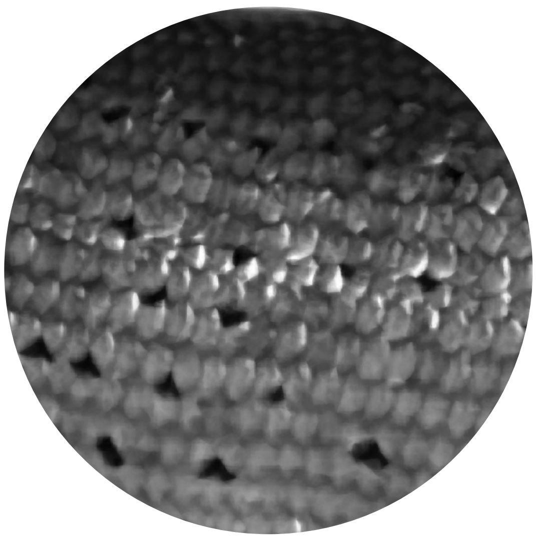
Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Fish and Aquatic Habitat

PART Two of a Series entitled:
The Need for Stream Vegetated Buffers:
What Does the Science Say?



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Introduction

All freshwater fish depend primarily on two things: 1) an adequate, clean water supply, and 2) a healthy system of riparian vegetation along our streams, lakes, and wetlands. These two items work in tandem to provide the necessary areas for breeding, feeding, resting, and avoiding predators during the different phases of a fish's lifecycle. One of the most effective tools available to local governments interested in minimizing the loss and degradation of fish habitat along streams is to set back structures and protect streamside buffers with native vegetation (hereafter referred to as "building setbacks with vegetated buffers"). In order to use this tool, however, decision makers and citizens alike must understand the science behind different buffer widths.

This second report, in a series, summarizes the scientific recommendations underlying the vegetated buffer size needed to protect fish and aquatic habitat. Two other reports were developed in this series on other key elements of stream protection, water quality and wildlife:

- *Part I: Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Water Quality*; and
- *Part III: Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Wildlife and Wildlife Habitat.*

Each of these reports is designed to explain the science behind one of the many functions provided by vegetated buffers found along streams. Other topics for this series are currently being considered because decision makers establishing building setbacks with vegetated buffers should also consider floodplains and seasonal water levels, stream migration corridors, density of development adjacent to the riparian corridor, and other factors.

For more information on how building setbacks relate to vegetated buffers, see page 3.

Building Setbacks and Vegetated Buffers

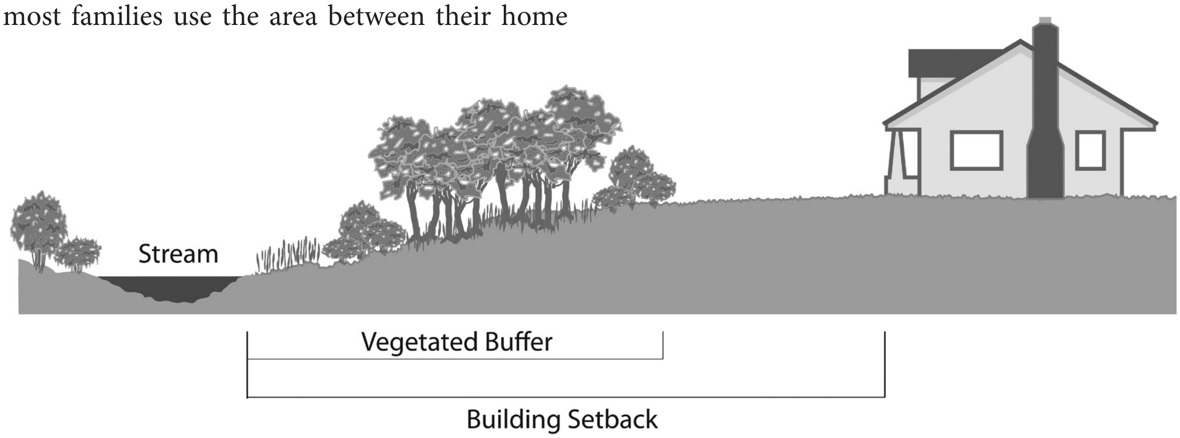
In order to understand setbacks and buffers, it is important to understand the following concepts:

Building setbacks or "no build areas" are the distance from a stream's ordinary high water mark to the area where new structures and other developments (such as highly polluting land uses—including roads, parking lots, and waste sites) are allowed.

Vegetated Buffers are not an additional area, but rather the portion of the building setback that is designated to remain undisturbed. These buffers are areas where all native vegetation, rocks, soil, and topography are maintained in their natural state, or enhanced by additional planting of native plants. Lawns should not be considered part of the vegetated buffer. With their shallow roots, lawns are not particularly effective at absorbing and retaining water, especially during heavy rains. Consequently, they do not significantly filter out water pollutants. They can also be a major source of fertilizers and pesticides—substances that should be prevented from entering our streams and rivers.

