



**Analysis of the Current
Science Behind
Riparian Issues**

**Report to the
Minnesota Forest
Resources Council**

**Riparian Science
Technical Committee
August 2007**

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Executive Summary

The Minnesota Forest Resources Council (MFRC) published comprehensive timber harvesting and forest management guidelines in 1999 and a revised edition in 2005. Protection of riparian forest functions and values is a major aspect of these guidelines. As part of development and revision, these guidelines were submitted for peer and public review three times each. Many of the comments submitted were critical of the guidelines suggesting that they were inadequate to provide the needed resource protection. The MFRC deferred addressing the comments directly to a future process, in part to give sufficient time to the forestry community to promote adoption and use of the guidelines.

In 2004, a Riparian Science Technical Committee (RSTC) was convened by the MFRC to bring forth the best applicable scientific knowledge in order to assist the MFRC in resolving outstanding riparian guideline questions. The RSTC evaluated the temporal and spatial impacts from forest management on three major functions: hydrology, geochemistry, and habitat. Various indicators were evaluated during the literature review that assessed both the three major functions as well as subfunctions within these categories through the use of indicators. These indicators provided a measurable response to the way the various functions respond before, during, and/or after forest management operations. It was determined that 30 indicators critical to riparian areas provided a response worthy of evaluation for this project.

Some key considerations concluded by the RSTC include the following:

- Waterbodies supported by the scientific literature as needing riparian management zones (RMZ) are streams, lakes, rivers, and open water wetlands (Cowardin types 3, 4, 5, and seasonal ponds).
- Consideration to the landscape component to address issues related to both hydrology and habitat indicators (e.g., peak flows, fragmentation) are important as these affect overall watershed conditions.
- Existing filter strip recommendations are consistent with the national literature on controlling sediment.
- RMZ width and residual basal area had small or fleeting impacts on a number of the geochemical indicators (e.g., nitrate, phosphorus, methyl mercury, dissolved oxygen, litter decomposition).
- Most shade functions are protected with moderate RMZ widths (e.g., 15-23 meters (m) [50-75 feet (ft)]) and dense shade.
- Riparian forests should be managed for mid- to late-successional species in northern Minnesota as an option to control beavers impacts. RMZs between 50 m (165 ft) and 91 m (300 ft) are needed to discourage excessive beaver colonization on coldwater streams.
- Using a normal range of variation (mature forest) as a reference condition, all nine terrestrial indicators (listed on page 40) exceeded their reference condition (more than 25 percent change) at low basal area for all RMZ widths. A wide RMZ (greater than or 61m [200 ft]) coupled with high residual basal area has the greatest likelihood of maintaining most terrestrial indica-

tors within these reference conditions.

- At low residual basal area, most of the terrestrial habitat indicators may not recover (in 10 years), regardless of RMZ width. Potential for recovery within 10 years is maximized with high residual basal area and wide RMZs (greater than 61 m [200 ft]).

RSTC members agreed waterbody size should be modified for specific guideline recommendations. They also recommend that riparian management zone (RMZ) widths and residual basal area (BA) should be revised to protect water resources. The RSTC also recommends that the differences in RMZ width and residual BA based on even-aged versus uneven-aged management should be eliminated. The priority for management should be on protecting the functions of the water resource rather than providing for additional timber for harvest.

Background

Minnesota has an abundance of fresh water in lakes, streams, and wetlands, much of it located in the forested regions of the state. Forested riparian areas adjacent to these water bodies are highly productive, perform important ecological functions, and provide substantial societal values. There is a strong consensus among forestry interests that protection of these riparian resources is desirable to maintain their sustainability. However, identifying and establishing effective management protections within riparian forests has been the subject of considerable debate among resource professionals and concerned citizens.

The Minnesota Sustainable Forest Resources Act of 1995 (SFRA) (Minnesota Statutes § 89A) mandated the development of comprehensive timber harvesting and forest management guidelines to address many of the impacts commonly associated with applying site-level forestry practices. These guidelines were first published in 1999 in the guidebook titled *Sustaining Minnesota Forest Resources: Voluntary Site-level Forest Management Guidelines*. A second edition was published in 2005. The SFRA also requires the Minnesota Forest Resources Council (MFRC) to periodically review and update the guidelines in response to new information; technology; and results from practices, compliance, and effectiveness monitoring. These guidelines recommend various practices to protect riparian functions and values in conjunction with timber harvesting and other forest management activities. As part of the process of their development, proposed guidelines have undergone three separate peer and public reviews. Many of the comments received through these reviews were related to concerns that the riparian guideline recommendations did not adequately protect the functions of riparian areas.

In 2002, the MFRC made the decision to defer addressing all public and peer review comments regarding management of forested riparian areas to a future process that would provide a thorough scientific review of this complex issue. In 2004, the MFRC appointed an interdisciplinary Riparian Science Technical Committee (RSTC) of nine scientists to begin the process of addressing and resolving these deferred comments and concerns and to evaluate current science regarding the management of riparian forests.

Riparian Science Technical Committee Charge

The MFRC is mandated in Minnesota Statutes §89A.05, Subd.1 to periodically review and revise its voluntary site-level forest management guidelines. Currently, the MFRC is seeking to better understand recent advances in scientific understanding of riparian areas related to forest management to inform their discussions on proposed guideline revisions. The RSTC (Table 1) was convened to bring forth the best applicable scientific knowledge and professional judgment from the cited literature in order to assist the MFRC in resolving outstanding riparian guideline issues, resulting from unresolved and deferred public and peer review questions and comments related to the management of riparian forests. The scope of the RSTC's work was limited to the physical,

chemical, and biological issues. It does not address social, aesthetic, political, and economic concerns. The RSTC output will complete the first step in the process to re-view the need to modify the existing riparian guidelines contained in the MFRC's 2005 edition of the guidebook.

Table 1 – RSTC Members and Affiliations

RSTC Member	Affiliation	Employment
Daniel Gilmore	silviculture	University of Minnesota, North Central Research & Outreach Center
Dave Grigal	forest soils	Emeritus Professor – University of Minnesota, Department of Soil, Water, and Climate
JoAnn Hanowski	wildlife	Natural Resources Research Institute
Mark Hanson	wetland biology	MN Department of Natural Resources, Wildlife Research
George Ice	forest hydrology	National Council Air and Stream Improvement, Inc
Lucinda Johnson	aquatic ecology	Natural Resources Research Institute
Randy Kolka	aquatic ecosystems	USDA Forest Service – North Central Research Station
Brian Palik	forest ecology, wetlands	USDA Forest Service – North Central Research Station
Sandy Verry*	fisheries	Ellen River Partners, LLC

*Replaced Charles Anderson, MDNR Fisheries as of October 2005

The following individuals provided staff support to the RSTC with project facilitation, technical guidance, and synthesizing and recording the information:

- Mike Phillips (MFRC Site-level Program Coordinator)
- Jenna Fletcher (MFRC Policy Analyst)
- Calder Hibbard (MFRC Policy Analyst-replaced Jenna Fletcher after April 7, 2006)
- Diane Desotelle (Desotelle Consulting)

Methodology

As a first step, the RSTC identified articles and published studies (Appendix A) related to the management of riparian forests. The relevant papers related to this review were copied and placed on the MFRC website for use by the RSTC members. This list was continuously revised and updated.

In order to provide structure to the RSTC work, the MFRC approved a sequence of questions/topics/ issues (QTIs) that helped focus the scientific enquiries of the RSTC. As part of their work, the RSTC was asked to provide answers to the QTIs for inclusion in the final report to the MFRC. The answers are provided in accordance to the scientific findings and professional judgments of the RSTC.

The RSTC used a modified Hydrogeomorphic Approach (HGM) to assess riparian functions. The critical functions identified were hydrology, geochemistry, and habitat. For each of these functions, the RSTC evaluated research from the scientific community based on the identification of key riparian indicators and the temporal and spatial response of these indicators to timber harvest. To the extent practical, this information was presented graphically (Appendix B). In addition, various reports were developed and presented to the RSTC to address topics which needed further consideration (Appendix C). Graphical relationships were anchored by data points derived from scientific research. Where the science was not definitive, the RSTC graphed its best professional judgment as to the response trends for these functions. Where possible, each of the data point anchors had a confidence level identified (i.e., high, moderate, low, no opinion) based on the professional judgments of the individual RSTC members.

Decisions were made at formal RSTC meetings after discussion and debate. The RSTC members were assigned to HGM subcommittees to allow for continued dialogue and review between formal meetings. The RSTC members prepared graphical representations of the relevant science and presented this material as part of the formal meetings.

Riparian Area Consideration

Riparian areas are considered among the most important and diverse portions of forest ecosystems. They support high soil moisture and a diversity of associated vegetation and wildlife, and they perform important ecological functions. The guidelines developed by the MFRC to protect these functions and values are contained in the guidebook titled: *Sustaining Minnesota Forest Resources: Voluntary Site-level Forest Management Guidelines (2005)*.

The RSTC agreed on a definition of “riparian area” (based on one of several proposed scientific definitions). This definition served as a boundary for the work of this scientific committee. (Note: the definition given below will not necessarily be the one included in the next revision of the site-level guidelines.)

Working definition of riparian area:

A riparian area is a zone of interaction between aquatic and terrestrial ecosystems along streams, lakes, wetlands, and other water bodies. Riparian areas both influence water bodies and are influenced by them. They perform important ecological functions that link aquatic and terrestrial ecosystems.

The RSTC initially considered all waterbody type needs for a protective riparian management zone (RMZ). The waterbodies considered were trout and warm water streams, intermittent streams, ephemeral drainages, rivers, lakes, open water wetlands, seasonal ponds, dry washes, non-open water wetlands, seeps, and springs (definitions for these waterbodies are given in the glossary). After the literature was reviewed, the RSTC developed a prioritized list of waterbodies for which the scientific literature suggests the need for RMZs. These include:

1. Streams and lakes (trout and warm water); and,
2. Open Water Wetlands (Circular 39 wetland types 3, 4, 5, and seasonal ponds from Shaw and Fredine 1956)

Excluded from the scope of this work are the following waterbody types: dry washes, intermittent streams with defined bed and bank, ephemeral drainages, springs, seeps, and non-open water wetlands - Circular 39 types 1, 2, 6, 7, and 8 (Table 2).

It is important to note that current guidelines are designed to protect these waterbody types via best management practices (BMPs) including filter strips, appropriately designed approaches and water crossings, and equipment exclusion zones. Current guidelines require intermittent drainages less than 1 m (3 ft) wide; wetland types 1, 2, 6, 7, and 8; springs; and seeps to have filter strips rather than RMZs. The rationale for exclusion of these waterbodies (Table 2) from the scope of the RSTC is that either adequate protection is provided by the current guidelines or there is insufficient science to support a recommendation for an RMZ adjacent to these waterbodies.

Photo 1: Forested Wetland by Diane Desotelle

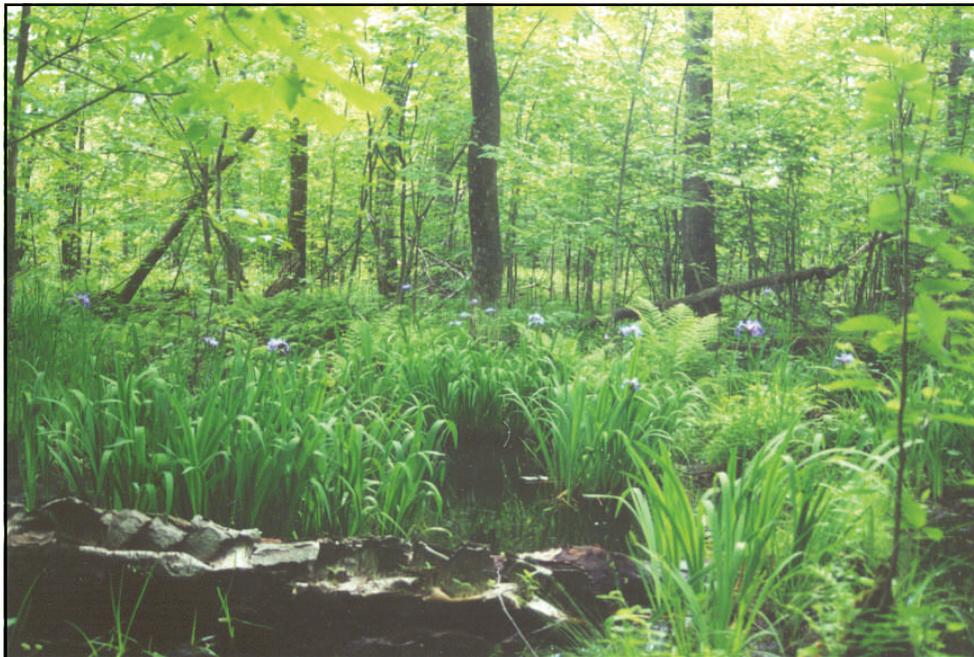


Table 2 – Rationale for Waterbodies Excluded from Consideration for RMZs

Excluded waterbodies	Sufficiency of current guidelines	Science availability	RSTC professional judgment
Dry washes	RSTC is unable to improve current guidelines which include: 1) selective cutting within 25 ft. 2) maintaining root structure	Science is not definitive to support recommendation for an RMZ. However, “deductive science” based on professional judgment and knowledge supports retaining the current guidelines.	Current guidelines are sufficient.
Intermittent drainages Ephemeral drainages with a defined bed and bank only.	RSTC is unable to improve current guidelines which include: 1) proper crossings for all drainages 2) RMZs on drainages greater than 3 ft	Science is not definitive to support recommendation for an RMZ. However, with the revised guidelines that require protecting the banks of intermittent streams, there is no need for RMZs on intermittent drainages.	Delete requirement for RMZs adjacent to intermittent streams > 3 ft. wide.
Seeps and springs	Current BMPs are appropriate and necessary	Science is not definitive to support recommendation for an RMZ.	Current guidelines are sufficient.
Wetland types 1,2,6,7,8	Current BMPs are appropriate and necessary	Science is not definitive to support recommendation for an RMZ.	Current guidelines are sufficient.

Approach for Assessing Management Impacts in Riparian Areas

The concept of hydrogeomorphic models was used as a means to list and classify the possible RMZ functions (and subfunctions) as well as the indicators used to assess these functions. The primary classes of functions included in HGM are hydrology, geochemistry, and habitat. Since this project addresses the scientific issues (i.e., physical, chemical, biological), and not the social, aesthetic, political, or economic issues, using these three HGM primary classes of functions was supported by the RSTC. Within these three function classes, a list of response indicators was explored across the various types of waterbodies. An indicator is what can be physically measured (e.g., flow velocity, temperature, amount of large wood) in order to help understand the importance of specific functions for riparian areas. The scientists involved in developing response indicators for the three classes of functions were:

- Hydrology – George Ice, Randy Kolka, Dan Gilmore, Sandy Verry
- Geochemistry – Lucinda Johnson, Dave Grigal
- Habitat – Brian Palik, JoAnn Hanowski, Sandy Verry, Mark Hanson

Hydrology Function

Hydrology is defined as the study of the movement, distribution, and quality of water throughout the earth. It is a term used to describe the amount and timing of runoff in streams or temporal and spatial patterns of water occurrence in the soil, earth, and waterbodies, as influenced by weather and vegetation. The RSTC concluded that hydrology at the site level must be considered in context with the watershed in which it lies. The watershed associated with a lake or river is much different than one for a stream or wetland. For example, the runoff patterns and volumes within a riparian area for a lake or river are not as influential to the waterbody because the watershed is often much larger than the riparian area. On the other hand, riparian areas of smaller waterbodies such as streams and wetlands are more influential as they can be a large part of the watershed for that waterbody. Other land uses within the watershed of these waterbodies will also impact the runoff velocities and volumes. The RSTC drafted a report to point out these issues. The full report is available in Appendix D. Below is a brief synopsis of the findings from that report.

The condition of the riparian forest influences hydrologic processes such as interception, snowmelt, evapotranspiration, infiltration, surface and subsurface runoff, and water storage. Figure 1 summarizes the key hydrologic functions of riparian forests and includes: 1) water inputs and outputs in yellow, 2) key subfunctions in green, 3) physical indicators that can be measured to assess subfunctions in blue, and 4) direct and indirect response variables in white. The RSTC confined its review and discussion of the hydrologic functions to water flow and yield and to the appropriate response indicators. These indicators are common regardless of whether the forest occurs adjacent to a stream, lake, or wetland. However, the magnitude of response to riparian forest condition depends on both the type and the size of the waterbody. For example, first, second, and third order streams (i.e., small streams in the upper part of the watershed) respond more to changes in the riparian area, but they are also more resilient, having developed with greater variability in flow.

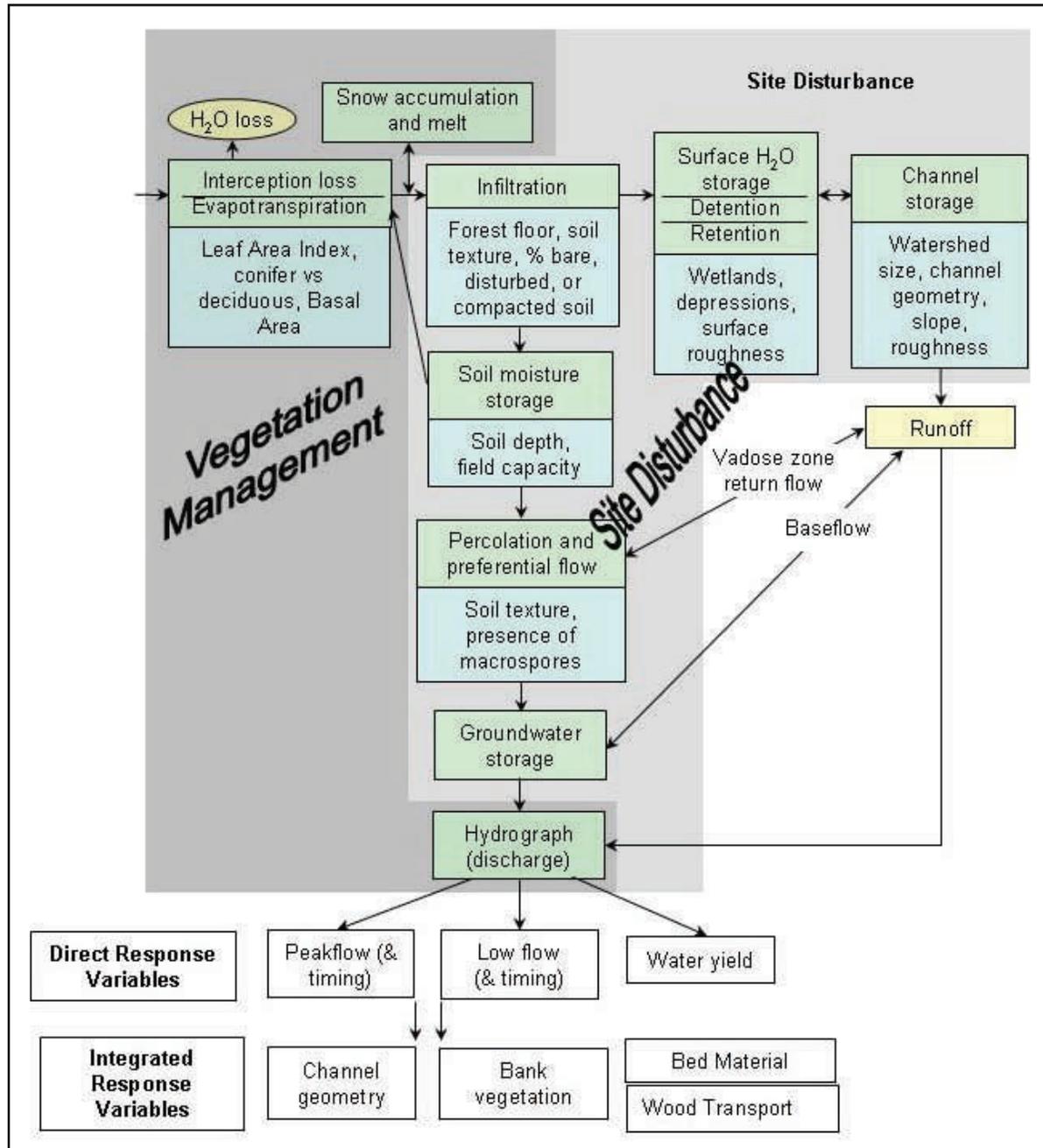
Streams – Research on the hydrologic influences to streamflow is available. A couple of examples important to note include Hornbeck and Kochenderfer (2004) whose research findings from the northeast report that, “*Initial increases in annual water yield of up to 350 mm (≈14 in) occur promptly after forest cutting; the magnitude roughly proportional to the percentage reduction in basal area (at least 25 to 30 percent of basal area must be cut to produce a measurable increase...*”). Verry (2004b) reports similar findings for the Lake States related to peak flows.

Lakes - Literature is limited on the hydrologic influences that harvesting or land use change has on lakes. Most concerns about forest management near lakes concern water quality, not lake stage.

Wetlands - Hydrology changes to wetlands vary in accordance to the type and size of the wetland. In general, the larger the wetland, the less the relative influence of the riparian area. Non-open water wetlands are yet another matter. These wetlands are

generally harvested in the winter. It is not known if leaving a ring of vegetation in place will protect a wetland that is harvested within the wetland as well as in the surrounding upland.

Figure 1. Hydrologic Functions of Riparian Forests



Management Implications and Overall Conclusions - At the site level, self-sustained hydrologic functions of riparian forests along streams, lakes, and rivers are most dependent on the level of vegetation management and site disturbance. Vegetation management most influences interception loss, evapotranspiration, and snow accumulation and melt. The status of vegetation in the riparian area can be measured using Leaf Area Index (LAI). For operators there may be a need to translate LAI to common field measurement techniques such as basal area (BA) determination. The site disturbance component consists of forest management activities that might cause soil disturbance, compaction, changes in storage, or routing of water across the riparian zone or in the channel. Based on this assessment:

- Riparian forest conditions are likely to have a somewhat disproportionate effect on the overall hydrologic response of a watershed, but evidence from this region suggests that overall watershed condition, not riparian forest condition, determines runoff patterns.
- The smallest waterbodies are likely to experience the largest changes, but these changes are probably not unlike those experienced due to annual variations in weather or natural disturbance events.
- While riparian forest conditions undoubtedly influence the hydrology of adjacent waterbodies, other concerns, such as water quality, are likely much more important.

Geochemistry Function

Geochemistry for purposes of this report is not only the chemistry of the earth's crust, but the interactions of the earth's chemical constituents as mediated by living organisms within forested ecosystems. Numerous studies have investigated the geochemistry effects of vegetation management and site disturbance at both the watershed scale and within riparian areas. Based on the knowledge of the RSTC members, subfunctions within the geochemistry function were primarily linked to stream indicators (Figure 2). Generally it was agreed that science has shown first and second order streams to be more strongly affected by the geochemistry subfunctions in riparian areas. These streams make up approximately 60-80% of the streams in a watershed. These indicators do not tend to change for rivers, lakes, and open water wetlands; the magnitude of response may alter slightly in its application to different waterbody types, however.

Variables according to waterbody type vary in complexity with the geochemistry function, but are necessary to consider for this project. These might include:

Streams - groundwater discharge versus groundwater recharge, surficial geology, water source, land use context, integrity of the riparian zone, and infrastructure effects (e.g., roads, culverts, crossings).

Lakes, open water wetlands, and seasonal ponds - basin size/morphometry, landscape position (lake order), land use context, lake classification (e.g., hard water/soft water, shallow/deep, geologic context), position in lake (e.g., embayment), riparian

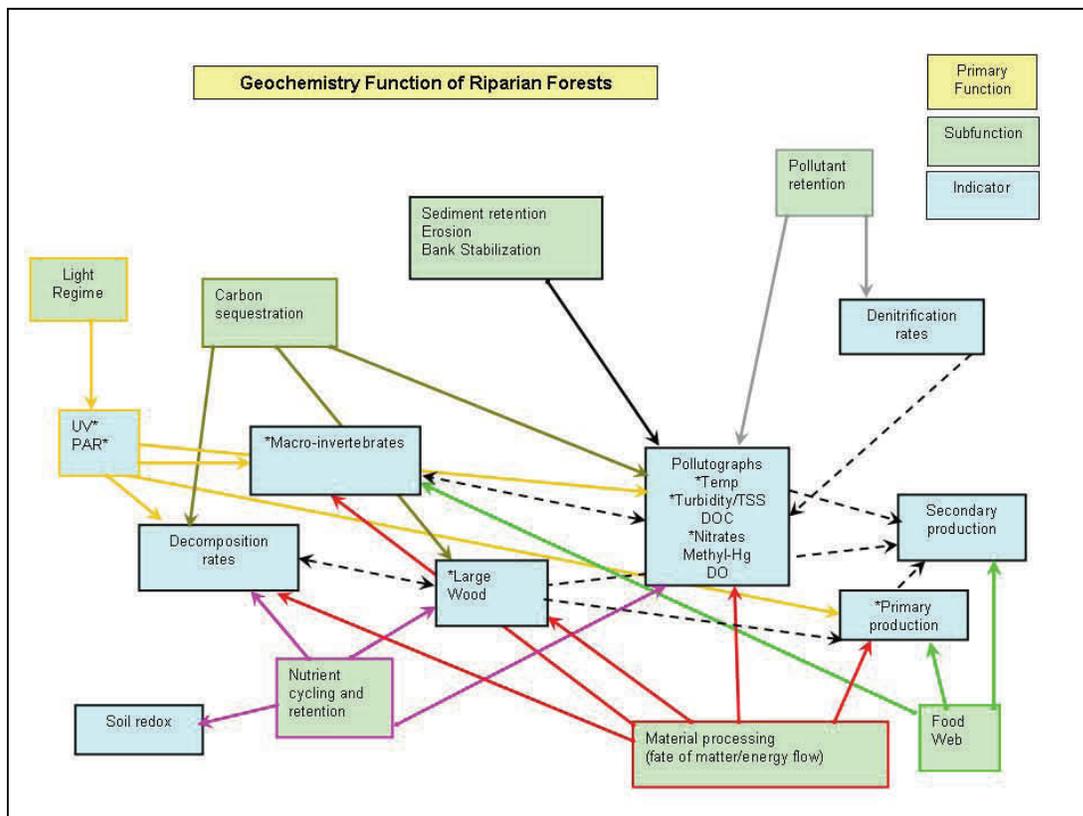
zone integrity and infrastructure effects (e.g., roads, culverts, crossings) need consideration.

Non-open water wetlands - (although they are not fish bearing, are connected to fish bearing waterbodies) - landscape position, isolation, and location (upstream, downstream).

Seasonal ponds - Since these waterbodies are occasionally wet, the RSTC regarded all seasonal ponds as open water wetlands for purposes of looking at the science.

Floodplains - There are so few acres harvested in floodplains that it is not enough to consider for this project.

Figure 2. Geochemistry Functions of Riparian Forests



Vegetation management and site disturbance have the potential to affect carbon and nutrient cycling, light regime, sediment dynamics, pollutant retention, food webs and the flow of energy and matter. Some of these subfunctions affected by vegetation management are closely linked to habitat subfunctions. Indicators of these subfunctions include surface water concentrations and fluxes of carbon (dissolved organic carbon (DOC) or total organic carbon (TOC)), nitrogen (nitrate, ammonium) and total suspended solids (TSS). Riparian alterations such as canopy removal near waterbodies have been shown to influence both air and water temperatures as well as the

incidence in ultra-violet (UV) radiation and Photosynthetically Active Radiation (PAR), leading to potential changes in the biotic community including both primary and secondary production. Similarly, riparian alterations have been shown to influence those indicators related to large wood accumulation which also influences habitat subfunctions.

Table 3 identifies the list of geochemistry function indicators and degree of confidence based on the scientific information available to assess response. A high degree of confidence indicates the indicator response is strongly supported in scientific literature and a low degree of confidence indicates the indicator is less apt to have specific research available. The scientific literature was first reviewed for the high confidence intervals to determine if a graph could be developed that showed a relationship between the indicator and the distance (and/or residual BA) to a stream, river, lake, or open waterbody.

Table 3. Geochemistry Function Indicator List by Confidence Level

High Confidence	Low Confidence	Very Low Confidence
Macroinvertebrate	Decomposition rate	Soil Redox
Temperature	Secondary production	Methyl-Hg
TSS	DOC	
Nitrification/denitrification	DO	
Primary production		
UV and PAR		
Large wood		

Habitat Function

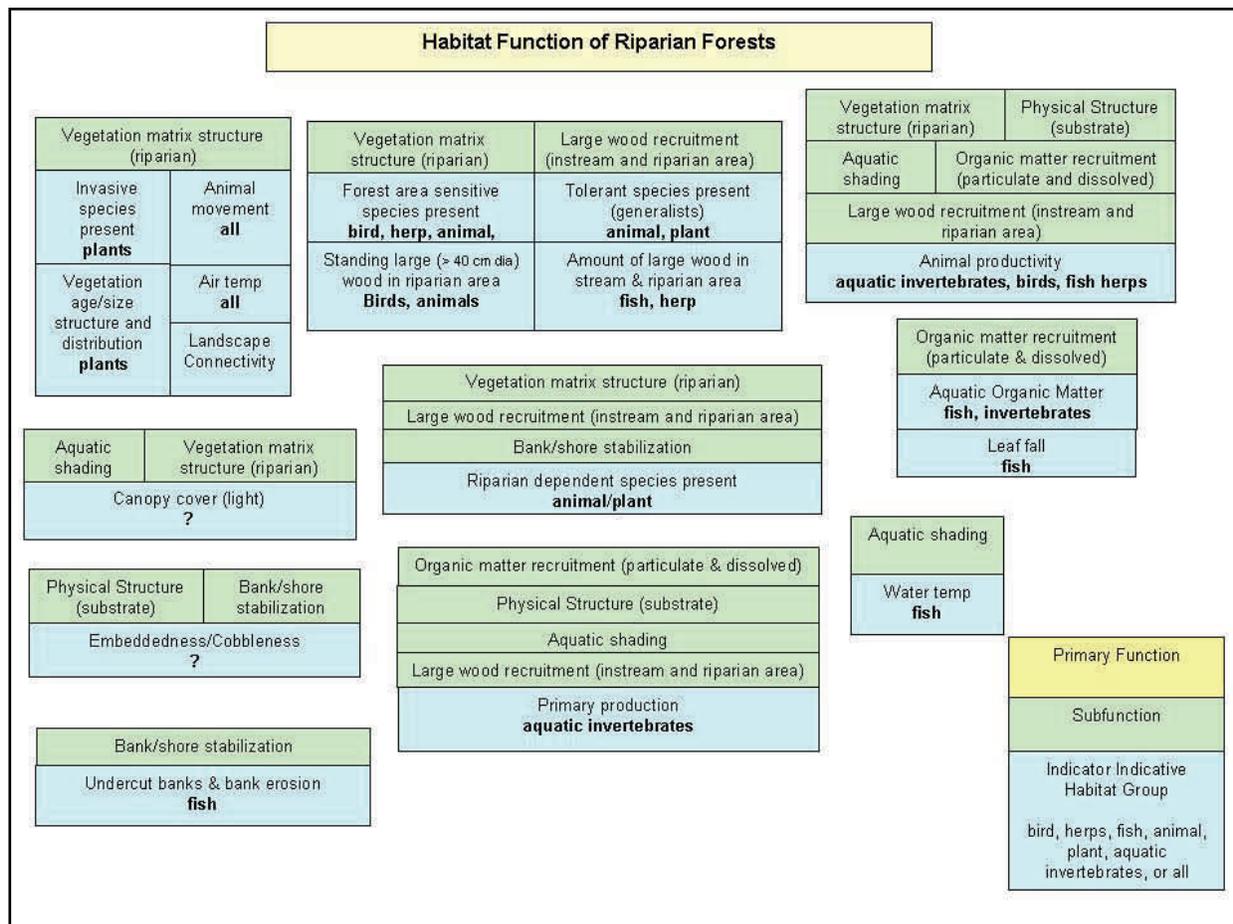
Habitat is defined as the sum total of environmental factors (including food, water and cover) that a species needs to survive and/or reproduce in a given area. The RSTC determined that the habitat function should be assessed according to the major animal/plant groups. These include: birds, fish, mammals, herpetofauna, macroinvertebrates, and plants. The subfunctions and indicators within the habitat function will vary depending on what animal/plant habitat group is being assessed. Figure 3 identifies the subfunctions and relevant indicators within them.

Considerable research has investigated the effects of vegetation management and site disturbance on habitat for a variety of species. Terrestrial organisms are most influenced by the resulting amount and structural make-up of vegetation following harvest. Vegetation alterations (e.g., canopy cover, number of snags, increased windthrow) influence bird community dynamics (both riparian and interior forest species) including diversity, richness and brood productivity. Additionally, vegetation disturbance influences the type and density of plant communities including affects to sensitive plant

species as well as invasive plant species. Vegetation management near waterbodies can also influence the presence and productivity of larger animals, most notably beaver, which can influence future riparian vegetation communities as they are dependent on specific tree species.

Geochemical and hydrological functions are closely tied to habitat subfunctions. For example, water quality, temperature, organic matter inputs and accumulation of large wood are directly linked to indicators that influence the presence, diversity and fecundity of aquatic dependent organisms such as macroinvertebrates, fish and herpetofauna and both primary and secondary productivity. Furthermore, vegetation management and the resulting influence on hydrological functions interact to influence stream substrates (e.g., embeddedness, cobble density) and bank stabilization which also influence habitat subfunctions for aquatic organisms.

Figure 3. Habitat Functions, Subfunctions, and Indicators of Riparian Forests



Refined Indicator Selection

After developing a wide array of indicators (Figures 1, 2, 3) in relation to the hydrology, geochemistry, and habitat functions, the RSTC reviewed the literature available for the various indicators. The availability and quality of scientific information varied from no data to substantial data with degree of confidence levels ranging from low to high. In any event, these indicators could be qualitatively ranked relevant to this process in terms of the following:

1. Relevance to site level decision-making and best management practices;
2. Robustness;
3. Supporting scientific data; and,
4. Usefulness for addressing watershed/landscape level decisions in context with the numerous site-level decisions that occur within a watershed.

After the initial scientific review, the list of indicators was refined (Table 4). These indicators and the RSTC members assigned to the literature review are provided in Appendix B along with the RSTC's summaries of the selected indicators as viewed in isolation from other indicators that may be associated with them. The information includes a summary of the scientific findings, graphic portrayals where appropriate, and professional judgment of the RSTC members.

Table 4. Refined Indicator List

Function	Indicator
HABITAT	
	Beaver interactions
	Bird productivity
	Canopy cover
	Emergent (herbaceous) macrophytes
	Forest amphibians
	Forest area sensitive plants (interior forest)
	Forest vegetation (age, size, structure, distribution)
	General disturbance associated plants
	Interior forest birds
	Invasive plants
	Large wood (as it relates to herpetofauna)
	Macroinvertebrates (shredders, collectors, gatherers)
	Macroinvertebrates (fairy shrimp, water boatman)
	Primary production (periphyton)
	Riparian dependent birds
	Snags
HYDROLOGY & GEOCHEMISTRY	
	Air temperature
	Dissolved oxygen
	Dissolved organic carbon
	Embeddedness
	Large wood
	Light
	Litter decomposition
	Methyl mercury
	Overhead canopy
	Soil moisture
	Soil redox, nitrates, and denitrification
	Turbidity and total suspended solids
	Water temperature (stream, lake, and wetlands)
	Windthrow

MFRC Questions/Topics/Issues (QTIs)

The MFRC approved a list of questions, topics, and issues (QTIs) for the RSTC to address. In keeping with this methodology, the QTIs are discussed below in accordance to the scientific findings and professional judgments of the RSTC.

QTI 1 – Which waterbody types require RMZs?

As previously discussed, the RSTC agreed the following waterbodies would be the basis for this project:

- Streams and Lakes (trout and warm water)
- Open water wetlands - Circular 39 types 3, 4, 5, and seasonal ponds

The waterbodies discussed below were excluded from the scope of work because either:

- Adequate protection is provided in current guidelines, or;
- There is insufficient science to support the revision of guidelines related to RMZs for these waterbodies.

Excluded from the scope of this work are the following waterbody types:

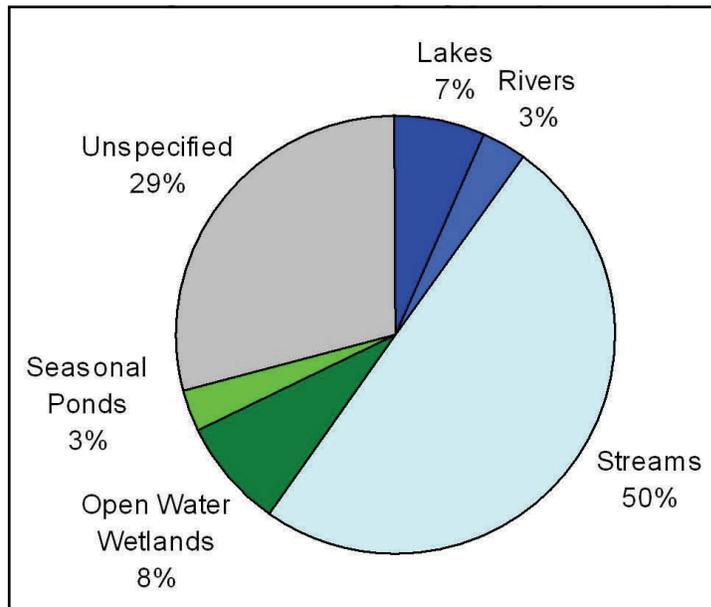
- Dry washes – dry bed of an intermittent stream
- Intermittent streams - defined bed or bank
- Ephemeral drainages - undefined bed or bank, water flows without a channel
- Springs and seeps - distinguished by the water table
- Non-open water wetlands - Circular 39 types 1, 2, 6, 7, and 8

However, it is important to note that current guidelines are designed to protect these excluded waterbody types through such BMPs as filter strips, appropriately designed approaches and water crossings, and equipment exclusion zones. Current guidelines require intermittent drainages less than 1 m (3 ft) wide; wetland types 1, 2, 6, 7, and 8; springs, and seeps to have filter strips. These waterbodies are not required to have RMZs.

Science

The waterbodies selected for RMZ guidelines were based on the RSTC's review of the available scientific literature. After sifting through over 600 references, approximately one third were selected to review in depth. This list of scientific literature is listed in Appendix A. The entire scientific literature list from which the selected list was developed is provided on the MFRC website at www.frc.state.mn.us. Figure 4 shows the percentage of studies reviewed by waterbody type. Some of the studies did not specify a particular waterbody type (unspecified), but rather researched riparian areas or buffers. Most important, Figure 4 shows that streams have been studied more extensively than the other waterbody types.

Figure 4. Percent of studies addressed by waterbody type within the reviewed scientific literature (206 studies).



Professional judgment

Although there are several waterbody types where scientific literature is limited, the RSTC agreed that the current guidelines calling for the protection of all waterbodies via filter strips is an important safeguard to continue and these should be modified appropriately in response to further research.

QTI 1A - For each waterbody type, what are the important riparian functions that could be affected by forest management activities?

All of the waterbody types explored in this review have similar riparian functions that could be affected by forest management activities at both the site and landscape level. Cumulative effects of site level disturbances need to be considered in context of the landscape. Site level forest management, land use, watershed area, presence of wetlands, channel morphology, riparian conditions, connectivity to surface waters and overall ecological sensitivity to alterations need to be assessed at the landscape level when trying to ascertain cumulative effects.

The primary classes of functions included in hydrogeomorphic models are hydrology, geochemistry, and habitat. The RSTC discussed these functions and concluded that they were appropriate not only from a functional perspective, but also from the areas of expertise within the RSTC. The process for determining the relevant riparian subfunctions and indicators within each of the primary class of functions is discussed in detail above. The synthesis section discussed under QTI 7 identifies the important riparian indicators based on current scientific knowledge and professional judgment.

QTI 2 – What are the key biotic and abiotic indicators of riparian functions that are most impacted by RMZs?

The key biotic and abiotic indicators were selected based on the available science as discussed in QTI 1A. The RSTC started with the list of indicators as shown in Figures 1-3; these indicators were refined to the indicators shown in Table 4 for which impacts could be ascertained and sometimes graphically represented. Detailed information for all of these indicators is available in Appendix B.

QTI 3 – For each waterbody type, should RMZs be fixed or variable-width?

The RSTC recommends that fixed-width RMZs be applied adjacent to the appropriate waterbodies.

Science

Variable-width (i.e., managing the forest based on its riparian characteristics) is strongly supported scientifically, but it is not easy to define or implement. In addition, the level of complexity increases in defining a variable-width for a group of indicators versus one indicator at a time. At this time, the RSTC supports a fixed-width because the majority of the studies cited are based on fixed-widths.

Professional judgment

Although, the science suggests that variable-width RMZs are preferred, the tools to evaluate this on a routine basis are currently not available. It is important to keep in mind that fixed-width RMZs will not be significantly different than variable-width RMZs along streams with minimal sinuosity variation. On the other hand, there is some concern for more sinuous streams as it is not clear how great the impact could be for a fixed-width RMZ versus requiring a variable-width RMZ. For example, a straight-line (average) fixed-width RMZ method could result in a harvest occurring too close to a waterbody, and the science does not support this. Applying a variable RMZ width (wavy boundary) to account for the sinuosity of the waterbody would seem more reasonable, but may be less practical.

The existing guidelines do have a variable-width RMZ by default (General Guidelines section, page 31 of the MFRC Voluntary Site-Level Guidelines), with the option to use a straight line (average) or variable-width based on the stream course. Figure GG-6, page 31 of the MFRC Voluntary Site-Level Guidelines shows fixed-width on one side (average) versus a variable-width on the other side. Another option is to define variable-width based on topography, but this would also need to be defined relative to many other indicators (e.g., total suspended sediments, shade). With a fixed-width approach, it is clear some reaches will have more and some less protection for functional benefits. This may not be all that significant if the range of protection versus impacts is within plus or minus 25% for functional benefits. In conclusion, since there is not enough data to define all the indicators based on a variable-width, a fixed-width RMZ

with respect to waterbody location and slope is reasonable at this time.

QTI 4 - Should fixed-width RMZs differ for different types and sizes of waterbodies?

This discussion is included with QTI 8 on page 51.

QTI 5 – Is a de minimus size for establishing RMZs adjacent to open water wetlands necessary? If so, what size?

Consensus was not reached for this QTI among the RSTC. There was agreement that waterbodies less than one acre in size should be classified as seasonal ponds where waterbodies greater than or equal to one acre in size should be generally classified as open water wetlands. Size is not the key factor here, but rather the hydrologic regime is what matters. It was suggested that the size of the wetland should be used to determine the leave patch size in order to provide protection on the site as a whole.

Science

See QTI 4 and QTI 8 (see page 51) for further explanations of the difference of open water wetlands and seasonal ponds.

Professional judgment

See QTI 4 and QTI 8 (see page 51) for further explanations of the difference of open water wetlands and seasonal ponds.



Photo 2: Seasonal Pond by Mark Hanson

QTI 6 – What waterbody characteristics will the RSTC evaluate to determine an RMZ width?

The RSTC found overlap between QTI 6 and QTI 1, QTI 4, QTI 5, and QTI 8. Therefore, the discussions under these QTI 1, QTI 4, QTI 5, and QTI 8 incorporate the conclusions associated with QTI 6.

QTI 7 What is the relationship between each of the key indicators and RMZ widths?

The RSTC committee reviewed the indicators indicative of RMZs based first upon the scientific literature and second upon professional judgment. The goal was to provide a minimum RMZ and residual BA for each of the riparian indicators, however the literature was not conclusive on all fronts. Following are the full reports discussing the data synthesis:

- ***A Synthesis of the Riparian Science Technical Committee Findings on Hydrologic and Geochemical Responses to Alternative Riparian Management Guidelines***
by George Ice, Sandy Verry, Randy Kolka, Dave Grigal, and Dan Gilmore
- ***A Synthesis of the Riparian Science Technical Committee Findings on Habitat Responses to Alternative Riparian Management Guidelines***
by Brian Palik, JoAnn Hanowski, Mark Hanson, and Lucinda Johnson

A SYNTHESIS OF THE RIPARIAN SCIENCE TECHNICAL COMMITTEE FINDINGS ON HYDROLOGIC AND GEOCHEMICAL RESPONSES TO ALTERNATIVE RIPARIAN MANAGEMENT GUIDELINES

Abstract: Two of the most important benefits from forested watersheds are favorable runoff and water quality. Management of riparian forests has the potential to influence these benefits. The Riparian Science Technical Committee (RSTC) reviewed the literature on riparian functions and how alternative forest management practices can affect twelve abiotic parameters of hydrology, water quality, and microclimate. Based on that review, the RSTC concluded that sediment and temperature are keystone parameters that should influence riparian management decisions. Direct sediment input to channels is addressed largely by the existing filter strip requirements, although roads and concentrated disturbance activities need continued attention. The use of slope as a modifier of filter strip width is consistent with the literature. Increased sediment from channel scour will result from elevated bankfull flows, but this issue is addressed only through landscape-level land use policies. Increases in stream temperatures can be managed by maintaining shade. Most shade functions can be provided with a 50 to 75 foot riparian management zone (RMZ) if shade is dense. Issues of risk to these functions and the rate of function recovery after disturbance influence decisions about appropriate dimensions of filter strips and streamside management zones. Two key risk factors that the Minnesota Forest Resources Council (MFRC) needs to consider are windthrow and beaver activity. RSTC team members dealing with hydrology and geochemical functions could not come to consensus on how to address these risk factors. Data are scant, but RMZs appear to be most vulnerable to windthrow in the outside 25 foot edge. Beaver dams can reduce sediment transport through a stream reach, resulting in sediment deposition and channel widening. This can be addressed by excluding early succession forests on streams where the impact is critical (e.g., cold water trout streams). Most foraging by beaver occurs within the first 10 m (33 ft) of water, but guidelines from Ontario recommend that vegetation management extend 50 m (165 ft) from the water to discourage beaver activity. Minnesota DNR Fisheries and Wildlife Division recommends a 91 m (300 ft) exclusion of timber sales on cold water trout streams. Beaver dams can also adversely modify stream channel geometry so that warming occurs. One conclusion is that windthrow risk for the outside 7 m (25 ft) edge of RMZs should be considered to protect riparian functions. For coldwater streams integrated pest management strategies are needed for beaver. An alternative position recommends a 61 m (200 ft) timber sale exclusion on cold water trout streams and their tributaries where aspen suckering would be the resulting tree regeneration, and 37-91 m (120-300 ft) RMZs to balance windthrow mortality with growth. All RSTC members agreed that there is clearly a lack of investment in watershed research to resolve management/water quality issues in this region. The Pokegama Watershed Study represents one of the few efforts to test alternative management practices.

INTRODUCTION

Favorable runoff and water quality are two of the most important benefits of forested watersheds. The use of best management practices (BMP) or guidelines is a widely recognized approach to maintain water quality and provide for fish habitat (NASF 2004). Perhaps the most universally accepted forest BMP is a riparian management zone (RMZ) or other management restriction near streams. Riparian areas represent the interface between the upland and streams, lakes, and other waterbodies. RMZs and filter strips are designed to keep disturbance away from the stream, provide shade or a source of fine or coarse organic materials, and generally attenuate upslope impacts. The Minnesota Forest Resources Council (MFRC) is mandated by Minnesota statute to review and revise its forest management guidelines periodically. The MFRC convened a Riparian Science Technical Committee (RSTC) to review existing information on the function of riparian management zones. Here we discuss the findings of the RSTC members who focused on hydrologic and water quality responses to alternative riparian management strategies.

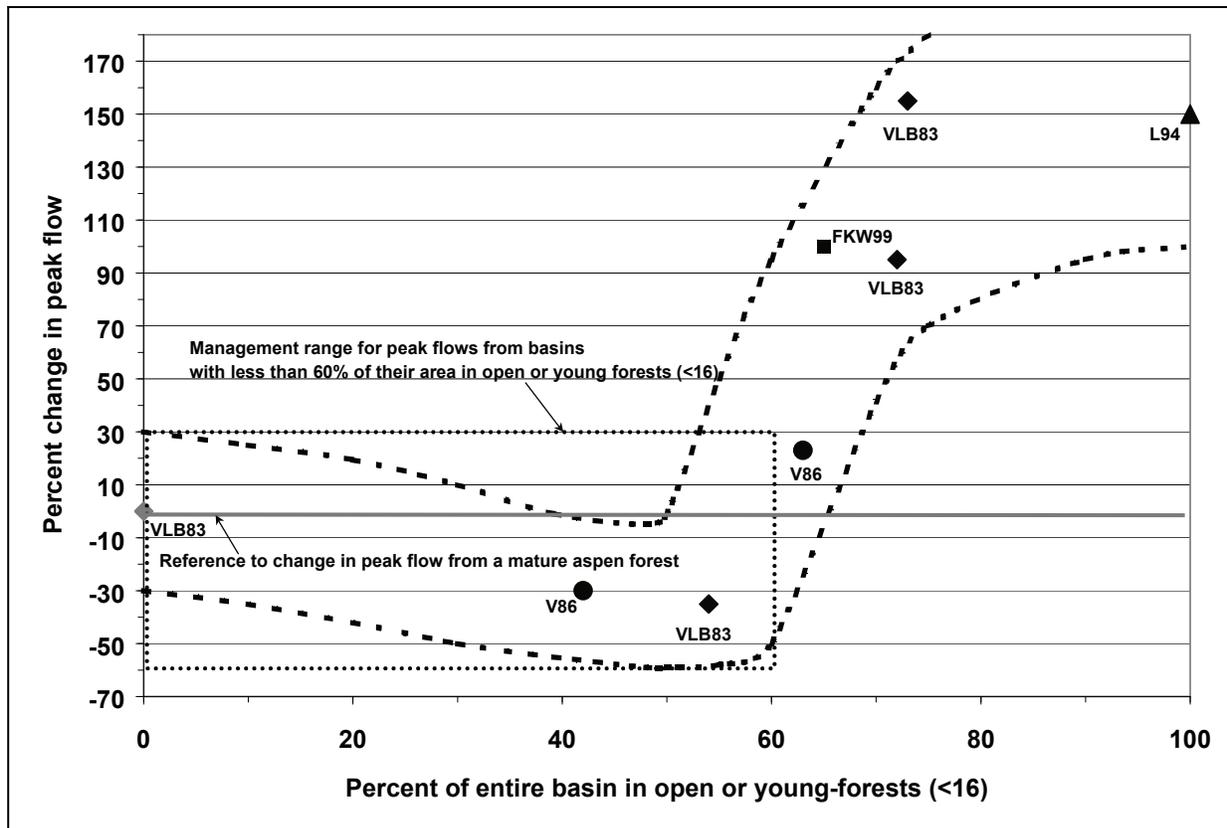
REVIEW OF ABIOTIC PARAMETERS' RESPONSE TO RIPARIAN ALTERNATIVES

Twelve abiotic parameters were evaluated to determine their responses to alternative riparian management guidelines. These included two hydrologic parameters (peakflow, water yield), three microclimate parameters (air temperature, light, soil moisture), and seven water quality parameters (nitrogen concentration, phosphorus concentration, methyl mercury, turbidity and total suspended solids (TSS), embeddedness, water temperature, dissolved oxygen concentration). In many cases these parameters interact. For example, dissolved oxygen concentration is complexly related to water temperature. Increases in water temperature decrease the solubility of oxygen, increase decomposition rates (biochemical oxygen demand), and increase the re-aeration (oxygen movement from the atmosphere to water) rate. Sediment transport competency (ability of a stream to transport sediment) is affected by flow and beaver activity (see discussions on hydrology, sediment, and beaver).

Hydrology

Hydrology reflects the amount and timing of runoff from a watershed. Riparian forests, like other forests, influence runoff to streams and waterbodies. Because of their proximity to water, riparian forests may exert a larger influence on watershed water balance than other parts of the watershed. Research in the Lake States indicates that overall watershed conditions, and not the width or extent of riparian forest, determine runoff response, measured either as water yield or peak flow (Figure 5). Further, as forests re-grow there is a recovery of hydrologic functions.

Figure 5. Response of streamflow peak discharge to percent of a basin in open land or young forest. Dashed lines show the range of response for watersheds with less than 60% of the area in open or young forest (Verry 2004b).



Key findings for hydrologic responses to alternative riparian management guidelines include:

- Riparian forest conditions are likely to have a somewhat disproportionate effect on the overall hydrologic response of a watershed, but evidence from this region suggests that overall watershed conditions, not riparian forest conditions, determine runoff patterns.
- Land use changes, including land conversion from forests to agriculture and high rates of forest harvesting in subwatersheds, will lead to an increase in channel-forming bankfull flows that destabilize channels before a new sediment/water transport equilibrium is reached.
- The smallest waterbodies are likely to experience the largest changes, but these changes are probably not unlike those experienced due to annual variations in weather or natural disturbance events.

Microclimate

Microclimate influences habitat conditions for both aquatic and riparian organisms, and can include such parameters as wind speed and relative humidity. The three parameters considered by the RSTC were air temperature, light, and soil moisture.

Air temperature studies in RMZs are rare. Upland studies of temperature responses to harvesting have been conducted but there is evidence that the presence of water may moderate microclimate, including air temperature and relative humidity responses in the riparian zone (Danehy and Kirpes 2000; Chan 2006). No literature was found on soil moisture responses to harvesting in the RMZ. Information is available about changes in light, which can influence plant growth and, indirectly, food availability for aquatic and riparian organisms. For RMZs with low residual BA, light increases will be large and are related to RMZ width. Of the three microclimate parameters, there is the most information for light level response but little guidance on interpreting the significance of changes in light. Recovery of light levels at the ground surface is expected to be rapid.

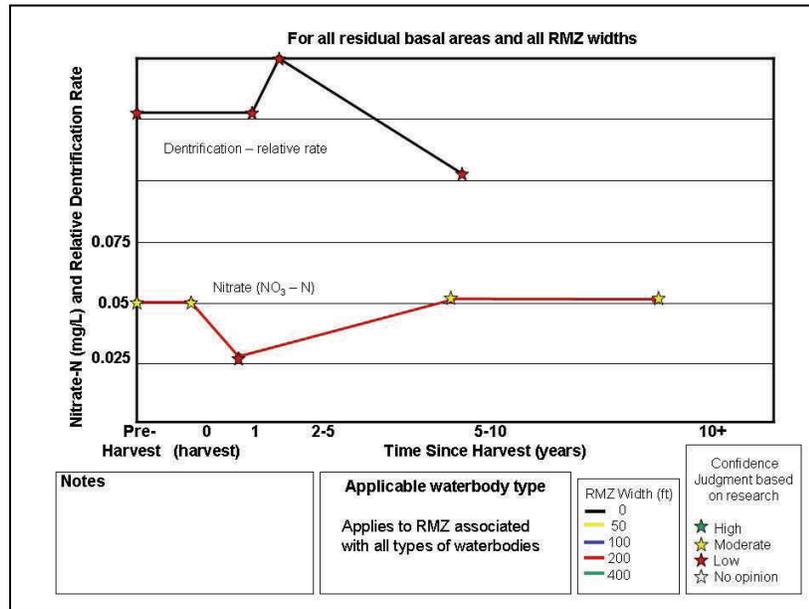
Water Quality

Seven water quality parameters were considered: concentrations of nitrate-nitrogen, phosphorus, methyl mercury, and dissolved oxygen; turbidity and total suspended solids (TSS); embeddedness; and water temperature.

Nitrate-nitrogen (NO_3^{-2}) is the most mobile form of nitrogen in water. Research throughout the United States has documented some cases where nitrate levels in runoff were elevated following timber harvesting (Ice 2000). Especially in situations where runoff with high nitrate levels comes off agricultural sites, riparian forests can reduce loads to streams by plant uptake and denitrification (reduction of nitrogen oxides to nitrogen gas by bacterial activity). Bacterial denitrification requires anaerobic (low oxygen) conditions.

Increased nitrate concentrations can lead to eutrophication (excessive plant growth) in some waterbodies, and at concentrations above 10 mg/L (expressed as nitrate-nitrogen) can create drinking water problems. Increases in nitrate concentrations following harvesting result from increased mineralization of organic matter and reduced recycling by plants. However, the RSTC found that the only research on decomposition rates in the region showed no significant difference between uncut areas and areas with high BA removal. Further, temporary increases in soil moisture (although, as reported earlier, there are no data on this, just professional judgment) will probably create anaerobic conditions that promote denitrification with resulting reductions in nitrate loads. The best professional judgment of the RSTC is that the width of the RMZ is likely to have little effect on nitrate loads to streams and there may even be a reduction in nitrate loads following harvesting due to elevated denitrification (Figure 6). This pattern is somewhat different than water quality response patterns observed elsewhere. The degree of uncertainty about specific patterns of water quality response reflects the lack of a watershed study under current Minnesota guidelines.

Figure 6. Best professional judgment about nitrate loading response to harvesting showing a similar pattern for all RMZ widths.

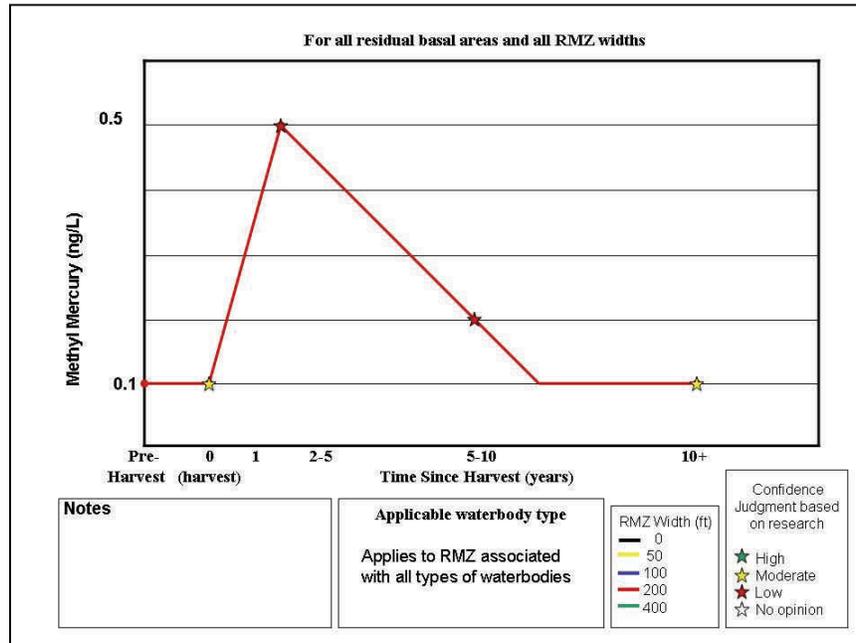


While nitrate concentrations may be insensitive to RMZ width, shading from the RMZ can be a factor in reducing the potential for eutrophication (Stewart 1997).

