Design of Forest Riparian Buffer Strips for the Protection of Water Quality: Analysis of Scientific Literature

Idaho Forest, Wildlife and Range Policy Analysis Group

Report No. 8

by

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FOREWORD

The Idaho Forest, Wildlife and Range Policy Analysis Group (PAG) was created by the Idaho legislature in 1989 to provide Idaho decision makers with timely and objective data and analyses of pertinent natural resource issues. A standing nine-member advisory committee (see inside cover) suggests issues and priorities for the PAG. Results of each analysis are reviewed by a technical advisory committee selected separately for each inquiry (see the acknowledgements on page *i*). Findings are made available in a policy analysis publication series. This is the eighth report in the series.

This report analyzes the design of stream protection zones (SPZs), a particular best management practice to protect water quality on timbered stream reaches in Idaho. The request for this analysis came from the Director of the Idaho Department of Lands (IDL), the agency responsible for implementing the Idaho Forest Practices Act. Developing consensus on the design of SPZs to protect water quality from the impacts of forest practices on some of Idaho's stream segments of concern has proven to be difficult. To facilitate the consensus-building process, the IDL Director requested that the PAG evaluate scientific information "regarding relationships between forest practices SPZs, water quality, and fishery habitats."

What does scientific research say about the effectiveness of streamside buffer zones in protecting water quality? The summary of research-based knowledge in this report answers that question. We hope this information will be useful in helping resolve the issue of how to design Idaho's stream protection zones.

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EXECUTIVE SUMMARY

The primary purpose of this report is to identify, evaluate, and synthesize research-based information relating riparian buffer strips to forest practices, water quality, and fish habitat. (Definitions of technical terms such as buffer strip, riparian, forest practices, and water quality are provided in a Glossary at the end of this report.)

Scientific literature documenting the role and importance of buffer strips in reducing the impacts of forest practices is extensive. More than 300 scientific papers were located and reviewed; nearly 100 papers and documents were found to be relevant and are cited in this report. Information was extensive on some topics and surprisingly limited on others. A substantial amount of information was found regarding stream temperature changes resulting from the removal of riparian vegetation. Much recent research has focused on the importance of large organic debris (LOD) and how it can be affected by timber harvest. In contrast, little information was found on slash burning and sediment production within buffer strips. Research on some topics was in a case study format, making generalization difficult.

Objectives for this report are stated as five focus questions around which the report is organized: [1] What is a buffer strip? [2] How do forest practices within buffer strips affect water quality and fish habitat? [3] How effective are buffer strips in reducing impacts of forest practices? [4] What are the issues in buffer strip design? [5] What models are available for use in buffer strip design? A summary of replies to these focus questions is provided in a short section immediately following this executive summary.

This literature review suggests that scientists are at different stages in their understanding of the several important functions provided by buffer strips, which include temperature moderation, sediment filtration, and LOD recruitment. The importance of buffer strips in moderating the impacts of forest practices on water quality and fish habitat is generally understood, even though quantitative relationships are difficult to establish. Research on the effects of canopy removal on stream temperature has resulted in a practical understanding of the problem and some useful predictive models. In two other areas that have received recent emphasis--the impacts of forest practices on LOD recruitment and the aquatic food chain--knowledge is more descriptive. Some predictive models have been developed, but their utility is limited.

Information on the sediment filtering function of riparian buffer strips is limited. Much of what is known is inferred from the special case of buffer strips between a road and a stream. The important problem of cumulative effects within buffer strips has not yet been satisfactorily addressed. Existing studies, including those on slash burning, point out the potential for the accumulation of nutrients and chemicals along with sediment from both agricultural and forestry operations in riparian areas and the possible impacts on water quality and fisheries.

Studies describing different approaches to establishing buffer strip widths are limited. Despite literature describing the utility of variable width buffer strip models and their use in other states in the Pacific Northwest, no studies were found documenting the advantages or disadvantages of variable width buffer strips, as compared to minimum fixed width buffer strips.

Based on this literature review, two ideas seem to stand out as having some potential to enhance the effectiveness of buffer strips: (1) the use of a simplified field procedure (such as the TFW model in the State of Washington) for determining the impact of canopy removal on stream temperature, and (2) the use of variable width buffer strip models to address site-specific biological or physical requirements of the stream or riparian zone.

FOCUS QUESTION SUMMARY REPLIES

[1] What is a buffer strip? By definition, buffer strips are riparian lands maintained immediately adjacent to streams or lakes to protect water quality, fish habitat, and other resources.

Buffer strips are required under the Idaho Forest Practices Act and are termed stream protection zones. Analysis of buffer strip requirements in the forest practices acts of Washington, Oregon, California, and Idaho shows many similarities and two major differences. In all four states, the types of beneficial use derived from a stream are used as a primary determinant of the need for, and width of, buffer strips.

The first difference is that in Idaho a minimum buffer strip width is specified, at 75 feet if the stream supports fish (a Class I stream), and at 5 feet if the stream is used by "only a few, if any, fish" (a Class II stream). Washington, Oregon, and California use additional site-specific factors to modify width prescriptions for their equivalents to Idaho's Class I streams, including stream width, proximity of a timber harvest area, or slope of the adjacent land. This approach creates a variable minimum width buffer with enhanced sensitivity to local stream protection needs. The other states do not specify a minimum width for their equivalent to Idaho's Class II streams, but each requires either a percent of existing canopy or a number of leave trees, whereas Idaho does not.

The second difference is the regulation of slash burning within buffer strips. In Washington, Oregon, and California, slash burning is generally prohibited within a buffer strip. In Idaho, slash burning within a buffer strip is not regulated.

[2] How do forest practices within buffer strips affect water quality and fish habitat? Timber harvesting within buffer strips can affect water quality and fish habitat in three major ways: (1) removal of the forest canopy (2) reduction in the potential supply of LOD, and (3) alteration of soil conditions. Slash burning is a fourth major category of affects on water quality.

(1) Removal of the forest canopy in the buffer strip can reduce shade and raise stream temperature. Increases in June to August temperature maximums in the Northwest have ranged from 2°C to 10°C, posing a potential threat to fisheries. Reduced canopy cover ma also alter primary food production within a stream, sometimes to the benefit of fish and sometimes to their detriment. Not enough is known about the relationship of canopy densit to the food chain to predict these effects.

(2) The supply of LOD is important for stabilizing stream channels and providing cover for fish. Recent studies have quantified the amount of LOD in streams, the in-stream benefits and problems with LOD, and ways to identify trees that may contribute LOD to the stream. Information is limited for defining an optimal quantity of LOD for the stream or the amount of standing timber needed to recruit or sustain this quantity of LOD over time and under different climatic conditions. Selective timber harvesting within buffer strips could reduce excessive LOD in some situations and result in a potential undersupply in others.

(3) The alteration of soil conditions from timber harvesting within buffer strips has received little attention. The method of yarding and the care equipment operators take are, of course, important considerations. The use of vehicles in timber harvesting operations generally exposes mineral soil, frequently resulting in increased sediment availability. In one study, streambank erosion increased 250% over pre-harvest levels after clearcutting but only 32% over pre-harvest levels where buffer strips were employed. Given the proximity of buffer strips to streams, it is logical to infer that sediment produced here would enter streams more readily than from sources more distant from the channel.

Vehicles also compact the soil surface, which reduces water infiltration.

(4) Slash burning near or within a buffer strip can affect water quality. Research in Idaho documented increases in nitrogen and phosphorus supplied to the stream. The quantity and timing of these effects are dependent on the season, location of the slash piles relative to the stream, and the degree of dilution that may occur before runoff enters the stream.

[3] How effective are buffer strips in reducing the impacts of forest practices? Buffer strip effectiveness is evaluated in five categories: (1) trapping sediment or nutrients, (2) moderating stream temperatures, (3) providing food and cover, (4) providing large organic debris, and (5) moderating cumulative watershed effects. Cost effectiveness is a sixth category.

(1) Trapping sediment and associated nutrients is one of the most commonly cited reasons for establishing buffer strips. In forested areas within mountainous terrain, water containing sediment regularly moves through buffer strips as channelized flow and less frequently as overland or sheet flow. Channelized flow moves sediment much greater distances than sheet flow does. Research shows sediment in channels can move a thousand feet or more, whereas sheet flow moves sediment three hundred feet or less.

Road construction is normally the largest single sediment source in forestry operations, and roads located adjacent to streams can be continuing sources of water quality problems. Because of this, much research effort has been directed at filter strips controlling sediment emanating from roads. These studies assumed overland flow, and indicated that the key factors controlling sediment movement within the filter strip are slope and the density of obstructions, such as vegetation, rocks and woody debris. Several studies provided recommendations for road filter strips in Idaho. Other Idaho studies provided information on the use of slash to reduce the movement of sediment from roads to filter strips. Research suggests four things about buffer strip design to trap sediment or nutrients: (1) buffer strips should be wider where slopes are steep, (2) riparian buffers are not effective in controlling channelized flows originating outside the buffer, (3) sediment can move overland as far as 300 feet through a buffer in a worst case scenario, and (4) removal of natural obstructions to flow—vegetation, woody debris, rocks, etc.—within the buffer increases the distance sediment can flow.

The effectiveness of buffer strips as a nutrient filter has not been examined extensively in the literature. As noted, nutrient loading of streams following harvest and slash burning can be a problem in Idaho. Present information, however, is insufficient to provide a basis for determining buffer strip effectiveness. Several studies have identified riparian buffer areas as important filters for sediment, nutrients, and other chemicals from agricultural lands. These studies pointed out the utility of riparian forest vegetation and wetlands as storage and nutrient cycling mechanisms, but no definitive means of estimating buffer strip requirements were provided.

(2) A substantial amount of literature describes the role of buffer strips in moderating stream temperature. Field experiments clearly show the advantage in leaving buffer strips after timber harvest to provide shade as a temperature moderating mechanism. For example, increases in June to August temperature maximums in the Northwest have ranged from 2°C to 10°C from the loss of riparian vegetation. Studies of heat energy exchange between streams and their environment indicate that solar radiation is the dominant energy source, so the major opportunity to control stream temperature is to moderate the sun's energy through shading. The canopy density of shade-producing

vegetation is the key factor that determines the amount of radiant energy reaching a stream. Buffer strip width was found not to be a good measure of buffer strip effectiveness in moderating stream temperature. Angular canopy density--a measure of the density of canopy actually capable of shading the stream--is the preferred measurement. The effectiveness of buffer strips in moderating stream temperature is currently best estimated using various computer simulation models.

