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IMPLEMENTATION COSTS OF KENTUCKY'S EROSION CONTROL BEST MANAGEMENT PRACTICES FOR SKID TRAILS

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ABSTRACT OF THESIS

IMPLEMENTATION COSTS OF KENTUCKY'S EROSION CONTROL BEST MANAGEMENT PRACTICES FOR SKID TRAILS

This paper describes a study designed to determine average labor and machine times required to implement erosion control and revegetation best management practices (BMPs) for skid trails in Kentucky. Labor and machine activities were recorded for 14,400 feet of skid trail on 10 nonindustrial private logging sites. Water bar construction and reshaping activities such as filling ruts and berm removal were filmed continuously with a video camera and then analyzed using time-motion study techniques. Labor activities for revegetation such as seeding and application of fertilizer were also timed. The average total machine time for retirement activities per 1000 feet was 51 minutes for sites using dozers and 52 minutes for sites using skidders. The average water bar construction time using a bulldozer was 1.5 minutes (n=112) while the average construction time using a skidder was 3.5 minutes (n = 21). The average amount of labor time required to seed 1000 feet of skid trail was 23 minutes (n = 5). Three methods of water bar construction were observed and analyzed to identify differences among them. While there were significant differences among the three methods, the data suggest that skid trail percent slope may have the greatest effect on water bar construction times.

Keywords: BMPs, Skid trail, Erosion control, Best Management Practices, Water bars, Revegetation

IMPLEMENTATION COSTS OF KENTUCKY'S EROSION CONTROL BEST MANAGE-MENT PRACTICES FOR SKID TRAILS

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2001

IMPLEMENTATION COSTS OF KENTUCKY'S EROSION CONTROL BEST MANAGEMENT PRACTICES FOR SKID TRAILS

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Forestry at the University of Kentucky

By

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Lexington, Kentucky

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2001

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Chapter one: Average machine and labor times required to implement Kentucky's erosion control BMPs for skid trails

Introduction

It would be difficult to overstate the importance of erosion control on disturbed areas associated with timber harvesting such as haul roads, skid trails and log landings given the well-documented pernicious effects of sedimentation on riparian habitats. Although the importance of erosion control on silvicultural operations is undisputed, it's implementation costs are not well defined. Since the 1970s and the passage of the Clean Water Act, considerable research has been conducted to determine the costs of state and federal erosion control programs. However, the majority of these derive overall harvesting costs using estimates of individual practices obtained from surveys of logging and forestry professionals. Lickwar et al. (1992) used the engineering method to determine BMP implementation costs on 22 logging jobs in Georgia, Alabama, and Florida. Table 1.1 expresses individual BMP costs in terms of percent of gross revenue, cost per acre and cost per timber volume for required BMPs and a set of enhanced BMPs. The individual BMP costs were estimated from pertinent literature and from inquiries to professional loggers and foresters. Shaffer et al. (1998) estimated the costs of individual BMPs from responses to questionnaires sent to 272 loggers in Virginia. The level of implementation was measured in the field on 46 logging sites that represented the three different physiographic regions of the state and had passed the state post-harvest inspection. The two were combined to estimate the per acre cost of BMPs in the different regions of the state (Table 1.2). Ellefson et al. (1985) selected six BMPs for cost analysis on 18 timber sales in five states. Table 1.3 represents the combined sale data of all eighteen sites to form a composite sale. The individual BMP costs were estimated from pertinent literature and from inquiries to professional loggers and foresters. Hewitt et al. (1998) used work study techniques and an 8mm video camera to measure the construction times of 191 water bars as well as several variables believed to influence construction time. The resulting regression model was able to account for only 21% of variation in construction time. Using $65 as a base hourly rate for dozer operation and a mean construction time of two minutes and nineteen seconds, they determined that the average waterbar cost to be $2.68.

While the latter study took an important first step in quantifying average machine times for a specific practice, none of these studies address total machine and labor times required for the retirement of skid trails. Retirement includes reshaping trail surfaces, construction of water control structures, and revegetation with grasses and/or legumes. During timber harvest, skid trails can become rutted and develop low outside embankments. Reshaping activities are defined by the removal of such features that channel water down the length of the skid trail or otherwise prevent drainage. The water bar is the control structure of choice for many operators and conditions. Water bars, or deep water breaks, are knee to waist high levees built at an angle across the width of the trail or road so that water is carried off the surface on the down hill side (Figure 1.1). Water bars are easily constructed with equipment typical of timber harvesting operations and, when properly installed, require no maintenance after installation. Revegetation activities are usually confined to seeding, but can also include application of lime, fertilizer, and mulch.

This study focused specifically on machine, labor, and materials used on active logging sites in Kentucky to reshape, construct water bars, and revegetate skid trails. Our main objective was to determine average machine and labor times required to implement skid trail retirement in the various physiographic regions of Kentucky. These averages can be used to provide forest managers, planners, and policy makers with information to generate broad estimates for BMP costs. A secondary objective was to identify a simplified method for loggers to calculate their own average machine and labor expenses, allowing individual operators to more accurately determine site specific costs.

Methods

Ten contract logging operations were identified for study by industrial foresters, forestry consultants, and loggers in Kentucky (Figure 1.2). All sites were upland nonindustrial private forestlands that had received little or no pre-harvest management. Due to an inability to measure key variables, one of the sites was not used in analysis of total machine and labor times. All ten sites were included in the analysis of water bar construction times and road profile measurements. Data collection was divided into site and crew information, skid trail condition prior to retirement, continuous filming of retirement operations, measurement of revegetation activities, and post retirement measurements of water bars and associated skid trail characteristics.

Site and crew information

For each machine operator the following information was collected:

- Years of experience in logging
- Years experience with the equipment used
- Years implementing BMPs
- Kentucky Master Logger graduate or not

Machine information collected included make, model, and horsepower. Linear regression was used to determine the effects of operator experience (logging, BMPs, and machinery operation) and machine size on water bar construction time and reshaping activities.

Skid trail condition prior to retirement

Since reshaping activities are defined by the removal of ruts and outside embankments, reshaping time required for any given length of skid trail will depend, at least partially, on the extent to which those conditions exist. Construction contractors are frequently required to estimate earth volumes so that a cost estimate may be made in terms of cubic volume to be moved. Reshaping is the same type of operation in that voids (ruts) must be filled and solids (embankments) must be cut to smooth or reshape the trail. To quantify the volume of soil to be moved to smooth the trail, cross-sectional profiles were obtained at points along the skid trail. A level line was established perpendicular to the length of the trail with a tripod-mounted laser level placed on the cut bank or uphill side of the skid trail. Using a leveling rod to measure the vertical distance from the level line to the trail surface and a loggers tape to measure the horizontal distance from the trail edge, XY coordinates were taken at each significant, angular change in the contour of the trail surface until the opposite trail edge was reached. For each site included in the study, sampling points along the skid trail were established by randomly selecting a distance (between 1 and 75 feet) from the beginning of the trail to locate the first sampling point and all subsequent points were established at 75 foot intervals until the end of the section of trail was reached. In some cases more skid trail was retired than was included in the profile measurements. In these cases the measured average cross-sectional profile was considered to be the average for the entire section of skid trail retired. Before cross-sectional profiles could be constructed, the profile was mathematically manipulated to account for insloping and outsloping. Also, since the level line was above the trail surface, the vertical distances from the level line to the trail surface were inverted. Both of these conversions were completed simultaneously with the following equation performed on each individual XY coordinate (Figure 1.3). Then the equation used is:

$(X_p - X_{p-1}) + [(Y_p/\text{total width}) * (\text{total vertical deviation across trail})]$

Where

p = point designation

X_p = elevation at point

Y_p = Distance to point from cut bank origin

The effect of this calculation is to set the first point (the origin) to zero and then raise or lower each point a proportionate amount depending on the percent inslope or outslope and the individual point's distance from the origin. More simply put, it raises or lowers the X axis to meet the first point and then rotates the profile (with the first point as the pivot) until the last point is also on the X axis. Once the corrected elevation values are established, the volume of solid or void between any two points was determined by multiplying the average of the two elevations by the horizontal distance between them. After this calculation was performed for each area between transect points, a zero line was established. By establishing an imaginary line drawn parallel to the X axis through the profile so that if all the solids (embankments) above the line were to be scraped off into the voids (ruts) below the line, the surface would be flat. In other words the dirt above exactly fills the ruts below and the trail surface is reshaped. This determination was accomplished by using the average of the corrected elevations to estimate the zero line elevation and then calculating the volume of solid above the line and the volume of void below the line. To accurately set the zero line so that the solids (positive) equaled the voids (negative), a Microsoft Excel® 2000 feature called Goal Seek was used. The positive value is the cut area and the negative value is the fill area. The cut area was averaged for each site and then multiplied by the total length of the sampled trail to estimate the earth volume moved during reshaping. Also extracted mathematically from the profile data were the trail width, average rut depth, and the depth of the deepest rut. In this study, a rut is a negative vertical deviation from a line perpendicular to the trail length that connects the base of the cut bank to the highest point on the opposite side of the skid trail and may or may not be associated with a wheel track. Average rut depth is the average of the two greatest negative deviations from the line. Multiple linear regression was used to establish relationships among cut area, trail width, average rut depth, and depth of the deepest rut. The data were transformed using log base 10 before applying a Shapiro-Wilk test for normal distribution that was not significant. The estimated volume of earth to be cut from the trail surface during reshaping was derived by multiplying the average cross-sectional area calculated above by the skid trail length. A simplified method for estimating the volume of earth to be cut from the trail surface during reshaping was developed.

Continuous filming of retirement operations

Reshaping and water bar construction activities were filmed continuously with an 8mm video recorder equipped with automatic time stamping. Differences in water bar construction and reshaping times among regions and machine types were evaluated using one-way analysis of variance tests.

Post retirement measurements of water bars and skid trail

After all machine operations were completed, the dimensions of each water bar were recorded and then used to calculate the volume of earth used for each bar. The dimensions of each water bar consisted of four measurable aspects; the uphill levee face length, the downhill levee face lengths, the inside angle of the levee peak, and levee length. Face lengths were measured by placing a leveling rod against the levee face on an estimated plumb line (neither askew to the left or right) roughly in the center of the skid trail with the foot of the leveling rod placed firmly on the skid trail surface. The measurement was taken to the nearest tenth of a foot at the peak of the levee. The inside angle of the levee peak was measured with an angle gauge placed on the flat surface of the leveling rod while the face lengths were being measured. The levee length was measured with a logger's tape from the cut bank to the end of the levee to the nearest foot. Using these four measurements, and considering the levee as half of a parallelogram, the cross-sectional area is equal to one half the product of the uphill face length, the downhill face length, and the sine of the inside angle of the levee peak (Figure 1.4). The volume is calculated by multiplying the cross-sectional area by the levee length. Total water bar volume was added to the volume of earth moved during reshaping to estimate the total volume of earth moved during retirement. Linear regression was used to establish a relationship between total volume moved and total machine time.

Trail characteristics associated with each water bar such as trail width, percent slope of the trail above the water bar, and the percent side slope were also measured. Trail width was measured to the nearest foot with a loggers tape while slope percents were measured with a Sunnto clinometer to the nearest percent.

To obtain volumetric soil moisture for each site, one soil sample per water bar was taken from several inches below the surface, aggregated, and sealed in an airtight plastic bag.

Revegetation activities

Another method of combating soil erosion on skid trails and other disturbed areas is to stabilize the bare soil by sowing quick growing vegetation such as grass. The Kentucky Forest Practice Guidelines (1997) manual suggests minimum pounds per acre based on the type of seed and the time of year. The BMPs also recommend that fertilizer, lime, and mulch be applied on top of the seed to improve germination and generally facilitate the establishment of ground cover. These activities require that the logger either contract the revegetation work, or remove at least one crew member from the production process to obtain revegetation supplies and apply them. The labor times were recorded to the nearest minute while the weights of seed, fertilizer, or lime used were calculated by recording the beginning weight of each material (an unopened sack in every case) and estimating the remaining amount after the revegetation activities were completed. In most cases the total amount of seed on hand was used (the entire sack or sacks). In those cases when less than the entire sack was applied, the percent of the remaining volume in the sack was visually estimated to determine the amount of seed applied. Having determined the number of pounds of each material applied, the acreage of skid trail retired was calculated using the trail length and average trail width. The method of application was also recorded. Linear regression was used to establish a relationship between revegetation times and length of skid trail retired.

Results

Machine and labor activities used to retire skid trails were recorded on nine non-industrial, private logging sites across three physiographic regions of Kentucky. Each of four sites within the Cumberland Plateau region as well as two sites in the Eastern Pennyroyal region used bulldozers to reshape and construct water bars while the remaining three sites were located in the Western Pennyroyal region and used wheeled skidders. Labor activities associated with skid trail revegetation such as seeding, fertilizing, and lime application were recorded on five of the nine sites used in total machine and labor time analysis.

Skid trail condition

A total of 103 cross-sectional profiles were determined on ten primary skid trails. The average cross-sectional area among the ten sites was 1.01 ft^2 (S.E. = 0.05). Linear regression revealed a significant positive relationship (r^2 = 0.79, $p < 0.0001$) between cut area and the depth of the deepest rut (Figure 1.5) as well as skid trail width (r^2 = 0.14, $p < 0.0001$). Figure 1.6 shows the regression of cut area to deepest rut multiplied by skid trail width. Table 1.4 gives a summary of skid trail characteristics. This study also provided a simple method for estimating reshape volume. Using a straight line established from the base of the cut bank to the opposite side of the skid trail, the deepest point from the straight line to the skid trail is measured. After an average of ten or so points is obtained, the regression equation (Figure 1.5) is used to estimate the average cross-sectional area. The area multiplied by the length returns the total estimated volume. For additional accuracy, skid trail width may be measured and added to the equation (Figure 1.6).

