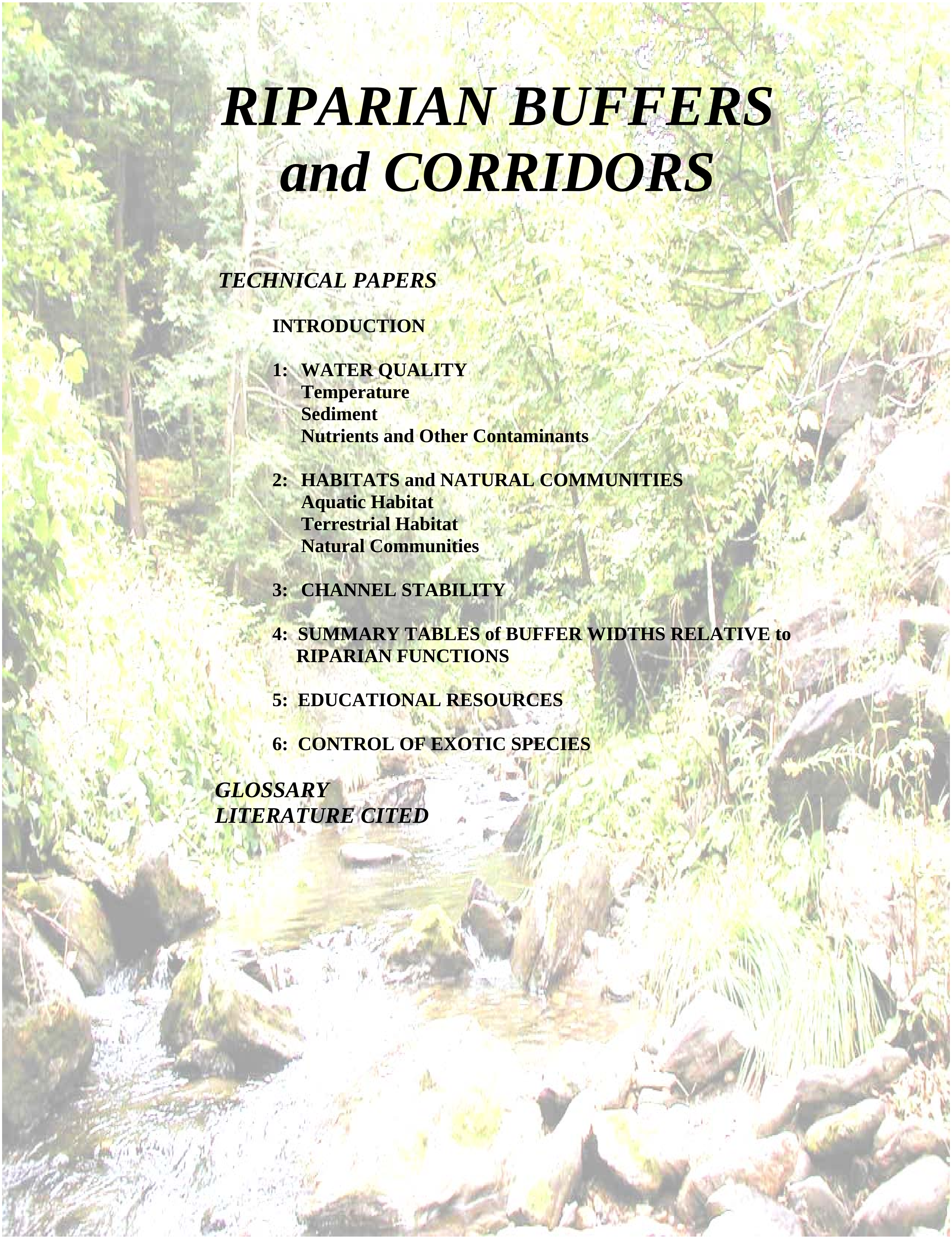

RIPARIAN BUFFERS and CORRIDORS

TECHNICAL PAPERS

Riparian Buffers and Corridors
Technical Papers

Vermont Agency of Natural Resources
Waterbury, Vermont
2005

INTRODUCTION

The word "riparian" means of or pertaining to the bank of a river or lake. Riparian areas are ecosystems comprised of streams, rivers, lakes, wetlands, and floodplains that form a complex and interrelated hydrologic system. They extend up and down streams and along lakeshores from the bottom of the water table to the top of the vegetation canopy, and include all land that is directly affected by surface water (Verry 2000). Riparian areas are unique in their high biological diversity. They are "characterized by frequent disturbances related to inundation, transport of sediments, and the abrasive and erosive forces of water and ice movement that, in turn, create habitat complexity and variability…resulting in ecologically diverse communities" (Verry 2000).

Because of the dynamic nature of riparian areas, they support a wide variety of plant and animal communities. These communities form an interconnected food web that ranges from tiny microorganisms to bears and humans. This web also includes insects, reptiles, amphibians, fish, plants, waterfowl, songbirds, bats, mink, and otter. Healthy riparian areas support species that inhabit them as well as species that use the lakes and streams near them, including those species that use the water only at certain times during their life cycles, such as during breeding or migration.

Riparian areas are not only important plant and animal habitat, but also contribute to the health of the waters near them. The downed wood, leaves, and other organic material that riparian areas contribute to aquatic systems are important components of the food base and habitat structure in Vermont's waterbodies. Mature trees in riparian areas also shade aquatic habitats, reducing water temperatures, and filter overland runoff, protecting water quality. Riparian vegetation also stabilizes lakeshores and streambanks, preventing excessive erosion and sediment buildup in aquatic habitats.

Riparian areas protect water quality for drinking and recreation, protect investments from flood and ice flow damage, and provide for recreation, education, and sense of place.

Conserving riparian ecosystems allows them to carry out their many functions, which include:

- Protecting water quality and aquatic habitats;
- Providing habitats for terrestrial wildlife, including travel and dispersal corridors;
- Supporting significant natural communities and adjacent wetlands; and
- Protecting channel-forming processes and channel stability.

Despite the numerous functions and values of riparian areas, an estimated 70% to 90% of natural riparian vegetation nationwide has already been lost or degraded due to human activities (Doppelt 1993). In Vermont, the riparian areas of many rivers, streams, lakes, and wetlands by 200 years of intensive human use of the land. Therefore, it is imperative to plan for and implement strategies that will conserve or provide long-term stewardship for this vital habitat.

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Riparian areas function as both **buffers** and **corridors**. A riparian area that is unmowed, undisturbed, and naturally vegetated buffers the waterbody and riparian ecosystem from the impacts of adjacent land uses. Buffer functions include protecting water quality and providing for aquatic and terrestrial habitats. As corridors, riparian areas provide travel and dispersal routes for wildlife and plants and sustain long-term river and stream channel functions, such as lateral channel migration and floodwater dissipation. These corridor functions help to maintain habitat connectivity and stream function longitudinally throughout the landscape. When planning for and implementing riparian conservation and restoration strategies, it is important to consider both the buffer and corridor functions of riparian areas.

The benefits forested riparian areas provide for the landscape have been known for well over a hundred years, and yet maintaining forested riparian areas remains one of the most challenging land use issues. The designation of riparian areas involves difficult land use decisions and compromises, as well as sorting through a myriad of information on the subject. These technical papers are summaries of recent scientific literature on effective riparian buffer and corridor widths for maintaining and/or restoring riparian functions. They also explain <u>how</u> riparian areas function. This document does not provide "the answer" to establishing riparian area widths, however, the information provided will help individuals and communities make sound decisions about how to effectively maintain and restore functioning riparian areas within the landscape.

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1: WATER QUALITY

Riparian areas are instrumental in protecting the water quality of surface waters. Forested riparian areas regulate water temperatures through shading of surface waters and infiltration of overland runoff, increasing dissolved oxygen levels in the water. Storing overland runoff also moderates stream flows, reducing peak flows and maintaining base flows during the drier months. Naturally vegetated riparian areas are effective in trapping sediments in overland runoff, reducing inputs of sediment to waterbodies, as well as reducing the load of nutrients and other contaminants bound to those sediments. The deep roots of riparian vegetation also bind together streambank and lakeshore soils, minimizing erosion and again reducing sediment loads to surface waters.

"It is a well known fact that the best fishing is where a forest is near the shore, and best of all where the limbs overhang the water. Not only do the trees afford shelter, furnish food and prevent evaporation, but at the same time they keep the water clear and cool in the summer. In the winter the forests afford protection by lessening the severity of the winter frosts, and in all forest regions the changes of temperature are not so severe as in treeless countries and on the open plain: and the effect upon the water is even greater….But the forests not only regulate the flow of water, as above stated, but they purify the water."
- Frank H. Carleton, from the Fifteenth Biennial Report of the Commissioners of Fish and Game of the State of Vermont, 1899-1900.

Temperature

Forest canopies influence surface water temperatures by decreasing the amount of direct solar radiation on the waterbody and insulating the water from dramatic air temperature changes, which is especially important in abating cold winter winds. Tree canopies, overhanging bank vegetation, and undercut banks shade surface waters, keeping them cool during the summer months. Colder water holds more oxygen than warmer water, and well-oxygenated water is essential for aquatic life.

Additionally lower water temperatures ameliorate adverse effects from organic and industrial pollutants by decreasing biological activity and chemical reactions that demand oxygen, thus diminishing the potential for "deoxygenation" of the waterbody.

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The shading and insulating functions of riparian areas are critically important in smaller streams, which have smaller water volumes (Wenger 1999). Riparian forest canopy is more effective at shading narrower streams than wide rivers because the canopy shades a greater portion of the water surface. Shading smaller streams is important in maintaining cool water temperatures in both the small streams and the larger rivers into which they feed (USACE 1991). In general, maintaining vegetation on small headwater streams achieves the greatest temperature reduction per unit length of riparian shade (Collier 1995)

Forested riparian areas also reduce the temperature of groundwater entering surface waters (Wenger 1999). This may be particularly important in mitigating temperature effects in urban areas, where pavement and similar impervious surfaces can cause air and ground temperatures to be 10^{o} to 12^{o} F warmer than in forested areas (METRO 1997). In areas where the groundwater runs close to the ground surface it is particularly important to maintain vegetative cover to prevent substantial increases in groundwater temperature. Woodall (1985) suggested that in some cases, upland land use needs to be managed to protect groundwater sources close to the surface (< 4 meters deep) by maintaining vegetative cover, even outside of the immediate riparian area, in order to ensure cool water temperatures in the stream channel.

Sediment

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Erosion of the landscape and the resulting addition of sediment to streams, rivers, and lakes is a naturally occurring process. Over time, stream and river channels form to effectively transport the sediment load produced by a watershed through its network of surface waters. However, when sediment loads are substantially increased in volume and/or frequency of loading, degradation of water quality, aquatic habitat, and channel stability are likely to occur. Chronic or excessive sediment loading often occurs as a result of land clearing and direct stream channel alterations associated with development, logging, and agriculture. Excessive sedimentation can reduce aquatic habitat quality and complexity, as well as impact water quality values such as aesthetics and drinking water supplies (Chase 1995). A detailed explanation of the effects of sediment on aquatic organisms and their habitat is provided in Section 2.

Maintaining forested riparian buffers adjacent to surface waters is one of the most effective ways to prevent sediment and associated pollutants from reaching waterbodies. Unmowed, undisturbed, naturally vegetated riparian buffers can effectively trap sediment by slowing overland runoff, allowing for absorption and retention of sediments in the riparian area. The leaf litter, duff layer, and vegetation of riparian buffers obstructs overland runoff, slowing it down and thereby allowing water to infiltrate into the soil, depositing sediment on top of the ground instead of in the waterbody. The amount of sediment and associated pollutants that is filtered out of overland runoff by riparian buffers is dependent on the slope of the land, soil type, type and density of vegetation, upland land uses, and width of the area vegetated.

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Riparian buffers typically need to be wider on steep slope to achieve infiltration and sediment retention in the buffer, as flows typically move faster and are more concentrated on steep slopes. Slopes greater than 10% are considered "steep" and may require additional protective measures (Baltimore County 2004). In Vermont, headwater streams are usually bordered by steep valley side slopes, and thus, are particularly sensitive to sedimentation associated with development and other land clearing activities. This is one reason for the specific regulation of development above 2,500 feet elevation under Vermont's Land Use Law (Act 250), for many of Vermont's steepest landforms occur above 2500 feet.

In addition to trapping sediments from overland runoff, riparian vegetation decreases sedimentation into waterbodies by stabilizing streambanks and lakeshores. Streambank and lakeshore vegetation dissipates stream energy and wave action such that channel and shoreline scour is reduced. Soils bound together by roots have greater tensile strength than unvegetated soils, and thus have greater resistance to the erosional forces of moving water (Fischer and Fischenich 2000). Further discussion of the role of riparian vegetation in maintaining streambank stability is provided in Section 3. Riparian vegetation also traps and stores fine sediments in the floodplain during high flow events, reducing the overall volume of sediments deposited in the channel as floodwaters recede.