(3) Buffer strip impacts on the aquatic food chain are reasonably well documented by studies comparing the effects of timber harvest with and without buffer strips. However, only a few studies were found that relate buffer strip characteristics to food production, allowing buffer strip effectiveness to be evaluated. These studies indicate that a 98-foot buffer strip is adequate to maintain macroinvertebrate diversity at pre-harvest levels, whereas a 33-foot buffer strip is inadequate. Aquatic ecosystem models relating invertebrate production to canopy density suggest that reducing canopy from 100% to 50% will decrease invertebrate production by 28%.

(4) Buffer strip effectiveness in providing LOD is not well defined in the literature. It is recognized that harvesting or other management practices that influence stand characteristics, such as species and stocking levels, also influence the timing and quantity of available LOD. Source distances for LOD--the distance from the rooting site to stream bank--have been studied in old-growth sites in Oregon. These studies suggest that a 98-foot buffer strip would supply 85% and a 33-foot strip less than 50% of the LOD from a natural stand. Tree height, distance of trees from the stream, and slope within the buffer strip are believed to be the controlling factors in LOD recruitment. Unfortunately, data are currently inadequate to predict either how much LOD is available or how much is required at a given stream reach.

(5) Little information was found addressing the effectiveness of buffer strips in moderating cumulative watershed effects. Cumulative effects are those individually minor, but collectively significant, management actions that take place at different times and locations in a watershed. For example, stream water temperatures may increase as a result of the cumulative effects of many riparian harvest operations if buffer strips are not employed. A Canadian study demonstrated that the loss of upstream buffer strips could increase mean stream temperature. Another important role of buffer strips and associated wetlands is to moderate flooding by the addition of storage area and hydraulic resistance. The combination of additional resistance to stream flow provided by the riparian vegetation and the added storage available in the wetlands slows the stream flow and tends to moderate downstream flood impacts.

(6) Cost effectiveness of buffer strips has been evaluated in several studies where financially optimal buffer widths have been determined. The problem with this approach is the difficulty in determining non-market benefits and costs associated with buffer strips now and in the future. For example, what value is to be placed on the contribution of a buffer strip to maintaining biological diversity now? How will this value change in the future, given the increasing concern for the environment? In short, determining buffer widths based on cost-effectiveness criteria involves values not reflected in the market and is therefore speculative and possibly short-sighted because of changing social values.

[4] Issues in Buffer Strip Design. Three significant issues associated with the design of a policy requiring buffer strips were identified during this review. (1) Should buffer strip widths be based on minimum requirements, or should the widths vary according to physical or biological characteristics of the stream and riparian zone? (2) How much vegetation can be removed from the buffer strip without impairing its buffering functions? (3) How can several design criteria be incorporated into a single buffer strip requirement?

(1) How wide should a buffer strip be? Minimum or fixed width buffer strips have the advantage of simplicity of implementation and administration. Variable width buffer strips have the potential to improve stream protection based on individual stream reach characteristics. Variable width buffers can be altered according to site characteristics or management objectives. For example wider buffer strips could be required where (a) adjacent slopes were steep, (b) streams were larger and additional width was need to protect the flood plain, (c) additional LOD recruitment was appropriate, (d) increased width would reduce the sediment load from a nearby harvest area or road. Similarly, buffer strip widths could be reduced (to a minimum) where (a) slopes were not steep, (b) stream temper-ature increases were not a concern, (c) LOD supplies were ample, etc. Buffer strip widths might also be altered to provide for wildlife access and movement within the drainage. Washington, Oregon, and California currently implement variable width buffer strips under their respective forest practice act regulations. Use of variable widths would allow buffer strip layout to more closely mimic natural ecosystem disturbance, in keeping with "new forestry" concepts. Although studies describing the utility of various variable width buffer strip models were found, no studies were found that document the advantages or disadvantages of variable width over minimum fixed width buffers.

(2) How much vegetation can be removed from a buffer strip without impairing its buffering functions? Under the Idaho FPA, selective logging of mature timber is allowed within the buffer strip (SPZ) as long as (a) the soil stabilization and sediment filtering effect are not destroyed, (b) at least 75% of the "current" pre-harvest shade over the stream is retained, and (c) leave trees for LOD recruitment are provided as prescribed. These requirements may or may not assure the intended level of protection. For example, retaining at least 75% of the current shade by definition allows removal of up to 25% of current shade, regardless of the actual on-site shade provided by the canopy. This may result in a significant increase in stream temperature, or it may not. Actual effects would depend on the temperature of the stream reach, canopy density, and the presence of fish in the stream. Similarly, the requirement for leave trees may be adequate or excessive, depending on conditions at the site.

(3) The issue of multiple buffer strip design criteria--how to assure that soil stability, canopy density, number of leave trees, and other concurrent requirements are met--is normally left to the professional judgement of field staff. Although this method has considerable merit, there are other approaches described in the literature whereby several criteria are combined into a single requirement. One example is the use of a cost-benefit ratio as a single criterion. Other approaches have been proposed, including spatial models and computer-based geograph-ical information systems.

[5] What models are available for use in buffer strip design? A number of models describing individual buffer strip functions were found in the literature. For example, several models describe stream temperature change resulting from the removal of riparian vegetation. One new method developed in Washington under the Timber, Fish and Wildlife Program, shows particular promise for field applications. Another model relates hillslope and road drainage characteristics to the travel distance of sediment below the road fill slope. Another model estimates the probability a riparian tree would contribute LOD to the stream channel. These models enhance our understanding of the buffering processes. They can be useful in designing more effective buffer strips for stream segments of concern, or to check the adequacy of existing buffer strips in meeting specific water quality concerns.

INTRODUCTION

The main purpose of this report is to identify, evaluate, and synthesize research-based information on the relationship of riparian buffer strips to forest practices, water quality, and fish habitat. If you are uncertain of the meaning of these and other technical terms, used in this report please refer to the Glossary at the end of the report.

Three basic opportunities exist for protecting water quality and aquatic habitat from nonpoint source pollution within a watershed. The first is in the upland areas where the source of erosion or water yield modification from forest practices such as road construction and timber harvesting can be reduced by best management practices, or BMPS. The second is to avoid cumulative effects in the watershed by attempting to minimize the combined impacts of forest practices in either time or space through scheduling. The third opportunity, and focal point of this report, is to provide additional protection in the riparian zone. More specifically, this report examines interrelationships between forest practices and stream protection activities with the riparian zone.

Protecting Idaho's water quality and aquatic habitats from pollution caused by forest practices is a major objective of the Idaho Forest Practices Act (FPA). The act regulates timber harvesting, road construction, reforestation, slash disposal, and the application of fertilizers and pesticides. Beginning in 1991, the FPA applies to national forest lands as well as state and private timberlands. The Idaho Department of Lands (IDL) administers and enforces the FPA using BMPs as minimum standards. BMPs are forest practices, or combinations of forest practices, set forth in the Idaho Forest Practices Act rules and regulations established by the State Board of Land Commissioners and published by the IDL (1990) pursuant to Title 38, Chapter 13, of the Idaho Code. Under the FPA, protection of water quality and aquatic habitat from activities in or near the riparian zone is done by establishing stream protection zones (SPZs), which are strips of land beside streams designed to buffer them from the impacts of land management activities. The vegetation, rocks, and debris in the SPZs limit the soil erosion, provide food and cover for fish and wildlife, moderate microclimatic extremes, and provide a barrier to overland movement of sediment.

The Idaho Forest Practices Act provides for the development of site-specific BMPs for land bordering on timber stream segments of concern by a local working committee (LWC). If the LWC fails to develop consensus on BMPs for stream segments of concern, the IDL is empowered to determine and implement appropriate measures. Recently the IDL has had to make several administrative determinations regarding site-specific BMPs because the LWC could not develop a consensus. Similar determinations will likely have to be made in the future. One of the key issues has been the design of SPZ, or riparian buffer strips to meet site-specific needs.

WHAT IS A BUFFER STRIP?

Within a watershed, generally the stream channel and adjacent land areas are divided into three zones: aquatic, riparian, and upland. The aquatic zone includes the stream and the area of the streambed that is normally underwater, i.e., the area below the high water mark. The riparian zone lies between the aquatic and upland zone and is an area of transitional vegetation influenced by its nearness to water. Riparian areas sometimes include other types of wetlands and may have distinctive soil characteristics (Helm 1985). Upland areas adjoin the riparian zone and are usually characterized by vegetation and soils different from those in the riparian zone.

To protect aquatic and riparian resources, buffer strips are established in the riparian zone directly beside the stream, and may extend to the adjacent upland zone. Buffer strips are defined as strips of vegetation left beside a stream or lake after logging (Helm 1985). Buffer strips are also referred to as filter strips or protection strips. The term buffer strip is also loosely applied to a variety of administratively designated protection zones managed by state and federal agencies, including Idaho's Stream Protection Zone (SPZ), Washington's Riparian Management Zone (RMZ), and the U.S. Forest Service's Streamside Management Zone (SMZ). These administratively defined terms all denote riparian areas where forest practices are limited by administrative or legislative requirements. Nutter and Gaskin (1988) noted the lack of a universal definition for such areas and described a U.S. Forest Service SMZ as "an area with often undefined boundaries, adjacent to a stream or wetland, with recognized sensitive biological and physical attributes that serve to ameliorate impacts of upland influences." In our report, the term buffer strip means a strip of land immediately adjacent to a stream designed to protect aquatic and riparian resources. The terms "filter strip" and "protective strip" are sometimes used in the literature, and mean the same thing as buffer strip.

Appropriately designed and managed buffer strips can contribute significantly to the maintenance of aquatic and riparian habitat and the control of pollution. Riparian buffer strips fulfill at least three basic roles. First, they help to maintain the hydrologic, hydraulic, and ecological integrity of the stream channel and associated soil and vegetation. For example, riparian vegetation contributes to the maintenance of stream bank stability and channel capacity. Riparian vegetation also contributes the large organic debris that provides hydraulic structure to the channel. Second, buffer strips help protect aquatic and riparian plants and animals from upland sources of pollution by trapping or filtering sediments, nutrients, and chemicals from forestry and agricultural activities. Third, buffer strips protect fish and wildlife by supplying food, cover, and thermal protection, and in some cases providing unique habitat.

Buffer Strip Requirements in Idaho, Washington, California and Oregon

This section highlights and summarizes regulations concerning buffer strip size, and shade, vegetation, and filter strip requirements in four western states. These summaries only highlight some of the regulations on buffer strips. More detail is contained in the respective forest practices acts in the four states.