Machine times

The average total machine time per 1000 feet was 52 minutes for sites that used dozers and 51 minutes for sites that used skidders (Table 1.5). Sites that used dozers spent 58 percent of their time reshaping and 32 percent of their time construction water bars while sites that used skidders spent 29 percent reshaping and 60 percent constructing water bars. Both dozers and skidders averaged 10 percent of their time traveling to and from the work area. It is interesting to note that there was much more variance in average water bar construction time per 1000 feet than for reshaping time per 1000 feet. No significant difference between total machine time and reshape time, water bar time, or travel time was found.

One-way analysis of variance of water bar construction times revealed no significant difference (p = .7438) between the eastern Pennyroyal and Cumberland Plateau regions (all dozer sites) while the western Pennyroyal region (all skidder sites) was significantly different ($p < 0.0001$) from the other two. Since there were no significant differences among regions that used dozers to conduct retirement operations and the average water bar construction time for the region that exclusively used skidders was significantly different from the regions that used dozers, further analysis of water bar construction time was conducted by machine type. One way analysis of variance revealed a significant difference ($p < 0.0001$) between dozer construction time of 1.5 minutes and skidder construction time of 3.5 minutes (Figure 1.7).

Results of linear regression analysis in Figure 1.8 shows a significant ($p = 0.002$, $r^2 = 0.94$) positive relationship between total machine time and skid trail length retired while Figure 1.9 shows a significant ($p = 0.004$, $r^2 = 0.89$) positive relationship between total machine time and estimated earth volume moved during reshaping and water bar construction. Regression analysis showed no significant relationships between total machine time for sites that used dozers and other variables such as operator experience, machine horsepower, water bar construction time, and skid trail physical characteristics. Linear regression analysis for skidder sites using the same variables were non significant. Table 1.6 lists the test statistics for all variables tested for both dozer and skidder sites.

Revegetation

Table 1.7 lists observed revegetation activity times, time per 1000 feet, and pounds per acre of each material applied. The average time per 1000 feet to apply a single material was 23 minutes. Linear regression was used to analyze relationships between seeding time and variables such as length of trail retired and lbs per acre. Figure 1.10 shows a significant ($p = 0.01$, $r^2 = 0.84$) positive relationship between seeding time and length of skid trail retired.

Discussion

The similarity in mean total machine times between sites that used dozers (52 minutes) and sites that used skidders (51 minutes) is counter intuitive given that dozers are designed to move earth and skidders to pull logs. While mean travel times were about the same between machine types, reshaping and water bar construction were quite different. The difference in mean water bar construction times between machine types (3.5 minutes for skidders vs. 1.5 minutes for dozers) was reflected in the mean water bar construction time per 1000 feet of 16.4 minutes for sites that used dozers and 34.6 minutes for sites that used skidders. The explanation for similar total machine times per 1000 feet between machine types lies in reshaping activities. Sites that used dozers meand 30.5 minutes per 1000 feet vs. 10.2 minutes for sites that used skidders ($p = 0.0248$). Looking again at Table 1.5 we see that skidder sites spent 60% of their mean total machine time installing water bars while dozer sites used nearly the same amount reshaping. One reason for this disparity in reshaping activities may be that skidders tend to reshape during water bar construction. Skidders, being much less efficient earth movers than dozers, have to back up several skidder lengths so that enough earth may be collected to build a water bar. The implication is that sites that use dozers may be able to reduce their total machine times by combining reshaping and water bar construction activities.

The labor information collected during revegetation activities suggests that the average time of 23 minutes per 1000 feet was not affected by the amount or type of material applied (Table 1.7). In both cases where more than one material was applied, the application time was the same for each material. Materials on all sites were spread with hand seeders. Given the wide range in the observed seed application rates, it seems likely that the persons seeding weren't exactly sure how much seed to sow. Another facet of revegetation time is the transportation of the materials to the retirement area. Most loaded the materials onto their dozer or skidder and then dropped them in the woods next to the trail for the person seeding. On site number five, an all terrain vehicle (ATV) was used to transport and shift the materials along the retired section of trail. Since more than one material was applied and there was nearly half a mile of trail to seed, use of the ATV made the task much easier but apparently not much faster.

Costs

The following paragraphs use the data generated by this study in conjunction with other data sources to provide cost averages and methods of cost calculation. While none of the data included in this study was collected under extraordinary circumstances and are representative of normal activities, all sites included were timberlands owned by large sawmills that hire experienced, high production, dependable crews. Conversations with foresters and loggers associated with each site indicated that sawmills are getting away from purchasing timber lands and relying more on independent loggers to feed their mills. The average crew size for Kentucky is 3.5

while the average for the 9 sites in this study was 6 crew members. In short, the logging conditions on which these costs are derived may not be indicative of average conditions in Kentucky.

The retirement costs displayed in Table 1.8 were developed using averages generated by this study in conjunction with information collected from outside sources. Since these costs are based on hourly machine and labor rates, they should be considered as the minimum cost to the logger for retirement. If retirement operations are conducted during scheduled work hours, the costs are calculated based on the hourly timber production of an individual crew member. Unless the logging firm (or a particular harvest) is unprofitable, retirement during scheduled work hours will always be more expensive than when retirement operations are conducted outside of scheduled work hours. In other words, the value of timber harvested during regular work hours should meet or exceed machine and labor costs used to extract it. Since skid trails are generally retired in sections as the harvest progresses, a crew member will spend only an hour or two away from production activities during the week. Without specific production information collected during both normal and retirement operations, it is difficult to say with any certainty what retirement costs are based on changes in productivity. Table 1.9 presents per acre costs for each site based on reported machine, labor, and production rates when retirement is done during productive time and outside of productive time. While these estimates offer a glimpse into retirement costs due to reduced production, a detailed study of daily production and retirement work is necessary to develop reliable averages.

At this point in the discussion it would be useful to compare and contrast the costs developed by this study with the costs listed in Tables 1.1 thru 1.3. However, the costs in those studies are presented in a way that do not lend themselves to comparison of the costs in this study. Water bars, for example, are mentioned in every table but no mention is made of reshaping in any of the studies. Reshaping may have been included in water bar construction but without additional information, no comparisons may be made. Two of the tables list seeding of landings only which were not measured in this study while the third lists combined costs for seeding and fertilizing for which this study has only one observation.

Another benefit of this study is the development of simple methods for calculating retirement costs. Using the following formula, per acre costs based on hourly machine and labor costs can be calculated easily using the ratio of retirement time (minutes) to length of skid trail retired (feet) and skid trail density averages (feet of skid trail per acre harvested).

$$\left[\frac{\left(\frac{\text{Time to retire in minutes}}{\text{Length retired in feet}}\right)\left(\frac{\text{5280 feet per mile}}{\text{36 acres}}\right)}{\text{60 minutes per hour}}\right] * \text{Hourly machine or labor cost}$$

Skid trail density was derived as described in Table 1.8. The time to length ratio (TLR) can also be thought of as the rate of retirement in minutes per foot. Using this equation and the averages of 51 minutes of machine time per 1000 feet (0.051 minutes per foot) and 23 minutes of labor time per 1000 feet (0.023 minutes per foot), the formulas for calculating per acre machine and labor costs become [0.125 x hourly machine cost] and [0.0562 x hourly labor cost (including fringe benefits)].

While the preceding condensed equations are useful for ballpark estimates of retirement costs, the full formula may be manipulated to calculate more accurate per acre retirement costs. If the TLR element is moved outside the brackets of the full equation, the remaining elements inside the equation may be reduced to a constant value. The equation is now reduced to three parts: TLR * Machine or labor costs * Constant. The logger can input his own time to length ratios and hourly machine and labor costs into the formula:

[TLR * Machine or labor cost * 2.444]

where the constant depends on the average skid trail density of 1mile of skid trail for every 36 acres of harvested area. Table 1.10 is actually three separate tables that use this formula to calculate the per acre costs for machine, labor, and materials under a range of time to length ratios and hourly machine costs. Tables 1.11 and 1.12 provide the same cost estimates for a higher skid trail density of 1mile of skid trail per 16 acres harvested and a lower skid trail density of 1 mile of skid trail per 56 acres harvested (the low and high densities are plus or minus one standard deviation from the mean of 36). Dividing these per acre costs by MBF per acre converts them to dollars per MBF harvested. Using this equation and the 120 Kentucky Division of Forestry BMP inspectors across Kentucky, more dependable machine and labor time averages could be developed. The following variables could be collected on two logging jobs per inspector per year, one in the dry season, and one in the wet.

1. total machine time
2. total labor time
3. amount and type of materials applied (seed, fertilizer, lime)
4. length retired (pace)
5. hourly machine and labor costs
6. county (region)

Data collection of this sort would allow more reliable averages to be developed in a relatively short period of time.

Table 1.1: BMP costs as percent of gross revenue at two levels of implementation.

practice	minimum	enhanced
Culvert instalation	0.17%	0.18%
Broad-based dips	0.72%	1.23%
Water bars	0.85%	0.85%
Seed, fertilizer, and mulch	0.81%	2.19%

(Lickwar et al., 1992)

Table 1.2**:** Individual BMP cost estimates in Virginia based on responses to questionnaires.

practice	cost for each
broad-based dips	$ 25
water turn out	$ 10
water bar	$ 15
culvert	$ 200
ford	$ 150
temp bridge	$ 737
SMZ	$ 76
seed and mulch landings	$ 268

(Shaffer et al., 1998)

Table 1.3**:** Percent reduction in net revenue caused by implementation of individual practice.

practice	% reduction in net revenue
culvert	5.0%
water bars	7.3%
broad-based dips	9.7%
seeding	15.9%

(Ellefson and Miles, 1985)