Studies on the impacts of logging with and without forested buffer strips on low order streams indicated that aquatic invertebrate community structure was not significantly disturbed when riparian buffers were at least 100 feet wide (Waters 1995). Another logging study suggests buffer widths of 25 to 165 feet (slope dependent) and 50 to 330 feet (slope dependent, for municipal water supplies) are needed to effectively prevent excessive sediment from entering the stream channel (Chase 1995). Similarly, Hartung and Kress (1977) recommended riparian buffer widths ranging from 25 to 450 feet (slope dependent with the widest buffers designed for municipal water supplies) to protect against excessive sediment input to a stream channel. In a watershed dominated by agricultural land use, Peterjohn and Correll (1984) found that 164 feet of riparian buffer trapped 94% of the suspended sediment that entered the riparian area. Numerous other studies on sediment removal indicate that vegetated riparian buffers widths ranging from 30 to 100 feet will prevent 75-92% of sediment in surface runoff from entering a waterbody (Fischer and Fischenich 2000).

Nutrients and Other Contaminants

Excess nutrients, like phosphorous and nitrogen, can cause eutrophication in surface waters (i.e., nutrient enrichment that stimulates aquatic plant growth). Plants need nutrients to survive; phosphorous, nitrogen, potassium, and minerals are essential ingredients to plant health. These elements in excess quantity, however, can cause rapid and excessive algal and plant growth in waterbodies. Algae are short-lived, and when they die they sink to the bottom of the waterbody where their decomposition consumes oxygen. The resulting decrease in dissolved oxygen levels in the water threatens aquatic organisms. Phosphorus is generally the limiting nutrient, meaning it is the one most likely to restrict aquatic plant growth because of its naturally low levels in the environment. Thus, even small increases in phosphorus loads to a waterbody can cause large algal blooms. Although not common, nitrogen loading can also cause algal blooms. Sources of nutrients include lawn and agricultural fertilizers, and human and animal waste.

Nutrients are almost always adsorbed to soil particles and transported by the movement of sediment. Reducing the amount of sediment entering a waterbody will therefore also decrease the amount of nutrients. Riparian buffers retain sediments and allow the terrestrial vegetation to take up nutrients in overland runoff before it reaches surface waters. The effectiveness of this buffer function depends on sedimentation rates, surface and subsurface drainage characteristics, soil and riparian vegetation characteristics, and the quantity of nutrients in relation to the size of the riparian area (USACE 1991).

Buffer widths sufficient to remove sediment from overland runoff should also trap phosphorous, since most phosphorous entering the buffer is attached to sediment (Peterjohn and Correll 1984). Forested riparian buffers 62 feet wide removed as much as 80% of excess phosphorous and 89% of excess nitrogen (Fischer and Fischenich 2000). Mander (1997) found total phosphorous trapping efficiencies of 81% for riparian buffers widths of 92 feet. Woodard and Rock (1991) found a 50-foot buffer of undisturbed hardwood forest reduced phosphorous concentrations in runoff from housing lots. At a minimum, riparian areas wide enough to prevent sediment input into the waterbody should provide short-term control of sediment-bound nutrients and other contaminants (Wenger 1999).

Human and animal waste impairs water quality in ways other than nutrient contamination. The waste includes pathogenic microorganisms as well as organic matter which, when broken down by aerobic bacteria in the water, rapidly consumes oxygen, leaving less for aquatic organisms. Sources of organic matter and biological contaminants include leaking sewer pipes, improperly functioning septic systems, wildlife and pet waste, animal waste sprayed onto fields, and waste lagoons.

Pesticides, which include insecticides, herbicides, and fungicides, can reach surface waters via runoff from roads, agricultural lands, lawns, and golf courses. Riparian areas are very important in keeping pesticide application away from streams, rivers, and lakes, preventing direct contamination or the waterbody and reducing the danger of drift (the movement of the pesticide at time of application away from the application target to the surrounding environment). Many pesticides are broken down within the soils of these vegetated buffers. Greater buffer widths increase the retention time for chemicals, allowing more opportunity for contaminants to decompose before reaching the waterbody. Asmussen (1977) found that a 78-foot grassed buffer reduced pesticide levels in surface runoff by about 70%. Studies by Hatfield (1995) and Lowrance (1997) suggest that significantly wider buffers may be required.

2: HABITATS and NATURAL COMMUNITIES

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Aquatic Habitats

Aquatic habitat includes all physical, chemical, and biological components of the waterbody. In this discussion, the definition of "habitat" is narrowed to describe the instream and riparian areas that influence the structure and function of the aquatic community in a stream. Much of this discussion also applies to the littoral (or shoreline) areas of lakes.

Many of the riparian buffer functions already described in Section 1 (Water Quality) are important to maintaining high quality aquatic habitat. Riparian areas moderate water temperatures and improve water quality by reducing sediment, nutrient and pollutant loads. In addition, riparian areas provide several other functions that are essential in providing for and protecting aquatic habitat. Snags derived from riparian areas provide important habitat for fish, reptiles, amphibians and aquatic invertebrates; and leaves, twigs and similar organic matter provide the energy basis for many aquatic food webs. Deep-rooted bank vegetation strengthens channel boundary conditions, which maintain the width, depth, and slope of the channel, thereby providing for the stream hydraulics important to creating and maintaining aquatic habitats. Riparian areas also play a role in maintaining stream flow during low flow periods and minimizing streambed and bank erosion associated with flood events.

In brief, the riparian buffer functions essential to maintaining high quality aquatic habitat are:

- protecting water quality and quantity
- providing food supply
- providing woody debris
- maintaining lakeshore, stream channel and floodplain stability; and
- maintaining adjacent wetlands.

Water Quality: Temperature

Maintaining water temperature is essential to aquatic biota, especially for species adapted to cold-water environments. As discussed in Section 1, forested riparian areas are important for both summer and winter water temperature regulation. In the summer, maintaining cool water temperatures in Vermont rivers and streams is necessary to maintain high dissolved oxygen levels for aquatic organisms and to minimize thermal stress on these organisms. A difference of even a few degrees in temperature can determine which species are present. Forested riparian areas help reduce daily water temperature fluctuations, minimizing thermal stress on aquatic organisms. Streams and rivers that maintain cool summer water temperatures with minimal daily temperature fluctuations and moderate (40°F plus) winter water temperatures offer more desirable

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habitat for cold-water fish, stream-dwelling salamanders, and other temperature-sensitive aquatic organisms (Chase 1995).

Forested watersheds and riparian areas infiltrate surface runoff moreso than unforested areas, which aids in groundwater recharge. This in turn helps moderate stream temperatures and flow fluctuations. In the Northeast, the discharge of groundwater into stream and river channels is essential to maintain stream flows, especially during the winter and late summer when precipitation is less (or frozen and unavailable to the waterbody) and stream flows naturally decrease. Maintaining groundwater inputs into surface waters helps to ensure that in most years both the volume and temperature of water in a channel will stay within a range to which the species present in that waterbody are adapted. Point sources of groundwater have been identified as refuge areas for trout from winter hazards such as ice buildup (Cunjak 1996). Brook trout are also known to spawn in areas where groundwater discharges into a stream (Webster and Eiriksdottir 1975; Witzel and MacCrimmon 1983; Curry and Noakes 1995; Waters 1995) and have been observed to overwinter in pools in proximity to groundwater discharges (Cunjak and Power 1986). Baird and Kruger (2003) noted that groundwater discharges within pools provided important thermal refuge for brook trout and rainbow trout in an Adirondack stream.

In Vermont, small forested headwater streams naturally have low biological production due to cold water temperatures and low light conditions. These conditions limit algal growth (the food base for many aquatic invertebrates) and often slow down the growth rates of fish, insects, and other aquatic organisms. In these areas, removal of a portion of riparian vegetation will increase light availability and water temperatures which may generate increased aquatic production (Allan 1995); however, excessive removal of riparian vegetation can result in elevated temperature conditions that are lethal to organisms adapted to cold water, like brook trout and slimy sculpin. Thus, any increase in food production resulting from increased light and water temperature may provide little benefit to the stream ecoystem if the organisms higher in the food chain cannot survive the increase in water temperature (Meehan 1991).

Many aquatic organisms can only survive within a relative narrow temperature range (Allan 1995). When temperatures deviate from a species preferred range, production or reproductive success of that species will decline (Verry 2000). In extreme cases, direct mortality may result. For example, adult brook trout typically cannot survive in waters above 24º C and below 0º C; they are most fit in temperatures ranging from 14º to 16º C (Meehan 1991).

Water Quality: Sediment Effects

Sediment can negatively affect aquatic biota primarily in two ways: suspended sediment, comprised of fine silts that float in the water column, making the water turbid (or muddy); and by embedded sediment, comprised of silts, sands, and small gravel that are “packed in” around larger substrates, like cobbles and boulders, in the channel bed. Waters (1995) provides a thorough discussion and review of literature regarding sediment effects on aquatic organisms in Sediment in Streams: Sources, Biological Effects and Control.

Suspended sediment can affect aquatic biota that breathe with gills (such as fish, larval salamanders, and many aquatic insects). Gills can be coated with sediment or physically eroded by sediment, both resulting in a reduction of oxygen uptake from the water. Gill damage can seriously impair an organism’s health, or in severe cases, cause death. Turbidity, caused by sediment suspended in the water, can also decrease detrital decomposition and algal production (Verry 2000), both important processes that provide food for aquatic invertebrates. It can also reduce feeding efficiency in fish species, such as trout, that locate their prey by sight (Berg 1982).

Embedded substrate reduces the available habitat for fish, amphibians, and aquatic invertebrates by filling in interstitial spaces between the gravel and cobble on the channel bed. Interstitial spaces provide winter refuge, summer cover, spawning, and foraging habitat for fish, amphibians, and invertebrates. When interstitial spaces become embedded with sediment, critical refuge and cover habitat for young fish, amphibians, and aquatic insects are lost. Sedimentation can result in the suffocation of eggs and newly hatched fish and amphibians due to lack of water circulation, which carries oxygen through the gravel. Where stream bottoms are severely embedded, spawning fish may be unable to penetrate the stream bed to prepare nests. Moring (1982) found that at least a 100-foot wide riparian buffer was needed to buffer spawning areas from sediment inputs from upland clear-cutting to allow for normal egg development of trout and salmon.

Figure 1. Embedded cobbles and gravels (above) are surrounded by sand and silt, eliminating interstitial spaces which are important habitat for many aquatic organisms. Unembedded substrate shown on left.

Water Quality: Nutrients and Other Contaminants

Excess nutrients in surface waters promote rapid algal and other aquatic plant growth, which reduces the level of dissolved oxygen in the water. The resulting low oxygen can cause fish kills and decreases in aquatic insect populations, as well as disrupt the normal food web and water chemistry balance. Buffer widths sufficient to remove sediment from runoff may also trap phosphorous, since most phosphorous entering the buffer is attached to sediment (Peterjohn and Correll 1984). See Section 1: Water Quality for a complete discussion of buffers and nutrient removal.

Human and animal waste contributes to aquatic habitat degradation in ways other than nutrient contamination. This waste contains organic matter which, when broken down by aerobic bacteria in the water, rapidly consumes oxygen, leaving less for aquatic organisms. Sources of waste-related organic matter include leaking sewer pipes, improperly functioning septic systems, animal waste sprayed onto fields and waste lagoons.

Pesticides can enter rivers via surface runoff from roads, agricultural lands, lawns, and golf courses. Many of these substances can kill aquatic organisms directly as well as enter the food chain. Many toxins accumulate in the food chain, ultimately harming higher predators that feed on aquatic organisms and making fish unsafe for human consumption. Riparian areas are very important in keeping pesticide application away from streams, rivers, and lakes, preventing direct contamination of the waterbody and reducing the danger of drift. See Section 1:Water Quality for a complete discussion of buffers and pesticide removal.

At a minimum, riparian areas wide enough to prevent sediment input into the waterbody should provide short-term control of sediment-bound nutrients and other contaminants (Wenger 1999).

Food Supply

Organic material derived from riparian areas is the ultimate energy source for aquatic food webs in most small to medium-sized streams (USACE 1991). This is also true for many ponds and lakes.

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Riparian vegetation provides leaves and other detritus that feed aquatic invertebrates; including aquatic insects such as stoneflies, mayflies, caddis flies, midges, and beetles, as well as crayfish, worms, clams (mussels) and snails. Aquatic invertebrates are important components of the stream system, and, because they are in the middle of the food chain, are excellent indicators of stream health. In streams, the dominant food for fish and most amphibians is invertebrates. Almost all fish species seek invertebrates from streambed substrates or other surfaces in the stream or actively forage on invertebrates suspended in the water column (Verry 2000). Additionally, most aquatic invertebrates emerge from the stream as adults and use the riparian zone vegetation for reproductive cover (Wenger 1999).

