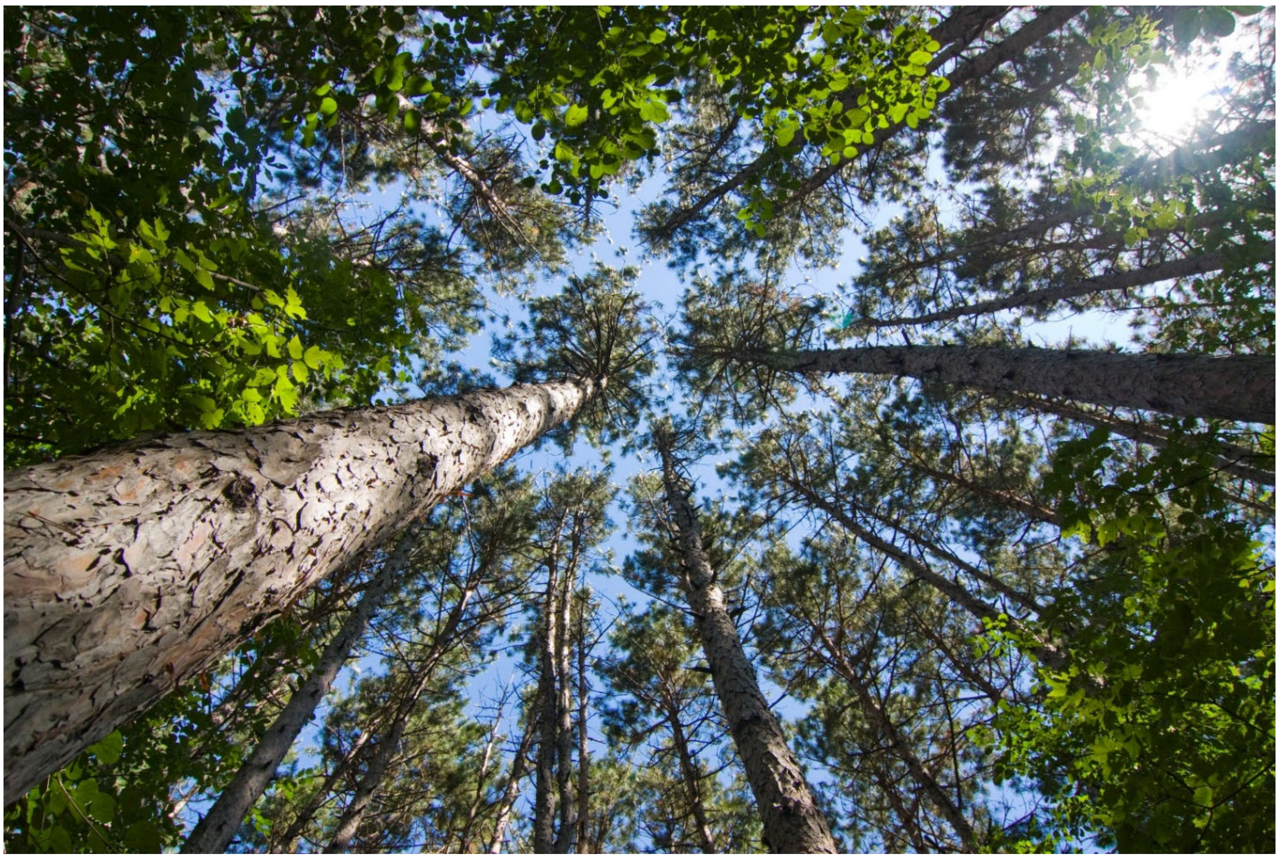
FORESTRY BEST MANAGEMENT PRACTICES TO INCORPORATE INTO THE SCENARIO APPLICATION MANAGER



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FORESTRY BEST MANAGEMENT PRACTICES TO INCORPORATE INTO THE SCENARIO APPLICATION MANAGER

TOPICAL REPORT RSI-2838

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ACRONYMS

BMP	Best Management Practices
GIS	Geographic Information System
HSPF	Hydrological Simulation Program-Fortran
HUC	Hydrologic Unit Code
MNDNR	Minnesota Department of Natural Resources
MNFRC	Minnesota Forest Resource Council
NLCD	National Land Cover Database
RMZ	Riparian Management Zone
SAM	Scenario Application Manager
SMZ	Streamside Management Zones
SSURGO	Services Soil Survey Geographic Database
TAC	Technical Advisory Committee
TSS	Total Suspended Solids

1.0 INTRODUCTION

Minnesota has established robust best management practices (BMPs) guidelines for timber harvesting (e.g., *Sustaining Minnesota Forest Resources: Voluntary Site-Level Forest Management Guidelines for Landowners, Loggers and Resource Managers*) that are designed to maintain water quality when implemented, and voluntary implementation rates are generally high. However, BMP implementation could be improved in certain ways which may increase overall water quality. To assess the effect of increasing BMP implementation to water quality, watershed and land managers can develop scenarios in the Scenario Application Manager (SAM) by modeling increased BMP use at harvest areas. SAM can also be used to compare the cost effectiveness of the increased implementation between different locations throughout the watershed.

This report outlines the BMPs that were identified for use in SAM and the assumptions made to represent the BMPs in the SAM framework. The assumptions and calculations detailed in this report are built into SAM. The BMPs were selected based on our literature research, consultation with the Technical Advisory Committee (TAC), and consultation with forestry researchers at the University of Minnesota. A list of the literature sources that were reviewed for this project and the members of the TAC and project team are included in Appendices A and B, respectively. After reviewing relevant literature and consultations with TAC members, the project team selected erosion-control practices, riparian management zones (RMZs)/filter strips as the BMPs to be included in SAM. Details on the selected practices and assumptions that were made to represent these practices in SAM are presented in this report. Specific information regarding combining RMZs and filter strips into one practice is in Chapter 2.0.

Future considerations for model improvements are included in Chapter 3.0. Future improvements were identified from meetings with the TAC. Improvements on forestland representation, harvesting effects, and their influence on estimations of pollutant loading and hydrological processes in the HSPF model were identified as key concerns.

To access SAM with the Forestry BMPs, please go to the RESPEC website (*https://www.respec.com/*) to download the software and SAM projects for watersheds across Minnesota. This webpage also provides the SAM user manual, support contact information, and tutorials to help new SAM users learn the software.