Idaho: Stream Protection Zones (SPZs). Buffer strips are termed stream protection zones (SPZs) in the Idaho Forest Practices Act (FPA). Their width is measured along the slope distance starting at the ordinary high water mark and determined by the beneficial uses of water in the stream. Streams used for domestic water supply, or important for spawning, rearing or migration of fish, are designated as Class I streams and are protected by a minimum 75-foot wide SPZ on each side of the stream. Headwater streams without a fishery whose principal value lies in their influence on downstream water quality are designated Class II streams and are protected by a minimum 5-foot-wide SPZ on each side of the stream.

SPZs different from those described above may be established for stream segments of concern (see Turner and O'Laughlin 1991). The width and other requirements for such zones are based on site-specific best management practices recommended by a Local Working Committee and adopted by the Idaho Department of Lands.

Additional requirements found in other sections of the Idaho FPA that protect aquatic and riparian zones within the SPZ are as follows (Idaho Department of Lands 1990):

(1) For Class I Streams, provide the large organic debris (LOD), shading, soil stabilization, wildlife cover, and water filtering effects of vegetation. Specifically, operators are to: (a) Leave hardwood trees, shrubs, grasses, and rocks wherever they afford shade over a stream or maintain the integrity of the soil near a stream; (b) Log mature timber from the Stream Protection Zone in such a way that filtering effects of the SPZ are not destroyed and 75% of the current shade is retained; and (c) Retain standing trees, including conifers, hardwoods and snags within 50 feet of the ordinary high-water mark on each side of all Class I streams in the minimum numbers per 1,000 feet of stream as shown in Table 1.

Table 1. Minimum number of standing trees to be left within 50 feet on each side of all Class I streams in Idaho, per 1,000 feet of stream.

Tree Diameter (at breast height)	Stream Width		
	More than 20 feet	10 to 20 feet	Less than 10 feet
0 - 7.9"	200	200	200
8 - 11.9"	42	42	42
12 - 19.9"	21	21	–
20" +	4	–	–

Source: Idaho Department of Lands (1990)

(2) For Class II streams, provide soil stabilization and water filtering effects by leaving undisturbed soils in widths sufficient to prevent washing of sediment into Class I streams. In no case shall this width be less than 5 feet sloped distance above the ordinary high-water mark on each side of the stream.

(3) Cable yarding within an SPZ shall be done so as to minimize disturbance to the stream bank vegetation and stream channel.

(4) Skidding logs in or through streams is prohibited. Tractor or wheel skidding is prohibited on slopes exceeding 45% gradient immediately adjacent to Class I or II streams.

(5) Temporary structures to carry stream flow are required for stream crossings and must be removed after use.

(6) Water bars must be provided for skid trails. New or reconstructed skid trails, landings, and fire trails must be located on stable areas outside of the SPZ.

(7) Slash must be removed from the stream and piled at least 5 feet above the high-water line on Class I streams. On Class II streams, slash must be removed if it could block the stream or there is sufficient water to transport the material.

(8) Forest practices are to be carried out to minimize the introduction of sediment, debris, petroleum products or other chemicals into streams. This includes planning for transportation networks to minimize road construction within SPZs and the replanting of vegetation between roads and streams as necessary.

(9) Use of chemicals is restricted in SPZs. A minimum of 100 feet of untreated strip must be left on each side of Class I or flowing Class II streams, and a minimum of 25 feet for ground application with power equipment.

(10) There is no prohibition against slash burning within SPZs.

Washington: Riparian Management Zones (RMZs). Under Washington's Forest Practices Rules and Regulations (Washington State Forest Practices Board 1988), buffer strips are provided to protect various uses such as water supply and fisheries. These variable width buffers, termed Riparian Management Zones (RMZs), are designed differently according to ecological needs for eastern and western Washington. Washington streams are divided into 5 classes according to use. In western Washington, RMZ widths are determined by stream class and stream width. RMZs are required to have a minimum width of 25 feet and a maximum width of 100 feet, measured horizontally from the high-water mark by map projection. In eastern Washington, RMZ width is measured from the ordinary high-water mark to the point where vegetation changes from wetland to an upland plant community. RMZ width is also determined by the type of timber harvest in the adjacent upland area. For partial cutting, the required range is from 30 to 50 feet on each side of the stream; for other types of harvest, the range is from 30 to 300 feet on each side of the stream.

Additional selected requirements for Washington's RMZs are as follows:

(1) Leave tree requirements are dependent on stream type, stream-bed material and width, the percent of harvest unit within RMZ, and the size of clearcut.

(2) Shade requirements are determined by temperature sensitivity based upon field data from a "...verified water temperature model or method acceptable to the department." Unless a waiver is obtained, operators must leave all unmerchantable vegetation that provides shade and leave sufficient merchantable timber, if it is necessary to provide 50% of summer shade on the water surface. Where the 7-day average water temperatures exceeds 60°F, 75% cover may be required.

(3) Slash disposal within RMZs must be by hand methods, e.g., lop and scatter, unless otherwise approved by the Department of Natural Resources.

California: Watercourse and Lake Protection Zones (WLPZs). Under California's Forest Practice Rules (California Department of Forestry and Fire Protection 1991), buffer strips are termed Watercourse and Lake Protection Zones (WLPZs) and are used to protect beneficial uses. California recognizes four classes of watercourse or stream, defined on the basis of beneficial use for water supply and fisheries. Widths of the WLPZs are determined by watercourse class and land-slope adjacent to the stream. WLPZs for Class I watercourses range from 50 to 200 feet, depending on four slope classes. For Class II watercourses, WLPZ widths range from 50 to 150 feet. For Class III and IV watercourses, WLPZ widths are determined by field inspection. Alternative prescriptions for WLPZs are allowed on a site-specific basis if they provide at least as much protection as the standard WLPZ requirements. California further requires that a written timber harvest plan be filed by a registered professional forester, which specifically states how watercourses and lakes will be protected.

Additional selected requirements for California's WLPZs are as follows:

(1) Residual vegetation requirements depend on watercourse class and slope. For service as filter strips and to provide shade on Class I watercourses, 50% of the overstory and 50% of the understory must be left standing and be well

distributed. For Class II watercourses, 50% of the overstory and/or 50% of the understory must be left in a similar manner. Future harvesting is restricted until the canopy is re-established. For Class III and IV watercourses, the residual vegetation must be sufficient to prevent degradation of downstream beneficial uses as determined on a site-specific basis.

(2) Materials such as soil, silt, bark, slash, or petroleum must not enter the watercourse or lake. If there is reasonable expectation that timber operations will cause this type of contamination, then the activities must be deferred until a time when equipment, another procedure, or corrective work are approved. Materials accidentally entering Class I,II, and III watercourses shall be immediately removed.

(3) Broadcast burning of slash is prohibited in WLPZs for Class I and II watercourses.

Oregon: Riparian Management Areas (RMAs). Under the Oregon Forest Practice Rules (Oregon Department of Forestry 1991), buffer strips are termed Riparian Management Areas (RMAs). Oregon is divided into three administrative regions: northwest, southwest and eastern. Stream protection regulations for the regions are similar and based on three classes of stream defined primarily on the basis of use as either water supply, fisheries, or recreation. For Class I streams, the width of RMAs is variable and set at three times the average width of the stream at high flow, but not less than 25 feet or greater than 100 feet. RMAs for estuaries are 100 feet and for lakes vary in width by region.

Additional requirements for Oregon's RMAs are as follows:

(1) Leave tree requirements vary with stream width and are specified as conifers per 1,000 feet of stream and basal area per 1,000 feet of stream for Class I streams. These trees must be in the 50% of the RMA nearest the stream or within 25 feet, whichever is greater. These requirements do not apply to the eastern region.

(2) For Class I and Class II (special protection waters), 50% of the tree canopy and all snags that are not hazardous must be left. Also downed timber present prior to harvest and unmerchantable logs must be left.

(3) Other requirements for Class II streams consist of "minimizing channel disturbance from yarding and avoiding tractor skidding in or through any stream" in the southwest and northwest regions. In eastern Oregon, operators are required to "leave stabilization strips of undergrowth vegetation along Class II streams sufficient to prevent washing of sediment into Class I streams below."

(4) For Class I and Class II (special protection waters), 75% of the shade present prior to harvest must be left.

(5) Slash burning is prohibited in riparian areas designated Class I water.

Comparison of Buffer Strip Requirements in Four States

The type of beneficial use derived from a stream is used by all four states as a primary determinant of the need for, and width of, a buffer strip. Washington, Oregon, and California use additional site-specific factors, such as stream width and the slope or type of harvest on adjoining land, to refine buffer strip width prescriptions. Research indicates that consideration of these and other factors enhances the effectiveness of buffer strips (Potts and Bai 1989, Steinblums et al. 1984, Brazier and Brown 1973, Haupt 1959a). In Idaho, buffer strip width is determined primarily by stream class on the basis of beneficial uses without consideration of site-specific factors, except in the special cases of stream segments of concern. The fixed minimum width, use-dependent approach used in Idaho has the virtue of simplicity in application, but has greater potential for providing either not enough or too much protection. The use of stream classification with additional site-specific factors in the other three states adds operational complexity but is more flexible with greater potential sensitivity to local stream protection needs.

Requirements in the four states for buffer zone width, shade or canopy, and leave trees are summarized in Table 2. Leave tree and shade requirements appear in the buffer strip designs for all four states. Because of the different prescriptions for the number, species, and sizes of trees to be left, it is difficult to compare the prescriptions. For example, California requires, in addition to marked leave trees, that 50% of the overstory and 50% of the understory be left on Class I streams; whereas in Oregon the number of leave trees is determined by the stream width and specified in terms of the number of trees per 1,000 feet of stream. The purposes of retaining leave trees and other residual vegetation such as snags and understory are to provide LOD, maintain bank stability, provide fish and wildlife habitat, and control of excessive stream temperature. The measure of the effectiveness of leave trees is not stated directly in terms of sedimentation prevented, fish cover provided, or reduced stream temperature. The exception is Washington, which requires an increase in residual canopy from 50% to 75% when water temperature is 60°F or more. In Washington, Oregon, and Idaho, the measure of effectiveness is stated as shade retained after harvest, expressed as a percent of that existing before harvest. California requires 50% of the overstory and understory be retained; residual shade is not specified. Methods for estimating or measuring the percent canopy or percent shade retained are not specified.

Restrictions on felling, bucking, yarding, and equipment operation within the buffer zones are similar but not identical. One important difference is the prohibition against slash burning within buffer strips along some stream classes that appears in the regulations of Oregon, California, and Washington, but not in Idaho (Skille 1990).