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Small streams in forested regions rely on heavily wooded stream banks for abundant inputs of plant litter and other detritus, while at the same time algal growth is reduced by the shade of the forest canopy. Leaves are of principal importance, but twigs, fruits, terrestrial insects, and wood are also used by stream biota. Even logs meet the nutritional needs of some invertebrates. The breakdown of autumn-shed leaves is an important source of coarse particulate organic matter to small woodland streams. The leaves provide substrate to insects that graze algae and fungi from their surfaces, and are food to insects that eat the leaves themselves. Coarse, fine and dissolved organic matter comprises a diverse array of potential food sources for consumers in water ecosystems. Invertebrates collect, gather and filter fine particulate organic matter as a food source. These organic contributions are of greatest importance where the opportunities for photosynthesis are least, such as small woodland streams and

large turbid rivers. Because most leaves falling into streams may be retained within several hundred meters of their entry point (Cummins 1989), a nearly continuous strip of riparian vegetation along stream channels may be essential to maintain riparian based aquatic food chains (USACE 1991). Few trees further than 50 feet (15 meters) from the stream bank are likely to contribute significant leaf fall to streams (USACE 1991).

Woody Debris

Large woody debris (LWD) is an important component of both lotic (flowing) and lentic (standing) waterbodies. It provides overhead cover for fishes, substrate for aquatic invertebrates, and velocity refuge in lotic waters. Additionally woody debris can be an important source of particulate organic matter adding to primary productivity of a stream. In naturally forested areas, LWD is a critical structural component of stream ecosystems. In headwater streams of forested areas 25-50% of the streambed is wood and wood-created habitat. It is also very important in lowland rivers where 70% or more of the bed is composed of sand, and wood provides the only stable substrate (Allan 1995). LWD captures food items transported in the water column by both accumulating detrital material (leaves, twigs) and providing surfaces for algal growth (Allan 1995). Thus, it is critical in helping to maintain the food supply of a lotic or lentic ecosystem.

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The importance of LWD for fish habitat also has been well documented (Meehan 1991). LWD influences stream flow, often creating pools, backwaters, shallow slack water, and variable flow velocities, adding to the overall complexity of aquatic habitat. LWD also traps sediments and retards scouring of the channel bed and banks during high flows, maintaining channel stability, which is also important for aquatic habitat (USACE 1991). Many of Vermont's headwater streams became wider and shallower when they were cleared of wood during the period of deforestation (1850-1950) and are still undergoing vertical and lateral channel adjustments due to the lack of sediment retention.

Large woody debris, such as snags, logs, and rootwads, are recruited from riparian areas into nearby waterbodies by means of natural aging and falling, wind throw, flood, and landslide. During high flows, forested floodplains next to large rivers are a primary source of woody debris (Hauer 1996), as are trees falling directly from the bank and riparian area into the channel. Studies have demonstrated that 99 percent of woody debris originates within 100 feet (30 meters) of the stream or river channel (USACE 1991). Of all the ecological functions of riparian areas, the process of woody debris loading into channels, lakes and floodplains requires the longest time for recovery after harvest (Wenger 1991).

Channel Stability

A geomorphically stable stream will transport the water and sediment produced in its watershed without aggrading or degrading (see Section 3 for a more detailed explanation). While most streams naturally undergo some rate of lateral bank erosion, the vertical stability of a stream is dependent on the fluvial processes that maintain the overall dimension (width and depth), pattern, and profile (or slope) of the channel. Fluvial processes, including floodplain connectivity, hydrology, and sediment and wood regimes, are critical to the formation of aquatic habitat and are moderated by the extent and vegetative characteristics of riparian buffers.

For low gradient streams in unconfined valleys, the movement of materials (water, sediment, and organic material) between the stream channel and its floodplain is as important for aquatic biota as it is for the channel itself. The floodplain is that area where the stream "spills its banks" and enters a generally flat area adjacent to the stream. Floodwaters that are not allowed to dissipate horizontally over a floodplain build up energy within the channel, often causing excessive scour of the channel bed and banks. During a flood event, the mobilization of large substrates in the channel bed can cause direct mortality of fish, amphibians, and other aquatic biota (USACE 1991). If floodwaters are able to spread out across the floodplain, reducing the energy in the channel, larger substrates that provide refuge for fish and amphibians during flood events will remain in place. Excessive or repeated bed scour can also lead to long-term vertical channel instability, which often results in a loss of habitat complexity through scour and sedimentation of bed forms such as riffles and pools. Riparian buffers provide space for the maintenance or re-establishment of floodplains, and riparian vegetation stabilizes stream banks, reducing sediment inputs to the channel and supporting undercut banks, which provide cover and cool water refuge for fish, reptiles, and amphibians.

Bed forms—whether boulder "steps" and plunge pools in steep mountain streams or pools and riffles in low gradient meandering streams—provide feeding, resting, cover and reproductive habitat for aquatic organisms. Bed form development relies on the magnitude, duration, and frequency of different flows and the size, quantity, and distribution of different sediments. Riparian buffers and their vegetative characteristics have both direct and indirect influence on the hydrologic and sediment regime characteristics of a stream. Riparian areas and vegetation play a direct role in maintaining watershed storage functions, moderating the flow of water, sediment and debris during runoff events. Indirectly, riparian buffers play a role in maintaining habitat by providing the space a stream needs to create and maintain a stable geometry. For instance, an alluvium-based channel denied the space to create meanders or the deep-rooted vegetation to maintain bank stability and channel dimensions will become a wide, shallow, featureless stream with little or no habitat value for species that require depth and large cover substrates to survive. Streams reaches where riparian vegetation has been restored have been found to narrow and deepen, creating more complex stream channels, and to increase in LWD accumulation and shading (Opperman and Merenlender 2004).

Maintenance of Adjacent Wetlands

Wetlands in the riparian corridor play critical roles in flood attenuation and the protection of water quality, both of which are critical for aquatic habitat. Wetlands adjacent to streams and rivers also provide nursery habitats for juveniles of many fish species, as well as spawning habitat for fish such as northern pike, largemouth bass, and brown bullhead.

Terrestrial Habitat

The distinctive terrestrial habitat provided by riparian areas is home to a number of plant and animal species rarely found outside riparian areas (Verry 2000). In Vermont, several species listed as state threatened or endangered are associated with riparian areas. Many species that are dependent on aquatic habitat, such as salamanders, frogs, turtles, mink, beaver, otter, and numerous bird species also use terrestrial riparian habitats. In some instances, continuous stretches of riparian buffer serve as wildlife travel corridors (Chase 1995; DeGraff and Rudis 1986).

Amphibians

Frogs and most salamanders require water for part of their life cycle, and are particularly abundant in riparian areas. Breeding habitats of amphibians are diverse; including intermittent and permanent streams, rivers, ponds, lakes, vernal pools, and wetlands. Once adult amphibians have laid their eggs, most travel

Figure 2. Blue-spotted salamander.

into adjacent upland habitats, such as forests, meadows or wetlands for food and shelter. These animals will move within the terrestrial habitat distances as great as 1000 feet or more from breeding water (Semlitsch 1998; Calhoun and Klemens 2002). Juveniles of these species also move out of the nursery areas and into this terrestrial habitat later in the year. Most amphibians spend the winters in hibernation in places that provide protection from freezing, either underwater or on land under rocks and logs or in rodent burrows. Many amphibians spend the greater part of their life cycle in riparian and upland areas adjacent to water. Forested riparian buffers can also provide habitat connectivity between waterbodies used for egg-laying, allowing for dispersal of juveniles and genetic interchange with other local populations.

Reptiles

Nine out of Vermont's nineteen reptile species are dependent on lakes, streams, and wetlands to fulfill their life requirements. Two snake species rely heavily on waterbodies, mainly for foraging on fish and amphibians. Eastern ribbon snakes occupy shallow water habitats including pools, wetlands and small streams. In winter, they may travel several hundred meters from water to upland hibernation sites in rocky outcrops. Northern water snakes occupy a wide range of habitats from pools and swamps to lakes and spillways. There are also seven turtle species dependent on water for survival. Turtles use streams, wetlands, lakes and surrounding uplands for foraging, breeding, nesting and over-wintering. The wood turtle and spotted turtle use upland habitat of old fields and woodlands for foraging and nesting. Wood turtles, which are considered a rare species in Vermont, are closely associated with riparian areas (Kaufman 1992; Parren 2005). These animals overwinter in rivers and streams and then move into the adjacent riparian areas in the spring and summer to forage, breed, and nest. The other turtle species, snapping turtle, painted turtle, map turtle, stinkpot, and spiny softshell, are aquatic feeders, but move onto the upland to dig nests in well-drained substrates. In Vermont most turtle species are either threatened or are species of special concern due to declining populations. Some turtle species are known to nest up to 1000 feet away from the aquatic habitat. Turtles hibernate primarily on the bottoms of streams, lakes and wetlands. As with amphibians, it is necessary to conserve both the aquatic and upland habitats of reptiles to maintain viable populations of these animals in Vermont.

Figure 3. Wood turtle.

Birds

Riparian areas support a wide variety of bird species from resident songbirds and neotropical migrants to waterfowl and birds of prey. The available food sources and habitats determine which bird species are present in an area. Insects are plentiful in riparian areas, as are berry and seed-producing plants. Nesting habitat may include erosional bluffs (for species such as belted kingfishers and bank swallows), wetlands (for wading ducks), cavity trees (for mergansers and wood ducks), large forested tracts and grassland habitat.

Often the diversity of bird species present in a riparian area is a function of the width of the vegetation. Larger areas will provide a greater variety of habitat types and food sources. In a study of selected third-order streams in Vermont, a vegetated riparian area of 150 to 175 meters (490 to 575 feet) from the high water mark was required to protect 95% of the bird species present (Spackman 1992). Narrow strips of vegetation provide habitat for edge species, like song sparrow, Northern cardinal, and common grackle (Keller 1993). Edge habitat provides an open area for foraging located directly adjacent to forested areas for nesting and cover. While edge habitat may offer benefits to some species it puts birds at greater risk from increased nest predation, nest parasitism from the brown-headed cowbird, and competition with the exotic European starling for nesting cavities. Many neotropical migrants require forest interior habitat for nesting, such as the Acadian flycatcher, wood thrush and certain warblers. In Keller's study (1993) these species were only found in riparian areas 300 to 800 meters (985 to 2625 feet) wide. Waterfowl also need large areas for nesting, since they are vulnerable to human disturbance. A study in Florida determined that areas greater than 100 meters are required to protect waterfowl from human disturbances, including hiking, boating, driving automobiles and ATVs (Rodgers 1997).

Most species of waterfowl in Vermont are dependent on wetlands for both nesting and foraging; though some forage in wetlands and nest on adjacent uplands. Birds of prey most commonly associated with riparian areas are osprey and bald eagle. These birds forage for fish in the water, and nest on adjacent uplands. Areas required to protect birds of prey will depend on the species, its particular habitat requirements, and sensitivity to human activity. Some riparian dependent bird species, such as bald eagle, great blue heron, and wood duck, may require buffers 600 feet or greater in width to meet their nesting and roosting habitat needs (Roderick and Miller 1991).

Mammals

Vermont is home to fifty-eight species of mammals, many of which spend a large portion of their lives on or near surface waters. Many species, including beaver, otter, muskrat, star-nosed moles, and water shrews, spend their entire lives within riparian areas. Some large mammals are not only dependent on these areas, but also play a role in determining the structure of the streams and riparian zones (Naiman and Rogers 1997). For example, beavers create wetlands in areas where they might otherwise not exist, increasing the overall diversity of the aquatic community in those regions (Snodgrass and Meffe 1998).

