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EVALUATION OF A CABLE YARDER HARVESTING STEEP SLOPES IN SOUTHEASTERN MINNESOTA'S BLUFF COUNTRY

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INTRODUCTION

Harvesting timber is becoming increasingly controversial throughout the United States due to concerns about the effects it can have on the forest. Potential effects include soil compaction and displacement, residual tree damage, sedimentation of water courses, and changes to wildlife habitat, aesthetics, and recreational opportunities. These impacts are becoming less acceptable to a growing population that places a greater value on the forest for recreation and noncommodity values than as a source of wood products.

In response to these concerns, states have developed Best Management Practices (BMPs) and/or have passed forest practices legislation that specify suitable practices to lower site impacts from forestry operations. The Forest Industry also began a program of self-regulation referred to as the Sustainable Forestry Initiative (SFI). Satisfying the stipulations of these programs will require the development and use of "light on the land" technologies. Demonstration of low-impact technologies may help convince a skeptical public that timber harvesting can be compatible with other forest values.

Harvesting systems that lessen impacts will also likely be well-suited to operating on difficult sites. There are many sites in the midwest where operability is severely limited using conventional logging techniques due to either steep terrain or wet ground. Building roads and operating conventional ground-based equipment in these areas can be unproductive, costly, and can result in undesirable environmental impacts. Systems that are economical and environmentally viable on steep slopes and unstable soils are needed. This will reduce the negative impacts associated with harvesting, permit better use of forest resources, and help maintain sustainable ecosystems.

Skyline cable yarding is an extraction system uniquely suited to harvesting timber on steep slopes and unstable soils (Figure 1). In its simplest form, this method consists of a yarder with two large powered winch drums, one carrying the skyline and one carrying the mainline. A tall, guyed spar (also part of the yarder) has pulleys at the top through which the winch lines run to provide lift. The skyline is pulled out, fastened to a tailhold (which is usually a large tree at the end of the yarding corridor), and tightened. A carriage runs along the skyline carrying the mainline with one or more chokers that are manually pulled out and attached to the logs. Logs are pulled to the yarder by powering the mainline winch drum.

The main advantage of skyline cable yarding is that heavy machines do not traverse the site, typically reducing soil impacts. Also, the log is usually transported to the landing with at least one end off the ground, further lowering soil impacts. Cable yarding can also reduce the total length of haul and skid roads needed to harvest the tract, lowering the costs and impacts associated with road building. These impacts include increased potential for water quality degradation, reduced site productivity, and reduced visual quality.

LITERATURE REVIEW

The skyline cable yarding system is commonly used on steep slopes in the western mountain regions, but has not been used extensively in the east since the early 1900's (Peters 1984). It was discontinued in the east after most of the old growth timber was harvested. Increasing log sizes and environmental concerns have brought renewed interest in cable yarding in the east for harvesting difficult sites. While cable yarding is most often used in steep slope applications, it has also been applied on more level terrain using intermediate supports to provide the needed lift to the logs.

Matics (1980; 1982), Keesee (1982), and Norton (1982) report the use of cable yarding in the southeast. Research by the Forest Service and others shows the level of interest in cable yarding in the southeast (Fisher and Peters 1982). Cable yarders studied include the Ecologger (Fisher et al. 1980a), the Urus yarder (Fisher et al. 1980b), the Clearwater yarder (Koten and Peters 1985; Sherar and Tillman 1984), the Koller K-300 yarder (Stuart and Rossi 1984), the Appalachian Thinner (Biller and Fisher 1984), and the Bitterroot Miniyarder (Cubbage and Gorse 1984; Baumgras and Peters 1985). All of these studies were done in steep slope applications.