Phosphorus and nitrogen are the two nutrients that most affect plant growth and the potential for eutrophication. Phosphorus tends to be even less responsive to forest management than nitrogen, but total phosphorus loads can be increased by practices that increase erosion and sediment delivery (Salminen and Beschta 1991). RMZs can affect erosion and sediment delivery, so they can play a role in controlling phosphorus loads to streams (see discussion of sediment).

Methyl mercury (MeHg) concentrations can increase in streams draining recently harvested watersheds. Elevated soil moisture following harvesting probably creates anaerobic (higher soil redox potential) conditions that favor methylation (Figure 7). However, the RSTC again judges that varied widths of RMZs will have little influence on methylation or delivery of MeHg to streams because this is largely determined by soil moisture. In at least some cases, recovery from elevated MeHg concentrations following harvesting is rapid (Strachan et al. 2006).

Figure 7. Methyl mercury response to harvesting for all RMZ widths and residual BAs.



Dissolved oxygen (DO) concentrations in water are important for respiration by aerobic organisms. Forest operations can reduce DO concentrations most directly by (a) increasing water temperature, which decreases the solubility of DO in water; and (b) introducing fresh and fine oxidizable organic matter (slash), which can be decomposed by microorganisms. RMZs and equipment exclusion zones that keep fresh slash out of the water or require that fresh slash be quickly removed, and that maintain shade will avoid major changes in DO.

Sediment parameters (turbidity, suspended sediment, total suspended solids (TSS), and embeddedness) are interrelated measures that are often (but not always) strongly related to sediment loads. Turbidity, suspended sediment, and TSS all relate to suspended particles in the water column. Turbidity results from an interference with the passage of light through water due to suspended matter. Suspended sediment refers specifically to inorganic sediment. The matrix of suspended material in the water column often includes some organic material as well. This can be algae, leaves, needles, and other small organic material. Together, suspended inorganic and organic matter make up TSS. Embeddedness is a measure of how much fine sediment deposits and surrounds coarse substrate on the surface of a streambed. Generally, coarse substrate will be buried deeper with additional fine sediment.

Turbidity, suspended sediment, and TSS are influenced by management when it affects erosion rates, sediment (solids) transport, and deposition of material. One of the most commonly recognized functions of riparian zones is their role as filter strips for sediment. As runoff-entrained sediment passes through a riparian area the sediment can be trapped and settle, resulting in a reduction in the amount delivered to the stream. Delivery ratios are always less than 1.0, but the sediment and suspended

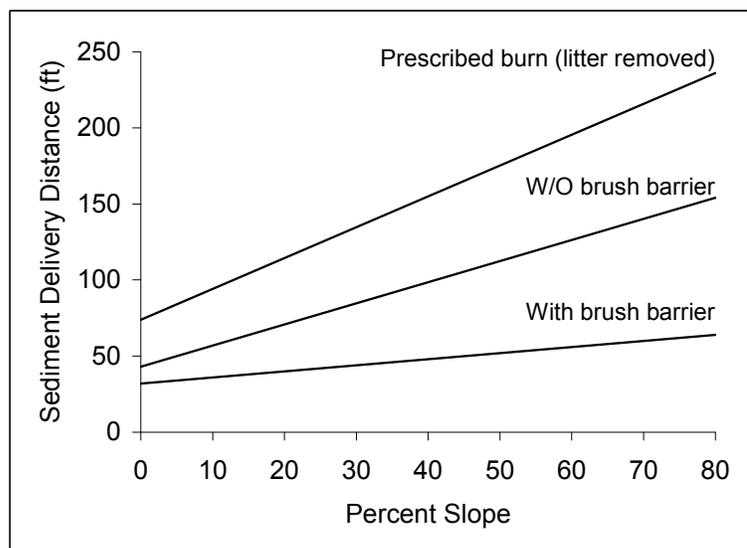
solid parameters are also influenced by other erosion and sediment transport processes in the riparian zone. Unlike with some other land covers, overland flow for forests generally only occurs in areas where flow concentrates, such as ephemeral channels and swales. Therefore, the role of RMZs as filter strips may be less important than for other land covers except to attenuate sediment losses from roads or landings.

Riparian areas and stream channels can be important sites for sediment storage. Bank and channel erosion can also be significant components of overall erosion from a reach. Due to stream proximity, disturbance in the out-of-channel riparian area will have high sediment delivery ratios. In both cases the condition of the riparian area can affect erosion processes. These multiple sediment control functions are summarized as follows:

- Riparian areas as filter strips for reducing delivery of sediment from outside the RMZ
- Channels and banks as sources of sediment due to channel disturbance or changes in stream power (including loss of root strength and removal of storage elements)
- Erosion from riparian area disturbance with a high delivery ratio

Most treatments of RMZs to reduce sediment delivery to streams involve their role as filter strips. Castelle and Johnson (2000) and CH2M Hill and WWA (1999) provided reviews of how the effectiveness of a riparian area to filter sediment changes with riparian area width. However, these synthesis efforts failed to account for key variables that can dramatically affect sediment filtration. The importance of slope and the condition of the filter strip is well represented in a series of graphs based on Swift (1986) (Figure 8).

Figure 8. 90% of sediment deposition distance for grassed slopes, grassed slopes with brush barriers, and slopes that have been burned (based on Swift 1986).



Lowrance et al. (1997) reviewed the effectiveness of riparian forest buffers for the Chesapeake Bay and concluded:

The estimated range of sediment deposition rates in riparian forests is large and apparently somewhat dependent on estimation techniques...Although the different methods give widely divergent numbers, in all cases sediment deposition accounts for 80%-90% of gross erosion from the uplands.

Like Megahan and Ketcheson in 1996 and Benoit in 1978, Rivenbark and Jackson (2004) concluded that sediment filtering was much less effective in sites where concentrated flows occurred. They studied observable concentrated flow paths carrying surface runoff and/or sediment from harvested and site-prepared sites in Georgia. They found about 5% of managed areas contributing to concentrated riparian breakthrough flows. Widening RMZs has little benefit in these cases, but special management of these contribution areas could have sediment delivery benefits. Merten and Newman (1998) pointed to a road crossing as a possible major contributor to a measured change in embeddedness for Little Pokegama Creek.

Harvesting a watershed can decrease evapotranspiration and result in some increase in sediment transport as a result of increased stream power and sediment transport capacity (Williams et al. 2000). Bank and channel erosion can be especially sensitive to increases where root strength is reduced as a result of disturbance to the vegetation or where wood or other sediment retention structures are disrupted. Castelle and Johnson (2000) pointed out the importance of root strength and bank stability. Tree roots not only reinforce the streambank, but may serve as a grade control to avoid headcutting in some eroding reaches.

Wood that is disturbed in the stream may release sediment from channel storage, resulting in elevated sediment concentrations and yields. Beschta (1979) reported that removal of large organic debris for fish passage improvement resulted in a large release of sediment. Megahan and Nowlin (1976) found large volumes of sediment in channel storage behind obstructions. Bilby (1981) reported that wood was important in storing sediment in streams in New Hampshire.

Figures 9a through 9d synthesize how riparian zones reduce sediment loads to streams. On a 10% slope a 50 foot RMZ will be highly effective. Trapping efficiency will be 90% or better and the RMZ will help avoid disturbance to the stream channel and bank. On a 70% slope a 50 foot RMZ will not provide a high level of sediment trapping but will protect the channel. The response levels projected by our synthesized graphs appear to be consistent with the filter strip guidelines in the Minnesota Voluntary Guidelines (MFRC 2005).

Figure 9a. Percent of sediment delivered to a stream with alternative RMZ widths compared to streams without RMZs based on slope angle of 10%;

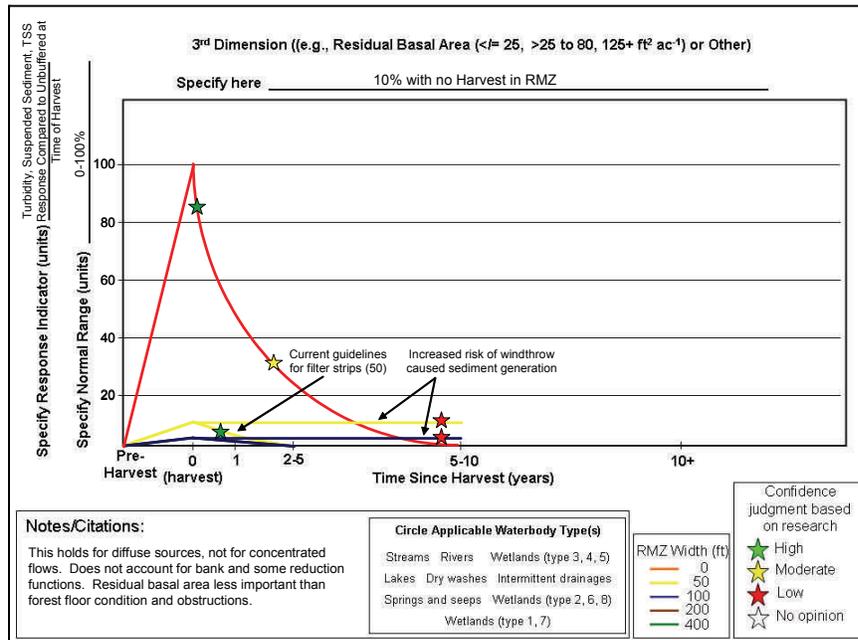


Figure 9b. Percent of sediment delivered to a stream with alternative RMZ widths compared to streams without RMZs based on slope angle of 20%

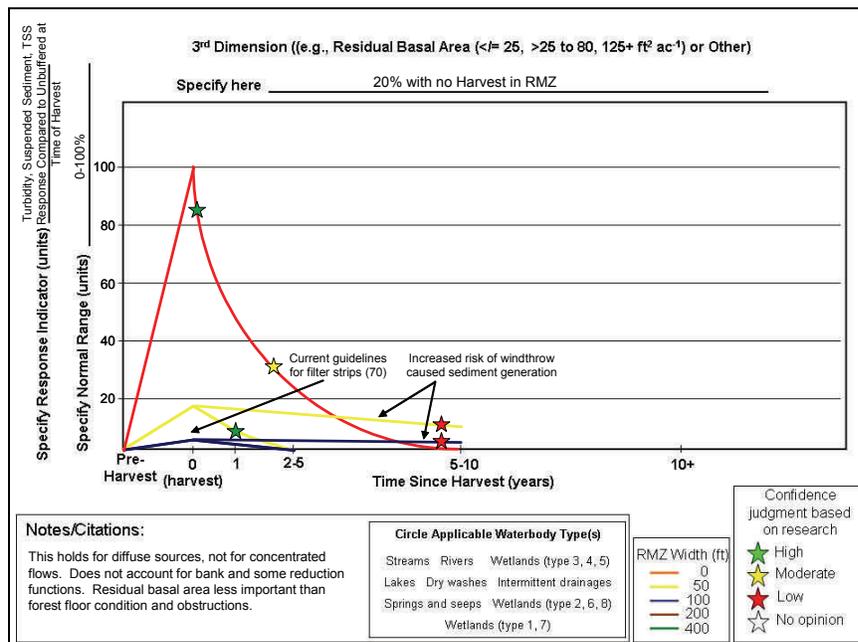


Figure 9c. Percent of sediment delivered to a stream with alternative RMZ widths compared to streams without RMZs based on slope angle of 40%

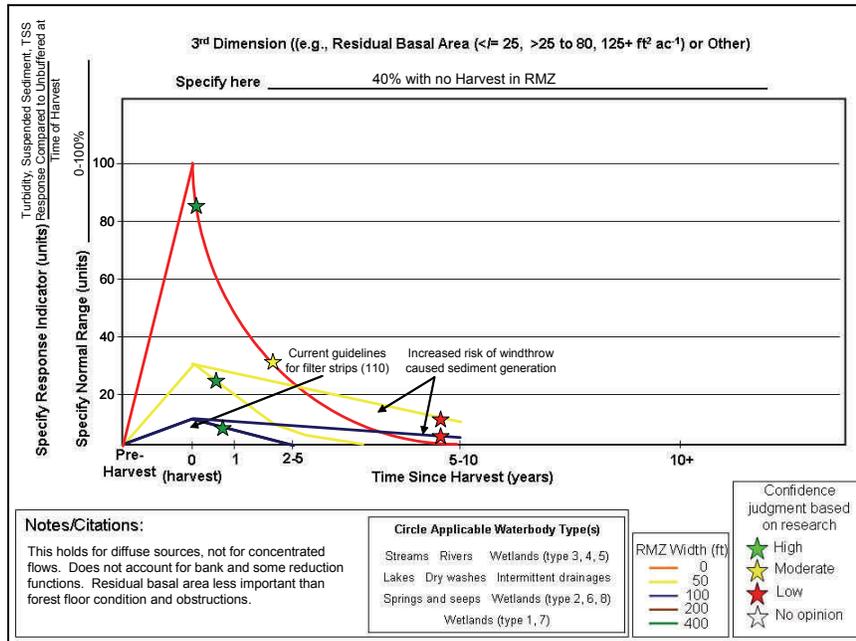
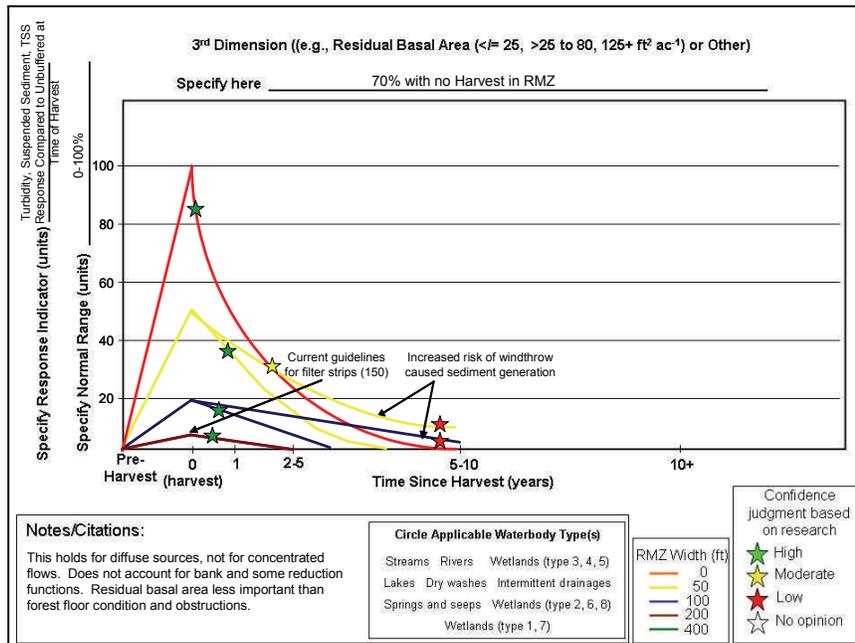


Figure 9d. Percent of sediment delivered to a stream with alternative RMZ widths compared to streams without RMZs based on slope angle of 70%



Windthrow events can result in increases or decreases in observed sediment loads downstream. It is likely that for small channels, wood delivered to streams will at least temporarily reduce downstream delivery of sediment (assuming the wood can form pools that result in settling). For example, Jackson et al. (2001) reported a finding of channel substrate when slash was deposited in a headwater stream. Buffered headwater streams did not initially experience this change in substrate, as the buffers kept slash out of the stream. Others have observed how uprooting along the bank and windthrow logs diverting the current can cause new scouring and bank erosion. Newman et al. (2004) showed no evidence of increased embeddedness for a study in Minnesota with different levels of riparian harvest. The influence of RMZ treatment was insignificant compared to the influence of one poorly constructed road crossing the stream. The RMZ is one component in controlling sediment, but it is not the only practice needed to reduce impacts, nor can it completely eliminate poor upslope practices.

Water temperature is an important measure of water quality because it controls biochemical rates. Research throughout the United States has shown that water temperature can be largely protected by providing shade over water. As a first approximation, it is estimated that a stream flowing through a harvest unit with less than 25 ft²acre⁻¹ of BA can experience an increase in maximum temperature of 4°C. This increase will disappear in about 2 to 5 years (Figures 10a, 10b, and 10c). However, many factors determine the actual magnitude of temperature change, including the nature of the upslope treatment; the width, length, and BA (surrogate for height and density of foliage) of the RMZ; the width, depth, and velocity of the stream; the amount of groundwater inflow; topographic (e.g., bank) shading; and thermal sinks and sources. Shallow streams tend to be more susceptible to heating than deep streams but narrow streams may experience a rapid recovery of shade from brush and small trees, while wider streams require more years for trees of sufficient size to grow and provide full potential shading.

The synthesis graphs (Figures 10a, 10b, and 10c) indicate that for dense, well-shaded riparian forest stands (as expressed by 125+ ft²acre⁻¹ of BA), there is little stream temperature response even with a 50 foot RMZ (Figure 10b). With moderate shade (as expressed by >25 to 80 ft²acre⁻¹ of BA) a 50 foot RMZ will reduce the potential temperature increase by 65% and a 100 foot RMZ will reduce the increase by 80%. BA is a surrogate for shade or angular canopy density.

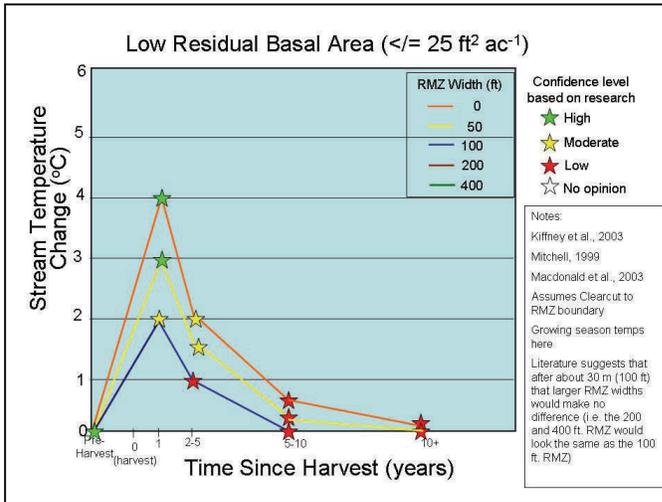


Figure 10a. Stream temperature response with low residual BA.

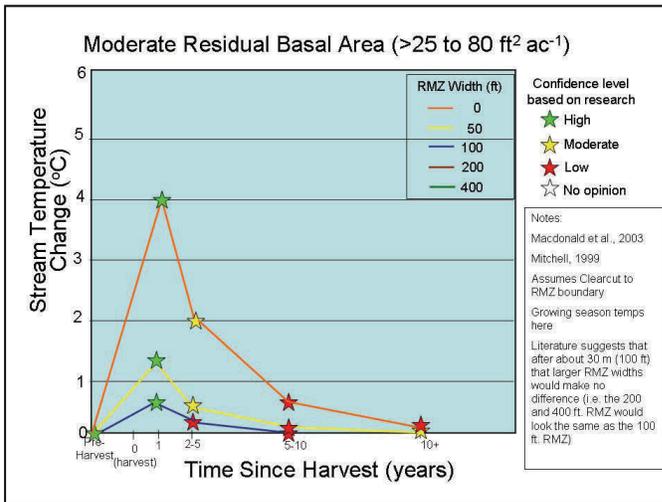


Figure 10b. Stream temperature response with moderate residual BA.

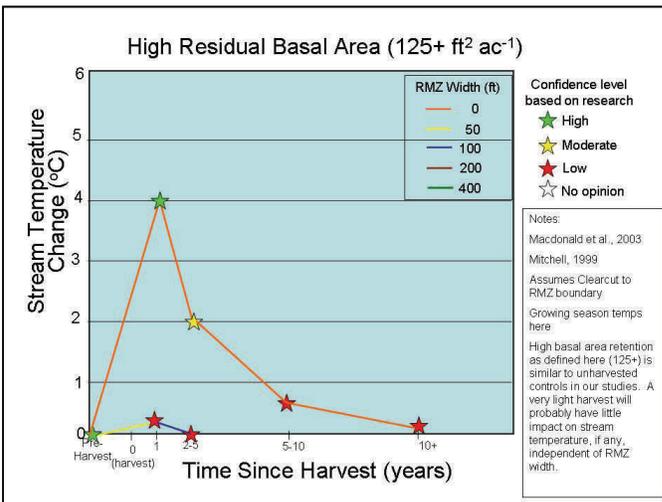


Figure 10c. Stream temperature response with high residual BA.

Two studies in particular confirm that relatively narrow RMZs can be effective in moderating temperature increases. Verry (2006) noted in the Pokegama Study that there was no difference between the temperature ranges of the various units with riparian leave strips (thinned) and control plots. The occurrence of 7 m (25 ft) high terraces within 15 m (50 ft) of the west to east running channels and high densities of herbs, shrubs, and suckers apparently provide as much shade as the mature forest for this 1.5 m (5 ft) wide, low-width/depth ratio (narrow and deep) channel. A study in Maine by the Manomet Center for Conservation Sciences used a replicated BACI (before-after-control-impact) design. Sites were located along streams in approximately 15 m (50 ft) tall stands with about 90% or more canopy closure (Wilderson et al. 2006). Clearcutting to the stream edge increased stream water maximum temperatures up to 4.4°C. Streams with 36 foot buffers (maintaining at least 60 ft²acre⁻¹ BA) reduced water temperature increases to about 25% (statistically not significantly different from the control) of the maximum observed when no buffer was used. Streams with a 23 m (75 ft) RMZ (maintaining at least 60 ft²acre⁻¹ BA) showed no difference in temperature compared to control streams.

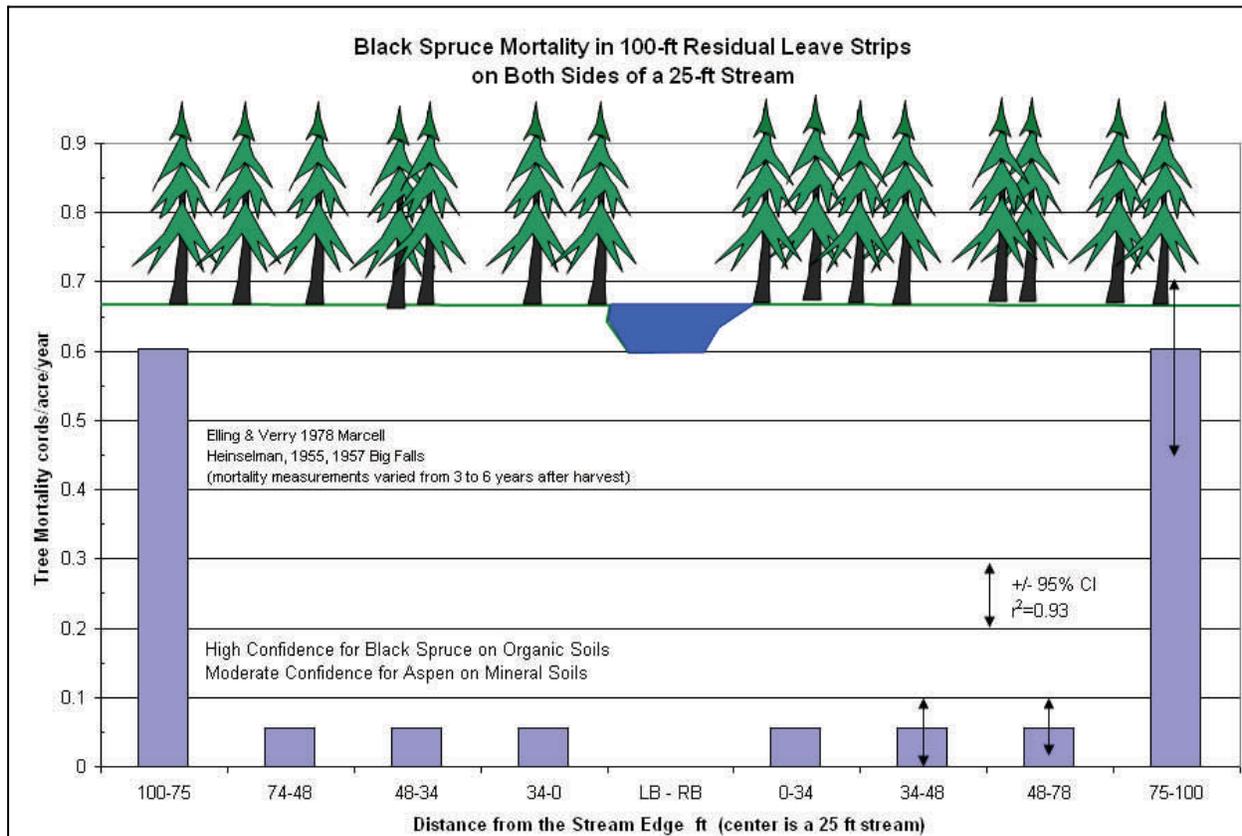
Based on this review, stream temperature would generally be protected with the existing RMZs if BA was maintained between 25 and 80 ft²acre⁻¹ and especially if the BA was greater than 80 ft²acre⁻¹. The Manomet research (Wilderson et al. 2006) provided even more confidence in RMZs with a minimum of 60 ft²acre⁻¹ BA. Verry (2006) noted that this is consistent with minimum forest management guidelines for fiber production.

RISKS TO CONSIDER FOR RMZS

We have been able to develop general RMZ and indicator patterns. However, this does not address two specific risk factors: blowdown and beaver.

Blowdown of riparian forests can be accelerated with exposure of stands to wind as a result of upslope harvesting. For black spruce stands, Elling and Verry (1978) reported that most mortality occurred in the first 7 m (25 ft) on the outside of the leave strip. This represented an annual loss of about 5% of the stand volume in the 7 m (25 ft) strip each year. Stand losses further into the strip were an order of magnitude lower than the first 7 m (25 ft) and growth exceeded losses (Figure 11). These data are for residual stands between clearcut strips and might underestimate blowdown because of the narrow (30 m [100 ft]) strip cuts that were studied. We might also assume this to be a worst-case response, given the wet, blowdown-prone sites that black spruce occupy. Near-stream and lake riparian sites might also experience wet soils and shallow rooting conditions. Data for hardwood stands are lacking. Further, infrequent catastrophic winds (greater than 80 mph) may result in higher RMZ losses. In some cases, blowdown may provide “dead” shade (Jackson et al. 2001), but excessive blowdown is likely to result in increased insolation of the stream.

Figure 11. Black spruce mortality in categories of distance from the outer edges of strips on either side of a 25 ft stream (Verry 2006).



Draft and preliminary work (Turner 2005; Dr. Brian Palik, personal communication) from re-surveys of the RMZs at Pokegama Creek confirm the observations by Elling and Verry (1978) that the outside reaches of RMZ are where trees are most vulnerable to blowdown. Blowdown was substantial (around 75-80%) for the partial cut RMZs and less for uncut RMZs (approximately 50%) and control riparian forest (10%) for the 9 years after harvest.

Beaver activity can also create additional risks to stream temperature and channel conditions. Beaver dams result in a number of channel, stream, and riparian modifications that create the risk of increased stream temperatures. Impoundment of the stream creates increased surface area (increased solar insolation), reduces stream velocity (increased travel time), and causes settling of sediment with a resulting reduction in stream depth. Beaver foraging may also preferentially remove shade adjacent to the stream. Returning again to the Pokegama Study, Verry (2006) noted that while treatment of the RMZs did not measurably affect observed stream temperatures, a downstream beaver pond did have a large impact. “Beaver have exploited the aspen forests and given rise to a density of beaver dams far in excess of pre-original logging.” A pulse of intense fires in the 1930s (three times the 1850 to 1890 rate) created two to three times as much early successional forest in Minnesota. Beaver dam construction

also increased dramatically after the 1930s, culminating in an extraordinarily high dam density (ten versus three dams per mile of channel). Where beaver dam densities are extraordinarily high, stream habitat is impaired because of over-wide streams. These over-wide streams cannot transport either normal or accelerated amounts of sediment, leading to filled in pool habitat and water temperatures 2 to 4°C higher in over-wide stream reaches and 10°C higher in pools behind dams.

While the RSTC members agreed that beaver create a risk to riparian functions, we could not come to consensus on how to depict these risks. Beaver dams can reduce sediment transport through a stream reach, resulting in sediment deposition and channel widening. This can be addressed by excluding early succession forests on streams where the impact is critical. Most foraging by beaver occurs within the first 10 m (33 ft) of water, but guidelines from Ontario recommend that vegetation management extend 50 m (165 ft) from the water to discourage beaver activity. Minnesota DNR Fisheries and Wildlife Division recommends a 91 m (300 ft). exclusion of timber sales on cold water trout streams. Beaver dams can also adversely modify stream channel geometry so that warming occurs. One position concluded that integrated pest management strategies are needed to address water resource concerns from beaver for critical stream reaches. An alternative position recommended a 61 m (200 ft) timber sale exclusion on cold water trout streams and their tributaries where aspen suckering would be the resulting tree regeneration. Management of beaver is most critical for cold water trout streams and where beaver populations are found in excess of normal densities of 1 to 4 dams per mile.

SYNTHESIS OF FINDINGS

Based on the review by the RSTC, the two hydrologic and water quality parameters most affected by management in the riparian zone are sediment and temperature. Current filter strip guidelines, although woefully understudied in Minnesota, appear to be consistent with national research. Perhaps the most important lessons from Minnesota sediment research and other national research are lingering legacy impacts on sediment, the importance of extreme events, and the potential for poorly designed or maintained roads to impact sediment.

Figure 12a and 12b show alternative perspectives on how RMZ width affects the shade function and risk to the RMZ from either windthrow or beaver activity. While both agree on the basic patterns and especially the shade functions, there is disagreement about the shape of the risk curves for windthrow and beaver.

Figure 12a. Synthesis graph showing shade function with RMZs having different residual BAs to maintain stream temperatures and risk from windthrow (based on maintaining a high level of riparian functions) and beaver activity compared to RMZ width. Other functions are largely achieved within the existing guidelines (see discussion) or are better addressed at the landscape scale.

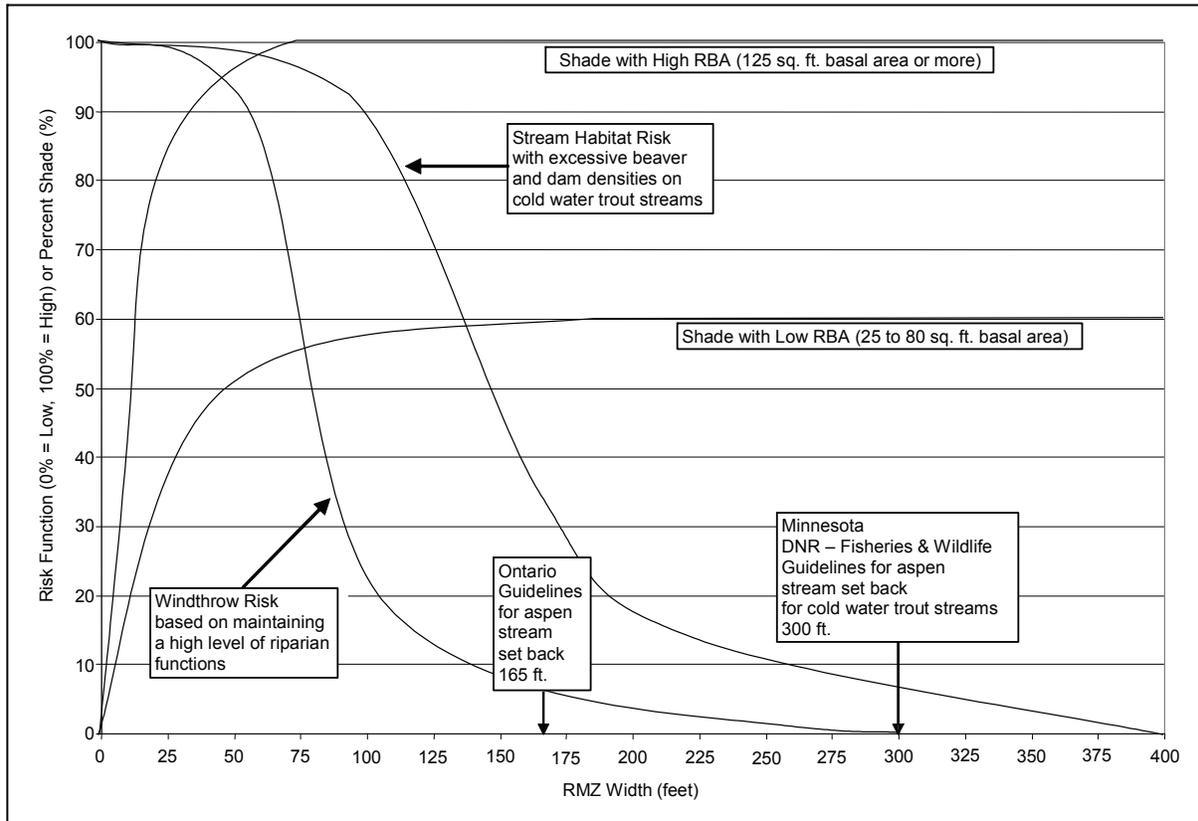
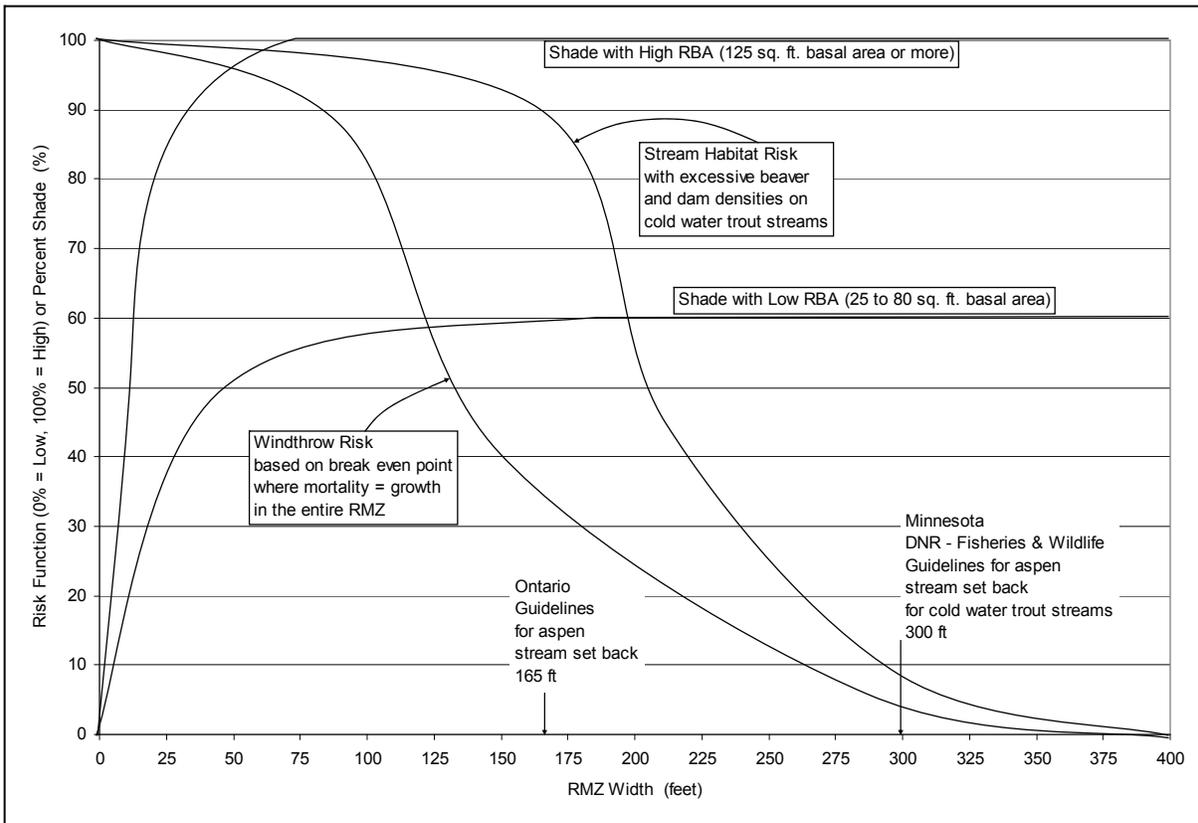


Figure 12b. Synthesis graph showing shade function with RMZs having different residual BAs to maintain stream temperatures and risk from windthrow (based on break even point for growth versus mortality in the entire RMZ) and beaver activity compared to RMZ width. Other functions are largely achieved within the existing guidelines (see discussion) or are better addressed at the landscape scale.



Another area in which there was a lack of resolution by the RSTC was how to treat non-trout streams less than 1 m (3 ft) wide. Based on the Pokegama Watershed Study, some believe that temperature and sediment responses will not be severe and that no minimum RMZ width is needed. Other RSTC members felt that a stringer of trees (perhaps all trees within 1.5 m (5 ft) of the stream) should be left along these streams to provide a physical barrier to equipment (protecting the streambank) and as a future source of large wood to the streams. These benefits may be counteracted by the high potential that the stringer would blow down and accelerate erosion.

The RSTC has worked diligently over a two year period to address the questions of the MFRC. The RSTC was faced with a wicked problem to synthesize and provide guidance where there has been a lack of research. Of particular concern is the lack of research for the unique geomorphic, climatic, and biological conditions of Minnesota. For example, there are no watershed studies designed to test the effectiveness of the current forest resource guidelines (MFRC 2005).

Some scientists are more comfortable extrapolating their experiences and observations than others, so our treatment may be uneven. We recognize that this effort to synthesize the information on RMZ functions provides only one step in the process of reconciling environmental, economic, and social goals. For example, in looking at Figure 11 the MFRC might recommend an RMZ with two zones, one nearest the stream (perhaps 25 to 50 foot wide) that would maintain a high level of BA and an outer RMZ with less BA for addressing beaver concerns and windthrow. Interpretations of the functions of RMZs and applications to specific waterbodies must include consideration of the sensitivity and rate of recovery of a waterbody to disturbance. Narrow streams, for example, may have shade functions provided rapidly by brush, while wider streams may need tall trees to provide these functions. Shade functions may be given higher priority for trout streams than for warm water streams. Considerably more detail is provided in individual written assessments and graphical representations in Appendix B.

Basic conclusions are:

- Riparian forest conditions are likely to have a somewhat disproportionate effect on the overall hydrologic response of a watershed, but evidence from this region suggests that overall watershed conditions, not riparian forest conditions, determine runoff patterns.
- Land use changes, including land conversion from forests to agriculture and high rates of forest harvesting in subwatersheds, will lead to an increase in channel-forming bankfull flows that destabilize channels before a new sediment/water transport equilibrium is reached.
- The smallest water bodies are likely to experience the largest changes, but these changes are probably not unlike those experienced due to annual variations in weather or natural disturbance events.
- Stream water temperature increases of 2 to 4°C can be avoided with forested RMZ widths of 15-30 m (50-100 ft), depending on BA.
- RMZ width and residual BA had no, small, or fleeting impacts on stream water nitrate, phosphorous, methyl mercury, or dissolved oxygen.
- Current filter strip recommendations are consistent with the national literature on controlling sediment. The only test of alternative RMZ treatments showed no effect of the alternative treatments but did demonstrate the importance of a poor road crossing.
- Beaver dam construction dramatically increased after the 1930s, due in part to early successional forests resulting from disturbance, culminating in an extraordinarily high dam density (ten versus three dams per mile of channel).
- Where beaver dam densities are extraordinarily high, stream habitats are impaired because these over-wide streams cannot transport normal or

accelerated amounts of sediment, leading to fill-in of pool habitats and water temperatures 2 to 4°C higher in over-wide stream reaches and 10°C higher in pools behind dams.

- Excessive blowdown of RMZs can negate some riparian functions such as shade production or bank stability but may enhance other functions such as recruitment of large wood. EPA's Watershed Assessment of River Stability and Sediment Supply or WARSSS (<http://www.epa.gov/warsss/rrisc/box15.htm>); figure 96) provides recommendations about limiting large wood accumulations to avoid reducing sediment competence and capacity. For some channel types, especially those with finer textured substrates, keeping woody debris from blocking more than 20% of the channel will keep risks moderate or less. Other channel types, especially steep reaches with coarse bed material, are less sensitive to wood blockage.
- Minnesota blowdown studies are limited to black spruce on organic soils, where RMZs of 30 to 40 m (100 to 130 ft) (one side and two sides, respectively) are needed to maintain a balance between tree mortality and growth.
- The RSTC is divided on whether a stringer of trees at the edge of a small stream is an effective deterrent to equipment or an invitation for blowdown and loss of timber value.

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A SYNTHESIS OF THE RIPARIAN SCIENCE TECHNICAL COMMITTEE FINDINGS ON HABITAT RESPONSES TO ALTERNATIVE RIPARIAN MANAGEMENT GUIDELINES

RIPARIAN AREAS AS HABITAT

Riparian areas provide and affect habitat for both terrestrial and aquatic species. The terrestrial portion of a riparian area provides habitat for riparian dependent animals, as well as facultative species (both plant and animal) that occur elsewhere in the landscape. Physical and biotic characteristics of riparian areas also affect habitat for aquatic species. Manipulation of riparian areas through management may alter habitat quality in both the terrestrial and aquatic portions of riparian areas. Here we attempt to summarize the major findings of the RSTC with respect to habitat functions of riparian areas. **This document is meant only as a synthesis of detailed findings presented in the report. For the specific details, refer to appropriate sections in the report including the individual written assessments and graphical representations in Appendix B. The synthesis is only meant to distill the major findings into an easily interpreted graphical format.** We divide our synthesis into three sections: terrestrial habitat indicators, aquatic habitat indicators, and forest dependent amphibians.

TERRESTRIAL HABITAT INDICATORS

The following indicators of terrestrial habitat were addressed by the RSTC in ways that allowed assessment of response as a function of residual BA, RMZ width, and time.

1. Interior forest birds (% of control population)
2. Bird productivity (% of control population)
3. Riparian dependent birds (% of control population)
4. Forest Area Sensitive Plants: Species richness (species/m²)
5. Forest Area Sensitive Plants: Recruitment (individuals * m⁻² * yr⁻¹)
6. Disturbance associated (generalist) plants: Species richness (species/m²)
7. Disturbance associated plants: Aspen regeneration (new crop stems/ac)
8. Snags (number/acre)
9. Canopy cover/leaf area (m²/m²)

Caveats to Interpretation

There are several caveats to interpretation of the synthesis tables.

1. The synthesis does not account for level of confidence in relationships to BA, RMZ width, and time since harvest. The reader should refer to specific indicator responses in the synthesis document to review confidence estimates.

2. Changes in indicators were assessed relative to normal ranges under reference conditions (mature forest). Changes can either reflect decreases (most indicators) or increases. Changes to values outside the normal reference range may or may not be considered detrimental. For instance, aspen regeneration is included as a response. Reduction in RMZ BA adjacent to upland clearcuts will result in large increases in aspen sprouting in the RMZ, above values that occur in closed canopy RMZs. We make no judgment as to whether this is good or bad, only that it represents a response to RMZ management that pushes the response value outside the range that occurs in the reference condition.
3. Not all RSTC members working on habitat functions assessed responses relative to the natural range occurring in a reference condition. In these cases (bird productivity, interior forest birds, riparian dependent birds), responses were judged to be outside of the normal range if a change exceeded 25 percent of a reference value.
4. Interpretations of response and recovery of aquatic indicators, as a function of residual BA, assumes BA is relatively stable over short time periods, that is, there is little to no blowdown within the RMZ. In reality, significant amounts of blowdown can occur after harvest (see separate blowdown report), greatly reducing residual BA in the years immediately after harvest. As such, response and recovery trends at specific BA levels should be interpreted with caution, since they assume a constant residual BA. Moreover, high blow down potential argues for recommending higher levels of residual BA and wider RMZs, to account for eventual blowdown.

Terrestrial Habitat Responses to RMZ Width and BA

The following table summarizes findings with respect to terrestrial habitat indicators. The table illustrates whether an indicator value declines below or exceeds the reference range, as a function of BA or RMZ width. Red indicates a change from the reference range, with I or D indicating whether the change is an increase (I) or decrease (D). Blue indicates no change beyond the reference range. Grey indicates that no studies were available on which to base a judgment.

Table 5. Terrestrial habitat indicators: change in response to residual BA and RMZ width.

		Increase or decrease	No change	No information		
		RMZ Width (ft)				
Indicator	Basal Area	0	50	100	200	400
1. Interior forest birds	<25	D	D	D	D	
	25-80	D	D	D	D	
	>125	D	D	D		
2. Bird productivity	<25	D	D	D	D	
	25-80	D	D	D	D	
	>125	D	D	D		
3. Riparian dependent birds	<25	D	D	D	D	
	25-80	D				
	>125	D				
4. Forest area sensitive plants (spp richness)	<25	D	D	D	D	D
	25-80	D	D	D		
	>125	D				
5. Forest area sensitive plants (recruitment)	<25	D	D	D	D	D
	25-80	D	D	D	D	D
	>125	D	D	D	D	
6. Disturbance associated plants (richness)	<25	I	I	I	I	I
	25-80	I	I	I	I	I
	>125	I	I	I		
7. Disturbance associated plants (aspen regeneration)	<25	I	I	I	I	I
	25-80	I	I	I	I	I
	>125	I	I	I		
8. Snags	<25	D	D	D	D	D
	25-80	D	D			
	>125	D				
9. Canopy cover	<25	D	D	D	D	D
	25-80	D	D	D	D	D
	>125	D	D			

Key Points

- Terrestrial indicators showed strong trends related to RMZ residual BA and width.
- All indicators changed beyond normal ranges at low residual BA (less than 25 ft²/ac), regardless of RMZ width.
- Potential impacts were reduced at moderate residual BA (25-80 ft²/ac), relative to low residual BA, but six indicators still had values outside of their normal range, across all RMZ widths.
- At high residual BA (greater than 125 ft²/ac) and narrow RMZ (30 m [100 ft] or less), five of nine indicators had values falling outside of their normal ranges. A wide RMZ (61+ m [200+ ft]) coupled with high residual BA has the highest likelihood of maintaining most indicators within their normal ranges.
- Interior forest birds, a key indicator of mature forest habitat quality, appear to need RMZs wider than 30 m (100 ft), even at high residual BA, to maintain populations within the range of reference conditions.
- In contrast, trends for riparian dependent birds suggest little impact to population sizes at moderate to high residual BA and at all RMZ widths. However, specific impacts would be dependent upon habitat characteristics on site before and after harvest (e.g., presence of super canopy trees and suitable cavities). Moreover, little data are available for interpreting responses of these species.

Recovery of Terrestrial Habitat Indicators

The following table summarizes the findings of the RSTC with respect to recovery of terrestrial habitat indicators, by 10 years after harvest. The table illustrates whether the value for a particular indicator fell outside of (either higher or lower) the reference range as a function of residual BA or RMZ width by year ten. In the table, red indicates either an increase or decrease exceeding the reference value or range by year 10, with I or D indicating whether the change is an increase or decrease, respectively. Blue indicates recovery to the reference value or range by year 10. Grey indicates insufficient information to make a judgment.

Table 6. Terrestrial habitat indicators: recovery in response to residual BA and RMZ width.

Indicator	Basal Area	Increase or decrease	No change	No information		
		RMZ Width (ft)				
		0	50	100	200	400
1. Interior forest birds	<25	D	D	D		
	25-80	D	D			
	>125	D				
2. Bird productivity	<25	D	D	D		
	25-80	D	D	D		
	>125	D				
3. Riparian dependent birds	<25					
	25-80					
	>125					
4. Forest area sensitive plants (spp richness)	<25	D	D	D	D	D
	25-80	D	D	D		
	>125	D	D			
5. Forest area sensitive plants (recruitment)	<25	D	D	D	D	D
	25-80	D	D	D	D	D
	>125	D	D	D	D	
6. Disturbance associated plants (richness)	<25	I	I	I	I	I
	25-80	I	I	I	I	I
	>125	I	I	I		
7. Disturbance associated plants (aspen regeneration)	<25	I	I	I	I	I
	25-80	I	I	I	I	I
	>125	I	I	I		
8. Snags	<25	D	D	D	D	D
	25-80	D	D			
	>125	D				
9. Canopy cover	<25					
	25-80					
	>125					

Key Points

- Ten years after harvest, at low residual BA (less than 25 ft²/ac), the majority of terrestrial habitat indicators may not recover to values falling within their normal ranges, regardless of RMZ width.
- At moderate residual BA (25-80 ft²/ac), the number of indicators that recovered within 10 years increased with increasing RMZ width. Five indicators, for which there was applicable information, had recovered to normal ranges by 10 years, with a 200 ft wide RMZ.
- At high residual BA (greater than 125 ft²/ac) and narrow RMZ (30 m [100 ft] or less), six of nine indicators recovered to their normal ranges within 10 years. Potential for recovery of indicator values to their normal ranges within 10 years is maximized (8 of 9 indicators) with high residual BA (greater than 125 ft²/ac) and wide RMZs (greater than 61 m [200 ft]).
- Interior forest birds, a key indicator of mature forest habitat quality, show little potential for recovery within 10 years at low residual BA and narrow RMZ width (less than or equal to 30 m [100 ft]), but good potential for recovery to reference condition with moderate to high residual BA and RMZ widths of at least 30 m (100 ft).
- In contrast, trends for riparian dependent birds show high potential for recovery to reference population levels within 10 years at all BAs and RMZ widths. However, this recovery is dependent upon the habitat condition of the riparian forest after harvest, (i.e., the RMZ must contain super canopy and cavity trees).

Summary of Terrestrial Indicators

It is the interpretation of the RSTC that RMZs less than 61 m (200 ft) wide and below 125ft²/ac residual BA provide suboptimal terrestrial habitat, relative to mature forest reference condition. This interpretation is based on the high proportion of indicators whose values either exceed or decline beyond their normal reference ranges after harvest, and the limited to moderate recovery of these indicators within 10 years after harvest.

AQUATIC HABITAT INDICATORS

The following indicators of aquatic habitat function were addressed by the RSTC in a manner that allowed some interpretation of response to RMZ management.

1. Stream primary production (periphyton productivity or biomass)
2. Stream large wood (volume per length of stream)
3. Stream macroinvertebrate abundance (number/m²)
4. Stream macroinvertebrate community structure (relative abundance of different organisms)
5. Wetland macroinvertebrate community structure (relative abundance of different organisms)
6. Wetland sedge production (percent cover)

Caveats to Interpretation

1. The summary for streams applies only to streams of small to moderate size for which the riparian forest is an important source of wood, organic matter, and shade. The RSTC did not evaluate indicators for larger stream or river systems.
2. The synthesis for wetlands applies only to seasonally inundated and small semi-permanent wetlands. The RSTC did not evaluate aquatic indicators for large wetlands or lakes.
3. Changes in aquatic habitat indicators were assessed relative to normal ranges under reference conditions (mature forest). Depending on the indicator, changes may reflect an increase or a decrease, relative to the reference condition. Values outside the normal ranges may or may not be detrimental. For instance, increases in stream wood after harvest could have a positive habitat influence if wood is lacking in the system.
4. Not all RSTC members assessed responses relative to the natural range occurring in a reference condition. In these cases (Table 7, indicators 1-5), responses were measured as percentage change relative to the reference condition and were judged to be outside of the normal range if the change exceeded 25 percent of the reference value.
5. Some responses to residual BA or width are inferred. For instance, if evidence indicated that an indicator decreased at moderate residual BA (25-80 ft²/ac) and narrow to moderate RMZ width, then it was inferred that a similar response would occur at low residual BA regardless of RMZ width.
6. Interpretations of response and recovery of aquatic indicators, as a function of residual BA, assumes BA is relatively stable over short time periods, that is, there is little to no blowdown within the RMZ. In reality, significant amounts of blowdown can occur after harvest (see separate blowdown

report), greatly reducing residual BA in the years immediately after harvest. As such, response and recovery trends at specific BA levels should be interpreted with caution, since they assume constant residual BA. Moreover, high blow down potential argues for recommending higher levels of residual BA to account for eventual blowdown.

Aquatic Habitat Responses to RMZ Width and BA

The following table summarizes findings with respect to aquatic habitat. The table illustrates whether values for indicators changed, decreased, or increased beyond the reference range, as a function of residual BA or RMZ width. In the table, red indicates a change beyond the reference value or range, with I or D indicating whether the change is an increase or decrease, respectively, and C indicating a community change that included both increases and decreases in component species abundances. Blue indicates no change beyond the reference value or range. Grey indicates that there were no studies on which to base a judgment.

Table 7. Aquatic habitat indicators: change in response to residual BA and RMZ width.

Indicator	Basal Area	Increase or decrease	No change	No information				
		RMZ Width (ft)						
		0	50	100	200	400		
1. Stream wood	<25	I*	I	I	I	I		
	25-80	I						
	>125	I	I	I				
2. Stream Productivity	<25	I	I	I	I	I		
	25-80	I	I					
	>125	I						
3. Stream macroinvertebrate abundance	<25	I	I	I	I	I		
	25-80	I	I	I				
	>125	I						
4. Stream macroinvertebrate community structure	<25	C	C	C	C	C		
	25-80	C	C	C				
	>125	C	C	C				
5. Wetland macroinvertebrate community structure	<25	C	C	C	C	C		
	25-80	C						
	>125	C						
6. Wetland sedge cover	<25	I	I	I	I	I		
	25-80	I	I	I	I	I		
	>125	I	I	I				

* - Increase in stream wood cells is a function of the harvest practices and blowdown

Key Points

- Increases in stream wood, even with low residual BA (less than 25 ft²/ac), reflects deposition of logging slash into the streams. Wood decay over a period of 10 to more than 100 years will slowly reduce levels of instream wood. Wood replacement is negatively impacted by harvest in the RMZ up to a distance of one to two tree heights.
- Low residual BA (less than 25 ft²/ac) consistently results in indicator responses falling outside of their natural ranges in reference conditions, regardless of RMZ width.
- There is some evidence that narrow RMZs (34 m (100 ft) or less) result in indicator responses falling outside of their natural ranges in reference conditions, regardless of residual BA.
- There is some evidence that wide RMZs (61 m (200) ft or more) and high residual BA (greater than 125 ft²/ac) result in no appreciable change in aquatic indicators.

Evidence for Recovery

The following table summarizes findings with respect to recovery of aquatic indicators at year 10. The table illustrates if a value was below or above a reference range, as a function of residual BA or RMZ width, by year ten. Red indicates a change from the reference value at year 10, with I or D indicating whether the change was an increase or decrease, respectively, and C indicating a community change that included both increases and decreases in component species abundances. Blue indicates recovery to the reference value by year 10. Grey indicates insufficient information to make a judgment.

Table 8. Aquatic habitat indicators: recovery in response to residual BA and RMZ width.

Indicator	Basal Area	Increase or decrease	Recovery	No information		
		RMZ Width (ft)				
		0	50	100	200	400
1. Stream wood*	<25	I	I	I	I	I
	25-80	I	I	I	I	I
	>125	I	I	I		
2. Stream Productivity	<25					
	25-80					
	>125					
3. Stream macroinvertebrate abundance	<25	I	I			
	25-80	I				
	>125					
4. Stream macroinvertebrate community structure	<25	C	C			
	25-80	C				
	>125					
5. Wetland macroinvertebrate community structure	<25	?				
	25-80	?				
	>125					
6. Wetland sedge cover	<25	?				
	25-80	?				
	>125					

* Wood volume has been found to increase for a period after harvest, generally due to inputs of slash and blowdown; however, after a period of about 10-120 years, wood decay results in decreased wood abundance relative to a reference range, with full recovery taking as long as 100 to 150 years.

? Evidence suggests that these indicators may just be approaching the 25% threshold (compared to reference conditions) by ten years.

Key Points

- Availability of evidence to assess recovery of aquatic systems is limited, so results should be interpreted with caution.
- The available evidence suggests that with the exception of stream wood, aquatic habitat functions may recover within 10 years, in RMZs of 30 m (100 ft) or wider.
- The evidence suggests that stream productivity, a key indicator of stream function, may recover within 10 years, regardless of RMZ width and residual BA.

Summary of Aquatic Habitat Indicators

It is the interpretation of the RSTC that RMZs should be at least 30 m (100 ft) wide and maintain moderate to high residual BA, to reduce changes in aquatic habitat variables to values outside the normal range for reference conditions. Moreover, it is the interpretation of the RSTC that some aquatic variables may recover to values falling within reference ranges by 10 years after harvest. However, given the research void for accurately assessing recovery, it is the interpretation of the RSTC that guidelines should be conservative (wider RMZ, higher residual BA). The RSTC concern is that the available evidence may fail to suggest substantial negative responses only because the amount of applicable research information is limited. In other words, negative responses and lack of recovery could have a high probability of occurring, but we lack the necessary research to demonstrate these results. This situation argues for conservative approaches to riparian management.

FOREST DEPENDENT AMPHIBIANS

The RSTC evaluated the response of wood frog abundance to RMZ width and time since harvest. Wood frogs are key riparian dependent species that breed in small wetlands, seasonal pools, and small streams, but spend most of their life in upland forest near these water bodies. Because of their biphasic life history (both aquatic and terrestrial), and the critical role they have in maintaining health of upland forests (through insectivory), the RSTC feels they deserve special consideration outside of the terrestrial and aquatic summary provided in this report. It is also the interpretation of the RSTC that forest dependent amphibian sustainability is arguably the most important indicator of terrestrial habitat response to riparian area forest management that was examined. As such, RMZ guidelines should give high priority to this indicator.

It is the interpretation of the RSTC that wood frog populations may be sustained within reference ranges (less than 20% reduction from reference conditions) when RMZ widths are at least 100 ft and with high residual BA (greater than 125 ft²/ac), **if the majority of the surrounding landscape is forested** within a radius of at least 0.6 miles around the wetland or stream. Where recent timber harvesting has occurred or will occur within this radius, the RSTC interpretation is that buffers having high residual BA should exceed 300 ft.

This concludes the synthesis reports addressing QTI 7. In keeping with the order of the QTIs as presented to the RSTC by the MFRC, the QTIs continue to be addressed below beginning with QTI 8 and QTI 4 which were determined to be best addressed together.

QTI 4 and 8 – Should fixed or variable-width RMZs differ for different types and sizes of waterbodies and, based on evaluation of other QTI key factors, what is the RSTC’s suggested RMZ width and related conditions (e.g., BA, even-aged, uneven-aged management)?

These two questions are best answered together as the discussions on RMZ width, BA, and even-, uneven-aged management are inter-related in the scientific findings and the RSTC discussions.

In general, the RSTC recommends fixed-width RMZs and fixed residual BAs, but varied by waterbody type and size. The purpose of this review was to summarize key literature based upon loss of forest cover, whether by natural (e.g., blowdown) or anthropogenic disturbance (e.g., timber harvest) since they may elicit similar environmental responses. Since the objective is to protect waterbodies, not to define forest management methods, the roles of even- and uneven-age management should be eliminated and reflected in “desired future condition” management plans prior to harvesting. Examples of possible cover types, desired future conditions, and management options associated with those conditions are provided in Appendix E.

