer. A relatively simple example would be a comparison of the extent of direct human impacts to buffers adjacent to backyards in fenced versus unfenced yards. However there are many more possible avenues of exploration in this area that could have immediate and direct applications in real world natural heritage planning. Research in this area would be of value to practitioners and natural heritage planners.

Practitioners should be mindful of these gaps when they recommend and evaluate buffers.

5.3 Summary of Findings

While we need to be mindful of the gaps in science, as described in **Section 5.2**, there is substantial empirical evidence that vegetative buffers can and do perform a number of functions that help protect various types of natural features and mitigate the impacts of human disturbances or changes in land use in the adjacent lands.

The information presented in **Tables 6, 7 and 8** will form the basis for moving forward with the buffer evaluation methodology as presented in **Section 6**, and is described in brief below.

Overview of Gaps in the Literature

An overview of the scientific and/or technical support in the literature for the various categories of buffer functions identified and organized by the natural heritage feature types is presented in **Table 6**.

This table replicates the function categories outlined in **Table 1,** is based on the literature review findings (as presented in **Section 3**) and is meant to illustrate the general level of support for the generally acceptable buffer width ranges presented in **Table 7**. This table reflects, to a large extent, the volume (or lack of) papers found in **Tables 2, 3 and 4**, which is also illustrated in **Appendix A**.

Table 6 is an important reference when considering the buffer width ranges presented in **Table 7**, as it illustrates where there is more (or less) empirical support for the ranges provided. In general, the most empirical science related to buffer effectiveness exists in relation to water quality functions adjacent to watercourses and wetlands. There is also some empirical data to support the effectiveness of buffers to watercourses and wetlands in relation to changes or disturbances in adjacent land uses, as well as core habitat protection.

There is virtually no empirical data (as discussed in **Section 5.3**) that provides direct guidance regarding appropriate buffer widths to upland woodlands or forests, with the exception of some technical research focusing on protection of root zones that can be extrapolated to the feature edge. **Table 6** should be used to link degrees of confidence with the suggested acceptable buffer ranges provided in **Table 7**.

Overview of Acceptable Buffer Ranges

Table 7 provides a risk-based illustration of acceptable buffer ranges for different natural heritage features and the likelihood of achieving different functions within certain ranges of widths based on the available science (as presented in **Section 3**). The ranges presented in this table are drawn from the empirical data on buffer widths summarized in **Tables 2, 3 and 4** respectively, but do not represent simple averages or means of the numbers. Rather, the ranges in **Tables 2, 3 and 4** represent representative and defensible ranges based on consideration of all the literature reviewed that provided quantitative guidance, with greater weighting given to the peer reviewed science, and trends identified in review papers based on the peer reviewed science.

A summary of the key sources used to inform the buffer ranges is provided in **Appendix A**. However, as indicated above, the values in all papers were not all weighted equally. Reviews and meta-analyses were generally given more weight than site-specific research. Where provided, different widths that were linked to different levels of effectiveness were considered as part of the risk assessment. In addition, the values provided in the edge effects literature related to woodlands and meadows were not directly extrapolated to buffer ranges but rather used to inform buffer considerations. In the case of woodlands, the precautionary principle was applied to develop appropriate buffer ranges based in the absence of any direct empirical evidence, but supported by the body of literature on edge effects. Categories with insufficient science to support any recommendations, even based on a precautionary approach, have been identified.

Unfortunately, due to the number of intrinsic and extrinsic factors that need to be considered in appropriate buffer determination, there is no “silver bullet” for buffer determination. Furthermore, as noted elsewhere in this review, buffers alone cannot sustain natural heritage features and their functions. Buffers can, however, be an effective tool when applied following comprehensive natural heritage planning that identifies the full extent of significant features (including critical function zones where appropriate). While some plans and policies have opted to set prescribed buffers to simplify the planning process and help ensure natural heritage protection, the more prescriptive a buffer, the less it considers site specific conditions and sensitivities, which can be very variable.

For this review, we have identified ranges of appropriate buffer widths and applied a risk level derived from a synthesis of the available science. . Three buffer risk levels – high, medium and low – are illustrated in **Table 7**. It is possible that any of these risk levels could satisfy goals and objectives of buffers at a given site, and "high risk" does not necessarily mean that a given buffer would not be successful, but rather it reflects the available science that indicates that buffers of this width are generally less effective at achieving the given function. Clearly, as buffer widths increase within the given range, their effectiveness also tends to increases. However application of only the widest recommended buffers (i.e., "low risk") without consideration for the site-specific conditions, or sensitivity of receiving attributes, might equally result in the identification of a buffer that is unnecessarily wide.

Given the gaps in the science (as described above), it could be argued that application of the precautionary principle[15] would result in the identification of buffers in the "low" to "medium" risk ranges in all cases. Indeed, the authors agree it is reasonable, where scientific data is lacking, to consider the precautionary principle in the ultimate buffer determination. However, in practice, the science is not so unequivocal as to preclude the need to balance such an approach with competing land uses, good planning, and the wise use of serviced lands, particularly in urban and urbanizing settings where land is at a premium.
Buffer ranges presented in **Table 7**, for the most part, fall between 1 m and 120 m, although core habitat protection functions are documented as extending beyond 120 m for all habitat types except for woodlands / forests. However, as discussed in **Section 5.1.1**, the scientific and technical literature does not always clearly distinguish between true buffer functions (i.e., protection of the core feature and its associated ecological functions) and the need for more core or supporting habitat area in the landscape in order to sustain certain habitat functions. While there are some cases where a larger buffer from adjacent land uses will help ensure that habitat for certain species within the protected feature can be sustained, it is important to distinguish these situations from cases where no amount of additional buffer will sustain the given species in the landscape because the overall amount of appropriate habitat has not been protected at the watershed or sub-watershed scale. Buffers are useful natural heritage planning tools, but should not be used to compensate for inadequate natural heritage planning. Buffers may, however, be used to provide one or more of the protective functions identified in this review (i.e., water quantity control, water quality, screening of human disturbance / changes in land use, core habitat protection). Notably, as discussed in **Section 3.3.3**, while buffers may overlap with hazard lands and provide hazard mitigation functions it is our opinion that this function should not factor into buffer width determination.

In general, **Table 7** illustrates that, in the scientific literature,:

- For all natural feature types (except for meadows where there in insufficient data), even narrow buffers (i.e., less than 5 m) have been shown to provide some functions related to water quality and screening against impacts associated with adjacent land uses;
- For watercourses and wetlands, the recommended ranges are the same, and most "high risk" buffer widths fall between 1 m and 10 m;
- For most buffer function categories and most habitat types (except for meadows), "medium risk" buffers range from 11 m to 30 m, except for woodlands / forests where "medium risk" buffers range from 5 m to 30 m; and

[15] . In general, the precautionary principle refers to a duty to prevent harm, even when all the evidence is not available

- The hazard mitigation function of buffers is recognized, but a review and analysis of the literature on this topic was not undertaken as part of this review, and therefore cannot be addressed quantitatively here.

While **Table 7** seems to suggest that wider buffers are often going to be more effective than narrower buffers, for most functions the ranges in buffer widths reflect different responses to different biophysical conditions (e.g., soil type) or different sensitivities of different species or guilds to changes in adjacent land uses more than increasing effectiveness. For example, nutrient attenuation of vegetated buffers on clay soils requires much greater widths than the same level of attenuation on loamy soils. Therefore, while there is a temptation to simply rely on the guidance provided in **Table 7**, it must be considered in the context of the limitations of the current science (as illustrated in **Table 6**), and applied with consideration for other key site-specific factors that can effect buffer efficacy, as summarized in **Table 8** (based on the research summarized in **Section 3.5**). It is also worth considering that buffer effectiveness is expected to decrease for many of these functions with increasing size of the feature, since with respect to core habitat protection, the value of a buffer generally tends to decrease as the size of the feature increases.