HOW DO FOREST PRACTICES WITHIN BUFFER STRIPS AFFECT WATER QUALITY AND FISH HABITAT?

This section examines the impacts of timber harvesting operations within a buffer strip on water quality and fish habitat. Results reported are based on studies where harvesting was done within a designated buffer strip or where the clearcut included streamside vegetation.

Effects of Canopy Removal

Removing vegetation in the buffer strip reduces canopy density, which in turn may affect stream temperature, cover, primary production, and habitat for salmonids–salmon, trout, and char.

Stream temperature. Increases in June-August maximum stream temperatures from 2°C to 10°C are common in the Pacific Northwest (Beschta et al. 1987). Summer stream temperature increases due to the removal of riparian vegetation have been well documented. (See Holtby 1988, Lynch et al. 1984, Rishel et al. 1982, Patric 1980, Swift and Messer 1971, Brown et al. 1971, and Levno and Rothacher (1967.) These studies generally support the findings of Brown and Krygier (1970) that loss of riparian vegetation results in larger daily temperature variations and elevated monthly and annual temperatures. This occurs in summer periods when stream flow is normally low and air temperatures are high. Measurements by Hewlett and Fortson (1983) under winter conditions also indicate that removal of riparian vegetation can reduce temperatures by about 10°F. These studies

Table 2. Stream buffer strip requirements in four states.

State	Stream Class	Buffer Strip Requirements		
		Width	Shade or Canopy	Leave Trees
Idaho	Class I[*]	fixed minimum (75 feet)	75% current shade[a]	Yes; # per 1,000 feet dependent on stream width[b] (see Table 1)
	Class II[**]	fixed minimum (5 feet)	none	none
Washington	Type 1, 2, and 3[*]	variable by stream width (5 to 100 feet)[c]	50%; 75% if temperature > 60°F	Yes; # per 1,000 feet dependent on stream width and bed material
	Type 4[**]	none	none	25 per 1,000 feet > 6 inches diameter
California	Class I & Class II[*]	variable by slope and stream class (50 to 200 feet)	50% overstory and/or understory; dependent on slope and stream class	yes; # to be determined by canopy density
	Class III[**]	none[d]	50% understory[e]	none[e]
Oregon	Class I[*]	variable; 3 times stream width (25 to 100 feet)	50% existing canopy, 75% existing shade	Yes; # per 1,000 feet and basal area per 1,000 feet by stream width
	Class II Special Protection[**]	none[f]	75% existing shade	none

[*] Human water supply or fisheries use.

[**] Streams capable of sediment transport (California) or other influence (Idaho and Washington) or significant impact (Oregon) on downstream waters.

[a] In Idaho, the shade requirement is specifically designed to maintain stream temperatures.

[b] In Idaho, the leave tree requirement is specifically designed to provide for the recruitment of large organic debris (LOD).

[c] May range as high as 300 feet for some types of timber harvest.

[d] To be determined by field inspection.

[e] Residual vegetation must be sufficient to prevent degradation of downstream beneficial uses.

[f] In eastern Oregon, operators are required to "leave stabilization strips of undergrowth...sufficient to prevent washing of sediment into Class I streams below."

have been summarized by Beschta et al. (1987).

Cover, primary production and salmonid habitat. Riparian vegetation provides extensive and needed cover for fish (Boussu 1954). Loss of riparian vegetation reduces direct cover provided by overhanging plants. Marcus et al. (1990) provided a concise summary of how salmonids respond to cover. In Alaska, stream reaches in clearcut areas without buffer strips had significantly less pool habitat area than reaches within old-growth forests (Heifetz et al. 1986).

Riparian vegetation is an important determinant of primary biological production in a stream. It is a major source of food for stream invertebrates, and also influences the production of aquatic plants by limiting solar energy (Miller 1986). In an Alaskan study, logging significantly altered the quantity, quality and timing of food for invertebrates, which in turn are an important source of food for salmonids (Duncan and Brusven 1985, 1986). In Oregon, Hawkins et al. (1982) found that streams without shade due to clearcutting had a higher abundance of invertebrates than did streams with riparian vegetation and shade. In Alaska, Duncan et al. (1989) demonstrated both increases and decreases in potential salmonid production based on production-response models where canopy density and riparian vegetation composition were independent variables. A Canadian study by Scrivener and Andersen (1982) suggested the enhanced biological productivity due to canopy removal tended to be relatively short lived (1-15 years) due to regrowth of vegetation, particularly in high elevation streams with steep channel gradients. Unfortunately, rigorous quantification of such relationships is not yet available, so prediction of canopy density and primary productivity interactions is not yet possible.

Effects of Timber Harvesting

The effects of timber harvesting within the buffer strip on water quality and fish habitat fall in to two general categories: [1] the recruitment of large organic debris (LOD) and [2] sediment production. On streams with low gradients, habitat changes caused by sediment deposition or changes in LOD may have a duration of 35-50 years (Scrivener and Andersen 1982). Where stream gradients are greater, the impact periods would be less.

Large organic debris (LOD). Large organic debris is the term used to describe pieces or parts of dead trees that have collected in the stream channel. LOD is important in controlling stream flow through the formation of small impoundments (Robinson and Beschta 1990) and in enhancing fish habitat through the provision of cover (Bisson et al. 1987). Sedell et al. (1988) indicated that logging within a buffer strip, and near enough to the stream for LOD to reach it through natural processes, reduces the potential recruitment of LOD, but may increase the availability of smaller limbs. Logging within buffer strips may also change riparian vegetation and result in the reestablishment of earlier successional stages. This would lead to an increase in smaller organic debris that are more easily broken, less well anchored, and therefore have a shorter residence time. Consequently, there may be a decrease in cover and pools adjacent to harvested areas as compared to streams in unlogged areas (Sedell et al. 1988). Following riparian logging in Alaska, Bryant (1980) noted that a large increase in floatable large debris severely affected established natural debris accumulations, in some cases causing natural debris dams to fail.

In Oregon, Andrus et al. (1988) found that riparian trees must be left to grow for 50 years or more in order to insure an adequate, long-term supply of woody debris. Steinblums et al. (1984) examined 40 buffer strips in Oregon and found the residual timber volume ranged from 22% to 100% of the initial gross volume. Windthrow following logging accounted for 94% of the volume lost. Windthrow was more closely correlated with species composition and topographical parameters then with buffer strip width, volume, or age. This suggests that selective harvesting within buffer strips could reduce excessive LOD in some situations and result in a potential undersupply in others.

Sediment production and soil compaction. The literature provides only limited information regarding sediment production or soil compaction due to harvesting within the buffer zone. Clinnick (1985) noted that within buffer strips, "...in the absence of soil disturbance and compaction caused by machinery, overland and channelized flow stand a greater chance of infiltrating the soil profile." Megahan (1980) stressed the importance of the method of yarding as a determinant of sediment production. Methods such as cable or helicopter yarding, where logs are kept completely or partially off the ground surface, cause less soil disturbance than tractor or rubber-tired vehicles that skid logs over the surface. Similarly, Rice et al. (1979) and Burwell (1970) pointed out that the quantity of sediment produced is determined to a large extent by the care taken by the operator. Toews and Moore (1982) reported stream bank erosion was more than 250% greater after logging than before in clearcut areas where no buffer strips were left. After clearcutting an area where a buffer strip 5 meters or less was used, streambank erosion increased only 32% over the preharvest rate. In an Australian case study, neither complete removal nor reduction of buffer strip widths by one-half--from 200 to 100 meters and from 100 to 50 meters--had a detectable effect on suspended sediment concentrations in adjacent streams (Borg et al. 1988).

Given that riparian buffer strips are right next to a stream, it is logical to infer that sediment produced within the buffer strip would enter the stream more readily than sediment from source areas more distant from the stream channel. Operators need to take extraordinary care with forest practices in the buffer strips.

Effects of Slash Burning on Water Quality

Slash burning within a buffer strip can affect water quality. In northern Idaho, Skille (1990) monitored the effects of fall slash burning in or near buffer strips and found substantial increases in nitrogen (N) and phosphorus (P) loading of streams following late fall rains. Early fall burning tended to reduce increases in stream concentrations of N and P because early rainfall was adequate to move the nutrients into the soil where they were depleted, but inadequate to carry them to the stream. A related study examined the influence of buffer strips on changes in water quality at three sites where slash was burned in selected clearcut openings (Snyder et al. 1975). Results from this study suggest that although clearcutting and slash burning increase many water quality attributes on-site, the effects of these changes immediately below the clearcut are reduced by passage through the buffer strip and by dilution. For example, within the clearcut area, the combined effects of the clearcutting and slash burning resulted in increases in pH, electrical conductivity, turbidity, filterable solids (sediment), bicarbonate, nitrate, sulfate, potassium, calcium, and magnesium. However, below the clearcut the only parameters that showed a statistically significant increase relative to water quality above the clearcut were bicarbonate, sulfate, calcium, magnesium, and electrical conductivity. The significance of such water quality alterations is highly dependent on current downstream conditions.

HOW EFFECTIVE ARE BUFFER STRIPS IN REDUCING IMPACTS OF FOREST PRACTICES?

Buffer strip effectiveness is evaluated in five categories: [1] trapping sediment or nutrients, [2] moderating stream temperatures, [3] providing food and cover, [4] providing large organic debris, and [5] moderating cumulative watershed effects. The first two categories each have several subsections, reflecting the greater availability of information in those two categories. The cost effectiveness of buffer strips is a sixth category addressed in this section.

Effectiveness Trapping Sediment or Nutrients

According to Brown (1985), streamside buffer strips are "of little value in handling erosion from side slopes above the buffer in most of the mountainous West." Erosion in western forests, unlike that from agricultural watersheds where sheet erosion is common, is more likely to occur as channelized flow through the buffer strip. This is due to the relatively high degree of slope dissection by ephemeral channels in upland areas adjacent to the riparian zone. These channels frequently continue through the buffer strip to the channel. Where these channels do not exist, however, sheet flows do move overland.

Effectiveness of buffer or filter strips is expressed in several ways. The more common measure of efficiency is the filter strip width required to contain a given percentage of the number of sediment flows. This can also be stated as the probability that flows will reach a given distance or exceed a given buffer strip width. An alternative expression of efficiency is the percent of sediment actually trapped. This is used when a barrier, such as a hay bale or brush, is placed in the path of the flow. Efficiency is calculated by comparing the quantity of sediment trapped behind the barrier with the quantity of sediment trapped plus that moving through the barrier.

The following sub-sections summarize research on the effectiveness of filter strips below roads, and the effectiveness of riparian vegetation in controlling nutrient and sediment losses from forest harvest sites and agricultural fields.