Below is a breakdown by waterbody type with discussions related to RMZ width and residual BA.

Science

Trout Streams and Lakes

At a minimum, provide a fixed-width RMZ of 50 m (165 ft) and a residual BA of 75 ft²/ac for all sizes. This is an average of the range supported by the science. The scientific rationale that supports this conclusion is discussed in Dr. Verry’s White Paper in Appendix C. In addition, eliminate even- and uneven-age management, unless there is a documented “desired future conditions” management plan justifying a lower BA.

Warm Water Streams Greater than 1 m (3 ft) Wide and Lakes

Provide a fixed-width RMZ of 34 m (110 ft) and a residual BA of 75 ft²/ac in addition to a 3 m (10 ft) wide stringer along the banks. This 3 m (10 ft) wide stringer is a no cut zone and will help provide shading and woody debris inputs. Finally, eliminate even- and uneven-age management, unless there is a management plan that documents “desired future conditions” justifying a lower BA.

From an abiotic perspective (e.g., sediment, temperature), the science suggests that a fixed-width RMZ of about 23 m (75 ft) with a residual BA of about 80 ft²/ac will provide adequate protection. The literature does not account for blowdown and loss of shade; Minnesota research on black spruce peatlands suggests that an RMZ width of 40 m (130 ft) would provide continued mid- to late-serial forest conditions.

From a biotic perspective the science suggests the need for wider RMZ widths. Generally the data concludes that residual BAs (greater than 125 ft²/ac) and an RMZ of around 61 m (200 ft) are necessary for habitat protection. Professional judgment suggests that management plans identify “desired future conditions” along with these criteria in order to harvest within those RMZs. This moves the RMZ discussion to a landscape perspective. For example, wider RMZs based on a landscape context are necessary for wood frog habitat or in watersheds where there is a mixture of various land uses and/or heavier harvests.

Consensus was not reached among the RSTC on how wide a stream should be before RMZs and/or residual BAs might change. One suggestion was that streams greater than about 120 m (40 ft) wide might take on some other form of RMZ requirement (e.g., protection for ospreys, eagles).

Open Water Wetlands (Circular 39 types 3, 4, 5, and seasonal ponds)

Open water wetlands (waterbodies greater than or equal to one acre) should be treated similar to lakes (see discussion above on lakes and streams) and open water wetlands (waterbodies less than one acre or seasonal ponds) should have an RMZ of at least 15 m (50 ft) wide and a residual BA of at least 75 ft²/ac (see discussion below on seasonal ponds).

Seasonal Ponds - Seasonal ponds often include a clearly defined dry period unlike open water wetlands. Unfortunately, they are not easy to identify. For example, seasonal ponds can not be definitely identified during dry periods by visual clues of reduced forest litter in a depression compared to the upland. Decomposition rates are widely variable due to differences in nutrient levels, pH, water movement, inundation levels, and moisture, making identification of dry ponds using the litter criteria problematic. In many cases, litter will decompose slower than the upland in a depression area due to longer periods of inundation, increased moisture, and reduced aeration. These sites may also include the presence of black ash. Shrubs can also range in the density from minor to abundant depending on factors such as the type of pond and its disturbance history. Although this is complex, it does not mean seasonal ponds should be exempt from an RMZ width or residual BA guideline if standing water and/or wet soils are absent during part of the growing season, or when the site is visited for timber sale layout.

The RMZ width for seasonal ponds should also include a high residual BA. The primary purpose for the RMZ is to help maintain indicator supported functional linkages between the seasonal pond and the adjacent forest by providing shade, maintaining

UV light levels within acceptable limits for pond breeding organisms, ensuring a continued supply of organic matter to the pond, and maintaining habitat requirements for animals in the RMZ (e.g., appropriate forest floor and litter conditions). These indicators are critical for sustaining the functional contributions of seasonal ponds to forest and landscape biodiversity, especially for pond breeding amphibians, such as wood frogs and spring peepers. Some RSTC members feel that it is unlikely, based on the science, that filter strips alone are sufficient to meet these requirements. Moreover, it is not clear to some members of the RSTC that a 5% leave patch for a harvest unit is or will be implemented in a way that protects seasonal ponds. Although there was a clear consensus that protection of seasonal ponds is critical, there was not universal agreement within the RSTC that seasonal ponds require the use of RMZs to provide that protection around some or all of the seasonal ponds.

The landscape size for pond breeding amphibians (a key biodiversity component of seasonal ponds), based on modal distances that individuals will migrate to find acceptable breeding habitat, will rarely exceed the size of typical timber sales (Semlitsch 1998, 2003). As such, there is a high probability that most seasonal ponds within the functional landscape for pond breeding amphibians, will be treated similarly at the time of harvest, thus reflecting a need for the inclusion of an RMZ guideline to protect continuity of function related to shading.

Consensus among the RSTC was not reached regarding the need for application of RMZs adjacent to seasonal ponds. It was agreed, however, that there is uncertainty in the literature regarding potential recommendations for RMZ width and residual BA for seasonal ponds. It was also agreed that the science does support an RMZ of at least 15 m (50 ft) wide and a residual BA of at least 75 ft²/ac.

Professional Judgment

There is compelling scientific evidence that biological communities (e.g. invertebrates, amphibians) in Minnesota seasonal ponds experience short-term changes as a result of harvesting without RMZs. There is scant information about population changes over the long term but some evidence suggests that populations can recover. It is the professional judgment of some of the RSTC members that management could be improved adjacent to these sites. Discussed options ranged from providing leave tree patches around some seasonal ponds to RMZs around all ponds. Some RSTC members feel strongly that it would be most beneficial to provide fewer, larger leave patches, which would be wind-firm and provide habitat for interior forest birds. There is a pressing need to assess the recovery of key populations in seasonal ponds following harvesting, the potential for re-colonization of these waterbodies, and the benefits of alternative management near seasonal ponds.

Desired Future Conditions Management Plans

The RSTC expressed concern that residual BA recommendations would be treated by land managers, agencies, the public, and even certification organizations as a rigid

standard regardless of circumstances. There will be conditions where more or less residual BA will be appropriate, given a “desired future conditions” management plan to achieve desired environmental benefits and future riparian conditions. For example, there are efforts to restore riparian conditions favorable to fish and wildlife habitat by emulating natural disturbance patterns (Cissel et al. 1998; Macdonald et al. 2004; Swanson 1994). Wilzbach et al. (2005) recently reported that increased solar radiation, where it does not lead to unacceptable stream temperature increases, can result in an increase in fish productivity.

QTI 9 What are the landscape/watershed considerations that affect decisions by landowners & resource managers for site-level management of riparian areas?

Science

This subject was a frequent topic among all the QTI discussions throughout this process. The landscape/watershed component is definitely a primary area of consideration and it is often difficult to separate site level considerations from the landscape context. Below are some considerations based on what the scientific literature has provided to date:

- Increased streamflow is related to cumulative harvest in the watershed rather than individual RMZ harvest areas. Increased streamflow means increased risk of erosion and sedimentation.
- Headwater streams are the most responsive at the watershed level. Guidelines need to address their protection.
- Landscape context is important for habitats of wood frogs and other amphibians as discussed in the seasonal pond section. In forested landscapes where clear cutting occurs, RMZs may be especially critical for wood frogs.
- Bird productivity can be maintained or enhanced in RMZs by maintaining interior forest habitat as well. Interior habitat provides habitat functions such as safe havens from nest predators. On a landscape scale, however these RMZs create more edge habitat and less interior habitat when they are applied uniformly to all waterbody types. Therefore, it is best to provide large forest patches for interior habitat on the landscape level and not within RMZs.

Professional Judgment

Very few of the riparian indicators reviewed can be interpreted independent of their landscape context, and this has been a consistent theme throughout the RSTC process. This is also illustrated by responses of biological communities. For example, at the site level, it is quite easy to document consequences of reduced habitat suitability for blue-spotted salamanders in response to timber harvest in adjacent uplands. However, site-specific data on amphibian declines stops far short of addressing questions about viability of actual populations in response to multiple disturbance events in fragmented landscapes. Maintaining viable populations of riparian-dependent organisms will re-

quire understanding of complex, nonlinear, scale-dependent responses to silviculture activities and other simultaneous disturbances in forested landscapes. The site-level focus of the RSTC may be justified because identifying indicators and clarifying site-level responses are reasonable starting points. However, this document can also provide the MFRC with the information to inform the revision of the forest management guidelines based on spatially explicit requirements of riparian communities and processes that reflect current scientific uncertainties at both site and landscape levels. To provide useful future guidance, the RSTC synthesis acknowledges landscape scale considerations, in spite of the fact that current riparian science is insufficient to provide much guidance. Below are some things to consider based on professional judgment in context of the available scientific literature to date:

- Where the landscape within a watershed is less than 50% forested, the forest should be managed with a different set of guidelines than for watersheds where the forested area is greater than 50%.
- Cumulative impacts are a landscape/watershed issue and guidelines should at least address the thresholds for cumulative impacts.
- There is a watershed/landscape component to controlling beaver related to silviculture and the promotion, retention, and management for riparian species that discourage beaver populations.

QTI 10 Current MFRC guidelines specify fixed-width RMZs. What scientific evidence supports whether these fixed RMZs as described are or are not adequate?

This item is previously discussed in QTI 3.

Questions Addressed for MFRC Regarding RMZ Management

The questions below were discussed with the RSTC and voted upon to clarify for the MFRC the extent of agreement among the RSTC members. There are nine RSTC members, however eight members were present for this specific meeting. The ninth RSTC member provided his response to the questions at a later date. Each RSTC member voted based on their scientific knowledge and professional judgment. A level of confidence follows each answer as follows:

- 1 = low confidence
- 2 = medium confidence
- 3 = high confidence

Science and Professional Judgment

- Should MFRC retain separation of even-age and uneven-age management?
No – 3 (unanimous)

- Should RMZ widths be changed for:
 - ◆ Warm water streams? Yes
2 (Lucinda, Sandy, George, Mark, JoAnn, Brian)
1 (Dave, Randy, Dan)
 - ◆ Trout streams? Yes
3 (Lucinda, Sandy)
2 (Randy, Mark, Dan, Dave, George, JoAnn, Brian)
 - ◆ Warm water lakes? Yes
2 (Sandy, JoAnn, Brian)
1 (Lucinda, Randy, Dan, Mark, Dave, George)
 - ◆ Trout lakes? Less science available (no opinion)
 - ◆ Open water wetlands? Yes
2 (Lucinda, Sandy, Dan, Brian)
1 (Randy, Dan, Dave, George, JoAnn)
 - ◆ Seasonal ponds? Mixed reviews
Yes 3 (Brian)
Yes 2 (Lucinda, Mark)
No 2 (Sandy, JoAnn), 1 (Randy, Dan, Dave, George)
- Should residual BA recommendations be modified and for which waterbodies? Yes for all waterbodies
3 (Sandy, Brian), abstain (Mark, George)
2 (Randy, Dan, Dave, JoAnn)
1 (Lucinda)
- Are filter strip guidelines adequate? Yes
3 (Dan, Dave, JoAnn, George)
2 (Lucinda, Sandy, Randy, Mark, Brian)
- Does the science support the current size of waterbodies requiring RMZs? No
3 (Sandy, Dan, Dave, JoAnn, George, Brian)
2 (Lucinda, Randy, Mark)

Identified Research Needs for Riparian Sustainability

In light of the indicators reviewed as well as professional judgment, responses by most of the indicators have not been sufficiently studied across a range of waterbody types. This does not mean that all indicators still need equal emphasis via focused research. Experiences of the RSTC illustrated the difficulties associated with interpreting biological responses to timber harvesting and other factors such as efficacy of harvest RMZs.

To date, physical and chemical processes (e.g., light, turbidity, dissolved oxygen, methyl mercury) and responses to silviculture are better understood than are their biological counterparts (e.g., bird productivity, macroinvertebrates, windthrow). This supports the need for future research that emphasizes the responses of biological communities. However, this must be weighed against difficulties inherent in interpreting biological responses (in contrast to chemical and physical processes that can often be elucidated more easily). Suggestions for future research are listed below.

1. Regarding needs for geochemical and hydrological variables, there is a preference toward variables improving the understanding of relationships between silviculture practices and water quality features. An important research need is in regard to hydrology of seasonal ponds. Site-to-site variability in relationships between surface and groundwater is not well understood for these areas, nor are hydrological responses to adjacent timber harvesting.
2. Regarding key biological indicators, there is a research need for all species and communities discussed during the RSTC process. Special attention should be given to three groups, riparian-dependent birds, amphibians, and aquatic invertebrates. It is widely believed that several duck species are declining in forested regions of northern Minnesota; however, status and trends of forest dwelling ducks, along with specific knowledge of disturbance responses by forest dwelling mallards, ring-necked ducks, and cavity-nesting species (e.g., wood ducks, common goldeneyes, hooded mergansers) are too poorly known to assess implications of current and future levels of timber harvest for resident populations of these species.
3. Amphibians warrant further study because, as a group, they show evidence of global declines. Also, research has already established links between viability of amphibian populations and light intensity and forest-floor litter; characteristics of riparian areas known to be critical for maintaining amphibian populations.
4. Macroinvertebrates need further study because they are typically the dominant fauna in many aquatic habitats in forested landscapes (such as seasonal ponds) and they have potential to inform investigators about subtle ecological relationships between riparian areas and adjacent uplands. Previous research has demonstrated both potential benefits and limitations of community-level approaches seeking to link complex macroinvertebrate communities to environmental gradients. This underscores a need for development of better research techniques.

RSTC's Identified Key Research Needs

- Identify better ways to assess organisms' habitat needs for sustainability on a landscape level for seasonal ponds.
- Develop tools to define and apply a variable-width RMZ.
- Collect long-term data on recovery of seasonal pond species (e.g., macroinvertebrates, herps) following disturbance.
- Research cavity nesting birds (there are three species in particular of great concern that are not important for hunting) and their habitat requirements.

- Develop a monitoring program to better identify and assess the natural variability in indicators.
- Implement monitoring to assess the effectiveness of the guideline influences on water quantity and quality, aquatic habitat and biotic communities.
- Research the linkage between ephemeral and intermittent drainages.
- Use digital elevation models to better identify seasonal ponds and provide maps.
- Research why there tends to be low BA around streams (e.g., blowdown, poor soils). The low BA can be due to many factors, but the obvious are seed recruitment, seed germination, seedling establishment, competition in juvenile stands, accelerated mortality from windthrow, disease and insects, and reduced growth where summer water tables are too high.

Glossary

Allochthonous: Organic matter in the stream that is produced outside of the stream, usually by riparian plants and trees.

Anoxic: An adjective that means without oxygen. For example, anoxic ground water is ground water that contains no dissolved oxygen.

Autothonomous: Organic matter that is produced in the stream, by algae and aquatic plants.

Autecology: The study of single organisms and how they relate to their environments.

Basal Area (BA): The total area of the cross-section of each tree, including bark, at breast height left standing. It is usually reported as square feet per acre or square meters per hectare.

Detrivore: Any organism which obtains most of its nutrients from the detritus in an ecosystem.

Embayment: Includes the following:

- An indentation in a shoreline forming an open bay.
- An area of water protected by land forming a bay such as Saginaw Bay.
- A small bay or any small semi-enclosed coastal water body where the opening to a larger body of water is restricted.

Ephemeral drainage: Depressions or swales, sometimes called drains, draws, or dry washes, that have no defined continuous channel and that are well-connected to intermittent or perennial streams. Ephemeral areas are characterized by water tables that often rise to the surface during high water table months of January-March, and these areas produce surface flow for short periods during and following rainfall. Forest floors in ephemeral areas are intact, and hydrophytic vegetation may or may not be present. Aquatic insects are usually not present in these areas. Soils in these areas may quickly become saturated during rainy or thawing periods. Soils in ephemeral areas feature finer textures and higher organic contents than soils in adjacent uplands. Fluvial power is generally low, but there may be evidence of small debris jams of leaf litter and other small organic matter deposited after surface flows. These areas are usually not identified on USGS or NRCS maps. Water from ephemeral areas may carry sediment and other contaminants directly into streams.

Epilimnion: Upper waters of a thermally stratified lake subject to wind action.

Eutrophication: (of a lake) characterized by an abundant accumulation of nutrients that support a dense growth of algae and other organisms, the decay of which depletes the shallow waters of oxygen in summer.

Filter strip: An area of land adjacent to a waterbody that acts to trap or filter out suspended sediment and chemicals attached to sediment before it reaches the surface water. Harvesting and other forest management activities are permitted in a filter strip as long as the integrity of the filter strip is maintained and mineral soil exposure is kept to a minimum (from Voluntary Site-Level Forest Management Guidelines book).

Functions: The biophysical processes that take place within an ecosystem. The three primary hydrogeomorphic classes used in this report are the physical, chemical and biological processes.

Geochemistry: The study of the chemical composition of the Earth, the chemical processes and reactions that govern the composition of rocks and soils, and the cycles of matter and energy that transport the Earth's chemical components in time and space.

Hypolimnion: The layer of water in a thermally stratified lake that lies below the thermocline, is noncirculating, and remains perpetually cold.

Intermittent Stream: Flows that are not continuous and occur in areas with a defined bed and bank.

Invasive Plants: Plants with the ability to thrive and spread aggressively outside its natural range. These invasive plants have the ability to invade and disrupt an ecosystem. While most species stay within a set range and have predators or other limitations on their growth, invasive species tend to overrun ecosystems into which they are introduced. Collectively they are one of the great threats to biodiversity and ecosystem stability. The reason invasive plants are so successful is multifaceted and is still an inconclusive issue.

Lake: Defined by the Minnesota Department of Natural Resources as waterbodies greater than 2 m (6.5 ft) in depth. There is no legislative definition of a lake.

Leaf Area Index (LAI): The area of green leaf per unit area of ground area.

Lentic: Pertaining to or living in still water.

Minerotrophic: Fens located in depressions that receive surface runoff and/or ground-water recharge from surrounding mineral-soil sources. Nutrients are more abundant and water is more alkaline--conditions that are suitable for a wide range of plants and which give rise to greater floristic diversity compared to bogs. The terms *oligotrophic* and *eutrophic* refer to more nutrient-poor and more alkaline, calcium-rich fens respectively.

Modal: Relating to or constituting the most frequent value in a distribution.

Morphometry: The physical characteristics of a lake such as size and shape of a lake basin, mean depth, maximum depth, volume, drainage area, and flushing rate.

Non-open Water Wetlands: Circular 39 (Shaw and Fredine 1956) Type 1 (seasonally flooded basin or flat), Type 2 (wet meadow), Type 6 (shrub swamp), Type 7 (wooded swamp or forested wetland) and Type 8 (bog). Type 1 wetland soils are saturated during variable seasonal periods but may be well-drained during the other periods. Wetland Types 2, 6, 7 and 8 have saturated or waterlogged soils during most of the growing season. Non-open water wetlands may occasionally be inundated with water.

Ombrotrophic: Includes the following scenarios:

- Areas where rain, which is very poor in minerals, is the main source of water.
- Areas where the trophic status is largely produced by rainwater rather than groundwater.
- Areas fed only by precipitation, not by water draining from the surrounding landscape.
- Raised or blanket bogs that receive all water and nutrients from direct precipitation. Neither groundwater nor runoff from surrounding land reaches the surface of the bog. Rain and snow provide the water source, and nutrients are derived from whatever blows in—dust, leaves, bird droppings and feathers, spider webs, animal fur, etc. Water chemistry tends to be acidic, and nutrients for plant growth are in short supply. Few plants can survive such extreme conditions, namely *Sphagnum* (peat moss) and pine.

Open Water Wetlands: Open water wetlands are greater than or equal to one acre (i.e., Circular 39 types 3, 4, 5).

Periphyton: Dense strands of algal growth that cover the water surface between the emergent aquatic plants.

Professional judgment: Use of knowledge, skills, and experience to make reasonable interpretations of the science and draw sound conclusions and extrapolations.

Response indicator: An environmental measure to provide evidence of the hydrological, geochemical, or habitat condition of a riparian function in response to a forest management activity.

Riparian area: A riparian area is a zone of interaction between aquatic and terrestrial ecosystems along streams, lakes, wetlands, and other water bodies. Riparian areas both influence water bodies and are influenced by them. They perform important ecological functions that link aquatic and terrestrial ecosystems. (see page 4 in this report).

Riparian Management Zone (RMZ): That portion of the riparian area where site conditions and landowner objectives are used to determine management activities that address riparian resource needs. It is the area where riparian guidelines apply. (from Voluntary Site-Level Guidelines book).

Seasonal Ponds: Generally less than one acre in size and often include a clearly defined dry period. Most seasonal ponds are likely to be less than ½ acre, however larger ones do exist and should be acknowledged. In many cases, litter will decompose slower in these areas versus the upland, due to longer periods of inundation, increased moisture, and reduced aeration. However, decomposition rates are widely variable due to differences in nutrient levels, pH, water movement, inundation levels, and moisture, making identification of dry ponds using the litter criteria problematic. Black ash may be absent naturally, due to site characteristics, or may be absent due to disturbance history. Shrubs can range from minor to abundant depending on the type of pond, its disturbance history, etc.

Seep: Wet area, normally not flowing, arising from an underground water source.

Spring: A point where groundwater flows out of the ground, and is, thus, where the aquifer surface meets the ground surface.

Streams (trout and warm water): Watercourses with a definable bank, including intermittent, streams with or without water (even if dry). Stream width is estimated at bank-full elevation at the narrowest portion of a straight channel segment within the management area. (Note: A 3-foot wide stream fits close to the definition of a 1st order stream. 1st order streams are a large proportion of stream miles (approximately 70%)).

Stream order: The designations (1, 2, 3, etc.) of the relative position of stream segments in a drainage basin network: The smallest, unbranched, perennial tributaries, terminating at an outer point, are designated order 1; the junction of two first-order streams produces a stream segment of order 2; the junction of two second-order streams produces a stream segment of order 3, etc.

Synecology: Community ecology is the study of the distribution, abundance, demography, and interactions between populations of coexisting species. It is part of the division of ecology known as synecology that studies the organization of ecosystems specifically at the level of the biotic community (or biocoenosis).

Waterbody: short hand for “a body of water” meaning any water feature found in the landscape.

Wildlife habitat: The sum total of environmental factors (including food, water and cover) that a species needs to survive and/or reproduce in a given area.

APPENDIX A

Literature Cited for the Minnesota Forest Resources Council Report

Analysis of the Current Science Behind Riparian Issues

by the Riparian Science Technical Committee

August 2007

Of the extensive list of references initially identified during the RSTC process, below is the selected list of relevant literature reviewed by the RSTC for this report. The pages are numbered A-1 through A-16. From this list tables were then prepared by the RSTC members of literature they used more extensively. The tables provide details of the content of the paper cited. The pages for the tables are numbered A-17 through A-47.

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Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Aspen Regeneration	Perala 1971	Forests	Minnesota, Michigan, Wisconsin	Several decades	Black spruce	Sets wind mortality at loss of annual growth, approx. 110 ft.	Growth and yield	Sandy Verry		
Beaver Interactions	Curry-Lindah 1967	Forests	Sweden	207 years: 1758-1965	Aspen-birch		Review	Sandy Verry	Beaver densities	
Beaver Interactions	Emme and Jellison 2004	Forest	Wyoming	Long-term, 100 years	Rocky Mountain (aspen, Douglas fir, ponderosa pine, lodgepole pine, etc.)		Long-term monitoring of beaver population	Sandy Verry	Long-term records show that beaver populations have fluctuated over the years; populations were increasing from 1914-1941, population now 20% of that in 1940's.	
Beaver Interactions	Naiman et al. 1986	Streams	Quebec, Canada		Black & white spruce, blasam fir, aspen, birch, alder, willow		Air photo and mapping on the ground	Sandy Verry	Beaver dam density	
Beaver Interactions	Verry 2006	River	Dark River, Minnesota	56 years: photos 1948-2003	Aspen-birch, alder		Air photo	Sandy Verry		
Beaver Interactions, Forest Patch size and relative amount of aspen	Maclean and Cleland 2003		Northern Lower Michigan					Sandy Verry		
Beaver Interactions, Forest Patch size and relative amount of aspen	Schulte et al. 2002		Northern Wisconsin					Sandy Verry		
Beaver Interactions, Forest Patch size and relative amount of aspen	White and Host 2003		North-central and Northeastern Minnesota.					Sandy Verry		
Beaver Interactions, Stream Geomorphology	Allen 1983	Streams	Colorado	1 year	Aspen-montane	NA	Modelling	Sandy Verry		
Beaver Interactions, Stream Geomorphology	Avery 1991	Streams	Pemebonwon River, Wisconsin	10 years	Aspen-birch	NA - beaver dam removal	Field measurement - repeated survey	Sandy Verry		

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Beaver Interactions, Stream Geomorphology	Avery 1992	Streams	Pemebonwon River, Wisconsin	10 years	Aspen-birch	NA - beaver dam removal	Fish. Temp. HBI	Sandy Verry		
Beaver Interactions, Stream Geomorphology	Collins 1976		Wyoming					Sandy Verry		
Beaver Interactions, Stream Geomorphology	Fortin and Laliberte 2002		Quebec, Canada	?	Aspen-birch boreal	165 ft of non-aspen/birch to discourage beaver	Observation	Sandy Verry		
Beaver Interactions, Stream Geomorphology	Gurnell 1998	Streams	Worldwide, mostly NA. North Europe	Literature spans 1914-1996	ALL	Beaver impacts occur on streams 6-52 feet wide	Literature review and synthesis	Sandy Verry		
Beaver Interactions, Stream Geomorphology	Howard and Larson 1985	Stream	Kitimat Valley, British Colombia, Canada	12 years: 1959-1971 photos	Coastal inland, western hemlock	NA	Airphoto analysis and habitat classification	Sandy Verry		
Beaver Interactions, Stream Geomorphology	Leidholt-Bruner et al. 1992	Streams	Coastal Oregon	2 years?			Survey summaries	Sandy Verry	Beaver dam densities	
Beaver Interactions, Stream Geomorphology	McCall et al. 1996	Streams	South Central Maine	4 years: 1988-1992	Boreal		Airphoto inventory	Sandy Verry	Beaver densities	
Beaver Interactions, Stream Geomorphology	McComb et al. 1990	Streams	Coastal Oregon	?	?		?	Sandy Verry	Beaver dam densities	
Beaver Interactions, Stream Geomorphology	Naiman et al. 1994	Streams	Kabetogama Peninsula	61 years: 1927-1988	Boreal		Air photo inventory	Sandy Verry	Beaver densities	
Beaver Interactions, Stream Geomorphology	Nordstrom 1972	Streams	New Brunswick, Canada	?	Boreal		Air photo	Sandy Verry	Beaver density	
Beaver Interactions, Stream Geomorphology	Robel and Fox 1993	Streams	Kansas	?	Cottonwood shrub		Air photo	Sandy Verry	Beaver density	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Beaver Interactions, Stream Geomorphology	VanDusen et al. 2005	Streams	Michigan	1 year	Northern Hardwood	Thinning in northern hardwood	logging site stream measurement	Sandy Verry	No width or thinning density prevented embeddedness, invertebrate loss, fish loss	
Beaver Interactions, Stream Geomorphology	Winchell and Upham 1884	Stream	Brule River, Wisconsin	1 week	Aspen boreal		Observational	Sandy Verry	Beaver dam density	
Beaver Interactions, Stream Geomorphology	Zhang et al. 1999		Upper Peninsula of Michigan					Sandy Verry		
Beaver Interactions, Stream Temperature	Butler and Malanson 1995	Beaver ponds	Oregon			NA	Sediment measurement behind beaver dams & stream width	Sandy Verry		
Beaver Interactions, Stream Temperature	D'Eon et al. 1995	Forests/Streams	Ontario, Canada	Decades of observation	Boreal	Beaver occurrence if forest strip < 165 ft.	Observational	Sandy Verry		
Beaver Interactions, Stream Temperature, Shading	Naiman et al 1988	Streams	Kabetogama, MN	61 years: 1927-1988	Aspen-birch boreal		Air photos	Sandy Verry	Beaver density	
Beaver Interactions, Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Koller 2005	Streams	Dark River, Chisholm, Minnesota	10 years	Aspen, birch, red pine		Annual fish surveys	Sandy Verry	Trout recovery after beaver dam removal	
Bird Productivity	Hanowski et al. 2001	Lakes, streams	Northern Minnesota	Computer simulation	All forest types	100 ft	Computer simulations	JoAnn Hanowski		
Bird Productivity	Lambert and Hannon 2000	Lakes	Alberta	1 year	Boreal	20, 100 and 200m	Experimental	JoAnn Hanowski	20m buffers do not support breeding ovenbirds, 100 and 200m buffers retain ovenbirds the first year after harvest	
Bird Productivity	Pierre et al. 2001	Lakes	Alberta	2 years	Boreal	50-150m	Comparative but small <i>n</i>	JoAnn Hanowski	Predation of artificial nest cavities did not differ among treatment or controls within 50, 100 or 150m buffers	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Bird Productivity	VanderHaegen and DeGraaf 1996	Rivers, Streams	Maine	Adjacent to 6-10 year old cuts	Boreal	20-40 and 60-80	Comparative but small <i>n</i>	JoAnn Hanowski	Artificial nest predation higher in small buffers, suggest a 150m buffer to maintain bird productivity in buffers	
Canopy Cover	Barnes et al. 1998	NA					Textbook	Dan Gilmore		
Canopy Cover	Kimmins 1997	NA					Textbook	Dan Gilmore		
Canopy Cover	Waring and Running 1998	NA					Textbook	Dan Gilmore		
Dissolved Organic Carbon (DOC)	Gergal et al. 1999	Lakes and Rivers	Many	Model	Many	NA	Model	Randy Kolka		
Dissolved Organic Carbon (DOC)	Kolka et al. 1999	Streams	Minnesota	3 years	Peatland watersheds	NA	Comparative	Randy Kolka		
Dissolved Organic Carbon (DOC)	Palik et al. 2001	Seasonal wetlands	Minnesota	2 years	Varied	NA	Comparative	Randy Kolka		
Dissolved Organic Carbon (DOC)	Tate and Meyer 1983	Streams	North Carolina	Chrono-sequence	Varied	0m	Harvest Comparative	Randy Kolka		
Dissolved Oxygen	Crompton et al. 2005	Forest/Agriculture	Georgia	3 site visits	Mixed		Observations	George Ice	Sediment oxygen demand can be an important factor in DO concentrations and may be predicted by bottom type.	
Dissolved Oxygen	Feller 1974	Forest	British Columbia, Canada	Multiple years	Conifer		Paired watershed study	George Ice	DO concentration depressed with slash introductions.	
Dissolved Oxygen	Ice 1990	Forest	Oregon	2 years	Conifer/mixed		Experimental	George Ice	Reaeration rates are high in steep forest streams and can be predicted from the energy dissipation rate	
Dissolved Oxygen	Ice 1999	Forest	Oregon	14 years	Conifer/mixed		Paired watershed study	George Ice	DO concentrations severely depressed with addition of slash and exposure of stream to solar radiation (0.6 mg/L in one reach).	DO concentrations largely returned to near saturation when slash was cleaned out of the stream and winter freshets scoured the channel of fine organic material.

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Dissolved Oxygen	Ice and Sugden 2003	Forest	Louisiana	3 days	Bottomland hardwood		Synoptic survey/observational	George Ice	Natural DO concentrations often below water quality criteria and predictable from turbulence and stream bottom type	
Dissolved Oxygen	Jackson et al. 2001	Forest	Washington	Multiple years	Conifer		Experimental	George Ice	Slash inputs differ with riparian management practices near headwater streams	Update of this study in press with Forest Science
Dissolved Oxygen	Krammes and Burns 1973	Forest	California	10 years	Conifer (Redwood/Douglas fir)		Paired watershed study	George Ice	Some depression of DO measured in isolated locations.	
Dissolved Oxygen	Moring 1975	Forest	Oregon	14 years	Conifer and some hardwoods		Paired watershed study	George Ice	Significant depression in DO with introduction of fresh slash and stream heating without buffer. Little or no change in DO or temperature with buffer.	
Dissolved Oxygen	Plamondon et al. 1982	Forest	Quebec, Canada	2 years	Boreal forest		Paired watershed study	George Ice	No significant change in DO for streams with buffers. Streams without buffers had severely depressed DO due to slash (down to 0 mg/L in one stream in June)	
Embeddedness	Beschta and Jackson 1979	Forest	Washington	Season	NA		Experimental streams	George Ice	If the channel is not mobilized fine sediments tend to bridge between coarse particles at the surface.	Time of sediment transport important for particle size distribution of lower gravels.
Embeddedness	Kramer 1989	Forest	Montana	NA	NA		NA	George Ice	Identified problems with the use of embeddedness.	Useful caution.

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Embeddedness	Merten and Newman 1998	Forest	Minnesota	2 years	Aspen		BACI design for riparian management	George Ice	Change in embeddedness after harvesting but the source was likely a road crossing and all reaches changed independent of riparian management.	Interesting observation about road impacts.
Embeddedness	Meyer et al. 2005	Forest/Agriculture	Georgia	2 years	Forest and agriculture - mixed		Field sampling and regression	George Ice	Stream velocity and riparian vegetation used to predict embeddedness.	Thoughtful study but riparian conditions influence by more than forestry.
Embeddedness	Newman et al. 2004	Forest	Minnesota	2 years, but ongoing	Aspen		BACI design for riparian management	George Ice	No significant differences in embeddedness reported.	Ongoing study.
Embeddedness	Sylte and Fishenich 2002	NA	National	NA	NA		Review	George Ice	Review and complication of embeddedness measurement techniques and results.	Very useful overview.
Emergent (herbaceous) Macrophytes	Batzer et al. 2000	Wetlands (small, depressional)	Georgia	23 years (+/-) Observation's across a time series	Conifer/swamp	No scale		Mark Hanson	Large increases in macrophyte prod via Carex spp.	
Emergent (herbaceous) Macrophytes	Kantrud et al. 1989	Wetlands (prarie potholes)	Prairie Pothole Region, USA				Report	Mark Hanson	Descriptions of marsh vegetation ecology	
Emergent (herbaceous) Macrophytes	Van der Valk and Davies 1978	Wetlands (prarie potholes)	Prairie Pothole Region, USA				Experimental	Mark Hanson	Descriptions of marsh vegetation cycles	
Forest Amphibians	Berven and Grudzien 1990							Lucinda Johnson		
Forest Amphibians	Burbrink et al. 1998	Stream	Illinois	NA	Hardwood forest	100-1000m	Comparative	Lucinda Johnson	100-1000m corridor width not correlated with species richness in buffers-distance to core habitat most important	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Forest Amphibians	Chazal and Niewiarowski 1998	Pond	Savannah River Ecol Laboratory, Georgia		Loblolly pine	Clearcut vs uncut	Experimental clearcut 5-6 mo post cut	Lucinda Johnson	Enclosures around pond; measured mole salamander body mass, and length, clutch size, egg lipids. No differences found.	
Forest Amphibians	Cory and Bury 1991	Headwater streams	Oregon Cascades				Review	Lucinda Johnson	Effects vary by species and location	
Forest Amphibians	Dupuis 1997	Stream	Vancouver Island, British Columbia, Canada		Spruce/fir		Comparative: OG, 54-75 yr; 17-18 yr old stands	Lucinda Johnson	3-6 x more amphib in OG than managed stands; clearcuts had no amphibians. (Results similar to Corn and Bury 1991; Petranka et al. 1991; Welsh 1990)In OG salamanders found under logs/bark; in managed stands ~ 50% salamanders under logsWood volume greatest in OG, lowest in 54-75 yr. Clearcut had ½ volume of OG.Abundances along streams in managed forests were similar to OG.Proximity to OG stands is important.Recommends 20-30m buffer for rivers and streams	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Forest Amphibians	Findlay and Houlihan 1997	Wetlands	SE Ontario, Canada			250m, 500m, 1000m, 2000m	Based on "found" data	Lucinda Johnson	30 wetlands; estimated forest cover and road density within buffers;.Reduced sp richness with decreasing forest cover for mammals and herps. Decline of forest cover from 50-30% forest within 2 km will lead to 17% decline in herp sp richness. (analogous to a 50% loss of wetland area)	
Forest Amphibians	Ford et al. 2002	Upland/ Streams	S. Appalachians - Chatahoochie National Forest	15-85 years post harvest	Cove hardwood		Comparative	Lucinda Johnson	Abundance and diversity of salamanders, including stream species, were + related to stand age, stand size, and amount of nearby habitat in cove hardwood stands. Concludes that these species are vulnerable to logging. No specific buffer widths were studied.	
Forest Amphibians	Hannon et al. 2002	Lake	Boreal Alberta, Canada	2 pre-, 2 post-harvest	Boreal mixed hardwood	20m, 100m, 200m, 800m	Experimental (birds, amphibians, mammals)	Lucinda Johnson	Before and after sampling found no difference in wood frog abundance in 20m vs 800 m sites. Huge amount of variability encountered.Song bird effects were found.	Pitfall traps were used to sample amphibians; they also sampled small mammals and songbirds.No effect was found on wood frogs and toads. Too much variability between sites. [Note: because there is so much forest habitat surrounding these harvested sites, it may not impact the frogs.]

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Forest Amphibians	Houlahan and Findlay 2003	Wetlands	Ontario, Canada	NA	Mixed	200-3000m	Comparative with multiple land use types	Lucinda Johnson	Effective wetland conservation will not be achieved through creation of narrow buffer zones between wetland and adjacent suitable habitats	
Forest Amphibians	Johnson et al. <i>in review</i>	Vernal pools	N. Minnesota			Varied	Comparative - fragmented vs unfragmented	Lucinda Johnson	Dispersal of wood frogs from ponds with partial forest and grassland vegetation favored forest (sig. effects of direction on dispersal). peak dispersal time was later in unfragmented vs fragmented sites. Higher sp richness at fragmented vs unfragmented sites. (Tree frogs and peeper)	
Forest Amphibians	MacDonald et al. 2006	Lake (same as Hannon et al. but pre-harvest)	Alberta, Canada		Boreal mixed hardwood	100m, 400m, 1200m	Comparative	Lucinda Johnson	20 stands near lake compared to upland habitat; wood frogs were more abundant u to 100m from the lake shore than in forest 400 - 1200m from open water. Boreal toad-ditto. [Note: Maximum dispersal distances for wood frogs range from 1.4 km (Berven and Gradzien 1990); 99.7 (max) in MN bog (Bellis 19650; 1119 M (Newman and Squire (2001). Mean for adults is far less.	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Forest Amphibians	Palik et al. 2001	Vernal pools	Minnesota	Chronosequence 7-101 yrs	Conifer/hardwood	NA	Comparative	Lucinda Johnson	Assessed 19 ponds for hydroperiod, chemistry, macroinvert, amphibs, vegetation, cpom, etc. Stand age was not significant predictor of larval abundance; richness did not vary with stand age. Also not a sig predictor of calling anurans.	
Forest Amphibians	Petranka et al. 1993	Streams or Seeps	S. Appalachian	2-10 years	Mixed mesophytic forest	NA	Comparative - 41 sites in clearcut & mature stands	Lucinda Johnson	Fewer salamander species and lower abundance in clearcut/harvested forests than mature forests. Wet areas had more species and animals than dry areas. Total catch increased with stand age for first 70 years of regrowth. Max levels at 50-70 years. Concludes that 50-70 years required to return to predisturbance levels.	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Forest Amphibians	Porej et al. 2004	Wetlands	Ohio - ~ 40% forest cover in ag matrix	NA	Mixed hardwood	200m,1000 m	Comparative	Lucinda Johnson	At 50% forest in the 200m buffer there is a 50% prob of finding spotted salamanders. Threshold for occurrence of spotted salamanders is 36% forest in the 200m buffer. Wood frogs were present when there was an avg of 58% forest in the 200m buffer, BUT there was an interaction with the amount of forest within 1 km. Concludes that landscape context is important for wood frogs. [LBJ note: In forested landscapes where clearcutting is occurring, buffers may be especially critical]	
Forest Amphibians	Russell et al. 2002	Wetlands	South Carolina	2 years	Loblolly pine	No buffers	Experimental	Lucinda Johnson	2 different treatments (clearcut and, clearcut with mech site prep and control (no response of species richness to harvest treatment) need for adjacent buffers will depend on specific landscape context (natural disturbance regimes) in which the wetlands occur	
Forest Amphibians	Semlitsch and Bodie 2003	Wetlands	Various	NA	Various		Review	Lucinda Johnson	Core habitat for amphibians 159 to 290m from edge of wetland, 127-289m for reptiles. Core habitat is the habitat needed to fulfill life history functions.	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Forest Amphibians	Welsh 1990							Lucinda Johnson		
Forest Area Sensitive (interior forest) Plants	Jules 1998	Forest	Oregon	35 years	Douglas fir	NA	Descriptive	Brain Palik		
Forest Area Sensitive (interior forest) Plants	Kern et al. 2006	Forest	Wisconsin	40 years	Northern hardwood	NA	Experimental	Brain Palik		
Forest Area Sensitive (interior forest) Plants	Nelson and Halpern 2005	Forest	Washington and Oregon	5 years	Douglas fir	NA	Experimental	Brain Palik		
Forest Vegetation (age, size structure, distribution)	Baker and Wiley 2004	Riparian zones	Lower Michigan	Short-term observational	Variable		Descriptive	Dan Gilmore	Riparian areas described with ordination techniques	
Forest Vegetation (age, size structure, distribution)	MacDonald et al. 2004	Lakes	Alberta, Canada	NA	Variable	Availability of suitable habitat features	GIS, Comparative	Dan Gilmore	Upland and riparian habitat not different from each other	
Generalist and Disturbance Associated Plants	Fraver 1993	Forest	North Carolina	NA	Mixed hardwood	NA	Descriptive	Brain Palik		
Generalist and Disturbance Associated Plants	Fredericksen et al. 1999	Forest	Pennsylvania	2-8 years	Northern hardwood; oak-hickory	NA	Comparative	Brain Palik		
Generalist and Disturbance Associated Plants	Kern et al. 2006	Forest	Wisconsin	40 years	Northern hardwood	NA	Experimental	Brain Palik		
Generalist and Disturbance Associated Plants	Nelson and Halpern 2005	Forest	Washington and Oregon	5 years	Douglas fir	NA	Experimental	Brain Palik		
Generalist and Disturbance Associated Plants	Palik et al. 2003	Forest	Minnesota		Aspen-northern hardwood	33m	Experimental	Brain Palik		
Interior Forest Birds	Darveau et al. 1994	Streams	Quebec, Canada	3 years	Boreal	20, 40, 60m	Experimental	JoAnn Hanowski	Tree mortality in narrow strips diminished habitat for forest birds	
Interior Forest Birds	Darveau et al. 1995	Streams	Quebec, Canada	3 years	Boreal	20, 40, 60m	Experimental	JoAnn Hanowski	By 3rd year, 20m strips had fewer forest birds- 60m strips required for forest birds	
Interior Forest Birds	Hagar 1999	Headwater streams	Pacific NW	NA	Hemlock, Douglas fir	0-75m variable	No before harvest data	JoAnn Hanowski	Birds need buffers >40m and with large trees	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Interior Forest Birds	Hannon et al. 2002	Lakes	Alberta, Canada	2 years	Boreal	20, 100, 200m buffers	Experimental	JoAnn Hanowski	20m buffers not sufficient for forest birds	
Interior Forest Birds	Hanowski et al. 2003	Streams	Minnesota	3 years	Deciduous	60m wide, different harvest equipment	Experimental	JoAnn Hanowski	Ovenbirds declined over time in both treatments	
Interior Forest Birds	Hanowski et al. 2005	Streams	Minnesota	4 years	Boreal	30m wide, variable retention one side of stream	Experimental	JoAnn Hanowski	No difference in forest interior guild in uncut, partial ,clearcut versus control. Community differences increased with time since harvest	
Interior Forest Birds	Hanowski et al. 2007	Seasonal ponds	Minnesota	3 years	Deciduous	17m wide, variable retention	Experimental	JoAnn Hanowski	Fewer ovenbirds and least flycatchers in treated buffers	
Interior Forest Birds	Hanowski et al. submitted	Streams	Minnesota	9 years post-harvest				JoAnn Hanowski		
Interior Forest Birds	Kinley and Newhouse 1997	Streams	British Columbia, Canada	NA	Montane Spruce	14 to 70m	Comparative	JoAnn Hanowski	Wider buffers had more riparian dependent and more birds than narrower buffers	
Interior Forest Birds	LaRue et al. 1995	Lake	Quebec, Canada	NA	Boreal	No harvest	Identified riparian-associated species	JoAnn Hanowski		
Interior Forest Birds	Whittaker and Montevecchi 1999	Lake	New Foundland, Canada	NA	Boreal	20-50m	Comparative	JoAnn Hanowski	3 of 6 forest interior species not present in these buffers compared to adjacent forests	
Large Wood (as it relates to herptofauna)	Burbrink et al. 1998	Riparian zone of river	Illinois	Short-term observational	Variable	100-1500m	Survey	Dan Gilmore	The natural history requirements of riparian dependent species must considered along with corridor width	
Large Wood (as it relates to herptofauna)	deMaynadier and Hunter 1995	Riparian & upland	North America	NA	Varied	Upland riparian	Review	Dan Gilmore	Herpetofauna require coarse woody debris for shelter and cover	
Large Wood (as it relates to herptofauna)	McClure et al. 2004	Riparian	Kentucky	Short-term	Not provided	0-15.2m	Efficacy study of BMPs	Dan Gilmore	Riparian widths of 15.2m may not be effective in maintaining short-term CWD	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Large Wood (as it relates to herptofauna)	Robison and Beschta 1990	Riparian streams	Pacific NW	Short-term	Douglas fir	Simulation equations	Mathematical derivations	Dan Gilmore	Trees need to be located within 50m of a stream to provide CWD	
Large Wood (as it relates to herptofauna)	Semlitsch and Bodie 2003	Riparian streams	United States	NA	Varied	117-368m	Review	Dan Gilmore	15-30m buffers are not adequate to protect reptiles and amphibians in many states	
Large Wood	Benda et al. 2003	Stream					Review	Lucinda Johnson	Source-distance effects were described.	
Large Wood	Bragg 2000	Stream	Jackson, Wyoming	150 years	Spruce/fir	95% >10 cm; 50% < 10cm harvested	Simulation	Lucinda Johnson	Return to undisturbed levels of LWD delivery following clearcutting = ~ 150 years. In-stream levels of LWD following clear-cut were reduced to < 10% of undisturbed levels. Recovery took ~ 100 yrs.	
Large Wood	Chen et al. 2004	Streams	British Columbia, Canada		Spruce/pine	Wildfire, harvest, decomposition	Observational (10 to 40 yrs post)	Lucinda Johnson	Time required to lose (transport, decay 50% and 95% of wood is 74 and 316 years.	
Large Wood	Colier et al. 1995, in Wenger 1999	Streams	New Zealand	?		Forest edge		Lucinda Johnson	Recommends at least 1 tree height RMZ, but 3x may be necessary to prevent windthrow.	
Large Wood	France 1997	Lake	NW Ontario-Canadian Shield					Lucinda Johnson	Estimates lowest rates will be reached 2 decades after harvest	
Large Wood	Hicks et al. 1991, in Wenger 1999	Stream	PNW & Alaska				Review Paper	Lucinda Johnson	Estimate 50-100 recovery period following logging in PNW & Alaska streams; 60 yrs in streams > 15m	
Large Wood	Hogan 1987	Stream	British Columbia (Queen Charlotte Islands), Canada				Comparative	Lucinda Johnson	Reduced abundance post logging; leads to smaller, more mobile logs. Long recovery.	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Large Wood	Johnson et al. 1998	Stream	Pokegama Creek and Little Knife River, Minnesota	1 yr	Aspen	RMZ clearcut & RMZ BA; No cut	Experimental	Lucinda Johnson	No change in LWD observed after 1 year. Large # of trees subsequently blew down following end of study	
Large Wood	Johnson et al. 2001	Streams	Pokegama Creek and Little Knife River, Minnesota		Spruce/aspen	RMZ clearcut & RMZ BA; No cut	Experimental	Lucinda Johnson	No change in LWD observed after 1 year. Large # of trees subsequently blew down following end of study	
Large Wood	Johnson et al. 2006	Streams	Midwestern US		Mixed hardwood	variable 0-100+m	observational	Lucinda Johnson	Large wood is an important habitat for macroinvertebrates in midwestern streams with little wood standing stocks	
Large Wood	Kreutzweiser et al. 2004	Stream	N. Ontario, Canada	?	Mixed hardwood and conifer	0 BA; 42% BA & 89% BA harvested in RMZ	Experimental	Lucinda Johnson	No effect on canopy cover and LWD for 42% BA removal; Sig effects noted at 89% BA removal on OM inputs & accumulation. CHECK FULL PAPER	
Large Wood	Kreutzweiser et al. 2005b	Stream	N. Ontario, Canada	NA	Boreal mixed hardwood and conifer	Wooded riparian; clearcut sites had 30-100m buffers	Observational	Lucinda Johnson	Streams near clearcuts experienced greater blowdown than those without harvest. LWD values were expressed as #/m.	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Large Wood	McClure et al. 2004	Stream	Appalachians -SE Kentucky	18 years	Oak/hickory	Unharvested control; 50' buffer; clearcut w/ slash	Comparative	Lucinda Johnson	LWD volume in the stream was greater in buffer (BMP) and clearcut (No BMP) than control. LWD length was greater in the clearcut (no BMP) treatment. Decay was more advanced in the No BMP. Conclude that 50' buffer may be too narrow, due to windthrow. Trends in abundance were similar to: Dolloff 1993; McLearn 1993; Hedman et al. 1996; McCarthy & Bailey 1994; Waldrop 1993; Bretz et al. 1996; McGee et al. 1999	
Large Wood	McDade et al. 1990	Stream	W. Washington and Oregon				Comparative	Lucinda Johnson	30m buffer provides 85% naturally-occurring LWD abundance; 10m buffer provides 50%.	
Large Wood	Murphy et al. 1981	Streams	Pacific Northwest					Lucinda Johnson		
Large Wood	Murphy et al. 1986	Stream	Alaska			15-130m		Lucinda Johnson	Streams with buffers had similar habitat quality for salmonids as those in OG forests; Clearcutting led to increased stream production.	
Large Wood	Robison and Beschta 1990	Stream						Lucinda Johnson	Buffer strips equal to 1 tree-ht provide maximum amt of naturally-occurring LWD	
Large Wood	Toews and Moore 1982	Stream	British Columbia, Canada	?			Comparative	Lucinda Johnson		
Light	Davies-Colley and Quinn 1998	Riparian areas	New Zealand	1 year	Native and pine	> 15 year old stands	Comparative	Randy Kolka		
Light	DeNicola et al. 1998	Riparian areas	Nebraska	1 year	Willow	Variation in % shade (65, 31, 19, 15%)	Comparative	Randy Kolka		

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Light	Kiffney et al. 2004	Riparian areas	British Columbia, Canada	1 year	Hemlock	Experimental with shade cloth	Comparative	Randy Kolka		
Litter Decomposition	Lee et al. 2002	Forest	Ontario, Canada	5 years	Aspen-Fir		Experimental	Dave Grigal		
Litter Decomposition	Prescott et al. 2000	Forest	British Columbia, Canada	4 years	Variety		Experimental	Dave Grigal		
Litter Decomposition	Prescott et al. 2003	Forest	British Columbia, Canada	5 years	Spruce-Fir		Experimental	Dave Grigal		
Litter Decomposition	Ritter 2005	Forest	Denmark	2 years	Beech		Experimental	Dave Grigal		
Litter Decomposition	Son et al. 2004	Forest	Korea	4 years	Larch		Experimental	Dave Grigal		
Macroinvertebrates (shredders, collectors, gatherers)	Brown et al. 1997	Intermittent streams	Arkansas Highlands	6 months	Mixed conifer and hardwood	10m buffer	Experimental; harvest techniques differed at the pool habitat level	Lucinda Johnson	Higher abundance in harvested, lower diversity in un-even cut, Higher EPT & Diptera in cut	
Macroinvertebrates (shredders, collectors, gatherers)	Carlson et al. 1990	Streams	NE Oregon	Varied from 6-17 years post	Spruce/fir	20m buffer	Comparative: paired logged and unlogged segments	Lucinda Johnson	More abundant in logged (20-113%), No diff in diversity & richness, More caddisflies, diptera, coleop	
Macroinvertebrates (shredders, collectors, gatherers)	Culp 1987	Stream	British Columbia, Canada			10m	Experimental?	Lucinda Johnson	Macroinv. density declined with 10m buffers	
Macroinvertebrates (shredders, collectors, gatherers)	Davies and Nelson 1994	Stream	SW Australia	1-5 years post	Eucalyptus	0-50m	Paired comparison upstream/downstream	Lucinda Johnson	Macroinv decreased abund by 80 w < 30m buffers %; browntrout decreased abund, Stoneflies and leptophlebiid mayflies decreased with <30m buffers	
Macroinvertebrates (shredders, collectors, gatherers)	Erman and Mahoney 1983	Stream	California					Lucinda Johnson	Initial decline in diversity w/o buffers - slow recovery, comm comp effect	
Macroinvertebrates (shredders, collectors, gatherers)	France 1997	Lake	NW Ontario Canadian Shield	4-10 years post	Aspen/birch, conifer	Clearcut	Experimental-colonization study	Lucinda Johnson		

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Macroinvertebrates (shredders, collectors, gatherers)	Fuchs et al. 2003	Streams	Interior British Columbia, Canada	<5 years, > 20 years	Boreal forest: Lodgepole pine, white spruce, subalpine fir, alder, willow	unknown	Comparative	Lucinda Johnson	No difference in guilds (comp), Biomass highest in recently logged; older logged same as ref	
Macroinvertebrates (shredders, collectors, gatherers)	Growns and Davis 1994	Stream	SW Australia	8 years post	Eucalyptus	100m buffer & clearcut buffer	Comparative: Paired watersheds - 1 undisturbed stream, 1 harvested stream in each wshed	Lucinda Johnson	Altered comm. comp. in clearcut stream; No diff in 100m buffer compared to reference	
Macroinvertebrates (shredders, collectors, gatherers)	Haggerty et al. 2004	Headwater streams	Coast Range, Washington State	1 year	Conifer	2.5 - 21m	Experimental	Lucinda Johnson	Densities higher in clearcut - intermediate in buffered streams for 1 year only, Shredders higher in clearcut and buffered (comm. Comp.), Shredder biomass > clearcut & buffered for 1 year only	
Macroinvertebrates (shredders, collectors, gatherers)	Hawkins et al. 1982	Stream	Oregon					Lucinda Johnson		
Macroinvertebrates (shredders, collectors, gatherers)	Hernandez et al. 2005	Stream	SE Alaska	< 5 years & 35-45 years	Conifer and alder	Unknown	Empirical	Lucinda Johnson	Mean density lowest in OG and young conifer; Density greatest in clearcut (cobble), Old growth (OG) had greater richness; Div lowest in clearcut & OG, Comm comp. Differed across treatment types; Scrapers dominant in clearcut; C-G high in all except OG; F-G > in all harvested , Mean biomass highest in clearcut cobble	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Macroinvertebrates (shredders, collectors, gatherers)	Kedzierski and Smock 2001	Streams	Virginia coastal plain	3 years	Pines and mixed hardwoods	No buffer	Comparative	Lucinda Johnson	Density greater in logged section, Collector-filt; collect-gath greater in logged, Prod incr in logged section; biomass greater in logged	
Macroinvertebrates (shredders, collectors, gatherers)	Kiffney et al. 2003	Streams	SW British Columbia, Canada	?		Clearcut, 10m, 30m buffers, no cut control	Experimental	Lucinda Johnson	Chironomidae Increased abundance > 10m and 30m compared to control, Periphyton biomass increased in clearcut and 10m buffer	
Macroinvertebrates (shredders, collectors, gatherers)	Kreutzweiser et al. 2005a	Stream	Ontario, Canada	3 years	Hardwood (maple/birch)	30-90m buffer required; 3m no-cut zone next to stream	Experimental: selective cut within the RMZ	Lucinda Johnson	Increased Gatherer taxa in mod-intensity	
Macroinvertebrates (shredders, collectors, gatherers)	Newbold et al. 1980							Lucinda Johnson		
Macroinvertebrates (shredders, collectors, gatherers)	Noel et al. 1986	Stream	New England	2,3 years	N. hardwood & spruce-fir	Zero to "thin buffer"	Comparative	Lucinda Johnson	Density greater in cutover, Mayfly dens higher; Diptera higher in cutover,	
Macroinvertebrates (shredders, collectors, gatherers)	Stone and Wallace 1998	Streams	North Carolina - Coweeta	1,5,16 years post	Oak, hickory, poplar, red maple	Buffer clearcut	Comparative	Lucinda Johnson	Abundance greater in harvested, Altered trophic structure; collectors 3x more abund; shredders & predators more abund, Biomass 2x higher in cut than ref; Prod 1.9x higher in cut	
Macroinvertebrates (shredders, collectors, gatherers)	Stout et al. 1993	Streams						Lucinda Johnson		
Methyl Mercury	Garcia and Carignan 1999	Lakes	Quebec, Canada	1 year (3 samplings)	Boreal mixed and coniferous		Comparative	Dave Grigal		
Methyl Mercury	Munthe and Hultberg 2004	Stream	Sweden	6 pre-harvest; 3 post-harvest	Spruce with pine		Experimental	Dave Grigal		