Overview of Biophysical Factors Affecting Buffer Width

Table 8 is an important companion to **Table 7** because it summarizes the key factors influencing buffer effectiveness, and indicates whether they are documented as increasing or decreasing effectiveness. The information in this table is drawn from the literature reviewed and summarized in **Section 3.5**. This table underscores the importance of site specific biophysical conditions and the ability of buffer composition and design to influence the width of buffer required for a given site.

For the purposes of application, **Table 8** should be updated and revised as new information becomes available.

Table 6. Overview of the Level of Support in the Scientific and / or Technical Literature for Ecological Buffer Functions by Feature Type

FUNCTION CATEGORY	SPECIFIC FUNCTION	Buffers to Water-courses*	Buffers to Wetlands	Buffers to Upland Woodlands / Forests	Buffers to Meadows
A. WATER QUANTITY	Attenuation of storm water flows**	+	+		
B. WATER QUALITY	Sediment attenuation	+++	+++		
	Nutrient attenuation / transformation	+++	+++		
	Fecal coliform attenuation	+	+		
	Toxin and heavy metal attenuation / transformation	+	+		
	Water temperature moderation	+	+		
C. SCREENING OF HUMAN DISTURBANCE / CHANGES IN LAND USE	Wind and noise attenuation	+	+	~~	
	Light dampening	+	+	~	
	Screening from physical disturbances (e.g., human activities such as mowing / walking / biking, dumping debris, construction, pets)	~~	++	~~	~~
D. HAZARD MITIGATION ZONE	Stream bank / slope stabilization	~	~		
	Mitigate consequences of potential large branch or tree fall			~	
E. CORE HABITAT PROTECTION	Maintaining microclimate conditions (e.g., shade / cooling for fish habitat and forest "interior" species)	+	~	~~	
	Contributing nutrients, large woody debris, and cover (for watercourses, water bodies and wetland areas)	++	~		
	Maintenance of protected area's biotic integrity:				
	• Limiting spread of invasive species	+	+	++	
	• Providing area for tree roots			~	
	• Species diversity	++	++	~~	

LEGEND: "+" represent empirical studies that tested buffer effectiveness for this function; "+" = few, "++" = more than a few, "+++" = many
"~" represent empirical or technical studies that did not test buffer effectiveness *per se*, but provide data that can inform buffer determination;
"~" = few, "~~" = more than a few, "~~~" = many

* As described in **Section 3.1**, many of the functions ascribed to watercourse buffers are assumed to apply to pond and lakeshore buffers as well. They may be less applicable to larger water features such as the Great Lakes where the biophysical scale requires different considerations, Notably, none of the scientific literature has examined the potential functions of buffers to riparian areas of watercourses (comparable to valleylands).

** This function is specifically related to the buffer's ability to attenuate overland storm flows.

Table 7. Ranges for buffer widths to natural heritage features based on the current science.

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
UPLAND WOODLANDS and FORESTS															
	A. Water Quantity	insufficient data													
	B. Water Quality	insufficient data													
	C. Screening of Human Disturbance / Changes in Land Use	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	MODERATE	MODERATE	MODERATE	LOW	LOW	LOW	LOW	LOW	LOW	LOW			
MEADOWS															
	A. Water Quantity	insufficient data													
	B. Water Quality	insufficient data													
	C. Screening of Human Disturbance / Changes in Land Use	insufficient data													
	D. Hazard Mitigation Zone	insufficient data													
	E. Core Habitat Protection*			HIGH	HIGH	MODERATE	MODERATE	MODERATE	MODERATE	MODERATE	MODERATE	MODERATE	MODERATE	MODERATE	LOW

*data available for area-sensitive grassland birds only

<u>Note 1:</u> In all cases the buffer is to be applied from the Critical Function Zone limit, not strictly the feature boundary.

<u>Note 2:</u> Supporting literature is identified in Appendix A.

Key: Risk of Not Achieving the Desired Buffer Function

HIGH
MODERATE
LOW

Table 8. Key biophysical factors to consider in buffer width determination.

Key Biophysical Factors to Consider**	Factors likely to enhance effectiveness*	Factors likely to reduce effectiveness*	Comments
HYDROLOGIC DYNAMICS	Catchment area size small relative to protected feature size (e.g., 100:1)	Catchment area size large relative to protected feature size (e.g., 1000:1 or more)	This applies to surface water quantity moderation and water quality control (i.e., overland storm water flow).*
	Entry runoff velocity low to moderate	Entry runoff velocity high	
	Sheet flow over buffer	Channel flow or buffer bypassed by drainage	
	Subsurface flow (seeps, high water table)	Flow path to deep or regional groundwater	This applies to water quality control.
SLOPES	Slopes of 0% to 12% towards protected feature	Slopes of 13% to 15% or more towards protected feature	This applies primarily to water quantity moderation and water quality control, but also hazard mitigation.
VEGETATIVE COMPOSITION OF BUFFER	A relatively dense herbaceous layer	Sparse herbaceous cover	This applies primarily to water quality control, but also slope stabilization.
	Presence of trees and shrubs with herbaceous understory	Sparse presence of trees and shrubs with herbaceous understory	Shown to improve water quality function and provide a better screen for light, wind, noise as well as better erosion control.
	Presence of coniferous trees and shrubs	Presence of deciduous trees and shrubs	Can provide a better screen for light, wind, noise, plus provides it all year round.
	Presence of woody debris	Absence of woody debris	Relates to water quantity and quality control by slowing flow pathways.
SOILS	Larger textured soils (e,g, sand, loams)	Finer textured soils (e.g., clays)	Relates to water quantity and quality control by influencing local permeability and infiltration rates.
	Soils permeable but not highly sandy	Compacted soils and/or soils with low permeability	
	Soil with organic matter, humus or mulch layer	Soil without organic matter, humus or mulch layer	This applies to water quality control, and particularly denitrification.

* It is recognized in the scientific literature that buffers, in and of themselves, only have a limited ability to moderate catchment-scale water quantity dynamics, and tend to lose effectiveness dramatically during intense storm events.

**Biophysical factors have the potential to interact with and influence each other, and therefore should not be considered independently.

6. Ecological Buffer Determination Methodology

Although the concept of a buffer zone may be straightforward, its design and its functioning in practice raise many challenges. Adequately understanding the interaction between human activities and species populations and the resulting dynamics is a complex issue; determining appropriate land uses is therefore far from easy.

Bennett and Mulongoy, 2006

It is impractical for agency staff to thoroughly review all relevant factors on each site and apply "tailor-made" buffer width(s) to each situation. It is therefore necessary to establish a baseline buffer width for the protection of wetlands and then to make adjustments to this buffer width as appropriate.

Norman, 1998

Properly sizing buffers requires an understanding of the incremental increases or decreases in ... functional effectiveness that result from increasing or decreasing buffer widths.