2.0 BEST MANAGEMENT PRACTICE REPRESENTATION IN SAM

To represent a BMP in SAM, three categories of data need to be quantified: the suitable area, pollutant-removal efficiency, and cost. These categories are needed to meet the SAM framework requirements to simulate the effects that the BMPs have on the HSPF-modeled loads.

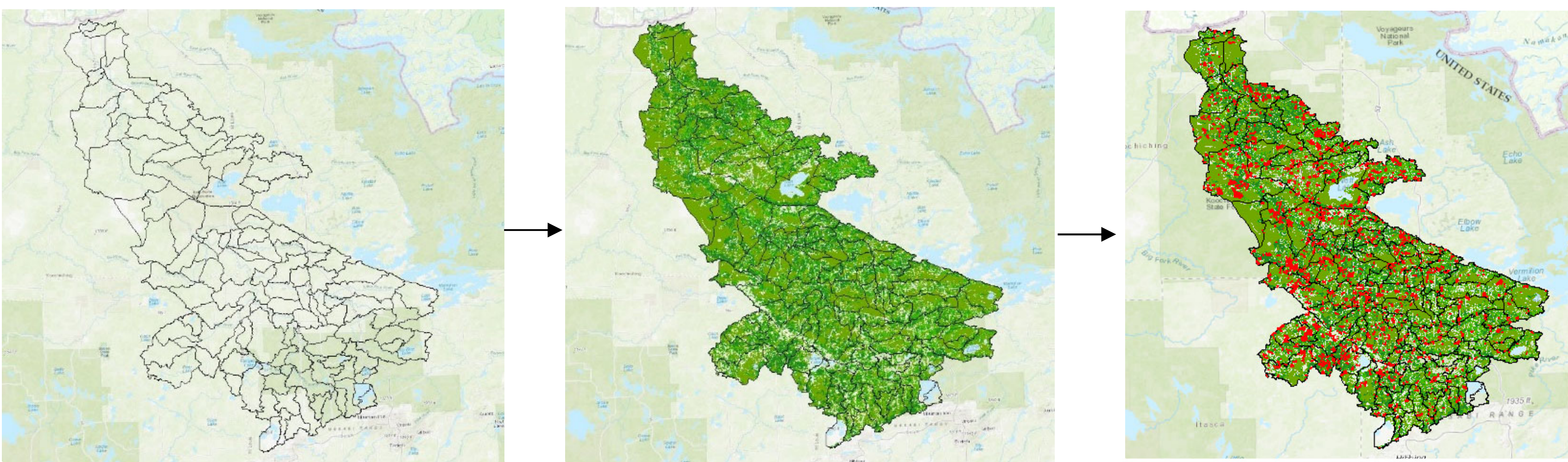
2.1 SUITABLE AREA ANALYSIS

The suitable area in SAM represents an estimate of the harvest area where a BMP can be practically placed. The suitable area analysis ensures that BMPs are applied to appropriate areas (i.e., forest harvest areas and riparian areas) that do not already have BMPs implemented.

The selected forestry BMPs are applied to harvested areas within the forested landscape in a modeled subwatershed. The forested areas are quantified at the modeled subwatershed scale (typically Hydrologic Unit Code- [HUC-] 14) by the National Land Cover Database (NLCD) 2011 land-use data. The harvest area was quantified by data from Dr. Vogeler's [Minnesota Legislation, 2015] most recent fast disturbance analysis and the Minnesota Department of Natural Resources (MNDNR's) Resource Assessment Program's disturbance work [MNDNR, 2017]. Dr. Vogeler's work identified the specific agent of fast disturbance at an annual time step from 1984 to 2015 from Landsat time-series data but was limited to the northeastern portion of the state. This dataset identifies areas that changed each year specifically from harvesting. The MNDNR's data provides the area of forest disturbance from 2000 through 2016 on a semi-annual basis (e.g., year-to-year for a period and every-other year for a period, depending on the watershed). The MNDNR's Resource Assessment Program's estimate for forest disturbance is higher than the actual harvest area because the estimate includes all disturbance types such as defoliation, fire, and wind throw events.

To estimate the forest disturbance specifically from harvesting for the entire state a conversion factor was developed where Dr. Vogeler's data overlapped with the MNDNR's data. In HUC-12 watersheds where both datasets were available (over 1,000 watersheds), the area specific to harvesting (Dr. Vogeler's data) was summed and compared to the total disturbance area (MNDNR's data) to calculate the percentage of forest disturbance area specifically from harvesting. On average, 42.4 percent of the area attributed to forest disturbance from the MNDNR's data was because of harvesting. This conversion factor was applied to the MNDNR's data for the watersheds that lacked specific harvest-area data from Dr. Vogeler's work to develop an annual average harvest area per HUC-12. To account for the regrowth time period of 5 years, the sum of the preceding 5 years of harvest area data were calculated for each year within the dataset (i.e., for any given year, the previous 5 years of harvest were summed to determine the harvest area). These annual summed values were averaged over the period of the dataset to estimate the area in each HUC-12 that was in the regrowth phase. The final output from this analysis is the average harvest area for each modeled subwatershed, which is represented as a percent of total forested land area. This calculated harvest area is ultimately used to estimate the area where the selected forestry BMPs can be implemented, which is shown in Figure 2-1.

Once the harvested area was determined for each subwatershed, data from the MNDNR and Minnesota Forest Resource Council [2013] monitoring reports were used to estimate the implementation rate of BMPs (or the portion of the harvested area that is being treated by existing BMPs).



Model Subwatersheds

Total Watershed Area: 1,199,237 acres

Forested Area

Total Area: 981,664 acres

Percent of Watershed: 82%

Forest Regrowth Area (2011-2015)

Total Area: 39,703 acres

Percent of Watershed: 3%

Figure 2-1. Suitable Harvest Area Determination Process.

The monitoring data are reported for selected areas at the HUC-8 scale, which identifies spatial variability in the implementation rates of BMPs. Monitoring has not been performed on all of the forested watersheds across the state. For forested watersheds that have not been monitored, the state averages for BMP implementation were applied. The implementation rate from the monitoring data was used to develop a percent-implementable factor. The percent-implementable area is the difference between the percent implemented and 100 percent, and this area is the percent of the harvest area where implementation of BMPs can be simulated in SAM. If a subwatershed has a harvest area of 100 acres and a 90 percent implementation rate (10 percent implementable), the SAM user can apply forestry BMPs that treat 10 percent of the sediment source area that is associated with the BMP. The source areas are assumed to contribute most of the sediment load that is delivered to the stream from the harvesting area and are defined in the pollutant-removal efficiency section of this report.