How much space should be placed between a building and a vegetated buffer? The building setback should be wide enough to prevent degradation of the vegetated buffer. As an example, most families use the area between their home and the vegetated buffer for lawns, play areas, swing sets, picnic tables, vegetable gardens, landscaping, etc. As a result, the building setback should extend at least 25–50 feet beyond the vegetated buffer (Wenger 1999). A smaller distance between a building and a vegetated buffer, such as 10 feet, will most likely guarantee degradation of the vegetated buffer. A greater distance between structures and a vegetated buffer is recommended if the:

- River has a history of meandering; the setbacks should ensure that people and homes will not unwittingly be placed too close to the river's edge, in harm's way.
- Vegetated buffer is narrower than scientific studies recommend; a deeper building setback can help protect water quality, fisheries, and aquatic habitat.
- Land is sloped and runoff is directed toward the stream (the steeper the slope, the wider a buffer or setback should be).
- Land use is intensive (subdivisions, crops, construction, development).
- Soils are erodible.
- Land drains a large area.
- Aesthetic or economic values need to be preserved.
- Wildlife habitat needs to be protected.
- Landowners desire more privacy.



A Definition of Riparian Areas

This term means "related to, living on, or located on" the bank of a stream or lake. Riparian areas occur along the shorelines of streams, rivers, lakes, and reservoirs. Some are narrow bands stretching along mountain streams, others stretch thousands of feet beyond the water's edge across broad floodplains. Plants associated with riparian areas include cottonwoods, willows, dogwood, alder, sedges, forbs, cattails, and more.

Vegetated Buffers, Fish & Aquatic Habitat

There is a growing concern in Montana over the status of our native fish communities. Keeping an adequate vegetated buffer along a stream is the most important thing that individual landowners can do to improve or maintain fish habitat—both for the stream passing thorough a landowner's property, as well as for the river downstream. In Montana, we have 85 species of fish that depend on healthy streams, including 51 species of native fish and 32 non-native (introduced) fish. Two additional species are possibly native. Twenty-six of these species are considered game fish, important to fishing and the economy (Holton and Johnson, 2003).

In order to understand the habitat requirements of fish, two basic principles should be understood. First, a stream with a healthy invertebrate population (e.g. aquatic insects, crustaceans, snails, and worms) usually indicates that the fish habitat is also healthy. Aquatic invertebrates are the major food source for many, if not most, freshwater fish. Even predacious fish feed heavily on invertebrates when they are juveniles. As a result, scientific studies on fish frequently focus on the health of a stream's invertebrate populations.

A second principle worth emphasizing is that natural stream processes are critical for most fish species because fish have evolved with natural processes—and the habitat requirements of fish are diverse. As an example, some fish prefer small streams (e.g. creek chub, brassy minnow, several species of sculpin, many spawning fish), others are primarily found in large rivers or lakes (e.g. burbot, gar, paddlefish, sturgeon, walleye); some require clear, cold water (e.g. trout, grayling, whitefish, mountain suckers), while others need turbid, warmer water (e.g. channel catfish, some chub, goldeye, sauger, sunfish); some species prefer pools and backwater areas (e.g. river carpsucker, largemouth bass), while others prefer strong currents (e.g. pallid and shovelnose sturgeon, stonecat); some like dense aquatic vegetation (e.g. carp, peamouth, pike, shiners, stickleback), while others need clear water and overhanging vegetation (many trout); and some fish prefer a gravel stream bottom (e.g. rock and smallmouth bass, many spawning fish), while others prefer a sandy or muddy bottom (e.g. largemouth bass, sand shiner, black bullhead) (Holton and Johnson, 2003). Additionally, fish can use different parts of the aquatic environment during different parts of their lifecycle. As an example, bull trout use larger streams or lakes during much of the year, but use small, clean gravel-bottomed streams to spawn. Because different fish have different habitat requirements, maintaining natural

Artwork of the burbot by Joe Tomelleri, courtesy Montana Fish, Wildlife & Parks.

stream processes is the simplest way to protect Montana's diverse fish populations.

Specific ways that streamside buildings and their associated development (roads, parking lots, construction sites, etc.) can impact fish and aquatic habitat are described below:

Riparian Vegetation and Woody Debris

Fish and aquatic insects need clean water. Riparian vegetation plays a critical role at keeping sediments and other pollutants out of our streams and rivers (see *Sedimentation* below). It also is the main source of leaves, twigs, and other organic material that provides a large proportion of the food and breeding grounds for invertebrates that, in turn, feed fish and other wildlife.