Trapping or filtering sediment from logging roads. Logging, grazing, fire, road construction, and mass wasting or landslides are common sources of sediment in forested watersheds. Road construction is generally recognized as the largest single source of sediment because removal of vegetation and construction of cut and fill slopes initially exposes large areas of erodible surface. (The exception would be in drainages where mass wasting was extensive.) Packer (1967) studied logging roads in the northern Rocky Mountain region and reported that "most sediment from forest lands that reaches stream channels originates on logging roads." Even after erosion control measures have been implemented, roads continue as sources of sediment for extended periods after logging is completed. Road construction as a sediment source has been well described (Burns 1972, Haupt and Kidd 1965, Megahan et al. 1986) and modeled (Leaf 1974, Burroughs and King 1989, Packer 1967). Mass wasting triggered by road construction is a significant problem. On granitic soils in the Idaho batholith, Megahan et al. (1978) found that almost 66% of landslides occurred on road cuts. In the Oregon coastal range, Beschta (1978) reported severe problems from mass failures caused by roads.

Because of the key role roads play in producing sediment, much attention has been focused on limiting sediment delivery from them. Assuming surface flow, factors controlling the movement of sediment from roads fall generally into two categories: [1] those controlling movement of sediment below the road and within the filter strip, and [2] those influencing sediment production and movement from the road surface. Studies pertaining to each category are described in the following paragraphs.

[1] The key factors controlling sediment movement within the filter strip are slope and the density of obstructions, or surrogate variables for these factors. Trimble and Sartz (1957) identified the average slope of the land below the road as the controlling factor in movement through the filter strip and recommended filter strip widths be increased

as the average slope between the road and the stream increased. Swift (1986) compared down-slope sediment movement from roads for various roadway and slope conditions by using as control variables the percent slope and type of surface obstruction, e.g., grass, litter, brush, and downed trees. In Idaho, Haupt (1959a, 1959b) related sediment movement in the filter strip to site conditions and road drainage factors, e.g., aspect, cross-ditch interval, road gradient, fill slope length, and the number and types of flow obstructions along the slope. A similar regional study in the northern Rocky Mountains by Packer (1967) found that travel distances from cross-drain outlets were determined by soil type, age of road, cross-drain spacing, initial distance to slope obstruction, and fill slope cover density.

[2] Several studies focused on mitigation measures to control sediment leaving the road surface and fill slope. Swift (1986) found that brush barriers and hay bales used in windrows are effective sediment traps when placed at the base of the fill slope. On 47% slopes without barriers, the maximum sediment travel distance was 314 feet and the average travel distance 81 feet. When brush barriers were used, these distances were halved. Cook and King (1983) examined the effectiveness of filter windrows on road fill slopes adjacent to streams. Windrows constructed from slash and cull logs obtained from the road right-of-way were 75-85% efficient in trapping sediment before it moved into the filter strip. Similarly, Burroughs and King (1985) compared sediment yields from treated fill slopes to the yields from fill slopes with a loose soil surface. Dense grass planted on a section of fill slope at a 67% slope reduced sediment yield by 97%, a wood fiber mulch reduced sediment yield by 91%, and a slash windrow reduced sediment yield by 87%. The effectiveness of road surface treatments in reducing sediment yields in comparison to unsurfaced roads was also examined. Gravel, dust, oil and bituminous surface treatments reduced yields by a factor of 4.3, 7.7, and 91 respectively.

Reported sediment travel distances and filter strip efficiencies showed considerable variation from study to study. The following studies highlight the difference in travel distance between sediment moving off road fill onto a vegetated filter strip and sediment moving from the road and into a channel formed below a drain. Filter strips on the order of 200-300 feet are generally effective in controlling sediment that is not channelized. Assuming an adequate water flow, sediment from drains can move several thousand feet or more. In New Hampshire, to trap 90% of the number of flows, Trimble and Sartz (1957) recommended filter strips ranging from 25 feet at zero percent slope to 165 feet at 70% slope. For areas where the "highest possible water quality standard" was to be maintained, presumably near 100% efficiency, they recommended doubling the distance. Swift (1986) measured travel distances through forest litter on 47% slopes. The maximum travel distance was 314 feet and the average distance was 65 feet. On burned forest floor at a 42% slope, the maximum travel distance was 198 feet and the average was 96 feet. Working in granitic soils in Idaho, Haupt (1959a, 1959b) reported minimum protective strip widths for a range of road and site conditions. For a road with a 10% gradient on a south slope where the side-slope gradient is greater than 56%, the required filter strip width would be 185 feet to dissipate 83.5% of the number of flows. An additional 45 feet would be needed to contain 97.5% of the flows. The maximum protective strip width recommended in this study was 200 feet for cross-ditch intervals of 130 feet. Packer (1967) reported protective strip widths needed to contain 83.5% of the number of flows on comparatively stable basalt soils ranged from 35 to 127 feet depending on the type of obstruction--e.g., slash or herbaceous vegetation--and spacing between obstructions. Efficiency of the protective strip could be increased to 97.5% by adding an additional 60 feet to the strip widths. In the Idaho batholith, Ketcheson and Megahan (1990) observed sediment deposition on slopes below roads and concluded that sediment originating from cross-drains where sediment can accumulate and water supply was relatively large could reach streams up to 4,500 feet down-slope. However, the probability of sediment from cross-drains traveling in excess of 300 feet is only 15%. Sediment discharged from other road sources--e.g., fill slopes, berm drains and rock drains--traveled no more than 200 feet, with a near-zero probability of exceeding 200 feet. In another Idaho study on steep slopes with soils derived from gneiss and schist parent materials, Burroughs and King (1989) examined sediment travel distances below road fill slopes. They found that 90% of the sediment flows below fill slopes traveled less than 88 feet. Where fill slope flows were influenced by flows from drains, 90% of the flows traveled 200 feet or less. In southwestern Washington, Bilby et al. (1989) documented the export of sediment from road surfaces and found that about 34% of the road drainage points studied entered first and second order streams via small channels. They observed that retention of sediment in these channels increased with particle size, and that the small channels became temporary storage repositories for sediment.

Results from the road filter strip studies summarized above have important implications for designing SPZs in Idaho. First, the Idaho study by Haupt (1959a, 1959b) and the regional study by Packer (1967) provided reasonable estimates of needed filter strip widths where the sediment source is a logging road and that road is located near a stream, a common situation in Idaho. Similarly, the erosion control work by Cook and King (1983) and Burroughs and King (1985) is applicable in the same context. Second, although results from the studies cited in this section are not directly applicable to situations where the sediment source is other than roads, they do provide useful general information about riparian buffer strip effectiveness. These studies specifically indicate that given a sediment source, non-channelized transport distance increases with slope and decreases with the number of obstructions within the filter strip. The studies also suggest that for non-channelized flow, sediment rarely travels more than 300 feet. Channelized flows through filter strips, however, can move thousands of feet and are limited primarily by the amount and frequency of flow. A survey of forest practice compliance by the Idaho Water Quality Bureau (1988) found that "...existing roads near stream channels is [sic] the most important factor currently contributing to water quality degradation."

These findings suggest four things about buffer strip design: [1] riparian buffer strip widths should be greater where slopes within the zone are steep, [2] riparian buffers are not effective in controlling channelized flows originating outside the buffer, [3] sediment flow through a buffer can travel up to 300 feet in a worst-case scenario, and [4] removal of natural obstructions to flow--vegetation, woody debris, rocks, etc.--within the buffer increases the distance sediment can flow.

Filtering nutrients and sediment from forest lands. The impacts of forest practices on nutrient cycling and the loss of nutrients through streamflow have received considerable attention in the literature (see Martin and Harr 1989, Tiedemann et al. 1988, Hornbeck et al. 1986, Clayton and Kennedy 1985, Martin et al. 1984, and Aubertin and Patric 1974 and are summarized well in the textbook by Brooks et al. (1991). However, the influence of riparian filter strips on sediment and nutrient discharge, with the exception of the previously discussed road-side filter strips, has not been examined extensively. In northern Idaho, Snyder et al. (1975) found that following clearcutting and burning of slash, buffer strips reduced the loss of certain nutrients and filterable solids, i.e., organic matter and sediment. Effectiveness of the buffer strips as filters was not determined in that study. In northern Idaho, Skille (1990) monitored the effects of fall slash burning in or near SPZs and noted substantial increases in nitrogen and phosphorus loading of streams following late fall rainfall. Although the effectiveness of buffer strips as filters was not evaluated, Skille noted that early fall burning tended to reduce increases in stream concentrations of N and P because early rainfall was adequate to move the nutrients into the soil, but inadequate to carry them to the stream.

These studies suggest that filter strips reduce the amount of nutrient loading following harvest and slash burning, but they do not provide a basis for determining the size or effectiveness of buffer strips. The studies also suggest that where nutrient loading is a problem, burning slash within the buffer is likely to increase the loading and the problem.

Trapping nutrients and sediment from agricultural lands. The utility of forest riparian zones as buffers for sediment and nutrients from agricultural lands is of interest because forested riparian lands are commonly used for containment of wastes. Statistical models were developed by Omernik et al. (1981) to relate nutrient levels in streamflow to the extent and proximity of forested and agricultural lands to streams. These models were unable to show that the proximity of forest lands impacted stream nutrient levels. Cooper et al. (1987) estimated that more than 50% of the sediment lost from cultivated fields was deposited in the channels within 100 meters of the fields and that only 25% reached a riparian swamp two kilometers distant. In the Southwest, Kuenzler (1988) found that freshwater forested wetlands were effective filters in removing suspended sediment and nutrients. In Georgia, Lowrance et al. (1984) examined nutrient cycling in a forested riparian ecosystem and reported it was potentially an excellent sink to store nutrient and chemical releases from agroecosystems. To maintain the capacity of the riparian ecosystem as a buffer, they suggested that "proper streamside forest management requires both periodic harvest of trees to maintain nutrient uptake and minimum disturbance of soil and drainage conditions." Lee et al. (1989) modeled phosphorus transport through grass buffer strips and found the transport process, via dissolved solids and sediment, to be largely controlled by buffer strip width and length, infiltration rates, grass spacing, the buffer strip slope, and Manning's roughness coefficient (see the Glossary). Transport of dissolved P was also sensitive to the amount of above-ground biomass.

These studies suggest the utility of forest vegetation and wetlands as filters for sediment, nutrients, and other chemicals; but provide no definitive means of estimating the dimensions of the required buffer strip.