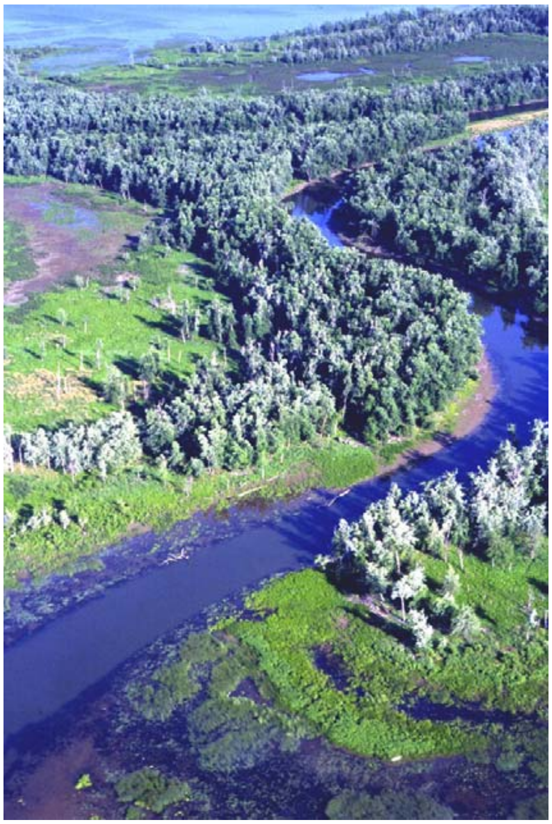
Other large mammals use riparian areas for cooling, foraging, travel corridors, and as connecting habitat through otherwise uninhabitable regions. Few studies have explicitly addressed how wide riparian areas need to be to support these functions. Research on beaver have shown that the forested upland within about 500 feet of their ponds is important as an area for them to forage for food and construction material (Saunders 1988). Moose and bear require extensive woodlands heavily interspersed with aquatic habitat. Each animal will use several different wetlands and waterbodies in the course of their travels. Upland habitats that provide food and cover are important, especially when they serve as travel routes extending to neighboring wetlands and aquatic habitats. A Vermont study shows use of riparian corridors to be important for black bear movement, particularly in providing travel corridors at road crossings (Hammond 2002). Many small mammal species are dependent on riparian areas as well. Mink travel and forage along aquatic habitats and construct their maternal dens up to 600 feet from water. Most other species of furbearers spend most of their lives within 300 feet of streams, rivers, and wetlands (Chase

1995). Smaller mammals generally require smaller riparian buffers. In Oregon, riparian buffers ranging from 9-20 meters (30 to 65 feet) at one site to 67 meters (220 feet) at a second site were required for a variety of small mammal communities (Cross 1985).

Several species of bats commonly hunt over water in Vermont, including the silver-haired bat, eastern pipestrelle, and little brown myotis. They are especially dependent on forested riparian areas that provide foraging and roosting habitat. Older stands of trees, which tend to include more large dead and diseased trees than younger stands, have features such as cavities and loose bark that provide roosting sites for many bats. Large dead and dying trees are very important for many other wildlife species for shelter and as a source of wood boring insects eaten by many birds and mammals (Chase 1995). Timber harvesting within established riparian buffers should be discouraged so as to maximize the number of old and dead trees available to wildlife.

Threatened and Endangered Species

Rare species of plants and animals at risk of becoming extirpated in Vermont are given a state status of threatened or endangered. This status gives species protection under the Vermont Endangered Species Law (10 V.S.A. Chapter 123). The law requires the State of Vermont to provide protection necessary to maintain and recover populations of threatened and endangered species. It also prohibits taking by collection, hunting or harassing of state listed species without an Endangered Species Permit. Species listed as endangered are in immediate danger of becoming extirpated in the state, while threatened species are believed to have a high possibility of becoming endangered in the near future. Many of the Vermont's threatened and endangered species use riparian habitats for some of their life cycle. Aquatic animals listed as threatened or endangered include six species of fish and ten species of mussels. Aquatic species are especially sensitive to water quality problems, particularly sedimentation. Changes in river or lake hydrology and morphology threaten their habitat. There are also two riparian-associated beetle species listed as state threatened. The cobblestone tiger beetle spends its life along the cobble shores of large rivers. The rough-necked tiger beetle is found on lake sand beaches on Lake Champlain.



Current lists of threatened and endangered animals and plants are available from the Vermont Fish and Wildlife Department's Nongame and Natural Heritage Program. Threatened and endangered bird species associated with riparian habitat include common loon, osprey, bald eagle, common tern, and black tern. These species use aquatic habitats for feeding, while nesting in adjacent forests or wetlands. Protection of these bird species requires the conservation of critical nesting and foraging areas, and preventing human disturbance of these areas. State listed reptiles include spotted turtle and spiny softshell turtle. The spotted turtle's habitat is typically swamps adjacent to streams, while the spiny softshell turtle is found in Lake Champlain and its drainage basins. All habitats used by the spotted and spiny softshell turtles during their life cycle need to be protected in order to maintain these species. Two bats, the Indiana bat (myotis) and eastern small-footed myotis, which are endangered and threatened, respectively, in Vermont, use riparian areas for foraging because of the large quantities of insects present in riparian areas.

There are also several state-threatened and endangered plant species associated with riparian areas, such as great St. John's-wort and Garber's sedge. A number of these species are found at the aquatic terrestrial interface and the riparian area acts as a buffer to protect their habitat. Plant species are at risk from loss of habitat by human alteration or changes in riparian functions, as some plant species are dependent upon riparian functions such as scouring, flooding, and deposition of materials. For example, Jesup's mild-vetch is found on ice scoured rocks along the Connecticut River.

Natural Communities

There are a wide variety of natural community types that occur along the shores of Vermont streams, rivers and lakes, including sparsely vegetated open shores, marshes, shrub swamps, and floodplain forests. The diversity of shoreline community types reflects the dynamic and stressful nature of this environment – floods, ice scour, wave action, and deposition and erosion of sediments by flowing water are all natural processes that affect shoreline communities. Shorelines are hot spots for rare natural communities and associated rare plants. These communities also provide a diversity of specific habitats for wildlife species as well as wildlife movement corridors. Shoreline natural communities provide buffers to streams, rivers, and lakes, but in some cases the shoreline communities themselves need upland buffers in order to ensure their protection.

A natural community is an interacting assemblage of plants and animals, their physical environment, and the natural processes that affect them. The same natural community can be found repeating across the landscape wherever similar environmental conditions occur. These environmental conditions include climate, soil type, nutrient availability, the amount of water or lack thereof, and the type of natural disturbance (such as wind, fire, and flooding). It is possible to describe and classify natural community types since they do repeat in similar environmental settings. This natural community concept helps explain some of the complexity in nature, including how plants and animals are distributed across the land. It also provides a strong tool for planning land management and conservation.

Natural community types may be considered rare because of the unique combination of environmental conditions that form them, or because there are few remaining examples of a particular type. For example, Calcareous Riverside Seeps are only found where calcareous groundwater surfaces over bedrock in rivershore areas scoured by flooding and ice. This combination of environmental conditions is rare and consequently the community type is also rare. Floodplain forests, however, are uncommon because of extensive land-use within the floodplains of Vermont's major rivers and lakes – floodplain soils are highly productive and most have been converted to agricultural land. To illustrate the small percentage of remaining riverine floodplain forests, a comparison was made between floodplain soils and existing floodplain forests in Franklin County. Of the 14,653 acres of floodplain soils present, only 1,652 acres were forested (Sorenson 1998).

Groups of natural communities commonly associated with riparian ecosystems include open upland shores, open wet shores, marshes and sedge meadows, shrub swamps and floodplain forests and swamps (Table 1).

Open upland shores and open wet shores differ in the duration and frequency of flooding or soil saturation. The plant species present reflect these differences. Open upland shore communities are influenced by flooding, ice scour, and water movement, but do not remain wet, and are therefore colonized by many upland plant species. For example, Riverside Outcrops are maintained by regular flooding events and ice scour, which keep the rocky outcrop open and allow for specialized upland herbs to colonize it. Open wet shores, such as Lakeshore Grassland, are dominated by wetland plant species since these natural communities are closer to the water and are inundated more often. Most woody plants are also excluded from this community by frequent flooding and ice scouring.

Marshes and sedge meadows are flooded for extended periods of time or may remain permanently saturated, and are found on shallow organic or mineral soils. For example, Deep Bulrush Marshes occur in permanent standing water along the shores of lakes that are exposed to larger waves, while Shallow Emergent Marshes are only flooded or saturated at some time during the growing season and occur in a variety of sheltered shoreline and basin settings. Shrub swamps are flooded less frequently than marshes and sedge meadows, allowing shrubs to dominate; but they are flooded frequently enough to exclude large trees.

Floodplain forests and swamps vary depending on the flooding regime and the texture of the sediments carried by the floodwaters. Floodplain Forests are divided into four types, which are distinguished by the different plant species that occupy them. The soil texture in floodplain forests is directly related to the gradient and energy of the adjacent river or stream, with high gradient streams carrying coarser-textured sediments. The soil type and the duration and frequency of flooding in turn, determine which plants will be present and which type of natural community will form. There is little sediment carried and deposited in floodplain swamps and these swamps typically develop deep organic soil layers due to more permanent saturation of the soils. Although natural communities can be classified into specific groups or types, they often form community mosaics where various types are present and grade into one another.

Table 1: Natural community types associated with rivers and lakes.

Open Upland Shores	**Open Wet Shores**	**Marshes and Sedge Meadows**	**Shrub Swamps**	**Floodplain Forests and Swamps**
Riverside Outcrop	Outwash Plain Pondshore	Shallow Emergent Marsh	Alluvial Shrub Swamp	Lakeside Floodplain Forest
Erosional River Bluff	River Mud Shore	Sedge Meadow	Sweet Gale Shoreline Swamp	Red or Silver Maple-Green Ash Swamp
Lake Shale or Cobble Beach	River Sand or Gravel Shore	Cattail Marsh		Red Maple-Northern White Cedar Swamp
Lake Sand Beach	River Cobble Shore	Deep Broadleaf Marsh		Silver Maple-Ostrich Fern Riverine Floodplain Forest
Sand Dune	Calcareous Riverside Seep	Wild Rice Marsh		Silver Maple-Sensitive Fern Riverine Floodplain Forest
	Rivershore Grassland	Deep Bulrush Marsh		Sugar Maple-Ostrich Fern Riverine Floodplain Forest
	Lakeshore Grassland			

More information on Vermont's natural communities can be found in *Wetland, Woodland, Wildland: A Guide to the Natural Communities of Vermont* (Thompson and Sorenson 2000).

3: CHANNEL STABILITY

Naturally vegetated riparian corridors are critical to maintaining functioning stream channels. Riparian areas disperse and reduce floodwaters and the effects of storm events on stream channels, stabilize streambanks, reduce ice damage, and maintain sediment transport and channel morphology. To fully understand these riparian functions it is important to also understand how streams naturally evolve in their landscapes over time, and how this determines effective riparian corridor widths for maintaining stream stability. Stream stability may be defined as: the ability of a stream channel, over time and in the present climate, to transport the flow, sediment, and debris of its watershed in such a manner that it maintains its dimension, pattern, and profile without aggrading or degrading its bed.

Riparian areas provide for channel stability in the following ways:

- flood attenuation
- reduced effects of storm events
- bank and shoreline stabilization
- ice damage control; and
- maintenance of sediment transport and channel morphology.

Channel Evolution Process

Streams are dynamic systems that change constantly over time. Streams may change slowly over decades or suddenly in one flood event. Recent advances in the study of channel fluvial geomorphology have shown that stream channels undergo physical changes in a systematic process, usually triggered by a change in the channel's sediment load or hydrology. This series of channel adjustments is referred to as the channel evolution process (Schumm 1984).

Streambank erosion is one obvious sign of channel change that can be seen throughout Vermont's watersheds. Streambank erosion is a natural process and plays an important role in contributing rock and woody material to a stream system; however, many streams in Vermont have lateral instability, where they are moving back and forth across their valleys at rates more rapid than that of a stable stream. This lateral instability is primarily due to lack of deep-rooted and dense vegetation on streambanks. These streams have access to their floodplains, so they typically do not experience bed erosion during floods, but they would exhibit considerably less streambank erosion if they had vegetation holding their banks together. See discussion below under Streambank Stabilization.

Other streams have eroded their channel beds and have become incised. These streams have lost access to their floodplains during the annual flood and their streambanks bear considerable stress during high water. Due to this increased stress on the streambanks the channel begins to erode outward, or laterally, and to widen. As the channel over-widens, it fills with sediment. Over time a new narrow channel forms again and new floodplains develop to either side of the new channel at a lower elevation in the landscape. The cumulative effects of streambank and bed erosion and the resulting channel adjustments cause loss of

Figure 4. Incised stream channel creating a new floodplain at a lower elevation. Recently abandoned floodplain visible on right at top of slope.

property, loss of aquatic and wildlife habitat, decreased water quality, and greater risk of flood-related damage.

The stability of a stream channel is based on maintaining a certain flow of water, shape and slope of the channel, and sediment load. When any of these change significantly, the river channel must change, typically resulting in erosion of the stream bed or banks. Between the 1700's and the 1800's, the building of roads and railroads within the floodplains, deforestation, and moving streams to accommodate agricultural fields and villages resulted in unstable river channels. Even in recent decades, large-scale channelization practices have been employed to reclaim damaged lands after large flood events. The 1970's and 1980's were also a period of extensive gravel mining in many Vermont streams. Post-flood channel straightening and gravel mining of point bars have the effect of steepening stream channels. A steep channel in a relatively flat valley may initiate a bed degradation, or downcutting, process referred to as "headcutting." Once a stream begins to headcut, it will typically erode its way through the five-stage channel evolution process depicted in Figure 1 until it has created a new floodplain at a lower elevation in the landscape.