Large woody debris (LWD), which is generally defined as pieces of wood at least 20 inches (51 cm) in diameter, is important to both Montana's cold and warm water fisheries. When trees, root systems, branches, and other LWD fall into streams, they create critical fish habitat by developing: scour holes, rifles, and areas for spawning gravels to accumulate; pool habitats that provide critical refuges when summer temperatures get high; and small dams that keep natural organic litter and food from washing downstream, which helps fish as well as the invertebrates they eat. Trees also provide underwater resting areas and cover from predators in roots, submerged logs, and other debris. Scientists consider LWD to be one of the most important factors in determining critical habitat for trout and salmon (salmonids) (Knutson and Naef 1997).

Construction of homes and their associated developments along streams and rivers often results in removal of riparian vegetation and woody debris because of the human tendency to "manage their property" and "tidy up the yard." Removing trees—including dead tree snags—in riparian areas or cleaning trees from the stream can cause stream channels to become simpler and less stable. Simpler stream channels mean fewer, shallower, and less-complex pool habitats; more distance between low-velocity refuges for fish during high flows; and fewer places for fish to hide or escape from predators. Additionally, less large woody debris in a stream reduces the retention and sorting of spawning gravels, as well as the amount of leaf litter and other organic material available for invertebrates.

> Local governments interested in determining the fish species using streams within their jurisdiction should contact their local office of Montana Fish, Wildlife & Parks and the Montana Natural Heritage Program located in Helena (406–444–5354 or http://nhp.nris.mt.gov/).

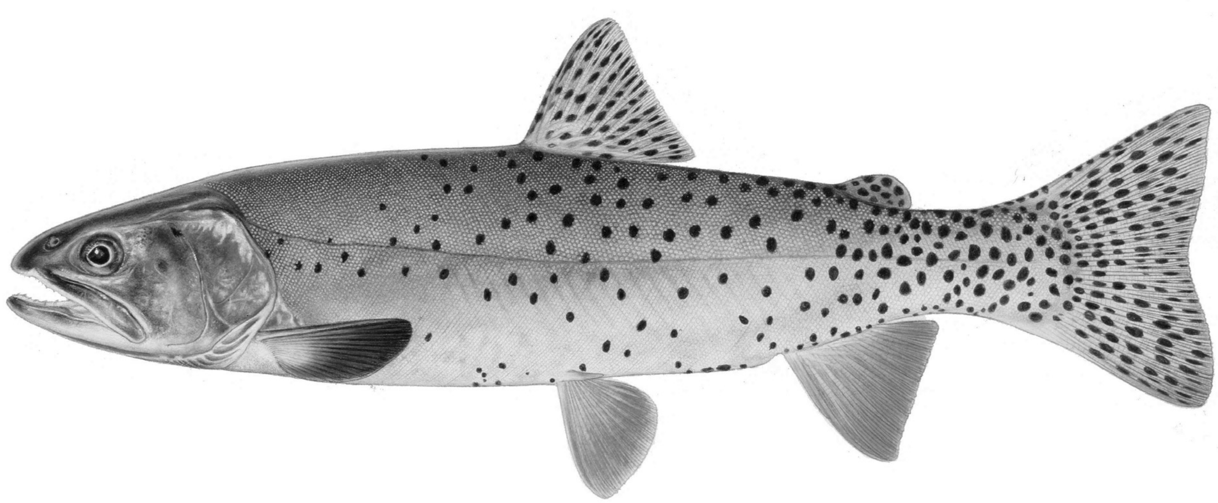
Stream Temperatures

Fish are 'cold-blooded' animals. Consequently, their body temperature is about the same as the water temperature in which they live (i.e. if the water is hot, the fish are hot)—and the water temperature directly influences their rate of development, metabolism, and growth. Water temperatures also influence the amount of dissolved oxygen in water, with less oxygen found in warmer temperatures. Both of these factors influence the range and distribution of fish species in Montana. As an example, we have cold water fish, primarily located in the western part of the state, and warm water fish, primarily located in eastern Montana. Cold water fish include trout, salmon, and whitefish; they are adapted to living in water temperatures lower than 65° F (<18° C). Warm water fish include largemouth and smallmouth bass, northern pike, tiger muskie, channel catfish, sauger, and pallid sturgeon; these fish must have summer water temperatures of 75 ° F or higher (>24° C). Because fish are so sensitive to temperature—even minor shifts in temperature can cause changes in the fish community—having shade over the surface of streams is a critical part of fish habitat. By shading sections of a stream channel, trees and shrubs, such as cottonwoods, birch, alder, pine, and willow, help control and moderate water temperature, keeping streams cooler in the summer and warmer in the winter. Streamside vegetation also protects streams from wind and increases the local humidity, both important factors for some adult stages of aquatic insects.

Removal of vegetation that provides shade can result in summer temperatures that can be stressful or lethal to invertebrates and fish—for both cold and warm water fisheries.