Castelle and Johnson 2000

As discussed in the previous sections, there are many factors that make appropriate buffer determination challenging. The combination of gaps in our understanding in buffer effectiveness for virtually all habitat types (but particularly upland habitats), variability in buffer effectiveness depending on local biophysical and hydrological conditions, and the variation in responses of different species guilds, and different species, to various stressors from outside natural areas, makes developing a relatively simple methodology rooted in the current science difficult, at best. Even the most recent ecological buffer guidelines released by the United States Department of Agriculture (Bentrup 2008) provide many qualitative guidelines, but virtually no quantitative guidance, and acknowledge that: "*There are still many gaps in our understanding of buffers and their ecological and socioeconomic functions and impacts".*

Nonetheless, land development in southern Ontario will not wait for a more comprehensive understanding of ecological buffers, and therefore there is a need to move forward based on careful consideration of both the scientific and applied data that are available. As illustrated in **Section 4**, current policies at the provincial level in some parts of the Province (i.e., the Greenbelt, Lake Simcoe Protection Plan) are moving forward with prescribed minimum buffers of 30 m for key natural heritage features, and selected conservation authorities and municipal jurisdictions are working towards implementing minimum buffers on protected features ranging between 5 m and 30 m.

This section focuses on providing a practical approach to buffer determination for areas where minimum buffers are not already prescribed that is rooted in the best available science and with consideration for the current policies and legislation, as well as the realities of trying to implement ecological buffers on the ground.

Notably, the available science only speaks to buffers to watercourses and wetlands, and to some extent (*via* extrapolation from edge effect science) woodlands, forests and meadows. Therefore, not all natural heritage feature categories identified in the Provincial Policy Statement are addressed through this review or proposed methodology. In particular, no information on buffers to valley features was available for consideration. In addition, buffers to somewhat specialized habitats that occur in southern Ontario (e.g., alvars, cliffs, shrub thickets) are not addressed because of the absence of any scientific or technical literature on buffers to them.

Section 6.1 presents the various approaches considered by the Steering Committee, while **Section 6.2** presents the recommended buffer determination approach. The recommended approach has been developed based on careful consideration for the available science, input from the Steering Committee, and the consulting team's applied knowledge based on their experience in the field. The recommended buffer evaluation method will also need to be reviewed once it is "field tested" based on ease and effectiveness of implementation. This will no doubt be an iterative process.

In addition, as with all processes that are based on aspects of the current science, the basic assumptions that have been derived from the science (i.e., **Table 7** and **Table 8**) should be reviewed and updated periodically as new science becomes available.

6.1 Overview of Approaches Considered

Five possible approaches to buffer determination were identified, as follows, listed from most prescriptive to most flexible:

1. PRESCRIBED BUFFERS: Strictly prescribed buffer widths for all protected features (e.g., 30 m to 50 m based on the "medium risk" to "low risk" ranges of effectiveness as identified in **Table 7**), with no Environmental Impact Study (EIS) required for buffer width determination.

2. BASE BUFFER + RISK-BASED ASSESSMENT: Combination of a base prescribed buffer width (i.e., based on the "high risk" range of effectiveness identified in the risk-based guidelines provided in **Table 7**) PLUS additional buffer width determined based on an EIS within the risk-based parameters provided.

3. RISK-BASED ASSESSMENT: Buffer width selected within the risk-based parameters (as provided in **Table 7**) but ultimately determined based on an EIS.

4. BASE BUFFER + EIS: Combination of a base prescribed buffer width (based on the "high risk" range of effectiveness identified in the risk-based guidelines provided in **Table 7**) PLUS additional buffer width, where appropriate, determined based on an EIS (without regard for the risk-based parameters and determined on a case by case basis).

5. CASE BY CASE - EIS: No minimum buffers prescribed, no consideration for risk-based parameters required, buffer requirements entirely determined based on an EIS.

Each of these approaches has different pros and cons. The first option is highly inflexible and while it keeps the process simple and ensures a consistent approach, it may not be practical or appropriate in all situations, and therefore may be difficult to implement and enforce. Land owners are usually not supportive of such inflexibility, and in practice poor land use decisions can result.

The approaches that are more responsive to site-specific circumstances (i.e., Options 4 and 5) are the most flexible and potentially responsive to site-specific conditions, but also the most prone to subjectivity and inconsistent application. These latter options represent the status quo which many conservation authorities are finding unsatisfactory with respect to buffer determination and implementation.

A number of examples from the technical and applied literature were examined in terms of buffer evaluation approaches that have been developed and implemented elsewhere:

- OPTION 4: Based on a review of more than 140 papers and an understanding of the local conditions, Wenger (1999) came up with three options for riparian buffer guidelines that are simple enough to be readily applied but that also recognize some of the findings from the science. These options all fall into the Category 4 outlined above and include: a base or minimum buffer (between 15 and 30 m), plus additional buffer based on increases in slope (i.e., 0.61m per 1% slope).

- OPTION 3: In Island County Washington, a wetland buffer ordinance was developed and approved March 17, 2008 that is based on a sophisticated matrix approach with numbers rooted in comprehensive studies of local conditions and the best available science. This allows for a site-specific approach that is still standardized and defensible, while still including consideration for the current science with respect to buffer functions.

    - Wetlands are categorized A-E, and ranked by relative sensitivity (e.g., A = bogs and mature forested wetlands, E = smaller wetlands dominated by non-native plants and not associated with any watercourses or estuarine systems).

    - Appropriate buffers within established ranges are then assigned based on consideration for: adjacent land use intensity, slope, and anticipated / desired buffer function (i.e., water quality or habitat protection). In examples found within the Environmental Law Institute (2008) review, water quality buffers were narrower than habitat buffer ranges (i.e., 6 to 54 m vs. 22 to 91 m), and steeper slopes (e.g., 15% or more) required wider buffers to achieve the same water quality benefits as narrower buffers on less steep slopes (e.g., 5 to 14%).

From a practical perspective having prescribed, single width buffers for different habitat types and different sites intended to cover a range of conditions is simpler from a planning perspective. However, given the number of site-specific factors that can influence buffer effectiveness (as described in **Section 3.5**), as well as the need to consider the functions being protected and the external land use influences, allowing for some flexibility and buffer width variability that accounts for these parameters, is a more appropriate, science-based approach (e.g., Polyakov *et al.* 2005; Okay and, Feldt 2010). The drawback of this approach is that it requires more time and a much greater technical understanding of the existing conditions, the anticipated conditions under the proposed land use change, and the state of the science regarding buffers. Another limitation is that the available science, particularly with respect to buffers to upland habitats (e.g., forests, grasslands), but also with respect to buffers for watercourses and wetlands intended to protect habitat functions, still has important gaps (as discussed in **Section 5.2**).

Based on consideration of the science, as well as the need to have an approach that is both implementable and defensible. Options 2 and 3 were examined in more detail for southern Ontario. These were considered options that are consistent with the best available science and practices, but that also accommodate for some flexibility in terms of considering site-specific biophysical and land use factors.

One of the recognized challenges facing Ontario planners and ecologists with respect to these different options is the danger of providing minimum buffer widths (based on the current science), and then finding the minimums become the standard. Indeed, the application of 15 m and 30 m buffers to warm and cold water creeks respectively continues to be implemented today as a result of minimums suggested by Castelle and Johnson (1994) nearly 20 years ago. However, Option 2 above tries to avoid this pitfall by requiring an EIS that considers the extent of additional buffer(s) required beyond the required "base" as it has been labelled here. The term "base" has been used intentionally (as opposed to "minimum") to imply that it needs to built on as part of the evaluation process.