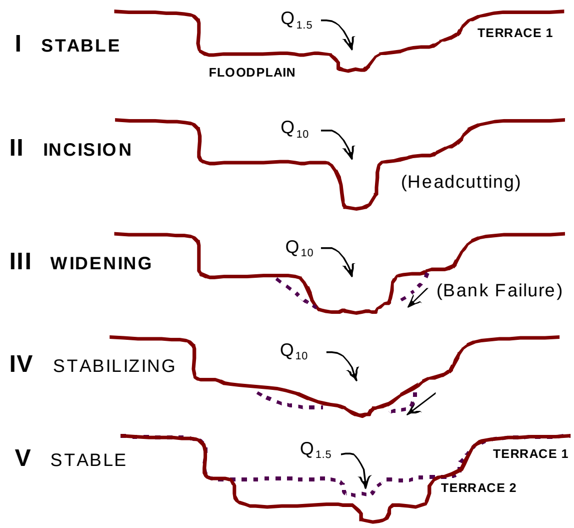


Figure 5. Five stages of channel evolution showing head cutting that leads to bed lowering (incision) and floodplain redevelopment.

The bed erosion that occurs when a meandering river is straightened in its valley is a problem that translates to other sections of the stream. Headcuts will travel upstream and into tributaries eroding sediments from otherwise stable streambeds. These bed sediments will move into and clog reaches downstream leading to lateral scour and erosion of the streambanks. Channel evolution processes may take decades to play out. Even landowners that have maintained wooded areas along their stream and riverbanks may have experienced eroding banks as stream channel slopes adjust to match the valley slopes.

Figure 6. A head cut is a steep drop in the channel bed that migrates upstream.

It is difficult for streams to attain a new equilibrium where the placement of roads and other infrastructure has resulted in little or no valley space for the stream to access or to create a floodplain. Landowners and government agencies have repeatedly armored and bermed reaches of Vermont's rivers to contain floodwaters in channels. These efforts have proven to be temporary fixes at best, and in some cases have lead to disastrous property losses and natural resource degradation. A more effective solution is to limit encroachments within the riparian corridor and maintain a buffer of woody vegetation between the stream and adjacent land uses. Maintaining vegetated riparian corridors and offsetting development limits the conflict between property investments and the natural processes of flooding and channel migration that occurs gradually over time. Given room, a channel can adjust its shape and slope to changes in flow and sediment load. In general, the space provided by an established riparian corridor allows the river or stream system to be more resilient to watershed changes, thereby protecting the fish, wildlife, and humans that depend on Vermont's rivers and streams.

Channel Evolution and Riparian Buffer and Corridor Widths

When establishing riparian buffers and corridors it is important to consider the point from which buffers should be measured - from the **top of bank** or **top of slope,** depending on the physical channel characteristics.

Measuring from top of bank: Figure 7 represents a stream channel with a relatively flat and wide floodplain, which the stream accesses during flows at or exceeding the average annual high water stage. When these channel characteristics are present riparian buffers and corridors can be measured from the top of bank, perpendicular to the channel. When contiguous wetlands are present in the floodplain, buffer measurement should begin at the upland edge of the wetland.

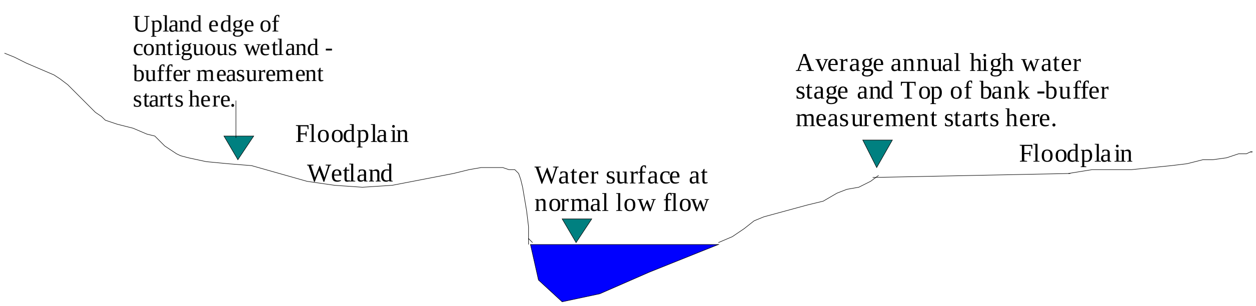


Figure 7. Top of bank typical of streams with flat, wide floodplains that the stream accesses during flows exceeding average annual high water. Upland edge of wetland typical of continguous wetlands sometimes present in the floodplain.

<u>Measuring from top of slope</u> There are at least three scenarios when riparian buffers should be measured from the top of slope.

Scenario 1: When a channel is contained in a narrow V-shaped valley that has steep side slopes riparian buffer zone measurement should begin at the top of slope (Figure 8). There is often little or no floodplain in this scenario, which increases the threat of slope toe erosion and slope failure, especially during storm and flood events.

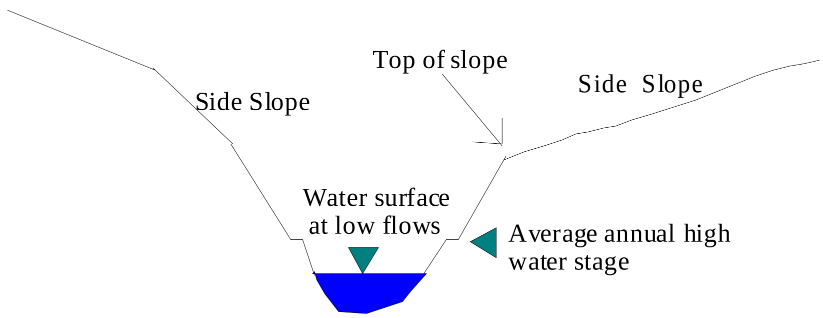


Figure 8. Top of slope typical of steep streams in narrow V-shaped valleys with little or no floodplain.

Scenario 2: When a channel has adequate floodplain on one side but borders a steep valley side slope or high terrace on the other, riparian buffer zone measurement should begin at the top of slope on the valley wall or terrace side and the top of bank on the floodplain side (Figure 9). The absence of a floodplain in areas where the channel runs adjacent to the steep valley side slope or high terrace increases the threat of slope toe erosion and slope failure.

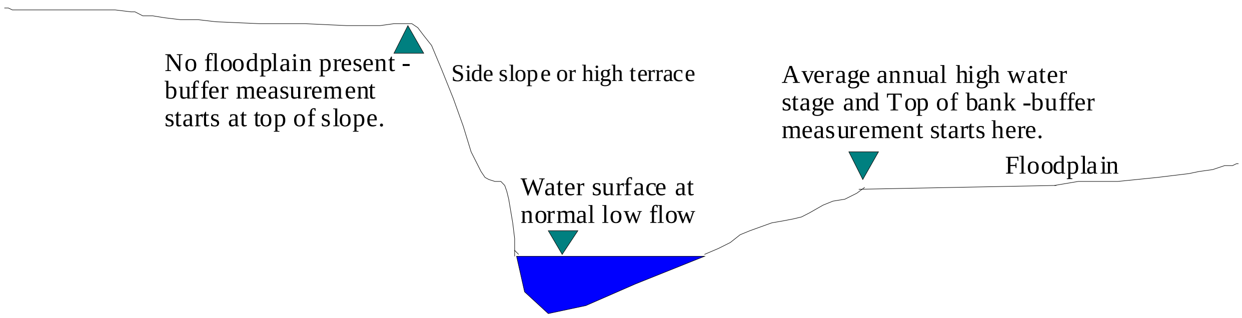


Figure 9. Top of slope typical of streams that run adjacent to steep slopes or high terraces on one side of the valley but have adequate floodplain on the opposite side of the valley.

Scenario 3: Where streams that once had access to floodplains have since steepened and incised, the top of slope is found at the edge of the floodplain undergoing abandonment (Figure 10). These streams are undergoing a channel evolution process, often taking decades to erode their banks and reestablish meanders, creating new floodplains at lower elevations. This often involves the cutting away of the toe of the steep slope, leading to slope failure. To ensure that streamside slopes are not compromised during this channel evolution process, riparian buffers should be established from the top of slope.

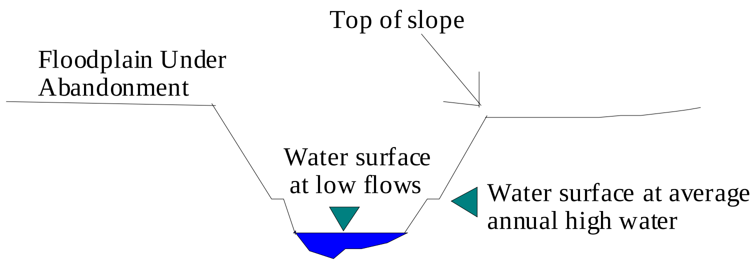
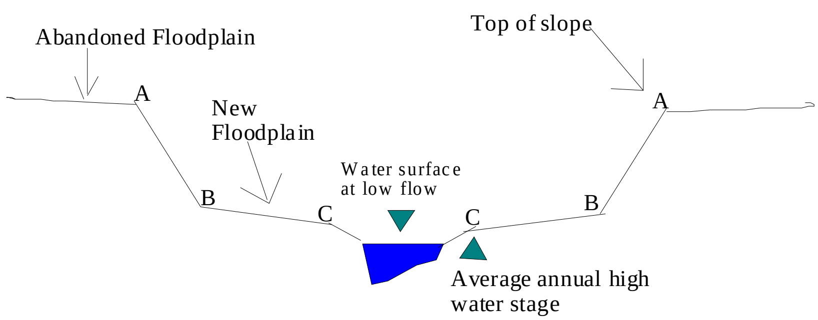


Figure 10. Top of slope typical of incised streams that have little or no access to their floodplains and have yet to establish a new floodplain.

After a stream has incised and widened, it develops a new floodplain at a lower elevation. Often these floodplains are contained in narrow valleys and are flanked by steep slopes. In the case of narrow floodplains, where the slope and depth of the stream is maintained by the stream's ability to meander across the full width of the floodplain, riparian buffer zones should be established from top of slope to protect the stability of the stream as well as the stability of the adjacent slopes (Figures 11 and 12).



Fi gure 11. Top of slope typical of streams that were once incised and have since reestablished a new floodplain at a lower elevation.

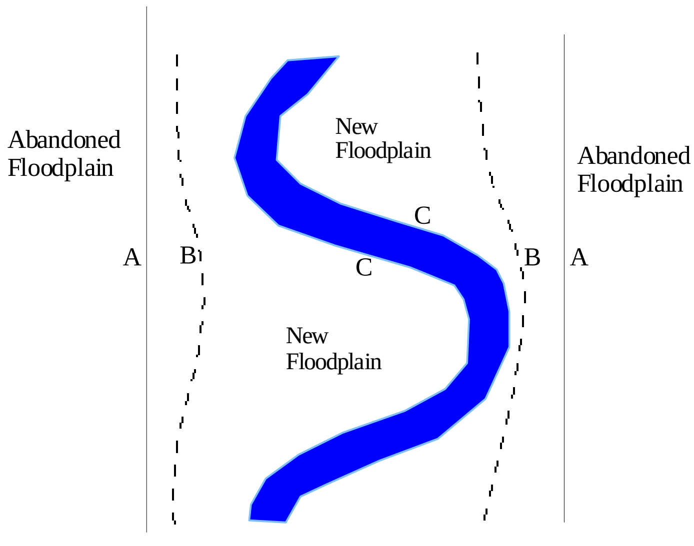


Figure 12. Bird's eye view of stream in Figure 11.
A=top of slope, B=outer edge of floodplain, C=top of bank.

Flood Attenuation

Flooding is a natural process essential to the ecological health of riparian and river systems. Human encroachment into the floodplain in many areas has drastically increased the potential economic impacts of flood events. Maintaining vegetated riparian buffers and corridors can help restore natural channel processes while simultaneously protecting human investments within and adjacent to the floodplain. During flood events, riparian areas allow floodwaters to spread out horizontally over the land, thereby reducing the force with which the floodwaters move downstream. This reduction in stream power is important not only for the protection of the human investments in and around the floodplain, but also for the protection of the channel itself. Soils and vegetation in the riparian zone obstruct and slow down floodwaters, and reduce floodwater volume through absorption. In addition, wetlands within the riparian zone can store floodwaters, thereby reducing the amount of water entering the channel over time, and thus reducing flood peaks.

Reduced Effects of Storm Events

Riparian vegetation and soil obstruct surface runoff, slowing it down and allowing it to infiltrate into the ground. This reduces the volume and rate at which surface runoff enters stream channels. In turn, this reduces the energy applied to the stream bed and banks, reducing the scouring ability of the high flow event. During a high flow event in a stable system, stream channels scour and subsequently fill with sediments; however, excessive stream power (caused by a change in the hydrology or sediment load of the stream system) can result in long-term channel instability. Over time the channel will re-stabilize, but this process may take decades or even centuries. Meanwhile, as the system recovers, aquatic life, human investments, water quality, recreation, and other functions and values of the riparian area will be at risk. Consideration of riparian corridors throughout a watershed is important in managing effects of storm events. A well-buffered low valley river is likely to still be heavily impacted by storm events if the tributaries that feed that river are not buffered with riparian vegetation.