The Role of Small Streams

Small, tributary streams need and deserve at least as much protection as larger rivers because they: contribute steady amounts of clean, cooler water to mainstem rivers; filter sediments and pollutants; play a key role in the retention and absorption of flood and storm water in a watershed; are an important water source, especially during low flow periods of the year; are a major source of woody debris and other organic matter necessary for aquatic organisms; and provide critical spawning sites for many fish species. In terms of temperature, even small streams that do not hold fish can benefit from shade, which keeps water cooler for habitat downstream. Additionally, small streams that are shaded provide the greatest temperature reduction per unit length—directly benefiting Montana's mainstem rivers. These streams are so critical for Montana's fisheries that an increase in the temperature and/or sedimentation of tributary streams can directly decrease the useable habitat for fish, as well as reduce their reproductive success.



Artwork of the Yellowstone cutthroat by Joe Tomelleri, courtesy Montana Fish, Wildlife & Parks.

This home was built out of the floodplain—but on an erosive bank overlooking the Shields River. In areas where streams are known to meander, building setbacks and vegetated buffers should incorporate non-floodplain areas overlooking the stream—because as valley stream channels naturally meander, these homes can become vulnerable to falling into the water.

Because of their size, small tributaries are very vulnerable to impacts from housing and other development: they are shallower, so removing trees and other shade-producing vegetation can result in harmful increases in temperature and increased evaporation rates; and they have less water, so it is easier for debilitating or toxic concentrations of pollutants to impact aquatic organisms in these streams. Additionally, many small tributaries are often dependent upon groundwater to maintain late summer stream flows. If a housing development reduces or eliminates their access to this groundwater, these streams can partially or entirely dry up—a condition that is obviously stressful or lethal to fish and other stream organisms.

Bank Stabilization

As described above, the long-term health of streams, fish, and aquatic habitat requires maintaining natural stream processes—which includes natural erosion processes. In a healthy valley stream or river, banks erode naturally and the material is deposited elsewhere, which in turn builds banks and their associated floodplain. As a result of this natural process, the location of the stream channel changes over time. If given space, meandering streams create a pattern where outside bends of the stream are dominated by cut banks (caused by natural erosion), and inside bends are dominated by sand or gravel bars (where sediment is deposited).

If homes or other developments are built too close to a meandering stream or on a bluff overlooking a river, landowners will eventually request that bank stabilization structures—riprap, weirs, barbs, and other structures—be built to protect their home from eventually falling into the water. As more bank stabilization structures are built, both short-term and long-term consequences arise. In the short-term, stabilization measures tend to physically secure one local stretch of riverbank or divert flows away from one bank to another. This can trigger increases in river flow velocities, exacerbate downstream bank erosion, and lead to further instabilities downstream. In other words, preventing natural erosion at one location can significantly increase erosion downstream of the project. Therefore the "problem" is neither controlled nor solved, but merely relocated from one spot to another, negatively impacting downstream landowners. Increased downstream erosion often causes affected landowners to put in structures to protect their property—and the cycle repeats itself over and over again. Scientific studies show that structurally diverse streams, unmodified by human activity, are critical to sustaining fish populations (e.g. Schmetterling et al 2001). In the long-term, bank stabilization structures negatively impact fish habitat by simplifying the structure of the stream, resulting in a loss of species and fish numbers. The simplest way to eliminate this problem is to not allow homes and other associated development to be built in the floodplain—and to establish setbacks in areas located above the floodplain where streams will likely meander.

Sedimentation

In addition to being sensitive to water pollutants, fish can be extremely intolerant of sediment in the stream. Sediments come from a variety of sources, including natural and human-driven stream bank erosion, agricultural fields, exposed earth at construction sites and on dirt roads, and other activities that remove vegetation and expose soil. Scientific studies show that, during heavy rainstorms, land covered with native riparian vegetation can absorb 95% of the precipitation, depositing only 5% of the relatively silt-free water into nearby streams (Knutson and Naef 1997). Although many Montana fish are somewhat tolerant of sediment, many of our trout species—including our native bull trout and cutthroat trout—tend to be very sensitive to siltation. As an example, trout require and seek out clean (silt-free) gravel to lay their eggs. Fine sediment suspended in water will suffocate eggs and interfere with the feeding of juvenile trout, reducing their growth rates. And trout are not the only fish affected by too much sedimentation: several of Montana's warm water fish need clean gravels to spawn, including the long-nosed dace, stonecat, and goldeye. Too much suspended sediment can also cause irritation of gill tissues and force fish to avoid a stream or section of stream altogether. The bottom line is that sediment deposited on stream beds reduces habitat for fish and for the invertebrates that many fish consume—and high levels of sediment can kill aquatic insects and fish.

Removing riparian vegetation, including manicuring the landscape, reduces the ability of natural vegetation to filter out sediments and other pollutants. As stated earlier, keeping an adequate vegetated buffer along a stream is the single most important thing individual landowners can do to improve or maintain fish habitat. For more information on the role that vegetated buffers play in protecting water quality, see the water quality report in this series (Ellis 2008).