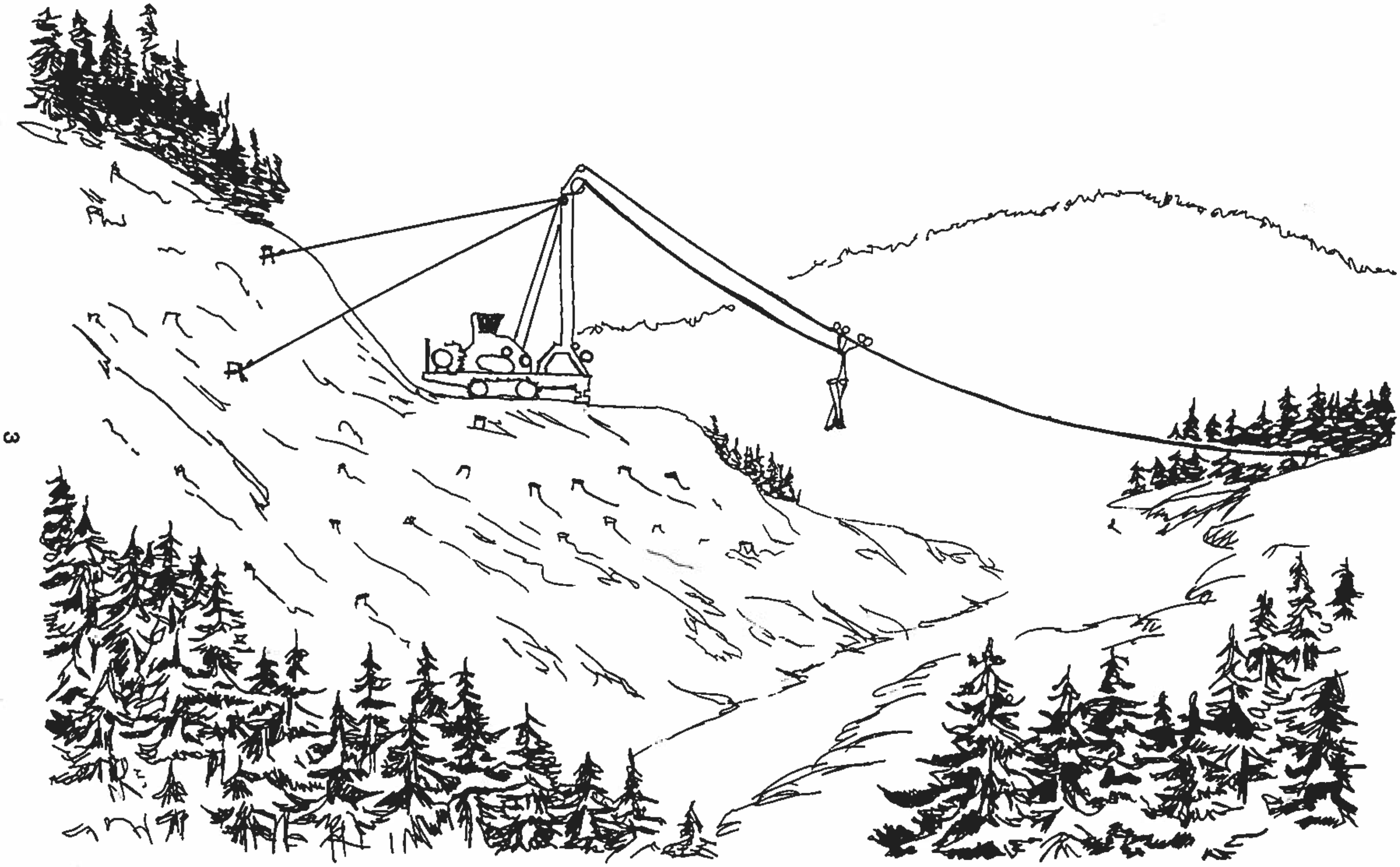


Figure 1. Schematic of a skyline cable yarding system pulling logs uphill

Very little research has been done to evaluate the application of skyline cable yarding systems in the Lake States. Conditions closest to that found in the Lake States were evaluated in a study in Upstate New York (Koten and Peters 1985). It is generally believed that the Lake States has very few sites that justify the use of cable yarding systems. However, Ziemer (1980) estimates that the potential area available for cable yarding within the Lake States is about 4 million acres, which includes both steep terrain and flat, wet sites. Cable yarding could help ensure compliance with BMPs, state regulations, and the SFI on these difficult sites.

OBJECTIVE

The purpose of this research was to evaluate the productivity, cost, and site impacts associated with skyline cable yarding on steep slopes in Minnesota and to evaluate site impacts of a conventional ground-based system on similar sites. A further objective was to demonstrate to managers, landowners, and loggers the extent to which skyline cable yarding can help meet regulatory requirements.

METHODS

Several forest stands of various sizes were selected on Minnesota Department of Natural Resources (MN DNR) land in southeastern Minnesota. The stands contained mostly oak on steep terrain carved out by tributaries of the Mississippi River. The stands were marked for either partial cutting (PC) or clearcutting (CC) as prescribed by MN DNR foresters. Marked trees on each site were chainsaw-felled prior to yarding by the local cooperating logger. The felled trees were yarded uphill to a landing using a Clearwater[1] double-drum cable yarder owned by the U.S. Forest Service (Figure 2). Yarded stems were extracted from the corridor with a crawler tractor and decked in a nearby field. The operation took place in October.

The performance of the yarding operation was evaluated using continuous time study techniques over a two week period for both a Forest Service and a local logging contractor crew. The Forest Service crew had prior experience, but were not full-time operators. The local logging crew had no prior experience with cable systems besides the three-week learning period before evaluation, but were full-time loggers. The felling operation was excluded from this evaluation. Measurements (or estimates) taken included detailed timing of each work cycle of the yarding operation, along with the corridor distance to the stop (the stop is a movable, mechanical device on the skyline used to stop the carriage at a specific point), height of the stop above the ground, lateral ground distance to the stop from the turn, lateral yarding angle from the stop to the turn, number of stems yarded per turn, and diameters and lengths of each log yarded (Appendix A)

Pre-harvest stand and site data and post-harvest disturbance data were collected on skyline cable-logged sites. Post-harvest disturbance data were collected on similar sites that were logged with conventional ground-based equipment (crawler tractors). Pre-harvest information was collected on the overstory, ground cover, and physical attributes of the site. Sample plots were located using a systematic sampling pattern. Plot centers were located at 198-foot intervals along lines spaced 132 feet or 198 feet apart. Plot lines were run at an angle to the contours (up to 10% difference) from random starting points.

Overstory trees larger than 4.5 inches diameter at breast height (dbh) were sampled using one-tenth acre circular plots. Measurements taken included dbh (nearest inch), species, merchantable height, and canopy class. Using the same plot centers, ground cover was sampled using 10 square meter circular plots. Woody vegetation less than 1 inch dbh were tallied by species and height class (<1 m, 1-2 m, and >2 m). Ground cover of herbaceous and deciduous vegetation was recorded using the values described in Kuchlers Physiognomic System. Ground cover was classified as litter, mineral soil, downed woody material, and rock. The aspect, slope, and slope position were also recorded for each plot.

[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. It does not constitute an official endorsement or approval of any product or service by the United States Department of Agriculture, the University of Minnesota, or the Minnesota Department of Natural Resources to the exclusion of others that may be suitable.