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Methyl Mercury	Porvari et al. 2003	Stream	Finland	8 year total; 3 years post-harvest	Spruce		Paired watershed	Dave Grigal		
Methyl Mercury	Strachan et al. 2006	Lakes	Alberta, Canada	Monitoring of treated and control lakes	Boreal		Comparative	Dave Grigal	MeHg concentrations increased but soon returned to normal	Mercury
Overhead Canopy	Brososke et al. 1997	Streams	Primarily Pacific Northwest	Variable	Variable	109 ft for 75% stream shade	Review of many studies and modelling	Sandy Verry		
Phosphorous	Ice 2000	Forest	Forest	Review Paper	Review	Mixed	Review	Dave Grigal	Nitrate-nitrogen more responsive to forest management than phosphorus; prescribed fire can mineralize forest floor and increase nitrogen loads.	
Phosphorous	Salminen and Beschta 1991	Forest	Forest	National review	Review	Mixed	Review	Dave Grigal	Phosphorous concentrations can change due to forest management activities but are relatively insensitive compared to other water quality impacts; sediment-bound phosphorous changes most likely.	
Phosphorous	Stewart 1997	Streams	Streams	Oregon	Mixed	Forest types across Oregon	Field observations	Dave Grigal	Summary of workshop, but some key observations about lack of eutrophication in response to increased nutrients for forest streams.	
Primary Production (periphyton)	Barton et al. 1985	Streams	Ontario, Canada	1 year	Deciduous, non-forested	No scale		Mark Hanson	Transition to algal filaments following clear cutting	
Primary Production (periphyton)	Batzer et al. 2000	Wetlands (small, depressional)	Georgia	23 years (+/-)	Conifer/plantation	No scale		Mark Hanson	Weak evidence of increased periphyton biomass	
Primary Production (periphyton)	Crumpton 1986	Wetlands (prairie potholes)	Prairie Pothole Region, USA				Report	Mark Hanson	Ecology of marsh algae	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Primary Production (periphyton)	Jones and Sayer 2003	Shallow Lakes	Norfolk, UK	1 year		Site Scale	Comparative	Mark Hanson	Functional influences of periphyton	
Primary Production (periphyton)	Kiffney et al. 2003	Streams	British Columbia, Canada	1 year	Coastal-conifer	100+		Mark Hanson		
Primary Production (periphyton)	Kiffney et al. 2004	Experimental Streams	British Columbia, Canada	1 year	Coastal-conifer			Mark Hanson		
Primary Production (periphyton)	Merrit and Cummins 1996	Aquatic - General	Global				Report	Mark Hanson	General treatment of aquatic insects	
Primary Production (periphyton)	Noel et al. 1986	Streams	New England	1 year	?	No scale		Mark Hanson	Periphyton cell density > 6X following clear cutting	
Primary Production (periphyton)	Robinson et al. 2000	Wetlands (prairie potholes)	Manitoba, Canada	10 years			Experimental	Mark Hanson	Ecology of marsh algae	
Primary Production (periphyton)	Stone and Wallace 1998	Streams	North Carolina	16 years (+/-)	Oak, hickory, poplar	No scale		Mark Hanson	Macroinvertebrate community communities fluctuated following clear cutting	
Primary Production (periphyton)	Wallace and Gurtz 1985	Streams	North Carolina	4-5 year	Oak-hickory	No scale		Mark Hanson	Periphyton biomass fluctuated 10X following clear cutting	
Primary Production (periphyton)	Webster et al. 1983	Streams	Variable	Variable	Variable	No scale		Mark Hanson	Responses to carbon fixation; increased 28X following clearcutting	
Riparian Dependent Birds	Castelle et al. 1994	Various Streams	United States	NA	Variable	Availability of suitable habitat features LARGE	Review	JoAnn Hanowski		
Riparian Dependent Birds	Hanowski et al. 2000	Various Streams Lakes	Minnesota	NA	Variable	Availability of suitable habitat features LARGE Trees	Review	JoAnn Hanowski		
Riparian Dependent Birds	Hanowski et al. 2002	Various Streams Lakes	Minnesota	NA	Variable	Availability of suitable habitat features LARGE Trees	Review	JoAnn Hanowski		
Riparian Dependent Birds	MacDonald et al. 2004	Lakes	Alberta, Canada	NA	Variable	Availability of suitable habitat features	GIS, comparative	JoAnn Hanowski		

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Riparian Microclimate	Chan 2006	Forest	Western Oregon	Ongoing	Coastal and Cascade Forest		Transects of microclimate across different treatments	Randy Kolka	Steep change in microclimate within first 45 feet of streams; small changes in microclimate within buffers; no changes in microclimate measured over streams where partial harvesting was occurring.	
Riparian Microclimate	Danehy and Kirpes 2000	Forest	East side of Cascades, Oregon and Washington	5-9 days in 1997	Interior		Transects away from streams at 12 sites	Randy Kolka	Microclimate gradient very steep with influence of stream	
Riparian Microclimate	Dong et al. 1998	Riparian areas	Washington	2 years	Fir-hemlock	0, 15, 30, 60, 180m, but various width buffers	Comparative	Randy Kolka		
Riparian Microclimate	Meleason and Quinn 2004	Riparian areas	New Zealand	1 year	Pine	5 and 30m	Harvest Comparative	Randy Kolka		
Snags	Graves et al. 2000	Forest	West Virginia	15+ years	Appalachian hardwoods	NA	Experimental	Brain Palik		
Snags	Harper and Macdonald 2002	Forest	Alberta, Canada	16 years	Aspen-boreal	NA	Comparative	Brain Palik		
Snags	Lee 1998	Forest	Alberta, Canada	100+ years	Aspen-boreal	NA	Chronosequence-descriptive	Brain Palik		
Snags	Lee et al. 1997	Forest	Alberta, Canada	100+ years	Aspen-boreal	NA	Chronosequence-descriptive	Brain Palik		
Soil Moisture	Ballard 2000	Uplands	Many places	NA	Various	NA	Review Article	Randy Kolka		
Soil Moisture	Burgess and Wetzel 2000	Uplands	Ontario, Canada	2 years	White pine	Thinning levels (not in riparian area)	Comparative	Randy Kolka		
Soil Redox, Nitrates, Denitrification	Binkley and Brown 1993	Streams	United States	Varied	Variety		Review	Dave Grigal		
Soil Redox, Nitrates, Denitrification	Silkworth 1980	Soil water	Minnesota	5 years	Aspen		Comparative	Dave Grigal		
Soil Redox, Nitrates, Denitrification	Verry 1972	Stream	Minnesota	2 years	Aspen		Paired watershed	Dave Grigal		
Stream Geomorphology	Annable 1995	Streams	Ontario, Canada	2 years	Spruce/fir and Riparian Corridors in Ag and Urban Areas	NA	Measured Stream Structure	Sandy Verry	Modal width depth ratios for all stream types	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Stream Temperature, Shading	Barnes and Dibble 1986	Rivers	Quebec, Canada	?	Boreal		Observational	Sandy Verry	Beaver impact on streams i.e. forest type	
Stream Temperature, Shading, Clearcutting	Bartholow 2000	Streams	Rocky Mountains/ Pacific Northwest	Several years	Spruce/fir	30m strips keep cooler stream temperatures	Review and modelling of various studies	Sandy Verry		
Stream Temperature, Shading, Stream Geomorphology	Jackson et al. 2001	Streams	Coast Range, Washington State	2 years (reported here)	Coastal conifer		BACI with multiple measurement points	George Ice	Wealth of information on channel and water quality responses to management near headwater streams; temperature response mixed depending on presence/absence of buffer and where measurements were taken; dead shade evident from slash accumulations.	
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Jackson et al. 2001	Streams	Coast Range, Washington State	2 years (reported here)	Coastal conifer		BACI with multiple measurement points	George Ice	Wealth of information on channel and water quality responses to management near headwater streams; temperature response mixed depending on presence/absence of buffer and where measurements were taken; dead shade evident from slash accumulations.	
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Wilderson et al. 2006	Streams	Maine	3 years; 1 pre-treatment, 2 post-treatment	Northern hardwood, spruce-fir and mixed hardwood		BACI design, upstream/downstream, 5 treatments	George Ice	Temperature changes became statistically insignificant with 11m buffers; no change in temperature for streams with 23m buffers and partial harvest	Stream temperature

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Donkor and Fryxell 1999	Forests	Ontario, Canada	?	Boreal	Beaver forage distance versus forest structure 165 ft.	Measured forest structure	Sandy Verry		
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Knudsen 1962	Forests/Streams	Wisconsin	Over a decade	Aspen-birch northern hardwood		Observational	Sandy Verry	Beaver versus trout	
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Liquori 2006	Forests/Streams	Western Washington	3 years	W. hemlock, douglas fir, w. red cedar	RMZ (60-150 ft) mortality (57%-2%) most in outer 25 feet - essentially the same as black spruce in Minnesota	Experimental - direct measurement	Sandy Verry		
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Moore and Miner 1997	Streams	Oregon	?	Pacific Northwest		Extension summary	Sandy Verry	General	
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Moore et al. 2003	Forest	Oregon, New Zealand, Germany, etc	Variable	Variable	Patches less than 1 ha don't survive windthrow	Review and synthesis	Sandy Verry		
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Rupp 1955	Streams	Maine	?	Boreal	NA	Impact of beaver dams on trout	Sandy Verry		
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Sridhar et al. 2004	Streams	Washington, Montana, California, Oregon	Several decades	W. hemlock, W. fir	RMZ > 100 ft. did not decrease stream temperature	Review of stream studies and modelling	Sandy Verry		
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Verry 1985	Water impoundment sites	North Central Minnesota, Upper Wisconsin	5 years	Aspen-birch			Sandy Verry	Set a limit on open water wetland size > 1 acre	
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Verry 2000	Streams	Eastern U.S.	1 year			Review of stream geomorphology	Sandy Verry	Guides for assessing over-wide streams	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Verry 2004a	Streams	Central and Upper Midwest	1 year			Review of stream impacts and mechanisms	Sandy Verry	Over-wide and shallow streams impair fish habitat	
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Verry 2004b	River	Midwest	1 year	All in Midwest		Review of midwest stream impacts	Sandy Verry	Over wide, shallow streams	
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Verry 2005	River	Dark River, Minnesota	55 years: photos 1948-2003	Aspen-birch, alder		Air photo	Sandy Verry	Stream width over-widened unable to handle sediment	
Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow	Wilde et al. 1950	Forests/Streams	Wisconsin	2 years?	Aspen-birch	Forest growth around dams	Aspen-birch	Sandy Verry		
Streamflow	Stone et al. 1978	Streams	Eastern USA	Many	Deciduous		Review	Dave Grigal		
Turbidity and Total Suspended Solids	Barton et al. 1985	Agriculture/forest	Ontario, Canada	June-August	Mixed		Field measures	George Ice	% of bank forested above monitoring site related to fine particulate material concentrations observed.	This could be both sediment and organic primary production.
Turbidity and Total Suspended Solids	Benoit 1978	Forest	Oregon	NA	Conifer		Interpretation of sediment data	George Ice	Relationship between landslope, percent of sediment delivered to a stream, and buffer strip width (based on interpretation of existing data)	
Turbidity and Total Suspended Solids	Beschta 1979	Forest	Oregon	2 years	Conifer		Repeated measurements	George Ice	5,000m3 of sediment released along 250m of stream the first year after woody debris was removed for fish passage improvement.	
Turbidity and Total Suspended Solids	Bilby 1981	Forest	New Hampshire	2 year/1 pre- and 1 post-treat.	Eastern hardwood		Experimental removal of LWD	George Ice	Organic debris important in retaining sediment. 500% increase in coarse and fine particulate matter export with LWD removal.	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Turbidity and Total Suspended Solids	Brake et al. 1999	Forest	Oregon	One measure	Conifer		Replicated plots	George Ice	Obstructions reduce sediment travel distance. Sediment plume distances with means between 5-9 m.	Extremely short travel distances.
Turbidity and Total Suspended Solids	Brown 1980	Forest	Oregon	Multi-year and storms	Conifer/mixed		Summary of other work	George Ice	Dynamic patterns of TSS and turbidity	
Turbidity and Total Suspended Solids	Carroll et al. 2004	Forest	Mississippi	2 years	Mixed		Paired/replicated experiment	George Ice	SMZ did not reduce TSS measured in streams probably due to the great variability of these headwater systems.	
Turbidity and Total Suspended Solids	Castelle and Johnson 2000	Forest/agriculture	NA	NA	NA		Literature synthesis	George Ice	Synthesis of the literature (mostly West)	
Turbidity and Total Suspended Solids	CH2M Hill and WWW 1999	Forest/agriculture	NA	NA	NA		Literature synthesis	George Ice	Synthesis of the literature (mostly West)	
Turbidity and Total Suspended Solids	Ice 1999	Forest	Oregon	14 years	Conifer/mixed		Paired watershed study	George Ice	Minimal buffer effective in reducing the TSS response to forest management. Probably due in part to streambank protection.	
Turbidity and Total Suspended Solids	Jackson et al. 2001	Forest	Washington	2 years	Conifer		BACI replicated blocks	George Ice	Buffer keep slash out of streams. Slash can trap sediment	
Turbidity and Total Suspended Solids	Jackson et al. 2005	Forest	Washington	4 years	Conifer		BACI replicated blocks	George Ice	Blowdown for headwater buffers was high	
Turbidity and Total Suspended Solids	Keim and Schoenholtz 1999	Forest	Mississippi	15 months	Bottomland hardwood		Replicated block experiment	George Ice	SMZs reduced TSS increases from logging. No harvest SMZs had more effect than cable-only SMZs on TSS.	
Turbidity and Total Suspended Solids	Kochenderfer and Edwards 1990	Forest	West Virginia	6 years	NA		Paired watershed study	George Ice	No significant increase in sediment in streams where various harvesting occurred due to the presence of SMZs	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Turbidity and Total Suspended Solids	Lowrance et al. 1997	Forest/agriculture	East Coast USA	Multiple studies	Mixed			George Ice	Synthesis of research for the East Coast of US. 81% reduction in sediment with grassed vegetated filter strip, but could be overwhelmed.	
Turbidity and Total Suspended Solids	MacDonald and Keller 1983	Forest	California	2 years			Field monitoring to treatment	George Ice	Removal of wood releases sediment	
Turbidity and Total Suspended Solids	MacDonald and Keller 1987	Forest	California	4 years			Field monitoring to treatment	George Ice	Removal of wood releases sediment	
Turbidity and Total Suspended Solids	Macdonald et al. 2003b	Forest	British Columbia (interior), Canada	6 years	Pine		Paired watershed study	George Ice	TSS concentrations increased despite SMZs but return to normal or below in 2 years. SMZs reduced channel disturbance but subsequent windthrow.	
Turbidity and Total Suspended Solids	Magette et al. 1989	Agriculture	Eastern USA	Series of tests	NA		Plot experiments	George Ice	A 4.6m vegetated filter strip reduced TSS 66% and a 9.2m strip effectively removed TSS from runoff.	
Turbidity and Total Suspended Solids	Megahan and Ketcheson 1996	Forest	Idaho				Field measurements	George Ice	A law of diminishing returns for sediment trapping and buffer distance	
Turbidity and Total Suspended Solids	Megahan and Nowlin 1976	Forest	Idaho	One-time measure	Conifer		Field measurement	George Ice	Large volumes of sediment stored behind channel obstructions- only 10% of stored sediment appeared as sediment yield.	
Turbidity and Total Suspended Solids	Merten and Newman 1998	Forest	Minnesota	2 years			BACI design for riparian management	George Ice	Change in embeddedness but likely upstream source	
Turbidity and Total Suspended Solids	Minnesota Forest Resources Council 1999	NA	Minnesota	NA	NA		NA	George Ice	Guidelines	
Turbidity and Total Suspended Solids	Newman et al. 2004	Forest	Minnesota	2 years (ongoing)			BACI design for riparian management	George Ice	No change in embeddedness noted	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Turbidity and Total Suspended Solids	Riedel and Vose 2002	Forest	Georgia	1 year	NR		Field monitoring	George Ice	TSS is often used as a surrogate for suspended sediment. Most impacts from bedload.	
Turbidity and Total Suspended Solids	Rivenbark and Jackson 2004	Forest	Georgia	Field season	Pine/mixed		Survey	George Ice	Breakthroughs an important source of sediment getting through riparian areas.	
Turbidity and Total Suspended Solids	Sawyer and McCarty 1967	NA	NA	NA	NA		NA	George Ice	Textbook on water quality.	
Turbidity and Total Suspended Solids	Sheridan et al. 1999	Agriculture/forest	Georgia	4 years	NR		Plot study	George Ice	Grassed portion of riparian forest buffer system (RFBS) was the location of most sediment removal. All RFBS types effective at sediment removal.	
Turbidity and Total Suspended Solids	Sweeney 1993	Agriculture/forest	Pennsylvania	Multiple years	NR		Field measurements	George Ice	Channel geomorphology affected by riparian vegetation type.	
Turbidity and Total Suspended Solids	Swift 1986	Forests	North Carolina	2 years	NA		Field measurements	George Ice	Sediment plume travel distance below roads increases with slope and decreases with obstructions.	
Turbidity and Total Suspended Solids	Williams et al. 2000	Forest	South Carolina	3 years	Pine and oak		Paired watershed study	George Ice	10-fold decrease in sediment yields with use of BMPs compared to impacts measured by Hewlett with unrestricted forest management	
Turbidity and Total Suspended Solids	Wong and McCuen 1982	Agriculture	Maryland (East)	NA	NA		Synthesis report	George Ice	Review paper	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Turbidity and Total Suspended Solids	Wynn et al. 2000	Forest	Virginia	6 years	Loblolly and hardwood		Paired watershed study	George Ice	BMPs including 15.2m buffer result in little change in sediment yield from treated watershed while no BMP watershed experiences significant increase.	
Water Temperature (streams, lakes, wetlands)	Batzer et al. 2000	Seasonal wetlands	Georgia	Chrono-sequence	Pine	Riparian removal	Harvest Comparative	Randy Kolka		
Water Temperature (streams, lakes, wetlands)	France 1997	Lakes	Ontario, Canada	1 year	Varied	Riparian removal	Harvest Comparative	Randy Kolka		
Water Temperature (streams, lakes, wetlands)	Kiffney et al. 2003	Headwater streams	British Columbia, Canada	1 year	Hemlock/cedar	0, 10, 30m	Harvest Comparative	Randy Kolka		
Water Temperature (streams, lakes, wetlands)	Macdonald et al. 2003a	Headwater streams	British Columbia, Canada	5 years	Spruce/fir	5, 20, 30m	Harvest Comparative	Randy Kolka		
Water Temperature (streams, lakes, wetlands)	Mitchell 1999	Small streams	Many	Model	Many	0m	Model	Randy Kolka		
Water Temperature (streams, lakes, wetlands)	Prepas et al. 2001	Lakes	Alberta, Canada	4 years	Varied	Riparian removal	Harvest Comparative	Randy Kolka		
Wetland Macroinvertebrates	Euliss et al. 1999	Wetlands (prairie potholes)	Prairie Pothole Region, USA				Report	Mark Hanson	General descriptions of wetland invertebrate taxa, habitat requirements, life histories, etc.	
Wetland Macroinvertebrates	Gernes and Helgen 2002	Wetlands (large, semipermanent)	Minnesota	4 years	NC Hardwood Forest Ecoregion	150+		Mark Hanson		
Wetland Macroinvertebrates	Hanson et al. 2004a	Wetlands (small, depressional)	Minnesota	4 years	Aspen/birch Laurentian Forest	Adjacent Site scale	Comparative + Experimental	Mark Hanson	Reported weak associations between aquatic invertebrates and characteristics of adjacent uplands	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Wetland Macroinvertebrates	Hanson et al. 2004b	Wetlands (small, depressional)	Minnesota	5 years	Aspen/birch Laurentian Forest	50	Experimental	Mark Hanson	Modest evidence that 50-ft harvest buffers mitigate against changes in wetland invertebrate communities	
Wetland Macroinvertebrates	Krapu and Reinecke 1987	Wetlands (general)	USA				Report	Mark Hanson	Descriptions of waterfowl nutrition requirements	
Wetland Macroinvertebrates	Murkin and Ross 2000	Wetlands (prairie potholes)	Prairie Pothole Region, USA				Report	Mark Hanson	Descriptions of prairie wetland invertebrate ecology	
Wetland Macroinvertebrates	Tangen et al. 2003	Wetlands (small, depressional)	Prairie Pothole Region, USA	1 Year		Adjacent/Site scale	Comparative	Mark Hanson	Reported weak associations between aquatic invertebrates and disturbance in adjacent upland areas	
Wetland Macroinvertebrates	Wiggins et al. 1980	Wetlands (general)	New England, USA				Report	Mark Hanson	Generalized descriptions of life history patterns of aquatic invertebrates	
Wetland Macroinvertebrates	Zimmer et al. 2000	Wetlands (prairie potholes)	Prairie Pothole Region, USA	2 Years		Site Scale	Comparative	Mark Hanson	Wetland invertebrate communities influenced by vertebrate predation	
Wetland Macroinvertebrates	Zimmer et al. 2002	Wetlands (prairie potholes)	Prairie Pothole Region, USA	4 Years		Site Scale	Comparative	Mark Hanson	Wetland invertebrates and amphibians influenced by vertebrate predation	
Windthrow	Huggard et al. 1999	Forest		2.7 years post-harvest	Eng. Spruce/Subalpine fir		Harvest Comparison	Brain Palik	5m (highest), declines to background rates by 25m; N and E aspects highest; measured 2.7 years after harvest	
Windthrow	McClure et al. 2004	Forest		18 years post-harvest	Mixed mesophytic		Harvest Comparison	Brain Palik	15m-evaluated 18 years after harvest	

Response Indicator	Reference	Habitat Type	Location	Study Duration	Forest Type	Linkage Width	Study Type	From	Findings	Comments
Windthrow	Reid and Hilton 1989	Forest		5+ years	Coast redwood, Douglas fir	150m		Brain Palik	150m-rates elevated over background rates up to this distance, over five years	
Windthrow	Ruel et al. 2001	Forest		9 years post-harvest	Blasam fir	20, 40, 60m	Harvest Comparison	Brain Palik	20m-42% mortality, 40m-25% mortality, 60m-30% mortality; measured nine years after harvest	
Windthrow	Elling and Verry 1978		Minnesota		Black spruce on organic soils	105 ft on one side, 130 ft on 2 sides of stream	Field sampling and regression	Sandy Verry		
Windthrow	Heinselman 1955		Minnesota		Black spruce on organic soils	105 ft on one side, 130 ft on 2 sides of stream	Field sampling and regression	Sandy Verry		
Windthrow	Heinselman 1957		Minnesota		Black spruce on organic soils	105 ft on one side, 130 ft on 2 sides of stream	Field sampling and regression	Sandy Verry		
Windthrow	Johnston 1977	Forest	Minnesota and Michigan	Several decades	Black spruce	Wind mortality significant < 105 ft.	Experimental	Sandy Verry		
Windthrow	Palik et al. 2001	Seasonal wetlands	Cass Lake, Minnesota	2 years	Aspen		Hydroperiod litterfall amphibian measurement	Sandy Verry	wetlands < 1 acre are not open water wetlands, they are seasonal	

APPENDIX B

Riparian Indicators - Literature Review

Scientific Summaries and Professional Judgment

by the Riparian Science Technical Committee

August 2007

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Introduction

After developing a wide array of indicators (Figure 1, 2, and 3 of the report) in relation to the hydrology, geochemistry, and habitat functions, the RSTC reviewed the literature available for the various indicators. The availability and quality of scientific information varied from no data to substantial data with degree of confidence levels ranging from high to low. These indicators were qualitatively ranked relevant to this process in terms of the following:

- Relevance to site level decision-making and best management practices;
- Robustness;
- Supporting scientific data; and,
- Usefulness for addressing watershed/landscape level decisions in context with the numerous site-level decisions that occur within a watershed.

After the initial scientific review of indicators, the indicators were refined. These indicators and the RSTC member principally assigned to the literature review for each are provided in Table B-1.

This appendix provides the RSTC's summaries of the selected indicators as viewed in isolation from other indicators that may be associated with it. The information includes a summary of the scientific findings, graphic portrayals where appropriate, and professional judgment of the RSTC members. They are not presented in any particular order.

Table B-1. Refined Indicators Selected from Literature Review

RSTC Member	Response Indicator
Dan Gilmore	Invasive Plants
	Forest Vegetation (age, size structure, distribution)
	Large Wood (as it relates to herpetofauna)
	Canopy Cover
Dave Grigal	Soil Redox, Nitrates, and Denitrification
	Methyl Mercury
	Litter Decomposition
Mark Hanson	Primary Production (periphyton)
	Emergent (herbaceous) Macrophytes
	Macroinvertebrates (fairy shrimp, water boatman)
JoAnn Hanowski	Riparian Dependent Birds
	Bird Productivity
	Interior Forest Birds
George Ice	Dissolved Oxygen
	Turbidity and Total Suspended Solids
	Embeddedness
Lucinda Johnson	Macroinvertebrates (shredders, collectors, gatherers)
	Large wood
	Forest Amphibians
Randy Kolka	Water Temperature (streams, lakes, wetlands)
	Air Temperature
	Dissolved Organic Carbon (DOC)
	Light
	Soil Moisture
Brian Palik	Snags
	General Disturbance Associated Plants
	Forest Area Sensitive Plants (interior forest) Plants
Sandy Verry	Windthrow
	Overhead Canopy
	Beaver Interactions

Invasive Plants

Scientific Summary

Invasive plants are defined as introduced species. An introduced species is an established plant or animal not native to the ecosystem, region, or country (Helms, 1998, SAF dictionary, pg. 100). The effect of riparian width on the presence of invasive species will be dependent on the intensity of the forest floor disturbance (e.g., season of harvest), dispersal mechanism (e.g., water, wind, animals), shade tolerance, and proximity of the invasive species being considered. Scientific literature relating to the presence or absence of invasive species in RMZs for any type of waterbody was not available.

Graphics

It is not possible to provide a reliable graph for this indicator due to the lack of scientific literature. Furthermore, the complexity and detail of graphical relationships under these circumstances would have to be produced for individual species or species groups.

Professional Judgment

If seeds, or plant parts in the case of vegetative reproduction, are not present; invasive species are not an issue. The number one factor that influences the introduction of invasive plant species is dispersal mechanisms and the proximity of viable seed beds. The next most important factors would be forest floor condition and light intensity. The importance of each of these parameters is dependent on the ecological characteristics of the species in terms of seed requirements and shade tolerance.

Forest Vegetation (age, size, structure, distribution)

Scientific Summary

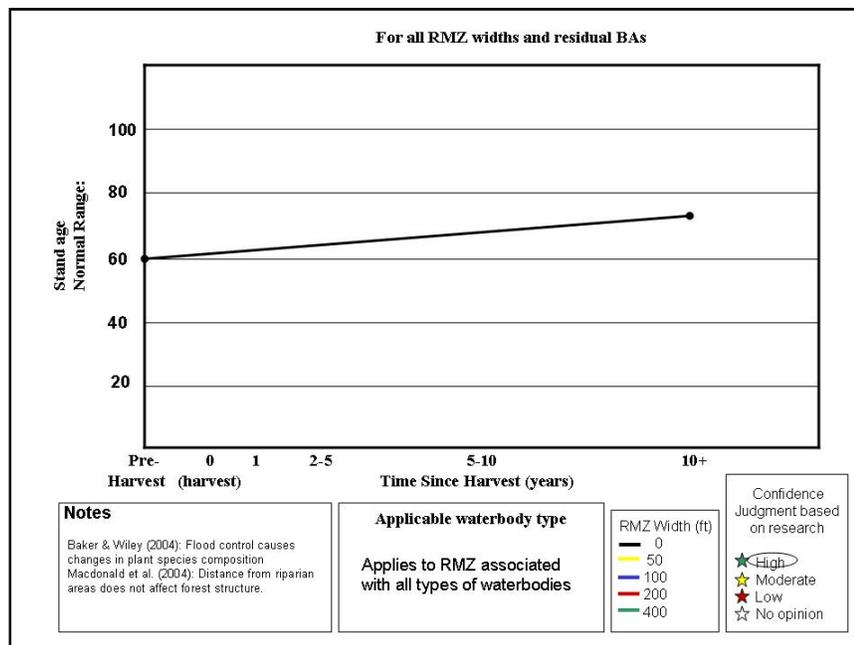
Forest vegetation is described as tree age or time since disturbance, diameter and diameter distribution, leaf area index, and forest age (even- or uneven-aged) class. The literature reviewed is surprisingly sparse in regards to data directly related to this indicator. Two important studies deserve mention. The first (Baker and Wiley 2004) had a stated goal of characterizing the range of variation in riparian forests across lower Michigan. They used ordination techniques to reveal some interesting patterns in their data indicating that forests developed along waterways with flood control have a greater amount of sugar maple than forests along non-controlled waterways. Unfortunately, data that characterized these forests in usable units of measure to the practitioner was not provided. Rather, data was provided as mensurational characteristics of the stands studied. The data was characterized using cluster analysis, relative abundance, and non-metric multi-dimensional scaling.

A second study (Macdonald et al. 2004) was a computer simulation study using a digital forest inventory database for the northern boreal forest. The results showed no difference in forest age and canopy composition based upon distances from lakes. The authors challenged the use of riparian guidelines if the goal of management is to emulate a natural disturbance.

Graphics

The metric graphed for this indicator is age (Figure B-1). The level of confidence based on the research is high because the forest will become older following a disturbance. It is important to note that age would vary for different vegetative life forms (e.g., forbs, shrubs, trees).

Figure B-1. Stand age for all RMZ widths and residual basal areas (BAs)



Professional Judgment

Using this study (Macdonald et al. 2004) as a guide, riparian width would have a minor impact on vegetation age, size structure, and distribution. However, riparian width and the intensity of harvest to the forest adjoining the riparian zone would influence the light entering the RMZ. A heavier harvest would enhance understory growth. Depending on the shade-tolerance of the tree species involved, a multi-aged forest could develop over time.

Large Wood (as it relates to herpetofauna)

Scientific Summary

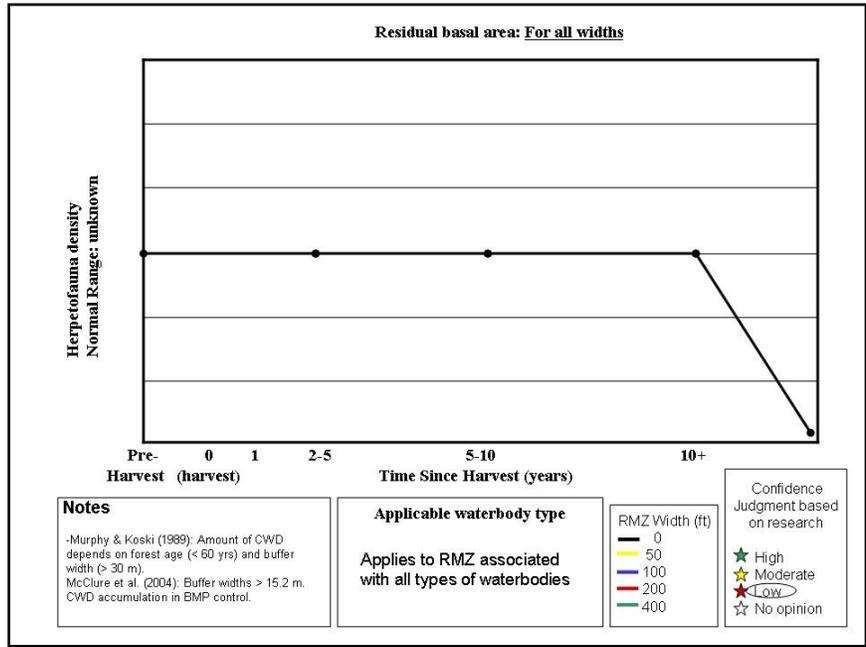
Large wood, coarse woody debris (CWD), large organic debris (LOD) or down wood debris (DWD) is defined as any piece(s) of dead woody material (e.g., dead boles, limbs, large root masses) on the ground in forest stands or streams (Helms, 1998, Dictionary of Forestry, pg 32). Scientific literature for large wood and its affects on herpetofauna was not available. It is well known, however, that herpetofauna require CWD for shelter (deMaynadier and Hunter 1995). A review by Semilitsch and Bodie (2003) suggested that current guidelines for buffer zones around wetlands and riparian areas were not adequate for amphibians and reptiles. Unfortunately, they never defined the habitat needs of these species. Rather, they reached their conclusion by reviewing dispersal distance of these species from a core area. Dispersal distances for amphibians ranged from 159 to 290 meters (m) (521-951 feet (ft)). Burbink et al. (1998), however, found no relationship between RMZs and amphibian numbers. Rather, they concluded that it is important to consider specific natural history (professional judgment views this as habitat) requirements of amphibian species in the design of riparian corridors.

Two papers were cited that studied the relationship between riparian areas and CWD (Robison and Beschta 1990, McClure et al. 2004). Each paper concluded that trees needed to be located with an average tree height width of approximately 15 m (49 ft) from a stream in order to provide CWD for the stream. McClure et al. 2004 suggested that the amount of CWD produced in a buffer zone was dependent on the intensity of harvesting practices adjacent to the buffer zone. In addition, numerous papers suggest that retention of a riparian buffer of some sort is required to maintain a source of CWD. In conclusion, none of this helps with how much CWD is required by herpetofauna as literature with data directly related to this is not available.

Graphics

Figure B-2 indicates that herpetofauna populations will decline as CWD levels decrease; however, there is no baseline information. Once herpetofauna populations become extirpated because of the lack of CWD, it is unknown if they will recover once CWD becomes available again.

Figure B-2. Herpetofauna density for all RMZ widths and residual BAs



Professional Judgment

There is a higher confidence about CWD, but not in relation to herpetofauna.

Canopy Cover

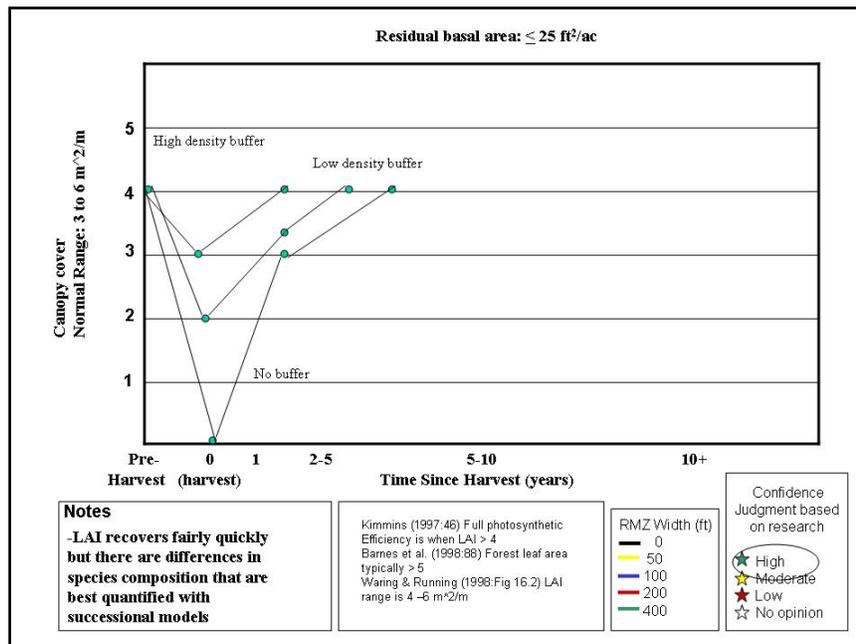
Scientific Summary

Canopy cover is defined as the proportion of ground or water covered by a vertical projection of the outermost perimeter of the natural spread of foliage or plants (Helms 1998). The literature reviewed did not provide information to directly address this indicator. There are several forest ecology textbooks (Kimmins 1997, Barnes et al. 1998, and Waring and Running 1998) that provide a range of baseline values for this important indicator. The Leaf Area Index (LAI) is the sum of all the upper or all-sided leaf surface areas projected downward per unit area of ground beneath the canopy (Helms 1998). LAI is a measure of photosynthesis potential. The textbooks indicate that full photosynthetic efficiency occurs when LAI is greater than 4 (Kimmins 1997). Typically a forest leaf area is greater than 5 (Barnes et al. 1998) but the range can be 4 to 6 (Waring and Running 1998).

Graphics

Figure B-3 indicates reductions in LAI from a baseline of 4 with complete forest cover removal (less than 25 ft²/ac residual basal area (BA)) and at two residual density buffer strip levels. This depiction of the relationship of LAI does not fully explain the effect of canopy cover, or light on plants. In the figure, LAI returns rapidly to pre-disturbance levels (generally in less than 5 years), however, there can be a substantial change in both species composition and life form (e.g., shrubs instead of trees) that is not detected solely by measures of LAI.

Figure B-3. Canopy cover for residual BA less than 25 ft²/acre



Professional Judgment

LAI can be used as one measure on how an ecosystem recovers from disturbance as well as a measure of photosynthetic capacity.

Soil Redox, Nitrates, Denitrification

Scientific Summary

Soil redox is an abbreviation for the reduction-oxidation status of a soil. In unsaturated soils, oxygen is present and aerobic bacteria use it as the terminal electron acceptor in biochemical reactions. When soils are saturated, there is a restriction of movement of oxygen into soil, leading to reducing conditions. These conditions provide an environment for anaerobic bacteria, wherein alternate electron acceptors are used in place of oxygen in reactions.

Nitrification is the biological oxidation of ammonium to nitrite and nitrate, a biologically induced increase in the oxidation state of nitrogen. This reaction requires the presence of oxygen.

Denitrification is the reduction of nitrogen oxides (usually nitrate and nitrite) to molecular nitrogen or nitrogen oxides with a lower oxidation state of nitrogen. This is carried out under reducing conditions by bacterial activity (denitrification), or in some cases by chemical reactions involving nitrite (chemodenitrification).

Assessment of the literature indicates that following harvest in the upland, soils in the riparian area are likely to be wetter than before harvest. Evapotranspiration decreases in the upland due to tree removal, so that more water is available for movement to the riparian area and aquatic system. As a result, streamflow will usually increase following harvest (Figure B-4). Added water to the riparian areas will increase soil moisture and produce a higher soil redox. As the stream returns to a more normal flow pattern and soil moisture levels return to normal levels in the riparian area, soil redox will approach the preharvest condition.

The higher soil redox (lower soil oxygen) in the riparian zone following harvest is likely to lead to an increase in denitrification. This will lead to a concomitant decrease in concentration of soil nitrate. Nitrate concentrations and denitrification rates can graphically be considered to be mirror images (Figure B-5). This effect is independent of residual BA and RMZ width. Harvest is expected to have a relatively small effect on nitrogen flux into water bodies. Although increased nitrate-N production in the upland may occur, increased denitrification in riparian area will likely offset the increase in nitrate-N (Figure B-5). However, the main affect on nitrogen flux will be determined by the changes over the entire harvest area, not predominately the riparian harvest.

Graphics

Figure B-4. Streamflow increases following harvest

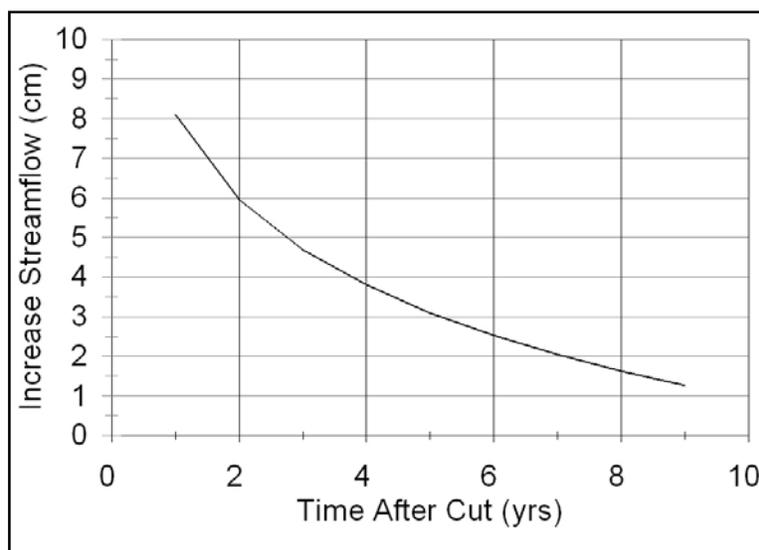
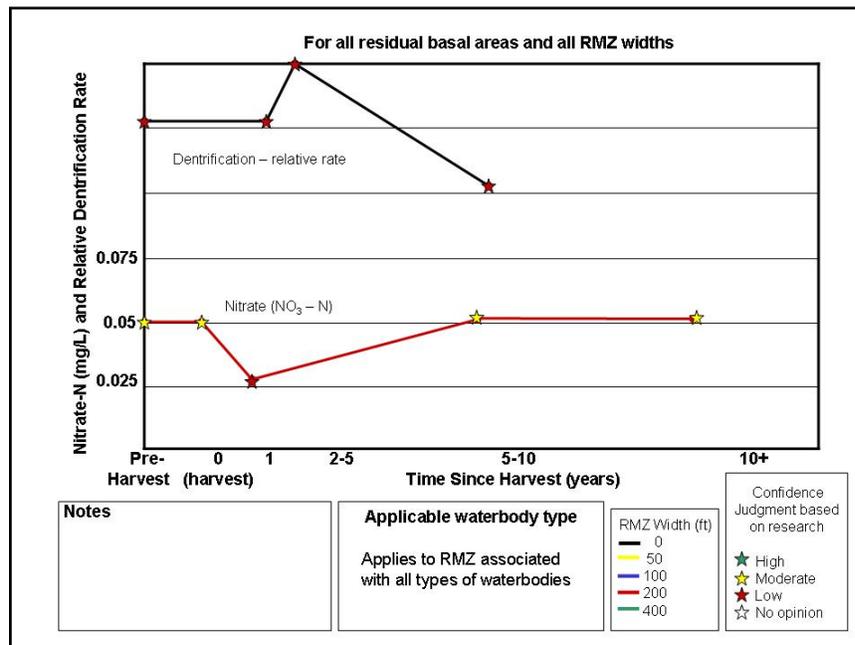


Figure B-5. Nitrate and denitrification rates for all RMZ widths and residual BAs



Methyl Mercury

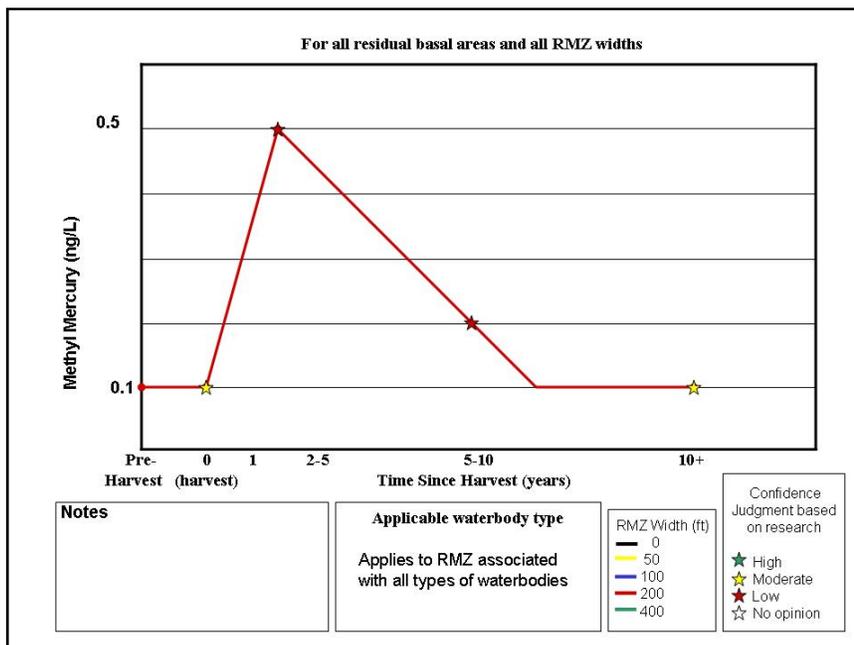
Scientific Summary

Methyl mercury is CH_3Hg^+ (often referred to as MeHg). It is the biologically active form of mercury, and is the form that accumulates in fish and is toxic to humans and wildlife. Methylation, the process of adding a methyl (CH_3^-) group to a mercury ion (Hg^{2+}), can occur either biologically or abiotically, but anaerobic sulfate-reducing bacteria are considered the primary methylators in terrestrial and aquatic systems.

There is limited data on methyl mercury levels. Generally as soil moisture increases (higher soil redox), the creation of temporary wet areas (see discussion for the soil redox, nitrates, and denitrification indicators) will lead to anoxic conditions that promote methylation. This is independent of RMZ width and residual BA. (Figure B-6). Because soil redox will be higher after harvest, methyl mercury production is likely to be higher in the riparian area with a resulting increase in methyl mercury in the stream. The important reason for this increase, however, is harvest over the entire area, and not activity in the riparian area *per se*. Note: The most abundant literature sources related to mercury and wetlands are from Sweden, Finland and Canada.

Graphics

Figure B-6. Methyl Mercury for all RMZ widths and residual BAs



Professional Judgment

Management in riparian areas has little to do with MeHg levels. Evidence indicates that following harvest, soil moisture increases as a result of less canopy cover, soil re-dox increases, and the result is an increase in the methylation of mercury. But this affect is accrued to the entire harvest area not to the riparian area.

Litter Decomposition

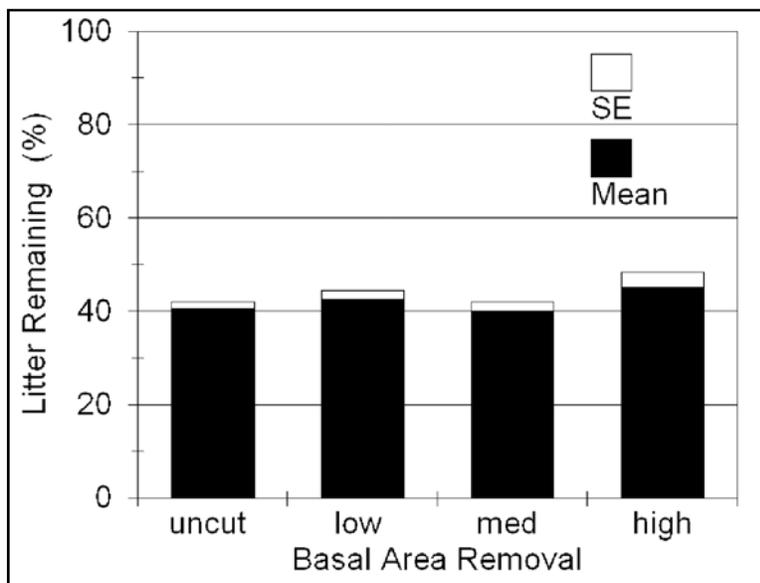
Scientific Summary

Litter decomposition is the loss of leaf mass and other material such as flowers and seed that fall from trees to the soil surface. Bacteria convert this material to energy and gases such as carbon dioxide. At intermediate steps in the decomposition, complex organic molecules are formed that contribute to soil organic matter.

The literature indicates there is no significant difference in the rate of litter decomposition following various harvest scenarios whether in a riparian area or not (Figure B-7). Decomposition is apparently independent of canopy cover; harvested and uncut areas have similar rates of decomposition. The reasons are not clear, but the differences in the amount of litter remaining in cut versus uncut stands are insignificant.

Graphics

Figure B-7. Litter decomposition for BAs whether in an RMZ or not



Professional Judgment

It is the opinion of the RSTC that there will not be an appreciable effect of harvest on levels of litter decomposition in riparian areas. This is independent of RMZ width and residual BA.

Summary of Riparian Response to Timber Harvest on Soil Redox, Denitrification Rates, Nitrates, Methyl-mercury, and Decomposition Rates

The summary above discusses the following five indicators; soil redox, denitrification rates, nitrates, methyl-Hg, and decomposition rates from a professional judgement point of view. Professional assessment of the literature indicates that following harvest in the upland, soils in the riparian area are likely to be wetter than before harvest because of the reduced transpiration in the upland. The result will lead to higher soil redox (lower soil oxygen) in the riparian zone. This is likely to lead to increased denitrification in the riparian zone. Although there may be increased nitrate production in the upland following harvest, increased denitrification in the riparian area will tend to mitigate or even eliminate this increase, so that nitrate in streams following harvest is likely to be at similar levels as before harvest. Because soil redox will be higher, methyl-Hg production is likely to be higher in the riparian area with a resulting increase in methyl-Hg in the stream. The important reason for this increase, however, is harvest over the entire area, and not activity in the riparian area *per se*. Finally, evidence in the literature indicates that rates of litter decomposition are not affected by harvesting; they are similar on uncut and harvested sites and hence any level of cutting in the riparian area will not change rates of litter decomposition.

Primary Production (periphyton)

Scientific Summary

Periphyton is comprised of a diverse, complex mixture of algae, bacteria, polysaccharides, and inorganic matter (Kiffney et al. 2003), and makes a significant contribution to primary productivity in many lotic and lentic ecosystems. For this reason, periphyton communities are widely believed to play important roles in productivity, food-chain support for higher-order consumers (such as macroinvertebrates and probably fish), and system-level properties in aquatic habitats (Crumpton 1986, Merritt and Cummins 1996, Robinson et al. 2000, Jones and Sayer 2003).

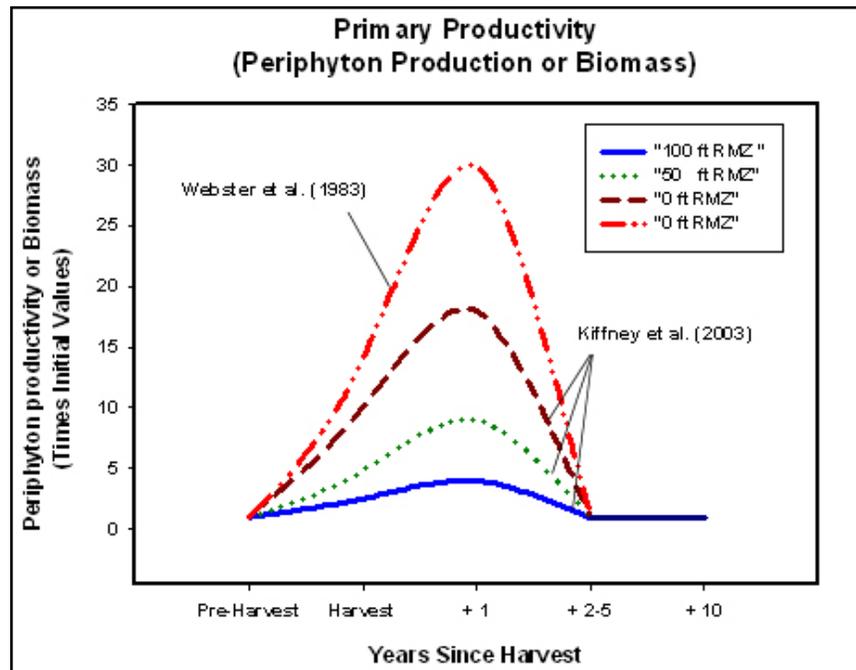
Periphyton communities have not been adequately studied across waterbody types. However, responses of in-stream periphyton (primary) production following adjacent clear-cut timber harvest are well documented. Two examples are useful to illustrate generalized periphyton responses from small streams. Webster et al. (1983) assessed short-term responses of periphyton productivity (measured using natural substrates in circulating chambers) in streams embedded in harvested and unharvested (control) watersheds on property managed by the Coweeta Hydrologic Laboratory in the southern Appalachian mountains (North Carolina). Webster et al. (1983) reported that, in the absence of harvest buffers, in-stream periphyton production ($\text{mg C m}^{-2} \text{ hr}^{-1}$) increased by a factor of approximately 30 times within 1-2 years following clear-cut timber harvesting in adjacent uplands. Similar results were reported by Kiffney et al. (2003) based on comparisons among 13 streams in the Malcolm Knapp Research Forest in British Columbia. The Kiffney et al. (2003) study also incorporated treatments with unharvested buffers (10 m [33 ft] and 30 m [98 ft]) from study streams, along with control and “no buffer” sites. Resulting data indicated that, following adjacent timber harvest, periphyton productivity (as algal mass measured on in-stream tiles) increased by approximately nine times; periphyton mass doubled in streams bounded by unharvested buffers of 10 m (33 ft). Kiffney et al. (2004) supplemented these studies with controlled experiments indicating that increased light availability was the primary mechanism responsible for increased periphyton production in the British Columbia streams. Unfortunately, the Kiffney et al. (2003) data were gathered only during a single year following timber harvest, thus do not allow evaluation of recovery patterns. Results from Webster et al. (1983) indicate that periphyton production returned to baseline levels within two years following timber harvest. Similar patterns should not be inferred for other waterbodies using these data. For example, Batzer et al. (2000) reported no significant responses of periphyton following adjacent timber harvest from small, depressional wetlands embedded in pine plantations in Georgia.

It is important to note that complex changes may accompany shifts in stream periphyton mass (or production) following adjacent clear-cutting. Some evidence indicates that, along with increased periphyton mass, elevated light intensity also induces shifts in taxonomic composition and growth forms within the algal portion of the periphyton matrix. For example in small streams, Kiffney et al. (2003) reported that, along with increased mass, periphyton shifted qualitatively from (largely) diatoms to filamentous al-

gae following adjacent harvesting. They also reported dramatically increased inorganic sediment mass in periphyton mats (presumably due to deposition of material transported from adjacent uplands), concurrent with increases in periphyton biomass and qualitative changes in algal taxa. It is plausible that increased inorganic mass results not only from increased sediment deposition in streams, but also from increased retention rates for periphyton mats dominated by filamentous algae (Kiffney et al. 2003). Regardless of the mechanisms, changes in taxonomic and inorganic composition of periphyton may have detrimental effects on consumers of these food resources, at least during 1-2 years following timber harvest. Thus, higher periphyton mass (or primary production) may not necessarily translate into increased secondary productivity for all macroinvertebrates, stream fishes, or other stream-associated organisms, even though short-term increases in some macroinvertebrates (Chironomidae) have been observed along with increased periphyton biomass following clear-cutting.

Graphics

Figure B-8. Relationships between two measures of primary production and adjacent forest harvesting summarized for small (second order) streams. Kiffney (2003a,b) values reflect responses (increases) of periphyton biomass (ash-free dry weight) as measured on ceramic tiles placed in streams. Webster (1983) values depict rates of carbon fixation ($\text{mg C} \cdot \text{m}^{-2} \cdot \text{hr}^{-1}$) measured in-stream using circulating chambers.



Notes on Figure B-8.

1. Plotted values based on Kiffney et al. (2003a,b) and Webster et al. (1983).
2. Disparity between studies may reflect different responses measured (mass/dry weight vs. carbon fixation).
3. All plots assume initial "moderate" BA (25-80 ft^2/ac).
4. Data depict trends in streams (2nd order) only. Moderate confidence level.

Professional Judgment

Evidence from research on small streams indicates that 1) periphyton biomass and composition responds to clear-cut harvesting in adjacent uplands during 1-2 yrs following tree removal, and 2) that RMZs have potential to mitigate against these effects. Unharvested buffers (or RMZs with high residual BA) approximately 30 M (100 ft) in width appear to prevent major changes to periphyton productivity following timber harvest. Effects of adjacent harvesting appear to be only dampened where buffers approximately 9 m (30 ft) wide are applied. Available literature indicates that periphyton characteristics of small streams will be most strongly affected because these systems show strong functional linkages to adjacent uplands and are often relatively shallow. Research on seasonal ponds has not indicated similar periphyton relationships between RMZs and clear-cutting adjacent to seasonal ponds.

Emergent (herbaceous) Macrophytes

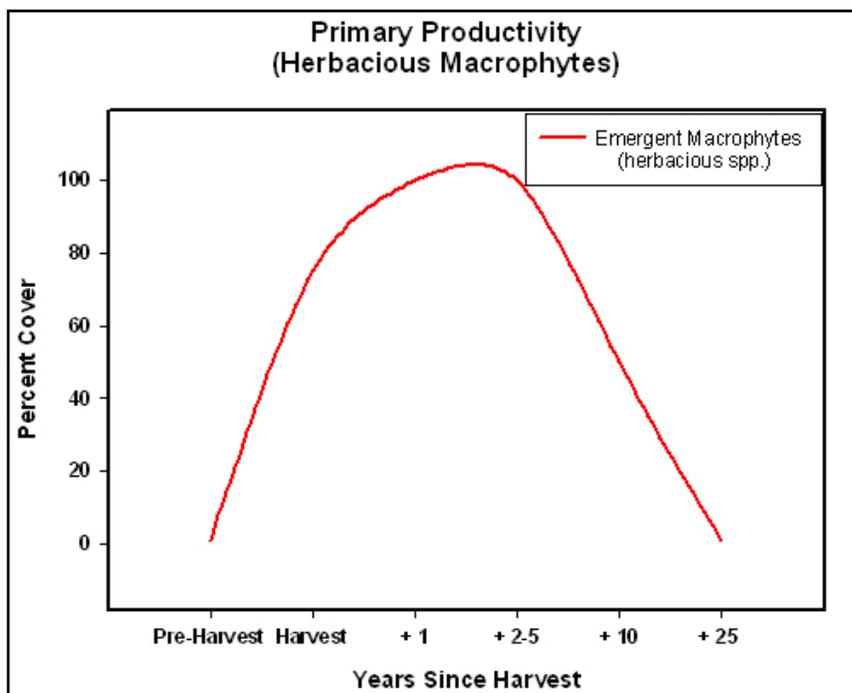
Scientific Summary

Aquatic macrophytes are key components of standing-water (lentic) ecosystems and are especially important in freshwater wetlands (van der Valk and Davis 1978, Kantrud et al. 1986). Emergent macrophyte communities are often well developed in forest wetlands where they provide litter inputs, habitat structure for aquatic organisms, and other functions. Emergent macrophytes respond to fluctuations in light availability and water dynamics, thus it is reasonable to expect that they would respond to changes resulting from timber harvest in adjacent uplands.

With few exceptions, relationships between herbaceous aquatic plant communities and silviculture have not been studied. However, Batzer et al. (2000) reported that *Carex* increased dramatically (Figure B-9) in seasonal wetlands immediately following clear-cut timber harvest of adjacent pine plantations. Similar responses of *Carex* and various grass species in small, seasonal wetlands in northcentral MN following clear-cutting in adjacent aspen/birch stands have also been observed (Hanson et al. unpublished data). Batzer et al. (2000) reported that this increase in *Carex* may persist for more than 10 years. Most likely, this “emergent macrophyte response” will be more dramatic in smaller wetlands where canopy closure contributes to proportionally higher shading of the wetland water surface. Following clear-cutting adjacent to these areas, increased light availability at the water surface (and underlying sediment surface) contributes to rapid proliferation of emergent macrophytes. In larger seasonal wetlands (greater than approximately 0.5 ac in surface area), *Carex* spp. are often well developed in mature timber stands, thus similar increases following adjacent timber harvest in these larger sites would not be expected.

Graphics

Figure B-9. Percent cover by emergent macrophytes (*Carex* and various grass species) in relation to years since clear-cut timber harvest in adjacent uplands. Data were derived from counts in plots located along random transects established through wetlands study.



Notes on Figure B-9.

1. Plotted values based on Batzer et al. (2000) and Hanson et al. (unpublished data).
2. All plots assume initial “moderate” BA (25-80 ft²/ac).
3. Data depict trends in small, “seasonal ponds” only.
4. Moderate confidence level.

Professional Judgment

Retention of harvest buffers (or RMZs with moderate to high residual BA) has potential to mitigate against changes in emergent macrophytes (e.g., increased stem density [mass], surface-area cover of *Carex* spp.) that are likely to develop quickly and persist during 15-20 years following clear-cut harvesting adjacent to seasonal ponds. Available literature is only marginally useful for assessing specific RMZ requirements necessary to maintain natural emergent vegetation, but 15 m (50 ft) RMZs with BA of 50-80 ft²/ac are probably minimal if objectives include maintaining natural proportional patterns of light availability and emergent macrophyte cover within seasonal ponds. RMZs appear to have little potential for maintaining natural light dynamics or vegetation community structure in larger seasonal ponds (surface area greater than 0.5-1.0 ac), open-water wetlands, or for other aquatic habitats.