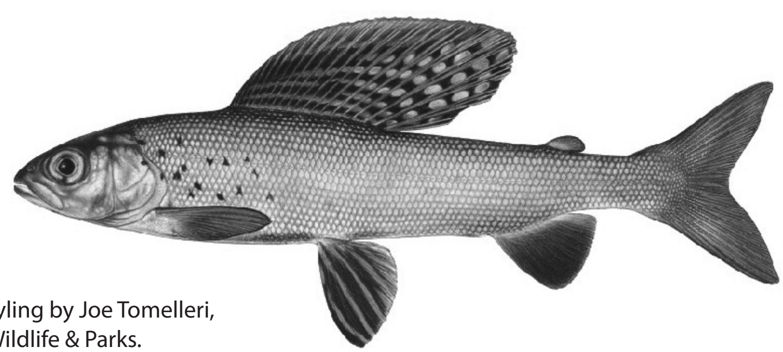
About This Report—Methods Used

This report summarizes the recommendations of more than 34 scientific studies that tested how various stream vegetated buffers protected fish and aquatic habitat (see *Appendix I*). These scientific studies were reviewed by the authors of 3 review publications. One additional source was included because it contains on-the-ground management recommendations for fisheries in Montana. Please note that the information in this report was taken from the text and tables of these 4 publications—and that the original studies were not reviewed. The 3 review publications are:

Castelle, A.J., A. W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements—a review. J. Environ. Qual. 23: 878–882.

Knutson, K. L. and V. L. Naef. 1997. Management recommendations for Washington's priority habitats: riparian. Wash. Dept. Fish and Wildlife, Olympia, WA. 181 pp.

Wenger, S. J. 1999. A review of the scientific literature on riparian buffer width, extent and



Artwork of the Arctic grayling by Joe Tomelleri, courtesy Montana Fish, Wildlife & Parks.

vegetation. Athens: Institute of Ecology Office for Public Service and Outreach, University of Georgia. 59 pp.

Appendix II contains the original references cited in these 3 review publications, allowing individuals using Appendix I to see the full title of all original references, as well as have sufficient information to access all references, if necessary.

Information from one additional publication is included in this report:

INFISH. 1995a. Inland Native Fish Strategy Environmental Assessment, Decision Notice and Finding of No Significant Impact for the Inland Native Fish Strategy, U.S. Forest Service, Intermountain, Northern and Pacific Northwest Regions, Coeur d'Alene, Idaho. 18 pp.

The Inland Native Fish Strategy (INFISH 1995a) was included in this report because it was specifically developed to protect native fish communities and their habitats on U.S. Forest Service and U.S. Bureau of Land Management (BLM) land in the inland West. In Montana the INFISH standards are currently used on BLM land in western Montana, as well as on the Bitterroot, Deerlodge, Flathead, Helena, Kootenai, and Lolo National Forests, which includes approximately the western third of Montana. The buffers established in INFISH are based on empirical science on the size of the stream buffer needed to ensure sediment is intercepted, shade trees are retained for the long-term, and large enough trees are preserved to supply woody debris over the long-term. More than 70 scientific references were used to develop these standards. Unlike traditional scientific papers, the specific studies that led to a specific buffer width are not referenced in the body of the text. Instead, the references all appear in Appendix C of the INFISH Environmental Assessment (INFISH 1995b). As a result, individule scientific studies used to establish the INFISH standards do not appear in Appendix I. Although the 1995 INFISH guidelines are called "interim," they are still in use today—either as part of updated National Forest management plans or as the on-the-ground policy used by National Forests with older management plans.

Summary of Scientific Recommendations

With growing concerns over the health of native fish communities, the future of Montana's fish populations depend on the protection of vegetated buffers along our streams. Consequently:

In order to maintain fish and aquatic habitat, scientific studies recommend that a:

- ***100-foot (30-meter) riparian vegetated buffer should be maintained at a minimum;***
- ***150-foot (46-meter) vegetated buffers should be maintained in forested areas—including areas in Montana with cottonwood gallery forests—so that large woody debris recruitment is sustained; and***
- ***Multi-tiered system should be considered in areas occupied by native bull trout and cutthroat trout, with 300-foot buffers recommended on fish-bearing streams (3 tree lengths); 150-foot buffers on non-fish-bearing streams and reservoirs; and 100-foot buffers on seasonally active (intermittent or ephemeral) streams (1 tree length).***

These recommendations are drawn from the conclusions of 4 publications that reviewed more than 34 separate scientific studies on fish, aquatic habitat, and stream vegetated buffers. Specific conclusions and recommendations by the 4 review publications are summarized or quoted in Table I.