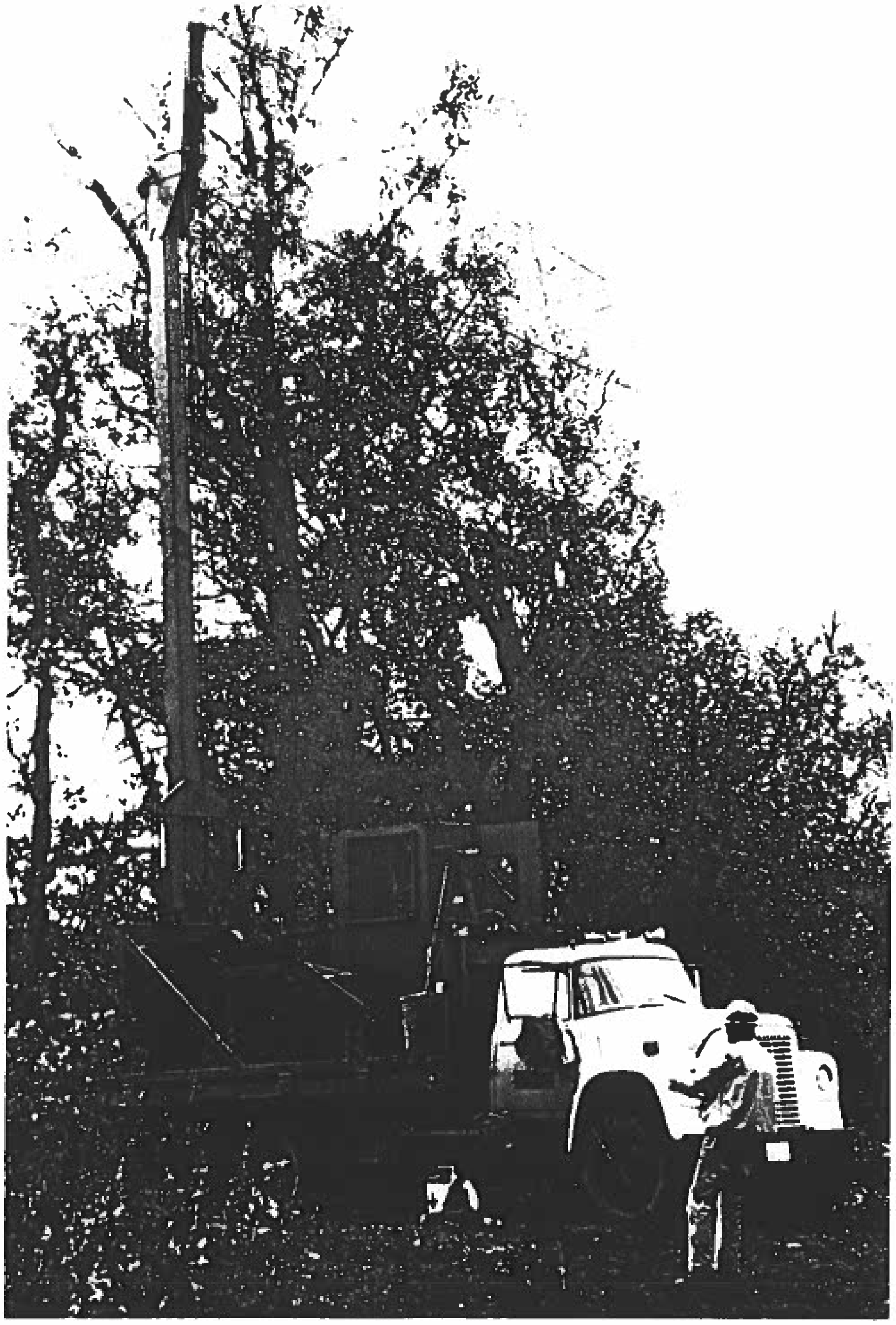


Figure 2. The Clearwater double-drum skyline cable yarder used in this study.

Post-harvest disturbance data was collected using line transects 40 meters long oriented at random azimuths from the pre-harvest sample plot centers discussed previously. Soil disturbances attributable to the harvesting operation were measured continuously along each transect. Measurements included the cause of the disturbance (felling, yarding, or skidding), the severity (low, moderate, high or none), the soil layer exposed (organic or mineral), rut depth, and mound height. The understory disturbance was classified as low, moderate, or high and the slash cover rated as light, moderate, or heavy.

Residual stand damage was determined by conducting a 100 percent survey of all residual trees within the partial cut areas (both yarded and skidded). Measurements for each damaged tree larger than 4.5 inches dbh included location on the slope, distance to the skid trail or yarding corridor, tree dbh, species, cause of the damage (felling, yarding, or skidding), location on the tree, scuff size, height and diameter of broken branches, potential crop tree or not, and other types of tree damage (uprooted, pinned, broken, leaning).

SITE DESCRIPTIONS

Four study sites were selected on which to test the cable yarder (Table 1). Slopes across the four sites averaged 46 percent with a slope length of 300 feet. The soils are generally a silt loam and are considered highly erosive due mostly to slope position. The streams and rivers in this area are considered sensitive to sedimentation because of the desire to maintain clean drinking water and healthy, viable fish populations. Also, these hillsides act as buffers between riparian areas and intensive, upland land uses, while providing important aesthetic values to the area.

Table 1. Attributes of the four cable-yarded study sites in southeastern Minnesota.

Site Attribute	Brightsdale	Caledonia-1	Caledonia-2	Diamond Crk	Overall
Area - acres	12.0	5.5	6.0	5.6	29.1
Slope Range - %	40-60	20-40	45-70	30-52	20-70
Slope Length - ft	200	300	450	350	300
Soil Type	Fayette silt loam	Lamoille Elbaville silt loam	LaCrescent cobbly silty clay loam	Fayette silt loam	
Type of Cut[1]	CC	CC	CC	CC and PC	
Crew	For. Serv.	Local	Local	Local	

[1] CC = clearcut, PC = partial cut

A preharvest assessment of the four cable-yarded study sites indicated a mean basal area of 110 ft² per acre in trees 4.5 inches dbh and larger (Table 2). The basal area ranged from 100 ft² per acre on the Caledonia-1 site (137 trees greater than 4.5 inches dbh) to 122 ft² per acre on the Diamond Creek site (150 trees greater than 4.5 inches dbh). Red oak accounted for the majority of the basal area and volume on all four sites, accounting for 58% of the total basal area and 80% of the total volume. Burr oak was a distant second with 17 other species identified (trees greater than 4.5 inches dbh) on at least one of the four sites.