Effectiveness Moderating Stream Temperatures

Stream temperature elevation and control following harvesting. Summer stream temperature increases from the removal of riparian vegetation have been well documented. Increases in June to August maximum stream temperatures of 2°C to 10°C are common in the Pacific Northwest (Beschta et al. 1987). These studies generally support the findings of Brown and Krygier (1970) that for summer periods when streamflow is normally low and air temperatures are high, loss of riparian vegetation results in larger diurnal temperature variations and elevated monthly and annual temperatures. Measurements by Hewlett and Fortson (1983) under winter conditions also indicate that removal of riparian vegetation can reduce temperatures by about 10°F. These studies have been summarized by Beschta et al. (1987).

The effectiveness of buffer strips in moderating stream temperature has also been studied. In West Virginia, Aubertin and Patric (1974) reported negligible changes in stream temperature after clearcutting and attributed this to a buffer strip and fast regrowth after harvest. In Pennsylvania, maximum monthly stream temperatures on a clearcut area where a buffer zone was left along a perennial stream showed only a slight change of less than 1°C in comparison to control watershed measurements (Rishel et al. 1982). Similarly, in North Carolina, a narrow buffer strip left in clearcut areas would moderate stream temperatures caused by harvesting (Swift and Baker 1973). Although these studies demonstrated the utility of riparian buffer strips, they provided limited information as to the dimensions or vegetative characteristics of the buffer strips that are required to make them effective.

Shade from riparian vegetation and stream temperature. Several studies of the heat energy exchange between a partially shaded stream and its environment have shown that solar radiation is the dominant source of energy, whereas evaporation and conduction to the channel bottom are the principal energy sinks (Brown 1969, Sullivan et al. 1990). Little can be done about the sinks in practice, so the major opportunity to control stream temperature is to moderate the input source--solar radiation from the sun. Buffer strips provide the opportunity.

The presence of shade-producing vegetation in buffer strips is a key factor determining the amount of radiant energy that reaches a stream. Other important determinants are local topography, stream reach orientation to the sun, and stream width and depth (Brown 1985). The volume of timber in a buffer strip is not well correlated with shade (Brazier and Brown 1973); however, statistically significant relationships have been found between buffer strip width and shade expressed as angular canopy density, or ACD (Steinblums et al. 1984, Brazier and Brown 1973). ACD effectively integrates spatial factors--e.g., stream width, tree height, and canopy density--for a given site. A series of ACD readings at intervals along a stream reach provides an average value of ACD for the stream reach.

Buffer strip width and stream temperature. Two studies in Oregon have demonstrated that buffer strip width is not a good measure of buffer strip effectiveness in protecting stream temperature. Steinblums et al. (1984) measured 40 riparian buffer strips. For 28 buffer strips with widths from 25 to 145 feet, ACD measurements ranged from 15% to 87%, with an average of 51%. On 12 other buffer strips of essentially infinite width, ACD measurements ranged from 26% to 83%, with an average of 62%. The relatively small and unreported statistical differences in these data and in their means illustrate the importance of factors other than buffer strip width in determining ACD, including species, tree height, stream width, and stream orientation. Also in Oregon, Brazier and Brown (1973) defined buffer strip effectiveness as net radiation or heat blocked by the canopy, and developed two statistical relationships: [1] between heat and ACD, and [2] between buffer strip width and ACD. They concluded that ACD is the most appropriate single measure of canopy effectiveness, and that buffer strip width alone is not a significant variable for predicting stream temperature. For the streams included in that study, maximum ACD occurred with an 80-foot buffer strip, and 90% of the maximum ACD could be obtained with a 55-foot strip.

In an Ontario trout stream study, Barton et al. (1985) demonstrated the relative insensitivity of stream temperature to buffer strip width. They found stream temperature declined an average of .015°C per meter of buffer strip width, or about .5°C for a 100-foot buffer strip.

Effectiveness Providing Large Organic Debris (LOD)

Large organic debris (LOD) enters streams on an irregular basis due to natural mortality, severe storms, and fire. Harvesting or other management practices that influence stand characteristics, such as tree species and stocking levels, also influence the timing and quantity of LOD contribution. Site characteristics, such as depth of water table and orientation to dominant winds, affect windthrow and hence LOD contribution (Steinblums et al. 1984). A Canadian study reported by Toews and Moore (1982) compared LOD recruitment from three clearcut areas. One was logged intensively, a second carefully, and a third was left with buffer strips 5 meters (16 feet) or less in width. The intensively and carefully logged areas--those without buffer strips--provided large amounts of LOD that resulted in reduced stability of LOD already in the channel as well as bank instability. LOD contributions from the clearcut area with a buffer strip were similar to natural LOD recruitment levels.

Source distances for coarse woody debris--the distance from rooting site to stream bank--were studied at 39 sites in western Oregon and Washington by McDade et al. (1990). Their analysis for old-growth conifer forests suggested that a 30-meter (98-foot) wide buffer strip would provide 85% and a 10-meter (33-foot) strip would supply less than half the amount of naturally occurring debris. Source distance and debris size was less in old-growth stands than in mature stands with shorter trees, indicating tree height was a factor in LOD recruitment. They also found that the number of debris pieces and the source distance increased with bank slope. Using effective tree height as a measure, Robison and Beschta (1990) determined the conditional probability that a tree would provide LOD to a stream. Effective tree height was defined as the height at which a minimum acceptable diameter size for LOD occurred. When the distance from a tree to stream was more than one effective tree height, the probability of the tree contributing LOD approached zero. This suggests that buffer strips with widths at least equal to the effective tree height would provide maximum amounts of LOD. Unfortunately, research data currently are inadequate to provide general guidelines as to how much LOD should be available or how much is required at a given stream reach.

Effectiveness Controlling Cumulative Effects

Cumulative effects are impacts on water quality or beneficial uses which result from the incremental impact of two or more forest practices (Idaho Legislature 1991). Cumulative effects can result from individually minor, but collectively significant, actions taking place over time or space. Although numerous studies of cumulative effects--e.g., water yield increase (Belt 1980, King 1989) and temperature increases (Beschta and Taylor 1988)--appear in the literature, research relating buffer strips to control of cumulative effects is limited. However, a few interesting examples were discovered. A Canadian study of the suitability of streams for trout (Barton et al. 1985) showed that the maximum 3-week average stream temperature was determined by the upstream length of forested buffer strip. In a study of 11 sites, the cumulative effect of the removal of upstream riparian vegetation was to increase the maximum on-site temperature. A simple mixing ratio equation (US EPA 1980) allows estimation of the cumulative effects of upstream temperature increases at downstream locations. Lowrance et al. (1984) noted that buffer strips are simultaneously sinks that retain and sources that release the cumulative effects of agricultural and forestry activities in the form of sediment, nutrients, and chemicals. This suggests that buffer strips and wetlands should be managed to enhance their storage capability. Buffer strips and adjacent wetlands can moderate flooding caused by the cumulative effects of timber harvest by adding the hydraulic resistance from riparian vegetation and additional storage capacity at flood stage.

Effectiveness Providing Food and Cover

Buffer strip impacts on the aquatic food chain are documented reasonably well by studies contrasting the effects of timber harvests with and without buffer strips. However, there are only a few studies where the characteristics of the buffer strip were related to food production so that buffer strip effectiveness could be evaluated.

A study by Erman and Mahoney (1983) in California measured buffer strip effectiveness relative to food production in terms of the rate of recovery of post-harvest macroinvertebrate diversity to preharvest levels. Diversity in streams at logged sites without buffer strips and with 30-meter (98-foot) buffer strips were compared to diversity in streams where no logging had taken place. The streams without buffer strips showed an increase in diversity but incomplete recovery after a 6-year period, while the streams with buffer strips maintained diversity at a constant level. In a similar New Zealand study, Graynoth (1979) compared impacts on clearcut watersheds, with and without buffer strips, with those on a third uncut catchment used as a control. After harvest, in the stream without a buffer strip water temperature and sediment increased while benthic invertebrate fauna and the number of fish declined. The stream with the buffer showed little or no impact, except for increased sediment. Culp (1987) reported that 10-meter (33-foot) buffer strips reduced fine sediment from bank erosion but did not prevent decreases in macroinvertebrate density. In southwest Alaska, Duncan and Brusven (1985, 1986) developed a series of energy-flow models that related the percent coverage of riparian canopy to three biological production variables–invertebrate, potential salmonid, and usable allochthonous production. These models also included the percentage of deciduous tree species and relative stream nutrient levels as variables. The model for invertebrate production showed that reducing the canopy from 100% to 50% caused a 28% decrease in invertebrate production. Conceptually these models could also be used to estimate the effectiveness of buffer strips in providing food and cover based on changes in riparian canopy density. The authors, however, cautioned that the models should be used to evaluate trends in production rather than absolute values.

Cost Effectiveness of Buffer Strips

Consistent with most analyses of the costs and benefits of natural resources management alternatives, the costs of buffer strips are relatively easy to quantify, but the benefits are not. Establishment of buffer strips normally results in additional costs to the landowner, public or private. Costs incurred include the loss of stumpage, higher costs of logging and road construction, and additional administrative costs (Streeby 1970). Benefits from buffer strips accrue largely to the public and include improved bank stability and water quality, enhanced fish and wildlife habitat, and greater aesthetic value.

Bollman (1984) noted that the costs of specific buffer strip prescriptions vary with market conditions, the type of stand, and other variables, but were relatively easy to evaluate. Conversely, benefits from the prescriptions were frequently non-market values–e.g., fish habitat, species diversity, and water quality–that were much more difficult to evaluate. The question of equity arises when private land owners or logging firms must bear the costs of operating in or around buffer strips that benefit sport fishermen, other industries such as commercial fishing, or the general public (Gillick and Scott 1975). In a detailed benefit-cost analysis of buffer strips in Washington, Gillick and Scott (1975) addressed these problems, and suggested the use of a "financially optimal buffer" with an optimal width where the harvest costs would be offset by the environmental gains. The optimal width is by their definition the most cost-effective width. Considering only the values of fish and logs, they found the "zero foot" buffer strip–i.e., no buffer strip at all–to provide the greatest net economic value.

In Puerto Rico, Scatena (1990) identified an "economically optimal buffer width...[where] ...marginal gain in buffer area equals the marginal increase in commercial basal area included in the buffer." In this case, buffer strip area was used as a surrogate for benefits.

and basal area included in the buffer as a surrogate for cost. Based on studies in several tropical catchments, this optimal buffer width was 22 meters (73 feet) for perennial streams and less than 10 meters (33 feet) for intermittent streams. This study, although not directly applicable to Idaho, illustrates an alternative approach to evaluation of buffers based on financial criteria.