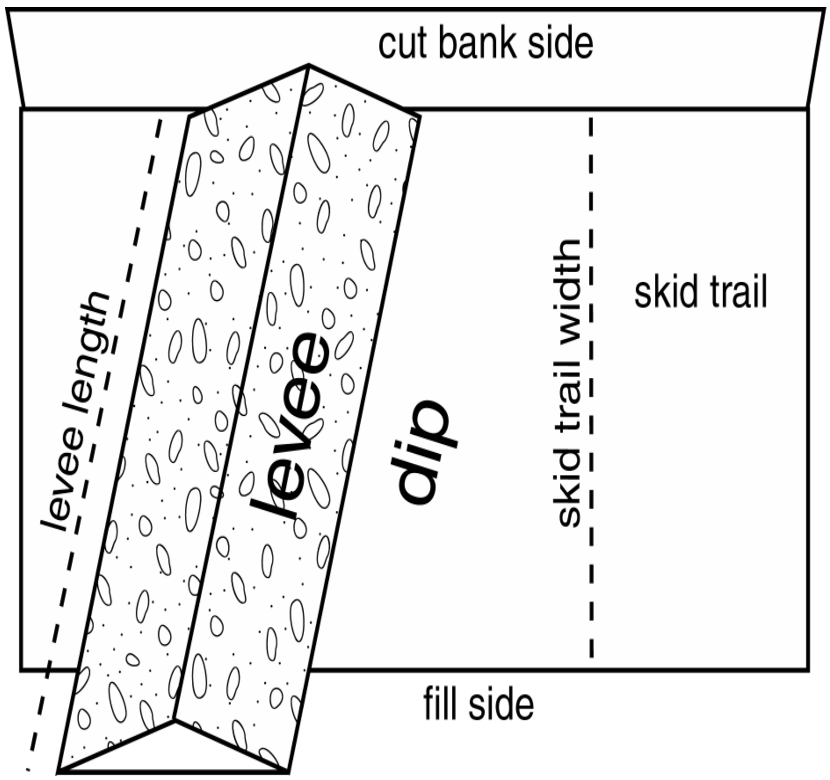

Figure 1.1: Water bar components

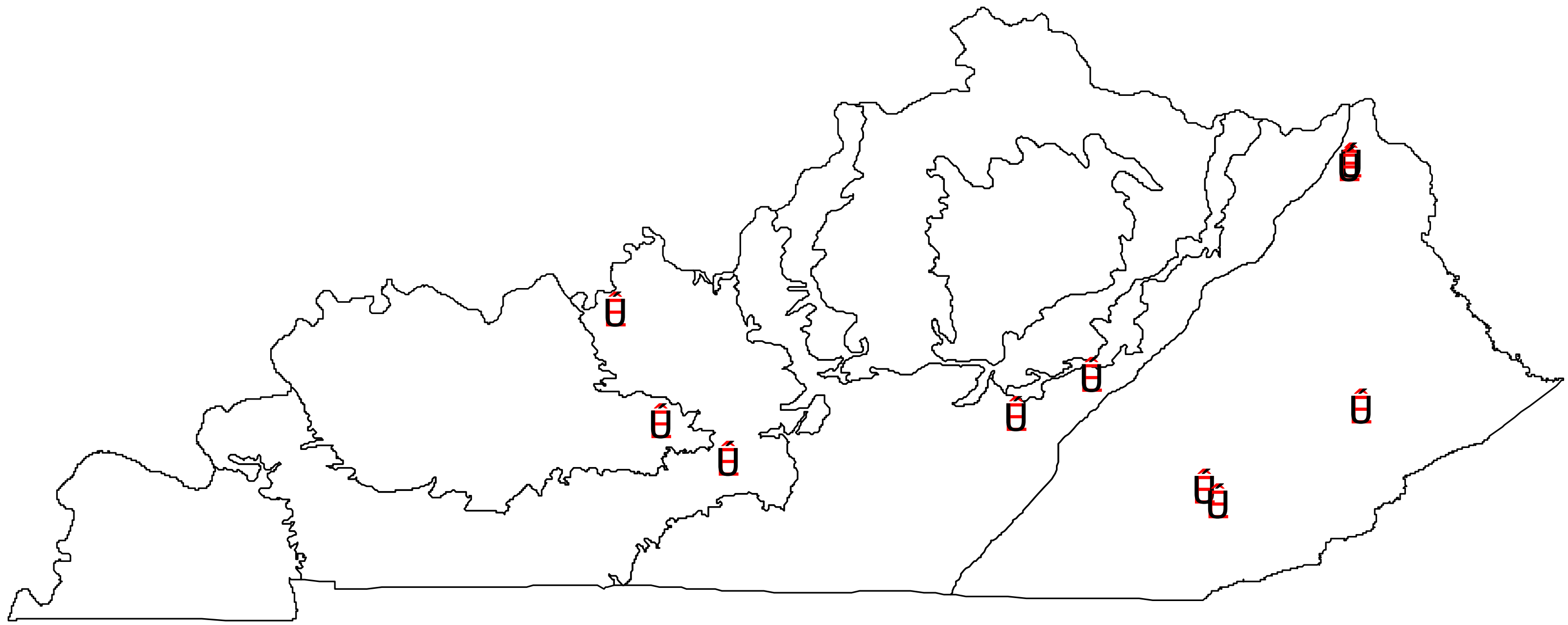

Figure 1.2: Site locations within the physiographic regions of Kentucky

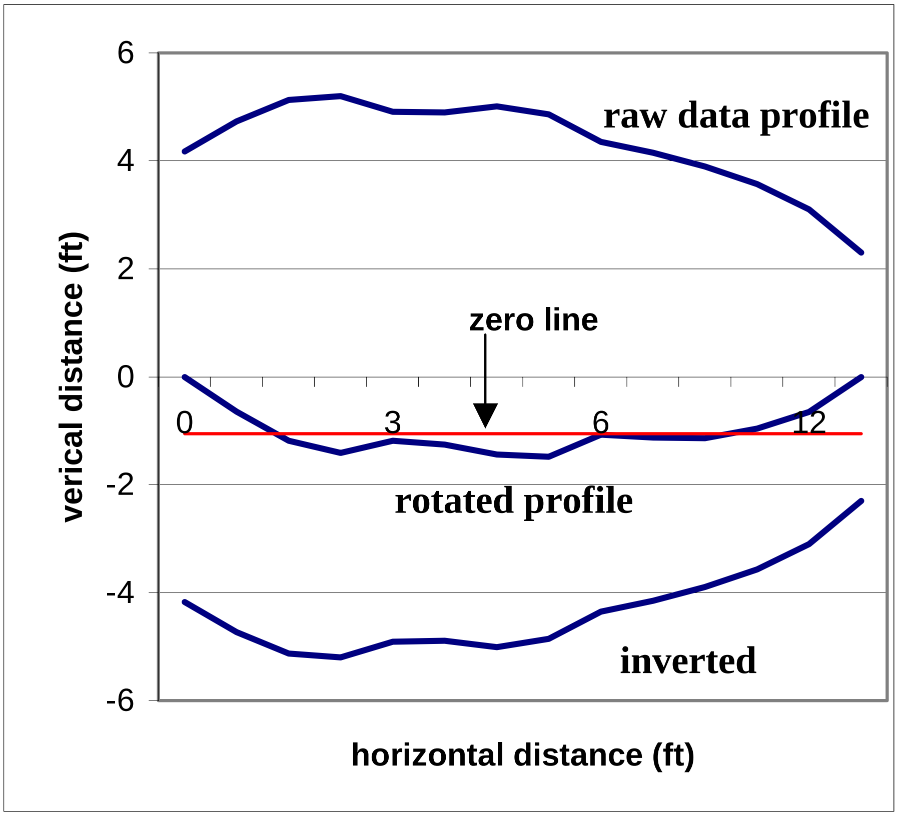

Figure 1.3: Profile manipulation
The raw data is first inverted to describe the true profile and then is rotated so that both ends intersect the X axis. The zero line is established parallel to the X axis and then lowered or raised until the area of the solid (cut) above the line exactly equals the area of the void (fill) below the line.

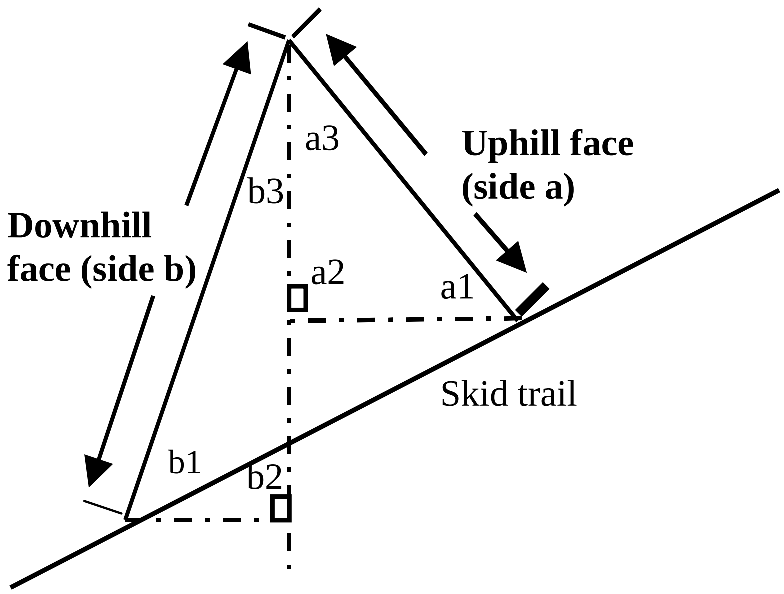

Figure 1.4: Determination of water bar levee cross-sectional area.
When the uphill face is measured for length, angle a1 is also taken using a device that measures the deviation in degrees from the horizontal line (dotted line from angle a2 to angle a1). Since we know that angle a2 is 90 degrees, we can subtract the sum of angle a1and angle a2 from 180 degrees (inside angles of triangle sum to 180) to obtain angle a3. Angle b3 is obtained in exactly the same fashion and then added to angle a3 to obtain the angle between the uphill and downhill face. The formula is: ½ (ab * Sin(a3 + b3))

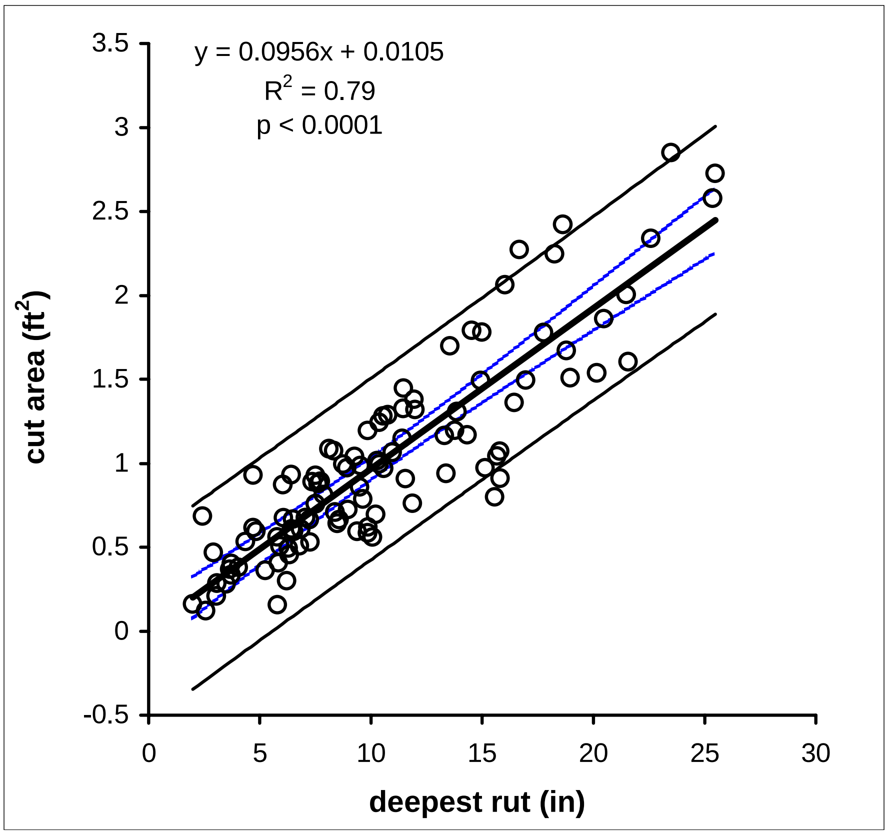

Figure 1.5: Regression of cut area versus deepest rut
The center line is the regression line. Moving outward from the regression line is the confidence interval band while the outer set of lines contains the prediction interval band at 95%.

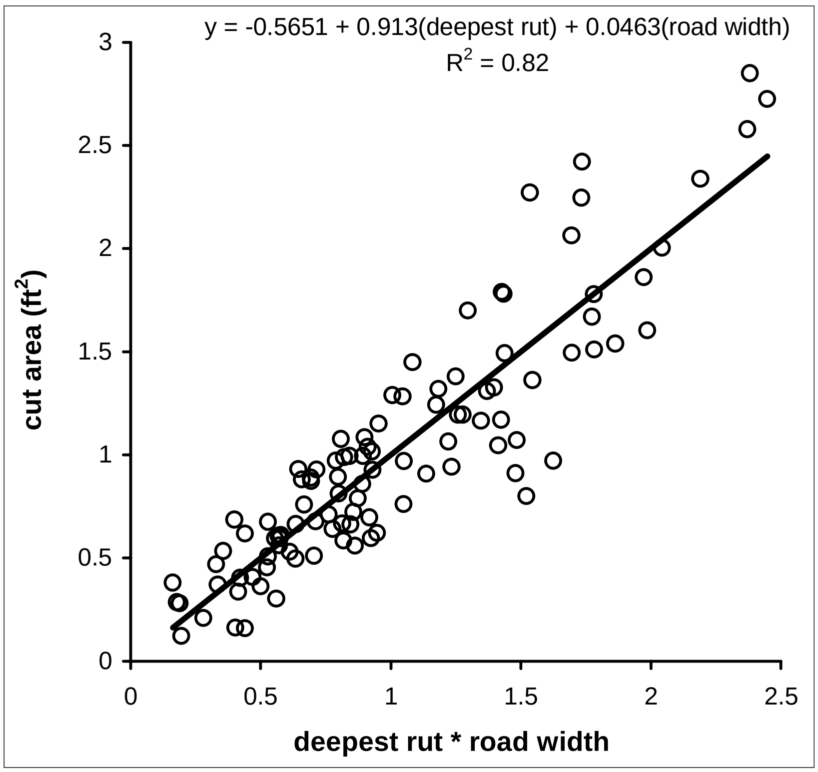

Figure 1.6: Regression of cut area vs. deepest rut and road width The center line is the regression line. Moving outward from the regression line is the confidence interval band while the outer set of lines contains the prediction interval band at 95%.

Table 1.4: Skid trail characteristics

	site #	length retired (ft)	trail width (ft)	% Soil moisture	% slope avg.	% slope min	% slope max	%side slope	cut volume (yd^3)	deepest rut (inches)
dozer	2	684	13	10%	15%	0	30	48	1.1	11
	3	878	16	18%	26%	8	37	23	0.5	6
	5	2194	17	10%	11%	3	17	48	0.7	15
	8	1125	16	12%	27%	20	33	42	1.5	11
	9	936	17	13%	26%	9	53	50	0.9	11
	10	3127	17	11%	23%	7	36	34	1.3	9
	avg.	**1491**	**16**	**13%**	**22%**	**8**	**34**	**41**	**1**	**10**
	S.E.	**963**	**1**	**3%**	**7%**	**7**	**12**	**11**	**0**	**3**
skidder	4	580	16	11%	17%	7	23	18	1.0	7
	6	935	19	11%	23%	13	32	0	0.8	11
	7	1148	15	25%	14%	12	17	7	0.9	7
	avg.	**888**	**17**	**15%**	**18%**	**11**	**24**	**8**	**1**	**8**
	S.E.	**287**	**2**	**8%**	**4%**	**3**	**8**	**9**	**0**	**2**

Table 1.5: Machine time recorded during reshaping and water bar construction activities.

	site	total length retired (ft)	**observed times (min)[1]** reshape	water bar (n)	travel[2]	total	**times per 1000 feet (min)[3]** reshape	water bar	travel	total	**times as a percent of total** reshape	water bar	travel
Dozer	2	684	28	12 (10)	6	**46**	41	17.5	9	**68**	60	26	14
	3	878	15	14 (8)	4	**33**	17	15.5	5	**38**	46	41	13
	5	2194	69	12 (15)	26	**107**	31	5.7	12	**49**	64	12	24
	8	1125	49	17 (8)	5	**72**	44	15.4	4	**64**	69	24	7
	9	936	14	34 (17)	0	**48**	15	35.8	0	**51**	30	70	0
	10	3127	106	26 (22)	3	**135**	34	8.2	1	**43**	79	19	2
	avg.	**1491**	**47**	**19**	**7**	**74**	**30**	**16.4**	**5**	**52**	**58**	**32**	**10**
	S.E.	**963**	**36**	**9**	**9**	**40**	**12**	**11**	**5**	**12**	**17**	**21**	**9**
Skidder	4	580	5	41 (10)	8	**54**	9	71.4	14	**94**	9	76	14
	6	935	12	23 (8)	1	**37**	13	24.6	2	**39**	33	63	4
	7	1148	10	9 (3)	3	**22**	9	8	2	**19**	46	42	12
	avg.	**888**	**9**	**25**	**4**	**38**	**10**	**35**	**6**	**51**	**29**	**60**	**10**
	S.E.	**287**	**4**	**16**	**3**	**16**	**2**	**33**	**7**	**39**	**18**	**17**	**6**

[1]Machine time referes to the amount of time the machine was operated to complete a particular task (engine hours). [2]Time required to transport equipment to retirement site. [3]Machine times per 1000 feet are calculated by multiplying 1000 times the ratio of time to total length retired.