Macroinvertebrates (fairy shrimp, water boatman)

Scientific Summary

Aquatic macroinvertebrates are important elements of wetland communities and food webs because they play key roles in processing organic matter, providing food chain support to higher order consumers (including amphibians, terrestrial and aquatic birds, and other vertebrate organisms), and influencing pathways and pools of major nutrients including phosphorus and nitrogen (Euliss et al. 1999, Murkin and Ross 2000). In small depressional wetlands (e.g., prairie potholes, seasonal forest ponds, vernal pools), macroinvertebrate communities are known to reflect influences of hydroperiods, physical habitat features, and, in some cases, disturbance within a wetland basin or the adjacent upland and/or riparian area. Small depressional wetlands are known to have unique macroinvertebrate communities, sometimes temporarily dominated by organisms with “fugitive life history strategies” or other life cycle features useful for avoiding depredation by vertebrate or invertebrate predators (Wiggins et al. 1980). In prairie regions, macroinvertebrates in small wetlands are known to be a key source of protein for nesting female ducks and young ducklings (during the first 2-3 weeks of life). In the case of adult female ducks, this is because protein requirements for egg laying cannot be satisfied without exogenous protein sources. In other words, female ducks cannot metabolize endogenous protein accumulated from foraging on wintering grounds as they do endogenous lipid reserves (body fat). Young ducklings also have extremely high dietary protein requirements; this requires that invertebrate food resources be available to ducklings in large amounts and in locations accessible to young birds long before they are capable of flight (Krapu and Reinecke 1987).

Very few studies have assessed relationships between macroinvertebrate communities in depressional wetlands and characteristics of adjacent forested uplands or riparian areas. Data gathered from 24 seasonal forest wetlands (seasonal ponds) in north central Minnesota was used to assess potential influences of forest stands and clear-cut timber harvest on adjacent wetland macroinvertebrates (Hanson et al. 2004a). Use of indirect gradient analysis (Redundancy Analysis, RDA) allowed measurement of influences of canopy closure on macroinvertebrate community structure. This approach is advantageous because it relies on an objective analytical linkage between macroinvertebrate community characteristics and associated environmental gradients (e.g., canopy closure), and because it allows simultaneous use of multiple invertebrate taxa rather than a greatly reduced subset of those data. Notable in these analyses were that, following adjacent clear-cut harvesting, invertebrate community variance explained by canopy closure increased by a factor of approximately four. Even though implications of such changes are difficult to estimate, these results provide quantitative evidence of functional linkages between wetland macroinvertebrates and characteristics of adjacent upland/riparian forests at the site level. Further research is needed to describe these relationships and to allow better understanding of implications for other components of wetland communities.

Aquatic macroinvertebrates have been widely used as indicators of disturbance in freshwaters. A few studies have assessed potential usefulness of macroinvertebrates as disturbance indicators in wetlands and these approaches have achieved mixed success. Nonetheless, some generalizations are possible based on research evaluating selected macroinvertebrates and site-level disturbance in uplands and riparian areas associated with wetlands in Minnesota and North Dakota (Gernes and Helgen 2002, Tangen and Butler 2003, Hanson et al. 2005b). Fairy shrimp (*Eubbranchipus*) and water boatmen (Corixidae) appear to be somewhat unique because they show especially predictable responses to disturbance in freshwater wetlands. Corixidae often show numerical (and proportional) increases in wetland communities following, or in association with, disturbance to wetlands or adjacent riparian areas (Gernes and Helgen 2002, Hanson et al. unpublished data, Zimmer et al. 2000, 2002). In contrast, *Eubbranchipus* is widely believed to reflect relatively “pristine” conditions in seasonal forest ponds. Data gathered from seasonal wetlands in north central Minnesota often indicated that relative abundance of *Eubbranchipus* was negatively associated with clear-cut timber harvest. At times, *Eubbranchipus* were more abundant in unharvested (control) wetland sites by a factor of approximately two to three times (Hanson et al. 2005b and unpublished data).

Graphics

Figure B-10. Pattern of variance in macroinvertebrate community structure explained by relationship to canopy closure over small, seasonal wetlands in north central Minnesota. Variance explained by influence of canopy closure increased following clear-cut timber harvest of adjacent aspen/birch stands and does not include variability contributed by temporal variability (time was treated as a covariable).

Notes on Figure B-10.

1. Plotted values based on Hanson et al. (2005a).
2. All plots assume initial “moderate” BA (25-80 ft²/ac).
3. Data depict trends in small, seasonal wetlands or “seasonal ponds” only.
4. Moderate confidence level.

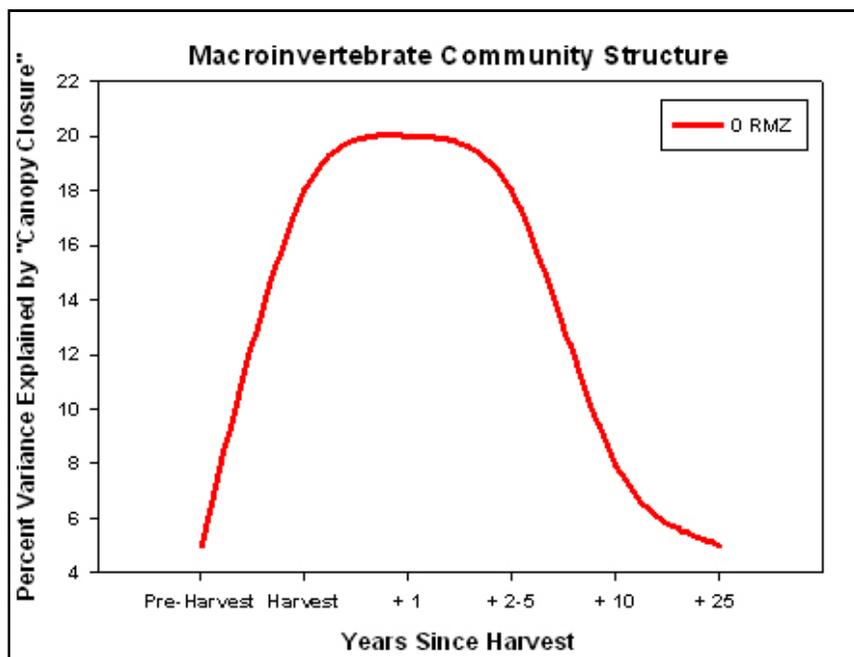
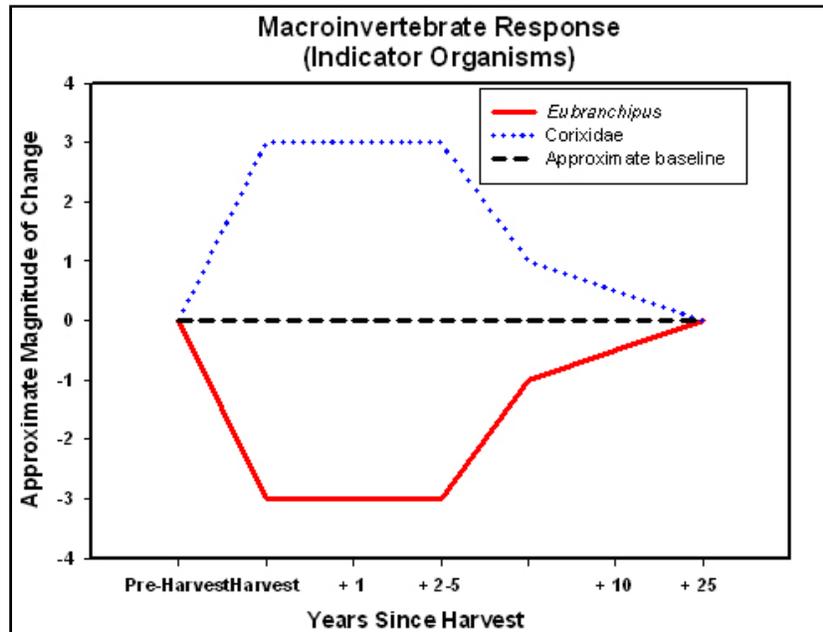


Figure B-11 depicts ranges of likely macroinvertebrate responses following disturbance and clear-cut timber harvesting adjacent to seasonal forest wetlands (seasonal ponds). Relationships depict proposed responses of two indicator taxa, water boatmen (Corixidae) and fairy shrimp (*Eubranchipus*) because these organisms are believed to exhibit strong, yet opposite responses to “disturbance” in adjacent riparian areas.

Notes on Figure B-11.

1. Plotted values are conceptual but based on data trends reflected by Gernes and Helgen (2002), Hanson et al. (2005b and unpublished data), and Zimmer et al. (2000, 2001, 2002).
2. All plots assume initial “moderate” BA (25-80 ft²/ac).



Professional Judgment

Based on available literature, data from several studies, and observations from wetland colleagues, the graph in Figure B-10 depicts expected trajectories for macroinvertebrate responses following disturbance in adjacent uplands. To the best of the RSTC’s professional judgment, causal mechanisms linking underlying associations between these taxa and adjacent riparian areas are unknown. This may reflect a lack of basic ecological information about these organisms and their responses to environmental gradients, along with uncertainty about their taxonomy.

Data trends from studies of seasonal ponds in northcentral Minnesota indicated that, where harvest buffers (or RMZs) are not retained, macroinvertebrate communities were altered in response to clear-cutting in adjacent upland areas. Available data (from Minnesota and elsewhere) are insufficient to assess ecological significance of these changes for other wetland-dependent processes and/or species reliant on invertebrates in seasonal ponds (including ducks), at site- or landscape-scales. However, data do indicate that harvest buffers (or RMZs with high residual BA) mitigate against invertebrate community changes during 1-5 years following adjacent clear-cutting. A key point may be that despite losses to windthrow, retaining RMZs (or residual trees in buffers) may help maintain natural invertebrate communities in seasonal ponds, at least during initial years following clear-cutting, the period with most potential for change in response to adjacent timber harvest.

Riparian Dependent Birds

Scientific Summary

Riparian dependent birds are defined as species that require forest features that are within a minimum distance to a water body. These species include cavity nesting waterfowl, canopy nesting herons, canopy nesting raptors, and a small number of passerines. There are few if any studies that have specifically addressed RMZ width requirements for riparian dependent birds.

Graphics

The projected response of riparian dependent birds to variable-width buffers and different residual BA shown in Figures B-12, B-13 and B-14 is based primarily on professional judgment. When creating these figures, it was assumed that riparian dependent bird species, if present in an RMZ before harvest would respond in a similar fashion to other bird species in RMZ forests. For example, there is generally not a big change in the RMZ bird community in the first year after harvest (a lag response of one year). In the second and subsequent years after harvest, bird communities change relative to unharvested RMZ bird communities and to uncut RMZ forest buffers. Bird communities become more similar to either early successional bird communities in composition (if a small amount of BA was retained), or to a bird community composed of species that are tolerant to partial canopy removal (if more BA is retained) or species that prefer edge habitats.

The longevity of the response by riparian dependent birds would depend on the forest features that were left in RMZ's during harvest. If long-lived super canopy trees and suitable large diameter softwoods were left standing, the length of impact would likely be shorter compared to the time of impact if none of these features were retained (or could be provided within a short period of time). If no habitat features are retained, the length of impact would be at least 60 years.

Although the figures are based on professional judgment, the confidence level is relatively high. Response is highly dependent upon presence of suitable habitat features and recruitment of future habitat features.

Figure B-12. Riparian Dependent Bird population in RMZs, no harvest along streams.

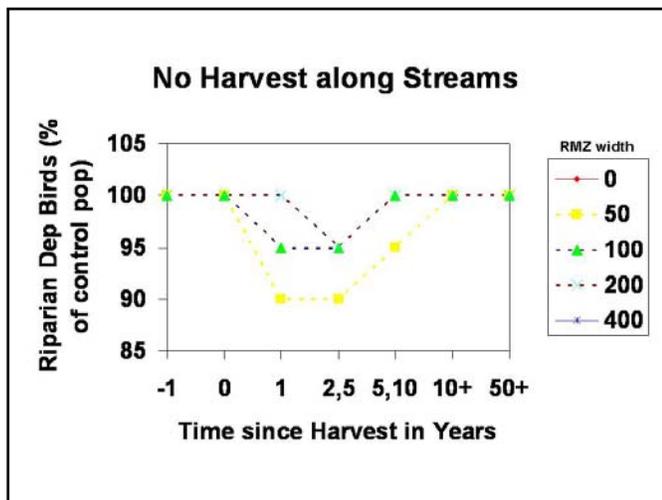


Figure B-13. Riparian Dependent Bird population in RMZs, 25-80 BA along streams.

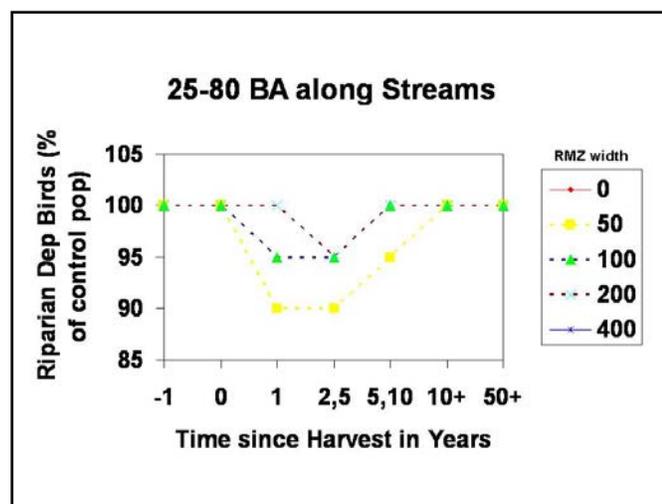
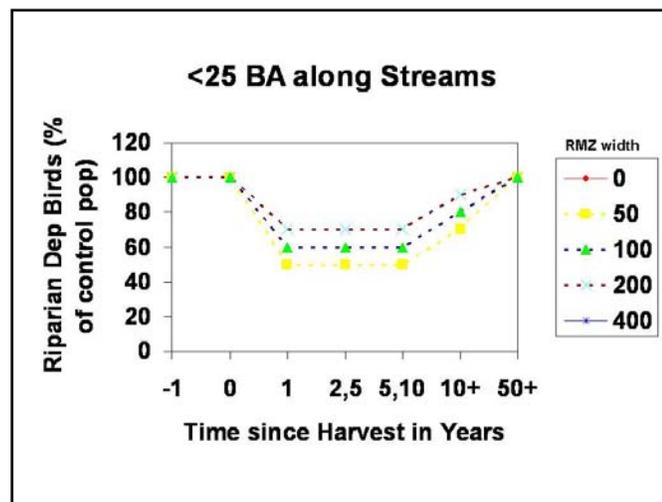


Figure B-14. Riparian Dependent Bird population in RMZs, less than 25 BA along streams.



Professional Judgment

Professional judgment suggests that neither fixed- nor variable-width RMZ's are required for any of the waterbody types in order maintain or enhance habitat for riparian dependent birds. Professional judgment would suggest that due to these species' life history characteristics (nesting and foraging requirements) that it is important to maintain or create habitat features for these species within RMZ's or within a minimum distance to water bodies. These features include super canopy trees for nesting eagles, herons and osprey (e.g., long-lived conifers). It is also important to provide suitable cavity nesting trees for waterfowl species (e.g., large diameter softwoods). Therefore, it is critical to specify a desired future condition of RMZ areas for riparian dependent birds that will maintain these areas in a condition that supports mature forest habitat features.

Bird Productivity

Scientific Summary

Bird productivity is defined as the reproductive success rate of individual birds. The scientific literature indicates that all waterbody types require RMZs to maintain bird productivity, especially critical for ground and shrub nesting species. The literature suggests that a fixed-width RMZ of at least 100 m (328 ft) is required to maintain ground and shrub nesting bird productivity. No evidence was found to conclude that cavity nesting birds require a similar RMZ width. However, evidence for the conclusion for cavity nesting waterfowl was based on a study with a small sample size. Bird productivity can be maintained or enhanced in RMZs by maintaining interior habitat that is "safe" for birds from potential nest predators. In a forested landscape, however, application of RMZs will create more edge overall in the landscape when they are applied uniformly to all waterbody types (Hanowski et al. 2001). On a site level, a 100 m (328 ft) RMZ would likely provide some interior habitat and provide safe nesting habitat. However, on a landscape scale, this is not the best solution for creating interior habitat. It is likely best to maintain or create large forest patches to provide interior habitat on a landscape level and not to do this solely within RMZs.

Graphics

The immediate response of bird productivity to variable-width buffers in Figures B-15 and B-16 is based on the literature and the projected response beyond two years is based primarily on professional judgment. When creating these figures, we assumed that bird productivity would respond in a similar fashion to bird community response in RMZ forests (see above for riparian dependent birds). The longevity of a negative response for this indicator would depend on the rate at which the adjacent forest matured to a point where edge habitat conditions are no longer prevalent. The time period for this to occur is not known for northern forests.

Although the graphics are based on a limited amount of scientific evidence and professional judgment, the confidence level is relatively high as the response is highly dependent upon the “green-up” of adjacent harvested forest. These studies were all completed in uncut forests which did not report riparian BA.

Figure B-15. Bird Productivity, Streams.

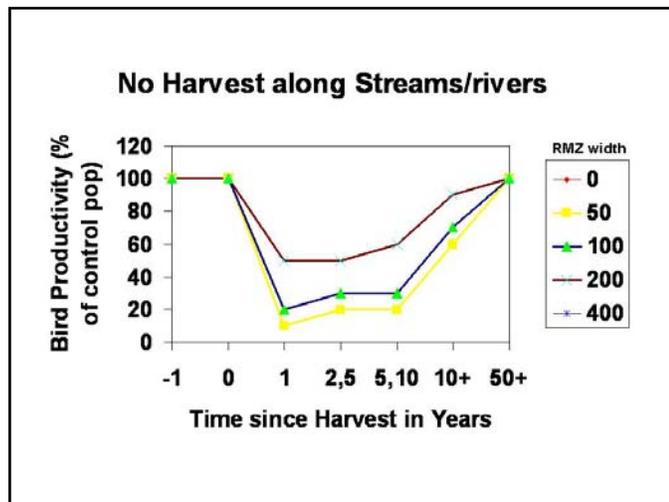
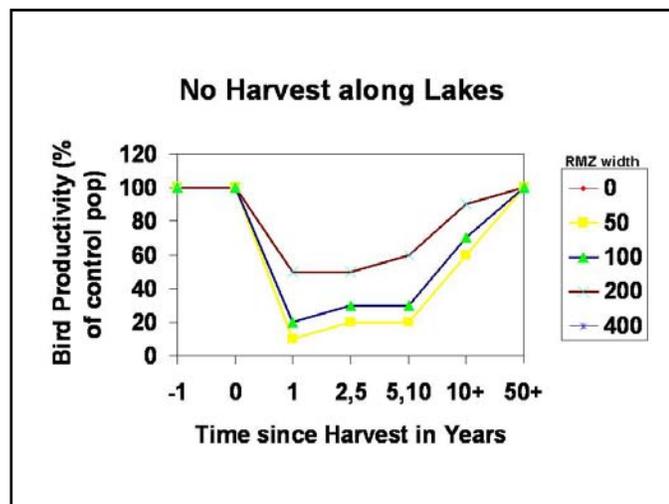


Figure B-16. Bird Productivity, Lakes.



Professional Judgment

There are no studies that address the issue of RMZ requirements for streams where harvest is completed on only one side of the stream (the other side is left un-cut). It could be argued that an RMZ would not be required on the cut side of the stream during harvest in these situations. This would not apply to lakes and wetlands. In an ongoing Legislative-Citizen Commission on Minnesota Resources study, this question should be partially addressed as bird surveys on the opposite (un-harvested side) of the streams are being completed.

Interior Forest Birds

Scientific Summary

Interior Forest Birds are defined as species that require forest patches that are a minimum size. The minimum size forest required varies across individual species and also by region of North America. The minimum size requirement is generally more critical in areas where a significant amount of a forested landscape has been permanently converted for human occupation or for agriculture. Most of the research presented here is relevant to northern forest landscapes in Minnesota. It has been shown that RMZs of at least 100 m (328 ft) provide some habitat for interior forest birds, however, it is possible that interior forest birds remaining in these RMZs are unable to reproduce successfully. Another important consideration is whether RMZs less than 30 m (98 ft) will provide future forest habitat conditions since a significant amount of blowdown occurs in narrow RMZs. Other issues (above) for forest bird productivity also apply to interior forest birds.

The immediate response of interior forest bird abundance to variable-width, variable BA retention and to different water bodies is shown in Figures B-17 to B-22. The figures are based on the literature and the projected response beyond three years is based primarily on professional judgment. Similar to bird productivity, the longevity of a negative response for this indicator would depend on the rate at which the adjacent forest matured to a point where edge habitat conditions are no longer prevalent. The time period for interior forest habitat to occur adjacent to harvest sites is not known for northern forests. Information from a recently completed study along northern Minnesota streams found that there was no difference in number of interior forest birds among harvest treatment types nine years after harvest. Unharvested buffers of 33 m (100 ft) on either side of first and second order streams had bird communities similar to control riparian plots within a decade after harvest. This study is the first completed in northern Minnesota that has documented impacts more than three years post-harvest (Hanowski et al. 2006). Bird communities in buffers that were harvested to a BA of less than 25 had more early successional bird species present compared to control plots nine years after harvest.

Graphics

Figure B-17. Forest Interior Birds in RMZs, no harvest along streams. High confidence for short-term response (up to four years post harvest) and medium response to longer term impacts.

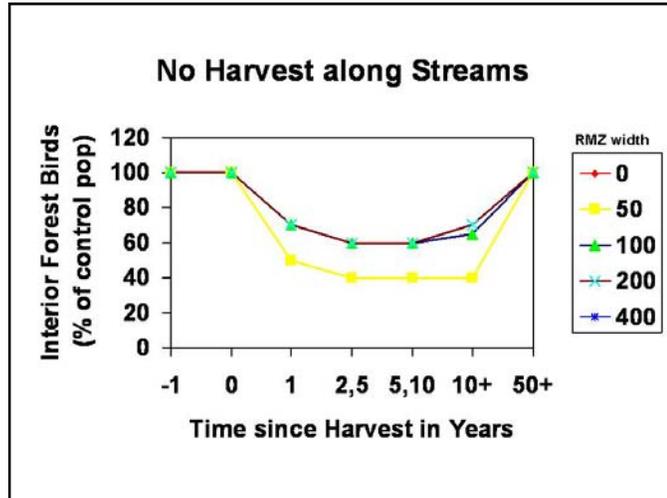


Figure B-18. Forest Interior Birds in RMZs 25-80 BA along streams. High confidence for short-term response (up to four years post harvest) and medium response to longer term impacts.

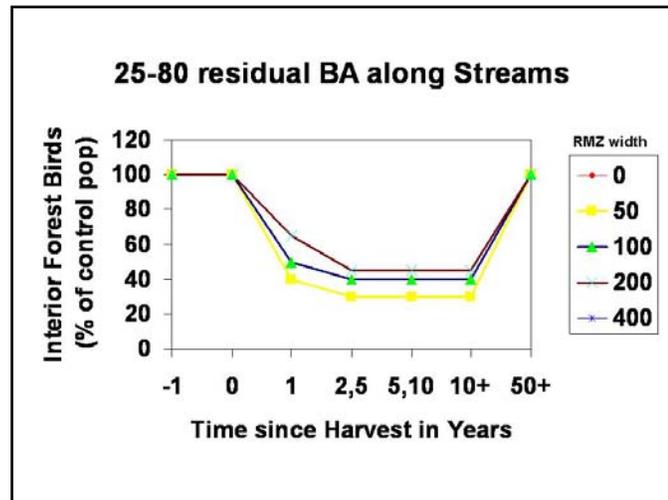
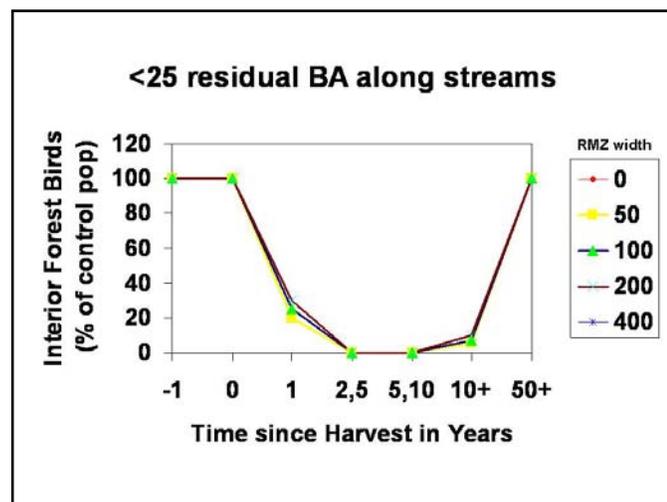


Figure B-19. Forest Interior Birds in RMZs, less than 25 BA along streams. High confidence for short-term response (up to four years post harvest) and medium response to longer term impacts.



Figures B-20. Forest Interior Birds in RMZs, no harvest along wetlands. High confidence for short-term response (up to four years post harvest) and medium response to longer term impacts.

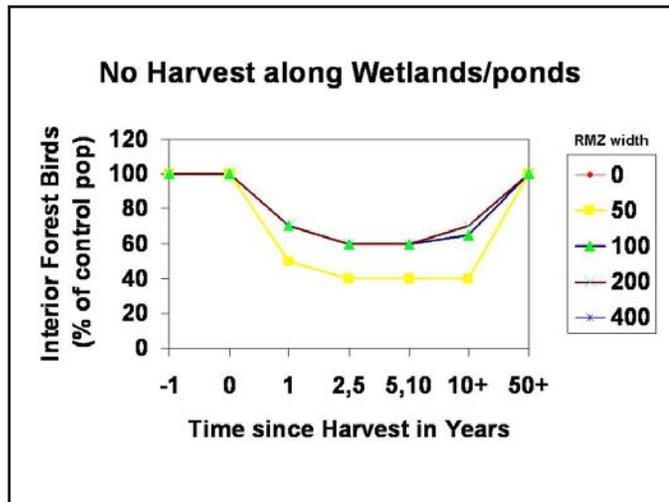


Figure B-21. Forest Interior Birds in RMZs 25-80 BA along wetlands. High confidence for short-term response (up to four years post harvest) and medium response to longer term impacts.

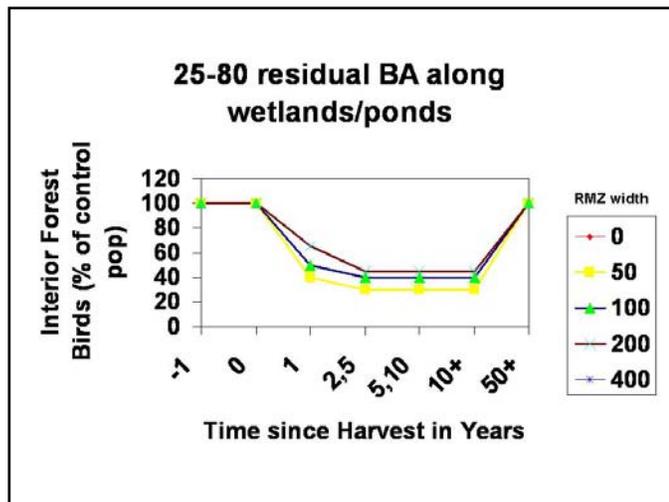
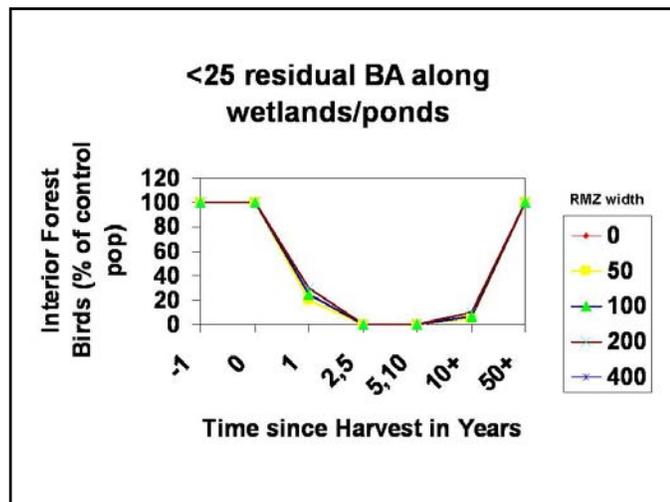


Figure B-22 - Forest Interior Birds in RMZs less than 25 BA along wetlands. High confidence for short-term response (up to four years post harvest) and medium response to longer term impacts.



Professional Judgment

Based on the science, an RMZ of at least 100 m (328 ft) wide should provide suitable habitat for interior forest breeding birds. However, from a management perspective, it is more efficient to maintain interior forest habitat across the landscape by minimizing edge habitat.

Dissolved Oxygen

Scientific Summary

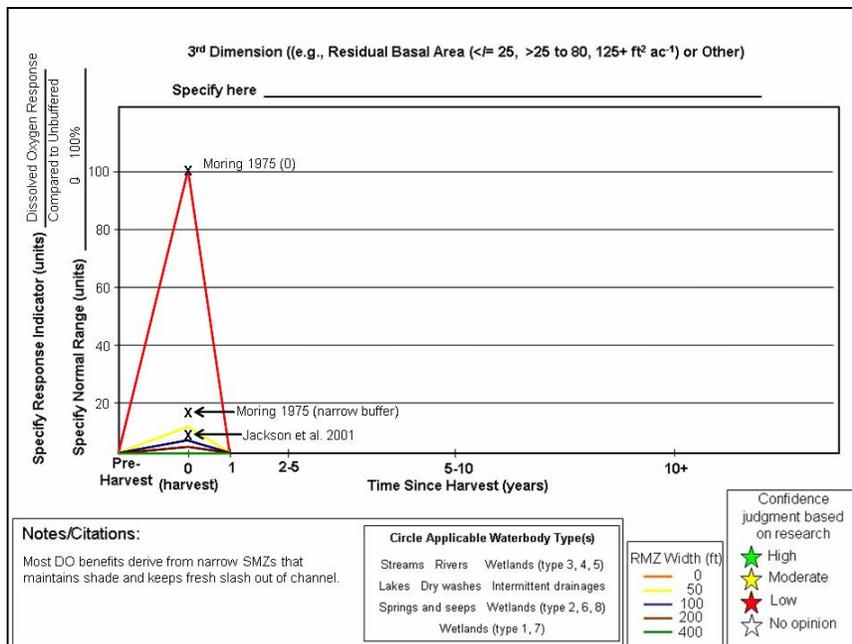
The concentration of dissolved oxygen (DO) in a stream is important for aerobic organisms, including fish. DO concentration is a traditional water quality parameter used in sanitary engineering to assess the condition of a waterbody and possible overloading from excess organic matter. A number of early forest watershed studies throughout the United States (Moring 1975; Krammes and Burns 1973) and Canada (Feller 1974; Plamondon et al. 1982) demonstrated the potential for forest management to cause an undesirable depression in DO concentrations in streams. The potential for depressed DO is greatest where water turbulence is low (Ice 1990) and water temperatures are high. Diurnal fluctuations can result from instream photosynthesis during periods of sunlight (increasing DO) and respiration at night (decreasing DO). DO deficits are often a warm weather phenomena as biological and chemical reactions utilize DO to oxidize organic matter and as part of respiration. However, DO concentration deficits are also possible in the winter when ice inhibits re-aeration. In lakes, stratification can cause a reduction in water exchange between the epilimnion and hypolimnion, resulting in depressed DO in the hypolimnion.

Forest operations can modify DO concentrations by (a) increasing water temperature, which decreases the solubility of DO and increases biochemical reaction rates; (b) introducing oxidizable organic matter (slash), which is decomposed by microorganisms; and (c) impounding the stream, which can potentially reduce turbulence and the re-aeration rate, and increase contact with organic material (Ice and Sugden 2003).

Buffers can help to avoid delivery of slash to a stream by keeping equipment and operations away from the stream and because the remaining stems and vegetation can act as a barrier. Jackson et al. (2001) studied headwater streams in Washington and found that "...buffered streams were protected from burial or coverage [by slash] because the trees left in the buffer act as a fence to keep out the organic debris." They found 94% of unbuffered headwater stream reaches were buried or covered by slash, while almost none of buffered stream reaches were covered or buried. Average buffers in that study ranged from 15 m (48 ft) to 21 m (68 ft) wide.

Graphics

Figure B-23. DO response for different RMZ widths compared to unbuffered conditions for all waterbodies. This figure integrates the benefits of RMZs on both slash delivery and shading. Low residual BAs will reduce shading (see stream temperature graphs) and reduce the effectiveness of the RMZ to maintain DO protection functions. Uncertainty about DO response results from the absence of research on this water quality parameter in Minnesota and with contemporary forest practices.



Professional Judgment

Waterbodies in Minnesota tend to be somewhat susceptible to depressed DO concentrations. Riparian management practices that keep fresh slash out of water, quickly remove slash (especially fine leaves, needles, and bark) that inadvertently gets into water, and maintain shade will avoid major changes in DO concentrations. Narrow buffers and directional felling are likely to achieve these goals, based on observations by Jackson et al. (2001). We do not know of any evidence of DO problems resulting from forest management activities in Minnesota. Other water quality parameters (sediment or total suspended solids) should be more sensitive to management activities and current guidelines provide a high level of protection against DO impacts.

Turbidity and Total Suspended Solids

Scientific Summary

Turbidity, suspended sediment, and total suspended solids (TSS) all relate to suspended particles in the water column. Turbidity results from an interference with the passage of light through water due to suspended matter (Sawyer and McCarty 1967). Several methods and standards have been used to measure turbidity. Common units are Jackson turbidity units (JTUs) and nephelometric turbidity units (NTUs). Suspended sediment refers specifically to suspended inorganic sediment. The matrix of suspended material in the water column often includes some organic material as well. This can be algae, leaves, needles, and other small organic material. Together, suspended inorganic and organic matter make up TSS. Data from other regions show that there tend to be general relationships between turbidity and TSS (Brown 1980) and between suspended sediment and TSS, but that these patterns can be very dynamic, changing with streams and even between storms or on different limbs of the hydrograph (Brown 1980; Riedel and Vose 2002).

Turbidity, suspended sediment concentrations, and TSS are influenced by management when it affects erosion rates, sediment (solids) transport, and deposition of material. One of the most commonly recognized functions of riparian zones is their role as filter strips for sediment. As entrained sediment passes through a riparian area the sediment can be trapped and settle, resulting in a reduction in the amount delivered to the stream. Delivery ratios are always less than 1.0, but the sediment and suspended solid parameters are also influenced by other erosion and sediment transport processes in the riparian zone. Unlike some other land covers, overland flow in forests generally occurs only in areas where flows concentrate, such as ephemeral channels and swales. Therefore, the role of riparian management zones (RMZs) as filter strips in forests may be less important than for other land covers except to attenuate sediment losses from roads or landings.

Riparian areas and stream channels can be important sites for sediment storage. Bank and channel erosion can also be significant components of overall erosion from a reach. Due to stream proximity, disturbance in the out-of-channel riparian area will have high sediment delivery ratios. In both cases the condition of the riparian area can affect the erosion processes. These multiple sediment control functions can be summarized as follows:

- Reducing delivery of sediment from outside the RMZ through trapping and settling (filter strip)
- Reducing channels and banks as sources of sediment due to channel disturbance or changes in stream power (including loss of root strength and removal of storage elements)
- Reducing erosion from riparian area disturbance with a high delivery ratio

Figure B-24 attempts to synthesize the full turbidity and TSS report discussion herein about the role of riparian zones in reducing sediment, TSS, and turbidity in Minnesota waterbodies. On a 10% slope, a 15 m (50 ft) RMZ will be highly effective. Trapping efficiency will be 90% or better and the RMZ will help avoid disturbance to the stream channel and bank. However, a 15 m (50 ft) RMZ may be subject to some delayed sediment generation with windthrow. While there is high confidence that the response patterns are confirmed by multiple sources, the long-term recovery and response to windthrow or other events is less predictable with current information. On a 70% slope a 15 m (50 ft) RMZ would not provide a high level of sediment trapping but would protect the channel. The response levels projected by our synthesized graphs appear to be consistent with the filter strip guidelines in the Minnesota Voluntary Guidelines (MFRC 2005).

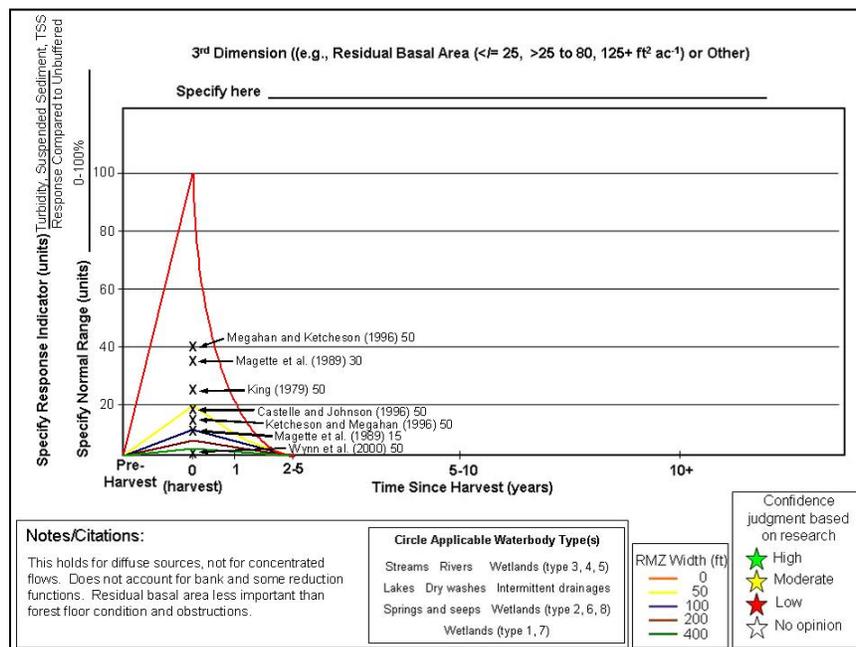
Windthrow events can result in either increases or decreases in sediment loads. It is likely that in small channels wood delivered to streams will at least temporarily reduce downstream delivery of sediment (assuming the wood forms pools that result in settling). For example, Jackson et al. (2001) reported a finding of channel substrate when slash was deposited in a headwater stream. Buffered headwater streams did not initially experience this change in substrate, as the buffers kept slash out of the streams. Others have observed how uprooting along banks and windthrow logs diverting currents can cause new scouring and bank erosion.

There is more ambiguity about responses for RMZs where management occurs. Keim and Schoenholtz (1999) reported that managed RMZs showed increased TSS compared to no-cut RMZs. Preliminary reports from Newman et al. (2004) showed no evidence of increased embeddedness for a study in Minnesota with different levels of riparian harvest.

One of the reasons hydrologic response was considered by the RSTC is that increases in discharge as a result of reduced evapotranspiration, accelerated snowmelt, or other factors can result in increases in both sediment loads and concentrations. As discussed in the hydrology synthesis, this is a basin-scale response more than a riparian response, although the riparian zone may have a proportionally larger influence on runoff than other parts of the watershed. The retention of root strength from riparian vegetation can increase the shear-strength of the streambank to resist erosion and channel widening.

Graphics

Figure B-24. Synthesis of the data for TSS. The major benefits of RMZs come from reduced disturbance to the channel and forest floor in the riparian area. Reduced BA in the RMZ would be expected to reduce the effectiveness of the RMZ to control turbidity and TSS to the extent that it reflects increase disturbance in the RMZ. Directional felling or keeping yarding equipment out the RMZ would moderate these potential impacts.



Professional Judgment

In summary and based on the scientific findings, it is the RSTC's professional judgment that RMZs reduce sediment by three mechanisms: maintaining the channel and bank integrity; reducing disturbance in riparian areas where delivery ratios are high; and filtering sediment from upslope activities. The first two may be most important in Minnesota, but there is more information on the last mechanism. Most of the benefits from retaining vegetation accrue from the riparian vegetation immediately adjacent to streams. The condition of a RMZ or filter strip (including roughness and slope) influences delivery of sediment to streams. Current filter strip guidelines are consistent with the literature regarding the width needed to reduce sediment. Windthrow can result in changes in stream sediments. In some cases wood delivered to streams temporarily traps material, while in other cases it activates bank cutting as flow is diverted. Uncertainty comes from the absence of studies on RMZ effectiveness in Minnesota and a research focus on sediment filtration and not the other important sediment control mechanisms of RMZs.

Embeddedness

Scientific Summary

Embeddedness is defined as “the degree to which fine sediments surround coarse substrate on the surface of a streambed” (Sylte and Fischenich 2002). As fine materials are introduced to a stream and settle out on the stream channel surface they tend to bury the coarse streambed particles. Sylte and Fischenich (2002) provided a review of the various definitions and procedures for characterizing embeddedness. Embeddedness provides an important measure of biological and physical stream processes. Physically, channel roughness is reduced with increasing embeddedness. Biologically, as fine sediments increase and bury coarse particles there is less and less habitat space for aquatic organisms, and there may be reduced water exchange between surface and subsurface waters. These may lead to negative biological responses.

Embeddedness provides a potential integrated measure of channel response to management activities. It was one of the physical measures assessed in the Little Pokegama Creek Study. Merten and Newman (1998) reported an increase in embeddedness for Little Pokegama Creek after harvesting (from 62.1 to 72.5%). Newman et al. (2004) reported that no significant change in embeddedness was detected (preliminary results) in a test of alternative riparian management in northern Minnesota. Meyer et al. (2005) found that embeddedness in Georgia could be predicted from maximum stream velocity and measures of riparian forest cover within 30 m (100 ft) of the stream.

Graphics

Graphics related to RMZs and embeddedness are not available but should follow the turbidity and TSS graphics.

Professional Judgment

This work clearly points out the need to assess embeddedness in the context of local channel conditions. However, Merten and Newman (1998) pointed out that much of the change in embeddedness found in their study may have resulted from sediment input from a road crossing and was independent of riparian management immediately adjacent to the channel.

Practices that reduce generation and delivery of fine sediment (e.g., less soil disturbance, better roads and erosion control measures) will benefit channel response as measured by embeddedness (see Turbidity and Total Suspended Solids section).

Macroinvertebrates (shredders, collectors and gatherers)

Scientific Summary

Macroinvertebrates are small organisms without a backbone that are visible to the naked eye and include insects, as well as crayfish and scuds. Most studies examining riparian harvest versus no-harvest in streams have found increased abundance and/or biomass in the clear-cut sections. The most consistent result is a shift in the community composition, with a reduction in shredders (organisms that process leaves and other organic matter) and predators, and an increase in collectors and gatherers (organisms that filter food out of the water column or scrape it off rocks and other hard surfaces; (Newbold et al. 1980; Murphy et al. 1981; Hawkins et al. 1982; Wallace and Gurtz 1986; Carlson et al. 1990; Brown et al. 1997; Fuchs et al. 2003; Grown and Davis 1991; Stout et al. 1993). These community effects were still visible after sixteen and seventeen years post-harvest at the Coweeta Hydrologic Laboratory in North Carolina (Figure B-25, Stone and Wallace 1998). The primary factor accounting for these changes is the increase in light availability. Few studies have examined variable buffer widths; however, these effects were apparent with 10 m and 30 m buffers in a SW British Columbia forest (Kiffney et al. 2003). Interestingly, the chironomid (midge) abundance did not differ between the clearcut and the no-cut control; it is speculated that the thick periphyton mat covering rocks precluded macroinvertebrate colonization. Changes in community composition were noted 3 years post-harvest in an Ontario forest when 42% BA was removed, but no significant changes were noted following a low-intensity harvest (20-25% BA removed) (Figure B-26, Kreutzweiser et al. 2005a).

Graphics

Figure B-25. Relative macroinvertebrate abundance in clearcut buffers for high gradient, small streams (Stone and Wallace, 1998). Low gradient streams show a dampened response.

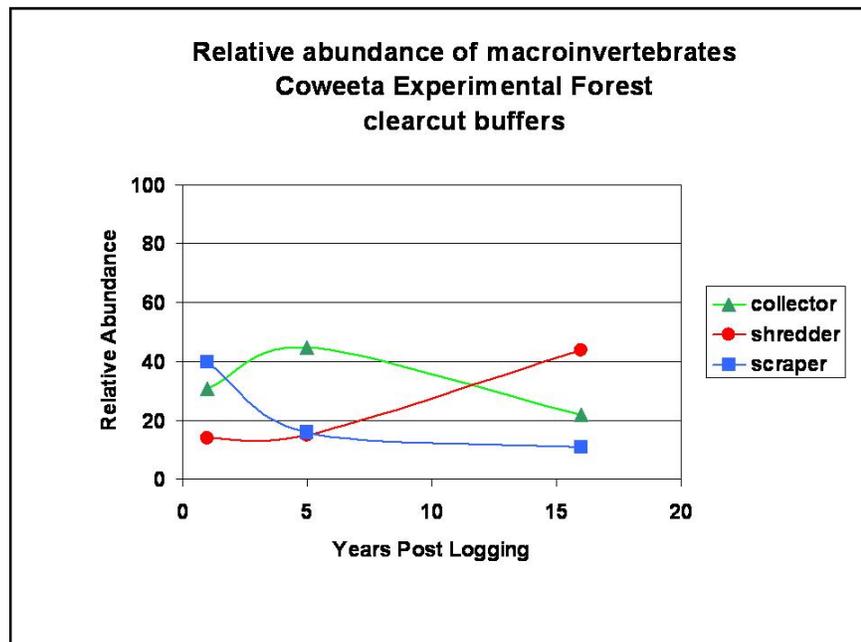


Figure B-26. Abundance of *Leuctra* (shredder) and *Dolophiloides* (gatherer/filterer) in moderate harvested forest (42% BA removed, assumed to be analogous to a 15 m (50 ft) buffer width). (Kreutzweiser et al. 2005a).

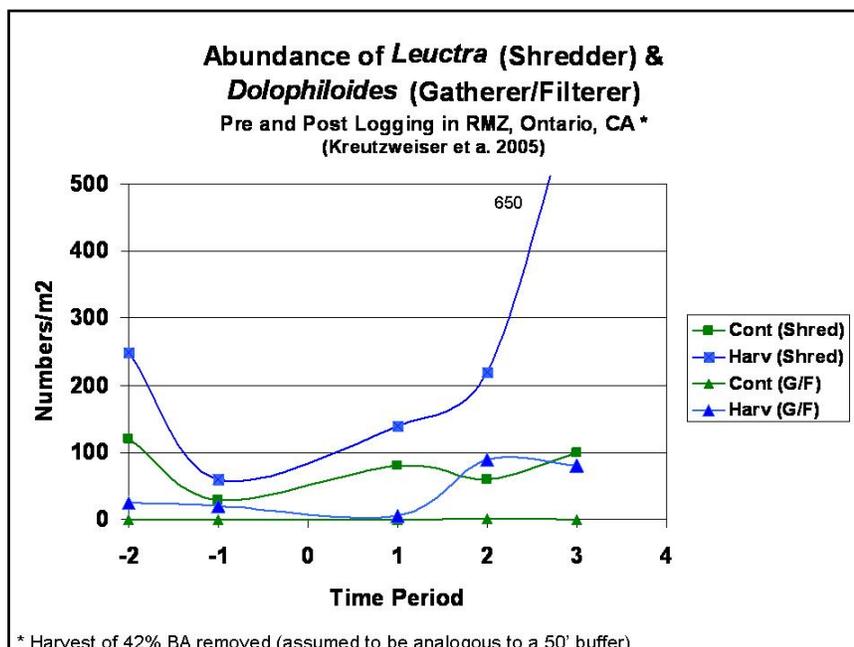
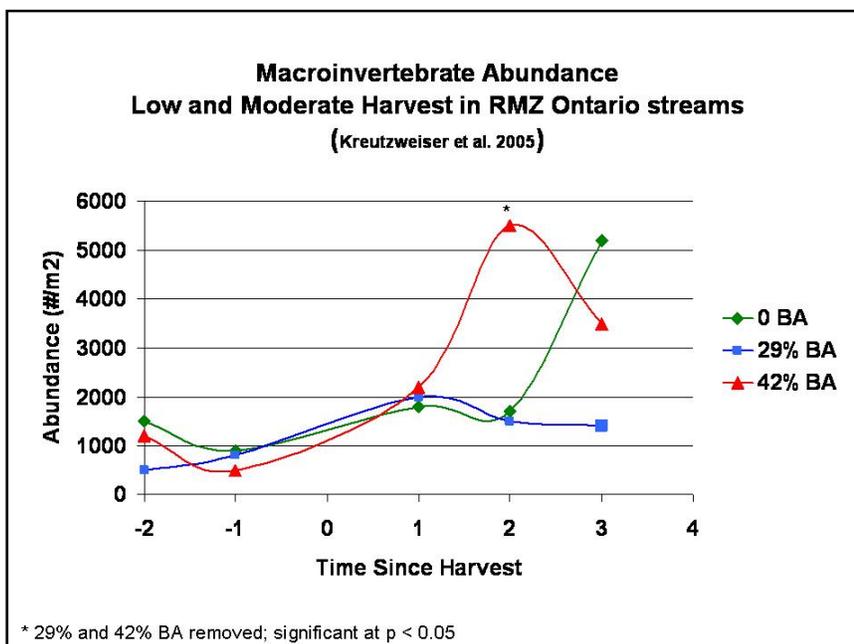


Figure B-27 - Abundance of *Leuctra* (shredder) and *Dolophiloides* (gatherer/filterer) in harvested forest (29% and 42% BA removed). 0 BA assumed to be analogous to a 122 m (400 ft) buffer, 29% BA to a 30 m (100 ft) buffer, and 42% BA to a 15 m (50 ft) buffer. (Kreutzweiser et al. 2005a).



Professional Judgment

The long-term implications of shifts in community composition are not known, particularly the cumulative impacts occurring in areas undergoing extensive harvest. It is very likely that complete recovery will occur as the canopy recovers as the light regime and organic matter inputs are restored. Depending on the size of the stream, this would occur within as few as five years to more than 20 years. Low intensity harvest (e.g., 24 BA removed) in the riparian zone and 30 m (100 ft) buffers appear likely to sustain eco-

system functions in streams.

Large wood

Scientific Summary

Wood is an important element of stream habitats, and all precautions should be made to enhance riparian tree cover to shade the stream, provide leafy and woody material to the channel for food, and large wood for overhead cover (habitat) for fish, as well as substrate for other stream biota (e.g., invertebrates and biofilm which serve as food for fish). Few experimental studies of wood input have been conducted.

Large wood enters predominantly low gradient streams through windthrow and erosion processes. Contributions of wood fragments (i.e., large branches) occur during ice storms and wind storms from blowdown. Erosion, however is one of the dominant delivery mechanisms of LWD to low-gradient streams. There is an interaction between channel erosion and RMZ (especially during storm events) (Wenger 1999). This interaction must be acknowledged when discussing the appropriate RMZ width for LWD delivery. In general wood enters the channel from the immediate areas surrounding the banks (e.g., within approximately 1-2 tree-heights of the channel). In low-gradient streams with extensive floodplains and/or braided channels, erosion and floods may transport wood into the active channel from distances further than 1-2 tree heights.

Many comparative studies have been performed post-harvest and there is evidence that recovery from riparian harvest takes anywhere from 20 years (France 1997) around boreal lakes, to 100 years within small streams (Table B-2). In Wyoming streams, clear-cuts depress wood volume to less than 10% undisturbed levels and impacts were observed for approximately 100 years post-harvest (Bragg et al. 2000).

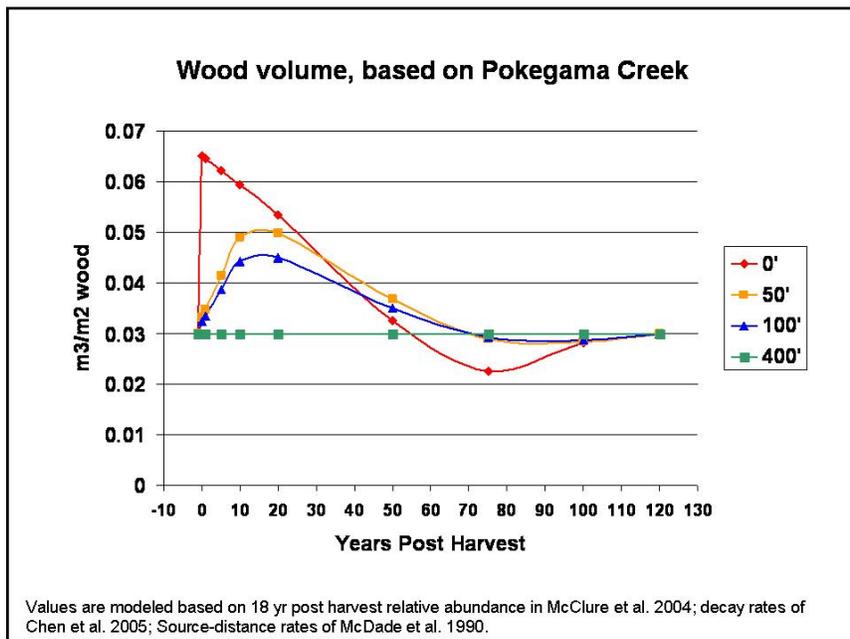
In an experimental study with a control, 15 m (50 ft) buffer, and clearcut with slash, McClure (2004) found that the LWD abundance was greater 18 years post-harvest in the clearcut and buffer sites, due to blowdown (Table B-2). They concluded that a 50 ft buffer may be inadequate to prevent windthrow inputs. This study and others have found that following harvest there are increases in LWD following harvest, with decay and transport causing depressed abundance for some time afterward. Recovery of in-stream LWD to pre-harvest levels is possible after tree cover has recovered to pre-harvest levels, where natural processes such as tree mortality, bank erosion, and storm inputs again replenish in-stream stocks.

Distance of increased mortality	Forest Type	Setting	Source
16 ft (5 m) (highest), declines to background rates by 82 ft (25 m); N and E aspects highest; measured 2.7 years after harvest	Eng. Spruce/ Subalpine fir	Mountainous	Huggard et al. 1999
66 ft (20 m) - 42% mortality 131 ft (40 m) - 25% mortality 197 ft (60 m) - 30% mortality; measured 9 years after harvest	Balsam fir	0-50% slopes, moderate to imperfect drain- age	Ruel et al. 2001
493 ft (150 m) -rates elevated over background rates up to this distance, over five years	Coast redwood, Douglas fir	Steep slopes	Reid and Hilton 1989
49 ft (15 m) - evaluated 18 years after harvest	Mixed mesophytic	Steep slopes	McClure et al. 2004

Table B-2. Studies showing evidence of post-harvest recovery rates.

Graphics

Figure B-28 Wood volume based on Pokegama Creek. $0.030 \text{ m}^3/\text{m}^2$; (or $300 \text{ m}^3/\text{ha}$). Stand type is mixed hardwood and conifer. (McDade et al. 1990) Estimate that 30 m (9 ft) buffer provides 85% of LWD, and 10 m (3 ft) buffer provides 50% LWD.

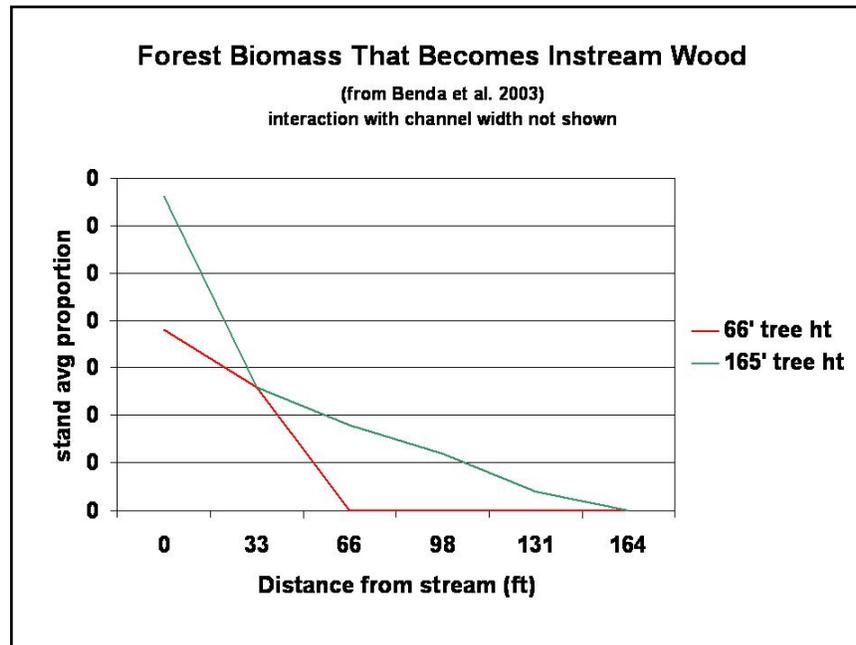


Notes for Figure B-28

1. McClure et al., (2004):

- In-stream wood increased after harvest by 17 to 50 times above non-harvested sites 18 years after harvest. Volume for no BMP is 66% greater than control; volume for a 15 m (50 ft) buffer is 78% greater than control after 18 years.
- No BMP, increase occurs due to slash in year 0. Year 0 calculated based on rate of decay relative to Year 18 value.
- Chen et al., 2004 estimates 50% decay in 74 years (0.0095/yr).
- Slash decays faster than resident logs, so decay rate is assumed to be 50% in 50 years instead of 74 years.
- For BMP assume: blowdown = 10% of amount from Year 18 (McClure et al. 2004) in year 1, 50% year 5; 95% year 10.
- Recovery to original levels at 120 years.

Figure B-29. Bank erosion and mortality are two factors that contribute wood to streams. As channel width increases, the forest stand biomass input to the stream increases. Erosion processes are related to input almost linearly as channel width increases, up to about 20 m (66 ft). Blowdown is not accounted for.



Professional Judgment

Wood dynamics are such that most wood is likely to enter the stream from 1 to 2 tree-lengths from the stream bank. However, in the floodplain, LWD can be transported to the channel, increasing the effective distance for LWD input. Windthrow plays a very large role in adding wood to the stream channel and to wetlands, following harvest. The narrower the riparian buffer strip, the more likely the trees are to exhibit windthrow. Therefore, both windthrow dynamics and transport dynamics must be considered when setting effective buffer widths for the RMZ. A minimum buffer of 15 m (50 ft) should be considered for streams and wetlands to account for both shade and organic matter input to the stream.