Attributes of the deciduous understory are presented in Tables 3 and 4. A total of 26 species of saplings from 1-4.5 inches dbh were identified. The top 6 species accounted for about 80% of the total number of stems per acre from 1.0 to 4.5 inches dbh. A total of 34 species of saplings less than 1 inch dbh were identified. The top 9 species accounted for 63% of the total number of stems per acre less than 1.0 inches dbh.

Table 2. Attributes of the deciduous overstory prior to harvesting on the four cable-yarded study sites.

Site Attributes	Red Oak	Burr Oak	American Basswood	American Elm	All Other	Overall Totals
	Species					
Brightsdale						
Trees - #/ac	40	73	13	17	30	160
Basal Area - ft^2/ac	61	38	2	7	7	115
DBH - inches	15.8	9.0	4.9	6.9	5.7	10.3
Volume - bd ft/ac	8053	1085	0	380	0	9518
Caledonia - 1						
Trees - #/ac	42	25	7	14	52	137
Basal Area - ft^2/ac	52	23	2	5	19	102
DBH - inches	14.3	11.8	6.7	7.3	7.6	10.5
Volume - bd ft/ac	4941	535	0	164	546	6186
Caledonia - 2						
Trees - #/ac	65	13	6	13	75	161
Basal Area - ft^2/ac	70	8	1	3	19	100
DBH - inches	13.3	9.4	3.8	5.5	6.4	9.7
Volume - bd ft/ac	5538	173	0	0	63	5773
Diamond Creek						
Trees - #/ac	63	28	25	12	35	150
Basal Area - ft^2/ac	73	14	22	5	9	122
DBH - inches	13.8	8.4	10.6	6.9	6.1	11.1
Volume - bd ft/ac	6133	527	2260	313	0	9233
Overall Averages						
Trees - #/ac	53	35	13	14	48	152
Basal Area - ft^2/ac	64	21	7	5	13.5	110
DBH - inches	14.3	9.7	7.0	6.7	6.5	10.4
Volume - bd ft/ac	6166	580	565	214	152	7678

* ac=acre

The herbaceous and decidous ground cover survey (Appendix B) identified 73 species occurring on at least one of the 18 plots established on three of the four sites (no ground cover information was obtained from the Brightsdale site). Twelve species were identified on 50% or more of the plots located on the two Caledonia sites and eleven species were identified on 50% or more of the plots on the Diamond Creek site (Table 5). American Basswood was the only significant deciduous species frequently identified and established in the ground cover. It was present on 58% of the Caledonia plots and 83% of the Diamond Creek plots. Red oak seedlings were found on only one of the 18 plots.

Table 3. Attributes of the deciduous understory (saplings from 1-4.5" dbh) on the four study sites.

Species	Brightsdale		Caledonia-1		Caledonia-2		Diamond Creek		Average	
	#/ac	%	#/ac	%	#/ac	%	#/ac	%	#/ac	%
Eastern hornbeam	5	1	51	24	266	67	105	33	107	31
American basswood	157	33	20	9	6	2	22	7	51	15
American elm	68	14	40	19	16	4	30	10	39	11
Sugar maple	12	2	28	13	30	7	65	21	34	10
Hackberry	78	16	6	3	11	3	17	6	28	8
Bitternut hickory	0	0	22	10	40	10	10	3	18	5
Slippery elm	58	12	0	0	0	0	0	0	15	4
Blue beech	0	0	0	0	0	0	45	14	11	3
Black cherry	18	4	11	5	4	1	5	2	9	3
Other (17 species)	76	16	35	16	23	6	16	5	36	10
Totals	472	100	214	100	396	100	315	100	349	100

* #/ac = number of stems per acre

Table 4. Attributes of the deciduous understory (saplings less than 1" dbh) on the four study sites.

Species	Brightsdale		Caledonia-1		Caledonia-2		Diamond Creek		Average	
	#/ac	%	#/ac	%	#/ac	%	#/ac	%	#/ac	%
Gooseberry	2591	24	2102	15	1619	11	1484	11	1949	15
Prickly ash	810	8	1775	13	1265	9	405	3	1064	8
Sugar maple	243	2	841	6	405	3	2362	18	963	7
American elm	162	2	1277	9	709	5	1552	12	925	7
Choke cherry	810	8	156	1	1063	7	1080	8	777	6
Buckthorn	2429	23	16	0	202	1	135	1	696	5
Black cherry	567	5	1059	8	860	6	202	1	672	5
Bitternut hickory	0	0	607	4	1316	9	607	5	633	5
Raspberry	405	4	950	7	658	5	405	3	604	5
American hazel	0	0	1121	8	405	2	742	5	567	4
Round-leaved dogwood	0	0	1152	8	152	1	877	6	545	4
American basswood	891	8	218	2	709	5	202	1	505	4
Eastern hornbeam	0	0	327	2	658	5	945	7	482	4
Panicled dogwood	162	1	654	5	506	3	135	1	364	3
Northern red oak	81	1	327	2	860	6	0	0	317	2
Alt.-leaved dogwood	0	0	0	0	658	5	472	3	283	2
Bur oak	162	1	109	1	709	5	135	1	279	2
Hackberry	810	8	93	1	152	1	0	0	264	2
Other (16 species)	567	5	1103	8	1611	11	1888	14	1292	10
Totals	10688	100	13874	100	14524	100	13630	100	13179	100

* #/ac = number of stems per acre

Table 5. Percent of plots with these herbaceous and deciduous ground cover species identified prior to harvesting (only those species found on at least 50% of the sample plots at one of the sites are shown).