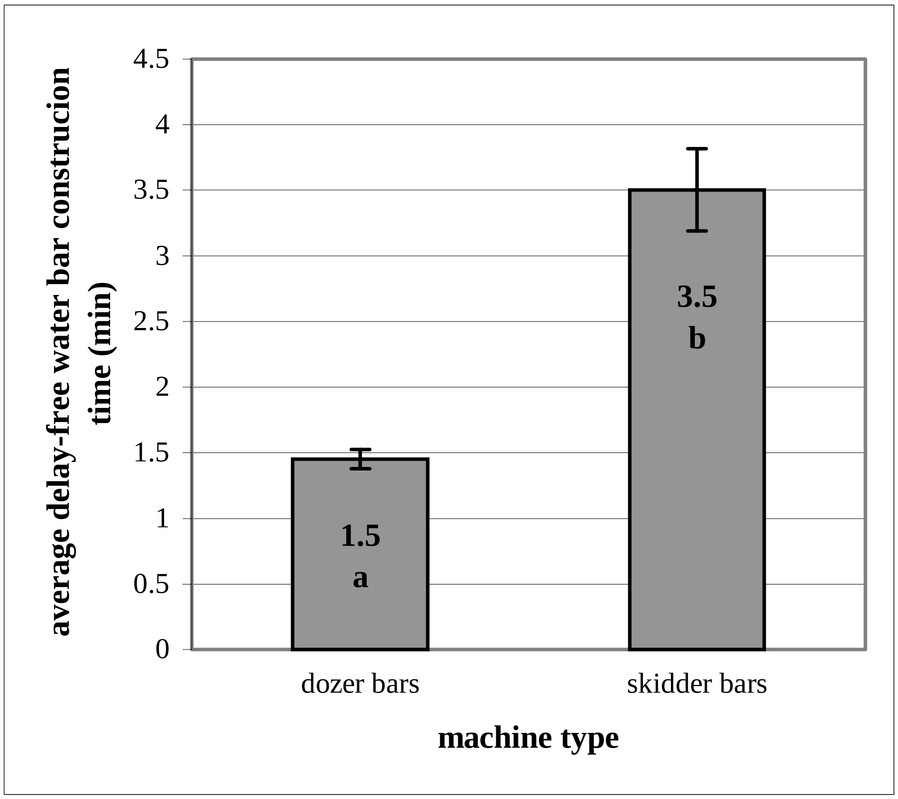

Figure 1.7: Average water bar construction delay-free cycle time by machine type.
Columns with different letters are significantly different ($p < 0.0001$). N = 112 for dozer bars and n = 21 for skidder bars.

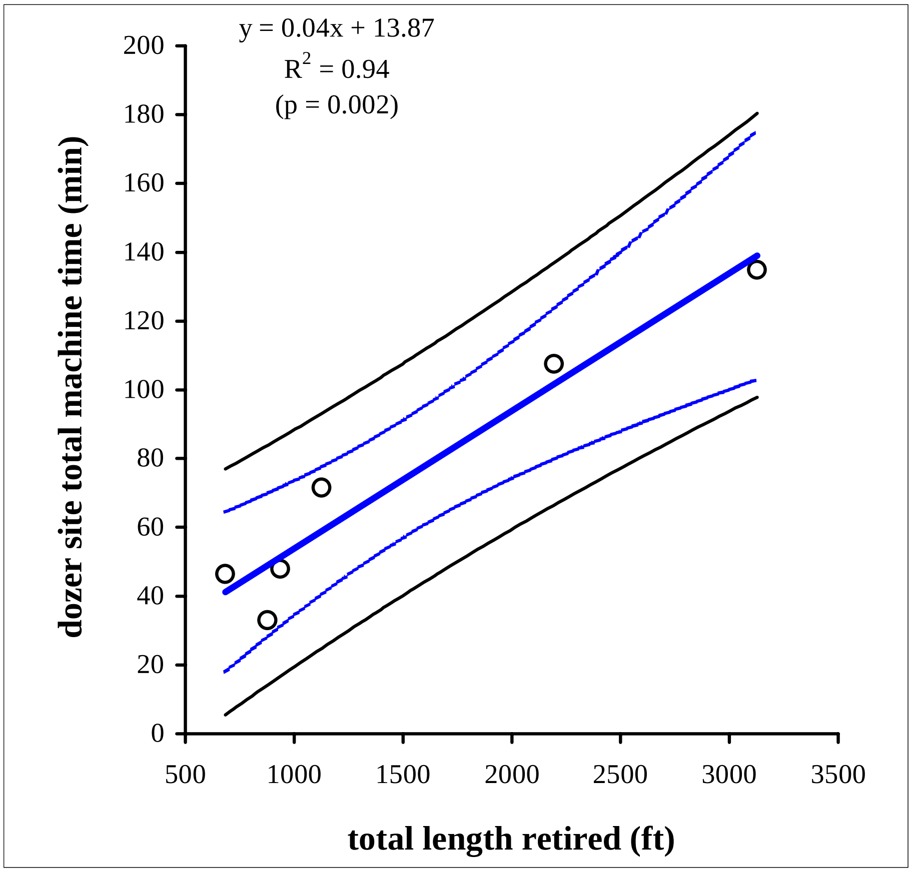

Figure 1.8: Total machine time (includes reshape, water bar, and travel time) vs. total length of skid trail retired (n = 6).
Closest pair of lines to the regression line is the confidence interval band while the outer set of lines contains the prediction interval band at 95%.

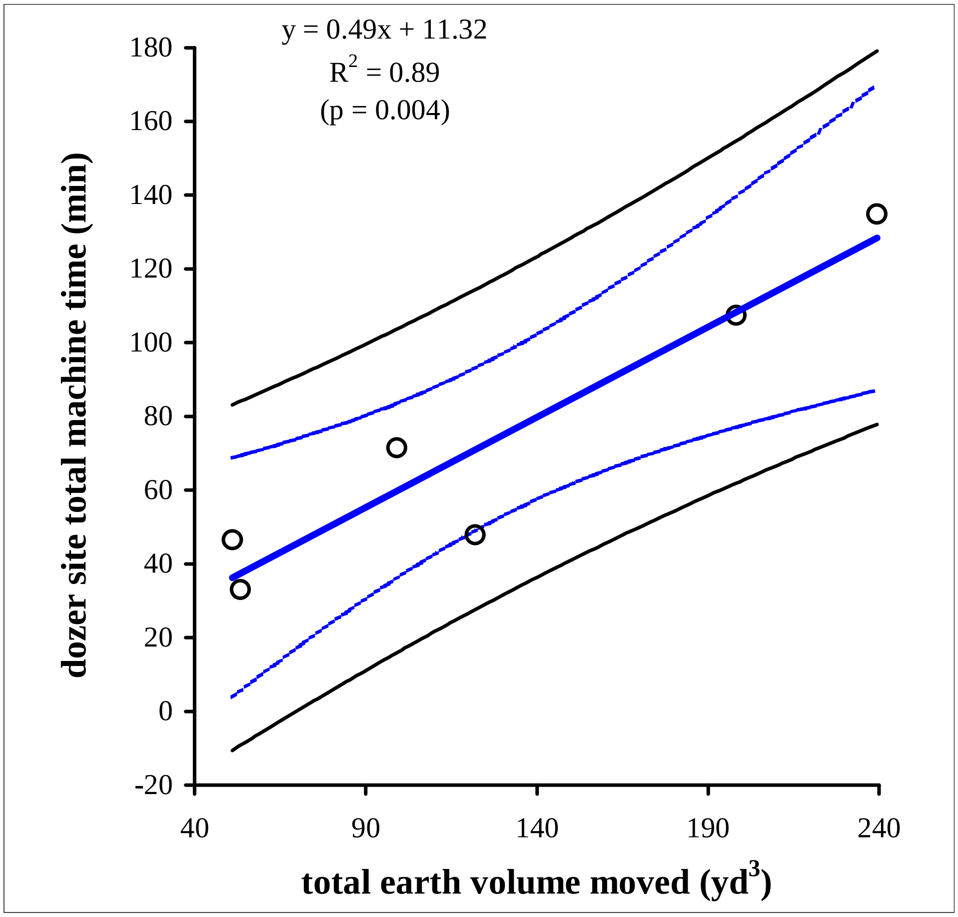

Figure 1.9: Total machine time vs. estimated volume of earth moved during reshaping and water bar construction (n = 6).
Closest pair of lines to the regression line is the confidence interval band while the outer set of lines contains the prediction interval band at 95%.

Table 1.6: Linear regression analysis results for total machine time and seeding time

	dozer			skidder		
variable	r^2	p value	intercept p value	r^2	p value	intercept p value
length of skid trail retired	0.94	0.0016	0.1995	0.99	0.0567	0.0336
total earth volume moved	0.89	0.0043	0.4095	0.72	0.3521	0.1676
water bar construction time	0.33	0.2298	0.0258	0.92	0.1777	0.5145
% slope of trail	0.06	0.6351	0.1120	0.05	0.8526	0.3983
trail width	0.15	0.3961	0.6499	0.11	0.7844	0.9465
soil moisture	0.07	0.5566	0.0691	0.67	0.3923	0.1872
horsepower	0.11	0.4585	0.1670	0.76	0.3266	0.2207
% side slope	0.00	0.9913	0.2892	0.45	0.5332	0.3102
years logging experience	0.03	0.7089	0.0730	0.70	0.3679	0.1394
years experience with BMPs	0.02	0.7844	0.0919	0.70	0.3679	0.6509
years experience with equipment used	0.03	0.7007	0.0387	0.70	0.3679	0.1466
seeding regression results						
labor time vs. length retired	0.96	0.0033	0.4588			

Table 1.7: Labor and materials used for skid trail revegetation

site	total length retired	observed labor times (min) seed	fertilize	lime	total time (min)	seed time/ 1000 feet (min)[3]	lbs/ acre[1] seed	fertilizer	lime	ATV use[2]
2	684	14			**14**	20	104			no
5	2194	50	50		**100**	23	71	214		yes
8	1125	30	30	30	**90**	27	152	456	243	no
10	3127	78			**78**	25	26			no
4	580	24			**24**	41	22			no
avg.	**888**	**39**	**40**	**30**	**109**	**27**	**75**			
S.E.	**1092**	**25**	**14**		**39**	**8**	**55**			

[1]Pounds per acre of material used are represented here in the same order that they occur in the table from left to right. [2]ATV use denotes the use of an all terrain vehicle to transport materials or otherwise facilitate revegetation activities. [3]Time per 1000 feet is calculated by multiplying the ratio of total time to total length retired by 1000.

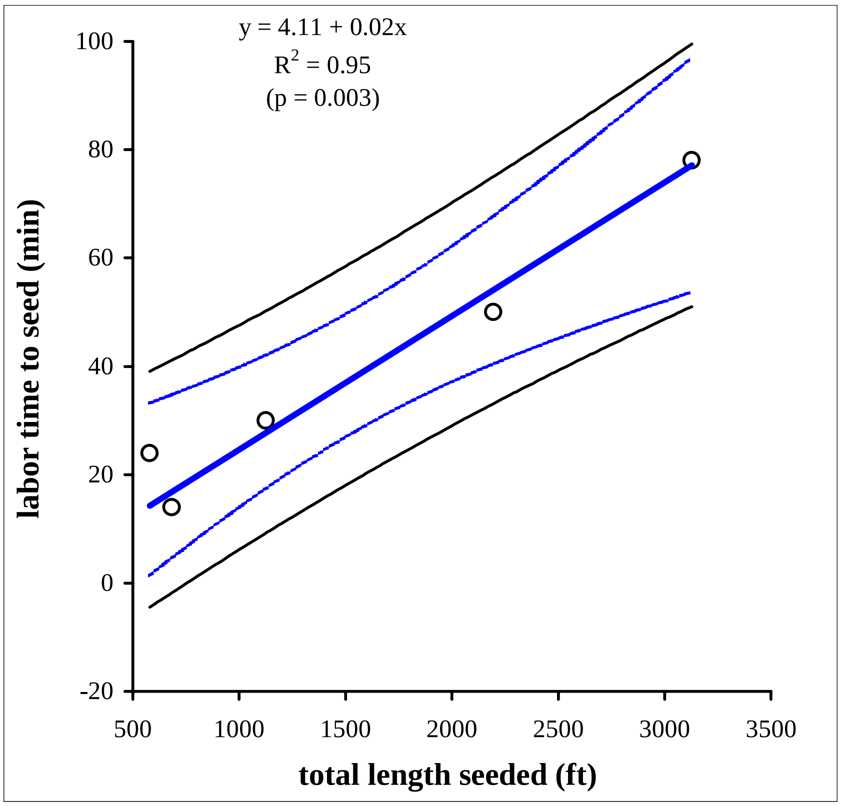

Figure 1.10: Total labor time to seed vs. total length seeded (n = 5). Closest pair of lines to the regression line is the confidence interval band while the outer set of lines contains the prediction interval band at 95%.

Table 1.8: Machine, labor, and materials costs for skid trail retirement

activity	per year hours	per year cost	per acre hours	per acre cost	per MBF[1] hours	per MBF[1] cost		% gross revenue
machine	166	$ 10,804	0.12	$ 8.10	0.05	$ 3.00		1.8%
labor	225	$ 2,699	0.17	$ 2.02	0.06	$ 0.75		0.5%
							sub total	**2.3%**
materials	lbs	cost	lbs	cost	lbs	cost		
seed	5387	$ 3,502	4.04	$ 2.63	1.50	$ 0.97		0.6%
lime	17455	$ 1,309	13.09	$ 0.98	4.85	$ 0.36		0.2%
fertilizer	24063	$ 5,775	18.05	$ 4.33	6.68	$ 1.60		1.0%
							sub total	**1.8%**
total cost		**$ 24,089**		**$ 18.07**		**$ 6.69**		**4.1%**

Cost variable values generated by this study[2]:

MBF per person per year	600	price per 1000 board feet	$ 165
average crew number	6	average skid trail width (ft)	16
avg. machine minutes per 1000 feet	51	hourly machine cost	$ 65
avg. labor minutes per 1000 feet	23	hourly labor cost plus fringe	$ 12
seed cost per pound	$ 0.65	seeding rate (lbs/acre)	75
lime cost per pound	$ 0.08	lime application rate (lbs/acre)	243
fertilizer cost per pound	$ 0.24	fertilizer application rate (lbs/acre)	335

Cost variable values from outside sources[3]:

MBF per acre	2.7
acres harvested per one mile of retireable skid trail	36

[1]Thousand board feet (Doyle scale).