Harvest sites that are adjacent to waterbodies (i.e., streams and lakes) are more likely to deliver pollutants to those waterbodies and impact downstream waters than sites that are farther from receiving waters. To address that issue, a water quality contribution factor was added to the analysis. The water quality contribution factor is the percentage of harvest sites that contain open-water wetlands, lakes, and streams. The water quality contribution factor is the percentage of sites with waterbodies multiplied by the percentage of waterbodies that are not non-open-water wetlands. To apply the water quality contribution factor to the above example, the 10 percent-implementable factor would be multiplied by the water quality contribution factor. If the water quality contribution factor is 20 percent, the final implementable percentage that is corrected for water quality contribution is 2 percent. The SAM user can apply a BMP that treats 2 percent of the sediment source area associated with the BMP. The water quality contribution factor can result in underestimating the treatable load, particularly for erosion control, because of the assumption that harvest sites that are not adjacent to waterbodies do not contribute sediment to surface waterbodies. Table 2-1 lists the factors needed to calculate the water quality contribution factor for the various watersheds with data derived from the monitoring reports.

2.1.1 RIPARIAN MANAGEMENT ZONE/FILTER STRIP

The MNDNR and Minnesota Forest Resource Council (MNFRC) monitoring data on RMZ implementation rates were used to quantify the implementation rate for the RMZs/filter strips BMP. The implementation rates of RMZs range from 28 to 100 percent, although most watersheds have implementation rates at 100 percent [MNDNR, 2016; MNDNR, 2018]. The implementation rates for the RMZs/filter strips BMP were taken from monitoring results of RMZs because the monitoring data specified the implementation rates by waterbody type, whereas the monitoring data for the filter strips were not specific by waterbody type. The implementation results of RMZs in SAM include RMZs that were in total compliance and RMZs in partial compliance (less than 50 percent). The implementation rates of RMZs on open-surface waterbodies (e.g., open-water wetlands, lakes, and streams) were used to represent the implementable area that has impacts to downstream waterbodies. In addition to the implementation rate for the BMP, the water quality contributing factor is applied to account for how many harvest sites have a waterbody present. Multiplying the water quality contribution factor and the implementable rate of RMZs/filter strips achieves the final implementable percent. The monitoring data that were used to derive the water quality contribution factor and implementation rates are provided in Tables 2-1 and 2-2, respectively.

Table 2-1. Water Quality Contribution Factors [MNDNR, 2016; MNDNR 2018]

Monitoring Period	Watershed Unit (HUC 8)	Total Sites Monitored (Number of Sites Per Watershed Unit)	Sites With Waterbodies (Number of Sites Per Watershed Unit)	Total Waterbodies in Monitored Sites (Number of Waterbodies Per Watershed Unit)	Non-Open-Water Wetlands in Monitored Sites (Number of NOWW Per Watershed Unit)	Water Quality Contribution (%)
2014 Through 2015	Mississippi River – Headwaters	35	29	108	95	10.0
	Lake Superior – North and South	30	28	120	101	14.8
	Rum River	28	27	155	148	4.4
	Mississippi River – Grand Rapids	29	27	132	112	14.1
	Vermillion River and Rainy River – Headwaters	26	26	107	84	21.5
	Red Lake, Clearwater River, and Wild Rice River	24	22	109	105	3.4
2016 Through 2017	Crow Wing River Watershed	31	18	171	145	8.8
	Lake of the Woods, Rapid River, Roseau River, and Rainy River	33	30	118	104	10.8
	Mississippi River – Brainerd and Sartell	34	34	180	153	15.0
	Upper St. Croix, Kettle, and Snake Rivers	34	34	334	317	5.1
	St. Louis, Cloquet, and Nemadji Rivers	35	33	155	108	28.6
	Root River, Zumbro River, and Mississippi River – La Crescent, Lake Pepin, and Winona	12	9	17	4	57.0

Table 2-2. Implementation Factors for Riparian Management Zones/Filter Strips [MNDNR, 2016; MNDNR 2018]

Monitoring Period	Watershed Unit (HUC 8)	Total Riparian Management Zones Meeting Guideline Recommendations (%)	Percent of Implementable Riparian Management Zones/ Filter Strips (%)	Water Quality Contribution (%)	Riparian Management Zone/Filter Strip Water Quality Contribution *Adjusted Percent Implementable (%)
2014 Through 2015	Mississippi River – Headwaters	100	0	10.0	1.0[(a)]
	Lake Superior – North and South	100	0	14.8	1.0[(a)]
	Rum River	28	72	4.4	3.1
	Mississippi River – Grand Rapids	100	0	14.1	1.0[(a)]
	Vermillion River and Rainy River – Headwaters	100	0	21.5	1.0[(a)]
	Red Lake, Clearwater River, and Wild Rice River	100	0	3.4	1.0[(a)]
2016 Through 2017	Crow Wing River Watershed	88	12	8.8	1.1
	Lake of the Woods, Rapid River, Roseau River, and Rainy River	100	0	10.8	1.0[(a)]
	Mississippi River – Brainerd and Sartell	100	0	15.0	1.0[(a)]
	Upper St. Croix, Kettle, and Snake Rivers	94	6	5.1	0.3
	St. Louis, Cloquet, and Nemadji Rivers	100	0	28.6	1.0[(a)]
	Root River, Zumbro River, and Mississippi River – La Crescent, Lake Pepin, and Winona	100	0	57.0	1.0[(a)]

*Adjusted % Implementable = % Implementable x Water Quality contribution %.

(a) 1% minimum was set to account for survey data limitations.