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"Before the country was cleared, the whole surface of the ground was deeply covered with leaves, limbs, and logs, and the channels of all the smaller streams were much obstructed by the same. The consequence was that, when the snows dissolved in the spring, or the rains fell in the summer, the waters were retained among the leaves, or retarded by the other obstructions, so as to pass off slowly, and the streams were kept up, nearly uniform as to the size during the whole year. But since the country has become settled, and the obstructions, which retarded the water, removed by freshets, when the snow melts or the rains fall, the waters run off from the surface of the ground quickly, the streams are raised suddenly, run rapidly, and soon subside. In consequence of the water being thus carried off more rapidly, the streams would be smaller than formerly during a considerable part of the year, even though the quantity of water be the same. It is a well known fact that the freshets in Vermont are more sudden and violent than when the country was new."

Zadock Thompson, Natural History of Vermont, 1853

Streambank and Shoreline Stabilization

Streambank and lakeshore stability is important in preventing excessive sediment from entering a waterbody, maintaining channel form, conserving soils, and protecting property values. Vegetation in riparian areas stabilizes streambanks and lakeshores, reducing erosion caused by downstream flow of water and wave action. Though some erosion is natural and the gradual migration of stream channels within the riparian corridor and floodplain is to be expected, root mass from riparian vegetation helps to moderate erosion processes. Stream channels lacking natural riparian vegetation are generally wider and shallower than channels that have naturally vegetated riparian areas (Gunderson 1968; Platts 1981). The change in channel dimensions may become significant as to alter the fluvial processes (see discussion below). Soils bound together by roots have greater tensile strength than unvegetated soils, and thus have greater resistance to erosional forces (Fischer and Fischenich 2000).

Unvegetated banks have been found to be 30 times more likely to erode than vegetated banks during high flows (Wenger 1999). Whipple (1981) observed that substantial bank erosion almost always occurred in riparian areas less than 50 feet wide, while riparian areas 50 feet wide or greater rarely experienced such erosion. In low order northern California streams 100-foot wide (30 meter) buffers were adequate to maintain streambank stability (USACE 1991). A relatively narrow buffer may maintain short-term streambank stability; however, maintaining a wider vegetated riparian corridor will be more effective in the long-term due to the possibility that a channel will naturally migrate out of a narrower buffer area (Wenger 1999).

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Ice Damage Control

During spring ice-breakup, forested riparian corridors trap ice slabs and other floating debris, reducing the potential for ice jamming at downstream constrictions. Jamming can result in backwater and flooding upstream, which can lead to channel instability, as well as property damage. Riparian vegetation also reduces the potential of ice slabs damaging infrastructure by obstructing the flow of ice into the outer floodplain during high spring flows and by absorbing the pressures of mid-winter ice push on lakeshores. Riparian vegetation serves a similar role during flood events, trapping floating debris and thereby reducing the potential of log and debris jams in the channel and reducing the potential of debris reaching the outer floodplain. Streambank erosion due to ice scour is reduced by streambank vegetation, which is often more resistant to ice scour than the soils in the streambank. Indeed, some plant species are specifically adapted to the scour and depositional forces that occur in riparian areas during flooding and snow melt events.

Maintaining Sediment Transport and Channel Morphology

Two basic functions of stream systems are the movement of water and sediment through the landscape. Stream systems receive water and sediment from their watersheds that determine the size and shape of the channel. If there are no substantial changes in the watershed that alter the amount of water and sediment a given channel regularly moves, that channel will maintain its ability to move its water and sediment load. Studies in fluvial geomorphology have shown that across the landscape stream channels in similar geographical locations with similar drainage areas have similar channel characteristics, such as the ratio of channel width to channel depth and meander belt width (Williams 1986). Maintaining these physical characteristics of the channel (or channel morphology) is essential for the channel to be able to transport its water and sediment load. Vegetated riparian corridors play a critical role in maintaining channel morphology through bank stabilization, flood attenuation, and providing the space necessary for the expression of meander geometry and the maintenance of channel slope. As discussed above, riparian vegetation increases streambank stability, which in turn influences channel width. The width of the channel determines how deep and at what velocity water flows through the channel, and together, depth and velocity, determine the channel's stream power. Stream power is the ultimate channel characteristic that determines sediment transport. Thus, a stream that loses its riparian vegetation is likely to widen due to bank instability and ultimately transport less sediment. (See discussion under Channel Evolution Process)

The natural extent of river meanders, referred to as the meander belt width, is governed by valley landforms, surficial geology, and the length and slope requirements of the river channel. Encroachments within a river corridor and riparian area, and subsequent channelization practices made to protect investments, often result in a shorter, steeper channel that no longer serves to attenuate the sediment storage requirements of the watershed. River corridors, defined through ANR Stream Geomorphic Assessments (2004), provide landowners, land use planners, and river managers with meander belt width determinations that accommodate the meanders and slope of a balanced channel. When conserved, the river corridor serves to maximize channel stability and minimize fluvial erosion hazards.

More information about the ANR Stream Geomorphic Assessment Program and fact sheets pertaining to channel stability and river corridor function are available through the DEC River Management Program web page: http://www.anr.state.vt.us/dec/waterq/rivers.htm.

4: SUMMARY of LITERATURE on BUFFER WIDTHS RELATIVE to RIPARIAN FUNCTIONS

The following tables provide reference to studies detailing specific riparian area functions and the observed buffer widths needed to achieve those functions.

Table 2. Recommended Buffer Widths for Riparian Functions. From Chase 1995, p. 67.

Author	Functions Protected	Range of Buffer Widths Recommended	Average of Range
Rogers, Golden & Halpbern, 1988	Water Quality - Nontidal Wetlands - Intermediate	25'-50'	37'
Budd et al., 1987	Water quality, temperature control, wildlife habitat, stream corridors	25'-50'	37'
Swift, 1986	Water quality (sediment) Filter strips for logging, with brush barrier	32'-64'	48'
Palmstrom, 1991	Water quality (subsurface)	50'	50'
Brown & Brazier, 1972 (in Palfrey & Bradley, 1981b)	Stream temperature	55'-80'	67'
Castelle et al., 1994	Water Quality, Temperature control Review of other literature	49'-98'	74'
Trimble, 1957	Water Quality (Sediment) Filter strip for logging, general situation, slope dependent	25'-165'	95'
Swift, 1986	Water quality (sediment) Filter strips for logging, without brush barrier	43'-154'	99'
Pinay	Water quality (nitrate removal) Winter Conditions	100'	100'
Stauffer & Best, 1980	Wildlife (breeding birds)	11'-200'	106'
Rogers, Golden & Halpbern, 1988	Water quality	75'-150'	113'
Welch, 1992	Water quality Riparian Forest Buffer	95'-150'	123'
Erman et al. 1977 (in Palfrey & Bradley, 1981b)	Water quality (sediment)	150'	150'
Wong and McCuen, 1981	Water quality (sediment)	150'	150'
Phillips 1989 (Nonpoint source....)	Water quality control along a coastal plain river, uses model	49'-260'	155'
Palmstrom, 1991	Water quality (sediment)	25'-300'	163'
Roman & Good, 1985	General	50'-300'	175'
Nieswand et al., 1990	Water quality	45'-300'	183'
Trimble, 1957	Water Quality (sediment) Filter strip for logging, municipal watershed, slope dependent	50'-330'	190'
Brady and Buchsbaum, 1989	Scenic value of resource Harvard School of Design	200'	200'
Brown et al., 1990	Water quality (sediment)	75'-375'	225'
Clark, 1977 (in Palfrey & Bradley, 1981b)	Nutrient removal	150'-300'	225'

Table 3. Recommended minimum riparian buffer widths for wildlife. From Chase 1995, p. 28.

Buffer Width	Wildlife Species	Reference
10-330 ft	amphibians, forest interior wetland birds, upland dependent reptiles and birds	Eddleman and Husban, unpublished manuscript
20 ft	small mammal habitat (riparian woods)	Cross 1985
30-70 ft	control temperature in small streams (important for wildlife)	Burton and Likens 1973
100-330 ft	amphibians and reptiles	Rudolph and Dickson 1990
100 ft	stream macroinvertebrates	Newbold et al. 1980
100-200 ft	belted kingfisher roosting sites	White 1953
100 ft	to protect invertebrates in steep mountain streams from siltation	Erman et al. 1977
100 ft	salmon breeding habitat (gravel streambeds)	Moring 1982
150 ft	endangered or threatened spp., or trout production areas	Golet et al. 1993
165 ft	pileated woodpecker nest sites; will nest up to 500 ft away from water	Schroeder 1983
180 ft	squirrel habitat	Dickson and Huntley1987
200 ft	forest interior birds nesting habitat	Tassone 1981
200 ft	boreal forest birds	Darveau et al. 1995
200 ft	interior forest birds	Tassone 1981
200 ft	marten (riparian habitat)	Spencer 1981
200-300 ft	retain plant structure within this distance for wetland dependent wildlife	Castelle et al. 1992
250 ft	forest birds	Small and Johnson 1985; Johnson 1986
300 ft	waterfowl nesting	Foster et al. 1984
300-330 ft	beaver, mink, dabbling ducks	Roderick and Miller 1991
330 ft	furbearers: coyote, bobcat, red fox, fisher, marten, beaver, otter, mink, muskrat	Dibello 1984
330 ft	beaver feeding habitat	Hall 1970
330 ft	mink den sites and habitat for most activity; use habitat up to 600 ft from water	Mequist 1981, Linn and Birks 1981
330 ft	area-sensitive forest birds	Keller et al. 1993
330 ft	forest interior birds, small mammals, reptiles, amphibians	Golet et a. 1993
450 ft	common loon (nesting), pileated woodpecker	Roderick and Miller 1991
575 ft	breeding bird communities in uplands adjacent to streams	Hooper (unpubl. manuscr.)
660 ft	songbird community	Scheuler 1987
660 ft	breeding bird communities	Stauffer and Best 1980
660 ft	travel corridors for all wildlife but black bears	Forman 1983
600 ft	bald eagle (nesting, roosting, perching); cavity nesting ducks (wood duck, bufflehead, goldeneye, hooded merganser), heron rookery	Roderick and Miller 1991
600 ft	wood duck - most nests within this distance from water	Grice and Rogers 1965
840 ft	average distance of blue-winged teal nests from water	Duebbert and Lokemoen 1976

Table 4. Wildlife habitat provided by a 100-foot riparian buffer. From Chase 1995, p. 26-27.

Wildlife Species	What 100 feet provides	What 100 feet does not provide
Stream Invertebrates and fish	shading, bank stability, organic debris, prevention of siltation and nutrient input	adequate floodwater abatement
Eastern newt	maintain water quality of wetlands and surface waters	habitat for terrestrial juveniles (efts)-travel for 2-7 year olds
Four-toed salamander	habitat for breeding (lay eggs within 4.3 in of water) and most activity	dispersal routes to neighboring wetlands beyond 100 ft
Northern dusky salamander	habitat for breeding (lay eggs within 19.5 in of stream edge) and most activity	dispersal habitat
Northern two-lined salamander	habitat for breeding and most activity	foraging area - adults may wander 330 ft on rainy nights; dispersal of juveniles (only 25% return to natal streams)
Green frog	usually stay within 65 ft of water	dispersal habitat
Wood frog	breeding habitat, if buffer area protects ephemeral woodland pools	habitat for most of terrestrial lifestyle, often well away from water
Spotted turtle	shading, large organic debris, streambank stability, protective cover, invertebrate and small vertebrate prey, winter hibernating habitat	habitat for most terrestrial activity - will travel up to ½ mile (2640 ft) from water to find temporary food sources.
Wood turtle	see above for spotted turtle; basking habitat in early spring (within 65 ft of water)	habitat for most activities; spend most of their time within 1000 ft of water, but will travel up to 1 mile away to search for food; nest up to 330 ft away; hatchlings stay within 130 ft of water
Northern water snake	habitat for most aquatic activities	habitat for dispersal and hibernation
Eastern ribbon snake	foraging habitat	may travel several hundred meters from water to mate; hibernate in upland sites
Bats	foraging habitat - commonly hunt over open water	roosting sites - prefer to roost within 1300 ft of water
Beaver	habitat for aquatic activity, lodge site, some foraging habitat	enough foraging habitat - most foraging is within 330 ft, dispersal routes
Mink	most foraging habitat and den sites	mink hunt up to 600 ft from water, den sites may be up to 330 ft from water
Black bear	foraging habitat, cover, travel corridors	den sites; enough area for travel - adult male black bears require up to 19 sq. miles depending on habitat and food sources
Bald eagle	foraging, perching, and roosting sites	nest sites - most eagle needs are within 1300 ft of shorelines; protection from human disturbance
Red-shouldered hawk	foraging habitat	nesting sites - this species is found only where buffers are 330 ft or more
Area-sensitive forest birds	some foraging and nesting habitat; problems characteristic of edge habitat (increased predation and nest parasitism)	sufficient breeding habitat for species that need riparian zones wider than 330 ft.