[2]All values listed here except the cost per pound of revegetation materials are averages generated by this study. The cost per pound of each revegetation material was obtained by surveying local suppliers.

[3]This information was obtained through sources not connected with this study. Average MBF per acre was obtained through personal communication with Kentucky Division of Forestry personnel and are based on several years worth of timber cruising information. The skid trail density (acres per mile of retireable skid trail) was derived using harvest acreage and length of retireable skid trail measurements collected during a survey of 100 retired logging sites in Kentucky. Retireable skid trail does not include skidding areas where reshaping, water bar construction, and revegetation are not required.

Table 1.9: Per acre machine and labor costs in dollars for retirement work completed during scheduled work hours vs. outside of scheduled work hours[1]

		during regular work hours			outside regular work hours		
	site #	machine	labor	total	machine	labor	total
dozer	2	5	10	**15**	5	7	**12**
	3	2		**2**	4		**4**
	5	8	14	**22**	7	4	**12**
	8	8	5	**12**	8	7	**14**
	9	7		**7**	7		**7**
	10	3	4	**8**	4	2	**6**
	avg.	**5**	**8**	**11**	**6**	**5**	**9**
	S.E.	**2**	**4**	**7**	**2**	**2**	**4**
skidder	4	14	12	**26**	7	5	**12**
	6	5		**5**	4		**4**
	7			**0**	1		**1**
	avg.	**9**	**12**	**10**	**4**	**5**	**6**
	S.E.	**6**		**14**	**3**		**6**

[1]Calculated based on reported machine, labor, and production rates, log prices, and tract acerage of timber sales on which operations were conducted. No cost information was available for site # 7.

Table 1.10: Per acre skid trail retirement costs for machine, labor, and materials (avg. skid trail density = 1mile/36 acres harvested)

MACHINE COSTS PER ACRE

hourly machine cost

TLR[1]	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125
0.020	$ 1.96	$ 2.20	$ 2.44	$ 2.69	$ 2.93	$ 3.18	$ 3.42	$ 3.67	$ 3.91	$ 4.16	$ 4.40	$ 4.64	$ 4.89	$ 5.13	$ 5.38	$ 5.62	$ 5.87	$ 6.11
0.025	$ 2.44	$ 2.75	$ 3.06	$ 3.36	$ 3.67	$ 3.97	$ 4.28	$ 4.58	$ 4.89	$ 5.19	$ 5.50	$ 5.81	$ 6.11	$ 6.42	$ 6.72	$ 7.03	$ 7.33	$ 7.64
0.030	$ 2.93	$ 3.30	$ 3.67	$ 4.03	$ 4.40	$ 4.77	$ 5.13	$ 5.50	$ 5.87	$ 6.23	$ 6.60	$ 6.97	$ 7.33	$ 7.70	$ 8.07	$ 8.43	$ 8.80	$ 9.17
0.035	$ 3.42	$ 3.85	$ 4.28	$ 4.71	$ 5.13	$ 5.56	$ 5.99	$ 6.42	$ 6.84	$ 7.27	$ 7.70	$ 8.13	$ 8.56	$ 8.98	$ 9.41	$ 9.84	$ 10.27	$ 10.69
0.040	$ 3.91	$ 4.40	$ 4.89	$ 5.38	$ 5.87	$ 6.36	$ 6.84	$ 7.33	$ 7.82	$ 8.31	$ 8.80	$ 9.29	$ 9.78	$ 10.27	$ 10.76	$ 11.24	$ 11.73	$ 12.22
0.045	$ 4.40	$ 4.95	$ 5.50	$ 6.05	$ 6.60	$ 7.15	$ 7.70	$ 8.25	$ 8.80	$ 9.35	$ 9.90	$ 10.45	$ 11.00	$ 11.55	$ 12.10	$ 12.65	$ 13.20	$ 13.75
0.050	$ 4.89	$ 5.50	$ 6.11	$ 6.72	$ 7.33	$ 7.94	$ 8.56	$ 9.17	$ 9.78	$ 10.39	$ 11.00	$ 11.61	$ 12.22	$ 12.83	$ 13.44	$ 14.06	$ 14.67	$ 15.28
0.055	$ 5.38	$ 6.05	$ 6.72	$ 7.39	$ 8.07	$ 8.74	$ 9.41	$ 10.08	$ 10.76	$ 11.43	$ 12.10	$ 12.77	$ 13.44	$ 14.12	$ 14.79	$ 15.46	$ 16.13	$ 16.81
0.060	$ 5.87	$ 6.60	$ 7.33	$ 8.07	$ 8.80	$ 9.53	$ 10.27	$ 11.00	$ 11.73	$ 12.47	$ 13.20	$ 13.93	$ 14.67	$ 15.40	$ 16.13	$ 16.87	$ 17.60	$ 18.33
0.065	$ 6.36	$ 7.15	$ 7.94	$ 8.74	$ 9.53	$ 10.33	$ 11.12	$ 11.92	$ 12.71	$ 13.51	$ 14.30	$ 15.09	$ 15.89	$ 16.68	$ 17.48	$ 18.27	$ 19.07	$ 19.86
0.070	$ 6.84	$ 7.70	$ 8.56	$ 9.41	$ 10.27	$ 11.12	$ 11.98	$ 12.83	$ 13.69	$ 14.54	$ 15.40	$ 16.26	$ 17.11	$ 17.97	$ 18.82	$ 19.68	$ 20.53	$ 21.39
0.075	$ 7.33	$ 8.25	$ 9.17	$ 10.08	$ 11.00	$ 11.92	$ 12.83	$ 13.75	$ 14.67	$ 15.58	$ 16.50	$ 17.42	$ 18.33	$ 19.25	$ 20.17	$ 21.08	$ 22.00	$ 22.92
0.080	$ 7.82	$ 8.80	$ 9.78	$ 10.76	$ 11.73	$ 12.71	$ 13.69	$ 14.67	$ 15.64	$ 16.62	$ 17.60	$ 18.58	$ 19.56	$ 20.53	$ 21.51	$ 22.49	$ 23.47	$ 24.44
0.085	$ 8.31	$ 9.35	$ 10.39	$ 11.43	$ 12.47	$ 13.51	$ 14.54	$ 15.58	$ 16.62	$ 17.66	$ 18.70	$ 19.74	$ 20.78	$ 21.82	$ 22.86	$ 23.89	$ 24.93	$ 25.97
0.090	$ 8.80	$ 9.90	$ 11.00	$ 12.10	$ 13.20	$ 14.30	$ 15.40	$ 16.50	$ 17.60	$ 18.70	$ 19.80	$ 20.90	$ 22.00	$ 23.10	$ 24.20	$ 25.30	$ 26.40	$ 27.50

LABOR COSTS PER ACRE

hourly labor cost plus fringe

TLR	10	12	14	16	18	20	22
0.020	$ 0.48	$ 0.58	$ 0.68	$ 0.77	$ 0.87	$ 0.97	$ 1.06
0.025	$ 0.61	$ 0.73	$ 0.86	$ 0.98	$ 1.10	$ 1.22	$ 1.34
0.030	$ 0.74	$ 0.89	$ 1.03	$ 1.18	$ 1.33	$ 1.48	$ 1.62
0.035	$ 0.87	$ 1.04	$ 1.21	$ 1.39	$ 1.56	$ 1.73	$ 1.91
0.041	$ 0.99	$ 1.19	$ 1.39	$ 1.59	$ 1.79	$ 1.99	$ 2.19
0.046	$ 1.12	$ 1.35	$ 1.57	$ 1.79	$ 2.02	$ 2.24	$ 2.47
0.051	$ 1.25	$ 1.50	$ 1.75	$ 2.00	$ 2.25	$ 2.50	$ 2.75
0.056	$ 1.38	$ 1.65	$ 1.93	$ 2.20	$ 2.48	$ 2.75	$ 3.03
0.062	$ 1.50	$ 1.80	$ 2.10	$ 2.41	$ 2.71	$ 3.01	$ 3.31
0.067	$ 1.63	$ 1.96	$ 2.28	$ 2.61	$ 2.94	$ 3.26	$ 3.59

REVEGETATION COSTS PER ACRE

price per lb

lbs per acre	0.1	0.2	0.3	0.6	0.7	0.8	0.9	1	1.1
30	$ 0.15	$ 0.30	$ 0.45	$ 0.91	$ 1.06	$ 1.21	$ 1.36	$ 1.52	$ 1.67
40	$ 0.20	$ 0.40	$ 0.61	$ 1.21	$ 1.41	$ 1.62	$ 1.82	$ 2.02	$ 2.22
50	$ 0.25	$ 0.51	$ 0.76	$ 1.52	$ 1.77	$ 2.02	$ 2.27	$ 2.53	$ 2.78
60	$ 0.30	$ 0.61	$ 0.91	$ 1.82	$ 2.12	$ 2.42	$ 2.73	$ 3.03	$ 3.33
70	$ 0.35	$ 0.71	$ 1.06	$ 2.12	$ 2.47	$ 2.83	$ 3.18	$ 3.54	$ 3.89
80	$ 0.40	$ 0.81	$ 1.21	$ 2.42	$ 2.83	$ 3.23	$ 3.64	$ 4.04	$ 4.44
90	$ 0.45	$ 0.91	$ 1.36	$ 2.73	$ 3.18	$ 3.64	$ 4.09	$ 4.55	$ 5.00
100	$ 0.51	$ 1.01	$ 1.52	$ 3.03	$ 3.54	$ 4.04	$ 4.55	$ 5.05	$ 5.56
110	$ 0.56	$ 1.11	$ 1.67	$ 3.33	$ 3.89	$ 4.44	$ 5.00	$ 5.56	$ 6.11
120	$ 0.61	$ 1.21	$ 1.82	$ 3.64	$ 4.24	$ 4.85	$ 5.45	$ 6.06	$ 6.67

[1]The time to length ratio is derived by dividing the time in minutes required to retire the observed skid trail by it's length in feet. Per acre costs are based on an average retireable skid trail density of 1 mile to every 36 acres harvested. Per acre costs may be converted to cost per MBF harvested by dividing by the state average of 2.7 MBF per acre or by using a known value for the harvested area.

Table 1.11: Per acre skid trail retirement costs for machine, labor, and materials (high skid trail density = 1mile/16 acres harvested)

MACHINE COSTS PER ACRE

hourly machine cost

TLR[1]	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125
0.020	$ 4.40	$ 4.95	$ 5.50	$ 6.05	$ 6.60	$ 7.15	$ 7.70	$ 8.25	$ 8.80	$ 9.35	$ 9.90	$ 10.45	$ 11.00	$ 11.55	$ 12.10	$ 12.65	$ 13.20	$ 13.75
0.025	$ 5.50	$ 6.19	$ 6.88	$ 7.56	$ 8.25	$ 8.94	$ 9.63	$ 10.31	$ 11.00	$ 11.69	$ 12.38	$ 13.06	$ 13.75	$ 14.44	$ 15.13	$ 15.81	$ 16.50	$ 17.19
0.030	$ 6.60	$ 7.43	$ 8.25	$ 9.08	$ 9.90	$ 10.73	$ 11.55	$ 12.38	$ 13.20	$ 14.03	$ 14.85	$ 15.68	$ 16.50	$ 17.33	$ 18.15	$ 18.98	$ 19.80	$ 20.63
0.035	$ 7.70	$ 8.66	$ 9.63	$ 10.59	$ 11.55	$ 12.51	$ 13.48	$ 14.44	$ 15.40	$ 16.36	$ 17.33	$ 18.29	$ 19.25	$ 20.21	$ 21.18	$ 22.14	$ 23.10	$ 24.06
0.040	$ 8.80	$ 9.90	$ 11.00	$ 12.10	$ 13.20	$ 14.30	$ 15.40	$ 16.50	$ 17.60	$ 18.70	$ 19.80	$ 20.90	$ 22.00	$ 23.10	$ 24.20	$ 25.30	$ 26.40	$ 27.50
0.045	$ 9.90	$ 11.14	$ 12.38	$ 13.61	$ 14.85	$ 16.09	$ 17.33	$ 18.56	$ 19.80	$ 21.04	$ 22.28	$ 23.51	$ 24.75	$ 25.99	$ 27.23	$ 28.46	$ 29.70	$ 30.94
0.050	$ 11.00	$ 12.38	$ 13.75	$ 15.13	$ 16.50	$ 17.88	$ 19.25	$ 20.63	$ 22.00	$ 23.38	$ 24.75	$ 26.13	$ 27.50	$ 28.88	$ 30.25	$ 31.63	$ 33.00	$ 34.38
0.055	$ 12.10	$ 13.61	$ 15.13	$ 16.64	$ 18.15	$ 19.66	$ 21.18	$ 22.69	$ 24.20	$ 25.71	$ 27.23	$ 28.74	$ 30.25	$ 31.76	$ 33.28	$ 34.79	$ 36.30	$ 37.81
0.060	$ 13.20	$ 14.85	$ 16.50	$ 18.15	$ 19.80	$ 21.45	$ 23.10	$ 24.75	$ 26.40	$ 28.05	$ 29.70	$ 31.35	$ 33.00	$ 34.65	$ 36.30	$ 37.95	$ 39.60	$ 41.25
0.065	$ 14.30	$ 16.09	$ 17.88	$ 19.66	$ 21.45	$ 23.24	$ 25.03	$ 26.81	$ 28.60	$ 30.39	$ 32.18	$ 33.96	$ 35.75	$ 37.54	$ 39.33	$ 41.11	$ 42.90	$ 44.69
0.070	$ 15.40	$ 17.33	$ 19.25	$ 21.18	$ 23.10	$ 25.03	$ 26.95	$ 28.88	$ 30.80	$ 32.73	$ 34.65	$ 36.58	$ 38.50	$ 40.43	$ 42.35	$ 44.28	$ 46.20	$ 48.13
0.075	$ 16.50	$ 18.56	$ 20.63	$ 22.69	$ 24.75	$ 26.81	$ 28.88	$ 30.94	$ 33.00	$ 35.06	$ 37.13	$ 39.19	$ 41.25	$ 43.31	$ 45.38	$ 47.44	$ 49.50	$ 51.56
0.080	$ 17.60	$ 19.80	$ 22.00	$ 24.20	$ 26.40	$ 28.60	$ 30.80	$ 33.00	$ 35.20	$ 37.40	$ 39.60	$ 41.80	$ 44.00	$ 46.20	$ 48.40	$ 50.60	$ 52.80	$ 55.00
0.085	$ 18.70	$ 21.04	$ 23.38	$ 25.71	$ 28.05	$ 30.39	$ 32.73	$ 35.06	$ 37.40	$ 39.74	$ 42.08	$ 44.41	$ 46.75	$ 49.09	$ 51.43	$ 53.76	$ 56.10	$ 58.44
0.090	$ 19.80	$ 22.28	$ 24.75	$ 27.23	$ 29.70	$ 32.18	$ 34.65	$ 37.13	$ 39.60	$ 42.08	$ 44.55	$ 47.03	$ 49.50	$ 51.98	$ 54.45	$ 56.93	$ 59.40	$ 61.88