6.2 Recommended Buffer Determination Process

A methodology based on a combination of Options 2 and 3 (as described in **Section 6.1**) is recommended as the basis for moving forward because it requires consideration of both the generalized findings from the current science and site-specific variables. The recommended approach consists of:

identification of a BASE BUFFER WIDTH
(derived from the "high risk" range from the science identified in the risk-based guidelines provided in **Table 7**)

+

ADDITIONAL BUFFER width, as appropriate
(determined based on site-specific biophysical and land use considerations identified through an EIS with consideration for the current science)

=

to arrive at the PRELIMINARY BUFFFER WIDTH which may be further modified based on consideration for site-specific constraints or opportunities

This approach will not be as simple to apply as a prescribed buffer, and will need to be implemented by professionals with a good understanding of hydrologic and ecological principles, but should be less variable than a case-by-case determination based on EIS.

In most cases it is expected that the final buffer width will fall within the "medium risk" zone (as identified in **Table 7**) and thereby represent a reasonable balance between achieving natural heritage protection and efficient land use planning objectives. Furthermore, using an additive approach which is based on the current science and is also responsive to site-specific conditions (i.e., BASE derived from the "high risk" end of a risk-based assessment of the science + ADDITIONAL buffer from site-specific considerations with consideration for the related science) will help ensure that the final recommended buffer is defensible, appropriate for the given site, and supportive of good land use planning.

It is important to emphasize that **Table 7**, which provides quantitative risk-based guidance based on a synthesis of the current science for buffer width determination (as described in **Section 3**) is an important tool in this exercise, but should not be applied generically or without consideration for site-specific biophysical variables that can influence buffer width determination (as presented in **Table 8**), or other site-specific considerations. Approaches for determination of appropriate buffer widths, particularly in urban and urbanizing settings, must consider intrinsic conditions (i.e., vegetative structure, soils, slope and hydrology) and extrinsic conditions (i.e., nature and extent of land use impacts related to changes in the immediately adjacent lands), as well as the sensitivities of the protected natural feature and functions, and the functions which the buffer is, or is not, expected to provide. Finally, there needs to be consideration for design and / or management options that may improve buffer effectiveness and still maintain its functions, potentially reducing original widths.

The proposed evaluation methodology, which is illustrated in **Figure 11**, considers all the factors alluded above, through an eight step process. The various factors that need to be considered through buffer width determination as part of the buffer evaluation process are presented in more detail in the following sub-sections. The process provided here is intended to be sufficiently generic to be applicable to almost any site requiring consideration of buffer determination (i.e., irrespective of feature type[16] or size, or of the nature or scope of development proposal), and also able to provide sufficient guidance to ensure all the appropriate findings from the science related to buffers and site-specific variables are considered.

The following steps correspond to those illustrated in **Figure 11**. Notably, Steps 1a, 1b, 2a, 2b and 3 in **Figure 11** are the basic steps required in completion of an Environmental Impact Study and therefore are not addressed in detail here. It is not until Step 4 that the process becomes specific to buffer determination and more guidance is provided. Nonetheless, the information from the previous steps is required to make an informed decision about the width, design and management options for the buffer, and is an important part of the process.

Although buffer width determination may not always occur as part of a site-specific EIS (or comparable study), it has been assumed for the purposes of this review that this process will normally be part of the EIS process. Although the process may need to be tailored to dovetail with other planning processes where buffer determination is required outside the EIS process, the information and guidance provided in this review should remain applicable.

<u>STEP 1a. Defining the natural heritage features and Critical Function Zone(s) (CFZ)</u>

As discussed in **Section 2** of this review, one of the most important steps in ensuring natural heritage protection is proper identification of the extent of the natural heritage feature to be protected, as well as any associated Critical Function Zones required (CFZs) (as defined in **Section 2.1**). CFZs may be required to support biophysical functions or attributes directly related to the feature of interest that are considered critical for the sustainability of the feature and the species of concern within it.

[16] With the exception, as noted above, of valley features and specialized habitat types such as alvars, cliffs or beaches.

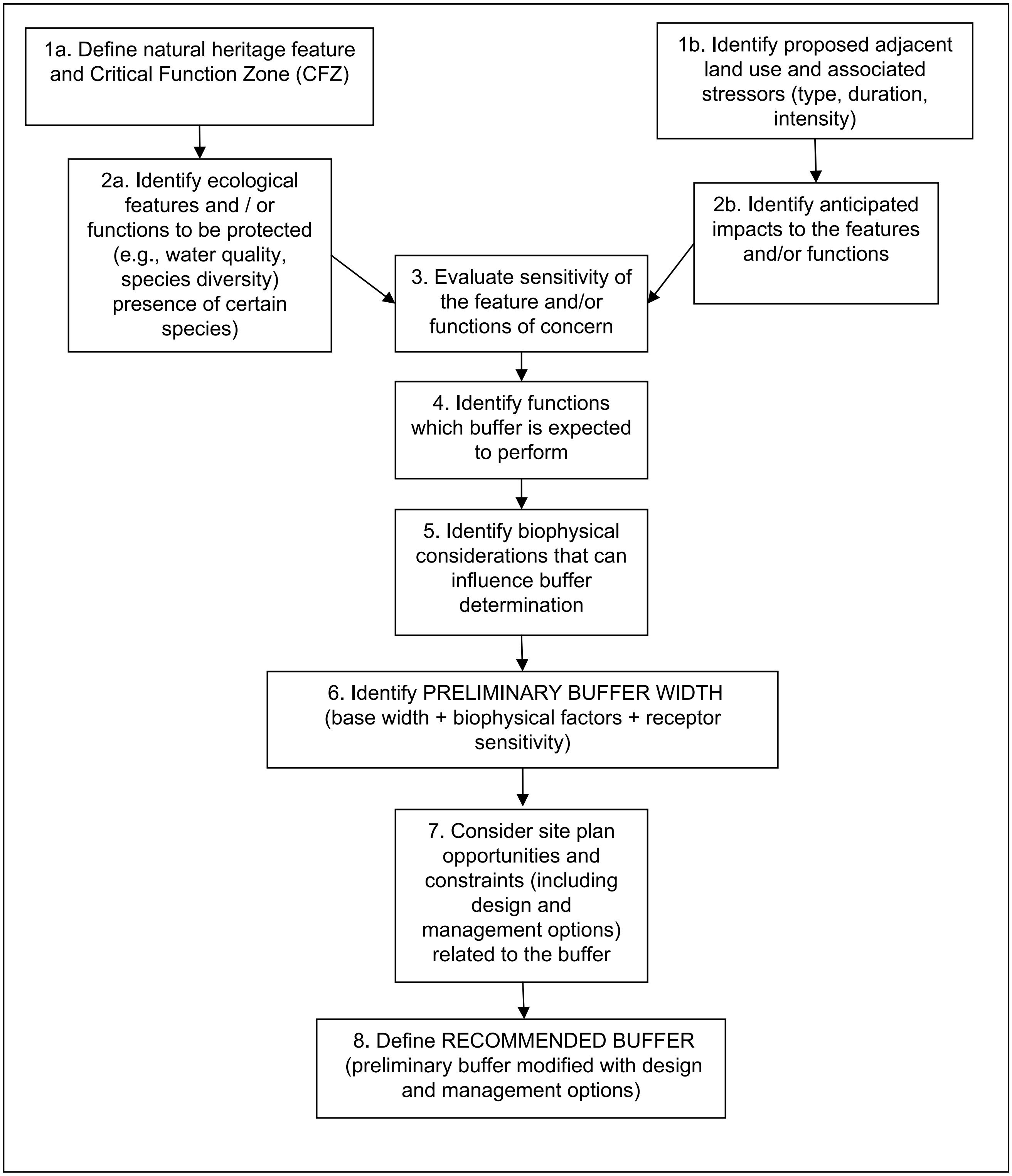


Figure 11. Recommended buffer determination process.