2.1.2 EROSION CONTROL

The monitoring data on erosion-control BMP implementation rates ranged from 0 to 67 percent [MNDNR, 2016; MNDNR, 2018]. The implementation rates were based on the percent of temporary forest road/skid trail approaches to waterbodies that were determined to need and have erosion control as well as water quality segments that had erosion control. Implementation factors for erosion control are provided in Table 2-3. Approaches are the sections of temporary forest roads and skid trails that immediately lead into a wetland or waterbody [MNDNR, 2016]. Water quality segments are stretches of skid trails and temporary forest roads that are near wetland and surface waterbodies [MNDNR, 2016]. The approaches and water quality segments are assumed to be the primary areas that could contribute sediment to surface waterbodies, which are defined as the load contributing area. The implementable percent for erosion control is the difference between 100 percent and the sum of currently implemented erosion control on approaches and water quality segments. The currently implemented erosion control is equal to the total approaches and skid trails/roads with erosion control divided by the total approaches and skid trails/roads needing erosion control multiplied by 100. Only approaches needing erosion control are included in this calculation because these approaches are assumed to be the only approaches with the potential to contribute sediment to surface waterbodies or the load contributing area. Approaches and skid trails/roads were merged together because of the limitations on sediment loading data for each source; therefore, their erosion potential and sediment load are assumed to be equal. The water quality contribution factor is applied to the implementable percent of erosion control to achieve the final implementable percent. The final implementable percent represents the percent of load-contributing area erosion control can be applied to in SAM.

2.2 POLLUTANT-REMOVAL EFFICIENCY

SAM represents a BMP's impact to water quality as a BMP pollutant-removal efficiency. Pollutant-removal efficiencies for RMZs/filter strips and erosion control were developed based on literature values. The only pollutant-removal efficiencies that were found in the literature research for the BMPs being added to SAM were for total suspended solids (TSS). A list of the literature reviewed is provided in Appendix A. To correctly apply the removal efficiencies within the HSPF model, the source of the TSS load that a BMP treats was identified. Erosion-control practices treat the sediment that comes from skid trails and temporary forest roads, and RMZs/filter strips treat the sediment that comes from cut-over areas. The TSS load from the forest land use was allocated to each source according to literature values or source-load contribution. The final BMP efficiency is based on the literature for removal efficiencies of the BMP and the source load that the BMP is treating. The modeled removal efficiency for a BMP is the literature value removal efficiency multiplied by the source-load percent of the total harvest area load.

2.2.1 RIPARIAN MANAGEMENT ZONE/FILTER STRIP

The values that were used to determine the RMZ/filter strip TSS removal efficiency are shown in Table 2-4. RMZs/filter strips treat TSS loads that originate from the cut-over area of a harvest site. The cut-over area contributes 10–20 percent of the TSS load from a harvest site. The cut-over load contribution values were derived from research by Christopher and Visser [2007] and our consultation with the research TAC (Appendix B). Pollutant-removal efficiencies for RMZs/filter strips range from 81 to 97 percent based on research on streamside management zones (SMZs) [Cristan et al., 2016; Lakel et al., 2010]. SMZ refers to a riparian area that maintains tree cover and vegetated ground cover.

Table 2-3. Implementation Factors for Erosion Control

Monitoring Time Period	Watershed Unit (HUC 8)	Approaches Needing Erosion Control (Number of Approaches Per Watershed Unit)	Approaches With Erosion Control Installed (Number of Approaches Per Watershed Unit)	Water Quality Segments (Number of Segments Per Watershed Unit)	Water Quality Segments with Erosion Control Installed (Number of Segments Per Watershed Unit)	Percent of Implementable Erosion Control (%)	Water Quality Contribution	Erosion-Control Water Quality Contribution Adjusted Percent Implementable (%)
2014 through 2015	Mississippi River – Headwaters	12	0	16	0	100	10	10.0
	Lake Superior – North and South	13	0	5	1	94	15	14.0
	Rum River	0	0	3	0	100	4	4.4
	Mississippi River – Grand Rapids	5	3	9	3	57	14	8.1
	Vermillion River and Rainy River – Headwaters	19	8	13	8	50	21	10.7
	Red Lake, Clearwater River, and Wild Rice River	3	0	3	1	83	3	2.8
2016 through 2017	Crow Wing River Watershed	1	1	6	1	71	9	6.3
	Lake of the Woods, Rapid River, Roseau River, and Rainy Rivers	2	0	0	0	100	11	10.8
	Mississippi River – Brainerd and Sartell	9	0	10	0	100	15	15.0
	Upper St. Croix, Kettle, and Snake Rivers	6	0	14	0	100	5	5.1
	St. Louis, Cloquet, and Nemadji Rivers	3	2	0	0	33	29	9.5
	Root River, Zumbro River, and Mississippi River – La Crescent, Lake Pepin, and Winona	11	5	9	7	40	64	25.6

However, Minnesota guidelines differentiate RMZs from filter strips. To apply pollutant-removal efficiencies for SMZs from the literature, RMZs and filter strips are assumed to be implemented in conjunction. Site-specific conditions may result in filter strips along a waterbody that has no RMZ; in this scenario, the pollutant-removal efficiencies for the RMZ/filter strip will still apply because the vegetated ground cover is the treatment mechanism of the BMP. To apply the pollutant-removal efficiency to the loads that originate from the harvest area in SAM, the source-load contribution is multiplied by the literature BMP removal efficiency that results in a modeled TSS efficiency. Because of the range of values for source-load contributions and pollutant-removal efficiency, a range of possible final efficiency values were calculated (Table 2-4). A default value that fell within the calculated range was selected using professional judgement; this value can be adjusted by the SAM user.

Table 2-4. Riparian Management Zone/Filter Strip Pollutant-Removal Efficiency Factors

Pollutant-Removal Efficiency Factor	Riparian Management Zone	Sources
Sources That the Best Management Practices Treats	Cut-over	N/A
Source-Load Contributions (Percent of Total Load)	10–20%	Christopher and Visser, 2007
Literature Best Management Practice Removal Efficiency Range	81–97%	Vinson et al., 2017 Wade et al., 2012 Sawyers et al., 2012 Wear et al., 2012 Brown et al., 2014
Possible Range of Modeled Total Suspended Solids Efficiencies	8–19%	N/A
Default Modeled Total Suspended Solids Efficiency	15%	N/A

Note that a list of the sources referenced is provided in Appendix A.