LABOR COSTS PER ACRE

hourly labor cost plus fringe

TLR	10	12	14	16	18	20	22
0.020	$ 1.09	$ 1.31	$ 1.52	$ 1.74	$ 1.96	$ 2.18	$ 2.39
0.025	$ 1.38	$ 1.65	$ 1.93	$ 2.20	$ 2.48	$ 2.75	$ 3.03
0.030	$ 1.66	$ 1.99	$ 2.33	$ 2.66	$ 2.99	$ 3.32	$ 3.66
0.035	$ 1.95	$ 2.34	$ 2.73	$ 3.12	$ 3.51	$ 3.90	$ 4.29
0.041	$ 2.24	$ 2.68	$ 3.13	$ 3.58	$ 4.02	$ 4.47	$ 4.92
0.046	$ 2.52	$ 3.03	$ 3.53	$ 4.04	$ 4.54	$ 5.04	$ 5.55
0.051	$ 2.81	$ 3.37	$ 3.93	$ 4.49	$ 5.06	$ 5.62	$ 6.18
0.056	$ 3.10	$ 3.71	$ 4.33	$ 4.95	$ 5.57	$ 6.19	$ 6.81
0.062	$ 3.38	$ 4.06	$ 4.74	$ 5.41	$ 6.09	$ 6.77	$ 7.44
0.067	$ 3.67	$ 4.40	$ 5.14	$ 5.87	$ 6.60	$ 7.34	$ 8.07

REVEGETATION COSTS PER ACRE

price per lb

lbs per acre	0.1	0.2	0.3	0.6	0.7	0.8	0.9	1	1.1
30	$ 0.34	$ 0.68	$ 1.02	$ 2.05	$ 2.39	$ 2.73	$ 3.07	$ 3.41	$ 3.75
40	$ 0.45	$ 0.91	$ 1.36	$ 2.73	$ 3.18	$ 3.64	$ 4.09	$ 4.55	$ 5.00
50	$ 0.57	$ 1.14	$ 1.70	$ 3.41	$ 3.98	$ 4.55	$ 5.11	$ 5.68	$ 6.25
60	$ 0.68	$ 1.36	$ 2.05	$ 4.09	$ 4.77	$ 5.45	$ 6.14	$ 6.82	$ 7.50
70	$ 0.80	$ 1.59	$ 2.39	$ 4.77	$ 5.57	$ 6.36	$ 7.16	$ 7.95	$ 8.75
80	$ 0.91	$ 1.82	$ 2.73	$ 5.45	$ 6.36	$ 7.27	$ 8.18	$ 9.09	$ 10.00
90	$ 1.02	$ 2.05	$ 3.07	$ 6.14	$ 7.16	$ 8.18	$ 9.20	$ 10.23	$ 11.25
100	$ 1.14	$ 2.27	$ 3.41	$ 6.82	$ 7.95	$ 9.09	$ 10.23	$ 11.36	$ 12.50
110	$ 1.25	$ 2.50	$ 3.75	$ 7.50	$ 8.75	$ 10.00	$ 11.25	$ 12.50	$ 13.75
120	$ 1.36	$ 2.73	$ 4.09	$ 8.18	$ 9.55	$ 10.91	$ 12.27	$ 13.64	$ 15.00

[1]The time to length ratio is derived by dividing the time in minutes required to retire the observed skid trail by it's length in feet. Per acre costs are based on an average retireable skid trail density of 1 mile to every 16 acres harvested. Per acre costs may be converted to cost per MBF harvested by dividing by the state average of 2.7 MBF per acre or by using a known value for the harvested area.

Table 1.12: Per acre skid trail retirement costs for machine, labor, and materials (low skid trail density = 1mile/56 acres harvested)

MACHINE COSTS PER ACRE

hourly machine cost

TLR[1]	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125
0.020	$ 1.26	$ 1.41	$ 1.57	$ 1.73	$ 1.89	$ 2.04	$ 2.20	$ 2.36	$ 2.51	$ 2.67	$ 2.83	$ 2.99	$ 3.14	$ 3.30	$ 3.46	$ 3.61	$ 3.77	$ 3.93
0.025	$ 1.57	$ 1.77	$ 1.96	$ 2.16	$ 2.36	$ 2.55	$ 2.75	$ 2.95	$ 3.14	$ 3.34	$ 3.54	$ 3.73	$ 3.93	$ 4.13	$ 4.32	$ 4.52	$ 4.71	$ 4.91
0.030	$ 1.89	$ 2.12	$ 2.36	$ 2.59	$ 2.83	$ 3.06	$ 3.30	$ 3.54	$ 3.77	$ 4.01	$ 4.24	$ 4.48	$ 4.71	$ 4.95	$ 5.19	$ 5.42	$ 5.66	$ 5.89
0.035	$ 2.20	$ 2.48	$ 2.75	$ 3.03	$ 3.30	$ 3.58	$ 3.85	$ 4.13	$ 4.40	$ 4.68	$ 4.95	$ 5.23	$ 5.50	$ 5.78	$ 6.05	$ 6.33	$ 6.60	$ 6.88
0.040	$ 2.51	$ 2.83	$ 3.14	$ 3.46	$ 3.77	$ 4.09	$ 4.40	$ 4.71	$ 5.03	$ 5.34	$ 5.66	$ 5.97	$ 6.29	$ 6.60	$ 6.91	$ 7.23	$ 7.54	$ 7.86
0.045	$ 2.83	$ 3.18	$ 3.54	$ 3.89	$ 4.24	$ 4.60	$ 4.95	$ 5.30	$ 5.66	$ 6.01	$ 6.36	$ 6.72	$ 7.07	$ 7.43	$ 7.78	$ 8.13	$ 8.49	$ 8.84
0.050	$ 3.14	$ 3.54	$ 3.93	$ 4.32	$ 4.71	$ 5.11	$ 5.50	$ 5.89	$ 6.29	$ 6.68	$ 7.07	$ 7.46	$ 7.86	$ 8.25	$ 8.64	$ 9.04	$ 9.43	$ 9.82
0.055	$ 3.46	$ 3.89	$ 4.32	$ 4.75	$ 5.19	$ 5.62	$ 6.05	$ 6.48	$ 6.91	$ 7.35	$ 7.78	$ 8.21	$ 8.64	$ 9.08	$ 9.51	$ 9.94	$ 10.37	$ 10.80
0.060	$ 3.77	$ 4.24	$ 4.71	$ 5.19	$ 5.66	$ 6.13	$ 6.60	$ 7.07	$ 7.54	$ 8.01	$ 8.49	$ 8.96	$ 9.43	$ 9.90	$ 10.37	$ 10.84	$ 11.31	$ 11.79
0.065	$ 4.09	$ 4.60	$ 5.11	$ 5.62	$ 6.13	$ 6.64	$ 7.15	$ 7.66	$ 8.17	$ 8.68	$ 9.19	$ 9.70	$ 10.21	$ 10.73	$ 11.24	$ 11.75	$ 12.26	$ 12.77
0.070	$ 4.40	$ 4.95	$ 5.50	$ 6.05	$ 6.60	$ 7.15	$ 7.70	$ 8.25	$ 8.80	$ 9.35	$ 9.90	$ 10.45	$ 11.00	$ 11.55	$ 12.10	$ 12.65	$ 13.20	$ 13.75
0.075	$ 4.71	$ 5.30	$ 5.89	$ 6.48	$ 7.07	$ 7.66	$ 8.25	$ 8.84	$ 9.43	$ 10.02	$ 10.61	$ 11.20	$ 11.79	$ 12.38	$ 12.96	$ 13.55	$ 14.14	$ 14.73
0.080	$ 5.03	$ 5.66	$ 6.29	$ 6.91	$ 7.54	$ 8.17	$ 8.80	$ 9.43	$ 10.06	$ 10.69	$ 11.31	$ 11.94	$ 12.57	$ 13.20	$ 13.83	$ 14.46	$ 15.09	$ 15.71
0.085	$ 5.34	$ 6.01	$ 6.68	$ 7.35	$ 8.01	$ 8.68	$ 9.35	$ 10.02	$ 10.69	$ 11.35	$ 12.02	$ 12.69	$ 13.36	$ 14.03	$ 14.69	$ 15.36	$ 16.03	$ 16.70
0.090	$ 5.66	$ 6.36	$ 7.07	$ 7.78	$ 8.49	$ 9.19	$ 9.90	$ 10.61	$ 11.31	$ 12.02	$ 12.73	$ 13.44	$ 14.14	$ 14.85	$ 15.56	$ 16.26	$ 16.97	$ 17.68

LABOR COSTS PER ACRE

hourly labor cost plus fringe

TLR	10	12	14	16	18	20	22
0.020	$ 0.31	$ 0.37	$ 0.44	$ 0.50	$ 0.56	$ 0.62	$ 0.68
0.025	$ 0.39	$ 0.47	$ 0.55	$ 0.63	$ 0.71	$ 0.79	$ 0.86
0.030	$ 0.47	$ 0.57	$ 0.66	$ 0.76	$ 0.85	$ 0.95	$ 1.04
0.035	$ 0.56	$ 0.67	$ 0.78	$ 0.89	$ 1.00	$ 1.11	$ 1.22
0.041	$ 0.64	$ 0.77	$ 0.89	$ 1.02	$ 1.15	$ 1.28	$ 1.41
0.046	$ 0.72	$ 0.86	$ 1.01	$ 1.15	$ 1.30	$ 1.44	$ 1.59
0.051	$ 0.80	$ 0.96	$ 1.12	$ 1.28	$ 1.44	$ 1.61	$ 1.77
0.056	$ 0.88	$ 1.06	$ 1.24	$ 1.42	$ 1.59	$ 1.77	$ 1.95
0.062	$ 0.97	$ 1.16	$ 1.35	$ 1.55	$ 1.74	$ 1.93	$ 2.13
0.067	$ 1.05	$ 1.26	$ 1.47	$ 1.68	$ 1.89	$ 2.10	$ 2.31

REVEGETATION COSTS PER ACRE

price per lb

lbs per acre	0.1	0.2	0.3	0.6	0.7	0.8	0.9	1	1.1
30	$ 0.10	$ 0.19	$ 0.29	$ 0.58	$ 0.68	$ 0.78	$ 0.88	$ 0.97	$ 1.07
40	$ 0.13	$ 0.26	$ 0.39	$ 0.78	$ 0.91	$ 1.04	$ 1.17	$ 1.30	$ 1.43
50	$ 0.16	$ 0.32	$ 0.49	$ 0.97	$ 1.14	$ 1.30	$ 1.46	$ 1.62	$ 1.79
60	$ 0.19	$ 0.39	$ 0.58	$ 1.17	$ 1.36	$ 1.56	$ 1.75	$ 1.95	$ 2.14
70	$ 0.23	$ 0.45	$ 0.68	$ 1.36	$ 1.59	$ 1.82	$ 2.05	$ 2.27	$ 2.50
80	$ 0.26	$ 0.52	$ 0.78	$ 1.56	$ 1.82	$ 2.08	$ 2.34	$ 2.60	$ 2.86
90	$ 0.29	$ 0.58	$ 0.88	$ 1.75	$ 2.05	$ 2.34	$ 2.63	$ 2.92	$ 3.21
100	$ 0.32	$ 0.65	$ 0.97	$ 1.95	$ 2.27	$ 2.60	$ 2.92	$ 3.25	$ 3.57
110	$ 0.36	$ 0.71	$ 1.07	$ 2.14	$ 2.50	$ 2.86	$ 3.21	$ 3.57	$ 3.93
120	$ 0.39	$ 0.78	$ 1.17	$ 2.34	$ 2.73	$ 3.12	$ 3.51	$ 3.90	$ 4.29

[1] The time to length ratio is derived by dividing the time in minutes required to retire the observed skid trail by it's length in feet. Per acre costs are based on an average retireable skid trail density of 1 mile to every 56 acres harvested. Per acre costs may be converted to cost per MBF harvested by dividing by the state average of 2.7 MBF per acre or by using a known value for the harvested area.