While there is fairly broad consensus on how to define the boundary of a waterbody, wetland, woodland / forest or meadow feature, there are varying approaches to defining the extent of a watercourse. It is outside the scope of this review to assess the different approaches to identifying this feature[17], but the salient point related to this methodology is that the buffer should be applied to whatever is considered the full extent of the actual feature, and should be identified for the primary purpose of protecting the feature from impacts related to changes in adjacent land uses, or mitigating these impacts.

This step is typically considered an assessment of the "existing conditions", and is usually undertaken through an Environmental Impact Study (EIS). The EIS or site assessment guidance should be explicit about how features are to be defined, and that CFZs are also to be identified and may, in some cases, go beyond the feature boundary. (An example of a CFZ going beyond the feature boundary would be the identification of foraging or overwintering habitat in a woodland adjacent to a pond supporting breeding amphibians).

This step should include the biophysical context for the site and provide descriptions of the local:

- hydrologic and hydrogeologic dynamics (including identification of high water table conditions);
- topography and geology;
- soils;
- climate;
- vegetation communities, including their structure and composition (with any significant communities or species noted); and
- wildlife habitats and documented wildlife species.

An accurate assessment of the site-specific biophysical conditions is fundamental to buffer determination since this provides the baseline against which the appropriateness of a given buffer width will be considered in Steps 4 and 5.

In all cases the buffer is to be applied from the Critical Function Zone (as defined in **Section 2.1**) limit, which may go beyond the feature boundary.

<u>STEP 1b. Identification of proposed adjacent land use and associated stressors (type, duration, intensity)</u>

This step will also typically be part of an EIS and will be based on a description of the development proposal. For appropriate buffer determination, the most important consideration is not just the type of development, but also the type(s) of stressor(s) on the protected natural area expected to be associated with the proposed development.

It is recognized in both the scientific and technical literature that the type and width of buffer required to protect a given feature is influenced by the proposed adjacent land use. The type and frequency of stressor can vary according to factors such as:

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[17] Some discussion of this issue is provided in **Section 3.1** and further guidance is expected to be forthcoming in TRCA's Revised Valley and Stream Corridor Guidelines.

- the type of development (e.g., residential, commercial, industrial, recreational);
- the duration of the development (e.g., temporary use, permanent change);
- the scale of the development (e.g., a single house versus a subdivision);
- the intensity of the proposed development (e.g., estate lots versus a condominium complex; sports fields versus passive open space with trails); and
- the anticipated level of activity (e.g., irregularly used passive open space versus intensively used open space to accommodate concert crowds or large group activities).

Unfortunately, no simple correlation can be drawn between types of developments adjacent to certain natural heritage feature types and buffer requirements because of the number of variables that need to be considered. Biophysical factors (such as site drainage patterns and the location of the protected feature in relation to those patterns) can be just as important as the type and intensity of the proposed development in considering an appropriate buffer width to mitigate anticipated water quality impacts to the protected feature. Furthermore, there are various options and strategies that can be considered in the design and layout of proposed developments that may result in greater or reduced buffer requirements. For example, strategic placement of impervious surfaces away from, and open spaces adjacent to, protected natural areas can result in reduced buffer requirements, whereas concentrated residential developments along a feature edge with a steep slope may require additional buffer width.

In addition to considering the specific type and nature of the proposed development, a key consideration for buffer determination are the types of stressors associated with the development, and the extent to which they are expected to irreparably or permanently impact the values for which the natural area is being protected. These include consideration of the following:

- impacts to water quantity being received by the area;
- impacts to water quality being received by the area;
- introduction of contaminants:
- changes to habitat-related food supply;
- introduction and / or spread of parasites, pathogens, and / or invasive species;
- introduction of urban-sponsored native and non-native predators;
- greater exposure to wind and noise;
- changes in exposure to light (including artificial light);
- direct and indirect human disturbances (e.g., human presence and recreational activities, trails, encroachments into natural areas); and
- impacts to habitat quantity and / or quality.

STEP 2a. Identification of ecological features and / or functions to be protected (e.g., water quality, species diversity)

Another key component of an EIS is an assessment of the natural heritage features on site (with consideration for features in immediately adjacent lands) in terms of an evaluation of their significance in relation to applicable regulations and policies, and an identification of which features and ecological functions are to be protected in the context of the proposed development.

As indicated in the introduction, where existing policies require application of prescribed buffers (e.g., portions of the provincial Greenbelt), analysis beyond confirmation of the feature type and its boundaries may not be required if the prescribed buffers are deemed sufficient in sustaining the protected feature and its key functions.

Notably, the information available in the scientific literature can be applied generally to watercourses, wetlands, and woodlands but does not correspond to the feature categories as laid out in the Provincial Policy Statement (2005). As discussed in **Section 3**, the literature tests the effectiveness of buffers directly adjacent to these features, but does not, for example, test the effectiveness of buffers to vegetated riparian areas. Therefore there is a gap between the science and the policy in so far as functions of buffers to watercourses and wetlands have been fairly well documented, while buffers to, for example, valleylands have not. While much of the research on buffers to watercourse and wetlands can probably be applied to the riparian areas of water bodies such as lakes and ponds, it cannot be so readily applied to valleylands which can encompass a range of features.

Furthermore, it is assumed that buffers to Significant Wildlife Habitat would be determined based on an understanding of the specific requirements of the species or group of species in question, as well as consideration for their sensitivity to changes in land use context.

STEP 2b. Identification of anticipated impacts to the ecological features and/or functions to be protected

Impact assessment is another core piece of an EIS. It basically takes the existing conditions and feature sensitivities, the evaluation of significance, and the proposed development into consideration for a synthesis of anticipated impacts to the identified significant features and functions.

For the natural heritage features and functions to be protected, one of the protective / mitigative measures typically considered is the identification of buffers. Although it is understood that this is only one of a number of protective and mitigative options that can be considered as part of an EIS, this process focuses on this one measure.

For buffers, the most important impacts to consider are those which will be site-specific as well as direct (e.g., noise from adjacent residences) and indirect (e.g., invasive plants spreading from residential yards), although some additive effects (e.g., trampling or *ad hoc* trail creation along the edge or into the feature) may also be relevant. While the broader landscape scale provides important context for site-specific biodiversity as well as hydrology and ecological linkages, impacts or deficiencies at the broader landscape or subwatershed scale can rarely be mitigated or compensated by site-specific buffers, and generally require broader scale approaches.

Again, it is important to emphasize that the impact assessment should address anticipated impacts to natural heritage features as well as functions to be protected, and not strictly focus on the features. This will ensure that the full range of potential functions that may be provided by a buffer can be considered.

STEP 3. Evaluation of the sensitivity of the feature and/or functions of concern

Evaluation of the sensitivity of the natural heritage feature(s) and/or function (s) of concern should consider a number of variables, including:

- hydrogeology of the feature (e.g., sensitivity to changes in groundwater levels) and hydrology of the feature (e.g., sensitivity to changes in surface water levels), and any relationships between the two;
- position in the landscape (e.g., a headwater stream versus a first order stream; upland versus lowland);
- area and shape of the feature (and particularly the amount of exposed edge in relation to the size of the feature as a whole);
- vegetative structure and quality of the feature; and
- diversity and types of species of conservation concern supported by the feature, and their sensitivity to anthropogenic disturbances.

The sensitivity of a feature to impacts from changes in adjacent land uses should not be confused with the rarity of a given feature in the landscape. Although some features that are rare may also have a high level of sensitivity, many do not.