2.2.2 EROSION CONTROL

The values that were used to determine the erosion-control TSS removal efficiency are shown in Table 2-5. Erosion control treats sediment loads that originate from the temporary forest road and skid trail area of a harvest site. The temporary forest road and skid trail area contributes 80–90 percent of the TSS load from a harvest site. The temporary forest road and skid-trail load contribution values were derived from research done by Christopher et al. [2007] and our consultation with the research TAC. Pollutant-removal efficiencies for erosion control range from 62 to 99 percent based on research on a slash treatment [Vinson et al., 2017; Wade et al., 2012; Sawyers et al., 2012]. To apply the pollutant-removal efficiency to the loads that originate from the harvest area in SAM, the source-load contribution is multiplied by the BMP literature removal efficiency value, which results in a modeled TSS efficiency. Because of the range of values for source-load contributions and pollutant-removal efficiency, a range of possible final efficiency values were calculated (Table 2-5). A default value that fell within the calculated range was selected using professional judgement; this value can be adjusted by the SAM user. The modeled TSS efficiency is applied to the loads in the areas that the SAM user specifies when developing a scenario.

Table 2-5. Erosion-Control Pollution-Removal Efficiency Factors

Pollutant-Removal Efficiency Factor	Erosion Control	Sources
Sources That the Best Management Practice Treats	Temporary Forest Roads, Skid Trails	N/A
Source-Load Contributions (Percent of Total Load)	80–90%	Christopher and Visser, 2007
Literature Best Management Practice Removal Efficiency Range	78–99%	Cristan et al., 2016; Lakel et al., 2010
Possible Range of Modeled Total Suspended Solids Efficiencies	62–89%	N/A
Default Modeled Total Suspended Solids Efficiency	75%	N/A

Note that a list of the sources referenced is provided in Appendix A.

2.3 COST

BMP costs are used to derive the benefit-cost ratio (pollutant removal per dollar) for individual BMP applications. SAM allows users to design an optimized scenario that ranks BMPs by the best value based on their individual impacts to downstream waterbodies. Default costs are calculated using the RMZ and filter strip or erosion-control methodologies, but SAM users can edit costs if specific cost data are available.

2.3.1 RIPARIAN MANAGEMENT ZONE/FILTER STRIP

Costs for the RMZs/filter strips came from the MNFRC [2010] report, titled *Economic Analysis of Potential Changes to the Riparian Forest Management Guidelines*. The costs account for the lost stumpage that a landowner faces when not harvesting in the RMZ/filter strip area. Based on the cost analysis, the median cost to landowners for the proposed RMZ guidelines was $4.84 per acre harvested for RMZs on lakes and streams. This cost value is relative to the stumpage rates and is subject to change over time. To apply the cost to the SAM framework, an implementation life is used to provide pollutant removal per acre per year. Based on a BMP implementation life of 5 years, the final cost for RMZs is $0.97 per acre per year.

2.3.2 EROSION CONTROL

Costs for moving slash with a track hoe was cited as $440–$660 per mile of skid trail [US Environmental Protection Agency, 1993]. The cost per mile converted to feet resulted in a range of $0.08 to $0.13 per foot. The default was set to $0.10/foot. To make this value usable in SAM, the value was converted to the average feet of approach skid trail and temporary forest road per acre of harvest. Using values from the Minnesota Forest Management Guidance document and monitoring report, an average of approximately 97.5 feet of skid trails and roads per harvest acre was established. This value is based on the assumption that 3 percent of harvested acres are skid trail or road acres, with 65 percent of that area consisting of 12-foot-wide skid trails and 35 percent consisting of 16-foot-wide forest roads. The average approach length of 1.5 feet per acre was calculated and assumes approximately 6 approaches per site or 0.11 approach per acre. Applying the trail and road width distribution of 65 percent (12-foot wide) and 35 percent (16-foot wide) of the total length of the approach, skid trail, and forest roads is 99 feet per harvest acre on average. When using 99 feet per acre, $0.10 per foot, and a BMP implementation life of 5 years resulted in a final erosion-control cost of $1.98 per acre per year. Appendix C provides more information about these calculations.

3.0 FUTURE CONSIDERATIONS

3.1 CURRENT HSPF FORESTRY REPRESENTATION

HSPF models have been developed throughout the state of Minnesota for the Minnesota Pollution Control Agency (MPCA). The dominant land covers vary depending on the location of the watershed. As a result, the representation of forestry is different based on the extent of the forested areas in the watershed and the impact they have on flow and water quality. In watersheds where forest area is less than 5 percent of the total area, forest may only be represented by one model category. In areas where forest is the dominant land cover, forest may be represented by multiple categories that differentiate the type of forest, soils, slope, and harvesting practices.

The type of forest is categorized using the most representative NLCD land cover data associated with the model simulation period. The forest types that can be represented include coniferous forest, deciduous forest, and woody wetland. The forest types may then be further categorized by hydrologic soil group using the National Resources Conservation Services Soil Survey Geographic Database (SSURGO) soils data. Soils are usually grouped into two categories of hydrologic soil group. Hydrologic Soil Groups A and B are represented as well drained, and Hydrologic Soil Groups C and D are represented as poorly drained. In some areas, where data are available, forest-harvesting practices are estimated and represented as a model category.

Cases where forest-harvesting practices have been represented include the Lake of the Woods and the Mississippi River – Headwaters major watersheds. The harvesting practices in these watersheds were estimated by using the MNDNR forest change coverage to identify areas with significant disturbance as determined by remote sensing with the year of change (2001–2010). This forest change GIS file was used to represent the forest disturbance in the Mississippi River – Headwaters model applications discussed above. The disturbances identified in the MNDNR forest change GIS file include all of the disturbances that result in converting mature forest to young forest and shifts from forest to developed or agriculture. Forests harvested within 15 years of the year represented by the land-cover raster (2013) were chosen to represent regrowth forest in the model. A time period of 15 years was selected because studies have shown that approximately 10–20 years or more are required for stream-water yields to return to preharvest quantities [Keppeler et al., 2008; Sebestyen et al., 2011; Moore and Wondzell, 2005]. Because the land-cover layer represents the surface classification for 2013, regrowth forest includes any forest that changed between 2001 and 2010.