Table I. A summary of the specific conclusions and recommendations of four publications on the size of vegetative buffer needed to protect fish and aquatic habitat.	
Castelle et al 1994	100-foot (30-meter) buffer was recommended.
INFISH 1995	INFISH recommends a multi-tiered system to protect fisheries in the western third of Montana:
	Fish-bearing Streams: vegetated buffers should "consist of the stream and the area on either side of the stream extending from the edges of the active stream channel to the top of the inner gorge, or to the outer edges of the 100-year floodplain, or to the outer edges of riparian vegetation, or to a distance equal to the height of two site-potential trees, or **300 feet slope distance (600 feet, including both sides of the stream channel)**, whichever is greatest."
	Permanently Flowing, Non-fish-bearing Streams: vegetated buffers should "consist of the stream and the area on either side of the stream extending from the edges of the active stream channel to the top of the inner gorge, or to the outer edges of the 100-year floodplain, or to the outer edges of riparian vegetation, or to a distance equal to the height of one site-potential tree, or **150 feet slope distance (300 feet, including both sides of the stream channel)**, whichever is greatest."
	Ponds, Lakes, Reservoirs, and Wetlands Greater than 1 Acre: vegetated buffers should "consist of the body of water or wetland and the area to the outer edges of the riparian vegetation, or to the extent of the seasonally saturated soil, or to the extent of moderately and highly unstable areas, or to a distance equal to the height of one site-potential trees, or **150 feet slope distance from the edge of the maximum pool elevation of constructed ponds and reservoirs or from the edge of the wetland, pond, or lake**, whichever is greatest."
	Seasonally Flowing or Intermittent Streams, Wetlands Less than 1 Acre in Size, Landslides, and Landslide-prone Areas: vegetated buffers should consist of the "intermittent stream channel or wetland and the outer edges of the riparian vegetation" and 1. For priority watersheds, a "distance equal to the height of one site-potential tree, or **100 feet slope distance**, whichever is greatest," or 2. For watersheds not identified as a priority, a "distance equal to the height of one-half site-potential tree, or **50 feet slope distance**, whichever is greatest."
Knutson and Naef 1997	The following average buffer widths were derived from scientific studies testing various components of fish habitat: • Control Erosion: 34-meter (112-foot) buffers; • Maintain Large Woody Debris: 45-meter (150-foot) buffers; • Control Temperature: 27-meter (90-foot) buffers; and • Filter Sediments: 42-meter (138-foot) buffers. However, to maintain fish populations and fish habitat, at least a 45-meter (150-foot) vegetated buffer is recommended because without adequate large woody debris recruitment, a critical habitat component is missing from the aquatic ecosystem.
Wenger 1999	To protect aquatic resources, a "30 m (98 ft) buffer" was recommended.
	"To provide maximum protection from floods and maximum storage of flood waters, a buffer should include the entire floodplain. Short of this, the buffer should be as wide as possible and include all adjacent wetlands."
	"Native vegetation should be preserved whenever possible."

In order to better understand the conclusions found above, Table II summarizes the scientific buffer width recommendations for various habitat components important to fish. It should be noted that because large woody debris recruitment is so important to fisheries, maintaining a 150-foot (45-meter) buffer is recommended in forested areas throughout the state, including areas with cottonwood gallery forests. Additionally, in order to maintain natural stream processes, all vegetative buffers should include the 100-year floodplain whenever possible.

Appendix I contains study-specific information for erosion control, large woody debris, temperature control, invertebrates, and specific fish species. It should be noted that many of the studies found in Appendix I underwent extensive peer review before they were published in a professional journal or report of a scientific government agency. It would be very costly to duplicate these studies on a case-by-case basis; hence the recommendations given here are intended to be protective in most situations, based on the findings of a wide range of studies. If localized information on area conditions is available (vegetation maps, floodplain maps, etc.), this information can also be used to ensure that buffers more accurately fit local conditions.

Table II. Summary of stream vegetated buffer widths recommended to protect fish and aquatic habitat. This table was compiled using information in the 4 publications reviewed in this report, from the detailed conclusions from scientific studies reported in Appendix I below. This table gives the average vegetative buffer width recommended for fish and aquatic habitats using all studies found in Appendix I. Where studies reported a range of values, the median of that range was used to calculate the average (mean) buffer width. Because each habitat component plays a critical role in the health of aquatic habitat, the overall recommendation to maintain fish and aquatic habitat is the largest distance needed by any one habitat component: approximately 150 feet is needed to maintain large woody debris recruitment and scientific studies recommend that vegetative buffers should include the 100-year floodplain whenever possible.

Purpose of Vegetated Buffer	Average Stream Buffer Width	Number of Studies Used in Calculating Desired Buffer Width
Erosion control	100-year floodplain, but at least 100 feet	Review article conclusion (Wenger 1999)
Flood control, includes channel migration ability	100-year floodplain	Review article conclusion (Castelle et al 1994)
Road Construction	150 feet	1
Large Woody Debris	155 feet	14
Water Temperature Control	77 feet	15
Fish Habitat and Invertebrates	110 feet	20
Stream Buffer Width Needed for Fish and Aquatic Habitat	155 feet or 100-year floodplain, whichever is greatest	

Appendix I.