5: EDUCATION

The Agency of Natural Resources is an informational and educational resource for Vermonters on a wide variety of natural resource issues, including the functions and values of riparian buffers and corridors. Information on the protection and enhancement of naturally vegetated riparian areas along rivers, streams, lakes and ponds is provided through the following means:

1. Education for school children.
The Department of Environmental Conservation is the Vermont sponsor of Project WET, a national teacher-training program on water resource issues. Contact: Amy Picotte, 802-241-3789

Water Quality Division Educational Tools Listing. 2000. A compilation of the division's audio-visual and educational materials. 6 pages. Contact: 802-241-3770 or 3777.

2. Review of town and regional plans and town zoning regulations
The Water Quality Division of the Department of Environmental Conservation and the Fish and Wildlife Department review draft town and regional plans and town zoning to provide input on river, stream, lake, pond and wetland protection strategies. Providing for the conservation of naturally vegetated riparian buffers and corridors is a primary recommendation.

3. Information for municipalities and local groups.
The Agency of Natural Resources provides educational materials to municipal planning commissions, conservation commissions, and select boards, and to watershed, lake, and river associations on how to conserve natural resources through town planning, zoning, and other locally-initiated mechanisms. The following publications provide information for communities on protecting riparian areas as well as other natural resource conservation strategies:

Agency of Natural Resources Publications - Many of these publications are available on-line at the Water Quality Division website (www.vtwaterquality.org).

Buffer Strips for Riparian Zone Management: A Literature Review. January 1991 U.S. Army Corps of Engineers for the State of Vermont, Water Quality Division.

Buying Lakeshore Property in Vermont, January 1991. 12 pages.

Citizens Lake and Watershed Survey, 1993. 25 pages.

Conservation of Lake and River Shorelands: What's in it for us?, 1993. 4 pages.

Conserving Vermont's Natural Heritage: A Guide to Community-Based Planning for the Conservation of Vermont's Fish, Wildlife, and Biological Diversity. 2004. Vermont Fish and Wildlife Department. 135 pages.

Controlling Nonpoint Source Pollution in Vermont: Resolutions Regarding Practices, Programs and Needs, August 1988. Vermont NPS Task Force. 34 pages.

For Your Lake's Sake, 1991, pamphlet.

Get the Facts. A series of fact sheets concerning specific non-point pollution sources. Topic include: septic systems, construction sites, developed areas, sand & gravel pits, chemical & petroleum storage, and hazardous waste storage. September 1995.

Lake and River Shoreland Conservation Conference Summary, 1993. 10 pages.

Lake Protection Through Town Planning, A Suggested Process, January 1991. 10 pages.

Local Planning and Zoning Options for Water Quality Protection, October 1999. 31 pages.

Local Planning and Zoning Options for Wetland Protection, 1997. 27 pages.

Native Vegetation for Lakeshores, Streamsides and Wetland Buffers, 1994. 43 pages.

Nonpoint Source Pollution. Lake Champlain Basin Program. Fact Sheet Number 2.
On-line at: http://www.lcbp.org/fs.htm

"Out of the Blue," Lakes and Ponds Unit bi-annual newsletter, Water Quality Division.

Planning for Lake Water Quality Protection, A Manual for Vermont Communities, August 1990. 113 pages.

Recreation Path and Trail Planning to Protect and Enhance Lakes and Rivers: Values and Considerations for Water Quality and Aquatic Habitat, October 1994. 9 pages.

Re-establishing a Lakeshore Buffer Strip, 1992. 4 pages.

The Streamside Sentinel, 2001. 12 pages.

When Rivers Become Unstable: How Streamside Woodlands Can Help Protect Land, 2001. Video, 23 minutes.

Other Publications

Chase, V., L. Demming, and F. Latawiec. 1995. *Buffers for Wetlands and Surface Waters: A Guidebook for New Hampshire Municipalities*. 80 pages. Audubon Society of New Hampshire

Wenger, Seth. 1999. *A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation*. Institute of Ecology, University of Georgia.

6: CONTROL OF EXOTIC SPECIES

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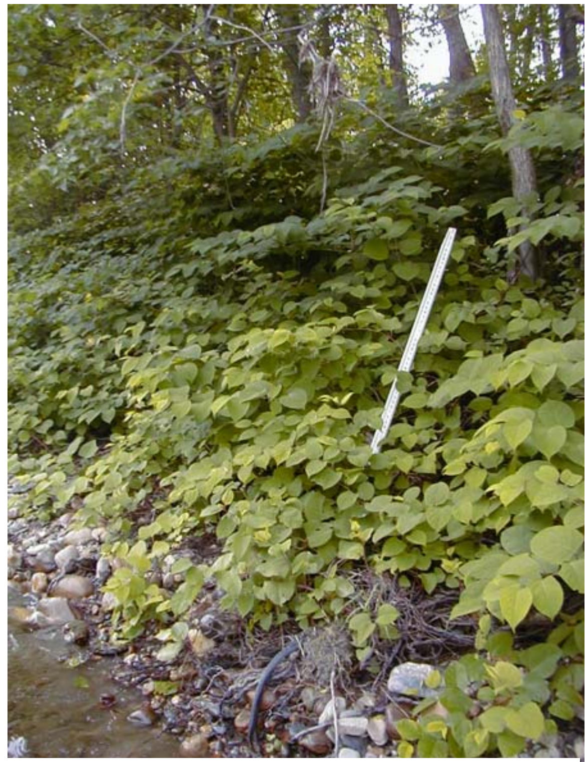


Figure 13. Japanese knotweed, an invasive exotic plant, dominates the riparian areas of many Vermont streams.

There are many non-native plants species that have been intentionally or accidentally introduced in Vermont, some of which have aggressive growth habits that have resulted in their spread throughout natural communities. Once established, these invasive exotic plants can substantially disrupt habitats. The exotics often lack the predators that keep them in check in their own native regions. As a result the plants can run rampant, out-competing native plants for space, sunlight, and nutrients. Native plants help keep an ecosystem healthy and stable and are more beneficial to native wildlife populations. (Vermont Agency of Natural Resources and The Nature Conservancy of Vermont 1998).

Transportation corridors (i.e., roads and railroads) have long been a major means by which some invasive plants spread to new areas. Reasons for this include: fill used to build and maintain roadways is contaminated with exotic plant seeds or root fragments; and native vegetation and soils along transportation corridors is often disturbed, creating an ideal habitat for exotic plant species that are adapted to disturbed soils. Since many riparian areas in Vermont are in close proximity to transportation corridors, riparian areas are vulnerable to invasive plant spread. In addition, streambanks are naturally disturbed during flood events and thus are ideal habitat for invasive exotics adapted to disturbed soils, such as Japanese knotweed (also called Northern bamboo). Japanese knotweed (*Polygonum cuspidatum*) and other invasive plants are also spread when root fragments and seeds are transported downstream by surface water. Riparian areas also usually have moist soil conditions, which is ideal habitat for exotic species such as yellow flag iris *(Iris pseudacorus)*, purple loosestrife *(Lythrum salicaria)* and common reed (*Phragmites australis)*.

Many of these exotic species need full-sun or nearly full-sun to thrive, thus maintaining forested riparian areas is one way to limit their spread along Vermont's waterways. When established riparian buffers are disturbed, vulnerability to these exotic invasive species is dramatically increased. Eradication is expensive, frustrating, and presents special challenges, since it is necessary to ensure that the control methods themselves (such as herbicides) do not further degrade the environment.

The *Vermont Invasive Exotic Plant Fact Sheet Series* was developed by the Agency of Natural Resources and The Nature Conservancy to increase awareness of existing and potential invasive exotic plant problems in Vermont, and to promote cooperative efforts to address these problems.

Following is a list of exotic plant species that are highly invasive in Vermont and are currently displacing native plants either on a localized or widespread scale.

Invasive Exotic Plants of Vermont: A List of the State's Most Troublesome Weeds

Key: a - aquatic, w - wetland, u- upland

Goutweed - *Aegopodium podagraria* (u,w)
Garlic mustard - *Alliaria petiolata* (u,w)
Flowering rush - *Butomus umbellatus* (w)
Yellow flag iris - *Iris pseudacorus* (w)
Morrow honeysuckle - *Lonicera morrowii* (u)
Tartarian honeysuckle - *Lonicera tatarica* (u)
Purple loosestrife - *Lythrum salicaria* (w)
Eurasian watermilfoil - *Myriophyllum spicatum* (a)
Common reed - *Phragmites australis* (u,w)
Japanese knotweed - *Polygonum cuspidatum* (u,w)
Common buckthorn - *Rhamnus cathartica* (u)
Glossy buckthorn - *Rhamnus frangula* (u,w)
Water chestnut - *Trapa natans* (a)

For more information please contact:

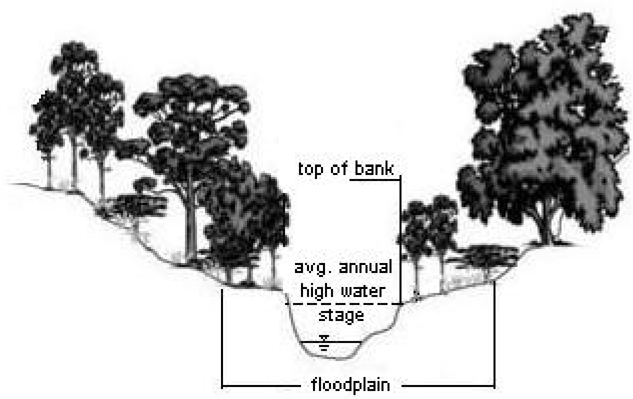
The Nature Conservancy of Vermont, 27 State Street, Montpelier, VT 05602 Tel: 802-229-4425 http://nature.org/wherewework/northamerica/states/vermont/
Vermont Department of Environmental Conservation, 103 South Main Street, Building 10 North Waterbury, VT 05671-0408 Tel: 802-241-3777 (for aquatic plants); Tel: 802-241-3770 (for plants in wetland or riparian areas) http://www.vtwaterquality.org
Vermont Fish and Wildlife Department Nongame and Natural Heritage Program, 103 South Main Street, Buildling 10 South Waterbury, VT 05671-0501 Tel: 802-241-3715 http://www.vtfishandwildlife.com

GLOSSARY

__Aquatic Habitat:__ A specific type of area with environmental (i.e., biological, chemical, or physical) characteristics needed and used by an aquatic organism, population, or community.

__Average Annual High Water Stage__: The stage or elevation at which the average annual high water begins to spill out of the active channel into the adjacent floodplains; also called the "channel-forming" or "bankfull" flow (see Figure 1).

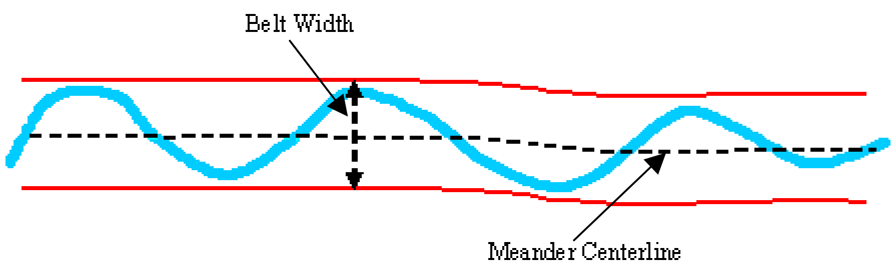
Figure 1: Schematic of a Generic Riparian Area



Adapted from: National Academies Press, 2002.

__Belt Width__: The horizontal distance which extends laterally across the stream valley, from outside meander bend to outside meander bend, thereby encompassing the natural planform variability of the channel necessary to accommodate the slope requirements of the stream (see Figure 2).

Figure 2: Determining Belt Width for a Geomorphically Stable Stream



__Channel Stability:__ A measure of the resistance and resilience of a stream to changes in its unique form, channel dimensions, and patterns that determines how well it adjusts to and recovers from these morphological changes and the change to the quantities of flow or sediment.

__Dissolved Oxygen:__ Concentration (mg/L) of oxygen dissolved in water, where saturation is the maximum amount of oxygen that can theoretically be dissolved in water at a given altitude and temperature.

__Embedded Substrate:__ The surrounding of the mineral material that forms the bottom of a waterbody by fine sediment.

Endangered Species: Species in immediate danger of becoming extirpated.

Eutrophication: Natural and human-influenced process of enrichment with nutrients, especially phosphorus and nitrogen, leading to an increased production of organic matter.

Floodplain: Land adjoining a waterbody that is covered by water during flows or water levels at or exceeding the average annual high water stage (see Figure 1).