These studies suggest potential difficulties in establishing buffer strip areas or widths based on economic criteria such as a benefit-cost ratio. First, although costs are relatively easy to determine, important non-market benefits are difficult to evaluate. Second, the value society places on non-market riparian benefits such as biological diversity is subject to not only measurement difficulties but also considerable changes in public perception and relative scarcity, all of which are likely to be substantially greater in the future. Consequently, establishing buffer strip areas or widths based solely on the economically optimal or most cost-effective methods illustrated by the two studies cited in this section could be short-sighted, as the public perception of benefits might be expected to increase over time faster than the costs.

WHAT ARE THE ISSUES IN BUFFER STRIP DESIGN?

Three significant issues associated with the design of a policy requiring buffer strips were identified during this review. First, should buffer strip requirements be of a minimum width, or should the width vary according to physical or biological characteristics of the stream and riparian zone? Second, how much, if any, vegetation can be removed from the buffer strip? The third issue is how can several design criteria be incorporated into a buffer strip design?

Fixed Minimum vs. Variable Widths

Minimum width buffer strips are relatively simple to implement and administer. Fixed minimum widths in Idaho are determined by the intended use--e.g., domestic water supply, fish production, etc.--rather than by the site-specific factors, such as nearby harvest areas, density or size of riparian vegetation, or the slope or stability of the riparian soils. In Idaho beneficial uses and water quality are protected by buffer strips defined by (1) a minimum width requirement and (2) qualitative requirements to provide soil stabilization and water filtering effects. Class I streams (drinking water and fish habitat) require a minimum 75-foot Stream Protection Zone (SPZ) or buffer strip to protect domestic water supplies for fisheries. Class II streams, defined as those not used for potable water or without a significant fishery, require a minimum 5-foot buffer strip. Compliance audits of timber sales and logging roads in Idaho do not indicate buffer strip widths are a problem (Idaho Water Quality Bureau 1988; Bauer 1985). But because actual buffer strip widths were not reported and widths greater than the minimum may be used, it is not logical to infer from the audits that the minimum widths were adequate.

In certain situations, minimum width buffer strips may provide more than adequate protection, and in others, inadequate protection. For example, envision a forested slope where land pitches up steeply from a Class I stream and a road has been constructed 200 feet up the slope. Would a 75-foot buffer be adequate, or would it be preferable to leave all 200 feet as a filter strip? Conversely, consider a 50-foot wide Class I stream segment passing through a deep valley with low erosion potential and topographically shaded most of the day by rock cliffs and trees within 50 feet of the stream. Does this segment require a 75-foot buffer strip to filter sediment or reduce thermal loading? Variable width strips allow greater flexibility and sensitivity to specific protection needs. For example, Bisson et al. (1987) suggested the use of variable width buffer strips to optimize LOD recruitment and minimize the number of residual but unrecruitable leave trees. They also envisioned the use of "clumped" buffer strips where minimum widths for bank stability and shade are left in some reaches, while adjoining reaches have larger clumps of trees, –i.e., extra wide buffer strips–affording better LOD recruitment and wildlife habitat. This approach would allow buffer strip layout to more closely mimic natural ecosystems, in keeping with "new forestry" concepts. Another approach to defining an appropriate variable width buffer was described by Potts and Bai (1989). Here the width is based on the riparian area needed to control surface runoff. This model is summarized in more detail below in the Models section of this report. As mentioned earlier in the report, variable width buffer strips are prescribed in Oregon, California, and Washington under forest practice legislation and rules and regulation. Site-specific factors such as stream width, slope of land adjacent to the stream, or type of harvest on adjoining land are used to refine the minimum or maximum widths prescribed in the law. Variable width buffer strips have the potential to improve stream protection benefits based on individual stream characteristics. However, although studies describing the utility of various variable width buffer strip models were found, no studies were found that document the advantages or disadvantages of variable width buffer strips, as compared to fixed minimum width buffer strips.

Removal of Vegetation

How much vegetation can be removed from the buffer strip without impairing its buffering functions? As previously described, riparian vegetation within the buffer strip serves many purposes including maintenance of bank stability, provision of LOD for moderation of stream temperature, and filtration of overland sediment flow. Under the Idaho FPA, selective logging of mature timber is allowed within the buffer strip (SPZ) as long as (1) the soil stabilization and sediment filtering effects are not destroyed, (2) at least 75% of the current preharvest shade over the stream is retained, and (3) leave trees are provided as prescribed.

Idaho water quality standards for salmonids require the maximum daily temperatures not to exceed 13°C and the average daily temperatures not to exceed 9°C. Retaining no less than 75% of current shade by definition means that removal of up to 25% of the current shade is permissible. This means that regardless of the existing level of shade, it can be reduced up to 25%. Given different tree species, canopy densities, stream widths, and reach orientations, the requirement to retain 75% of current shade may or may not protect a stream from thermal loading. In terms of protection of water quality and fish habitat, research does not show that maintaining 75%, or any other pre-harvest level of shade, will assure the salmonid temperature standards are met. Similarly, the Idaho FPA leave tree requirement specifies the number of conifers, hardwoods, and snags that must be left within 50 feet of the highwater mark on each side of a thousand-foot stream segment to provide LOD. While the intent to provide LOD is clear, the effectiveness of this general prescription in accomplishing this end for all stream reaches is not clear from the literature. The prescribed leave trees may be essential or unneeded, depending on the existing and future in-stream requirements for LOD. Finally, neither the literature nor the FPA suggest that the vegetation removal constraints–i.e., the 75% current shade and the leave tree requirements–will generally meet the qualitative requirement to provide soil stabilization and water filtering effects.

Multiple Design Criteria

The problem of multiple criteria is not effectively addressed in the literature reviewed. In previous sections of this report several design criteria have been discussed that determine either buffer strip width or other attributes such as canopy density or number of residual leave trees, based on their various protection or supply functions such as temperature moderation or LOD recruitment. Given the practical need for simplicity in field applications, the operable question then is how these multiple criteria can be incorporated in field applications.

Idaho and adjoining states currently use a regulatory approach where multiple buffer strip criteria are simply stated as separate requirements—e.g., width, number of leave trees, etc.—and their interpretation and implementation is left to field staff. This approach has considerable merit, but there are several others with potential where the multiple criteria are combined into a single requirement.

One example is a "cartographic" approach where a spatial model is used in conjunction with a geographical information system or GIS (Dick 1991). This method uses a single criterion, temperature moderation, and allows the mapping of a buffer strip based on existing trees capable of providing shade to the stream. This "status quo" buffer width would provide pre-harvest levels of shade and temperature. Extension of this approach to multiple criteria would be possible if additional criteria could be expressed in spatial terms and incorporated in a cartographic model.

A second, maximum protection, approach would be to evaluate each of several criteria in terms of buffer strip width and then adopt the greatest width so as to accommodate all criteria. This approach is illustrated in the following scenario. Suppose the width of a buffer strip is to be determined based on three criteria: temperature moderation, LOD recruitment, and sediment filtration. First a "status quo" buffer width (Dick 1991) for moderating stream temperature based on existing trees capable of providing shade to the stream is calculated to be 65 feet. Then the buffer strip width required for LOD recruitment, based on the proximity of a tree to the stream and the conditional probability it will fall into the stream, is found to be 85 feet. Finally, the buffer strip width needed to filter sediment in unchannelized flow below a road is computed to be 125 feet based on Haupt's (1959a) road model. The buffer strip width used would then be 135 feet.

A third regional method that might be used to determine buffer strip widths is based on a regional analysis of buffer strip widths using a GIS. For example, in a region where fisheries are a major concern, shade and LOD recruitment could be used as criteria for buffer strip width determination. Buffer strip widths for each criterion would be determined at selected stream reaches within the region. A regional buffer width would then be determined from these data based on its statistical applicability. For example, a regional buffer width could be selected so as to meet the shade criterion at 90 percent of the reaches and both criteria at 67 percent of the reaches within the region.

WHAT MODELS ARE AVAILABLE FOR USE IN BUFFER STRIP DESIGN?

Although several compliance audits of the Idaho FPA have been made evaluating how well operators have met the FPA rules (Bauer 1985), no studies were found that show compliance with FPA rules will result in meeting the water quality standards such as stream temperature. Several models that could be adapted for such purposes are described in this section of the report. These models could be used to design more effective buffer strips for stream segments of concern, or when specially requested by operators as provided for under the Idaho FPA.

Water Temperature Models

Several water temperature simulation models that have been developed for stream reaches were recently analyzed by a Timber, Fish and Wildlife (TFW) "Temperature Work Group" in the state of Washington (Sullivan et al. 1990). The criteria used were accuracy, reliability, and practicality in estimating the impacts of timber harvest on stream temperature (Sullivan et al. 1990). The TEMP-86 model developed by Beschta and Weatherred (1984) had the greatest accuracy. However, the TEMPEST model formulated by Adams and Sullivan (1990) ranked highest when other criteria, such as data requirements, were also considered. Brown's (1969) model, which is less detailed and a forerunner of the more recent modeling efforts, ranked third. (See Sullivan et al. (1990) for other models and more detailed discussion.)

Sullivan et al. (1990) described a water temperature protection method in Washington referred to as the "Recommended TFW Temperature Method." This method consisted of two components: [1] a screening procedure to obtain a rough estimate of existing stream reach temperature and relate it to water quality and forest practice standards, and, if needed, [2] the TEMPEST simulation model for a more accurate estimate of existing and harvest-induced increases in water temperature. These two components of the water temperature models mentioned in the preceding paragraph are further discussed in the following sub-sections.

TFW water temperature screening model. The screening model is used to estimate the existing water temperature at a given site and determine if it exceeds thresholds established in Washington water quality or forest practice standards. The predictive relationship between water temperature, site elevation, and percent of stream surface shaded was based on field observations at approximately 42 sites in Washington. In application, the elevation and percent of shade at a given site can be used to determine which temperature threshold (high, medium, or low) is being met and if reduced shading due to harvest will alter the temperature threshold. This approach is well conceived, has been peer reviewed, and appears to be a promising tool.

TEMPEST model. This model was developed in Washington by Adams and Sullivan (1990) and is an unpublished computer simulation model designed to estimate the effects of buffer strips on water temperature, based on an assessment of the heat energy budget for a stream reach. A principal feature of the TEMPEST model is the use of several simplifying assumptions that reduce the number of input data required (Sullivan et al. 1990). Data required to run the model include geographic location, elevation, percent shade, and stream depth. The model predicts hourly stream temperature over any specified interval. In reliability tests using measured stream temperature for reference, 95% of the time the model predicted average water temperature within plus or minus 2°C.