Forest Amphibians

Scientific Summary

Many studies examining harvest effects on amphibians have been conducted as comparative studies of forested versus non-forested, or old growth versus managed forest ecosystems. Reduced forest cover resulted in overall reductions in herpetile species richness in SE Ontario (Findlay and Houlahan 1997). Other studies have observed more amphibians in old growth than in managed forest stands (Dupuis 1997; Cory and Bury 1991; Petranka et al. 1991; Welsh 1990). Wood frogs were present when there was at least 58% forest cover, but there was an interaction with the amount of forest

within 1 km in an Ohio landscape; spotted salamanders occurred when there was at least 36% forest cover in the 200 m (660 ft) forested buffer surrounding an agricultural field (Porej et al. 2004). In areas where forests are fragmented or are not the dominant land cover type, wood frog abundance appears to be significantly impacted by the amount of forest cover and the size of the buffer (Porej et al. 2004; Johnson et al. in review).

In a comparative study of 41 clearcut and mature forest stands in the Southern Appalachian mountain streams and seeps, amphibian abundance was found to be reduced overall in clearcut forests, and it appears that recovery times have been considerable (Petranka et al. 1991). Experimental logging with different buffer widths in a forested landscape in Alberta detected no significant change in abundance of the wood frog, due to very large variability (Hannon et al. 2002).

A 23-30 m (75-98 ft) buffer has been recommended around streams (Dupuis 1997). A review of literature by Semlitsch and Bodie (2003) concluded that to fulfill all life history requirements, a 159-290 m (522-951 ft) buffer is required around a wetland.

Graphics

Figure B-30. Amphibian responses in a forested landscape.

Notes: Assumes that 200 m (656 ft) core area is required to complete life history functions (Semlitsch and Bodie 2003); recovery takes 50-70 years (Petranka et al. 1991); effects of disturbance are minimal in a forested landscape (Hannon et al. 2002, Palik et al. 2005); maximal dispersal distance is around 1 km (3,280 ft) for wood frogs (Berven 1990), but home ranges are much smaller.

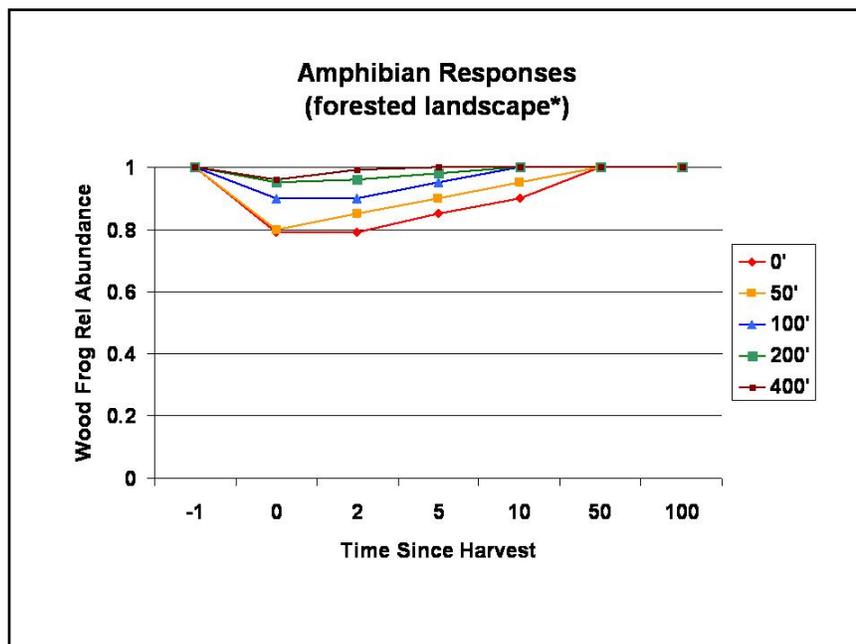
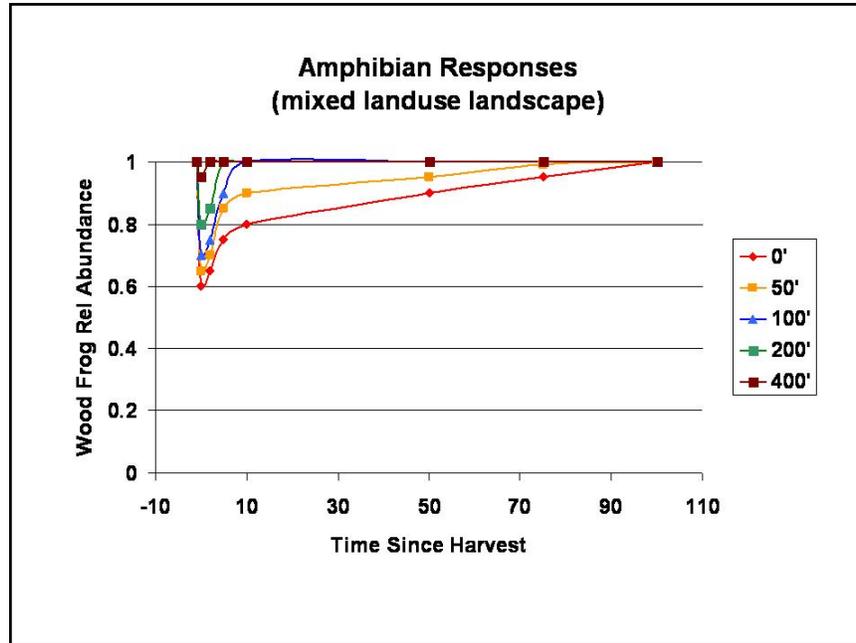


Figure B-31. Amphibian responses in a mixed landuse landscape.

Notes: Assumes that core area needed to complete life history functions is 200 m (656 ft) (Semlitsch and Bodie 2003); assume that requires 50-70 years to recovery (Petranka et al. 1991); disturbance levels estimated based on Porej et al. 2004.



Professional Judgment

Some amphibian species are sensitive to the amount of forest cover, while others appear to have quite general habitat requirements. For example, tree frogs and spring peepers increased in abundance with forest fragmentation (C. Johnson et al. *in review*); however, it must be noted that even the fragmented areas contained considerable forest cover. Wood frogs appear to be susceptible to lack of forest cover in areas where the matrix is not completely forested, as there was no significant effect of stand age or harvest noted in areas that are predominantly forested. Therefore, in landscapes with mixed land cover, clear cutting may have a significant impact on some amphibians, and recovery could take a considerable amount of time. The maximum dispersal distances for wood frog juveniles range from 99.7 m (327 ft) in a Minnesota bog (Bellis 1965), 1.4 km (4,593 ft) (Berven and Gradzien 1990) in Appalachian Mountain ponds to 1,119 m (0.7 mile) in the Prairie Pothole Region (Newman and Squire 2001). The mean for adults is far less. To protect dispersing wood frogs, a larger buffer is required for juveniles than for adults. It is recommended that buffer distances for wetlands in mixed landscapes within the geographic range of wood frogs, be larger than those in landscapes dominated by forests (at least 91 m [300 ft]). In forested landscapes, buffers should be 30 m (100 ft) around both streams and wetlands.

Water Temperature (streams, lakes, wetlands)

Scientific Summary

Stream Temperature

Stream temperature has been characterized following numerous types of riparian area management, including various harvesting scenarios (Kiffney et al. 2003, Macdonald et al. 2003, Mitchell 1999). From the literature it is apparent that stream temperatures increase following riparian area disturbance such as from harvesting. The amount of harvesting performed and the width of the riparian area are the two main determinants that affect the rise in stream temperature. If clearcut harvests occur up to the edge of the stream, the literature suggests, given our latitude, that we could expect up to a 4°C increase in stream temperature. If less than 100% of the forest canopy was removed, we can expect less of an increase that is directly related to level of removal (i.e. if 75% of the canopy was removed we would expect about a 3°C increase in stream temperature). The width of the harvest is also important because of the angle of the sun at our latitudes. The literature suggests that harvest in riparian areas with widths up to about 30 m (100 ft.) will influence stream temperatures. After 30 m (100 ft) harvest intensity will not dramatically affect stream temperature. Figures B-32 through B-34 illustrates this discussion.

Lake Temperature

Two studies were found that assessed lake temperature in relation to riparian management. France (1997) found that harvested or burned riparian zones around Ontario Lakes produced a thermocline that was 2 m (6.5 ft) deeper than in lakes surrounded by forest. In addition, there was a large replicated lake study with variable-width riparian buffers, known as the TROLS Lake Program (Terrestrial and Riparian Organisms, Lakes and Streams) in Alberta (Prepas et al. 2001). This study also found thermal stratification to increase in post treatment years. No other references were found that related forest harvesting to lake temperature.

Open Water Wetlands, Seasonal Ponds and Water Temperature

One study was found that assessed water temperature in open water wetlands following timber harvesting (Batzer et al. 2000). This study evaluated water temperature in open water wetlands where pine plantation harvests were up to the wetlands edge. The study assessed a chronosequence of similar sites for a number of parameters including water temperature. Not surprisingly, water temperatures decreased with time since harvest. A linear relationship with time since harvest explained 62% of the variability in water temperature. Over 25 years, the wetland water temperatures decreased by about 1.3°C. Other work has monitored water temperature in a seasonal pond study but that data has yet to be thoroughly analyzed or reported.

Graphics

Figure B-32. Schematic graphic of stream temperature fluctuations for BA less than or equal to 25 ft²/ac based on scientific literature.

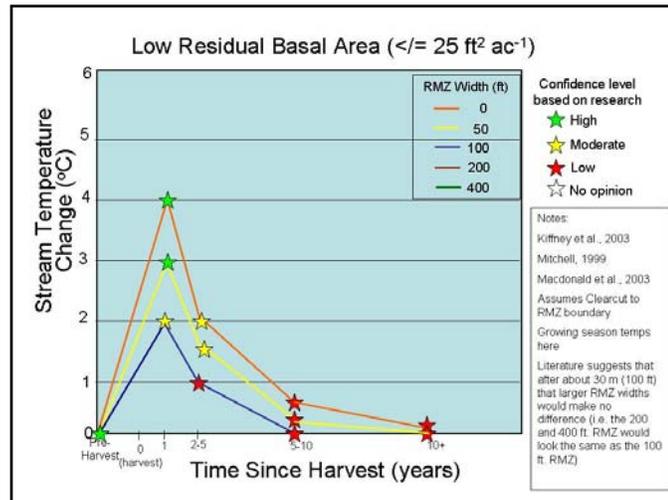


Figure B-33. Schematic graphic of stream temperature fluctuations for BA between 25 and 80 ft²/ac based on scientific literature.

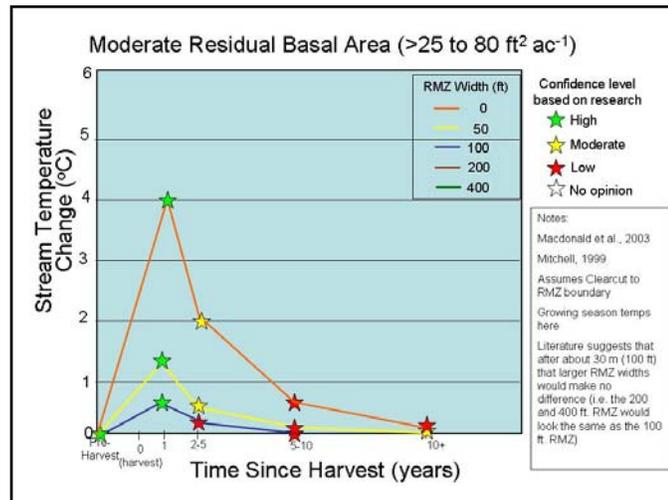
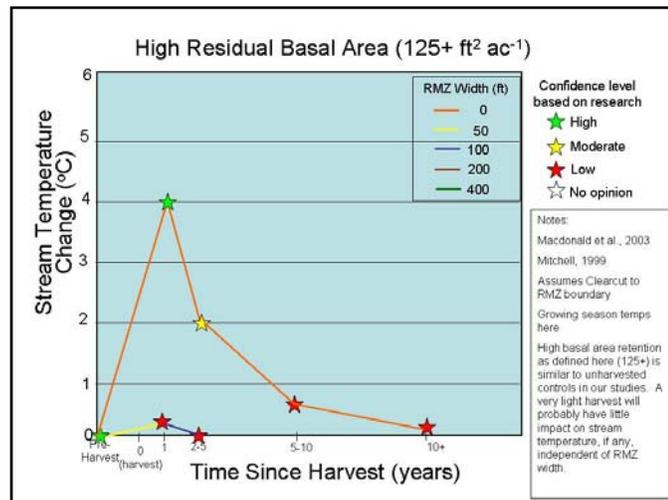


Figure B-34. Schematic graphic of stream temperature fluctuations for BA greater than 125 ft²/ac based on scientific literature.



Professional Judgment

Stream Temperature

Based on the literature reviewed and Minnesota's climate, an estimated maximum increase in temperature of about 4°C is expected. Other estimates are scaled from this baseline.

Lakes Temperature

The implications of lake temperature are for cold-loving fish that would effectively have less habitat by having a deeper thermocline in the growing season.

Open Water Wetlands, Seasonal Ponds and Water Temperature

Although there are few studies that have assessed water temperature in open water wetlands and seasonal ponds following harvest, one would expect changes in water temperature following riparian harvesting around these systems. Like streams, the changes would be related to both the amount of canopy removed and the width of the riparian area. In the case of open water wetlands, the change in temperature would also be related to the size of the wetland. Small wetlands that are surrounded by a forest canopy would be more responsive than large ponds that already have direct solar radiation affecting the wetland water temperature. Forested seasonal ponds that are harvested would likely see the most dramatic increase in temperature likely approaching the 4°C that the literature suggests for streams.

Air Temperature

Scientific Summary

Only two papers (Meleason and Quinn 2004, Dong et al. 1998) were found that assessed air temperature in relationship to harvesting in riparian zones. Both papers suggest higher daytime temperatures (3-5°C), but also lower night time temperatures (-0.5 to -1.0°C), for clearcut RMZs. Therefore, a mean of approximately 2°C was used for the low residual BA graph. Higher BA retentions should reduce the air temperature differences as shown in Figures B-35 and B-37. Studies comparing both air temperatures in the RMZ with those in the stream were not identified.

Graphics

Figure B-35. Schematic graphic of air temperature fluctuations for BA less than or equal to 25 ft²/ac based on scientific literature.

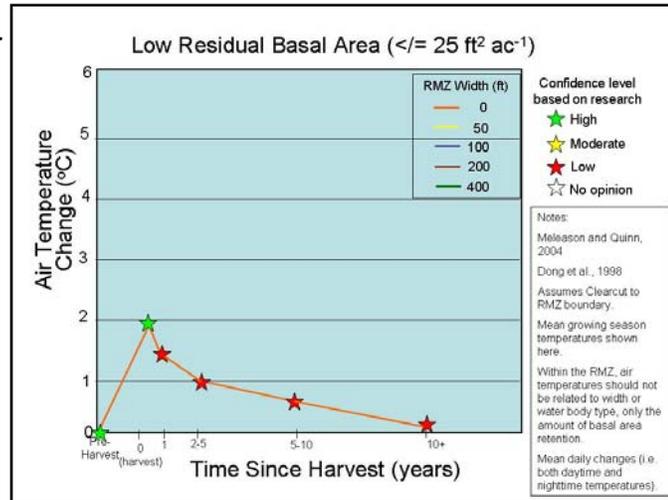


Figure B-36. Schematic graphic of air temperature fluctuations for BA between 25 and 80 ft²/ac based on scientific literature.

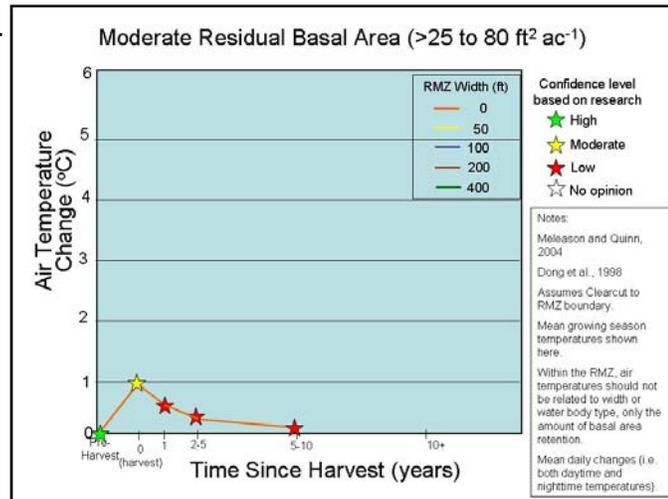
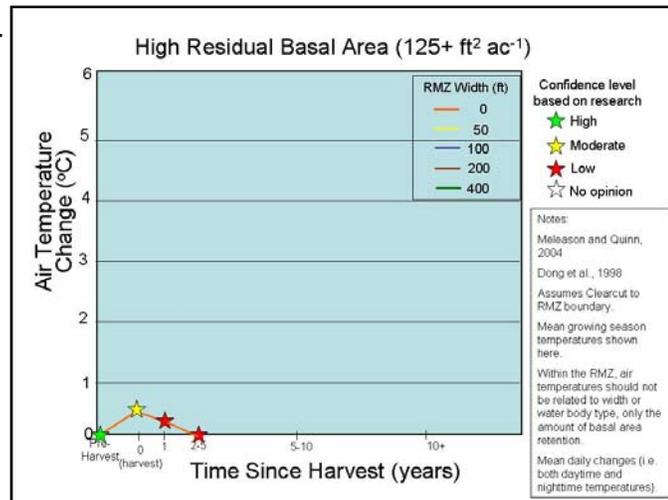


Figure B-37. Schematic graphic of air temperature fluctuations for BA greater than 125 ft²/ac based on scientific literature.



Professional Judgment

Air temperature within the riparian area would be expected to increase following riparian area harvesting or disturbance depending on the level of canopy removal. If there is complete canopy removal, one would expect a maximum of a 5°C increase in air temperature during the day and a 1°C decrease in air temperature at night.

Dissolved Organic Carbon (DOC)

Scientific Summary

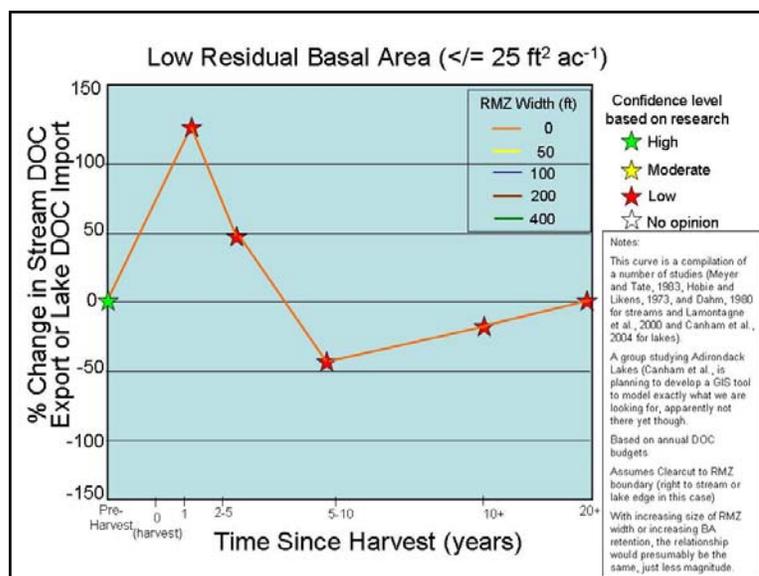
There is very little available literature to assess DOC concentrations or fluxes related to forest harvesting in the riparian area for streams and lakes. There are a few studies assessing watershed level harvesting on stream DOC but they vary in the response. Sometimes DOC increases, sometimes decreases, sometimes stays about the same. Most studies that see increases relate DOC increases simply to flow increases. One paper (Tate and Meyer 1983) gives a conceptual model of how DOC transport might be affected by forest disturbance. The one line graph for streams is based on their conceptual model and the references listed (Figure B-38). The amount of DOC is a balance between production and consumption. Many of the same processes that increase production also increase consumption. Temperature, pH, available C and redox status all can dramatically affect the production/consumption of DOC. Harvesting generally increases soil temperatures (more decomposition, higher DOC) but also reduces redox status (higher water tables, lower DOC). With increases in runoff and organic matter inputs following harvesting, one might expect DOC export to be high. As vegetation recovers, runoff declines, easily decomposable OM is consumed; the DOC export would be expected to decline, even to levels below that prior to harvest. The recovery of DOC will slowly rise to pre-disturbance levels as the vegetation community recovers, probably 15-20 years in Minnesota.

A number of studies have demonstrated that the amount of wetlands, especially peatlands, controls watershed level transport of DOC in streams (Gergel et al. 1999, Kolka et al. 1999). If there are wetlands present in the watershed, that factor overwhelms any vegetation management factor controlling DOC transport.

Only a single reference was found that reported DOC concentrations in open water wetlands or seasonal ponds (those not associated with peatlands). Palik et al. (2001) reported DOC concentrations for seasonal ponds across a gradient of sites in northern Minnesota but no relationships were developed between DOC and landscape or vegetation variables.

Graphics

Figure B-38. Schematic graphic of dissolved oxygen for BA less than or equal to 25 ft²/ac based on a conceptual model from the scientific literature.



Professional Judgment

With increases in runoff and organic matter inputs following harvesting, one might expect DOC export to be high. As vegetation recovers, runoff declines, easily decomposable OM is consumed and DOC export would be expected to decline, even to levels below that prior to harvest. The recovery of DOC will slowly rise to pre-disturbance levels and the vegetation community recovers, probably 15-20 years in Minnesota.

Light

Scientific Summary

Light penetration is a function of the amount of cover taken from the RMZ's during harvest. As such, the graphs should be fairly synonymous with canopy cover; however, ground vegetation growth will also inhibit light penetration to the soil surface. As a result, one would expect light at the ground surface to recover more quickly than canopy cover. It's possible that light extinction at the soil surface maybe even greater at some period after harvest because of the increased growth from shrub and tree regeneration, forbs, grasses, etc. at the soil surface. The curves (Figures B-39 through B-41) are a compilation from a few studies (Kiffney et al. 2004, DeNicola et al. 1992, Davies-Colley and Quinn 1998) and professional judgment.

Graphics

Figure B-39. Schematic graphic of light for BA less than or equal to 25 ft²/ac based on scientific literature.

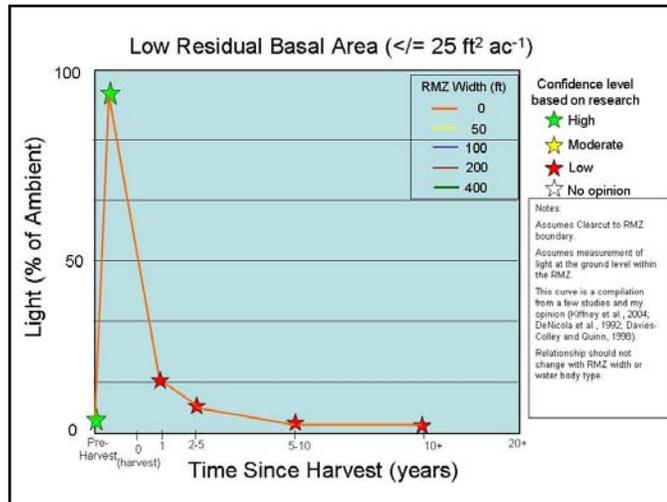


Figure B-40. Schematic graphic of light for BA between 25 and 80 ft²/ac based on scientific literature.

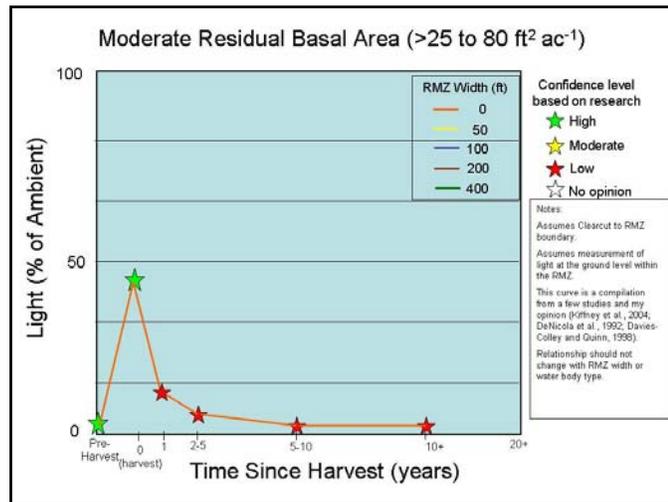
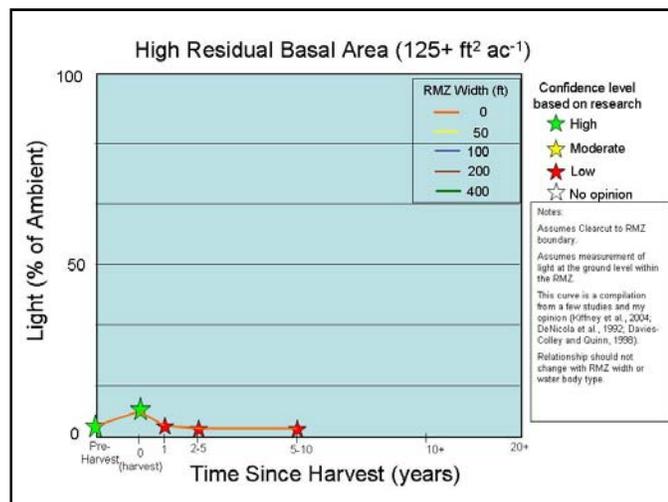


Figure B-41. Schematic graphic of light for BA greater than 125 ft²/ac based on scientific literature.



Professional Judgment

Light will undoubtedly be affected by riparian area disturbance or harvesting depending on the level of canopy removal. In a closed forest environment very little light reaches the forest floor. When the canopy is fully or partially removed, the amount of light reaching the forest floor is directly related to the level of removal. However, the amount of re-growth following canopy removal will dramatically affect the recovery of pre-disturbance light conditions. In Minnesota, it would be expected that the light reaching the forest floor would recover in fairly short time frames (5-10 years).

Soil Moisture

Scientific Summary

Literature that measured soil moisture in riparian zones during any kind of riparian disturbance was not found. There are a few articles on soil moisture changes following upland harvest (e.g., Burgess and Wetzel, 2000; Ballard, 1999) but it is not clear how to apply these given that riparian areas also receive water from these upland sources following harvest.

Graphics

Figure B-42. Schematic graphic of soil moisture for BA less than or equal to 25 ft²/ac based on professional judgment.

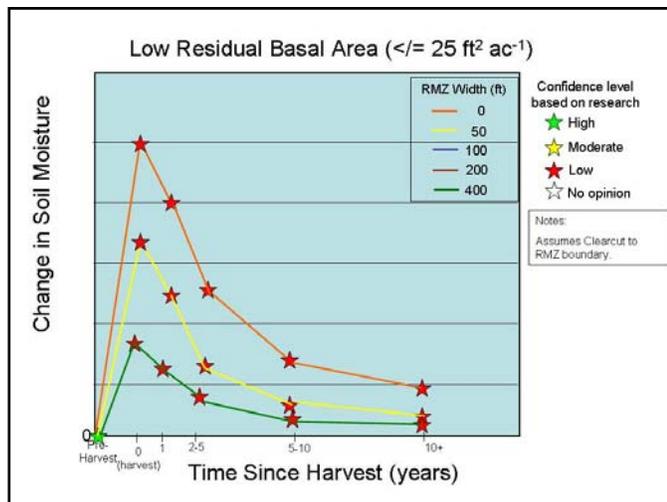


Figure B-43. Schematic graphic of soil moisture for BA between 25 and 80 ft²/ac based on professional judgment.

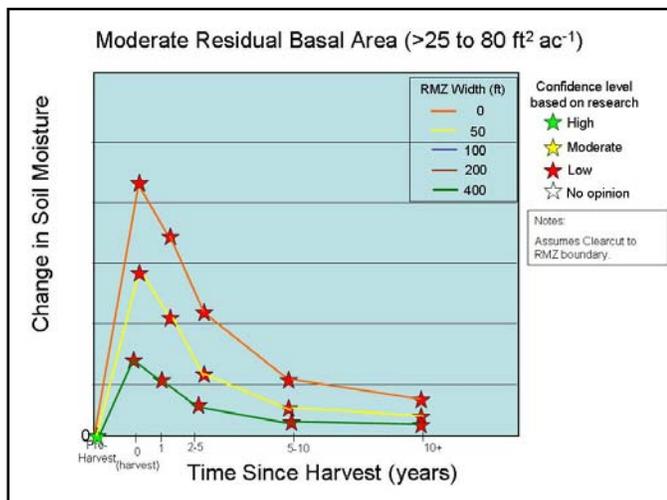
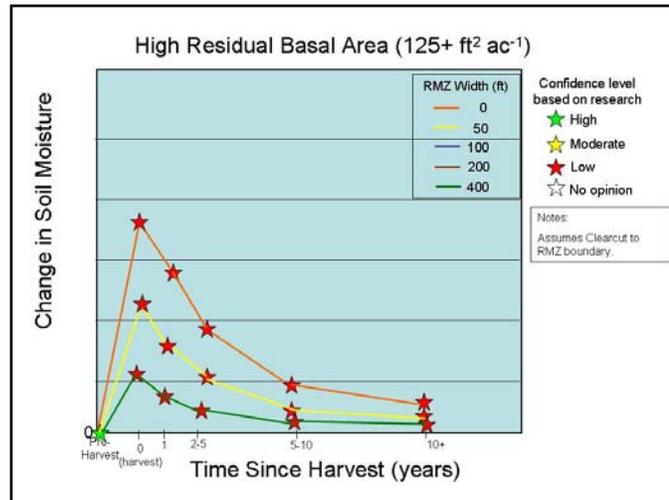


Figure B-44. Schematic graphic of soil moisture for BA greater than 125 ft²/ac based on professional judgment.



Professional Judgment

Because of the well established record of study indicating that streamflow increases following harvest, it is safe to assume that soil moisture also increases (both in the upland and riparian areas). However, the magnitude of those changes is related to the harvest intensity (both in the upland and riparian area), and the soil water connectivity between the upland and the riparian area. For example, one might expect increased soil moisture in an unharvested riparian area if the surrounding upland is harvested. Greater increases in soil moisture would also be expected if the riparian area was also partially harvested. Finally, maximum increases in soil moisture would occur if both the upland and riparian area were completely harvested. The graphs reflect expectations based on this concept only, and therefore there is uncertainty in magnitude so no units were placed on the y-axis.

Snags

Scientific Summary

Heavy cutting in the RMZ removes potential future snag trees. Moreover, blowdown of residual snags and potential snag trees will be high after harvest, particularly at lower residual BA and with narrower RMZ width. Partial cutting in the RMZ may help maintain snag densities above levels found at low BA (e.g., less than 25) (Graves et al. 2000), but densities still will be depressed, relative to reference conditions, due to blowdown (Harper and Macdonald 2002). Even at high BA, blowdown of snags and potential snag trees will be high at the edge (Harper and Macdonald 2002). Consequently, a narrow RMZ, with high BA, may function like an RMZ with low BA. (i.e., one having few potential snag trees available). At least 40-60 years would be needed to grow new trees to 40-centimeter (16-inch) diameter at breast height 1.3 m (4.2 ft) for potential snags. This is supported by research indicating that 40-60 years is required to recover to initial normal snag densities after harvest of aspen (Lee 1998, Lee et al. 1997).

Graphics

Figure B-45. Schematic graphic of snags for BA less than or equal to 25 ft²/ac based on scientific literature.

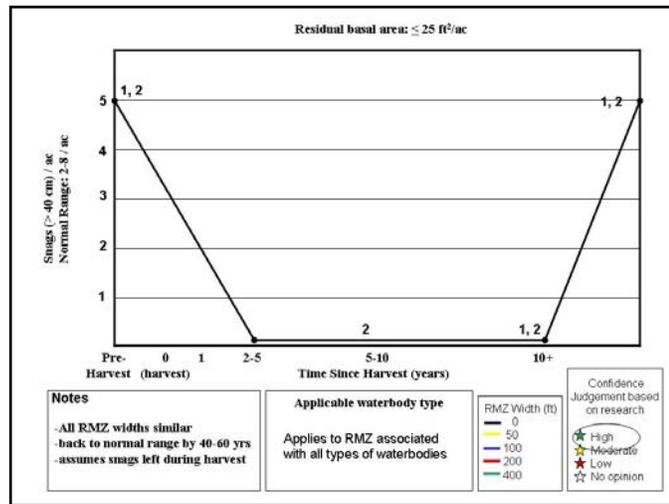


Figure B-46. Schematic graphic of snags for BA between 25 and 80 ft²/ac based on scientific literature.

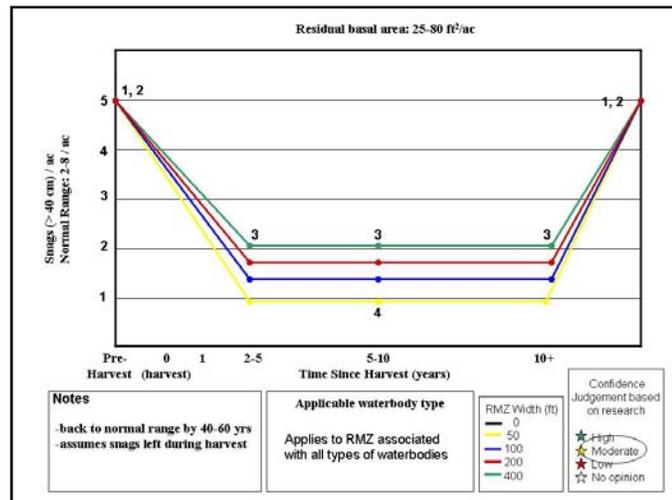
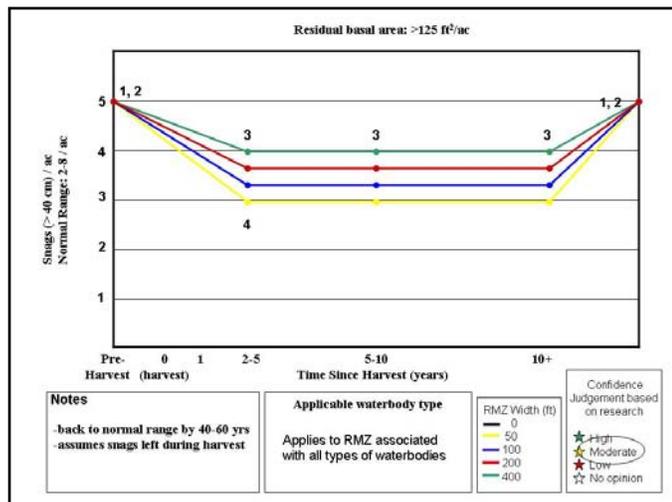


Figure B-47. Schematic graphic of snags for BA between greater than 125 ft²/ac based on scientific literature.



Notes: Figures B-45 through B-47 refer to the following literature.

1. Lee, P. 1998. Dynamics of snags in aspen-dominated midboreal forests. *Forest Ecology and Management* 105: 263-272.
2. Lee, P. C., Crites, S., Nietfeld, M., Van Nguyen, H., and Stelfox, J. B. 1997. Characteristics and origins of deadwood material in aspen-dominated boreal forests. *Ecological Applications* 7: 691-701.
3. Graves, A. T., Fajvam. M. A., and Miller, G. W. 2000. The effects of thinning intensity on snag and cavity tree abundance in an Appalachian hardwood stand. *Canadian Journal of Forest Research* 30: 1214-1220.
4. Harper, K. A., and Macdonald, S. E. 2002. Structure and composition of edges next to regenerating clear-cuts in mixed-wood boreal forest. *Journal of Vegetation Science* 13: 535-546.

Professional Judgment

RMZs would need to be at least 122 m (400 ft) wide and maintain at least 80 ft²/ac BA to maintain snag numbers within the normal range of uncut forest. Potential snag trees should be identified prior to harvest and consist of the most wind-firm species and individuals present. Wide RMZs, with high residual BA, protect snag resources to a greater degree than narrow RMZs or RMZs with low BA.

Generalist and Disturbance Associated Plants

Scientific Summary

Generally for any forest, including riparian areas, there is an increase in generalist and disturbance associated plants within the first 2-3 years after heavy cutting (Nelson and Halpern 2005, Frederickson et al. 1999). This increase may be relatively short-lived (10-20 years) until the harvested stand closes (Kern et al. 2006). Consequently, generalist and disturbance associated plant species will likely increase in abundance in harvested and partially harvested RMZs. Aspen species are classic disturbance associated plants that reflect these patterns. Little or no residual overstory is best for maximizing productivity of a new cohort of aspen. New sprouting occurs in partially cut (or even uncut) RMZs due to edge effects, suggesting that narrow RMZs (less than 30 m [100 ft]) will function like heavily cut RMZs (Palik et al. 2003).

Graphics

Figure B-48. Schematic graphic of generalist plants for BA less than or equal to 25 ft²/ac based on scientific literature.

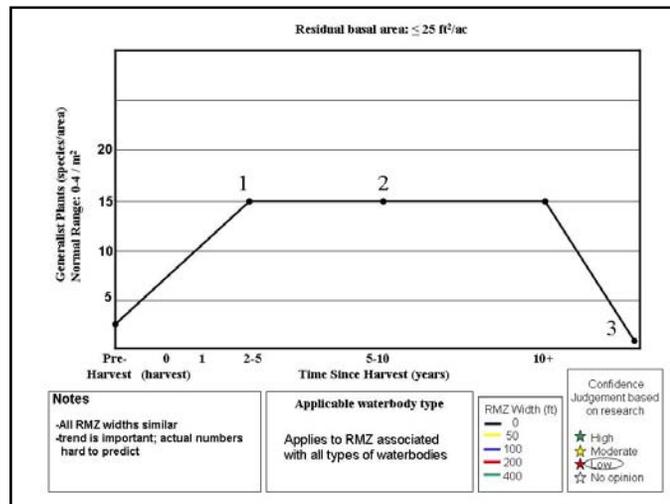


Figure B-49. Schematic graphic of generalist plants for BA between 25 and 80 ft²/ac based on scientific literature.

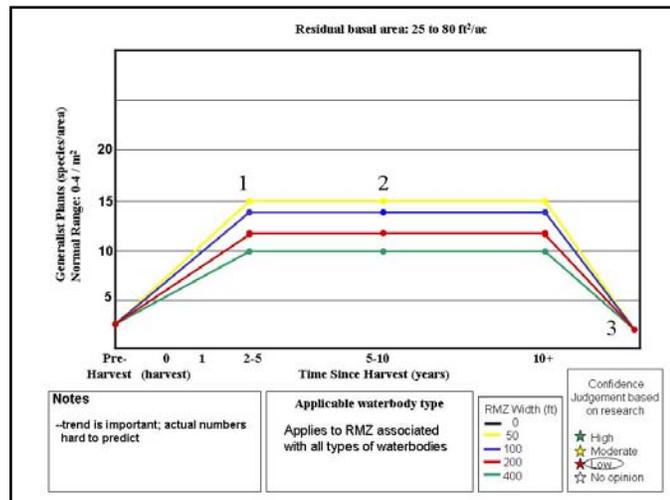
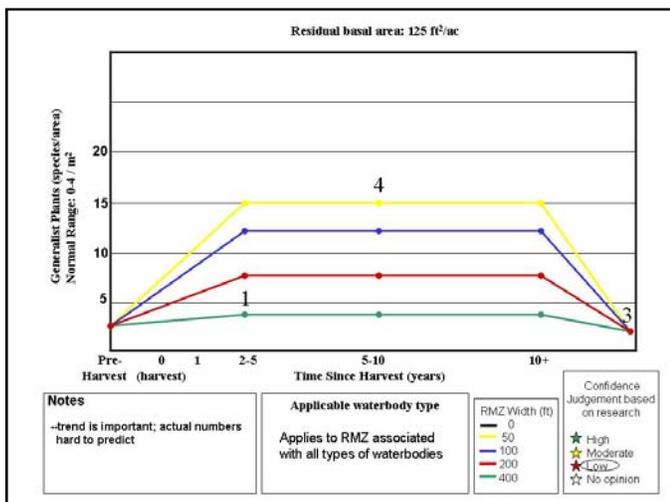


Figure B-50. Schematic graphic of generalist plants for BA greater than 125 ft²/ac based on scientific literature.



Notes: Figures B-48 through B-50 refer to the following literature:

1. Nelson C. R., and Halpern, C. B. 2005. Edge-related responses of understory plants to aggregated retention harvest in the Pacific Northwest. *Ecological Applications* 15: 196-209.
2. Fredericksen, T. S., Ross, B. D., Hoffman, W., Morrison, M. L., Beyea, J., Johnson, B. N., Lester, M. B., Ross, E. 1999. Short-term understory plant community responses to timber-harvesting intensity on non-industrial private forestlands in Pennsylvania. *Forest Ecology and Management* 116: 129-139.
3. Kern, C. C., Palik, B. J., and Strong, T. F. 2006. Ground-layer plant community responses to contrasting silvicultural treatments in Wisconsin northern hardwood forests. *Forest Ecology and Management* (In press).
4. Fraver, S. 1993. Vegetation responses along edge-to-interior gradients in the mixed hardwood forests of the Roanoke River Basin, North Carolina. *Conservation Biology* 8: 822-832.

Figure B-51. Schematic graphic of aspen as a generalist plant for BA less than or equal to 25 ft²/ac based on scientific literature.

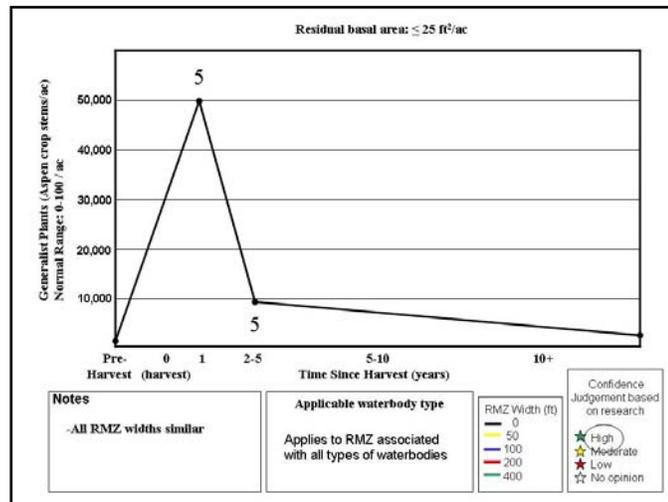


Figure B-52. Schematic graphic of aspen as a generalist plant for BA between 25 and 80 ft²/ac based on scientific literature.

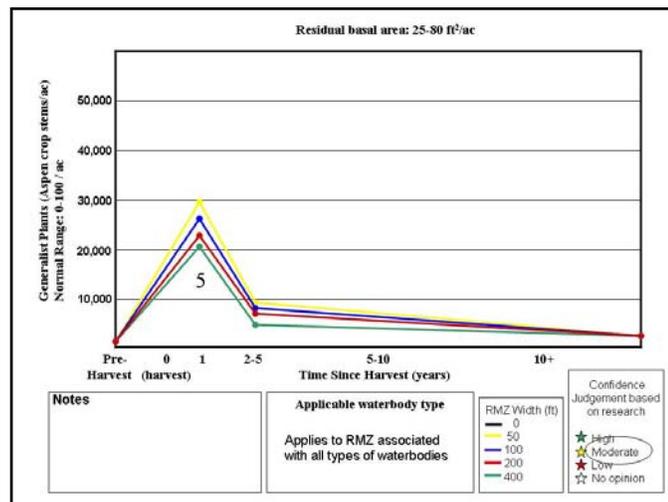
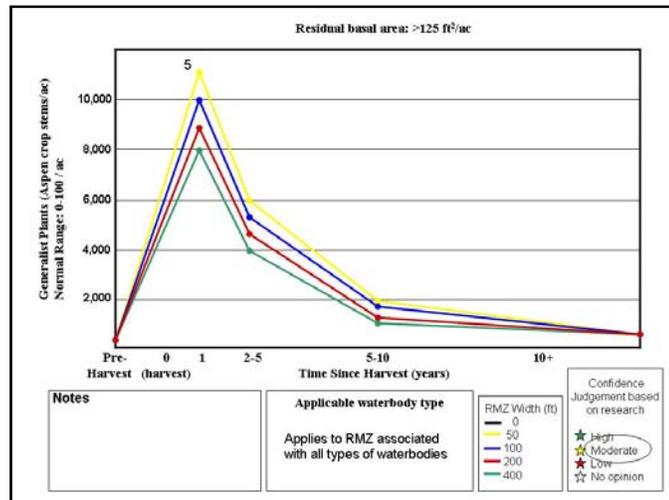


Figure B-53. Schematic graphic of aspen as a generalist plant for BA greater than 125 ft²/ac based on scientific literature.

Notes: Figures B-51 through B-53 refer to the following literature:

1. Palik, B., Cease, K., Egeland, L., and Blinn, C. 2003. Aspen regeneration in riparian management zones in northern Minnesota: effects of residual overstory and harvest method. *Northern Journal of Applied Forestry* 20: 79-84.



Professional Judgment

RMZs would need to be at least 122 m (400 ft) wide and maintain at least 125 BA if abundances of generalist and disturbance associated plants, including aspen, are to remain low and within the normal range for closed forest.

Forest Area Sensitive (interior forest) Plants

Scientific Summary

For any forest, including riparian areas, the loss of interior (area sensitive) plant species after harvest is initially less pronounced than the increase in generalist and disturbance associated plants. That is, for area sensitive species, there is a lag in their decline after a disturbance (Nelson and Halpern 2005). Declines in area sensitive plant species should begin between two and ten years after harvest of a riparian area, if the RMZ is narrow, due to increased edge effects. Changes in environmental conditions (microclimate, herbivores) may be causes for this reduction, as well as reduced resource availability during the stem exclusion stage of new stand development. Declines should be greater with decreasing BA and, even when BA is higher, with narrower RMZ, due to increased edge effects. There may be little difference in species richness between harvested and unharvested RMZ after 60-80 years of recovery (Kern et al. 2006). However, some individual plant species may be prone to local extirpation due to reduced rates of recruitment of new individuals into the species population in RMZs (Jules 1998). This would be more likely in narrow RMZs and in RMZs with low BA, particularly if these conditions were maintained for several decades, as decreased recruitment rates for interior forest herb species in forest fragments has been shown to last at least 30 years (Jules 1998).

Graphics

Figure B-54. Schematic graphic of forest area sensitive plants for BA less than or equal to 25 ft²/ac based on scientific literature.

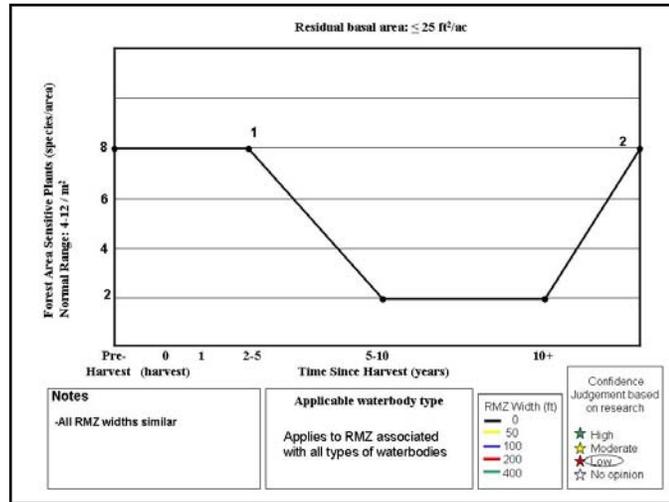


Figure B-55. Schematic graphic of forest area sensitive plants for BA between 25 and 80 ft²/ac based on scientific literature.

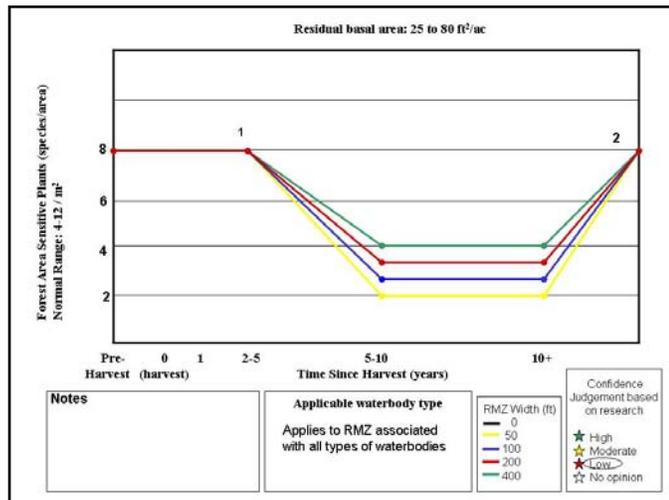
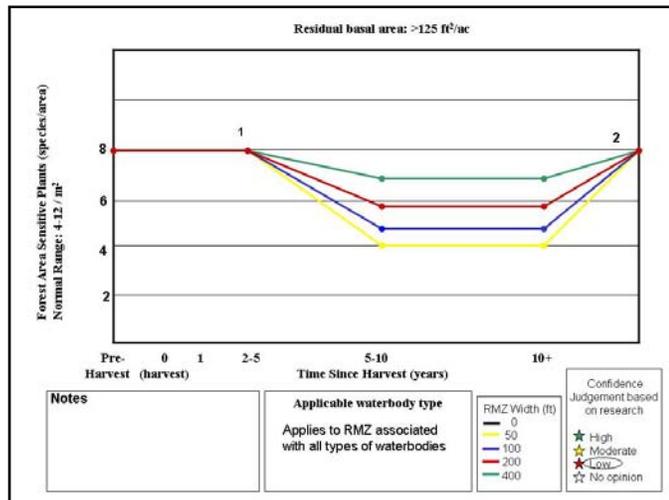


Figure B-56. Schematic graphic of forest area sensitive plants for BA greater than 125 ft²/ac based on scientific literature.



Notes: Figures B-54 through B-56 refer to the following literature:

1. Nelson C. R., and Halpern, C. B. 2005. Edge-related responses of understory plants to aggregated retention harvest in the Pacific Northwest. *Ecological Applications* 15: 196-209.
2. Kern, C. C., Palik, B. J., and Strong, T. F. 2006. Ground-layer plant community responses to contrasting silvicultural treatments in Wisconsin northern hardwood forests. *Forest Ecology and Management* (In press).

Figure B-57. Schematic graphic of forest area plants recruitment rates for BA less than or equal to 25 ft²/ac based on scientific literature.

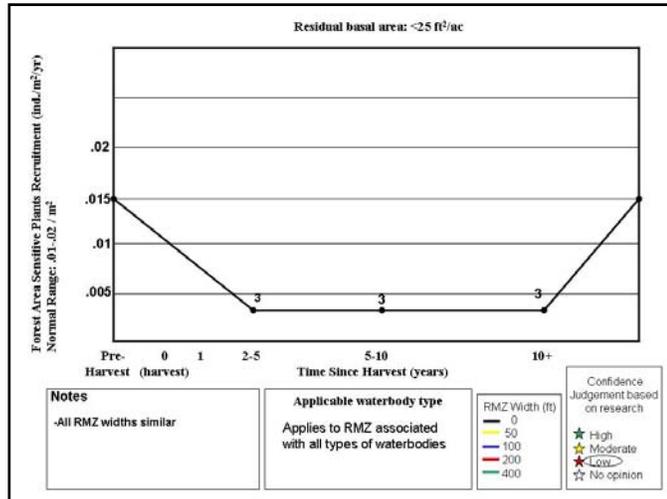


Figure B-58. Schematic graphic of forest area plants recruitment rates for BA between 25 and 80 ft²/ac based on scientific literature.

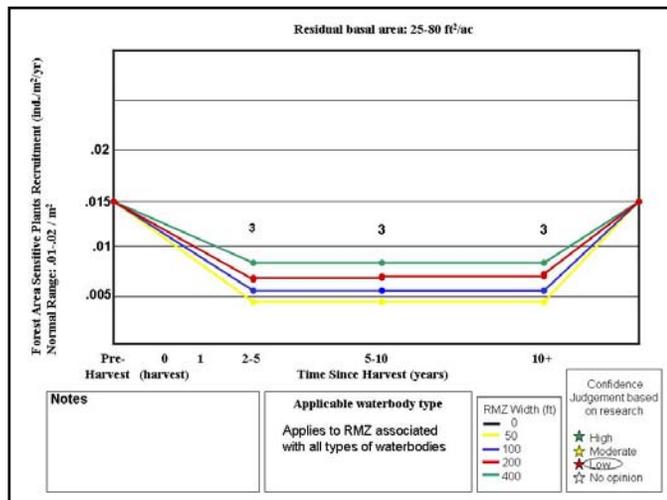
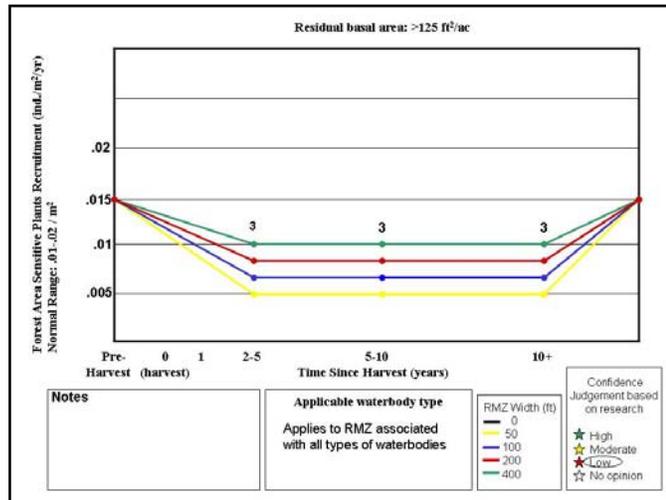


Figure B-59. Schematic graphic of forest area plants recruitment rates for BA greater than 125 ft²/ac based on scientific literature.

Notes: Figures B-57 through B-59 refer to the following literature:

1. Jules, E. S. 1998. Habitat fragmentation and demographic change for a common plant: *Trillium* in old-growth forest. *Ecology* 79: 1645-1656.



Professional Judgment

RMZs with at least 125 ft²/ac BA may be needed to maintain the species richness of forest interior plants within the normal range for uncut mature forest. RMZs that are at least 122 m (400 ft) wide and with at least 125 ft²/ac BA may be needed to maintain populations of some interior forest, area sensitive plants over the long term.

Windthrow

This discussion is based on the white papers listed below:

- Verry, E. S. 2006. Contributions to the Riparian Science Technical Committee Minnesota Forest Resource Council – Impacts of Beaver and Vegetation Management on Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow.
- Palik, B. 2006. Evaluation of Windthrow in RMZs.

Scientific Summary

There is much less information on windthrow or blowdown in the literature than was expected, particularly for the eastern US and, more specifically, for the Great Lakes region. The available literature gives a moderate confidence in any estimate because there are a whole host of factors that contribute to blowdown potential including: soil moisture, soil type, forest type, tree height, tree age, site quality, stocking, topographic relief, time since cutting, and aspect. It also makes a difference whether the RMZ is on one side or both sides of the stream since most of the windthrow is in the outer 7 m (25 ft) of the leave strip. Accounting for all of these in a literature comparison is difficult. That said windthrow is a critical indicator to consider especially considering the nearly total blowdown at the Pokegama Creek study as discussed below.

There are 7 black spruce stands in Minnesota where blowdown studies have been done (Heinselman 1955, 1957; Elling and Verry 1978). The black spruce studies are on organic soils (presumably less wind firm than mineral soils) and generally for trees shorter than aspen (typical aspen height is 21-23 m [70-75 ft]) and other conifers and hardwoods (typical heights upwards of 29 m (95 ft). The highest evaluated black spruce height for this evaluation was 19 m (62 ft), but are typical for Site Index 12 m (40 ft) black spruce at age 120. Site Index 40 is near average for the species.

With Site Index 40 trees, the actual height of trees measured at age 120 was about 19 m (62 ft) and windthrow balanced the net growth with RMZ widths of 34-40 m (110-130 ft) for one or two RMZ strips respectively (Figure B-60). For Site Index 30, where trees were about 14 m (47 ft) tall, RMZ widths of 30-37 m (100-120 ft) had static growing stock retention over time. For Site Index 50, where trees were about 24 m (78 ft) tall, RMZ widths of 37-43 m (120-140 ft) had static growing stock retention over time.

One could argue that this analysis is based on data from a condition that is not very applicable to the "typical" riparian forest condition in Minnesota. However, there is little available literature that is any more applicable. That said it is believed that the literature suggests that the probability of elevated blowdown after harvest likely extends farther than 7.6 m (25 ft) in many instances.

Other studies indicate higher than background blowdown rates extend from 15 to 25 m (49-82 ft) from a cut edge including the following:

Although tree heights are not given for all of these studies, it may be more instructive to think about the distance-blowdown relationship as a function of dominant tree height. That is, the width of the elevated blowdown zone increases with height of site potential trees (the blowdown zone is wider with taller trees). As such, the distances and rates presented in Ruel et al., 2001 and McClure et al., 2004 may be most applicable to our region (i.e. 15-20 m [49-82 ft]) for elevated windthrow distances, as heights of site potential trees for these two studies should be similar to ours.

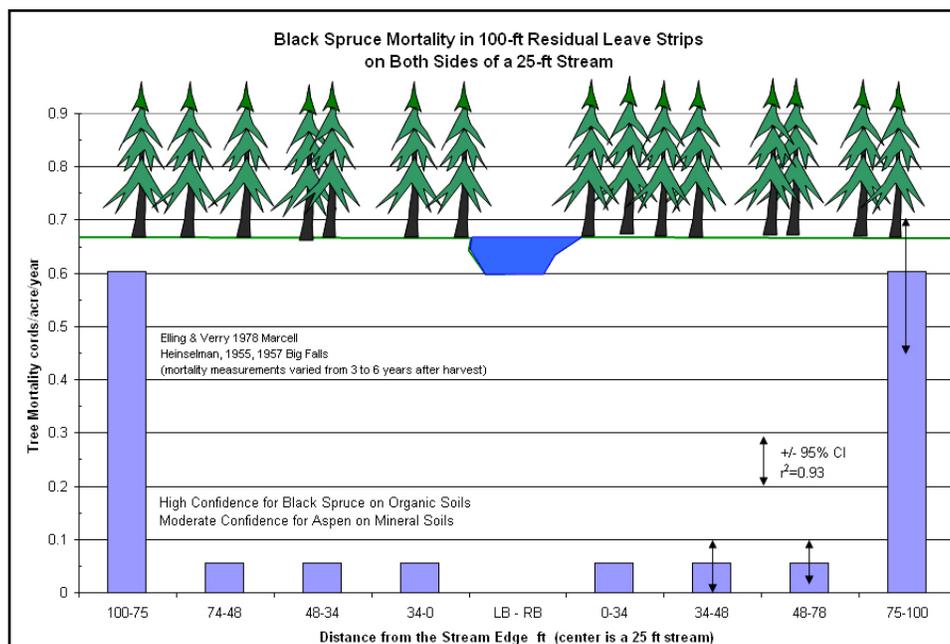
The literature suggests that elevated rates of blowdown mortality decline to background rates by around five years after harvest (Steinblums et al 1984; Reid and Hilton 1989; Ruel et al. 2001). This results from several factors, including compensation of residual trees, as they develop more wind-firm growth forms, and eventual loss of susceptible trees to blowdown in the first few years after exposure.