Chapter two: Time and motion study of skid trail retirement

Introduction

Water bar construction and reshaping are practices that every ground skidding operation in Kentucky must employ. In the absence of standard methods, machine operators develop individual methods for completing repetitive tasks such as these. As with any manufacturing process, some methods will be more productive than others. Time and motion study techniques were developed in the steel industry at the beginning of the 20th century to discover not only which method was the most effective but also why. Due to the usefulness of time and motion studies they have become common place in any industry where workers conduct repetitive tasks (Neibel, 1993). Given the repetitive nature of water bar construction and reshaping activities, they are prime candidates for the use of time and motion studies to analyze and improve the effectiveness of these operations.

This study presents the results of time and motion analysis of reshaping activities and water bar construction. The observed average times for each activity may be used to determine implementation costs while motion studies may be used to identify the most efficient methods for completing each task. Since these practices are used by all logging operations installing BMPs and standard methods have not been developed, time and motion analysis may prove useful in helping to reduce the cost of these activities. Reducing the cost of these activities will make it easier for logging firms to apply them and thus aid in the reduction of nonpoint source pollution.

Methods

Ten contract logging operations were identified for study by industrial foresters, forestry consultants, and loggers in Kentucky. The measured skid trail sections were selected by the logger. Data collection was divided into machine and operator information, skid trail condition prior to retirement, continuous filming of retirement operations, post retirement measurements, and time and motion analysis of reshaping and water bar construction. Each of these except time and motion analysis are described in detail in Chapter one.

Time and motion analysis of reshaping and water bar construction.

Time and motion analysis of any manufacturing process requires preliminary observations to identify it's main components (Neibel, 1993). After observing machine activities during the retirement of a typical section of primary skid trail in eastern Kentucky, two sub processes were identified, reshaping and water bar construction. Reshaping motions included:

Forward	Reverse
• Moving earth	• Moving earth
• Moving brush	• Moving brush
• Positioning	• Positioning

Water bar construction motions included:

Forward	Reverse
• Main earth movement	• Main earth movement
• Auxiliary earth movement	• Auxiliary earth movement
• Positioning	• Positioning
• Travel	• Travel

Main movements were defined as those that produced a perceptible and measurable change in water bar volume or shape. Auxiliary movements were defined as those producing no perceptible structural change. Construction time, or cycle time, for each water bar began when the blade was lowered to make the first movement (main or auxiliary) and ended when the blade was lowered to begin the next water bar or to travel to an activity other than water bar construction. Other machine time elements not specific to reshaping or water bar construction were also recorded including machine and operator delay and machine travel to and from the retirement work areas. All video segments were classified as reshaping, water bar construction, travel, or delay elements.

Construction times were transformed using log base 10 before applying a Shapiro-Wilk test for normal distribution. Differences in water bar construction time among regions and machine types were evaluated with one-way analysis of variance tests. Simple linear regression was used to detect relationships among water bar construction time and operator experience, machine horsepower, water bar volume, skid trail physical characteristics, and the number of forward and reverse movements used to construct each water bar. Differences among regions, machine types, and methods of water bar construction were evaluated using one-way analysis of variance tests for soil moisture, skid trail width, water bar volume, percent slope above the water bar, number of movements per water bar, and percent side slope. Water bar and reshaping cycle elements were analyzed using linear regression to evaluate their effects on the total times of each.

Results

Data were collected on the ten sites previously described in Chapter 1.

Reshaping time and motion

There was a positive trend ($r^2 = 0.65$, $p = 0.05$) between estimated volume moved and reshaping time. There was also a significant positive relationship between total earth volume moved (re-shaping and water bar construction volumes combined) and total machine time ($r^2 = 0.89$, $p = 0.004$). Reshaping cycle elements are presented in Table 2.1 as a percent of total reshape time for each site.

Water bar construction time

A total of 133 water bars, 112 built with dozers and 21 built with skidders, were filmed during construction. Table 2.2 lists descriptive statistics for water bar construction times for each site while Table 2.3 provides other descriptive information of the sites included. Shapiro-Wilk tests for normal distribution were not significant. Simple linear regression was used to identify the most influential factors in water bar construction time (Table 2.4). Linear regression analysis indicated that delay free cycle time could best be predicted from the total number of movements per water bar with an r^2 of 0.58 ($p < 0.0001$) for water bars built with a dozer and $r^2 = 0.78$ ($p < 0.0001$) for water bars built with a skidder (Figures 2.1 and 2.2). Water bar construction time also had significant positive relationships with water bar volume ($r^2 = 0.30$, $p < 0.0001$) and skid trail slope percent ($r^2 = 0.16$, $p < 0.0001$) for water bars built with dozers (Table 2.4). No such relationships were found for water bars built with skidders.

Operator experience, percent side slope, skid trail width, soil moisture, and machine horsepower were tested and found to have no significant effect on water bar construction time. Total water bar volume was added to the estimated reshaping volume and regressed against total machine time (reshaping, water bar construction, and travel) that showed a significant positive relationship ($r^2 = 0.89$, $p = 0.004$)(Figure 1.9).

Water bar motion study

Each water bar construction element was considered as a percent of the mean water bar construction time for each site (Table 2.5). Multiple linear regression was used to identify relationships among each element and average water bar construction time (Table 2.4). A highly significant ($r^2 = 0.94$, $p = 0.004$) relationship was found between construction time and percent of time spent on forward auxiliary movements of earth and forward positioning (Figure 2.3).

Observation of water bar installation identified 3 distinctive construction methods:

1. Ditching method: the cut bank side of the blade is tilted downward so that the lower corner of the same side is the lowest point of the blade. The blade point is inserted into the skid trail adjacent to the cut bank and moves forward until there is sufficient dirt against the bank to block any surface flow of water. Without repositioning the blade, the dozer turns towards the fill bank side of the skid trail at an appropriate angle and cuts a ditch across the width of the trail. The dirt from the ditch is cast towards the lower slope of the skid trail which has the effect of building the water bar levee on the downhill side of the ditch.
2. Successive berms from the cut bank to the fill bank (SBC): A levee of earth is built across the width of the trail in successive forward and reverse motions from the cut bank side to the fill bank side. The first main forward movement creates a berm that each successive main forward movement adds to. The series of connected berms creates the water bar levee. After the levee is created, a final sweep is made with the blade that cleans debris from the base of the water bar levee and creates a clear channel to the downhill side of the trail.

3. Successive berms from the fill bank to the cut bank (SBF): This method is implemented in exactly the same fashion as the SBC method except that levee construction begins on the fill bank side of the trail.

While it was not possible to separate operator and method variances, analysis of construction times among methods was completed to indicate whether further research into methodologies would be justified. Using one-way analysis of variance tests, significant differences were revealed among the methods for average construction time, water bar volume, number of movements per water bar, and skid trail percent slope (Table 2.6).

Discussion

While a limited number of sites were incorporated in this study, the operations were typical of those used in Kentucky and the machine times can be used to establish reasonable estimates of BMP implementation.

Reshaping and skid trail condition

While all skid trails included in this study were in relatively good condition with limited rutting, most had a moderate amount of outside embankments or berms. Results of the road profile analysis indicated that rut depth (a relatively easy measure) was significantly related to the total earth volume to be cut from the trail surface. There was also a positive trend between reshape time and the volume to be moved, suggesting that skid trail condition can have a significant effect on machine time required to implement skid trail retirement BMPs. The estimated average volume of earth to be moved during reshaping was 35 yd^3 per 1000 feet with a range of 20 yd^3 to 53 yd^3. This is equivalent to 6 average water bars (5.5 yd^3, 16 ft trail width, 3.8 ft uphill face length, 5.0 downhill face length) moved during reshaping with a range of 3.5 to 9.5. If the volume is spread out over 1000 feet of skid trail with an average width of 16 feet, about 7/10 of an inch would have to be removed over the entire surface.

While linear regression showed no relationships between total reshape time and each component, the information is still useful when coupled with field observations. Dozer sites used an average of 10% of their time moving brush with a range of 0% to 34% (Table 2.1). In some instances loggers prefer to lay tree tops and limbs across retired skid trails to impede ATV traffic as well as provide additional cover for grass seed and in some cases to provide additional water diversion. However, the benefits of this practice should be weighed against an increase in skid trail retirement costs when it occurs before reshaping and water bar activities are conducted. While it may not always be possible to avoid dropping trees across or into trails before retirement, the cost associated with their removal to facilitate retirement warrants planning of felling and layout to minimize costs.

One difference between sites that used skidders and those that used dozers was the general retirement process. All of the dozer operators conducted reshaping operations on the way down the skid trail and then installed water bars on the way back up. Skidder operators conducted both activities simultaneously. Since skidders are much less efficient earth movers than dozers and are required to back up several skidder lengths to gather enough earth to build a substantial water bar, reshaping occurs as a matter of course during water bar construction. Conducting reshaping and water bar construction activities simultaneously may be one method for sites that use dozers to reduce their total machine times. Another factor that may have an effect on reshaping time is the machine operator's perception of why reshaping activities are conducted. In discussions with operators, it seemed that most loggers did not have a clear idea of exactly what should be done during reshaping. This sort of confusion may cause some loggers to spend too much time reshaping and others to not reshape at all and should be a topic covered in future logger education programs.

Water bar construction time

The logging firms in this study reported an average of 600 MBF harvested per person per year and an average of 6 persons per crew. Using the Kentucky state average of 2.7 MBF per acre, the average area harvested annually by the crews in this study annually is 1,333 acres. Queary (1998) found that logging jobs in Kentucky will average one mile of retireable skid trail for every 36 acres harvested and that skid trails (primary and secondary) averaged 17% slope. Using these parameters and Kentucky's BMP guidelines for water bar intervals, a typical logging firm can expect to install 3620 water bars per year. The average water bar construction times derived in this study indicate that a logging firm that uses a dozer to install water bars will spend 90 hours per year while a firm that uses a skidder will spend 211 hours. While this comparison demonstrates the potential difference in annual water bar construction costs between machines, it is important to note that all of the skidder sites were in the western Pennyroyal region. Figures 2.4 and 2.5 illustrate the differences in percent side slope and skid trail slope among regions. Less precipitous slopes and lower average percent slopes on skid trails in the western Pennyroyal region translate to fewer water bars per mile of skid trail for either machine operating in this region.

Water bar motion study

The significant positive relationship between water bar construction time and the average number of movements used to complete each water bar was evidence of the importance of operator efficiency (Figures 2.1 and 2.2). This evidence is supported by the analysis of each water bar element as a percent of the average construction time that shows, for sites that used dozers, a significant positive relationship among average construction time, forward auxiliary movements, and forward positioning (Figure 2.3). Forward positioning and auxiliary movements usually occur together when an operator has just moved in reverse and then moves forward with the blade up, and then lowers the blade just in front of the water bar to make some minor adjustment. Looking at Table 2.1, we see that sites that used dozers spent 8.2% of the average construction time engaged in these two activities whereas sites that used skidders spent 13.8%. While most auxiliary earth movements by definition are unnecessary, some forward positioning is necessary. If these movements are reduced to the minimum observation of 1.5% for dozers, annual water bar time can be reduced from 90 hours to 84 hours. Using the skidder sites minimum value of 9.1% can reduce their annual construction times from 168 hours to 160 hours. Observation of these movements may be used as indicators of operator efficiency when compared with the average.

This study also suggests, given the relationship between the number of movements and average construction time, that operator experience does not necessarily equate to operator efficiency since no significant relationships were found between operator experience and any other variable included in this study.

The difference among the average construction times of the observed water bar construction methods appears to be clear with the ditching method having a significantly lower construction time than either of the successive berm methods and the SBC method having a significantly lower construction time than the SBF method (Table 2.6). These averages are supported by the average number of movements used to build each water bar that was found to have a significant positive relationship with water bar construction time. However, further inspection of Table 2.6

reveals that the ditching method had a significantly lower average water bar volume than the SBC method and that the SBC method had a significantly lower water bar volume than the SBF method. Differences in water bar volume among the methods, coupled with the average percent slopes of the skid trails on which each method was implemented and a significant positive relationship between water bar volume and skid trail percent slope, indicates that the ditching method may have had lower average construction times due to lower average skid trail percent slopes. Lower slope percents allowed the ditching method to build smaller water bars and hence use fewer movements per water bar leading to lower average construction times.

While it may be intuitive to assume that using a more powerful dozer would have a significant impact on construction times, results showed no relationship between machine size and volume per movement. It is interesting to note that there was no difference in average volume of earth moved per machine movement among the methods. Assuming that the volume of earth moved is evenly distributed among the forward pushes, we could say that each forward push averages 1.1 yd^3 of earth. The smallest of the dozers used in this study has a blade capacity of 2.21 yd^3, double the average amount. Under utilization of blade capacity suggests that machine size and/or blade capacity have very little effect on water bar construction times. The limited effect of machine size is supported by Layton et al. (1992) who concluded that, for sections of road less than 2.5 miles, using the smallest dozer capable of doing the job in forest road construction would result in a cost advantage. In sum, skid trail retirement costs may be reduced by limiting skid trail percent slope and using the smallest dozer possible.

An analysis of the minimum number of movements per water bar required by each method may be helpful in deciding which observed method is the most efficient. Assuming that both of the successive berm methods use three main pushes forward, one reverse positioning movement for each main push forward, a final push forward to clean the water bar out, and then travels in reverse to the next water bar, a minimum of 8 movements would be required for each water bar. Since the ditching method makes a continuous movement across the trail width, additional pushes to connect successive berms and to clean the water bar out may be eliminated. After accumulating sufficient earth during a main push forward using the successive berm method, the dozer continues forward while raising the blade so that the accumulated earth creates a pile instead of falling back into the water bar channel. The ditching method requires no such refinement. A comparison of average time per main push forward reveals that the ditching method is significantly faster ($p = 0.0005$) than either of the successive berm methods. During reverse movements, the successive berm method must position the dozer so that the next main push will connect with the previous berm (similar to parallel parking) whereas the ditching method can move backwards in exactly the same path as the previous main push forward. A significantly ($p = 0.0005$) lower average number of reverse movements suggests that the ditching method may be more efficient. The ditching method appears to be the most efficient in terms of movements although percent slope likely plays a significant role.