Fluvial: Pertaining to or living in streams or rivers, or produced by the action of lowing water.

Headcutting: A stream bed erosion process where an over-steepened area of the stream bed erodes in a head-ward or upstream direction resulting in an incised channel

Headwater Stream: A stream that has few or no tributaries, and typically has a steep, incised channel that is often associated with active erosion, seeps, or springs. Headwater streams are referred to as first order streams.

Incised Channel: A stream that has eroded its channel through rapid down-cutting into the channel bed substrate to a lower base level than existed previously or than is consistent with the current hydrology.

Large Woody Debris (LWD): Large organic debris (e.g., logs and trees). Also referred to as coarse woody debris.

Lateral Bank Erosion: Stream bank erosion that results in the lateral or sideways movement of the channel.

Lotic Waters: Rapidly flowing waters such as brooks, stream, or rivers, where the net flow of water is unidirectional from the headwaters to the mouth.

Natural Community: An interacting assemblage of plants and animals, their physical environment, and the natural processes that affect them.

Organic Matter: Materials resulting from vegetative growth, decay, and accumulation that range in size from fine particulate matter to large trees.

Pesticide Drift: The movement of pesticide droplets or particles at the time of application away from the application target to the surrounding environment.

Primary Productivity: The total rate of photosynthesis including the organic matter used in respiration.

Riparian Area: Of, pertaining to, situated, or dwelling on the margin of a river, stream, lake, pond, or other waterbody.

Riparian Buffer Zone: The width of land adjacent to lakes or streams between the top of the bank or top of slope or mean water level and the edge of other land uses. Riparian buffer zones are typically undisturbed areas, consisting of trees, shrubs, groundcover plants, duff layer, and a naturally vegetated uneven ground surface, that protect the waterbody and the adjacent riparian corridor ecosystem from the impact of these land uses.

Riparian Corridor: The waterbody and the width of adjacent land that supports a distinct ecosystem with abundant and diverse plant and animal communities (as compared with upland communities). For streams, this includes the belt width required for channel stability.

Sediment Load: General term that refers to sediment moved by a stream in suspension (suspended load) or at the bottom of the channel (bed load).

Stream Power: Energy or ability of a stream to move substrates and scour streambanks; based on gravity, slope, discharge, and water velocity.

Threatened Species: Species believed to have a high possibility of becoming endangered in the near future.

Top of bank: The point along a streambank where an abrupt change in slope is evident, and where the stream is generally able to overflow the banks and enter the adjacent floodplain during flows at or exceeding the average annual high water stage (see Figure 1).

Top of slope: A break in slopes adjacent to steep-banked streams that have little or no floodplain; or a break in slope where the side slopes adjacent to an incised, or deeply cut, channel meet floodplains that have been abandoned or are undergoing abandonment.

Turbidity: Measure of the extent to which light penetration in water is reduced by suspended materials present in the water column.

Wetlands: Lands that are inundated or saturated by surface water or groundwater with a frequency sufficient to support significant vegetation or aquatic life that depend on saturated or seasonally saturated soil conditions for growth and reproduction. Such areas include but are not limited to: marshes, swamps, sloughs, potholes, river and lake overflows, mud flats, fens, bogs, and ponds. References to wetlands in this Guidance are those adjacent to streams or lakes.

LITERATURE CITED

Allan, J. D. 1995. Stream Ecology Structure and Function of Running Waters. Chapman and Hall.388 pp.

Asmussen, L. E., A. W. White, E. W. Hauser, and J. M. Sheridan. 1977. Reduction of 2,4-D load in surface runoff down a grassed waterway. Journal of Environmental Quality. Vol 6: 159-162.

Baltimore County, Environmental Protection and Resource Management Division. 2004. Buffer Management and Protection Ordinance.

Berg, L. 1982. The effect of exposure to short-term pulses of suspended sediment on the behavior of juvenile salmonids. Pages 177-196 *in* Hartman (1982).

Calhoun, A. J. K., and M. W. Klemens. 2002. Best development practices: conserving pool-breeding amphibians in residential and commercial developments in the northeastern United States. MCA Technical Paper No. 5, Metropolitan Conservation Alliance, Wildlife Conservation Society, Bronx, New York.

Carleton, Frank H. 1899-1900. Why forest preservation should interest fisherman. 15th Biennial report of the Commissioners of Fisheries and Game of the State of Vermont. p. 98-110

Chase, V., L. Demming, and F. Latawiec. 1995. Buffers for Wetlands and Surface Waters: A Guidebook for New Hampshire Municipalities. 80pp. Audubon Society of New Hampshire

Collier, K. J., A. B. Cooper, R. J. Davies-Colley, J. C. Rutherford, C. M. Smith, R. B. Williamson. 1995. Managing Riparian Zones: A Contribution to Protecting New Zealand's Rivers and Streams. Vol. 2: Guidelines. Wellington, New Zealand: Department of Conservation.

Cross, S. P. 1985. Response of small mammals to forest riparian perturbations. In: *Riparian Ecosystems and Their Management: Reconciling Conflicting Uses.* Ft. Collins, CO: Rocky Mountain Forest and Range Experiment Station (Gen. Tech. Report RM-120).

Cummins, K. W., M. A. Wilzbach, D. M. Gates, J. B. Perry, and W. B. Taliaferro. 1989. Shredders and riparian vegetation. BioScience 39: 24-30.

Cunjak, R. A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 53 (Suppl. 1):267-282.

Cunjak, R. A. and G. Power. 1986. Winter habitat utilization by stream resident brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta). Canadian Journal of Fisheries and Aquatic Sciences 43:1970-1981.

Curry, R. A. and D. L. G. Noakes. 1995. Groundwater and the selection of spawning sites by brook trout (Salvelinus fontinalis). Canadian Journal of Fisheries and Aquatic Sciences 52:1733-1740.

DeGraff, R. M. and D. D. Rudis. 1986. New England Wildlife: Habitat, Natural History, and Distribution. U.S. Department of Agriculture. Forest Service. General Technical Report NE-108.

Doppelt, B., M. Scurlock, C. Frissell, J. Karr. 1993. Entering the Watershed: A New Approach to Save American River Ecosystems. Island Press. Washington, D.C.

Fischer, R. A., and Fischenich, J. C. 2000. Design Recommendations for riparian corridors and vegetated buffer strips, EMRRP Technical Notes Collection (TN EMRRP-xx-2), U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Gunderson, D. R. 1968. Floodplain use related to stream morphology and fish populations. Journal of Wildlife Management 32(3): 507-514.

Hammond, F. M. 2002. The Effects of Resort and Residential Development on Black Bears in Vermont. Final Report. Waterbury, VT: Fish and Wildlife Department, Vermont Agency of Natural Resources.

Hartman, G. F., editor. 1982. Proceedings of the Carnation Creek workshop: a ten-year review. Canadian Department of Fisheries and Oceans, Nanaimo, British Columbia.

Hartung, R. E., and J. M. Kress. 1977. Woodlands of the northeast: erosion & sediment control guides. U.S. Soil Conservation Service and U.S. Forest Service, Upper Darby, Pennsylvania.

Hatfield, J. L., S. K. Mickelson, J. L. Baker, K. Arora, K. P. Tierney, and C. J. Peter. 1995. Buffer strips: Landscape modification to reduce off-site herbicide movement. In: *Clean Water, Clean Environment, 21st Century: Team Agriculture, Working to Protect Water Resources, Vol.1*. St. Joseph, MI: American Society of Agricultural Engineers.

Hauer, F. R., and G. A. Lamberti, editors. Methods in Stream Ecology. Academic Press Boston, 1996.

Kaufmann, J. K. 1992. Habitat Use by Wood Turtles in Central Pennsylvania. Journal of Herpetology 26:315-321.

Keller, C. M. et al. 1993. Avian communities in riparian forests of different widths in Maryland and Delaware. Wetlands. 13:137-144.

Lowrance, R., G. Vellidis, R. D. Wauchope, P. Gay and D.D. Bosch. 1997. Herbicide transport in a managed riparian forest buffer system. Transactions of the ASAE40 (4): 1047-1057.

Mander, U., V. Kuusemets, K. Lohmus, T. Maruing. 1997. Effects of urbanization on small stream in the Puget Sound Lowland Ecoregion. Watershed Protection Techniques 2(4): 483-494.

Meehan, W. R, editor. 1991. Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication 19.

METRO Growth Management Services Department. July 1997. Policy Analysis and Scientific Literature Review for Title 3 of the Urban Growth Management Functional Plan: Water Quality and Floodplain Management Conservation.

Moring, J. R. 1982. Decrease in stream gravel permeability after clear-cut logging: an indication of intragravel conditions for developing salmonid eggs and alevins. Hydrobiologia 88:295-298.

Naiman, R. J. and K. H. Rogers. 1997. Large animals and system-level characteristics in river corridors: Implications for river management. Bioscience 47(8): 521-529.

Opperman, J. J. and A. M. Merenlender. 2004. The effectiveness of riparian restoration for improving instream fish habitat in four hardwood-dominated California streams. North American Journal of Fisheries Management 24:822-834.

Parren, S. 2005. Personal communication.

Peterjohn, W. T. and D. L. Corell. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology 65(5) 243-258.

Platts, W. S. 1981. Sheep and streams. Rangeland 3(4):158-160.

Roderick, E. and R. Miller. 1991. Management recommendations for Washington's priority habitats and species. Washington Department of Wildlife.

Saunders, D. A. 1988. Adirondack Mammals. State University of New York, College of Environmental Sciences and Forestry. 216pp.

Schumm, S. A. 1984 Incised Channels: Morphology, Dynamics and Control. Water Resources Publications (ISBN-0918334-53-5), Littleton, CO.

Semlitsch, R. D. 1998. Biological delineation of terrestrial buffer zones for pond-breeding amphibians. Conservation Biology 12: 1113-1119.

Sorenson, E., M. Lapin, B. Engstrom, and R. Popp. 1998. Floodplain Forests of Vermont: Some Sites of Ecological Significance. Published by Nongame and Natural Heritage Program, Vermont Department of Fish and Wildlife.

Spackman, S. C. 1992. Streamside buffers, where to draw the lines: Investigating the relationship between stream corridor width and species richness in Vermont. Masters Thesis UVM.

Spackman, S. C., and J. W. Hughes. 1995. Assessment of minimum stream corridor width for biological conservation : species richness and distribution along mid-order streams in Vermont, USA. Biology Conservation 71: 325-332.

Snodgrass, J. W. and G. K. Meffe. 1998. Influence of beavers on stream fish assemblages: Effects of pond age and watershed position. Ecology 79: 928-942.

Thompson, E. H. and E. R. Sorenson. 2000. Wetland, Woodland, Wildland: A Guide to the Natural Communities of Vermont. Published by Vermont Department of Fish and Wildlife and The Nature Conservancy. distributed by University Press of New England. 456p.

Thompson, Zadock. 1853. Natural History of Vermont with Numerous Engravings and an Appendix. Stacy and Jameson.

U.S. Army Corps of Engineers (USACE). 1991. Buffer strips for riparian zone management: A literature review. Prepared for the State of Vermont. New England Division. Waltham, MA. 56pp.

Vermont Agency of Natural Resources and The Nature Conservancy of Vermont, Spring 1998. Vermont Invasive Exotic Plant Fact Sheet Series.

Vermont Agency of Natural Resources. 2004. Stream Geomorphic Assessment Protocol Handbook. Waterbury, Vermont.

Verry, E. S., J. W. Hornbeck, and C. A. Dolloff (eds). 2000. Riparian management in forests of the continental Eastern United States. Lewis Publishers, Boca Raton, FL. 402p.

Waters, Thomas, 1995. Sediment in Streams: Sources, Biological Effects, and Control. American Fisheries Society: Bethesda, MD, 251 pp.

Webster, D. A. and G. Eriksdottir. 1976. Upwelling water as a factor influencing choice of spawning sites by brook trout (Salvelinus fontinalis). Transactions of the American Fisheries Society 105:416-421.

Wenger, Seth. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Institute of Ecology, University of Georgia.

Whipple, W. Jr., J. M. DiLouie, and T. Pytalr, Jr., 1981. Erosional potential of streams in urbanizing areas. Water Resources Bulletin 17:36-45

Williams, G. P. 1986. River Meanders and Channel Size. Journal of Hydrology 88:147-164.

Witzel, L. D. and H. R. MacCrimmon. 1983. Redd-site selection by brook trout and brown trout in southwestern Ontario streams. Transactions of the American Fisheries Society 112:760-771.

Woodall, S. L. 1985. Influence of land treatments on temperature variations of groundwater effluent to streams. Thesis. University of Georgia, Athens, GA.

Woodard, S. E. and C. A. Rock. 1991. The role of natural buffer strips in controlling phosphorous and sediment runoff. Water Pollution Control Federation, Alexandria, Virginia. Water Pollution Control Federation 64th Annual Conference and Exposition. Toronto. #AC91-044-004.