The literature is equivocal as to the effect of stocking level (BA after thinning) on blowdown rate. Some studies have found no increase in blowdown rate in thinned versus unthinned buffers (Ruel et al. 2001), while others find elevated rates in thinned buffers (Reid and Hilton 1989). It seems the response is dependent on the specifics of the thinning (e.g., were healthy trees left or removed?, what was the stocking level after thinning?). As such, making generalizations about effect of BA levels on blowdown probability is difficult.

In conclusion, data collected over 3 to 6 years after harvest of the mortality of 62 foot (19 m) tall black spruce as a function of distance from clearcut edge in 33 m (100 ft) buffers along streams running through peatlands showed high mortality rates within the first 7.6 m (25 ft) of the edge with significant decline inside of this distance. Cumulative evidence from a variety of studies around the country (see additional literature above) suggests that elevated rates of blowdown in the RMZs can extend 15-24 plus m (50-80 plus ft) from the clearcut edge.

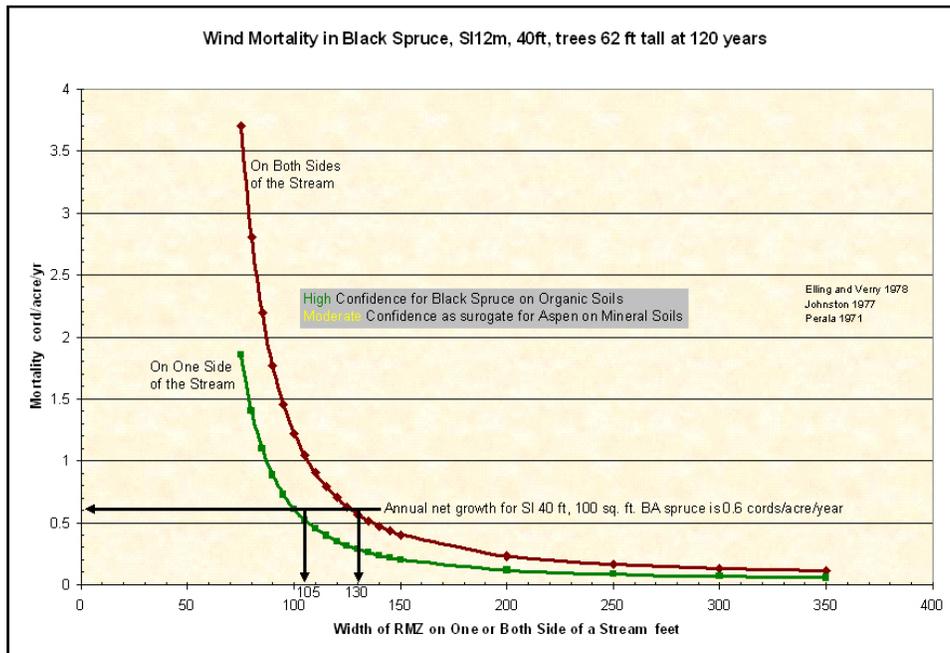
Graphics

Figure B-60. Black spruce mortality in categories of distance from the outer edges of strips on either side of a 25-foot stream.



Notes: The 95% confidence range and the high r square give these relationships a high confidence for black spruce on organic soil. These relationships were developed from 7 stands on the Big Falls and Marcell Experimental Forests with mortality data collected 3 to 6 years after harvesting adjacent strips. Mortality is concentrated within 7 m (25 ft) of the strip edge. The total amount of mortality can be evaluated on an RMZ width basis for either one or two sides of a stream.

Figure B-61. Annual black spruce mortality in leave strips of variable-width.



Notes: Elling and Verry (1978) evaluated the economics of leave strip mortality by simply comparing the width alternatives needed to attain net annual growth equal to annual wind mortality, in other words, a break even point in terms of cords per acre. The relationship of width to total, annual RMZ windthrow mortality is shown. Figure B-61 shows the annual black spruce mortality in leave strips of variable-width. This relationship is for a typical Site Index of 12 m (40 ft) for a black spruce stand with 100 BA. The actual tree height for a 120 year old stand is 19 m (62 ft). Annual mortality for this stand is 0.6 cords/acre/year. The curves in Figure B-61 represent a family of curves depending on the Site Index value. For a Site Index of 30 the distance values are shifted about 3 m (10 ft) lower and for a Site Index of 50 the distance values are shifted about 3 m (10 ft) higher.

Professional Judgment

Professional judgment leads to an RMZ estimate of 32 m (105 ft) for one-sided RMZs and 40 m (130 ft) for two-sided RMZs to compensate economically for this growing stock loss.

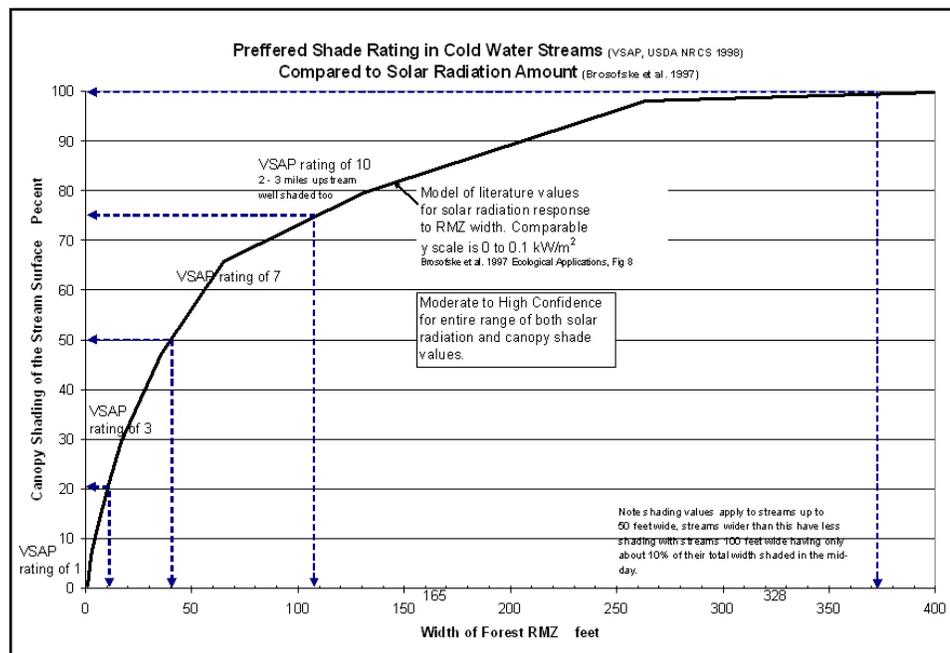
Overhead Canopy

Scientific Summary

Canopy cover has long been a desired characteristic of stream habitat for channels up to 15 m (50 ft) wide and greater. Above 15 m (50 ft) tree canopies do not touch across the river and thus the channel receives more and more direct solar radiation as the channel widens. Two overhead cover relationships against RMZ width are shown in Figures B-62 and B-63. One is based on the Natural Resources Conservation Service's (NRCS) Stream Visual Assessment Protocol (VSAP) originally based on the Izaak Walton League recommendations using 150 years of cold water fishing experience. The second is based on modeling of a series of studies measuring solar radiation on the stream water surface (Broszofski, Chen, Naiman, and Franklin, 1997). There is remarkably good agreement between the two systems. The RMZ width associated with the highest VSAP rating of 10 is 34 m (110 ft).

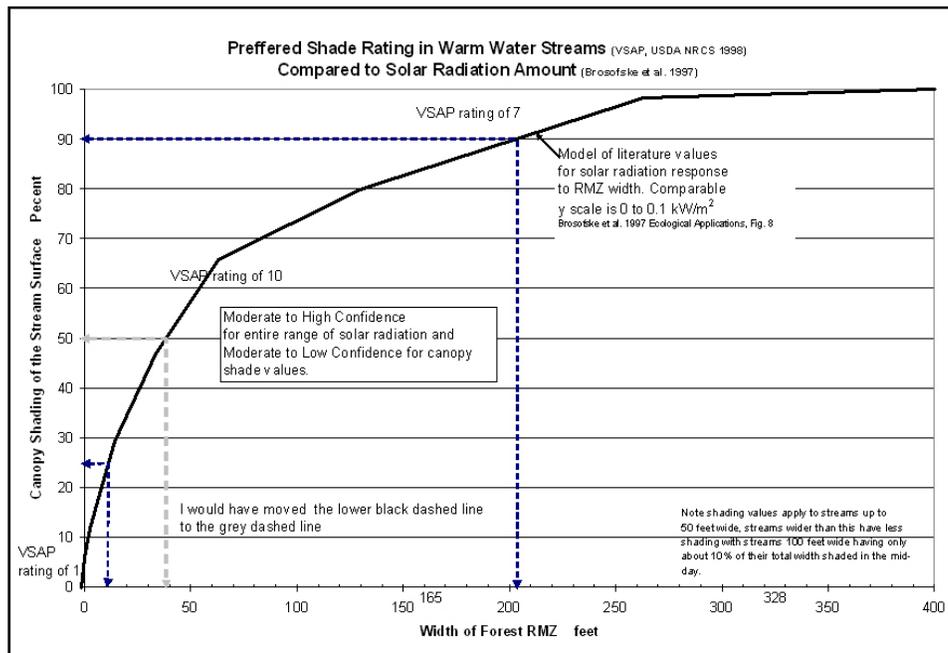
Graphics

Figure B-62. Overhead cover relationship against RMZ width.



Notes: Canopy shading of the stream surface is shown on the Y axis, The VSAP categories and their rating values are delimited by the dashed arrows. Solar radiation at the stream surface is shown by the solid line. It has a scale of 0 to 0.1 kW/m² (assumed stretched across the Y axis on the left).

Figure B-63. Overhead cover relationship against RMZ width.



Notes: Canopy shading of the stream surface is shown on the Y axis. The VSAP categories and their rating values are delimited by the black dashed arrows. The exponential receipt of solar radiation at the stream surface is shown by the solid line. It has a scale of 0 to 0.1 kW/m² (assumed stretched across the Y axis on the left).

Professional Judgment

The VSAP rating of 1 should apply up to the 50% shade value at a distance of about 12 m (40 ft). Since the Izaak Walton group has historically concentrated on cold water fisheries perhaps this difference is to be expected. The NRCS may have also changed the final expression for warm water streams.

Beaver Interactions

Scientific Summary

There has been a coincidence of second and third growth, early succession, aspen and birch forests in the Lake States with the recovery of beaver populations over the previous century. White and Host (2003) conclude for north central and northeastern Minnesota: “The legacy of this pulse of frequent, high intensity disturbance was a more homogenous forest landscape where dominance shifted from later successional or mid-serial conifer hardwood species (white pine, white spruce, black spruce, balsam fir, white cedar, tamarack, red oak, yellow birch) to early successional sprouting hardwood species (Populus spp., paper birch). Similar conclusions have been made for the Upper Peninsula of Michigan (Zhang, Pregitzer, and Reed 1999), the Northern, Lower Peninsula of Michigan (Maclean and Cleland 2003) and Northern Wisconsin

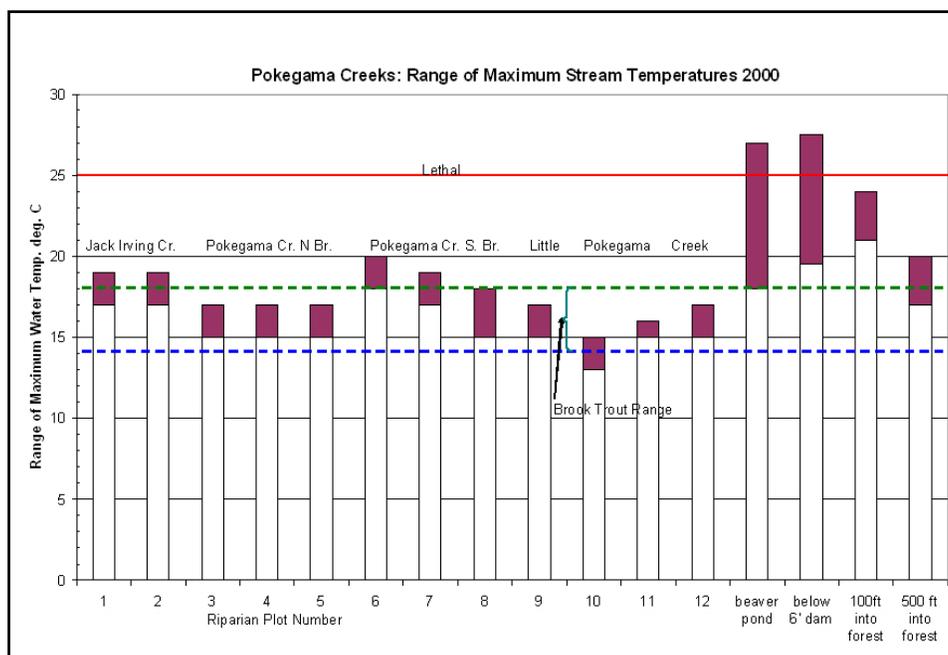
(Schulte, Mladenoff, and Nordheim 2002). Fisheries Biologists have seen the combination of early successional forests and high beaver populations drastically reduce native brook trout populations on cold water streams where beaver dam density is excessively high. Upon review of the literature documents, it was found that excessive levels of beaver dams can occur where conifer and northern hardwood forests are replaced by aspen and birch. Beaver dam frequencies of 0.2 to 4 dams per mile is the normal rate of colonization in North America and is documented for the Brule River in Wisconsin in 1680 (3 per mile). Today where aspen forests and cold water streams occur together, beaver dam frequencies of 10 to 20 per mile can block upstream fish migration, over widen streams from sediment deposition, cause water warming, and reduce overhead cover.

Stream temperatures documented at the MFRC Pokegama Creek study show water temperature rising by 10°C (reaching lethal levels in excess of 25°C, Figure B-64) in a beaver dam impoundment on a cold water brook trout stream. Figures B-65 and B-66 illustrate brook trout recovery in the Dark River where 11 dams per mile occurred. Brook trout recovery takes 8 to 10 years because of population dynamics and only occurs where the channel has normal width/depth ratios. In several reaches of the Dark River (three, one mile reaches) recovery remains limited because over wide channels persist even after dam removal.

A general response curve of stream width/depth ratios to beaver dams or beaver exclusion is given in Figure B-67. All streams regardless of stream type (some are wider and shallower than others) have a normal distribution of width/depth ratios about a mode. An example of this skewed distribution is shown on the left side of the figure along the Y-axis. When stream width/depth ratios exceed 25% of the mode, they are considered unstable, over-wide, shallow, and unable to move enough of the fine sediments to restore normal width/depth ratios. There is a high level of confidence in this value because of the some 1200 plus width/depth ratios that went into the normal range (plus or minus 25% of the mode). The distance scale is based on feeding ranges of beaver. Wildlife managers in Ontario and Quebec recommend 50 M (165 ft) to discourage beaver colonization. Many sources cite 100 m (328 ft) as the maximum foraging distance, but this seems to be rare.

Graphics

Figure B-64. Range of maximum daily temperatures at the Pokegama Creeks MFRC study area. Jack Irving Creek flows to Pokegama Lake directly it is the farthest north of the study plots. Pokegama Creek N Branch and S Branch form a confluence above the beaver dam (just below plots 5 and 9). Pokegama Creek flows into the southern tip of Sherry's Arm of Pokegama Lake. Little Pokegama Creek is a separate tributary flowing into the stream south of Sherry's Arm.



Notes for Figure B-64. There is no difference between the temperature ranges of various riparian leave strip widths and control plots (2, 5, 7, and 9) and they are mostly within the preferred range for brook trout. Temperatures in the beaver pond and below the dam were lethal to brook trout. The dam, about 2 m (6 ft) high was a total block to trout passage upstream.

Figure B-65. Number of beaver dams removed on the Dark River and its tributaries by the USFS. Dark columns show years when beaver trapping was on-going.

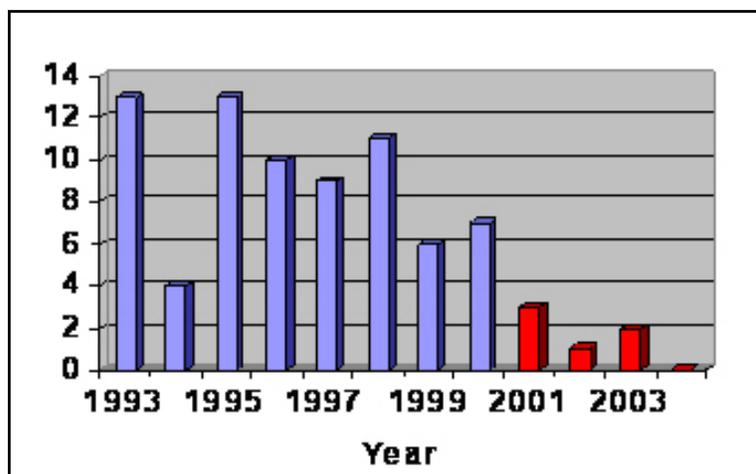


Figure B-66. Response of brook trout young of year (squares) and adult trout (circles) over a period of dam removal followed in 2001, and on, by beaver trapping on the Dark River north of Dark Lake.

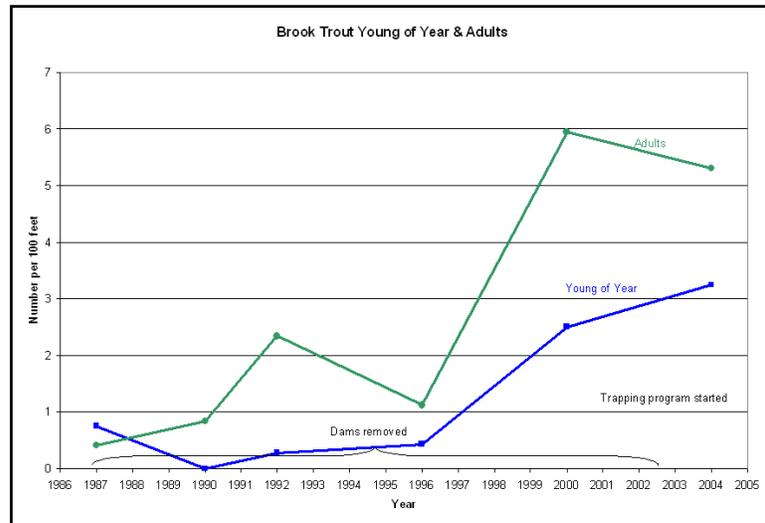
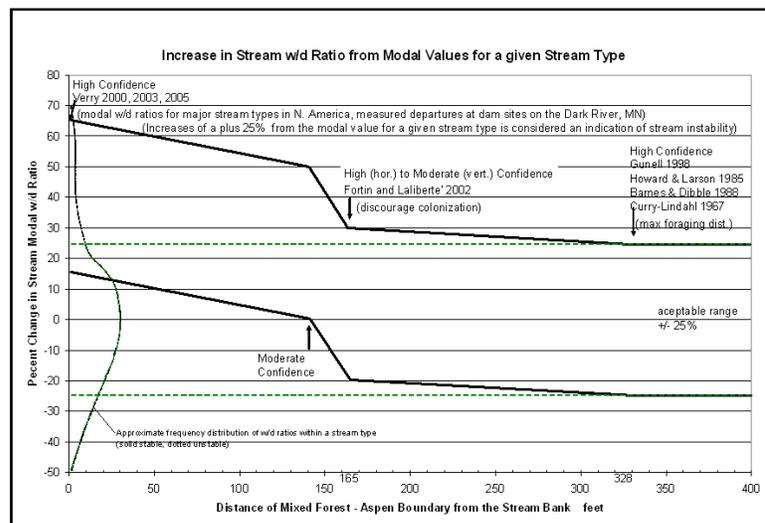


Figure B-67. Change in channel width/depth ratio as the distance of a mixed forest/aspens boundary moves away from the stream bank.



At any given distance, think of the mixed forest being on the *left* and the aspen forest being on the *right*. Thus, at a distance of 0 there is no mixed forest with only aspen to the left, at a distance of 50 m (165 ft), there are 50 m (165 ft) of mixed forest to the left and aspen forests to the left. A typical frequency distribution of w/d ratios for a given stream type is shown along the y axis. It is not typically normally distributed. Values less than a + 25% are normal and negative values are actually preferred because of a narrower, deeper channel. Values greater than +25% denote unstable streams not able to transport the sediment, water and debris of a watershed without major changes in stream geomorphology.

The ability to discourage beaver colonization is the key variable. Fortin and Laliberte' (2002) have set this based on experience at 50 m (165 ft) in Quebec and similarly by D'Eon et al. (1995) in Ontario. The 100 m (328 ft) data is based on many studies quoting this distance as the maximum browsing distance of beaver. The arrow shown with "Moderate Confidence" denotes that there must be a step function (they dam and colonize or don't) somewhere after the 50 m (165 ft) discourage recommendation.

Professional Judgment

On the basis of professional judgment it is recommended that a distance greater than 50 m (165 ft) as discouraging beaver use is not enough, as efforts to colonize at all should be discouraged. An RMZ between 61 and 91 m (200 and 300 ft) is a more comfortable zone.

APPENDIX C

Additional Reports and Findings

by Members of the Riparian Science Technical Committee

August 2007

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Blowdown Issues

Brian Palik, RSTC Member

March 13, 2006

Evaluation of Windthrow in RMZs

I was asked to do some further literature searching and review of studies that document windthrow potential in riparian buffers, as a function of width and residual basal area. This exercise was done to supplement Sandy Verry's earlier evaluation of the topic for the February RSTC meeting.

My approach to this was to search journals, proceedings, etc. in Google Scholar and Agricola, using keyword searches inclusive of riparian, blowdown, winthrow, clearcut edge, buffer, RMZ, and similar terms. A fundamental conclusion is that there is much less information on this topic in the literature than I had believed, particularly for the eastern US and, more specifically, for the Great Lakes region.

Here I attempt to make some general conclusion that could help to inform the guideline revision discussion.

Sandy's evaluation was based on mortality of 62 feet (ft) (19 meters (m)) tall black spruce as a function of distance from clearcut edge in 100 foot (33 m) buffers along streams running through peatlands. His conclusion was that mortality rates are high within the first 25 ft (7.6 m) of the edge and decline significantly (to background rates?) inside of this distance. This conclusion is based on data collected over 3 to 6 years after harvest. He further estimates that an RMZ would need to be 105 ft (32 m) or 130 ft (40 m) wide (one sided and two sided, respectively) to compensate economically for this growing stock loss (this assessment seems to ignore the economic loss of leaving wider RMZs?).

One could argue that this analysis is based on data from a condition that is not very applicable to the "typical" riparian forest condition in MN. However, there may be little available literature that is any more applicable. That said, I believe the literature does suggest that the probability of elevated blowdown after harvest likely extends farther than 25 ft (7.6 m) in many instances.

As an aside, the reason we should have moderate confidence in any estimate based on the available literature is that there are a whole host of factors that contribute to blowdown potential including:

-soil moisture, soil type, forest type, tree height, tree age, site quality, stocking, topographic relief, time since cutting, aspect

Accounting for all of these in a literature comparison is difficult.

There are several studies that indicate that higher than background blowdown rates extend from 15 to 25 m from a cut edge including the following:

Distance of increased mortality	Forest Type	Setting	Source
5 m (highest), declines to background rates by 25 m; N and E aspects highest; measured 2.7 years after harvest	Eng. Spruce/ Subalpine fir	Mountainous	Huggard et al. 1999
20 m-42% mortality 40 m-25% mortality 60 m-30% mortality; measured nine years after harvest	Balsam fir	0-50% slopes, moderate to imperfect drain- age	Ruel et al. 2001
150 m-rates elevated over background rates up to this distance, over five years	Coast redwood, Douglas fir	Steep slopes	Reid and Hilton 1989
15 m-evaluated 18 years after harvest	Mixed mesophytic	Steep slopes	McClure et al. 2004

Although tree heights are not given for all of these studies, it may be more instructive to think about the distance-blowdown relationship as a function of dominant tree height. That is, the width of the elevated blowdown zone increases with height of site potential trees (the blowdown zone is wider with taller trees). As such, the distances and rates presented in Ruel et al. and McClure et al. may be most applicable to our region; i.e. 15-20 m elevated windthrow distances, as heights of site potential trees for these two studies should be similar to ours.

The literature suggests that elevated rates of blowdown mortality decline to background rates by around five years after harvest (Steinblums et al 1984; Reid and Hilton 1989; Ruel et al. 2001). This results from several factors, including compensation of residual trees, as they develop more wind-firm growth forms, and eventual loss of susceptible trees to blowdown in the first few years after exposure.

The literature is equivocal as to the effect of stocking level (basal area after thinning) on blowdown rate. Some studies have found no increase in blowdown rate in thinned versus unthinned buffers (Ruel et al. 2001), while others find elevated rates in thinned buffers (Reid and Hilton 1989). I believe the response is dependent on the specifics of the thinning; e.g., were healthy tree left or removed?, what was the stocking level after thinning?. As such, making generalizations about effect of residual basal area levels on blowdown probability is difficult.

In conclusion, this literature suggests that buffers of up to 15-25 m have the potential for extensive blowdown of residual trees throughout their entire width, particular when located in more susceptible sites and landscape positions.

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Seasonal Pond Guidelines
RSTC Habitat Committee
March 13, 2006

To: Riparian Science Technical Committee
From: Mark Hanson, Lucinda Johnson, Brian Palik
Re: Seasonal pond management guidelines

The Minnesota Voluntary Site Level Management Guidelines address seasonal ponds in a limited way, specifically on pages 36-38 of the Wildlife Habitat subsection and on pages 72-73 of the General Guideline subsection. The former section defines seasonal ponds, provides some considerations relative to amphibians and waterfowl, but provides no guidelines. The latter section repeats some of the same definitional material as the Wildlife subsection and provides considerations and guidelines. We have reviewed the definition, considerations, and guidelines. We put forth the following suggested revisions to these guidelines. We suggest that any revision should be consistently made in both the Wildlife Habitat and General Guideline subsections.

Definition

1. The opening statement should state explicitly that seasonal ponds often include a clearly defined dry period. The point we feel needs emphasis is that a site is not exempt from guideline application if/because standing water and/or wet soils are absent during part of the growing season, or when the site is visited for timber sale layout.
2. The seasonal pond size criterion should be increased to 1 ac (currently ½ ac). It is true that most seasonal ponds are likely to be less than ½ ac in size, however larger ones to exist and should be acknowledged.
3. The statement regarding identification of seasonal wetlands during dry periods by less forest litter in the depression compared to the upland is inaccurate and should be eliminated. In many cases, litter will decompose slower in the depression proper, than the upland, due to longer periods of inundation, increased moisture, and reduced aeration. However, decomposition rates are widely variable due to differences in nutrient levels, pH, water movement, inundation levels, and moisture, making identification of dry ponds using the litter criteria problematic.
4. Revise the statement about the presence of black ash to read "may include the presence of back ash". Black ash may be absent naturally, due to site characteristics, or may be absent due to disturbance history.
5. The comment about minor presence of shrubs (e.g., alder) along the pond margins should be reconsidered. Shrubs can range from minor to abundant depending on the type of pond, its disturbance history, etc.

Considerations

The current guidelines contain "considerations" relative to leaving residual vegetation around seasonal ponds. The user is asked to consider leaving residual trees around ponds to maintain shade, retain sufficient vegetation to prevent sedimentation, and to provide a source of coarse wood and leaf litter. Moreover, the user is asked to consider meeting site level leave tree and patch requirements (5% of harvest area retained) by targeting application around seasonal ponds. Emphasizing this considera-

tion is especially important if there continues to be no RMZ requirement for seasonal ponds (as is the case currently, but see below). However, the description of leave tree requirements in general in the guidelines is cryptic; consider revising for increased clarity.

Guidelines

Currently, there are two specific guidelines for seasonal ponds: i) apply filter strips guidelines and ii) avoid disturbances such as ruts, compaction, excessive disturbance to litter layer, and addition of fill. These guidelines are appropriate and should be maintained. However, there are not sufficient for sustaining seasonal pond functionality.

It is our collective belief that there should be an RMZ guideline added for seasonal ponds, specifically one that provides for a high level of residual tree basal area around the pond. The primary functional reason for the RMZ is to help maintain functional linkages between the pond and the adjacent forest by providing shade, maintaining UV light levels within acceptable limits for pond breeding organisms, ensuring a continued supply of organic matter to the pond, and maintaining habitat requirements for animals in the RMZ (e.g., appropriate forest floor and litter conditions). These functions are critical for sustaining the contributions of seasonal ponds to forest and landscape biodiversity, especially for pond breeding amphibians, such as wood frogs and spring peepers. It is unlikely that filter strips alone are sufficient to meet these requirements. Moreover, it is not clear to us that the 5% leave patch guideline for a harvest unit is or will be implemented in a way that protects seasonal ponds

It has been argued that an RMZ around seasonal ponds may be warranted only if the majority of such wetlands in a landscape are treated similarly, i. e., adjacent forest around all or most ponds is harvested within a short time period (i.e., cumulative impacts). The reality is that the landscape size for pond breeding amphibians (a key biodiversity component of seasonal ponds), based on modal distances that individuals will migrate to find acceptable breeding habitat, will rarely exceed the size of typical timber sales (Semlitsch 1998, 2003). As such, there is a high probability that most seasonal ponds within the functional landscape of a pond breeding amphibian, will be treated similarly at the time of harvest, thus arguing for the inclusion of an RMZ guideline to protect continuity of function related to shading.

We are uncertain about the exact recommendations for width and residual basal area in a seasonal pond RMZ. Our belief is that it should be at least 50 feet wide and contain at least 75 ft²/ac of preharvest basal area. Where they naturally occur, conifers should be retained, or their establishment encouraged, as they provide shade year round.

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BASAL AREA QUALIFIER

George Ice, RSTC Member

January 2006

The Riparian Science Technical Committee (RSTC) expressed concern that the 80 ft²/acre basal area recommendation would be treated by land managers, agencies, the public, and even certification organizations as a rigid standard regardless of circumstances. There will be conditions where more or less basal area will be appropriate, given a management strategy to achieve desired environmental benefits and future riparian conditions. For example, there are efforts to restore riparian conditions favorable to fish and wildlife habitat by emulating natural disturbance patterns (Cissel et al. 1998; Macdonald et al. 2004; Swanson 1994). Wilzbach et al. (2005) recently reported that increased solar radiation, where it does not lead to unacceptable stream temperature increases, can result in increased fish productivity. Concerns about stream temperatures in Minnesota may be largely associated with beaver pond development, so management to create unfavorable habitat for beaver near streams and lakes may be the most effective water quality management strategy (Verry 2006). Therefore, ***the RSTC proposes the use of an asterisk to modify the 80 ft²/acre basal area recommendation.*** This asterisk would indicate that the recommended basal area to be retained should be adjusted if justified by a designed management strategy.

Even with the use of an asterisk the RSTC is concerned that active management will not be routinely used to achieve favorable desired future conditions. In Oregon, the active management option has been utilized for riparian forest stands only 7% of the time compared to the no-cut option (Hairston 1996). Landowners and forest managers may be reluctant to use active management options because of possible short-term risks to water quality and habitat conditions, increased exposure to criticism by the public or others, and increased costs of active management without compensating economic benefits. There was some agreement that a management plan to silviculturally achieve a desired riparian condition would be one approach to modifying the standard basal area recommendation. Other methods (e.g., some standard approaches to achieve desired conditions) might also be used to reduce the cost of developing individual plans for harvest units while leading to a desired condition. Realistic incentives to encourage active management may also be needed.

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Impacts of Beaver and Vegetation Management on Stream Temperature, Shading, Stream Geomorphology, and RMZ Windthrow

Contributions to the Riparian Science Technical Committee
Minnesota Forest Resource Council

E. S. Verry, Hydrologist
Ellen River Partners
January 11, 2006

Introduction

I spent 3 hours on the phone with Charles Anderson reviewing his take on stream impacts and getting his reading of how fishery biologists in the state see their role in protecting stream habitat. As is common nationwide, cold water fisheries get the most attention when stream temperatures come into play. In SE Minnesota trout populations have increased in the last 25 years. There is a strong emphasis on channel restoration with an emphasis on lunger structures. Streams in this region of the state are likely in a long term recovery from catastrophic gully erosion followed by the burying of floodplains 4 to 6 feet deep in fine sands during floods in the late 1930s following wide scale land use change. Fortunately, high relief in the area gives rise to strong ground-water flows and cold inflows to channels.

In NE Minnesota fishery biologists are concerned about harvesting and beaver impacts to brook trout systems because trout stream temperatures are at the upper end of the optimal range and fears of global warming, forest harvesting and beaver impacts can easily combine to render existing temperatures marginal.

Elsewhere in the state, warm water fisheries in streams have traditionally not had the same emphasis as cold water fisheries. However, many fishery biologists have recently become aware of the impact of land use and riparian condition on stream width, depth and cover and are now addressing a multitude of restoration opportunities including stream crossings.

I will address trout beaver interactions and how stream temperature, and stream width and depth are impacted. The blowdown of trees in riparian management zones is not a trivial topic. While little is known about leave strip mortality in Minnesota, studies on peatlands near Bigfork and Marcell provide prediction equations that I will use to guide tree survival until upland studies can verify or change these predictions.

This review is based on literature in North America and field measurement and experience with streams and their riparian areas in the northeastern United States with emphasis on Lake State conditions.

My conclusions about beaver and trout have changed over the last 10 years. First, I simply thought they existed together for millennium so they should be able to get along

just fine. Then, with continued exposure to fishery biologists I thought the beaver should be beat to death and all their dams blown to so the trout could prosper. During the last 10 years my measurement of stream temperature, stream sediment, stream width and depth and a 60-year evaluation of beaver dam activity on the Dark River north of Chisholm have led me to a different set of conclusions.

Prior to original logging by European settlers, my first conclusion was probably right. As we know, original logging was preceded by the minimization of most beaver populations in North America. The rebuilding of beaver populations in North America has coincided with the maturation of shade intolerant second and third growth forests on a scale unprecedented in history. Beaver have exploited the aspen forests and given rise to a density of beaver dams far in excess of pre original logging. The construction, destruction and rebuilding of these dams has left parts of the cool and cold water trout streams unable to physically repair themselves to modal width and depth ratios typical of streams before the extra high incidence of beaver in Lake State ecosystems.

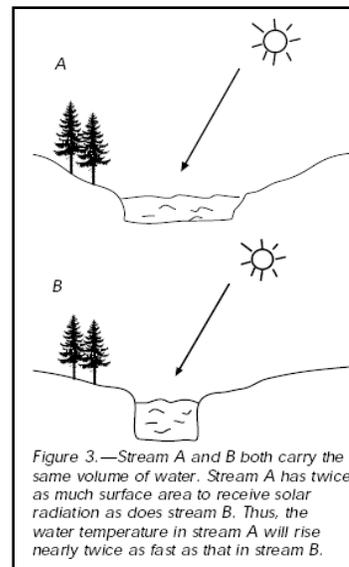
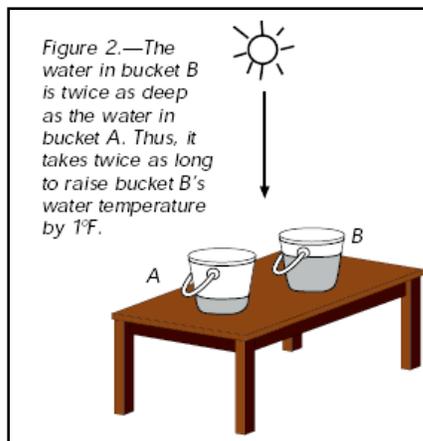
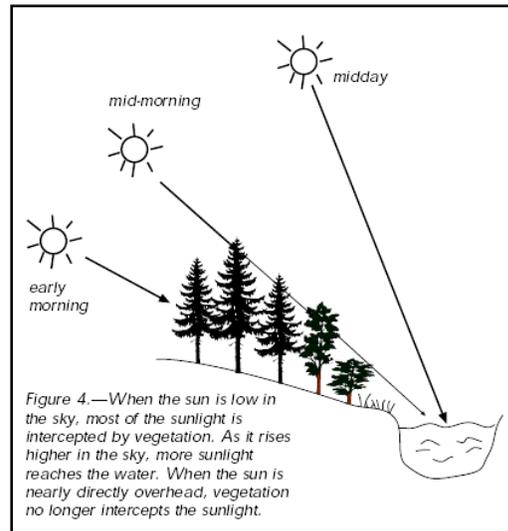
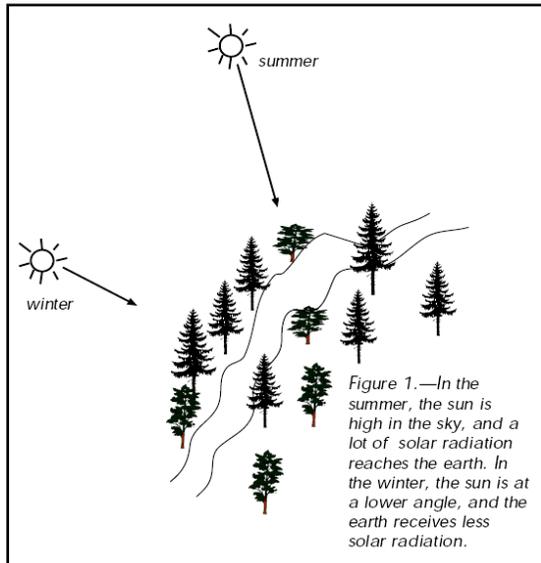
Now, I would temper my conclusion based on the literature and field measurements, and say that where beaver and their dams occur at pre original logging numbers and their dams do not exceed 3 or 4 feet in height, they provide added trout habitat and do not block the migration of fish downstream or adult fish upstream. Where beaver dams occur, fail and rebuild at rates exceeding pre-logging levels, stream geomorphology is impaired such that trout avoid these areas because of fine sediments, shallower water, high water temperatures and a lack of overhead cover. Where beaver dams exceed 5 or 6 feet in height, fish migration upstream is blocked. Stream riparian areas in the landscape where these later factors are pronounced occur at stream confluences where larger, flat floodplains have developed, but good damning sites can occur elsewhere in the basin too. When these areas are perpetuated in aspen forests, trout stream quality is permanently impaired.

This is the gist of my conclusions. I will attempt in the rest of the paper to provide a combination of literature, field measurements, data from the MFRC studies at Pokegama Creek, and the application of the scientific method through deductive reasoning to apply these conclusions to a simplified set of riparian guidelines.

Review of Principles and Data

The Oregon State Extension Service has published several fact sheets for the lay person that include such fundamental facts about streams and temperature they no longer need a long list of research citations to support them.

Figure 1. These diagrams (Oregon's Figures 1-4) are taken from the Oregon State Univ. Extension Service Bulletin EC 1489, 1997. They remind us that more solar radiation is received at the stream surface during summer and mid day (upper panels) and that shallow water whether in a bucket or a stream is warmed quicker than deep water (lower panels). In particular, note that for the same water volume, shallow and wide streams heat twice as fast as narrow and deep streams (Figure 3 in the panel).



In summary, the Oregon State Bulletin summarizes how to cool a stream: keep it shaded, keep it narrow, keep it flowing. They also add the influence of springs on surface water cooling. All of these factors apply precisely to the interaction of beaver and trout in streams.

Incidence of beaver dams or colonies in North America

Angela Gurnell at the Univ. of Birmingham, UK is one of the few authors who summarized the beaver literature with an eye toward stream geomorphology (Gurnell 1998). While her review includes work on both the European *Castor fiber* and the North American *Castor Canadensis*, it is very thorough in its review of North American literature. I have used authors cited in Gurnell's review, ongoing studies of my own with the MN DNR Fisheries and Wildlife Division, Minnesota, work by Naiman et al., and Wisconsin work by Avery to document the density of beaver dams and colonies in North America (**Table 1**).

Table 1. Number of beaver dams or colonies per distance and number per area.

Location	Year	No./km	No./mile	Meters between	Feet. between	Citation
Brule River, WI	1680	1.9	3.0	5,263	1760	Winchell & Upham 1884
Coastal Oregon	1992	1.2	2.0	8,333	2,734	Leidholtbruner et al. 1992
Eastern Oregon	1995	0.14	0.2	71,429	23,435	McComb 1995
Alaska	1983	0.6	1.0	16,667	5,468	Boyce 1983
Truckee R. CA	1987	0.7	1.1	14,286	4,687	Beier & Barrett 1987
Wyoming	1976	0.9	1.4	11,111	3,645	Collins 1976
New Brunswick	1972	1.3	2.1	7,692	2,524	Nordstrom 1972
Kansas	1993	1.4	2.3	7,143	2,343	Robel & Fox 1993
Massachusetts	1985	0.8	1.3	12,500	4,101	Larson 1985
Dark River MN	1940	2.5	3.7	4,675	1,425	Verry, 2005
Dark River MN	1989	6.6	10.6	1,333	496	Verry, 2005
Pemebonwon R., WI Mainstem	1982	6.8	11.0	1,471	480	Avery 1991, 1992
Pemebonwon R., WI Tributaries	1983	11.8	19.0	847	278	Avery 1991, 1992
Location		No./sq.km	No./sq. mile			
Maine	1996	0.3				McCall et al. 1996
Minnesota	1927	0.2				Naiman et al. 1994
Kabetogama Penin. Minnesota	1988	2				Naiman et al. 1994

In the latitudes of the mid 40s and farther south, beaver dam or colony density ranges from 0.2 to 3.7 per mile. Note that the Dark River data in 1940 was following major fires and floods in the 1930s. The oldest record of beaver dam density I know of is from the journals of Sir DuLuth reported in Winchell and Upham's classic geography of Minnesota. In 1680, the beaver dam density on the Brule River in Wisconsin was 3 per mile (Verry 2000, 2005).

In contrast study areas identified by fishery biologists with excessive dam densities are those on the Dark River (in 1989) in north central Minnesota, the Pemebonwon River

and its tributaries in NE Wisconsin, and on the Kabetogama Peninsula in northern Minnesota. All of these areas, in the 1980s, had beaver dam densities of 10 to 16 dams per mile, generally 2½ to 4½ times the average in North America. A similar ratio exists for the few studies reported in dams or colonies per area (McCall et al. 1996 and Naiman et al. 1994). These are densities for populations in the low to mid 40 latitudes. A denser population of dams exists in sub arctic regions and in regions with dams on channels between lakes where channel slopes are nil (Naiman et al. 1986).

Stream Characteristics, Wood Size and Foraging Distance

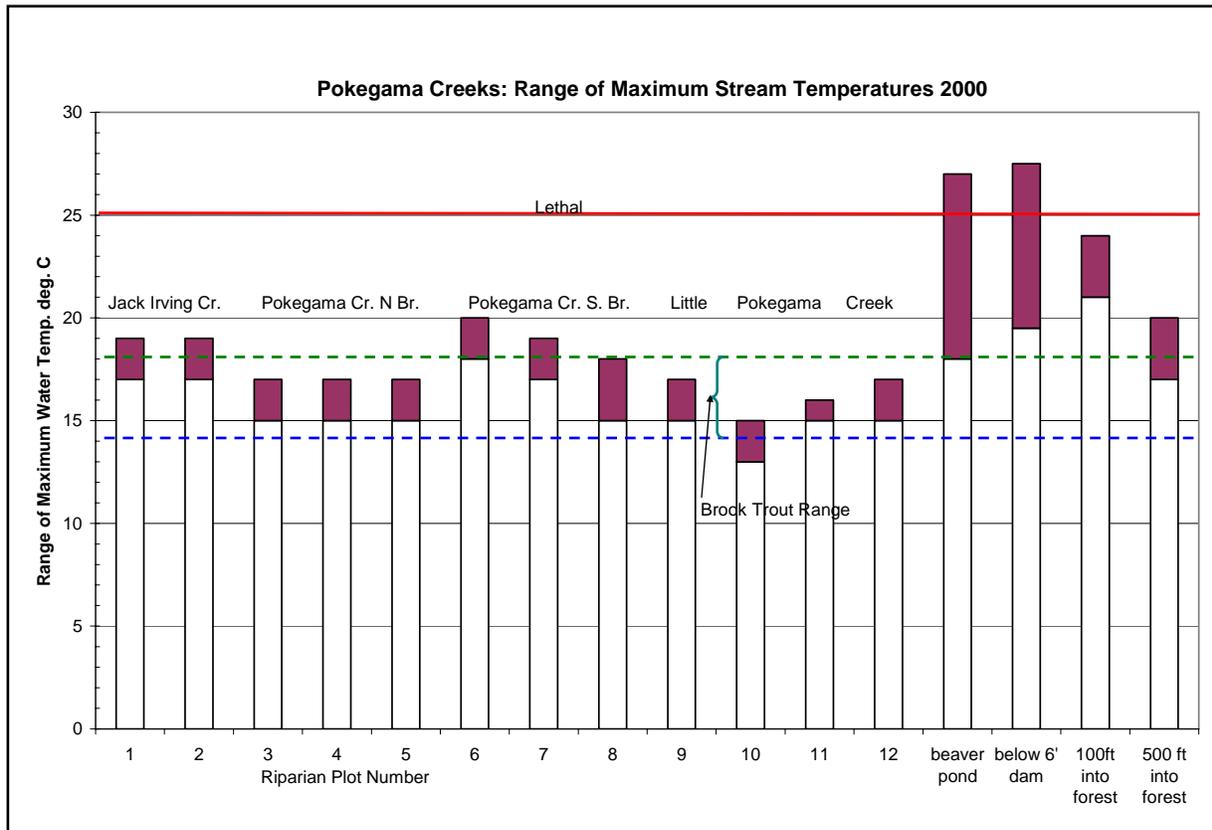
Beaver build dams on streams 5 to 50 feet wide (Gurnell 1998). Smaller streams do not have enough water to support perennial ponds and large rivers have annual peak flows sufficient to destroy damming attempts. Aspen is strongly preferred over all other woody species, but birch, willow, cottonwood, alder, maple and ash are also utilized (Busher, 1996). Stems less than 2 inches are preferred, but dams frequently contain wood up to 3 inches in diameter. Beaver commonly browse within 33 feet of water, but this distance increases as dam height and flooding extent increases. Maximum browsing distances occur at 330 feet (Howard and Larson, 1985, Nolet et al., 1994, and Allen 1983). To dissuade beavers from settling in streams, hardwoods should be discouraged and conifers encourage within 165 feet of stream banks (Fortin and Laliberté 2002).

Wisconsin and Minnesota Studies of Dam Removal and Trout Response

Pokegama Creek MFRC Study Area

Stream temperatures at the Pokegama Creek study area did not show any significant change with respect to the optimal range for brook trout habitat. However, a beaver dam at the confluence of the plot 3,4,5 tributary with the plot 6,7,8 tributary showed dramatic temperature increases that persisted well into the forested area below the dam (**Figure 2**). The beaver pond increased water temperatures by 10°C from 17°C to 27°C and over 500 feet of shaded forest channel below the dam was required to bring water temperatures within a degree or two of the stream above the beaver pond. Brook trout prefer summer maximum water temperatures from 16°C to 18°C.

Figure 2. Range of maximum daily temperatures at the Pokegama Creeks MFRC study area. Jack Irving Creek flows to Pokegama Lake directly it is the farthest north of the study plots. Pokegama Creek N Branch and S Branch form a confluence above the beaver dam (just below plots 5 and 9). Pokegama Creek flows into the southern tip of Sherry’s Arm of Pokegama Lake. Little Pokegama Creek is a separate tributary flowing into the stream south of Sherry’s Arm.



There is no difference between the temperature ranges of various riparian leave strip widths and control plots (2, 5, 7, and 9) and they are mostly within the preferred range for brook trout. Temperatures in the beaver pond and below the dam were lethal to brook trout. The dam, about 6 feet high was a total block to trout passage upstream.

Wisconsin Dam Removal Study

Avery (1992) published the results of a study (1982 to 1989) on 9.8 miles of the Pemebonwon River in NE WI and 22.7 miles of tributaries to the Pemebonwon River. Dam occurrence is shown in **Table 1**. In 1982 and 1983, 546 dams were removed.

Trout response between 1982 and 1986 differed between the mainstem and the tributaries. Trout density (no./mile) declined by 15% in spring inventories and by 22% in fall inventories on the mainstem, but trout density (no./mile) on the tributaries increased by 29% in the spring and 74% in the fall. Trout were present in 4 of 7 tributaries sampled in 1982, but occurred in all tributaries in 1986. Natural reproduction was evident in 2 of

6 tributaries sampled in 1982 and all 6 sampled in 1986.

Peak stream temperatures rose after dam removal on the mainstem from 1982 to 1983: 0.5 to 3.2 °C, but air temperatures also rose 5 °C. On the tributaries, stream temperatures rose 0.6 to 5.4 °C.

In 1984, air temperatures were again 2 °C higher than in 1982; however, stream water temperatures on the mainstem cooled 0.7 °C to 2.0 °C and 0.7 °C to 4.5 °C on the tributaries. The delayed cooling may have resulted from gradual changes in the wide shallow channels to somewhat narrower and deeper channels, but primarily from shade as new vegetation grew along the narrower channels.

No data on the actual width and depth of streams was recorded. After dam removal channels may be slow to regain normal width/depth ratios because of their over-wide condition caused by dam building and dam removal.

Minnesota Dam Removal Study

The Dark River north of Chisholm, MN has been a study area for beaver dam removal since 1987. From the late 1980s through the late 1990s dams were removed by the Chisholm Sportsmen’s Club and by fur trappers. Records were incomplete in the early years of dam removal. The Superior N.F. began removing dams in 1993 and recorded these removals (**Figure 3**). The response of brook trout young of the year and adults sampled from 4, 300-ft stations is shown in **Figure 4**.

Figure 3. Number of beaver dams removed on the Dark River and its tributaries by the USFS. Dark columns show years when beaver trapping was on going.

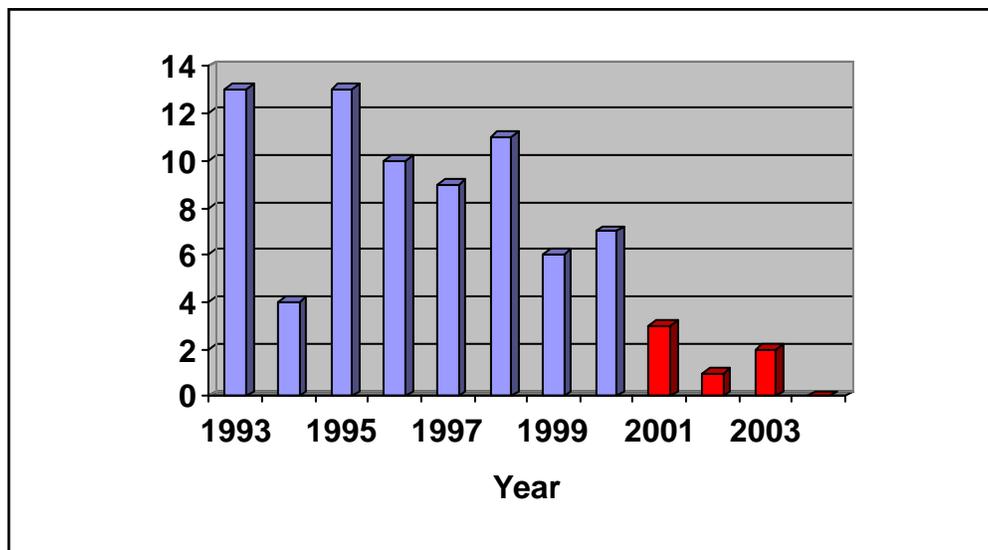
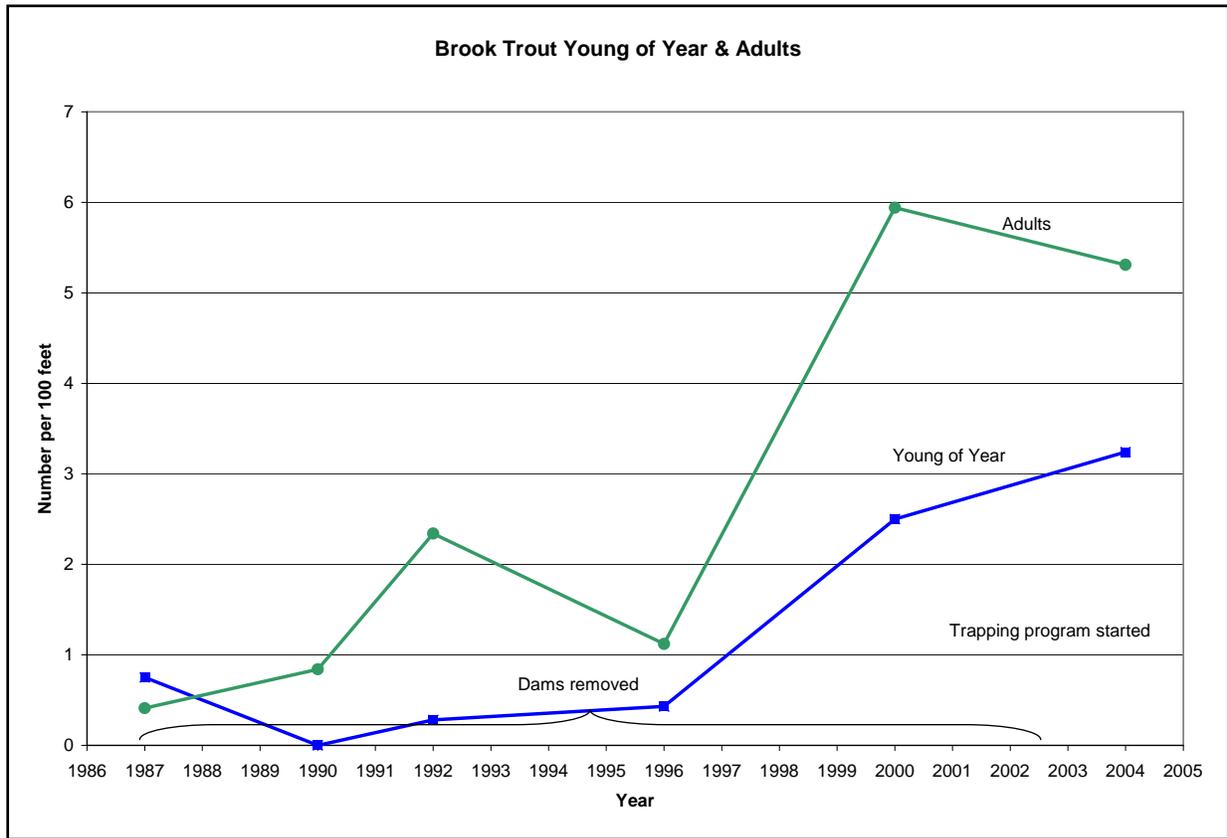


Figure 4. Response of brook trout young of year (squares) and adult trout (circles) over a period of dam removal followed in 2001, and on, by beaver trapping on the Dark River north of Dark Lake.



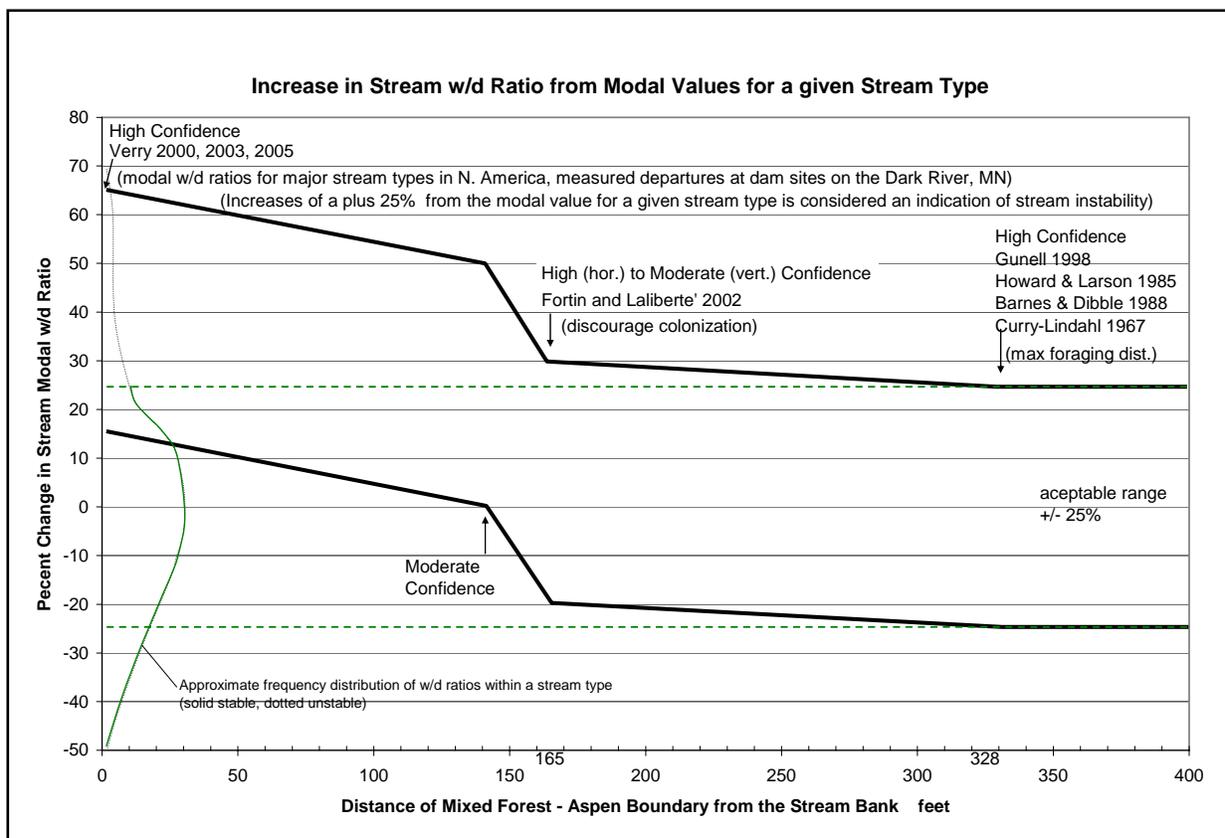
The trout data from the Dark River show significant brook trout responses, but these data are from parts of the Dark River with modal or normal width/depth ratios (Verry 2004a). Reaches of the river with high dam densities have width/depth ratios exceeding 25% of modal values and trout recovery in these areas is nil. Water temperatures have also been monitored and show areas of groundwater recharge with little change in water temperatures in areas of over-wide channels or areas where cold water tributaries have been poorly connected (stretches of over-wide and shallow channel) at the confluence with the mainstem (Verry 2004a, 2005). A survey and analysis of 8.6 miles of the Dark River have indicated three, approximately 1-mile long reaches of over-wide and relatively shallow channel scheduled for channel restoration work. Many riparian areas have been planted to conifers and some reaches received large wood additions.