Summary of more than 34 Scientific Studies Conducted on the Size of Stream Vegetated Buffers Needed to Protect Fish and Aquatic Habitat. The information in this table was taken from the text and tables of the 4 publications described above. This table summarizes (1) the purpose of the buffer that was tested in a scientific study (Vegetated Buffer Function); (2) the size (in meters and feet) of the vegetated buffer tested; (3) the author of the scientific study who tested the buffer's function and size; and (4) the name of the publication where the scientific study was summarized. As much as possible, the studies in this table are listed from most protective to least protective. Note that information about removal of sediment and other pollutants appears in Part I of this report series, *Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Water Quality*.

GENERAL STREAM PROTECTION AND BANK STABILITY* *Depends on slope, soils, etc.				
Vegetated Buffer Function	**Distance from stream in meters**	**Distance from stream in feet**	**Author of Original Scientific Study**	**Name of Review Article**
Flood Control—Flood water elevation reduced 50% in forested vegetation	100-year floodplain	100-year floodplain	Bertulli 1981	Castelle et al 1994
Sediment control from roads—minimize locations of roads within 150 feet of streams (for sediment control)	46	150		INFISH 1995a
Bank erosion control—must allow channel migration	100-year floodplain	100-year floodplain		Wenger 1999
Bank erosion control—to prevent unnatural erosion	30	100	Raleigh et al 1986	Knutson and Naef 1997
Bank erosion control—1 effective tree height around channel migration zones; some tree harvest allowed between 20–100 feet	30	100		INFISH 1995a
Bank erosion control—in areas prone to high mass wasting (where large masses of rock or earth are likely to move down slope)	38	125	Cederholm 1994	Knutson and Naef 1997
General Stream Protection—Provides minimal maintenance of most stream functions	15–30	50–98	Johnson and Ryba 1992	Knutson and Naef 1997

LARGE WOODY DEBRIS RECRUITMENT				
Vegetated Buffer Function	**Meters**	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Long-term large woody debris recruitment—minimum buffer to provide adequate large woody debris in streams	100	328	K. Koski, pers. comm.	Knutson and Naef 1997

LARGE WOODY DEBRIS RECRUITMENT (continued)				
Vegetated Buffer Function	**Meters**	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Long-term large woody debris recruitment—3 tree lengths needed long-term in forested areas for stability (e.g. to minimize windthrow, where trees are uprooted by wind)	90	300	Collier et al 1995	Wenger 1999
Long-term large woody debris recruitment—1 effective tree height around all channel migration zones needed	30 meters from channel migration zone	100 feet from channel migration zone		INFISH 1995a
Large woody debris in stream maintained	55	180	Thomas et al 1993	Knutson and Naef 1997
Large woody debris in stream maintained	55	180	U.S. For. Serv. et al 1993	Knutson and Naef 1997
Large woody debris in stream maintained	46	150	McDade et al 1990	Knutson and Naef 1997
Large woody debris in stream maintained	46	150	Robison and Beschta 1990	Knutson and Naef 1997
100% of large woody debris for stream recruited within this distance	50	165	Van Sickle and Gregory 1990	Knutson and Naef 1997
99% of large woody debris for stream recruited within this distance	30	100	Murphy and Koski 1989	Knutson and Naef 1997
80% of large woody debris for stream recruited within this distance in coniferous riparian forest	30	100	Van Sickle and Gregory 1990	Knutson and Naef 1997
80% of large woody debris recruited within this distance in multiple canopy forest area	15	50	Van Sickle and Gregory 1990	Knutson and Naef 1997
Large woody debris contributed to stream structure within this distance	31	103	Bottom et al 1983	Knutson and Naef 1997
Tree falling distance—maximum distance of tree-fall (source of coarse woody debris)	45	148	Harmon et al 1986	Knutson and Naef 1997
Tree falling distance—median distance of tree-fall (source of coarse woody debris)	15	50	Harmon et al 1986	Knutson and Naef 1997
Short-term large woody debris recruitment—one tree height necessary for recruitment	30	100	Collier et al 1995	Wenger 1999
Winter fish habitat—salmonid survival in winter depended upon the amount of woody debris in streams; buffers this wide provided sufficient woody debris recruitment	15–130	49–427	Murphy et al 1986	Wenger 1999