Area is also an important consideration although, as discussed in **Section 5**, there is no scientific or technical research that has specifically examined buffer size in relation to feature size, and any relationships that this ratio may have relative to buffer effectiveness. Nonetheless, it should not be assumed that larger features require wider buffers. In fact, although it may be somewhat counter intuitive, it is possible that smaller features may require higher buffer: feature ratios because of their relatively greater exposure to impacts from adjacent land uses.

The extent of buffer is also closely related to the extent of feature edge that is exposed to a change in adjacent land use, which is determined by a combination of feature area and shape. It is worth noting again that a buffer to a long, narrow feature surrounded by residential development may be able to mitigate against encroachments, but generally cannot compensate for the lack of interior habitat (and should not be identified for this purpose).

Sensitivity related to the range of species of present, with particular consideration for those of conservation concern, can be the most challenging to assess because of the variability in species requirements, and the gaps in our understanding of many species' sensitivities to stressors. Strategies for addressing this challenge include consideration of habitat requirements and sensitivities for the better studied species that occur, as well as use of "umbrella" species whose habitat requirements are expected to overlap with and encompass the needs of other species within the same ecosystem.

STEP 4. Identification of functions the buffer is expected to perform

As part of the assessment process, there should be a screening for which functions the buffer is expected to perform. The use of the list of functions developed for this review (as listed in **Table 1**) is suggested as a reference:

A. WATER QUANTITY
- Attenuation of storm water flows
- Groundwater recharge

B. WATER QUALITY
- Sediment attenuation

- Nutrient attenuation / transformation
- Fecal coliform attenuation
- Toxin and heavy metal attenuation / transformation
- Water temperature moderation

C. SCREENING OF HUMAN DISTURBANCE / CHANGES IN LAND USE

- Wind and noise attenuation
- Light dampening
- Screening from physical disturbances (e.g., human activities such as mowing / walking / biking, dumping debris, construction, pets)

D. HABITAT TRANSITION / HAZARD MITIGATION ZONE

- Streambank / slope stabilization
- Provide setback from potential large branch or tree fall

E. CORE HABITAT PROTECTION

- Maintaining microclimate conditions (e.g., shade / cooling for fish habitat and forest “interior” species)
- Contributing nutrients, large woody debris, and cover (for watercourses, water bodies and wetland areas)
- Maintenance of protected area’s biotic integrity
- Limiting spread of invasive species
- Providing area for tree roots

This list represents a synthesis of the documented buffer functions that have been considered and tested in the scientific and technical literature, and is intended to be comprehensive. However, updates and refinements to it may be considered as new information becomes available.

Undertaking this assessment will:

1. clearly illustrate what functions the buffer is expected to perform in the given site-specific context using a standardized checklist (based on the list above) for ease of reference; and

2. allow from easy cross referencing with the risk-based buffer ranges provided in **Table 7** by the proponents and the conservation authorities to provide guidance as to what ranges should be considered (i.e., typically those that fall within the medium to high risk ranges).

This exercise may also help identify what ecological functions the buffer cannot perform and support in the identification of other enhancements or restoration activities where appropriate.

STEP 5. Identification of biophysical considerations

Given the extent to which site-specific biophysical factors have the ability to affect buffer effectiveness (as discussed in **Section 3.5**), it is important to consider the broader contextual and biophysical information for the entire site and focus on the specific biophysical qualities of the potential buffer area. Key variables to consider are summarized in **Table 9** below and linked with the supporting research from the scientific and technical literature.

Table 9. Supporting literature for key biophysical factors to consider in buffer width determination.

Biophysical Factor*	Increases to buffer widths *may not* need to be considered	Increases to buffer widths *could be* considered	Supporting Literature	Comments
HYDROLOGIC DYNAMICS	Catchment area size small relative to protected feature size (e.g., 100:1)	Catchment area size large relative to protected feature size (e.g., 1000:1 or more)	Adamus 2007; Leavitt 1998	Buffers in and of themselves only have a limited ability to moderate catchment-scale water quantity dynamics; this ability is directly related to the pattern and intensity of flows (Dillaha *et al.* 1986a, Leavitt 1998, Lee *et al.* 2003, Woodard and Rock 1995).
	Entry runoff velocity low to moderate	Entry runoff velocity high	Lee *et al.* 2003; Woodard and Rock 1995	
	Sheet flow over buffer	Channel flow or buffer bypassed by drainage	Castelle and Johnson 2000; Adamus 2007	
	Subsurface flow (seeps, high water table)	Flow path to deep or regional groundwater	Angier *et al.* 2005	Groundwater that manifests itself near the surface can contribute to denitrification.
SLOPES	Slopes of 0% to 12% towards protected feature***	Slopes of 13% to 15% or more towards protected feature	Wenger 1999; Woodard and Rock 1995; Schueler 1987; Norman 1998; Castelle and Johnson 2000; Adamus 2007	The literature indicates that slopes of more than 12% to 15% tend to result in reduced buffer effectiveness related to water quality functions. Soil type and vegetative cover also factor in to buffer effectiveness on slopes.
VEGETATIVE COMPOSITION OF BUFFER	A relatively dense herbaceous layer	Sparse herbaceous cover	Hook 2003; Castelle *et al.* 1992; Wilson and Imhof 1998	Herbaceous cover is generally more effective at attenuation of contaminants in surface runoff (while woody vegetation is generally more effective at attenuation of contaminants in sub-surface runoff). Treed buffers also provide a better screen for light, wind, noise as well as better erosion control. Coniferous buffers provide these functions all year round.
	Presence of trees and shrubs with herbaceous understory	Sparse presence of trees and shrubs with herbaceous understory	Lee *et al.* 2003	
	Presence of coniferous trees and shrubs	Presence of deciduous trees and shrubs	Brown *et al.* 1990; Lowrance and Sheridan 2005; Knight et al. 2010	
	Presence of woody debris	Absence of woody debris	Sheldon et al. 2005	Relates to water quantity and quality control by slowing flow pathways.
SOILS	Larger textured soils (e,g, sand, loams)	Finer textured soils (e.g., clays)	Brown *et al.* 1990; Wilson 1967; Sullivan *et al.* 2007;	Relates to water quantity and quality control by influencing local permeability and infiltration rates. Organic matter also contributes to denitrification.
	Soils permeable but not highly sandy	Compacted soils and/or soils with low permeability	Polyakov *et al.* 2005	
	Soil with organic matter, humus or mulch layer	Soil without organic matter, humus or mulch layer	Mayer *et al.* 2006; Gift *et al.* 2010; Bradley *et al.* 2011	

* Biophysical factors have the potential to interact with and influence each other, and therefore should not be considered independently

While **Table 9** provides guidance as to when buffer widths may need to be widened in response to biophysical factors (or not) there is insufficient data from the literature to support specific recommendations for what additional widths (or ranges) may be appropriate, and in any case previously discussed parameters need to be considered.

Some examples of recommended buffer widths from the literature are provided in relation to the biophysical factors above for consideration. However, these examples reflect the site-specific considerations from the geographic areas in which the research was undertaken. They cannot necessarily be transferred directly to any specific situation in southern Ontario. Nonetheless, these examples illustrate that ranges in effective buffer widths drawn from the science may incorporate considerations related to different biophysical conditions.

- SLOPES: Wenger (1999) suggests a base buffer width of 15.2 m or 30.5 m for watercourses depending on watercourse sensitivities (in Georgia) plus an additional 0.61 m per 1% slope over 10% with slopes of more than 25% requiring additional setbacks.