Species	Caledonia - combined (percent)	Diamond Creek (percent)	Average (percent)
Geum canadense	92	67	84
Circaea lutetiana	83	67	78
Tilia americana	58	83	66
Cypridpedium (species unknown)	67	50	61
Amelanchier (species unknown)	83	17	61
Thalictrum dioicum	83	0	55
Viburnum rafinesquianum	42	67	50
Prunus virginiana	42	67	50
Zanthoxylum americanum	50	50	50
Aster lateriflorus	75	0	50
Asarum canadense	75	0	50
Rhus radicans var. rydbergii	42	50	45
Parthenocissus inserta	42	50	45
Cryptoteania canadensis	42	50	45
Cornus alternifolia	67	0	45
Aster cordifolius	67	0	45
Rubus strigosis	50	0	33
Galium concinnum	0	50	17

RESULTS AND DISCUSSION

Productivity and cost

The amount of time spent on various activities while cable yarding steep slopes in southeastern Minnesota is presented in Table 6 for the Forest Service crew, the local logging crew, and the average of the two crews. The felling operation was not studied and is not included in this analysis. Each time element may or may not have occurred during each cycle. Ancillary Work Time included supportive work activities that allow the work to continue, such as re-choking stuck logs, clearing brush, re-setting the carriage stop, etc. Preparatory Time included setting up and rigging the yarder, clearing the new corridor, rigging the tail tree, etc. All times were observed except Rest and Meal Time and Service Time, which were assumed from experience to be a fixed portion of the total cycle time to account for expected long-term variability and data comparability.

Overall average cycle time for both crews was 9 minutes per cycle with an equipment utilization rate of about 47%. Average cycle time for the Forest Service crew (9.66 minutes) was more than a minute longer than for the local logging crew (8.45 minutes). This can be attributed mainly to a slightly larger lateral yarding distance and smaller piece size, which increased Outhaul and Hook and Ancillary Work Times because more cycles required multiple stems to achieve the optimum payload.

The productivity, cost, and other attributes associated with cable yarding are presented in Table 7 for the Forest Service crew, local logging crew, and the average of the two crews. The combined average yarding productivity was about 4.1 Mbf per scheduled hour (SH), which is similar to that observed in other studies of this equipment (Koten and Peters 1985). The local logging crew outproduced the Forest Service crew by 0.69 Mbf per SH, due mainly to larger piece size. Overall average yarding cost was about $28 per Mbf, also comparable to previous results (Koten and Peters 1985).

Table 6. Average times for cable yarding on steep slopes in southeastern Minnesota.

Time Element	Forest Service Crew		Local Crew		Overall Average	
	Minutes	Percent	Minutes	Percent	Minutes	Percent
Productive:						
Clear and raise skyline	0.17	1.8	0.27	3.2	0.22	2.5
Carriage to stop	0.29	3.0	0.30	3.6	0.30	3.3
Walk to line	0.12	1.2	0.15	1.8	0.13	1.4
Outhaul and hook	1.36	14.1	1.11	13.1	1.23	13.7
Clear and signal	0.27	2.8	0.09	1.1	0.17	1.9
Lateral yard	0.69	7.1	0.61	7.2	0.65	7.2
Carriage to landing	1.08	11.2	1.10	13.0	1.09	12.1
Walk and unhook	0.40	4.1	0.53	6.3	0.47	5.2
Total Productive Time	4.38	45.3	4.16	49.3	4.26	47.3
Other:						
Ancillary Work Time	1.03	10.7	0.57	6.7	0.78	8.7
Preparatory Time	1.78	18.4	1.55	18.4	1.66	18.4
Rest and Meal Time	1.50	15.6	1.32	15.6	1.40	15.6
Service Time	0.97	10.0	0.85	10.0	0.90	10.0
Total Other Time	5.28	54.7	4.29	50.7	4.74	52.7
Total Cycle Time	9.66	100.0	8.45	100.0	9.00	100.0

Table 7. Productivity, cost, and other attributes associated with cable yarding steep slopes in southeastern Minnesota.

Attribute	Forest Service Crew	Local Crew	Overall
Total Volume - Mbf	86.0	108.4	194.4
Total Cycles	142	173	315
Ave. Volume per Cycle - bf	606	626	617
Total Pieces	203	202	405
Volume per Piece - bf	424	536	480
Ave. Yarding Distance - ft	280	310	298
Ave. Corridor Distance - ft	218	253	238
Ave. Lateral Distance - ft	62	57	60
Productivity - Mbf per SH	3.76	4.45	4.11
Hourly System Cost - $ per SH[1]	114.14	114.14	114.14
Yarding Cost - $ per Mbf	30.36	25.65	27.77

[1]Includes yarder, crawler tractor, and three operators.

Regression analysis was used to evaluate the effect that piece size, number of pieces per turn, corridor yarding distance, and lateral yarding distance had on the productive yarding time per cycle. The coefficients developed from this regression are presented in Table 8, along with the associated correlation coefficients. The four variables explained from 29 to 49% of the variation in the cycle times. Most of this was explained by corridor and lateral yarding distances. These coefficients and regression constants can be used to estimate productive yarding time for different values of these variables, or in sensitivity analyses.

Table 8. Regression coefficients and other statistical attributes associated with the observed productive yarding times.

Attribute	Forest Service Crew	Local Crew	Combined
Coefficients for:			
Corridor Distance (ft)	0.00546	0.00578	0.00529
Lateral Distance (ft)	0.01237	0.01917	0.01496
Pieces per Cycle (number)	0.20610	0.77207	0.45832
Volume per Piece (Mbf)	0.24917	0.58833	0.34917
Regression Constant	1.96	0.36	1.31
Standard Error	1.16	0.87	1.03
Correlation (r^2)	0.29	0.49	0.37
Number of Observations	142	173	315

Residual Stand Damages

Partial cut operations were conducted with both a skyline cable yarding system and a conventional tractor skidder system. A primary consideration in partial cut harvests is the amount of residual stand damage caused by the logging system. Both felling and yarding/skidding damages were assessed (Table 9). In each case, the number of potential crop trees that were damaged was also noted.