I have used this review of beaver occurrence and vegetation literature to evaluate the width of riparian management zone (RMZ) required to discourage beaver colonization of cool and cold water trout streams. The arrangement of data is with respect to how the channel is changed following dam construction or destruction. **Figure 1** (Oregon Figure 3) illustrates the general change in channel width/depth ratio when channels are dammed. The accumulation of sediment behind the dam widens and shallows the

channel. Scour may occur directly below a dam when it breaks, but similar widening and shallowing occurs farther downstream.

My evaluation is presented in terms of the changes in the width/depth ratio of stream channels as a percentage deviation from modal values for the major stream types in the Lakes States (**Figure 5**, Verry, 2000). Note the range of modal w/d ratios shown between the two dashed lines and the relative shape of the w/d ratio distribution curve.

Figure 5. Change in channel width/depth ratio as the distance of a mixed forest/aspens boundary moves away from the stream bank. At any given distance, think of the mixed forest being on the *left* and the aspen forest being on the *right*. Thus, at a distance of 0 there is no mixed forest with only aspen to the left, at a distance of 165, there are 165 feet of mixed forest to the left and aspen forests to the left. A typical frequency distribution of w/d ratios for a given stream type is shown along the y axis. It is not typically normally distributed. Values less than a + 25% are normal and negative values are actually preferred because of a narrower, deeper channel. Values greater than +25% denote unstable streams not able to transport the sediment, water and debris of a watershed without major changes in stream geomorphology.



The ability to discourage beaver colonization is the key variable. Fortrin and Laliberte' (2002) have set this based on experience at 165 feet in Quebec and similarly by D'Eon et al. 1995 in Ontario. The 328 foot data is based on many studies quoting this distance as the maximum browsing distance of beaver. The arrow shown with "Moderate Confidence" denotes that there must be a step function (they dam and colonize or don't) somewhere after the 165 foot discourage recommendation.

Thoughts on Shading by Overhead Cover in All Streams

Canopy cover has long been a desired characteristic of stream habitat for channels up to 50 feet wide and over. Above 50 feet tree canopies do not touch across the river and thus the channel receives more and more direct solar radiation as the channel widens. Rather than review many papers on this topic I chose to use the Stream Visual Assessment Protocol (SVAP) developed by the NRCS and compare it with detailed modeling of various riparian microclimate using the solar radiation models of Brosofske et al. 1997. Canopy cover is one aspect of a larger SVAP rating system. The canopy cover relationships were developed originally by the Izaak Walton League using over a century of primarily cold water fishing experience.

Rating values are asymmetric with respect to the amount of water surface shaded. Complete shading is discounted in warm water systems.

Table 2. Cold water rating of shading using the Stream Visual Assessment Protocol, NRCS

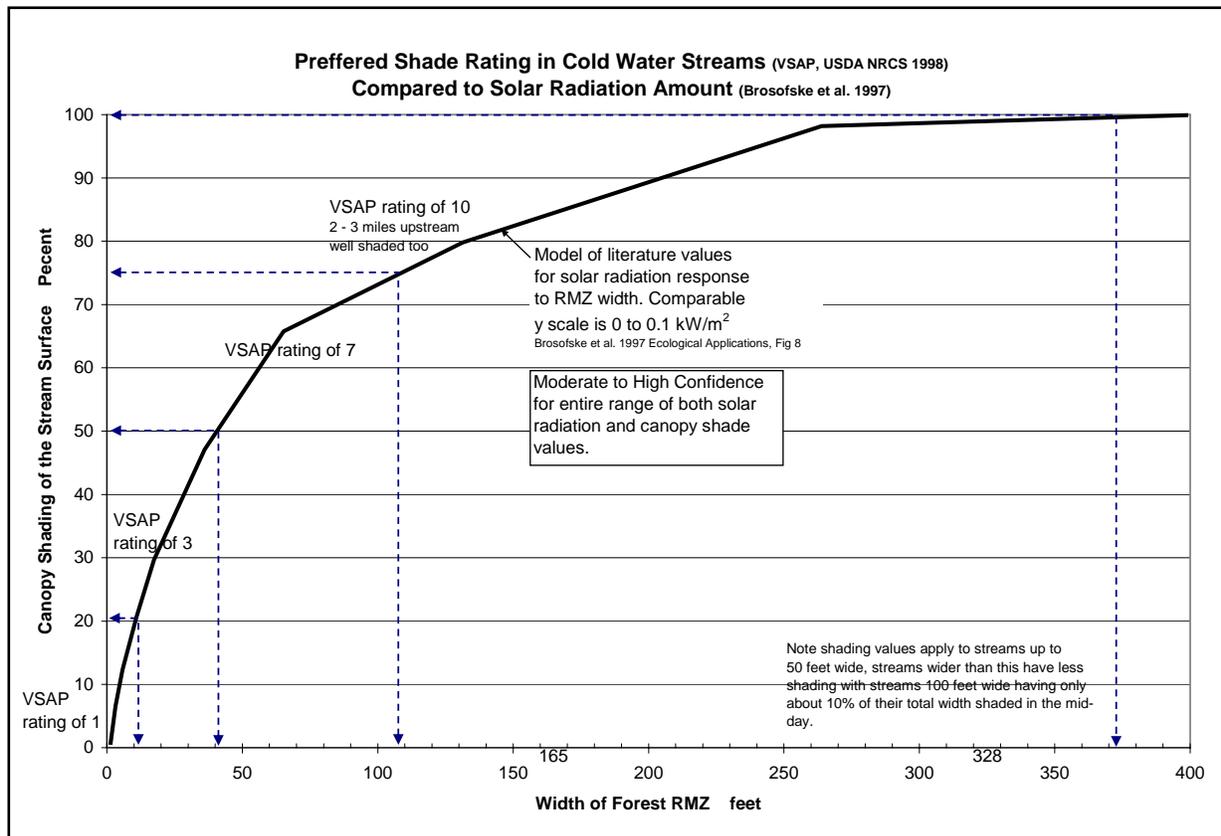
Rating	Amount of Shading
10	>75% of surface water shaded and upstream 2 to 3 miles generally shaded
7	> 50% or >75% if upstream 2 to 3 miles is poorly shaded
3	20 to 50% shade
1	< 20% shade

Table 3. Warm water rating of shading using the Stream Visual Assessment Protocol, NRCS

Rating	Amount of Shading
10	25 to 90% of surface water shaded; mixture of conditions
7	> 90% shaded; full canopy: same shading condition throughout reach
3	blank
1	< 25% shade in the reach

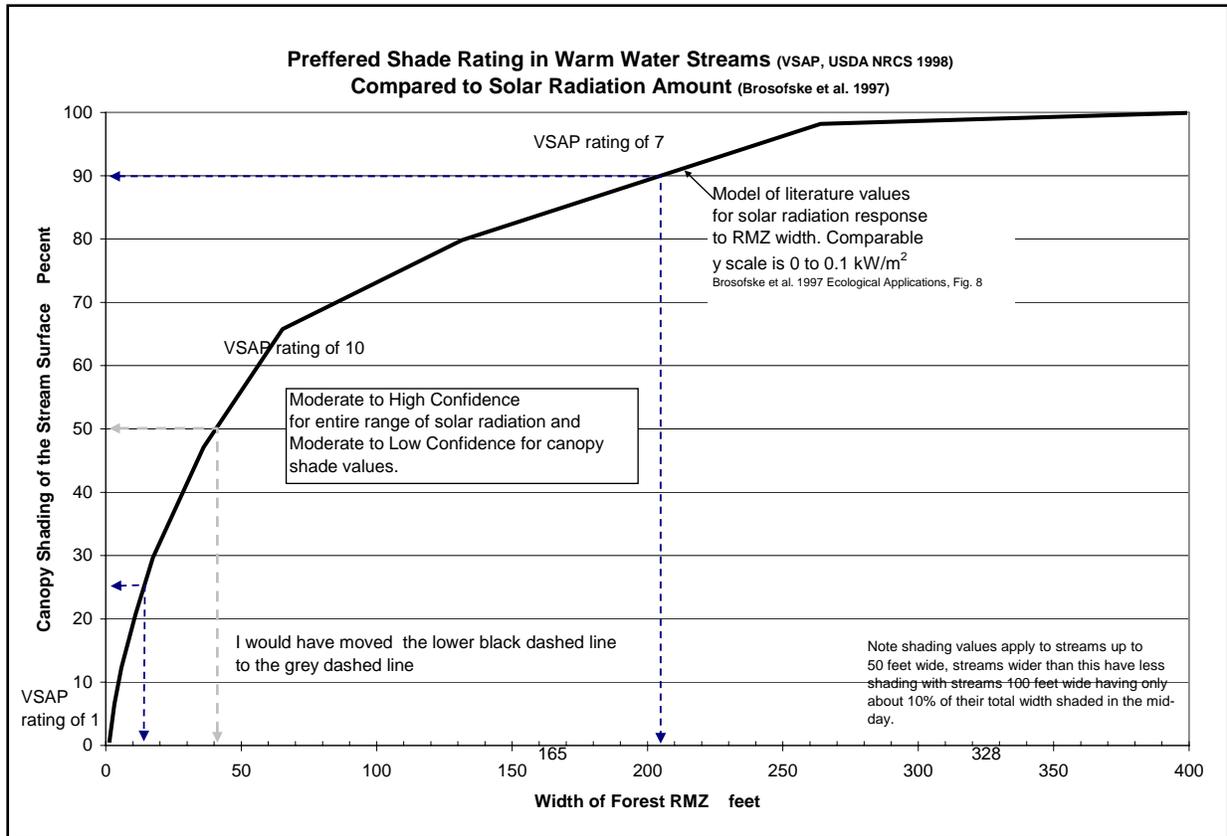
While these are broad categories, they have been used and trusted for over a century, it is doubtful review of a series of studies will improve on this and comparison with the modeling work of Brosofske et al. 1997 confirms this for cold water streams (**Figure 6**).

Figure 6. Canopy shading of the stream surface is shown on the Y axis, The SVAP categories and their rating values are delimited by the dashed arrows. Solar radiation at the stream surface is shown by the solid line. It has a scale of 0 to 0.1 kW/m² (assumed stretched across the Y axis on the left).



I believe the percent canopy shading and the relative ranking values from the SVAP and the solar radiation modeling agree remarkably well. A similar display is shown for warm water streams in **Figure 7**.

Figure 7. Canopy shading of the stream surface is shown on the Y axis. The SVAP categories and their rating values are delimited by the black dashed arrows. The exponential receipt of solar radiation at the stream surface is shown by the solid line. It has a scale of 0 to 0.1 kW/m² (assumed stretched across the Y axis on the left).



My personal judgment is the VASP rating of 1 should apply up to the 50% shade value at a distance of about 40 feet. Since the Izaak Walton group has historically concentrated on cold water fisheries, perhaps this difference is to be expected. The NRCS may have also change the final expression for warm water streams.

Fine Sediment

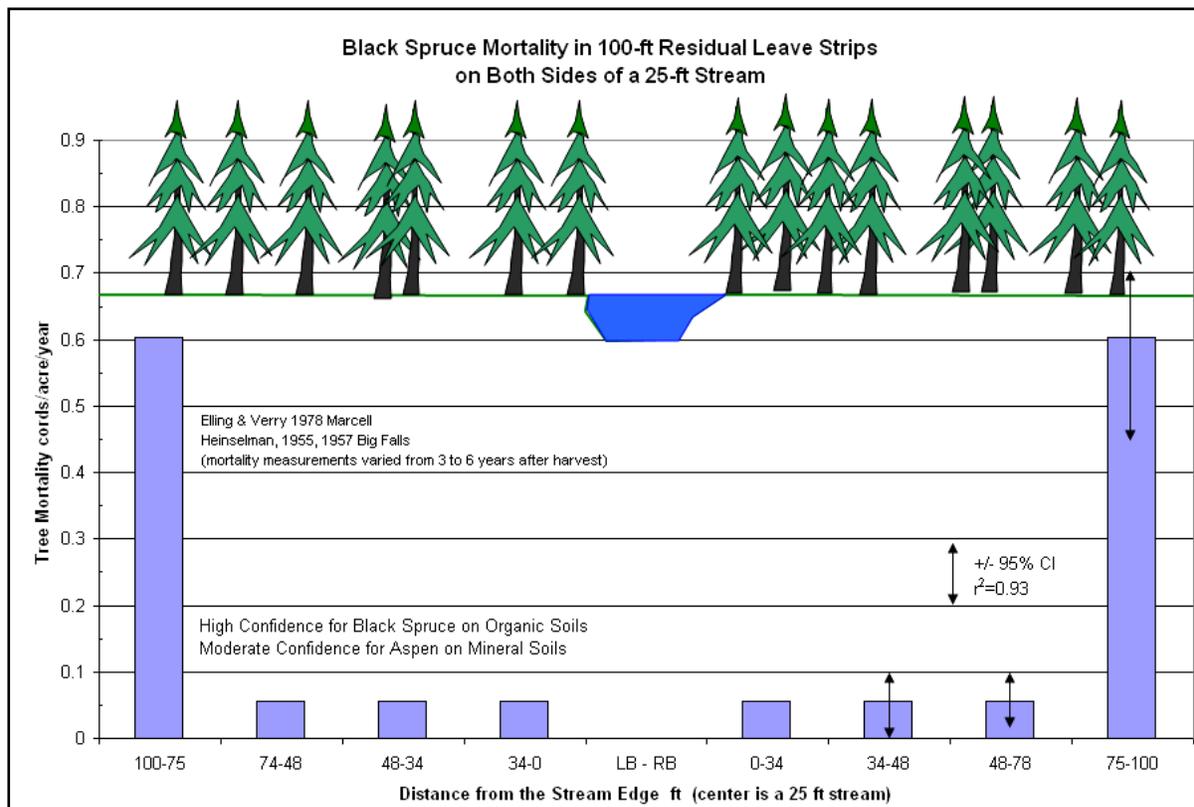
I have not made a review of fine sediment because most fines sediment is streams is a function of the native material the stream is running through, land use changes that increase bankfull discharge (Verry 2004b), or direct input of fines from poorly constructed stream crossings. However, VanDusen et al. (2005) note a negative correlation of recently logged sites in Michigan with brook trout density and biomass and higher fine sediment content.

Evaluation of Windthrow in RMZs

I did not see any attempt to evaluate windthrow in RMZs at our last meeting. However, windthrow is a trump card. Why recommend something resulting in failure? I do not know of any hardwood windthrow studies we could use to evaluate RMZ survival, but there are a number of conifer studies in the literature and several specific to Minnesota (Heinselman 1955, 1957, and Elling and Verry 1978). These studies are for black spruce on organic soils, but until aspen studies are available for the Lake States I would rather examine and use these than nothing at all.

I have analyzed these with respect to an RMZ on one or two sides of a stream. I had not thought of it before, but that makes a significant difference on the overall mortality of the RMZs. The black spruce studies were based on black spruce site index as a predictor. I have also included actual height of the black spruce trees in this evaluation. Heights of 62 feet are the highest evaluated, but are typical for Site Index 40 (ft) black spruce at age 120. Site Index 40 is near average for the species. A presentation of the study results shown with respect to stream side RMZs are shown in **Figure 8**.

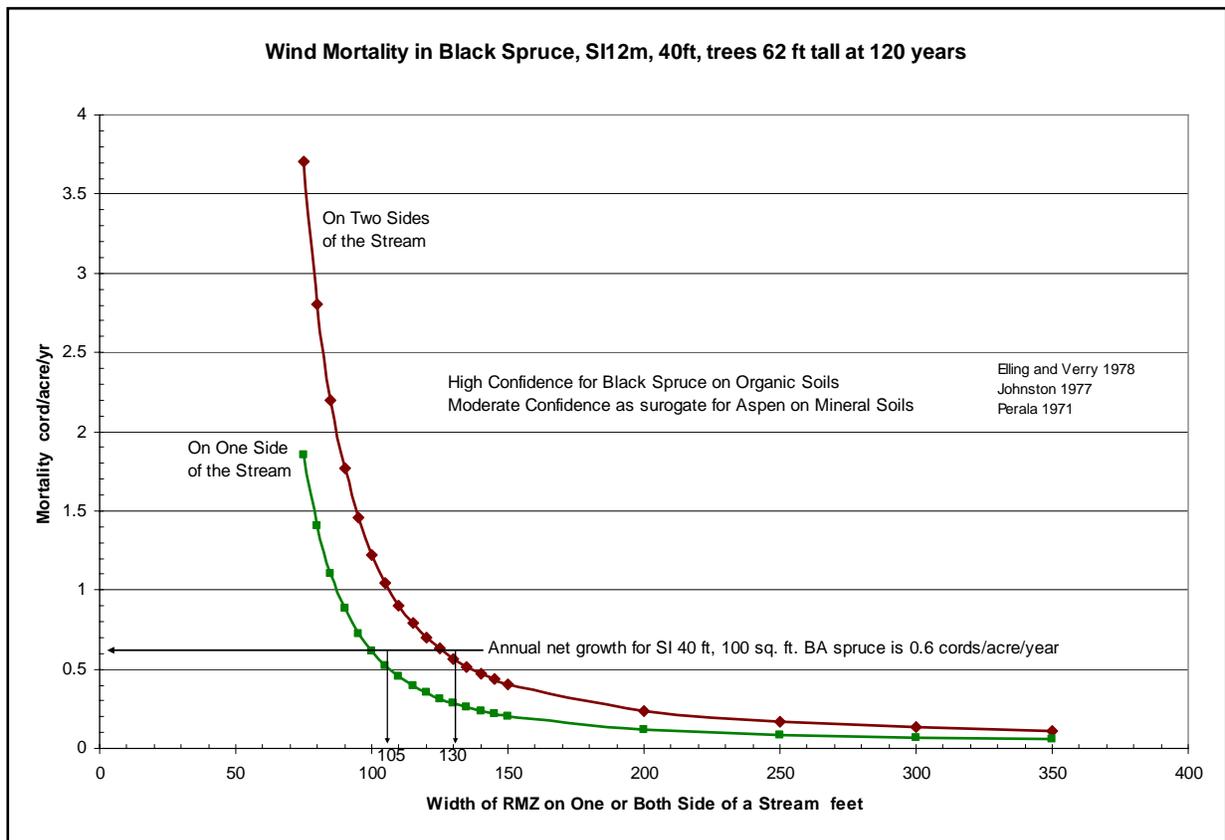
Figure 8. Black spruce mortality in categories of distance from the outer edges of strips on either side of a 25-ft stream. The 95% confidence range and the high r square give these relationships a high confidence for black spruce on organic soil.



These relationships were developed from 7 stands on the Big Falls and Marcell Experimental Forests with mortality data collected 3 to 6 years after harvesting adjacent strips. Mortality is concentrated within 25 feet of the strip edge. The total amount of mortality can be evaluated on an RMZ width basis for either one or two sides of a stream.

Elling and Verry (1978) evaluated the economics of leave strip mortality by simply comparing the width alternatives needed to attain net annual growth equal to annual wind mortality, in other words, a break even point in terms of cords per acre. The relationship of width to total, annual RMZ windthrow mortality is shown in **Figure 9**.

Figure 9. Annual black spruce mortality in leave strips of variable width. This relationship is for a typical SI 40 ft. black spruce stand with 100 sq. ft of basal area. The actual tree height for a 120 year old stand is 62 ft. Annual mortality for this stand is 0.6 cords/acre/year. Categories of RMZ width where annual net growth is balanced by annual wind mortality are 105 feet and 130 feet for an RMZ on one or two sides respectively.



The curves in **Figure 9** represent a family of curves depending on the value of SI. For a SI of 30 the distance values are shifted about 10 feet lower and for a SI of 50 the distance values are shifted about 10 feet higher.

Considerations for Simplifying the General Riparian Guidelines

We have all bemoaned the use of multiple basal areas with multiple silvicultural systems in the current guidelines. I also advocated putting guidelines for streams on an equal basis with guidelines for silviculture. In thinking through the existing guidelines and incorporating recent seasonal pond studies (e.g. Palik et al. 2001) and permanent open water wetland studies (Verry 1985), I also see an opportunity to put open water wetlands and seasonal pond wetland guides in the same table.

Lastly, I see no reason to break lakes at 10 acres compared with open water wetlands. With these things in mind and the relationships developed in this report, I suggest consideration for the following consolidated guides for trout and non trout streams, lakes, open water wetlands and seasonal ponds.

The guidelines for trout streams, tributaries, and lakes (**Table 4**) is based on **Figure 5** and the recommendations of Fortin and Laliberte'. It eliminates the dubious difference between 60 and 80 square feet of basal area. In its place, is a single basal area taken from all of the Manager's Handbooks for commercial tree species in the Lake States.

The data are taken as the lowest basal area for a fully stocked stand (see foot notes). My take as an average for all of them is 75 square feet per acre. I see no logical reason to use 60 as most loggers won't even bid on sales with this few trees. Seventy-five is a realistic bottom end. The distance taken from Fortin and Laliberte' just happens to be about the difference between the two old values (150 and 200 feet); however, there was no attempt on my part to take an average. Instead I relied on **Figure 5** and took it literally.

Otherwise, streams, vegetation, soil and wildlife considerations outside the RMZ are given equal footing and displayed in a single line. Forgive my want to detail the stream bank stuff, but it seems to fit with the basal area, filtered strip, and wildlife notes.

The guidelines for non-trout streams, lakes, open water wetlands, and seasonal ponds (**Table 5**) collapses 6 lines of basal values in the current guide to 2. The single width is based on the windthrow relationships in Figure 9 suggesting 120 feet (the average) would retain existing stand volumes without a net loss over time. This might be changed by studies in aspen. The shading classes from the SVAP and the solar radiation models suggest a minimum width of 110 feet at least for cold water streams (**Figure 6**).

There are a plethora of aspen stand edges and leave strips in Minnesota where a rather quick aspen edge mortality study could be done. The current Riparian Study may also provide opportunity to define a windthrow mortality relationship for aspen. Note that the Pokegama Creeks study had a variety of basal areas left in the RMZ with thinning near the outer edges and a 30-ft no touch area by the channel.

There are sound hydrologic reasons to make a break between open water wetlands and seasonal wetlands at 1 acre. Given this knowledge, why leave the old break at < 10 acres; might as well define the difference and include both open water and seasonal ponds in the guide.

Palik et al., 2001 includes a description of seasonal pond size on the Sucker Lake watershed near Cass Lake, MN. They range in size from .04 to 1.23 acres with most being less than 0.5 acre. If we use 1 acre as a reasonable limit to seasonal pond size, then the current BMP guides that consider open water wetlands less than 10 acres (Table GG-4) can actually be define down to 1 acre and those less than 1 acre as a seasonal ponds.

Verry, 1985 approached the size of wetland issue from the permanent open water side by calculating the size of watershed needed to sustain water in an open water wetland over the growing season using general water balance data for the Lake States. Ratios of watershed area to open water wetland area for the eastern half of Minnesota range from 18 to 3 (drier to wetter climate). For a 1 acre open water wetland the added radius of upland beyond the 1 acre is 100', 150', 200', 250', and 300' corresponding to watershed to open water wetland area ratios of 3 to 17. These are reasonable upland slope distances for the boundary between open water wetlands and seasonal ponds.

Table 4. Guidelines for trout streams, tributaries and lakes (Table GG-4).

Trout Streams, Tributaries, and Lakes¹						
Guide for Stream Banks²	Guide for Riparian Vegetation		Guide for Soil	Guide for Harvest Areas Outside RMZs		
Designated, BMP Crossings ³	Minimum RMZ Width	Minimum RMZ Basal Area	Designated Ski Trails ⁵ Harvest Back to Front. Walk on Slash	Snags	Live Leave Trees ⁶	5% of area in Leave Patches
Designated, BMP Crossings ³	165 ft	75 sq. ft. ⁴	Designated Ski Trails ⁵ Harvest Back to Front. Walk on Slash	All sound	3 to 5+ per acre	¼ acres to several acres ⁷

¹ Each county & DNR Region office has maps of trout streams, tributaries to trout streams, and trout lakes designated by legislature.

² Guide for dry washes in S.E. Minnesota: Use only a selective harvest within 25 ft. of the slope break at the top of gullies. Leave sufficient live trees and their root systems to bind the gully top (leave tree spacing should be 15 to 30 feet along the gully top).

³ Designate all stream crossings (1 to 100 feet wide) on and accessing the sale area. Crossings should protect the bank from crushing and, where needed, allow for fish passage.

- Large streams with permanent crossings:
 - Match culvert, arch, or bridge width to bankfull channel width,
 - Bury culverts 1/6th their diameter
 - Lay on same slope as channel riffle tops
- Fords: rock bottoms (1½- to 4-inch diameter) & rocked (1 ½-inch diameter) approaches (3:1 slope).
- Temporary crossings: use smaller culverts and bridges, or ice and snow bridges in combination with smaller culverts. Remove prior to high flows
- Small streams (with little or no flow): cross on cull logs, brush, and/or snow and ice placed to fill the channel and support the banks. Remove prior to high flows.

⁴ Residual stand basal areas (sq. ft./acre) taken from the Manager's Handbooks for the North Central states are: aspen 60, balsam fir 80, black spruce 60, elm ash cottonwood 50 to 100, jack pine 60, oaks 60 to 75, and red pine 80. An RMZ minimum of 75 avoids recommending borderline under-stocked conditions.

⁵ Timber harvesting methods that consistently protect the soil from compaction, poor tree nutrient status, and reduced productivity are:

- Harvest from the back to the front (access road) of the sale to reduce the traffic on soils that become wetter after trees are cut.
- Transport trees or logs on major, designated, skid roads prior to the sale.
- Pack the designated skid trails with 1 to 2 feet of slash to support repeated traffic.
- Scatter other slash in front of harvesting equipment to support harvest equipment at the stump and forwarding (hauling) equipment to major skid roads.

⁶ Vary the number per acre from 3 to 15 or more with a spacing of 120 to 55 feet respectively. Favor conifer and mast trees (see Table WH-4).

⁷ Leave patch sizes of ¼-acre to several acres in the harvest areas adjacent to the RMZ. In total, they should amount to 5% of the total sale area. The area of the RMZ is not used to calculate the recommended minimum, 5% leave trees in clumps, strips or islands. Patches can be against the RMZ boundaries.

Table 5. Guidelines for non-trout streams, lakes, open water wetlands, and seasonal ponds (GG-6).

Non-Trout Streams, Lakes and Open Water Wetlands, and Seasonal Ponds^{1,2}							
Guide for Riparian Vegetation			Guide for Soil		Guide for Harvest Areas Next to RMZs		
Stream, Lake or Wetland	Min. RMZ Width (ft)	Min. RMZ basal area (sq ft ³)	Filter Strip ⁴ (ft)	Designated Skid Trails ⁵ Harvest Back to Front. Walk on Slash	Snags	Live Leave Trees ⁶	5% in Leave Patches
Streams > 3 ft Lakes > 1 acre Open Water Wetlands > 1 acre	120	75	50-150	Designated Skid Trails ⁵ Harvest Back to Front. Walk on Slash	All sound	3 to 5+ per acre	¼ to several acres ⁷
Streams < 3 ft Lakes < 1 acre Seasonal Ponds < 1 acre	n.a.	n.a.	50-150	Designated Ski Trails ⁵ Harvest Back to Front. Walk on Slash	All sound	3 to 5+ per acre	¼ to several acres ⁷

¹ See Trout Guide for Details on Designated, BMP Stream Crossings.

² Additional guide for dry washes in S.E. Minnesota: Use only a selective harvest within 25 ft. of the slope break at the top of gullies. Leave sufficient live trees and their root systems to bind the gully top (leave tree spacing should be 15 to 30 feet along the gully top).

³ Residual stand basal areas (sq. ft./acre) taken from the Manager's Handbooks for the north central states are: aspen 60, balsam fir 80, black spruce 60, elm ash cottonwood 50 to 100, jack pine 60, oaks 60 to 75, and red pine 80. An RMZ minimum of 75 avoids recommending borderline under-stocked conditions.

⁴ Filter strips are areas where no more than 5% of the soil surface is disturbed. It is vegetated with at least grasses or sedges. The width of filter strip varies with land slope between the activity and water body: (0-10%: 50ft.), (10-20%: 51 – 70 ft.), (21-40%: 71 – 110 ft.), (41 – 70%: 111 – 150 ft.).

⁵ Timber harvesting methods that consistently protect the soil from compaction, poor tree nutrient status, and reduced productivity are:

- Harvest from the back to the front (access road) of the sale to reduce the traffic on soils that become wetter after trees are cut.
- Transport trees or logs on major skid roads designated by the logger, forester, or landowner prior to the sale.
- Pack the designated skid trails with 1 to 2 feet of slash to support repeated traffic.
- Scatter other slash in front of harvesting equipment to support harvest equipment at the stump and forwarding (hauling) equipment to major skid roads.

⁶ Vary the number per acre from 3 to 15 or more with a spacing of 120 to 55 feet respectively. Favor conifer and mast trees (see Table WH-4).

⁷ Leave patch sizes of ¼-acre to several acres in the harvest areas adjacent to the RMZ. In total, they should amount to 5% of the total sale area. The area of the RMZ is not used to calculate the recommended minimum 5% leave trees in clumps, strips or islands. Patches can be against the RMZ boundaries.

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APPENDIX D

HYDROLOGIC FUNCTIONS OF THE RIPARIAN FOREST

by George Ice, Randy Kolka, and Dan Gilmore

August 2007

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HYDROLOGIC FUNCTIONS OF THE RIPARIAN FOREST

G. Ice¹, R. Kolka², and D. Gilmore³

Riparian Functions

Riparian forests, like other forests, influence runoff to streams and other waterbodies. The condition of the riparian forest influences hydrologic processes such as interception, snowmelt, evapotranspiration, infiltration, surface and subsurface runoff, and water storage (see Figure 1). Because of their proximity to water, riparian forests may exert a larger influence on a watershed water balance than other parts of the watershed that are remote from a waterbody. For example, Hicks et al. (1991) found an initial increase in lowflows from a harvested watershed in the Oregon Cascades (due to reduced evapotranspiration) but a subsequent decrease in lowflows. In this case phreatophytic⁴ riparian vegetation left in a buffer may have experienced increased insolation (reduced shading) with removal of the upslope forest stand. In the Southwest, some managers have proposed removing phreatophytes in riparian areas to increase water yields. Hibbert (1981) found that "...the potential for increased water yield in the upstream riparian areas can be greater per unit area than for any other vegetation type." However, he went on to caution that "...extensive removal of trees and shrubs from these areas could...adversely affect channel stability..." and other riparian benefits. The role of phreatophytes is likely more important in the Southwest, where plant access to water may be limited to stream margins during periods of maximum potential evapotranspiration, than in the Lake States.

Figure 1 summarizes key hydrologic functions of riparian forests. These functions are common regardless of whether the forest occurs adjacent to a stream, lake, or wetland. However, the magnitude of response to riparian forest condition depends on both the type and the size of the waterbody. For example, first, second, and third order streams (small streams in the upper part of the watershed) respond more to changes in the riparian area, but they are also more resilient, having developed with greater variability in flow. Figure 1 shows water inputs and outputs in yellow, key functions in green, physical indicators that can be measured to assess functions in blue, and direct and indirect response variables in white. Forest management options can be designed to address either the condition of the vegetation (interception, evapotranspiration, and snow accumulation and melt) or condition of the forest floor and storage components (infiltration, surface storage, and runoff routing). Vegetation management options could include a minimum residual leaf area index (LAI) for sites or a surrogate minimum basal area (BA) restriction. For example, Waring and Schlesinger (1985) report that "...transpiration from forests may be quite similar over a wide range in species composition, size, and stocking densities, particularly if the canopy LAI exceeds 3.0..." Similarly, infiltration rates are frequently correlated with the percent of the contributing area that has bare mineral soil, disturbed soil, or is compacted (Ward and Elliot 1995).

¹ Principal Scientist, NCASI, PO Box 458, Corvallis, OR 97339; (Tel) 541-752-8801; (email) GIce@wrc-ncasi.org

² Project Leader, USDA Forest Service, 1831 Hwy 168E, Grand Rapids, MN 55744-3399; (Tel) 218-326-7115; (email) rkolka@fs.fed.us

³ Professor of Silviculture, University of Minnesota, Dept. of Forest Resources, 1861 Hwy 169 East, Grand Rapids, MN 57744-3396; (Tel) 218-327-4522; (email) dgilmore@umn.edu

⁴ A phreatophyte is "a plant that derives its water supply from groundwater [or hyporheic water] and is more or less independent of precipitation (Helms, J.A. 1998. *The Dictionary of Forestry*. Society of American Foresters, Bethesda, MD.

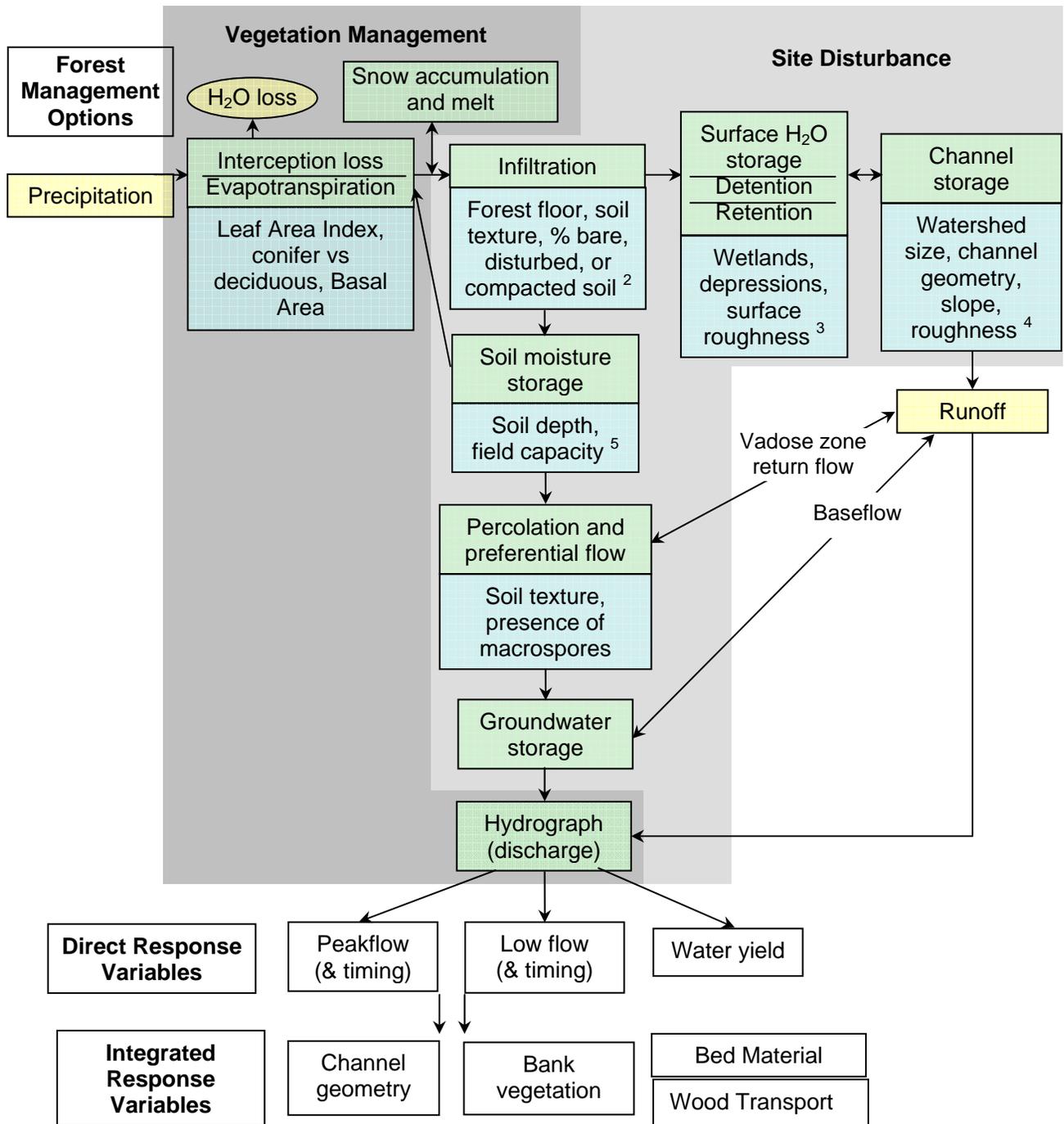


Figure 1. Hydrologic Function of Riparian Forests

Assessing Riparian Forests Compared to Overall Watershed Forest Condition

Streams

Riparian areas must be put in context with the watersheds in which they occur. Hornbeck and Kochenderfer (2004), summarizing research findings from the northeast, report that, "Initial increases in annual water yield of up to 350 mm occur promptly after forest cutting; the magnitude roughly proportional to the percentage reduction in basal area (at least 25 to 30 percent of basal area must be cut to produce a measurable increase..." (Figure 2). Verry (2004) reports similar findings for the Lake States related to peak flows (Figure 3).

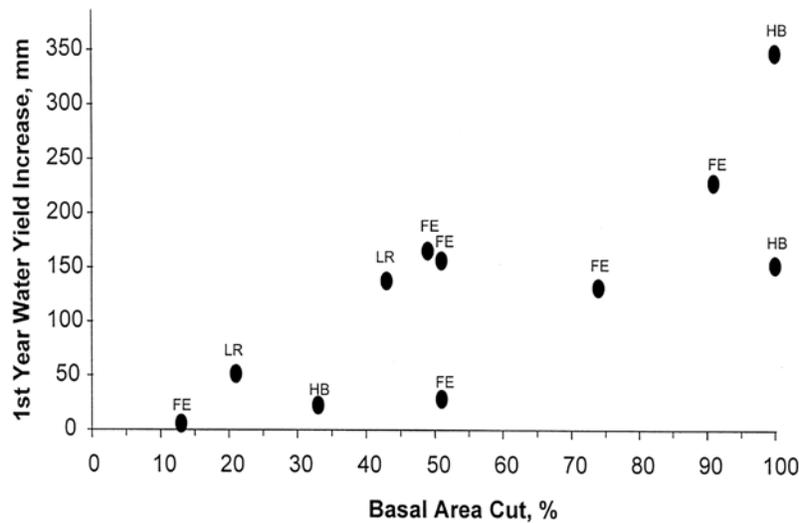


Figure 2. First-Year Water Yield Increases vs Cutting

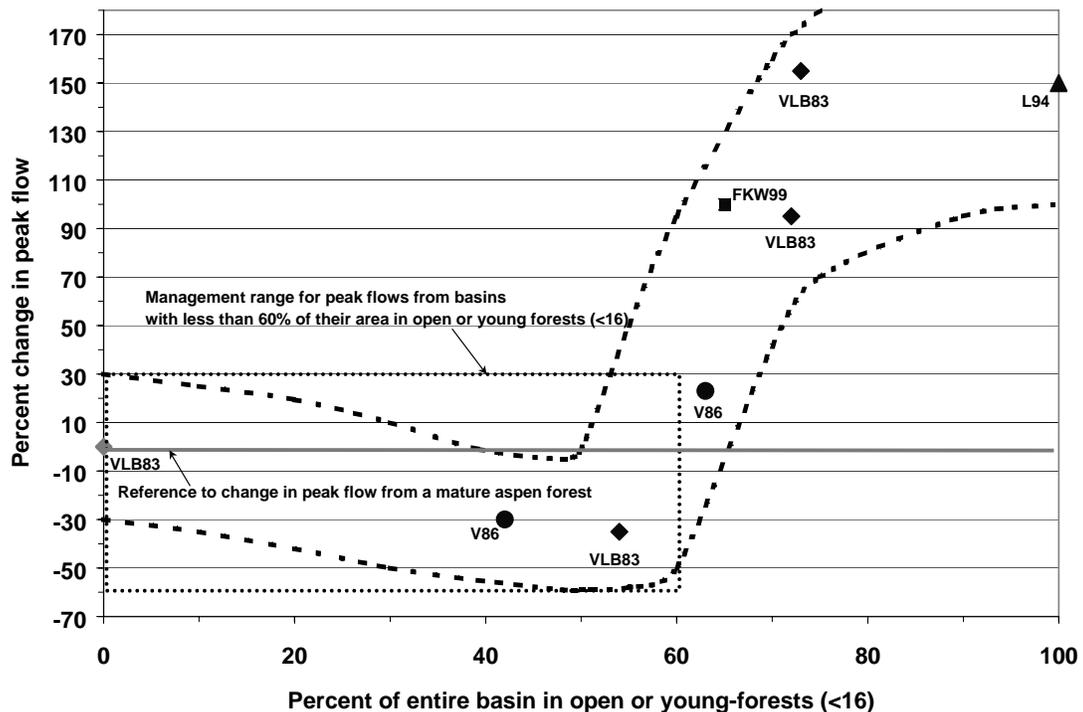


Figure 3. Response of streamflow peak discharge to percent of a basin in open land or young forest. Dashed lines show the range of response for watersheds with less than 60 percent of the area in open or young forest (Verry 2004)

Figure 3 by Verry (2004) shows data for peak discharge response to the percent of the basin in open or young forest. Peak flow is often the response of greatest concern. As shown by Hornbeck and Kochenderfer (2004), the annual discharge relationship is likely to be similar. In regions where snowmelt is a major source of runoff there can be a strong relationship between water yield and peak flows. Where other runoff mechanisms dominate, peak flows may be poorly correlated to water yield. Reidel et al. 2001 report that channel incision for the Nemadja River in eastern Minnesota and northwest Wisconsin occurred in response to increases in "...water yield, particularly bankfull discharge..." The experimental data shown in Figure 3 are small watershed manipulation studies, but data from the Mississippi River before and after settlement also fit within the confidence envelope.

Figure 4 provides another demonstration of the basin-wide role of forests on hydrology. This figure is a double-mass curve that graphs the cumulative peak flow for two basins, one that remains relatively unchanged (Red River) and another (Upper Mississippi River at St. Paul) that experienced land conversion from forest to agriculture around 1908. Departure from the original slope of the graph represents a change in the relationship. This figure shows how the cumulative effects of land use change at the large river scale can increase flows. The key message is that the overall condition of the watershed dominates the hydrologic response and that response is relatively insensitive until greater than 60% of the watershed is in an open or young forest condition.

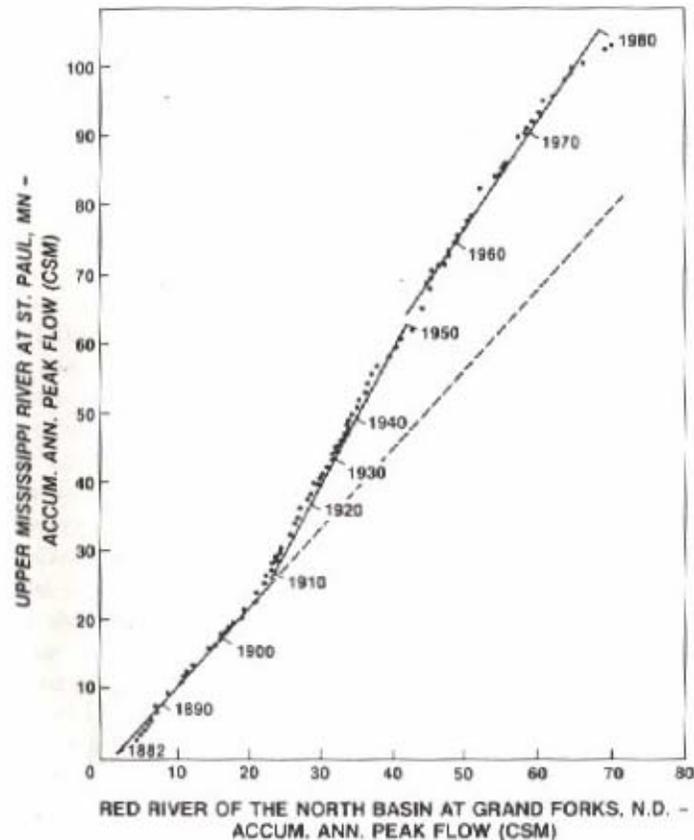


Figure 4. Annual peak flow on the Mississippi River at St. Paul, MN. Peak flows increased approximately 43% in 1908 coincident with the conversion of native forests to agricultural or young forest land (redrawn from Miller and Frank 1982).

Lakes

There isn't much literature on the hydrologic influences that harvesting or land use change has on lakes. Again, most concerns about forest management near lakes is about water quality, not lake stage. Here we present a hypothetical example of lake response.

Let's assume a 150 ha lake and a mean depth of 1.5 m, which is typical of a small lake in this region. The lake volume of this dimension lake is 2,250,000 m³. Let's assume that the watershed for the lake is 500 ha (lake is 30% of watershed) and we clearcut all 350 ha around the lake. The first year after cutting (maximum response scenario) we would expect 9 cm of additional runoff (Verry 1986), which is 315,000 m³ of additional water. That is about 14% of the lake volume, which seems somewhat significant. If this much extra water is added to the lake, the mean lake level would increase to 1.71 m, or 21 cm higher. However, that would be if the lake had vertical slopes. If the lake had a 5-degree slope then the water increase would be only 4 or 5 cm and lake surface area would change only slightly. With increased surface area the lake would likely experience increased evaporation loss. So, for lakes, even small ones, this doesn't seem to be a big issue. Annual variations in precipitation are likely to cause greater changes in lake depth. We conclude that lakes are not likely to see large or immediate hydrologic changes due to riparian harvesting. Furthermore, riparian areas around lakes are more often not harvested due to water quality, habitat, and aesthetic considerations.

Wetlands

We have a number of wetland types and cut scenarios. The first scenario was tested on a bog at Marcell (Verry 1986). The bog was harvested with the upland left uncut. The response of the bog was to have similar water table levels but somewhat more variability over time (Figure 5).

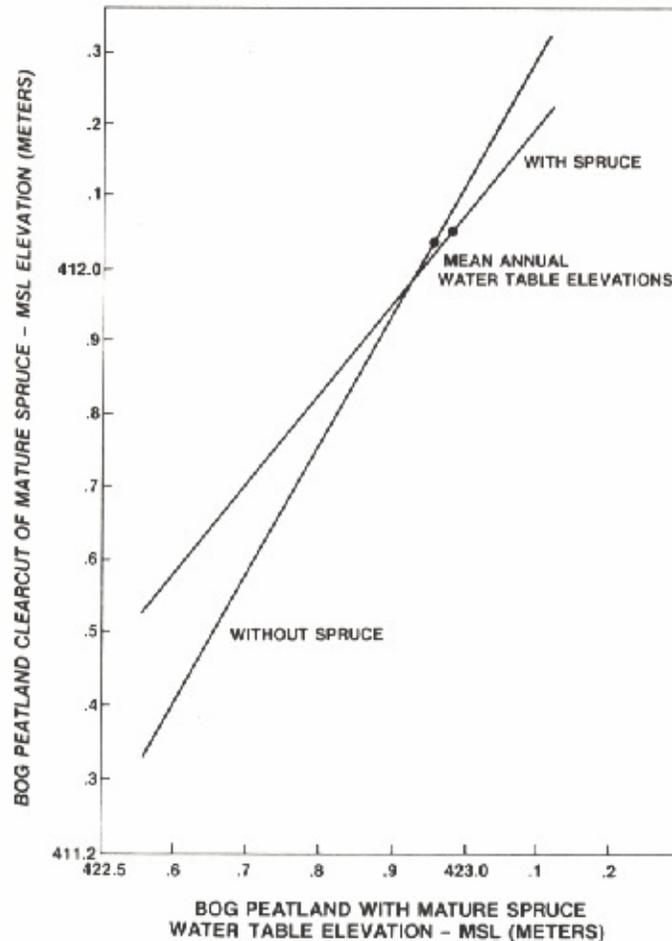


Figure 5. Water table response in bogs clearcut of black spruce. Range in water table elevation is greater for the clearcut than the uncut.

In bog watersheds, because they are domed, little or no response is seen in water table elevation in a bog itself following clearcutting in the upland. Instead there is a watershed-level response because of increased flow through the lagg⁵ to the outlet, but not in the center of the bog.

In fens, because they are groundwater driven, response is greatly dampened following either upland or fen cutting. Cutting in the fen itself may give a similar but a dampened response as that shown in Figure 3. Cutting the upland surrounding a fen may influence water table levels if those additional inputs are a measurable percentage of the groundwater flow through the system. This is not a likely occurrence.

⁵ Natural drainage around the perimeter of the raised bog.

We are just beginning to understand the hydrologic response of seasonal wetlands to harvesting. A current study (Kolka et al. 2004) indicates there may be an initial water table response following the harvesting of the upland. We are not aware of any studies that have harvested the wetland itself and monitored water stage outside of research in the southern United States. Work by Tom Williams at the Bella Baruch Hydrologic Institute (cited in Jackson et al. 2004) shows a strong water table response to both precipitation and evapotranspiration, similar to that bogs.

Hydrology changes to wetlands vary in accordance to the type and size of the wetland. In general, the larger the wetland the less the relative influence of the riparian area. Non-open water wetlands are yet another matter. These wetlands are generally harvested in the winter. We wonder how leaving a ring of vegetation would protect a wetland that is harvested from within.

Management Implications and Overall Conclusions

On the site level, self-sustained hydrologic functions of riparian forests along streams, lakes, and rivers seem most dependent on the level of **vegetation management** and **site disturbance**.

Vegetation management and condition most influence interception loss, evapotranspiration, and snow accumulation and melt. The status of vegetation in the riparian area can be measured using Leaf Area Index (LAI). For operators there might be a need to translate LAI to basal area (BA) or some other measure. The site disturbance component consists of forest management activities that might cause soil disturbance, compaction, changes in storage or routing of water across the riparian zone or in the channel. The disturbances can be largely controlled through equipment exclusions zones or other restrictions that avoid excessive disturbance of the forest floor and bank near a waterbody. Based on this assessment:

- Riparian forest conditions are likely to have a somewhat disproportionate effect on the overall hydrologic response of a watershed, but evidence from this region suggests that overall watershed conditions, not riparian forest condition, determines runoff patterns.
- The smallest waterbodies are likely to experience the largest changes, but these changes are probably not unlike those experienced due to annual variations in weather or natural disturbance events.
- While riparian forest conditions undoubtedly influence the hydrology of adjacent waterbodies, other concerns, such as water quality, are likely much more important.

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The work group determined that the hydrologic function can be simplified a bit as the geochemistry and habitat indicators are reflective of the hydrologic alterations as well. Therefore, a report will be drafted by March 30, 2005, to go out to the RSTC for review. The report will entail the landscape concepts, literature, and graphs on leaf and/or basal area related to the hydrograph, and a discussion of the differences in responses between lakes, rivers, streams, and wetlands.

APPENDIX E

Desired Future Conditions

Examples of Cover Types, Desired Future Conditions, and Management Options

by JoAnn Hanowski and Dan Gilmore

August 2007

Cover Type	Desired Future Conditions	Management options
Spruce-fir	<ul style="list-style-type: none"> ● Maintain current cover-type and promote the presence of long-lived super canopy trees ● Develop a wind-firm stand 	<ul style="list-style-type: none"> ● Manage using even-aged systems of strip clear-cutting with reserves, seed tree, or extended shelter woods ● Orient strips parallel with the water body and make them no more than 50 feet wide ● Maintain the presence of healthy specimens of long-lived species (e.g., white pine, white spruce) when their successful establishment is indicated by the ECS guide ● Manage the stand within the 100-120 sq ft of basal area range to promote windfirmness ● Maintain a live crown ratio of 30% or greater
Jack pine	<ul style="list-style-type: none"> ● Maintain current cover type ● Develop a wind-firm stand 	<ul style="list-style-type: none"> ● Thin early, light, and often to develop wind-firmness ● Manage the stand within the 100-120 sq ft of basal area range to promote windfirmness ● Maintain a live crown ratio of 30% or greater
Red pine	<ul style="list-style-type: none"> ● Maintain current cover type ● Develop a wind-firm stand ● Promote the presence of long-lived super canopy trees 	<ul style="list-style-type: none"> ● Thin early, light, and often ● Due to shoot blight diseases that severely affect red pine regeneration, alternate dominate cover type with other pines. ● Maintain reserve trees throughout successive rotations ● Manage the stand within the 100-120 sq ft of basal area range to promote wind firmness ● Maintain a live crown ratio of 30% or greater
Northern hardwoods	<ul style="list-style-type: none"> ● Maintain current cover type ● Develop a wind-firm stand ● Promote the presence of long-lived super canopy trees 	<ul style="list-style-type: none"> ● Deer management is a must to promote successful hardwood regeneration ● Manage specifically for maintaining long-lived sugar maple and oaks ● Maintain a live crown ratio of 30% or greater
Aspen-white birch	<ul style="list-style-type: none"> ● Maintain current cover type ● Promote the presence of long-lived species when appropriate 	<ul style="list-style-type: none"> ● Even-aged management ● Maintain the presence of healthy specimens of long-lived species (e.g., white pine, white spruce) when their successful establishment is indicated by the ECS guide ● Maintain a live crown ratio of 30% or greater
Mixed aspen-birch-conifer	<ul style="list-style-type: none"> ● Maintain current cover type. ● Promote the presence of long-lived species when appropriate 	<ul style="list-style-type: none"> ● Even-aged or uneven-aged management ● Maintain the presence of healthy specimens of long-lived species (e.g., white pine, white spruce) when their successful establishment is indicated by the ECS guide ● Maintain a live crown ratio of 30% or greater

APPENDIX F

Guideline Recommendations

**As determined by MFRC staff from the
Riparian Science Technical Committee Report**

August 2007

RSTC Guideline Recommendations Cited from Appendix B

Below is text as cited from Appendix B that was interpreted as leaning toward actual guideline recommendations. Most of them appear in the scientist's professional judgment section and are separated out here for future consideration only.

Page from Appx B	Section	Guideline Recommendation
19	Riparian Dependent Birds, Professional Judgment	<p>...it is important to maintain or create habitat features for these species within RMZ's or within a minimum distance to water bodies. These features include super canopy trees for nesting eagles, herons and osprey (e.g., long-lived conifers). It is also important to provide suitable cavity nesting trees for waterfowl species (e.g., large diameter softwoods). Therefore, it is critical to specify a desired future condition of RMZ areas for riparian dependent birds that will maintain these areas in a condition that supports mature forest habitat features. It is recommended that specific information for desired future conditions for RMZs and management prescriptions that would provide these features should be in the voluntary site-level forest management guidelines along with the riparian guidelines. In the current guidebook, this information is in the wildlife section (see Appendix E for example).</p> <p><i>(Note: last sentence here was removed from the report)</i></p>
19	Bird Productivity, Scientific Summary	However, on a landscape scale, this is not the best solution for creating interior habitat. It is likely best to maintain or create large forest patches to provide interior habitat on a landscape level and not to do this solely within RMZs.
21	Interior Forest Birds, Professional Judgment	However, from a management perspective, it is more efficient to maintain interior forest habitat across the landscape by minimizing edge habitat.
22	Dissolved Oxygen, Professional Judgment	Riparian management practices that keep fresh slash out of water, quickly remove slash (especially fine leaves, needles, and bark) that inadvertently gets into water, and maintain shade will avoid major changes in DO concentrations. Narrow buffers and directional felling are likely to achieve these goals, based on observations by Jackson et al. (2001).
24	Turbidity and Total Suspended Solids, Graphics	Directional falling or keeping yarding equipment out the RMZ would moderate these potential impacts.

Page from Appx B	Section	Guideline Recommendation
26	Embeddeness, Professional Judgment	Practices that reduce generation and delivery of fine sediment (less soil disturbance, better roads and erosion control measures) will benefit channel response as measured by embeddeness.
28	Large Woody Debris, Professional Judgment	A minimum buffer of 50 feet should be considered for streams and wetlands to account for both shade and organic matter input to the stream.
29	Forest Amphibians, Professional Judgment	It is recommended that buffer distances for wetlands in mixed landscapes within the geographic range of wood frogs, be larger than those in landscapes dominated by forests (at least 300 feet). In forested landscapes, buffers should be 100 feet around both streams and wetlands.
39	Windthrow, Professional Judgment	Professional judgment leads to an RMZ estimate of 105 ft (32 m) for one-sided RMZs and 130 ft (40 m) for two-sided RMZs to compensate economically for this growing stock loss. Considering potential economic impacts, a practical solution for non-trout streams is not to require RMZs for streams less than three feet wide and to require 120 foot wide RMZs for streams greater than three feet wide.
42	Beaver Interactions	On the basis of professional judgment it is recommended that a distance greater than 165 feet as discouraging beaver use is not enough, as efforts to colonize at all should be discouraged. An RMZ between 200 and 300 feet is a more comfortable zone.

RSTC Guideline Recommendations Removed from the Body of the Report

The following text was removed from the body of the main report and placed here under the premise that they leaned toward actual guideline recommendations.

Page from Report	Section	Guideline Recommendation
11	QTI 5, paragraph 1	These leave patches should be placed in such a fashion so they connect up with other seasonal ponds.
14	QTI 4 & 8, Science, last paragraph	In addition, conifers should be retained where they naturally occur or their establishment encouraged as they provide shade year round.
14-15	QTI 4 & 8, Professional Judgment, 2 nd paragraph	Concerns about stream temperatures in Minnesota may be largely associated with beaver pond development, and therefore, management to create unfavorable habitat for beaver near streams and lakes may be the most effective water quality management strategy (Verry 2006).
15	QTI 4 & 8, Professional Judgment, paragraphs 3, 4, 5	<p>It is recommended that residual BA should be adjusted if justified by a “desired future condition” management strategy. However, even with this recommendation there is concern that active management will not be routinely used to achieve favorable “desired future conditions”. For example, the active management option in Oregon has only been utilized for riparian forest stands 7% of the time compared to the no-cut option (Hairston 1996). Landowners and forest managers may be reluctant to use active management options because of possible short-term risks to water quality and habitat conditions, increased exposure to criticism by the public or others, and increased costs of active management without compensating economic benefits.</p> <p>There was some agreement that a management plan may be desirable to silviculturally achieve a desired riparian condition. Examples of “desired future conditions” and management options are shown in Appendix E.</p> <p>Other methods (e.g., some standard approaches to achieve “desired future conditions”) might also be used to reduce the cost of developing individual plans for harvest units while leading to a “desired future condition”. Realistic incentives to encourage active management may also be needed.</p>
25	Hydrology/ Geochemistry synthesis report	Based on observations by Moring (1975) and Jackson et al. (2001), narrow buffers and directional felling are likely to achieve these goals.