3.2 POTENTIAL HSPF FORESTRY IMPROVEMENTS

The research and analysis performed during this project to add forestry BMPs to the SAM BMP database has provided a better understanding of forest-harvesting practices and their impacts to watershed runoff and water quality. As a result, potential improvements can be made to the HSPF model representation of forest harvesting practices. The primary improvements include improved estimates of harvesting area across the entire state, improved understanding of forest land-cover loading rates, improved understanding of harvesting impacts on local hydrology, and incorporation of factors that impact delivery to the stream such as the proximity to a hydrologically connected stream. Continued research, particularly in Minnesota, will help address some of these data gaps while other data needs (like hydrologic impacts) require a consensus from the research community. A study currently underway by the University of Minnesota examines a harvest site located adjacent to the West Swan River south of Hibbing, Minnesota (Examining the Effects of Timber Management on Water Quantity and Water Quality in the Upper Midwest by Lucy Rose and Diana Karwan) could provide some of this information.

Specific actions that can address some of these concerns include expanding the long-term forest disturbance analysis data from Dr. Vogeler statewide along with adjusting the forest recovery time period in the HSPF model. Currently, 15 years is used as the disturbance regrowth time, but this time frame is primarily estimating recovery from completely removing vegetation. As a part of future enhancements, the regeneration time should be tailored to site-specific characteristics to better represent the variation in regeneration times from one harvest site to another. The Minnesota forestry harvest guidelines recommend practices that promote a faster recovery of the forest stand after harvest. By more accurately representing the land-cover regrowth time period within the HSPF model, SAM users would be able to run scenarios to compare the impacts from multiple regrowth times. Combined with improved forest disturbance analysis and understanding of runoff and sediment loading rates, this method would allow the differentiation between harvesting forest disturbances and other forest land-cover categories.

3.3 POTENTIAL SCENARIO APPLICATION MANAGER FORESTRY BEST MANAGEMENT PRACTICE IMPROVEMENTS

The effort to add BMPs to the SAM BMP database produced two BMPs that represent the primary treatment of sediment that can originate from harvesting areas. As more data and information on the impact of these BMPs and others become available, including phosphorus and nitrogen efficiencies, impacts to stream temperatures, and other practical BMPs can be included in the SAM BMP database. Additional BMPs that could potentially be added in the future as more data become available would be the season of harvest and improved harvesting methods. Including land ownership data in SAM can be another tool added to future improvements of SAM to allow a finer level of detail for targeting BMP implementation. Metrics in the implementation monitoring data are available to help estimate the suitable areas, but better information about their impacts to runoff and water quality are needed to estimate their reduction efficiencies. In addition to expanding BMP representation in SAM, better representation of forest and harvest areas in the HSPF model will improve scenario development in SAM. Scenarios could be created to detect the influences on pollutant loads and hydrology from different stand compositions and widespread land-use changes.

For those interested in using SAM and the newly added forestry BMPs, visit the RESPEC website (*https://www.respec.com/sam-file-sharing/*) to download the software and SAM projects for watersheds across Minnesota. This webpage also includes the general SAM user manual, contact information for help, and a tutorial that is specifically tailored to forestry BMPs. Moving forward, users will be invited to provide feedback on their experiences using SAM and forestry BMPs to help the project team improve future iterations of the tool.

4.0 REFERENCES

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APPENDIX A
LITERATURE REVIEWED

APPENDIX A: LITERATURE REVIEWED

Number	Title	Author(s)	Date		Location of Source
			Month	Year	
1	Sustaining Minnesota forest resources: voluntary site-level forest management guidelines for landowners, loggers and resource managers	Minnesota Forest Resources Council		2012	Minnesota
2	National best management practices for water quality management on national forest system lands	US Forest Service	April	2012	
3	Streamside forest buffer width needed to protect stream water quality, habitat, and organisms: a literature review	Bernard W. Sweeney, J. Deins Newbold	June	2014	
4	Efficiencies of forestry best management practices for reducing sediment and nutrient losses in the Eastern United States	Pamela J. Edwards, Karl W.J. Williard	July/August	2010	
5	Stormwater Management benefits of trees/ draft report	Stone Environmental, Inc.	January	2014	Vermont
6	Minnesota's forest management guidelines field guide	Minnesota Forest Resources Council		2014	Minnesota
7	Minnesota forest resource assessment	MNDNR	June	2010	Minnesota
8	Conservation thresholds for land use planners	Environmental Law Institute		2003	
9	Timber harvesting and forest management guidelines on public and private forest land in Minnesota 2004, 2005, 2006 results compared	Richard Dahlman	April	2008	Minnesota
10	Research gaps related to forest management and stream sediment in the United States	Christopher J. Anderson, B. Graeme Lockaby	December	2010	
11	Analysis of the current science behind riparian issues	Riparian Science Technical Committee	August	2007	
12	Timber harvesting and forest management guidelines on public and private forest land in various watersheds in Minnesota 2014 and 2015 monitoring implementation results	Richard Rossman, Jennifer Corcoran, Robert Slesak	March	2016	Minnesota
13	Sediment associated with forest operations in the Piedmont Region	Kristopher T. Brown, W. Michael Aust, Kevin J. McGuire		2013	Appalachian Mountains
14	The effectiveness of forestry best management practices for sediment control in the Southeastern United States: a literature review	Christopher J. Anderson, B. Graeme Lockaby		2011	Auburn
15	Forest practices as nonpoint sources of pollution in North America	Dan Binkley, Thomas C. Brown	October	1993	Colorado
16	The influence of partial timber harvesting in riparian buffers on macroinvertebrate and fish communities in small streams in Minnesota, USA	Christopher J. Chizinski, Bruce Vondracek, Charles R. Blinn, Raymond M. Newman, Dickson M. Atuke, Keith Fredricks, Nathaniel A. Hemstad, Eric Merten, Nicholas Schlesser	February	2010	Minnesota
17	Effectiveness of forestry best management practices in the United States; Literature Review	Richard Cristan, W. Michael Aust, M. Chad Bolding, Scott M. Barrett, John F. Munsell, Erik Schilling		2016	