Table 9. Total number of trees damaged in felling and extraction by damage class from cable yarding and conventional tractor skidding in partial cut stands (each being 3.25 acres in size) on steep ground of southeastern Minnesota.

	Cable-Yarded			Tractor-Skidded		
Cause of Damage	Scuffed Boles	Broken Branches	Other[1] Damages	Scuffed Boles	Broken Branches	Other Damages
Felling	1	6	4	3	5	22
# Crop Trees	0	0	0	0	3	9
Yarding/Skidding	13	0	1	14	0	2
# Crop Trees	0	0	0	4	0	0
Total	14	6	5	17	5	24

[1] Other damages include uprooted, leaning, broken, and pinned trees.

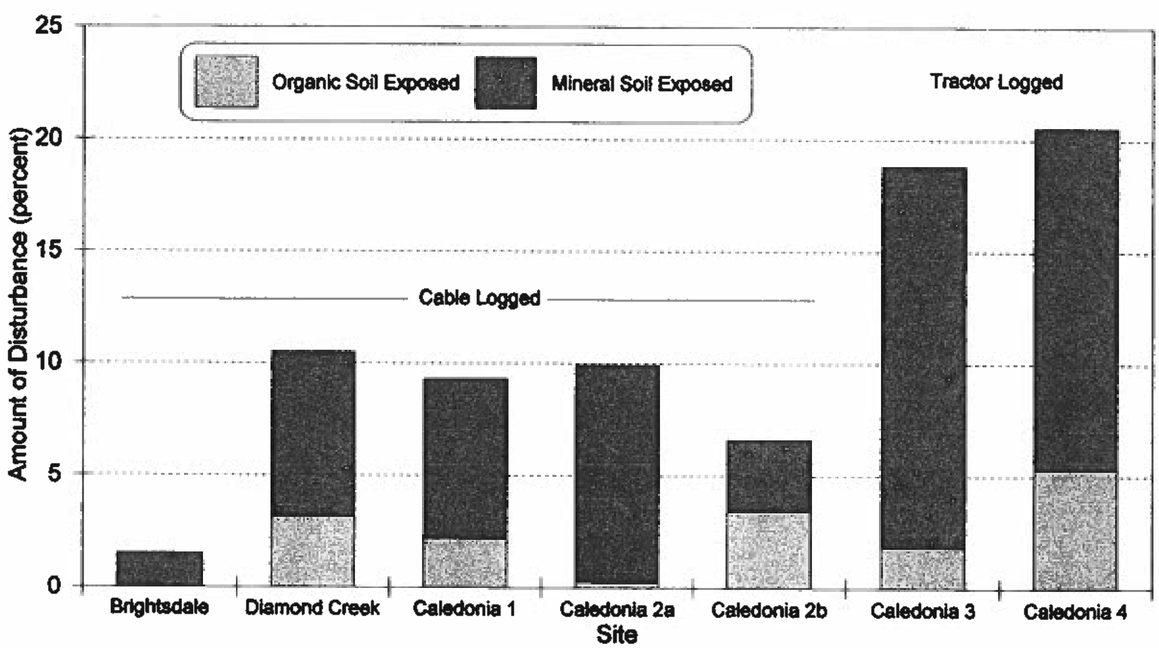
No difference in damage is apparent between cable yarding and tractor skidding (14 and 16 boles damaged, respectively). The major difference between the damage caused by the two systems was in the "other damages" category caused by felling. The felling crew for the tractor skidding system caused 22 other damages compared to only 4 for the cable yarding system. The crews performing the felling were not necessarily the same crew for both operations; therefore, this difference is likely due to sawyer differences. Of all the trees damaged, 23% are considered potential crop trees.

Site Disturbance

After harvesting, the degree of soil disturbance was assessed on the four cable-yarded sites and on two nearby conventionally-logged (tractor-skidded) sites. For analysis of site disturbance, the Caledonia-2 site was divided into the clearcut (Caledonia-2a) and partial cut (Caledonia-2b) portions. Tractor-logged sites were clearcut (Caledonia-3) and partial cut (Caledonia-4). The total amount of soil disturbance by cable yarding was less than that caused by tractor skidding (Figure 3). Soil disturbance on the cable-yarded sites ranged from 1.5 to 10.5% (average 5%) and was mainly a function of topography; greater log suspension resulted in less soil disturbance. Soil disturbance on the two tractor-skidded sites, on the other hand, was consistent and ranged from 18.5 to 20.5% (average 20%) of the area.