WATER TEMPERATURE CONTROL				
Vegetated Buffer Function	**Meters**	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Amount of stream surface shaded—provided 60–80% shading of streams at minimum flow	46	151	Steinblums et al 1984	Knutson and Naef 1997
Amount of stream surface shaded—provided 50–100% shading of streams	30–43	100–141	Jones et al 1988	Knutson and Naef 1997
Amount of stream surface shaded—same level of shading provided as that of an old growth forest	30	100	Beschta et al 1987	Knutson and Naef 1997; Castelle et al 1994
Amount of stream surface shaded—provided 50–100% shading of streams	18–38	60–125	U.S. Forest Service et al 1993	Knutson and Naef 1997
Amount of stream surface shaded—provided 60–80% shading of streams	18	59	Moring 1975	Knutson and Naef 1997
Amount of stream surface shaded—provided 60–80% shading of streams	15–30	49–100	Hewlett and Fortson 1982	Knutson and Naef 1997
Amount of stream surface shaded—provided 60–80% shading of streams	12	39	Corbett and Lynch 1985	Knutson and Naef 1997
Amount of stream surface shaded—provided 60–80% shading of streams	11–38	35–120	Johnson and Ryba 1992	Knutson and Naef 1997
Amount of stream surface shaded—provided 60–80% shading of streams	11–37	35–125	Brazier and Brown 1973	Knutson and Naef 1997
Water temperature maintained within 1 ºC (~ 0.6 ºF) of former average temperature	30	100	Lynch et al 1985	Knutson and Naef 1997; Castelle et al 1994
Water temperature maintained within 1º of baseline	30	100	Johnson and Ryba 1992	Knutson and Naef 1997
Water temperature important upstream—to maintain temperatures for fish, 80% of banks for 2.5 km (1.5 miles) upstream had to have at least a 10 meter buffer	10	33	Barton et al 1985	Wenger 1999
Canopy maintained	23	75		INFISH 1995a
Small stream water temperature sufficiently maintained on small streams by forested buffer of this size.	24	73	Brazier and Brown 1973	Castelle et al 1994
Small streams water temperature adequately controlled with buffers of this size	15	50	Broderson 1973	Castelle et al 1994
Small streams water temperature effectively maintained, especially on smaller streams	10–30	33–100	Osborne and Kovacic 1993	Wenger 1999

FISH AND AQUATIC HABITAT				
Vegetated Buffer Function	**Meters**	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Fish-bearing streams—greatest distance: 300 feet, or edge of 100-year floodplain, or distance equal to 2 site-potential trees, or outer edge of riparian vegetation	91	300		INFISH 1995a
Ponds, lakes, reservoirs, and wetlands—greatest distance: 150 feet, or edge of 100-year floodplain, or distance equal to 1 site-potential tree, or outer edge of riparian vegetation	46	150		INFISH 1995a
Non-fish-bearing streams—greatest distance: 150 feet, or edge of 100-year floodplain, or distance equal to 1 site-potential tree, or outer edge of riparian vegetation	46	150		INFISH 1995a
Seasonally flowing or intermittent streams—greatest distance: 100 feet, or distance equal to 1 site-potential tree, or outer edge of riparian vegetation	30	100		INFISH 1995a
Invertebrates—macroinvertebrate density begins to increase with buffer this size	30	100	Newbold et al 1980	Knutson and Naef 1997
Invertebrates—macroinvertebrate diversity—Shannon index of macroinvertebrate diversity same as control with buffer of this size	30	100	Gregory et al 1987	Knutson and Naef 1997
Invertebrates—maintain riparian invertebrate populations	30	100	Roby et al 1977	Knutson and Naef 1997
Invertebrates—minimum width of riparian buffer to avoid affecting food supply of benthic invertebrates	30	100	Erman et al 1977	Knutson and Naef 1997; Castelle et al 1994
Invertebrates—protect aquatic insect communities from sedimentation	30	100	Erman et al 1977	Knutson and Naef 1997
Aquatic habitat—maintain leaf litter in medium to large streams	30	100		INFISH 1995a
Aquatic habitat—maintain leaf litter in small streams	15	50		INFISH 1995a
Fish habitat—maintain fish habitat for brook trout	30	100	Raleigh 1982	Knutson and Naef 1997
Fish habitat—maintain fish habitat for chinook salmon	30	100	Raleigh et al 1986	Knutson and Naef 1997
Fish habitat—maintain fish habitat for cutthroat trout	30	100	Hickman and Raleigh 1982	Knutson and Naef 1997
Fish habitat—maintain fish habitat for rainbow trout	30	100	Raleigh et al 1984	Knutson and Naef 1997
Fish habitat—recommended buffer to control erosion of undercut banks for cutthroat, rainbow, and brown trout; and chinook salmon	30	100	Raleigh et al 1986	Knutson and Naef 1997

FISH AND AQUATIC HABITAT (continued)				
Vegetated Buffer Function	**Meters**	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Fish spawning—buffer needed by salmonid eggs for normal development	30	100	Moring 1982	Castelle et al 1994
Instream habitat—minimal maintenance of most functions	15–30	40–100	Johnson and Ryba 1992	Knutson and Naef 1997

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