TEMP-86 model. This model was developed in Oregon by Beschta and Weatherred (1987), and is designed to evaluate the effects of buffer strips on stream temperature. The model is based on a stream reach heat energy budget, with solar radiation as prime energy source. Canopy height and density are the model variables that influence solar energy input to the stream. Stream reach geometry is a required input. The model allows the user to compare the effects of different riparian buffer designs on water temperature. For example, different widths and canopy heights or densities predict hourly water temperatures for any given day and geographical location. Model data requirements are relatively extensive. Once the data are entered into the program, however, the effects of different harvest methods or leave tree requirements on water temperature can easily be compared. The model has been coded for personal computers, is menu driven, and is available from Oregon State University.

Surface Runoff-Based Variable Width Buffer Model

This model was developed in Florida to protect water quality in the Suwannee River, which retains natural riparian areas but is affected by urban development. Potts and Bai (1989) described a model for determining variable width buffer zones that would protect the river from urban pollutants carried in surface runoff. The model determines the width of a buffer required to maintain runoff volume from land converted to an urban land use near the river at the same volume as that which would be produced by the same land in an undisturbed natural condition. The model relies on the USDA Soil Conservation Service runoff curve number (RCN) method for determining the amount of runoff expected for a given soil, slope, vegetative condition, and amount of impervious surface. Graphs relating buffer strip width to the RCN were developed for four soil and five land use types occurring along the river. The graphs and knowledge of the soil type and RCN for undisturbed conditions allow determination of the appropriate buffer strip width for a particular site and land use. This approach reduces the volume of water available to transport pollutants rather than the amount of pollutants. While not directly applicable to Idaho, this approach minimizing runoff using the RCN method may be useful.

Sediment-Based Road Filter Strip Model

In a southwestern Idaho study on steeply sloping granitic soils, Haupt (1959a, 1959b) determined the minimum width of a protective strip required to dissipate surface runoff and erosion from a logging road. The protective strip width was related to road drainage factors, including cross-ditch interval, road gradient, fill slope length, and the number and types of flow obstructions along the slope. Minimum protective strip widths for a range of road and site conditions, including aspect, were reported in tabular form. For a road with a 10% gradient on a south slope where the side-slope gradient is greater than 56%, the required filter strip distance would be 185 feet to dissipate 83.5% of the number of flows. An additional 45 feet would be needed to contain 97.5% of the flows. The maximum protective strip width recommended was 200 feet for cross-ditch intervals of 130 feet.

LOD Recruitment Model Based on Conditional Probability

A conditional probability model that can be used to identify trees in riparian areas that can provide large organic debris (LOD) to streams was developed by Robison and Beschta (1990). Conditional probability is the chance that a tree at a given distance from the stream will fall into the stream. The model can be used to estimate the width of a buffer strip that will provide the maximum LOD possible to a stream, or to select leave trees within a buffer strip that may contribute LOD. The model does not provide a means of estimating the actual number of trees or quantity of LOD that will be provided to a stream. The model is based on two probability assumptions, both related to the distance from tree to stream. The probability of a tree providing LOD to a stream [1] approaches zero when the distance between tree and stream is more than the effective tree height, and [2] approaches 100% when the tree is immediately adjacent to a stream. Effective height is defined by the smallest diameter of tree (measured at the top) acceptable as LOD. By using the developed empirical equations and mensurational data for a particular tree species that relate effective tree height and basal area, a wedge prism factor for identifying LOD trees within the buffer can be calculated. The model is available in equation form only.

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GLOSSARY

The following definitions are helpful in understanding the technical material presented in this report. The use of bold italics within a definition indicates another term defined in the glossary.

Allochthonous - Originating elsewhere and transported to the site, e.g., terrestrial plant matter in a stream (Society of American Foresters 1983).

Angular canopy densiometer - A one-foot-square plane mirror mounted on a 1.5-foot tripod. The densiometer surface is divided into sixteen 3-inch squares. In operation, the densiometer is placed in the stream, orientated toward the south (in the northern hemisphere), and tilted at an angle so its surface is perpendicular to the sun's rays during the warmest portion of the year.

Angular canopy density (ACD) - ***Canopy density*** measured with an ***angular canopy densitometer***. ACD is a measure of shade provided by ***riparian vegetation*** (Brazier and Brown 1973). ACD is the density of the ***canopy***, expressed as a percent, measured along the path of incoming solar radiation.

Autochthonous - Originating on site, e.g., aquatic plants found in the stream (Society of American Foresters 1983).

Beneficial use - The reasonable and appropriate use of water for a purpose consistent with Idaho state laws and the best interest of the people. They include, but are not limited to, domestic water supplies, agricultural water supplies, fish and wildlife habitat, and recreation on or in the water (Idaho Water Quality Bureau 1989).

Best management practices (BMPs) - A practice or combination of practices determined to be the most effective and practicable means of preventing or reducing the amount of pollution generated by ***nonpoint*** sources (Idaho Water Quality Bureau 1989). ***Forest practices*** BMPs are determined by the Idaho State Board of Land Commissioners in consultation with the Department of Lands and the forest practices advisory committee (Idaho Department of Lands 1990).

Buffer strip - A protective area adjacent to an area requiring special attention or protection (Idaho Department of Lands 1990).

Canopy - The more or less continuous cover of branches and foliage formed collectively by the crowns (or top portions) of adjacent trees (Society of American Foresters 1983).

Canopy density - The degree of completeness of the tree ***canopy***, i.e., the degree of canopy closure and therefore an aggregate expression of crown cover (Society of American Foresters 1983).

Channelized flow - Water flow concentrated by a channel, e.g., a rill or gully.

Class I stream - Streams which are used for domestic water supply or are important for the spawning, rearing or migration of fish. Such waters shall be considered Class I upstream from the point of domestic diversion for a minimum of 1,320 feet (Idaho Department of Lands 1990).

Class II stream - Streams that are usually headwater streams or minor drainages that are used by only a few, if any, fish for spawning or rearing. Their principal value lies in their influence on water quality or quantity downstream in ***Class I streams*** (Idaho Department of Lands 1990).

Computer simulation model - A computer algorithm that mimics the structure and function of ecosystems (or parts thereof) and is used to predict impacts of various management activities to those systems.

Conditional probability - The chance that an event will occur that depends on the occurrence of a different event.

Cross-ditch interval - Cross-ditches are shallow trenches placed across the road surface to collect surface water and channel it to the side of the road. Cross-ditch interval is the distance between trenches measured along the road surface.

Cumulative effects - Impacts on water quality or ***beneficial uses*** which result from the incremental impact of two or more ***forest practices*** (Idaho Legislature 1991). Cumulative effects can result from individually minor but collectively significant actions taking place over time or space.

Cut Slope - The slope of the residual soil surface after excavation for road construction.

Fill slope - The slope of excavated fill material placed on the natural slope during road construction.

Filter strip - A ***buffer strip*** designed specifically to trap sediment.

Filter windrows - Logging ***slash*** piled at the base of a road fill slope to retard the movement of sediment.

First order stream - A stream which has no tributaries.

Forest practices - Harvesting of forest tree species, road construction associated with harvesting, reforestation, ***slash*** disposal, and the use of chemicals and fertilizers for growing or managing forest tree species (Idaho Department of Lands 1990).

Large organic debris (LOD) - Live or dead trees and parts or pieces of trees that are large enough, or long enough, or sufficiently buried in the stream bank or bed, to be stable. LOD creates diverse fish habitat and stable stream channels by reducing water velocity, trapping stream gravel, and allowing scour pools and side channels to form (Idaho Department of Lands 1990).

Leave tree - An individual tree that is not removed during the harvest of forest tree species, e.g., trees in a ***buffer strip***.

Manning's roughness coefficient - An empirical coefficient used as a measure of the hydraulic roughness of a channel.

Nonpoint source - A source of surface water pollution that is diffuse and intermittent and related to land surface disturbing activities such as mining, grazing, crop production, or ***forest practices***. Nonpoint sources of pollution are generally geographic areas yielding pollutants to surface waters in contrast to point sources that have identifiable points of entrance to surface waters (Idaho Water Quality Bureau 1989).

Protective strip - A ***buffer strip***.

Riparian - An adjective referring to something on or near the bank of a river or other body of water.

Riparian vegetation - Vegetation growing in close proximity to a watercourse, lake, or spring and dependent on its roots reaching the water table during some portion of the year.

Second order stream - Stream formed when two ***first-order streams*** join together.

Sediment yield - The quantity of sediment, measured in dry weight or by volume, transported through a stream cross-section in a given time, e.g., tons/hour/acre. Sediment discharge consists of both suspended and bedload sediments (Schwartz et al. 1976, sediment discharge).

Sheet flow - Water flow over the ground surface (surface run-off) in a more or less continuous sheet (Society of American Foresters 1983).

Site-specific best management practice - A ***BMP*** that is adapted to and takes account of the specific factors influencing ***water quality***, water quality objectives, on-site conditions, and other factors applicable to the site where a ***forest practice*** occurs, and which has been approved by landowner agreement with the Department of Lands, or by the State Board of Land Commissioners in consultation with the Department of Lands and the Forest Practices Advisory Committee (Idaho Department of Lands 1990).

Slash - Residue left on the ground after timber harvesting, including unutilized logs, uprooted stumps, broken or unrooted stems, as well as branches, twigs, leaves, bark, and chips (Society of American Foresters 1983).

Stream protection zone - In Idaho, for ***Class I streams*** is the area encompassed by a slope distance of 75 feet on each side of the ordinary highwater mark. Stream protection zone for ***Class II streams*** is the area encompassed by a minimum slope distance of 5 feet on each side of the ordinary highwater mark (Idaho Department of Lands 1990).

Stream reach - An arbitrarily defined subsection or segment of a stream.

Stream segment of concern - A specific stream segment or body of water that has been published in the most current Final Basin Area Report, which is developed every 2 years for each of the six basins in Idaho (Idaho Department of Lands 1990).

Timber, Fish, and Wildlife (TFW) - A conflict resolution program and process adopted by the state of Washington to reach agreement on environmental issues.

Upland - The ground above a floodplain; that zone sufficiently above or away from transported water as to be dependent on local precipitation for its water supply.

Water quality - The characteristics or properties of water. A term used to describe the chemical, physical, and biological characteristics of water in respect to its suitability for a ***beneficial use*** (Idaho Water Quality Bureau 1990).

Wetland - Areas that are permanently wet or intermittently water covered, such as swamps, marshes, bogs, muskegs, potholes, swales, glades, and overflow land of river valleys (Schwartz et al. 1976).