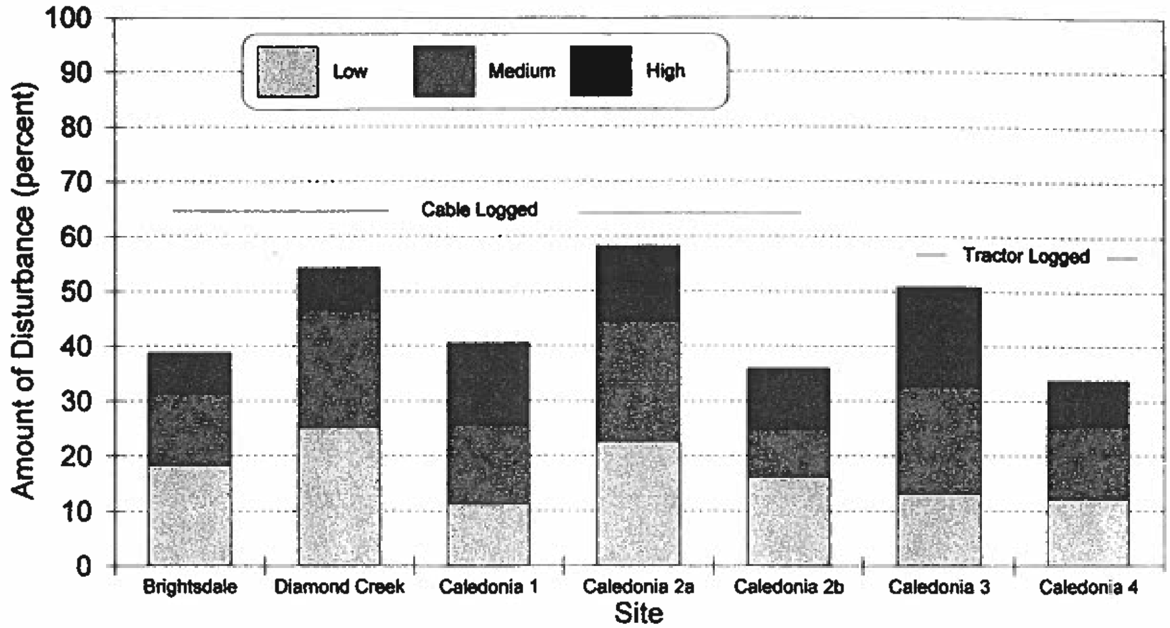
The amount of organic soil exposed was only slightly more for the tractor-skidded sites (3.7% average) than for the cable-yarded sites (1.8% average). However, tractor skidding exposed more mineral soil (15.8% average) than cable yarding (6.0% average). This difference can be attributed to the mechanics of driving a large, heavy tracked machine up and down the slopes vs stringing some cables above the slopes along which logs are dragged. This difference is important relative to the impact soil disturbance has on erosion (and the resulting sedimentation of streams) of these steep slopes in southeastern Minnesota.

Figure 3. Area of organic and mineral soil exposed for the cable-yarded and tractor-skidded sites evaluated in southeastern Minnesota.



The degree of understory disturbance (low, medium, and high) associated with cable yarding and tractor skidding was assessed on each study site. Although soil disturbance levels were more severe from tractor skidding than for cable yarding, understory disturbance levels were very similar (Figure 4).

Figure 4. A comparison of understory disturbance caused by cable yarding and tractor skidding.



SUMMARY AND CONCLUSIONS

Although steep terrain is not usually associated with Lake States forests, there are likely up to 100,000 acres on slopes greater than 45 percent (Ziemer 1980). The conventional method of harvesting these steep sites is with ground-based cable skidders or crawler tractors. While the weight distribution of crawler tractors allows operation without prepared trails, rubber-tired skidders require trails cut into the hillside. The productivity of ground-based cable skidders on these steep sites is typically greater than that observed in this study for skyline cable yarding (4.11 Mbf per SH). Likewise, the usual direct harvesting cost for cable skidding is less than that observed for cable yarding ($28 per Mbf).

Direct harvesting costs, however, do not include the costs associated with excessive soil disturbance, which results in sedimentation, site degradation, and negative aesthetic effects. The skyline cable yarding system evaluated in this study produced similar levels of residual stand damage in partial cuts as the ground-based crawler tractor system. However, cable yarding caused less soil disturbance (5 vs 20% of the area in this study) than the crawler tractor. The level of soil disturbance caused by a particular extraction system rather than the direct operational cost is likely to be the limiting factor on these steep, erosive sites in the future.

Therefore, although the skyline cable yarding system is not the most economic system available to harvest steep sites at present, it may be in the future if ground-based systems are deemed unnacceptable in best management practices or local regulations. Even now, some landowners are not allowing ground-based cable skidder operations on their land, but would allow a cable yarding operation due to differences in soil and aesthetic impacts.

LITERATURE CITED

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APPENDIX A

FIELD DATA SHEETS

Woods Timing Sheet

STUDY MN Cable Yarding SYSTEM____ STAND____ DATE__________

Watch Time	Cycle #	Walk to Line	Outhaul and Hook	Clear and Signal	Lateral Yard	Landing Time	Delay			Comments

Landing Timing Sheet

STUDY MN Cable Yarding SYSTEM____ STAND____ DATE____________

Watch Time	Cycle #	Carriage Out	Woods Time	Inhaul	Walk and Unhook	Raise Skyline	Delay			Comments

Distance Measurement Sheet

STUDY MN Cable Yarding SYSTEM____ STAND____ DATE__________

Watch Time	Cycle #	Corridor Distance	Height of stop	Lateral Ground Distance	Lateral Angle	# of Logs				Comments

Wood Measurement Sheet

STUDY MN Cable Yarding SYSTEM____ STAND____ DATE____________

Watch Time	Cycle #	Diameter 1	Diameter 2	Length	Diameter 1	Diameter 2	Length	Diameter 1	Diameter 2	Length	# Logs	Comments

APPENDIX B

HERBACEOUS AND DECIDUOUS GROUND COVER

Herbaceous and deciduous ground cover

Percent of Plots where Species Present
(in order of frequency on Caledonia sites)