Number	Title	Author(s)	Date		Location of Source
			Month	Year	
18	Sediment delivery in managed forests; a review	J.C. Croke, P.B Hairsine	February	2006	
19	Modeling soil erosion and transportation on forest landscape	Ge Sun, Steven G. McNulty		1998	
20	Sediment deposition in streams adjacent to upland clearcuts and partially harvested riparian buffers in boreal forest catchments	David Kreutzweiser, Scott Capell, Kevin Good, Stephen Holmes		2009	
21	Sediment trapping by streamside management zones of various widths after forest harvest and site preparation	William A. Lakel III, Wallace M. Aust, M. Chad Bolding, C. Andrew Dolloff, Patrick Keyser, Robert Feldt		2010	
22	Quantitative review of riparian buffer width guidelines from Canada and the United States	Philip Lee, Cheryl Smyth, Stan Boutin		2004	
23	Relations between fish abundances, summer temperatures, and forest harvest in a northern Minnesota stream system from 1997 to 2007	E. C. Merten, N. A. Hemstad, S. L. Eggert, L. B. Johnson, R. K. Kolka, R. M. Newman, B. Vondracek		2010	Minnesota
24	Riparian microclimate and stream temperature response to forest harvesting; a review	R. Dan Moore, D. L. Spittlehouse, Anthony Story	August	2005	
25	Compendium of forestry best management practices for controlling nonpoint source pollution in North America	Erik Schilling	September	2009	Florida
26	Effectiveness of timber harvesting practices for controlling sediment related water quality impacts	Edward B. Rashin, Casey J. Clishe, Andrew T. Loch, Johanna M. Bell	October	2006	
27	Concentrated flow breakthroughs moving through silviculture streamside management zones; Southeastern Piedmont, USA	B. Lane Rivenbark, C. Rhett Jackson	August	2004	
28	A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration	J.M. Bosch, J.D. Hewlett		1982	
29	A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation	Alice E. Brown, Lu Zhang, Thomas A. McMahon, Andrew W. Western, Robert A. Vertessy		2005	
30	Boreal forest disturbance and streamflow response, northeastern Ontario	J.M. Buttle, R.A. Metcalfe		2000	Ontario
31	Effects of hydrogeomorphic region, catchment storage and mature forest on baseflow and snowmelt stream water quality in second-order Lake Superior Basin tributaries	Naomi E. Detenbeck, Colleen M. Elonen, Debra L. Taylor, Leroy E. Anderson, Terri M. Jicha, Sharon L. Batterman		2003	Minnesota
32	Adapting the water erosion prediction project (WEPP) model for forest applications	Shuhui Dun, Joan Q. Wu, William J. Elliot, Peter R. Robichaud, Dennis C. Flanagan, James R. Frankenberger, Robert E. Brown, Arthur C. Xu		2009	
33	Rainfall generated stormflow response to clearcutting a boreal forest: peak flow comparison with 50 world-wide basin studies	Francois Guillemette, Andre P. Plamondon, Marcel Prevost, Denis Levesque		2005	

Number	Title	Author(s)	Date		Location of Source
			Month	Year	
34	Long-term impacts of forest treatments on water yield: a summary for northeastern USA	J.W. Hornbeck, M.B. Adams, E.S. Corbett, E.S. Verry, J.A. Lynch		1993	
35	Assessing best management practices effectiveness at the watershed scale	G.G. Ice		2011	
36	Evaluating and managing cumulative effects: process and constraints	Lee H. MacDonald		2000	
37	Monitoring the effects of timber harvest on annual water yield	John D. Stednick		1996	
38	Long-term trends from ecosystem research at the Hubbard Brook Experimental Forest	US Forest Service	October	2007	
39	Effects of forest harvesting best management practices on surface water quality in the Virginia coastal plain	T.M. Wynn, S. Mostaghimi, J.W. Frazee, P.W. McClellan, R.M. Shaffer, W.M. Aust		2000	Virginia
40	Hydrologic effects of a changing forest landscape	National Research Council		2008	
41	Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment	W.T. Swank, J.M. Vose, K.J. Elliot		2001	North Carolina
42	Final generic environmental impact statement study on timber harvesting and forest management in Minnesota	Jaakko Poyry Consulting, Inc.		1994	
43	Effectiveness of water diversion and erosion control structures on skid trails following timber harvesting	Ali Masumian, Ramin Naghdi, Eric K. Zenner		2017	
44	Effectiveness of best management practices that have applications to forest roads: a literature synthesis	USFS		2016	
45	Forestry best management practices for timber harvesting and site preparation in the eastern United States: an overview of water quality and productivity research during the past 20 years (1982-2002)	Michael Aust, Charles Blinn		2004	
46	Evaluation of bladed skid trail closure methods in the ridge and valley region	J. Andrew Vinson, Scott M. Barrett, W. Michael Aust, M. Chad Bolding	August	2017	Virginia
47	Comparison of five erosion control techniques for bladed skid trails in Virginia	Charlie R. Wade, M. Chad Bolding, Wallace M. Aust, and William A. Lakel III		2012	Virginia
48	Operational forest stream crossings effects on water quality in the Virginia Piedmont	Wallace M. Aust, Mathew B. Carroll, M. Chad Bolding, and C. Andrew Dolloff		2011	Virginia
49	Forestry best management practices for erosion control in haul road ditches near stream crossings	A.J. Lang, W.M. Aust, M.C. Bolding, K.J. McGuire, and E.B. Schilling		2017	Virginia
50	Stream crossing methods, costs, and closure best management practices for Virginia loggers	Scott E. McKee, Luke A. Shenk, M. Chad Bolding, and W. Mike Aust		2012	Virginia

Number	Title	Author(s)	Date		Location of Source
			Month	Year	
51	Effectiveness and implementation costs of overland skid trail closure techniques in the Virginia Piedmont	B.C. Sawyers, M.C. Bolding, W.M. Aust, and W.A. Lakel III		2012	Virginia
52	Effectiveness of best management practices for sediment reduction at operational forest stream crossings	Laura R. Wear, W. Michael Aust, M. Chad Bolding, Brian D. Strahm, C. Andrew Dolloff		2012	
53	Streamside management zones affect movement of silvicultural nitrogen and phosphorus fertilizers to Piedmont Streams	Joseph M. Secoges, Wallace M. Aust, John R. Seiler, C. Andrew Dolloff, and William A. Lakel		2013	Virginia
54	The effect of increasing gravel cover on forest roads for reduced sediment delivery to stream crossings	Kristopher R. Brown, Kevin J. McGuire, W. Michael Aust, W. Cully Hession, and C. Andrew Dolloff		2014	Virginia
55	Methodology for evaluating post-harvest erosion risk for the protection of water quality	Edwin A. Christopher, Rien Visser		2007	Virginia

APPENDIX B
TECHNICAL ADVISORY COMMITTEE

APPENDIX B: TECHNICAL ADVISORY COMMITTEE

A Technical Advisory Committee (TAC) was created to solicit professional judgment from individuals working in a wide range of positions within the forestry industry. Those who could participate in the TAC met on two separate occasions in Carlton County in December 2017 and May 2018. The December 2017 meeting provided background information to TAC members on the HSPF model, the SAM user interface, and solicited input on what forestry BMPs to include based on available research and real-world applications. After the initial TAC meeting, a research TAC was formed to help the project team identify all relevant studies on pollutant removal efficiencies for specific forestry BMPs. The project team used the information provided by the research TAC to determine which BMPs had sufficient data to be represented in SAM. After selecting BMPs to include in SAM, the project team met with the research TAC to review the final project assumptions. The project team then presented their findings to the general TAC in May 2018 to allow for their review of the selected forestry BMPs, assumptions, and results from a SAM demonstration.