- SLOPES: Rules of thumb for adjusting buffer widths in relation to slope from a range of technical and policy sources in North America as synthesized by Adamus (2007) are:
    - Increases in 0.3 m to 0.9 m for every degree increase in slope;
    - Increase in 3 m for every degree increase in slope for slopes greater than 15%;
    - Increases in 0.6 to 1.5 m for every per cent increase in slope; and
    - 50% increase in the recommended buffer for slopes greater than 30%.

- VEGETATIVE COVER: Lee *et al.* (2003) found riparian buffers with grass and shrubs to be 20% more effective at nitrogen assimilation than buffers with grass alone.

- SOIL TYPE: Wilson (1967) found sediment attenuation to be most effective with 3 m buffers on sandy soils, 15. 2 m buffers on silty soils, and 122 m with clay soils.

BUFFERS TO HEADWATER STREAMS: Although no specific guidance is provided with respect to buffer widths, Anbumozhi *et al.* (2005) and Fisher *et al*. (2000) identify the importance of the location of a stream in the watershed, and emphasize that vegetated buffers to watercourses in the headwaters (i.e., first, second and third order systems) can have a much greater influence on overall water quality than buffers along other streams in the watershed.

Some general guidance is provided through the risk-assessment ranges in **Table 7** in so far as sites with biophysical factors that trigger consideration of increases to base buffer widths should generally be falling within the medium to high risk range for the feature and function(s) in questions.

STEP 6. Identification of preliminary buffer width

The preliminary buffer width should be based on the following three considerations:

1. base width (as per the recommendations in **Table 10)**;
2. biophysical factors (as listed in **Table 9** above);
3. sensitivity and importance of receptors.

Table 10. Recommended base buffer widths for different habitat types for different buffer functions in southern Ontario.

Natural Heritage Feature Category	Buffer Function Category	Recommended Base Buffer Width*
WATERCOURSES and WATER BODIES		
	A. Water Quantity	Not applicable at site level
	B. Water Quality	10 m
	C. Screening of Human Disturbance / Changes in Land Use	10 m
	D. Hazard Mitigation Zone	insufficient data
	E. Core Habitat Protection	10 m
WETLANDS		
	A. Water Quantity	Not applicable at site level
	B. Water Quality	10 m
	C. Screening of Human Disturbance / Changes in Land Use	10 m
	D. Hazard Mitigation Zone	insufficient data
	E. Core Habitat Protection	10 m
UPLAND WOODLANDS and FORESTS		
	A. Water Quantity	insufficient data
	B. Water Quality	insufficient data
	C. Screening of Human Disturbance / Changes in Land Use	5 m
	D. Hazard Mitigation Zone	insufficient data
	E. Core Habitat Protection	5 m
MEADOWS		
	A. Water Quantity	insufficient data
	B. Water Quality	insufficient data
	C. Screening of Human Disturbance / Changes in Land Use	insufficient data
	D. Hazard Mitigation Zone	insufficient data
	E. Core Habitat Protection	10 m

*** The "base buffer width" is the smallest possible width for a buffer which will typically be increased based on site-specific biophysical and feature sensitivity considerations to generate the "preliminary buffer", as follows: <u>Preliminary Buffer = Base Buffer + Biophysical Considerations + Feature Sensitivity Considerations.</u>**

The prescribed numbers in **Table 10** have been derived from buffer ranges in **Table 7** that are based on the available science (as illustrated in **Appendix A**). These numbers have been identified as a defensible generic starting point for appropriate buffer determination to be built on with site-specific information (i.e., biophysical conditions and feature sensitivity, including consideration of specific requirements for specific species). The preliminary buffer will, in most cases, be wider than the prescribed base buffer. The base buffers, as identified in **Table 10**, do not account for any biophysical conditions (as identified in **Table 9**), feature sensitivities, or specific species requirements that may warrant additional buffer widths. Therefore:

PRELIMINARY BUFFER = BASE BUFFER + BIOPHYSICAL CONSIDERATIONS + FEATURE SENSITIVITY CONSIDERATIONS

Exceptionally, the base buffer may be equivalent to the preliminary buffer. For example, a single family dwelling on a lot of record where a higher risk may be considered acceptable because the proposed undertaking interacts with only a small part of the feature and no particular sensitivities have been identified. However, in most cases the "preliminary buffer" will exceed the "base buffer". It stands to reason that sites with more biophysical factors that require consideration of wider buffers, as well as sites with features that have greater sensitivities to changes in adjacent land uses, will end up with preliminary buffers at the higher end of the medium risk ranges or well within the lower risk ranges identified on **Table 7**.

Notably, preliminary buffers (or the final buffers, as identified in Step 8 below) should not be confused with regulatory setbacks. As discussed in **Section 2.1**, although regulatory setbacks and ecological buffers can, and often do, overlap, they will usually not be the same because the functions for which they are being identified are different.

STEP 7. Consideration of site plan opportunities and constraints (including design and management options) related to the buffer

This is the step where creative design options and management options related to the site-specific proposal can be considered. Depending on these options, the preliminary buffer may need to be increased or decreased.

- EXAMPLE 1 (increase): A preliminary buffer to a wetland that was identified as 30 m may need to be expanded to 36 m if it is to accommodate a maintained community trail along its edge.
- EXAMPLE 2 (decrease): A buffer to an upland woodland surrounded by residential lots that had a preliminary width of 15 m for screening from human impacts may be able to be reduced to 10 m if the design includes an un-gated chain-linked fence with a mown strip of grass in front of it to reduce the extent of anticipated encroachments .

Other options, as discussed in **Section 3.6** of this review, include restoration of woody components to herbaceous buffers (which obviously requires time), establishment of zoned buffers, integration of Low Impact Development (LID) infiltration measures, and creation of earth berms (i.e., to screen natural areas and discourage encroachment). Given that there is very little science on the effectiveness of these various options, a measure of professional judgement will need to be applied in terms of how each of these may increase or decrease preliminary buffer widths.

It is also important to keep in mind that buffers need not be uniform and that there may be elements specific to a site that warrant a wider buffer in one location than another (e.g., greater exposure to development of one feature edge, presence of a wetland within a larger wooded feature that is highly sensitive to hydrologic dynamics). Opportunities to address site-specific situations should be explored as part of the buffer determination process.

STEP 8. Defining the recommended buffer

The final recommended buffer will essentially be the preliminary buffer modified with design and management options, as described above.

RECOMMENDED BUFFER = PRELIMINARY BUFFER ± DESIGN CONSIDERATIONS

6.3 Concluding Remarks

As discussed, there are many factors that make appropriate buffer determination challenging. Buffer determination is complex; it is influenced by the stressors, the receiver, the nature of the buffer itself and of course project objectives. Clearly there are situations where a buffer of a few or even zero metres will suffice and others where more than a 100 m may be required.

We have noted a number of important gaps in the scientific literature relating to buffers. Nonetheless, the recommended approach for buffer determination combines current science-based guidance that is available, together with direction for the consideration of site-specific factors to provide a sound and defensible approach. However, the available science only speaks to buffers to watercourses and wetlands, and to some extent (*via* extrapolation from edge effect science) woodlands. In particular few or no data are available for valleylands, special features, including most significant wildlife habitat,, meadows and thickets). Therefore, not all natural heritage feature categories identified in the Provincial Policy Statement are directly addressed through this review. However, as additional data become available the review can be updated on a regular basis and this methodology can be applied. As with all processes that are based on aspects of the current science, the basic assumptions that have been derived from the science (i.e., **Table 7** and **Table 8**, and **Appendix A**) should be reviewed and updated periodically as new science becomes available.