Species	Caledonia Sites (combined) (percent)	Diamond Creek (percent)
Geum canadense	92	67
Amelanchier (species unknown)	83	17
Circaea lutetiana	83	67
Thalictrum dioicum	83	0
Asarum canadense	75	0
Aster lateriflorus	75	0
Cornus alternifolia	67	0
Aster cordifolius	67	0
Cypridpedium (species unknown)	67	50
Tilia americana	58	83
Zanthoxylum americanum	50	50
Rubus strigosis	50	0
Aster (species unknown)	42	33
Cryptoteania canadensis	42	50
Galium aparine	42	0
Fraxinus pennsylvanica	42	17
Viola pubescens	42	0
Quercus macrocarpa	42	0
Prunus virginiana	42	67
Pteridium aquilinum	42	17
Viburnum rafinesquianum	42	67
Parthenocissus inserta	42	50
Rhus radicans var. rydbergii	42	50
Carya cordiformis	42	17
Caulophyllum thalictroides	42	33
Vitis riparia	42	33
Agrimonia gryposepala	42	33
Osmunda claytoniana	33	33
Botrychium virgianum	33	0
Ulmus americana	33	33
Phryma lepostachia	33	33
Smilax herbacea	33	0
Hydrophyllum appendiculatum	25	0
Geranium maculatum	25	33
Diervilla locinera	25	33
Solidago (species unknown)	25	0
Polemonium reptans	25	0
Acer negundo	17	0
Smilacina racemosa	17	33
Solidago flexicualis	17	0
Adiantum pedantum	17	0
Rubus (species unknown)	17	33
Sanguinaria canadense	17	0
Athyrium angustum	17	17
Mitela diphyllum	17	0
Carex (species unknown)	17	0
Hydrophyllum virginianum	17	0
Cornus rugosa	17	0
Sanicula gregaria	8	0
Cornus foemina	8	0
Celtis occidentalis	8	17
Fragaria virginiana	8	33
Desmodium glutinosum	8	17
Fraxinus nigra	8	0
Corylus americanum	8	0
Uvularia perfoliata	8	0
Prunus serotina	8	0
Ostrya virginiana	8	33
Ulmus rubra	8	0
Aralia racemosa	8	0
Amphicarpaea bracteata	8	0
Ribes (species unknown)	8	0
Apocynum androsaemifolium	8	0
Quercus rubra	8	0
Viburnum lentago	0	17
Galium concinnum	0	50
Ariseama triphyllum	0	33
Aralia nudicaulis	0	17
Hepatica acutiloba	0	17
Pilea pumila	0	17
Osmorhiza longistilus	0	17
Juglans cineara	0	17

APPENDIX C

MACHINE RATE CALCULATIONS

MACHINE RATE CALCULATIONS
(off-road equipment)

month: Jan.
year: 1997

Description

Machine(make,model,type) Clearwater Yarder
Accessories or modifications ______
Engine(Hp,type) 100 HP Diesel

Initial Investment(P) - F.O.B delivered cost = $ 100,000
Economic Life(n) 5 years
Salvage Value(S) 20 % of P = $ 20,000
Scheduled Hours(SH) per Year 2000 hours
Machine Utilization(U) 50 %
Productive Hours(PH) per Year 1000 hours

Average Annual Investment(AAI) = $\frac{(P-S)(n+1)}{2n} + S$ = $ 48,000 /yr

Ownership Costs

Depreciation(D) - straight line method = $\frac{P-S}{n}$ = $ 16,000 /yr
Interest 12 %
Insurance 7 %
Taxes 3 %
Overhead 8 %
Total 30 % x AAI $ 48,000 /yr = $ 14,400 /yr

Total Ownership Cost per Year = $ 30,400 /yr

Total Ownership Cost per Scheduled Hour = $ 15.20 /SH

Operating Costs

Repair & Service (% of D) 50 % x $\frac{(D)\$\ 16{,}000\ /yr}{1000\ PH/yr}$ = $ 8.00 /PH

Fuel 100 Hp x 0.022 gal/Hp-hr x $ 1.15 /gal = $ 2.53 /PH

Oil & Lubrication 0.5 % of the fuel cost = $ 1.27 /PH

Tires $\left(\frac{n \times PH/yr}{tire\ life} - 1\right)\left(\frac{1.15 \times \#\ tires \times cost/tire}{n \times PH/yr}\right)$ = $ 0.14 /PH

Total Operating Cost per Productive Hour = $ 11.94 /PH

Labor Costs

Hourly Wage (operator and choker setter) = $ 20.00 /SH

Wage Taxes 50 % of the hourly wage = $ 10.00 /SH

Fringe Benefits 25 % of the hourly wage = $ 5.00 /SH

Total Labor Cost per Scheduled Hour = $ 35.00 /SH

Machine Rate

Total Cost per SH = ownership + operating x U + labor = $ 56.17 /SH

MACHINE RATE CALCULATIONS
(off-road equipment)

month: Jan.
year: 1997

Description

Machine(make,model,type) Medium Crawler Tractor
Accessories or modifications
Engine(Hp,type) 140 Hp diesel

Initial Investment(P) - F.O.B delivered cost = $ 135,000
Economic Life(n) 5 years
Salvage Value(S) 20 % of P = $ 27,000
Scheduled Hours(SH) per Year 2000 hours
Machine Utilization(U) 60 %
Productive Hours(PH) per Year 1200 hours

Average Annual Investment(AAI) $= \frac{(P-S)(n+1)}{2n} + S$ = $ 91,800 /yr

Ownership Costs

Depreciation(D) - straight line method $= \frac{P-S}{n}$ = $ 21,600 /yr

Interest	12 %	
Insurance	7 %	
Taxes	3 %	
Overhead	8 %	
Total	30 %	x AAI $ 91,800 /yr = $ 27,540 /yr

Total Ownership Cost per Year = $ 49,140 /yr

Total Ownership Cost per Scheduled Hour = $ 24.57 /SH

Operating Costs

Repair & Service (% of D) 100 % x (D)$ 21,600 /yr / 1200 PH/yr = $ 18.00 /PH

Fuel 140 Hp x 0.039 gal/Hp-hr x $ 1.15 /gal = $ 6.28 /PH

Oil & Lubrication 37 % of the fuel cost = $ 2.22 /PH

Tires $\left(\frac{n \times PH/yr}{\text{tire life}} - 1\right)\left(\frac{1.15 \times \#\ \text{tires} \times \text{cost/tire}}{n \times PH/yr}\right)$ = $ -NA- /PH

Total Operating Cost per Productive Hour = $ 26.50 /PH

Labor Costs

Hourly Wage = $ 10.00 /SH

Wage Taxes 50 % of the hourly wage = $ 5.00 /SH

Fringe Benefits 25 % of the hourly wage = $ 2.50 /SH

Total Labor Cost per Scheduled Hour = $ 17.50 /SH

Machine Rate

Total Cost per SH = ownership + operating x U + labor = $ 57.97 /SH