B.1 INVITED TO TAC

Name	Organization	Name	Organization
Ashlee Lehner	MN Forest Industries	Jennifer Corcoran	MN DNR
Barbara Weisman	MN DNR	Lindberg Ekola	MN Forest Resources Council
Brian Fredrickson	MPCA	Lucy Rose	U of M
Charlie Blinn	U of M	Mark Weber	St Louis Land Manager
Chuck Regan	MPCA	Mike Kilgore	U of M Forestry
Dan Steward	BWSR	Mitch Lundeen	Aitkin SWCD
David Bengston	USFS	Patrick Carey	MPCA
Dennis Thompson	Aitkin SWCD	Peter Jacobson	MN DNR
Diana Karwan	U of M	Rachel Peterson	MN Logger Education Program
Dick Rossman	MN DNR	Randy Kolka	USFS
Don Deckard	MN DNR	Ray Higgins	MN Forest Industries
Dr. Sandy Verry	USFS (Retired)	Reed Larson	MPCA
Eli Sagor	U of M Ext; Cloquet	Rob Slesak	MN Forest Resources Council
Emily Peters	MN DNR	Scott Hillard	MN DNR
Greg Bernu	Carlton County	Stephen Sebestyen	USFS
Heather Baird	MN DNR	Steven Olson	Tribal
Jason Meyer	St Louis Land Manager	Wayne Brandt	MN Forest Industries

B.2 GENERAL TAC

Name	Organization	Name	Organization
Ashlee Lehner	MN Forest Industries	Lucy Rose	U of M
Barbara Weisman	MN DNR	Mark Weber	St Louis Land Manager
Brian Fredrickson	MPCA	Mike Kilgore	U of M Forestry
Charlie Blinn	U of M	Mitch Lundeen	Aitkin SWCD
Chuck Regan	MPCA	Patrick Carey	MPCA
Dan Steward	BWSR	Peter Jacobson	MN DNR
Diana Karwan	U of M	Rachel Peterson	MN Logger Education Program
Dick Rossman	MNDNR	Randy Kolka	USFS
Don Deckard	MN DNR	Ray Higgins	MN Forest Industries
Eli Sagor	U of M Ext; Cloquet	Reed Larson	MPCA
Emily Peters	MN DNR	Rob Slesak	MN Forest Resources Council
Greg Bernu	Carlton County	Scott Hillard	MN DNR
Heather Baird	MN DNR	Stephen Sebestyen	USFS
Jason Meyer	St Louis Land Manager	Steven Olson	Tribal
Jennifer Corcoran	MN DNR	Wayne Brandt	MN Forest Industries

B.3 RESEARCH TAC

Name	Organization	Name	Organization
Charlie Blinn	U of M	Lucy Rose	U of M
Diana Karwan	U of M	Rob Slesak	U of M/MN Forest Resources Council
Jennifer Corcoran	MN DNR		

B.4 PROJECT TEAM

Name	Organization	Name	Organization
Angus Vaughn	MPCA	Phil Votruba	MPCA
Greg Johnson	MPCA	Seth Kenner	RESPEC
Julie Blackburn	RESPEC	Tom Estabrooks	MPCA
Karen Evens	MPCA	Tony Donigian	RESPEC
Paul Marston	RESPEC		

B.5 SUITABILITY DATASETS

Reference	Responsible Party	Use
Forest Disturbance	Resource Assessment Program, MN DNR	Harvest area determination
Forest Most Recent Fast Disturbance	Dr. Jody Vogeler, LCCMR	Harvest area determination
Timber Harvesting and Forest Management Guidelines on Public and Private Forest Land in Forested Watersheds in Minnesota: 2014-2017 Monitoring Implementation Results	MN Forest Resources Council, MN DNR	Current BMP implementation rates

B.6 TAC CONCERNS

- Make clear to users that this is a large-scale watershed model. Forestry practitioners work on a site-scale basis, making it important to emphasize the scale at which the SAM tool is useful and accurate.
- Concerned with what the baseline values are in the model and how it is currently representing harvest land.
  - Future improvements identified in Section 3.0 can help address this concern.
- Consider including year to year variations in harvest area in addition to annual averages for each watershed.
  - If the agent of change forest disturbance work by Dr. Vogeler is expanded to cover the entire state this can be looked into further in future projects.
- Lack of land ownership data connected to harvest areas in a given subwatershed. Land ownership is connected to implementation and will have impacts on the suitability factor.
- Representation of forest hydrologic processes in the HSPF model and the impacts to hydrology by harvesting.

APPENDIX C
EROSION CONTROL COST CALCULATIONS

APPENDIX C: EROSION CONTROL COST CALCULATIONS

LENGTH OF TRAILS/ROADS

0.03 acres of trails or roads per acre harvested

35% are 16-ft wide, 65% are 12-ft wide = 0.35 × 16 + 0.65 × 12 = 13.4 feet average trail or road width

0.03 acres × 43560 ft^2/acre/13.4 feet = **97.5 feet** of trails or roads per acre harvested

LENGTH OF APPROACH

6 approaches per site = 0.11 approaches per acre harvested on average

0.11 × 13.4 feet = **1.5 feet** of approach per acre

COST PER ACRE HARVESTED PER YEAR

$0.1 per foot of slash treatment (from the $440-660 per mile range converted to feet)

99 feet approach, roads, and trails = 97.5 feet + 1.5 feet

$0.1 per foot × 99 feet / 5 years = **$1.98** per acre harvested per year