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Appendix A

Scientific and Technical Literature Supporting Ranges for Buffer Widths to Different Natural Heritage Features

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Appendix A

Scientific and technical literature supporting ranges for buffer widths to different natural heritage features.

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 [b]															
	A. Water Quantity			3, 4	1, 3, 4	1, 3, 4	1, 3, 4	1, 3, 4	1, 3	1, 3	1, 3	1,2, 3	1, 3		
	B. Water Quality	3, 4, 6, 7, 11, 17, 19	3, 4, 7, 9, 11, 12, 13, 15, 17, 19	4, 7, 9, 11, 12, 13, 15, 16, 17, 19	4, 5, 7, 8, 9, 11, 13, 14, 15, 19, 22	4, 7, 8, 10, 11, 12, 14, 18, 19, 21	4, 5, 7, 8, 11, 12, 19	4, 11, 19	4, 19	4, 19	4, 19, 20	4, 19	4, 19	19	19
	C. Screening of Human Disturbance / Changes in Land Use [f]														
	D. Hazard Mitigation Zone	should be based on consideration of hazards, but may overlap with buffers													
	E. Core Habitat Protection [e]		25, 26	4, 9, 15, 23, 25, 26, 28	4, 9, 15, 25, 26	4, 25	4, 24, 25, 27	4, 25	4, 25	4, 25	4, 25	4, 5, 25	4, 25	4, 25	4, 25
WETLANDS[b]															
	A. Water Quantity														
	B. Water Quality	32	30, 32, 34, 36	30, 31, 32, 33, 35	30, 31, 32, 33, 35	25, 29, 30, 31, 32, 34	25, 29, 30, 31, 32, 33, 34	25, 29, 30, 31, 32, 33, 34	25, 30, 31, 32	25, 30, 31, 32	25, 30, 31, 32	30, 32	30, 32	30, 32	30, 32
	C. Screening of Human Disturbance / Changes in Land Use	37	37	37	31, 37	31, 37	31, 37	37							
	D. Hazard Mitigation Zone	should be based on consideration of hazards, but may overlap with buffers													
	E. Core Habitat Protection [f]		32	23, 32, 38, 42	23, 27, 32, 42	32, 34, 42	32, 34	32, 34	32, 31, 34	31, 32, 34, 39	31, 32, 34	30, 32, 34	30, 34, 41	30, 34, 41	30, 34, 40, 41

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
UPLAND WOODLANDS and FORESTS [c]															
	A. Water Quantity	insufficient data													
	B. Water Quality	insufficient data													
	C. Screening of Human Disturbance / Changes in Land Use [e]	53	47, 50, 53	46, 47, 50, 51	46, 47	46	46, 48, 49, 55	46	46	46	46	44, 46	45, 46	45, 46	40, 43, 45, 46, 52, 53, 54, 56
	D. Hazard Mitigation Zone	should be based on consideration of hazards, but may overlap with buffers													
	E. Core Habitat Protection [f]	58, 59	51, 57, 59	53, 59, 60, 61	53, 60	53, 60	53, 60, 62	53, 60, 62	53, 60, 62	53, 60, 62	53, 60, 62	53, 60, 62	53, 60, 62	53, 60, 62	60, 62
MEADOWS [c]															
	A. Water Quantity	insufficient data													
	B. Water Quality	insufficient data													
	C. Screening of Human Disturbance / Changes in Land Use	insufficient data													
	D. Hazard Mitigation Zone	insufficient data													
	E. Core Habitat Protection [f]		64	64	47, 64, 65	47, 54, 64, 65	47, 54, 65	47, 54, 65	47, 54, 65	47, 54, 65	47, 54, 65	47, 54, 65	47, 54	47, 54	47, 53, 54, 63

IMPORTANT NOTES

[a] This summary table has been provided to illustrate the numbers of papers used to support recommendations related to low, medium and high risk scenarios related the effectiveness of different buffer widths to different feature types. However, this summary does not illustrate that some of the papers were weighted more heavily if they were based on reviews of multiple papers or how some papers or values were discounted as outliers (i.e., not representative of the normal ranges found to be effective). Also, ranges were included wherever provided, but in a number of cases only means or recommended minimums are provided.

[b] Papers cited for watercourses / waterbodies and wetlands are almost all based on empirical studies on buffer functions and, particularly for water quality, include research related to a wide range of inputs (e.g., nitrogen, phosphorus, sediments, pesticides, other contaminants).

[c] Papers cited for woodlands / forests and meadows are entirely based on edge effects research, which cannot be directly extrapolated to appropriate buffer widths. For meadows, data was available for area-sensitive grassland birds only.

[e] Extrapolated from wetland data on this topic.

[f] Some of the research on related to responses to changes in land use and core habitat protection fails to distinguish between provision of core habitat functions and strictly protecting those functions, resulting in buffer recommendations that are inflated. Therefore many of these have been discounted in our analyses.

Key: Risk of Not Achieving the Desired Buffer Function

HIGH
MODERATE
LOW

Literature Cited
(see Section 7 for full citations)

1. Blaha *et al.* 2002
2. Diana *et al.* 2006
3. Fisher and Fischenich 2000*
4. Johnson and Ryba 1992*
5. Environmental Law Institute 2003*
6. Sullivan *et al.* 2007
7. Buffler 2005*
8. Mayer *et al.* 2007*
9. Wenger 1999*
10. Hickey and Doran 2004*
11. Wilson and Imhof 1998*
12. Osborne and Kovacic 1993*
13. Lowrance *et al.* 2002
14. Young *et al.* 1980
15. Castelle and Johnson 2000*
16. Lee *et al.* 2003
17. Gharabaghi *et al.* 2006
18. Peterson *et al.* 1980
19. Wilson 1967
20. Dickey and Vanderholm 1981
21. Schueler 2000
22. Zhang *et al.* 2010*
23. Castelle *et al.* 1994*
24. Crawford and Semlitsch 2007
25. Norman 1998*
26. Pollett *et al.* 2010
27. Semlitsch and Bodie 2003*
28. DeWalle 2010
29. Thompson *et al.* 2004
30. Brown *et al.* 1990*
31. Castelle at al. 1992*
32. Sheldon *et al.* 2005*
33. Skagen *et al.* 2008*
34. Environmental Law Institute 2008*
35. Woodard and Rock 1995
36. Hook 2003
37. Cooke 1992
38. Palik and Kastendick 2010
39. Powell *et al.* 2010
40. Eigenbrod *et al.* 2008
41. Erwin 1989
42. Rodgers and Smith 1997*
43. Deng and Guo 2005
44. Manolis *et al.* 2002
45. Taylor and Knight 2003
46. Richardson and Miller 2007
47. Fernandez-Juricic *et al.* 2004
48. Hamberg *et al.* 2008
49. Malmivaara *et al.* 2008
50. McWilliam *et al.* 2010
51. McWilliam *et al.* 2011
52. Bayne *et al.* 2008
53. Forman and Deblinger 2000
54. Reijnen *et al.* 1997
55. Ortega and Capen 1999
56. Benitez-Opez *et al.* 2010
57. Boutin and Jobin 1998
58. Gover *et al.* 2007
59. de Jong *et al.* 2008
60. Vila and Ibanez 2011*
61. Burke and Nol 1998
62. Ries *et al.* 2004*
63. Zande *et al.* 1980
64. Miller *et al.* 2001
65. Bollinger and Gavin 2004

* review paper or meta-analysis of multiple studies