Table 2.1: Reshape activities as a percent of total reshape time

	site #	total length retired	total reshape time (min)	forward (%) position	forward (%) moves earth	forward (%) moves brush	forward (%) **subtotal**	reverse (%) position	reverse (%) moves earth	reverse (%) moves brush	reverse (%) **subtotal**
Dozer	2	684	28	4	70	0	**74**	26	0	0	**26**
	3	878	15	25	22	14	**60**	30	10	0	**40**
	5	2194	69	26	39	0	**66**	19	15	0	**34**
	8	1125	51	3	51	0	**54**	40	6	0	**46**
	9	936	14	5	30	34	**69**	28	3	0	**31**
	10	3127	106	0	49	2	**51**	49	0	0	**49**
	avg.	**1491**	**47**	**11**	**43**	**8**	**62**	**32**	**6**	**0**	**38**
	S.E.	**963**	**36**	**12**	**17**	**14**	**9**	**11**	**6**	**0**	**9**
Skidder	4	580	5	0	69	0	**69**	31	0	0	**31**
	6	935	12	1	70	0	**71**	15	14	0	**29**
	7	1148	10	22	31	0	**53**	42	5	0	**47**
	avg.	**888**	**9**	**8**	**57**	**0**	**64**	**28**	**10**	**0**	**36**
	S.E.	**287**	**4**	**12**	**22**	**0**	**10**	**13**	**7**	**0**	**10**

position = The machine position is changed in forward or reverse, without moving any earth, to facilitate further construction the the water bar. **Subtotals** for the two sections, forward and reverse, sum to 100 in each row.

Table 2.2: Water bar construction time descriptive statistics

	Site	n	Mean (min)	SE
Dozer	**2**	10	1.20	0.12
	3	7	1.95	0.19
	5	15	0.83	0.11
	8	8	2.16	0.28
	9	17	1.97	0.29
	10	22	1.17	0.10
	11	33	1.46	0.09
Skidder	**4**	10	4.14	0.36
	6	8	2.88	0.38
	7	3	3.04	1.52

Table 2.3: Observed machine times and site characteristics

		site characteristics				observed machine times[1] (min)					machine times per 1000 feet[3] (min)			
	site #	length retired (ft)	trail width (ft)	% soil moisture	% slope	reshape	water bar (n)		travel[2]	total	reshape	wb	travel	total
dozer	2	684	13	10%	15%	28	12	(10)	7	47	41	18	9	68
	3	878	16	18%	26%	15	14	(8)	4	33	17	16	5	38
	5	2194	17	10%	11%	69	12	(15)	26	108	31	6	12	49
	8	1125	16	12%	27%	51	16	(8)	5	72	44	15	4	64
	9	936	17	13%	26%	14	34	(17)	0	48	15	36	0	51
	10	3127	17	11%	23%	106	26	(22)	3	135	34	8	1	43
	avg.	**1491**	**16**	**13%**	**22%**	**47**	**19**		**7**	**74**	**30**	**16**	**5**	**52**
	S.E.	**963**	**1**	**3%**	**7%**	**36**	**9**		**9**	**40**	**12**	**11**	**5**	**12**
skidder	4	580	16	11%	17%	5	41	(10)	8	54	9	71	14	94
	6	935	19	11%	23%	12	23	(8)	2	37	13	25	2	39
	7	1148	15	25%	14%	10	9	(3)	3	22	9	8	2	19
	avg.	**888**	**17**	**15%**	**18%**	**9**	**25**		**4**	**38**	**10**	**35**	**6**	**51**
	S.E.	**287**	**2**	**8%**	**4%**	**4**	**16**		**3**	**16**	**2**	**33**	**7**	**39**

[1]Machine time referes to the amount of time the machine was operated to complete a particular task (enging hours). [2]On site travel time to and from location of retirement area. No machine delay was recorded and all operator delay resulted from interaction with the researcher and as such is not included in total machine time. [3]Machine times per 1000 feet are calculated by multiplying 1000 times the ratio of time to total length retired.

Table 2.4: Linear regression results of water bar construction time

variable	dozer r^2	dozer p value	dozer intercept p values	skidder r^2	skidder p value	skidder intercept p values
total number of movments	0.58	< 0.0001	< 0.0001	0.68	< 0.0001	0.2826
water bar volume	0.30	< 0.0001	< 0.0001	0.03	0.4203	0.0154
% slope of trail	0.15	< 0.0001	< 0.0001	0.19	0.0493	< 0.0001
trail width	0.21	< 0.0001	0.2291	0.13	0.1039	0.8388
auxialiary push forward	0.49	< 0.0001	< 0.0001	0.21	0.0356	< 0.0001
forward positioning	0.32	< 0.0001	< 0.0001	0.04	0.3673	< 0.0001
soil moisture	0.08	0.0023	0.0013	0.07	0.2544	< 0.0001
horsepower	0.04	0.0334	< 0.0001	0.22	0.0322	0.0002
% side slope	0.02	0.1108	< 0.0001	0.14	0.0948	< 0.0001
years logging experience	0.01	0.2649	< 0.0001	0.02	0.5171	0.5475
years experience with BMPs	0.02	0.1846	< 0.0001	0.02	0.5171	< 0.0001
years experience with equipment used	0.01	0.3013	< 0.0001	0.02	0.5171	< 0.0001

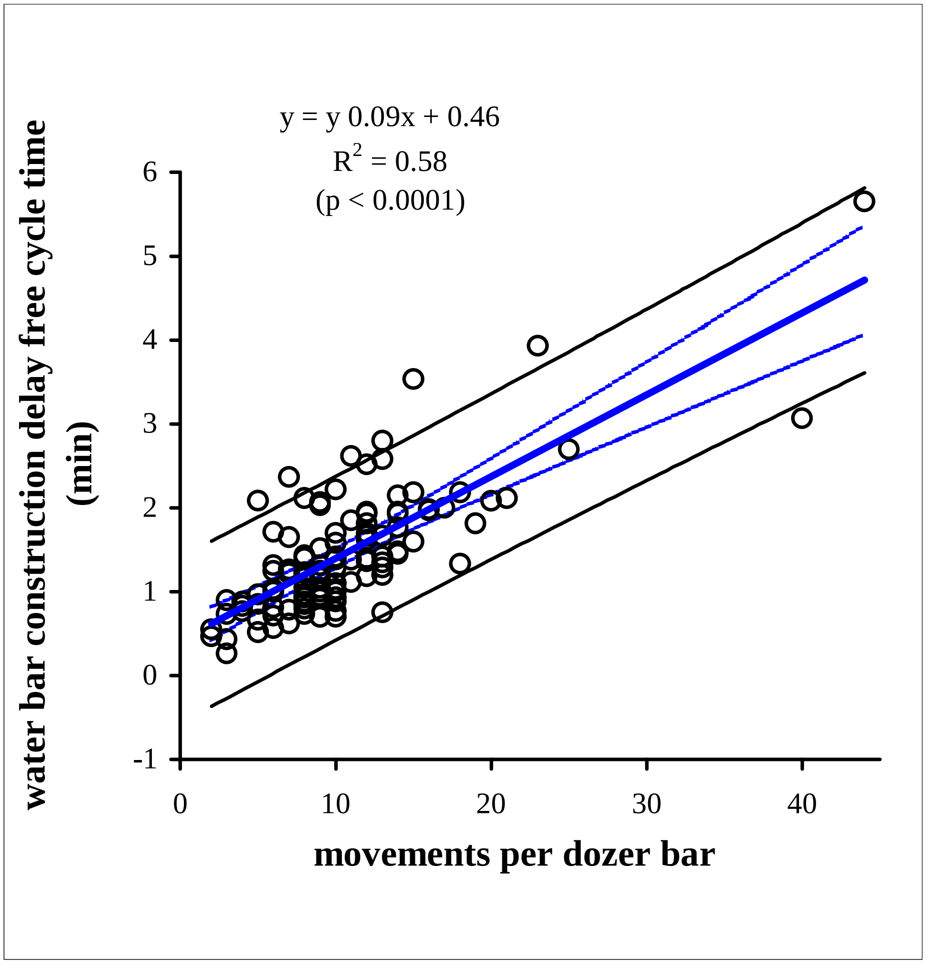

Figure 2.1: Linear regression of dozer water bar construction times vs. total number of movements per water bar (n = 112).
The center line is the regression line. Moving outward from the regression line is the confidence interval band while the outer set of lines contains the prediction interval band at 95%.

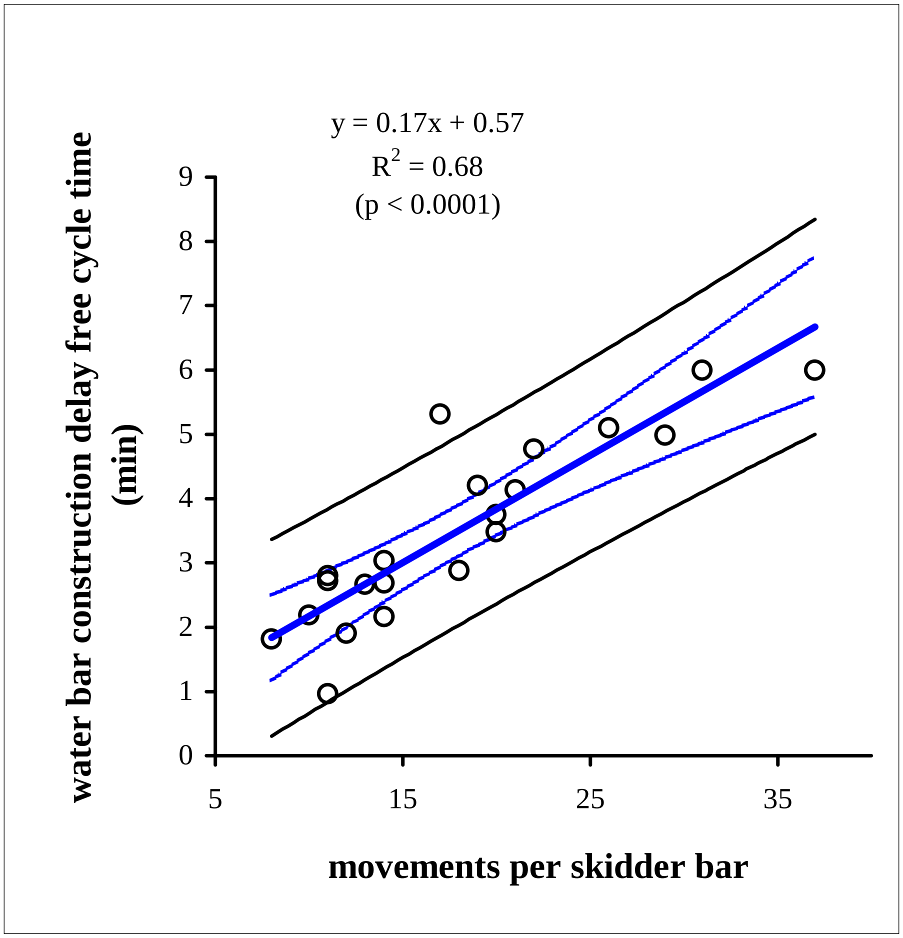

Figure 2.2: Linear regression of skidder water bar construction time vs. total number of movements per water bar (n = 21).
The center line is the regression line. Moving outward from the regression line is the confidence interval band while the outer set of lines contains the prediction interval band at 95%.

Table 2.5: Water bar construction elements as a percent of construction time

	Site	avg. DFCT (min)	forward (%) main	forward (%) aux.	forward (%) position	forward (%) travel	forward (%) subtotal	reverse (%) main	reverse (%) aux.	reverse (%) position	reverse (%) travel	reverse (%) subtotal
Dozer	2	1.20	32.5	5.6	0.1	16	**55**	0.0	0.0	21.5	23.9	**45**
Dozer	3	1.95	33.2	6.7	4.8	0	**45**	0.0	0.0	22.2	33.1	**55**
Dozer	5	0.83	30.7	1.2	0.4	11	**44**	1.9	0.0	4.7	49.8	**56**
Dozer	8	2.16	24.2	8.6	4.1	5	**41**	8.4	2.3	19.7	28.2	**59**
Dozer	9	1.97	29.8	8.8	1.3	4	**44**	1.7	0.0	28.5	26.2	**56**
Dozer	10	1.17	33.1	6.6	0.1	0	**40**	0.0	0.0	25.0	35.2	**60**
Dozer	11	1.46	33.8	8.7	0.2	5	**47**	0.0	0.0	23.1	29.6	**53**
	avg.	**1.53**	**31.0**	**6.6**	**1.6**	**6**	**45**	**1.7**	**0.3**	**20.7**	**32.3**	**55**
	S.E.	**0.50**	**3.3**	**2.7**	**2.0**	**6**	**5**	**3.1**	**0.9**	**7.6**	**8.6**	**5**
Skidder	6	2.88	46.8	11.1	1.2	0	**60**	0.0	0.9	27.5	12.0	**40**
Skidder	7	3.04	17.3	14.1	5.8	1	**38**	0.0	0.0	25.4	36.7	**62**
Skidder	4	4.14	45.7	8.0	1.1	2	**57**	0.0	0.0	29.5	13.3	**43**
	avg.	**3.35**	**36.6**	**11.1**	**2.7**	**1**	**52**	**0.0**	**0.3**	**27.5**	**20.6**	**48**
	S.E.	**0.68**	**16.7**	**3.0**	**2.7**	**1**	**12**	**0.0**	**0.5**	**2.1**	**13.9**	**12**

DFCT = Delay free cycle time. It is the sum of the water bar cycle time elements, expressed here as an average for each site.
main = A push or drag of earth that visibly changes the shape or volume of the water bar
aux. = A push or drag of earth that does not visibly change the shape or volume of the water bar
position = The machine position is changed in forward or reverse, without moving any earth, to facilitate further construction the the water bar
travel = Forward or reverse movement towards the next water bar with no work being done.

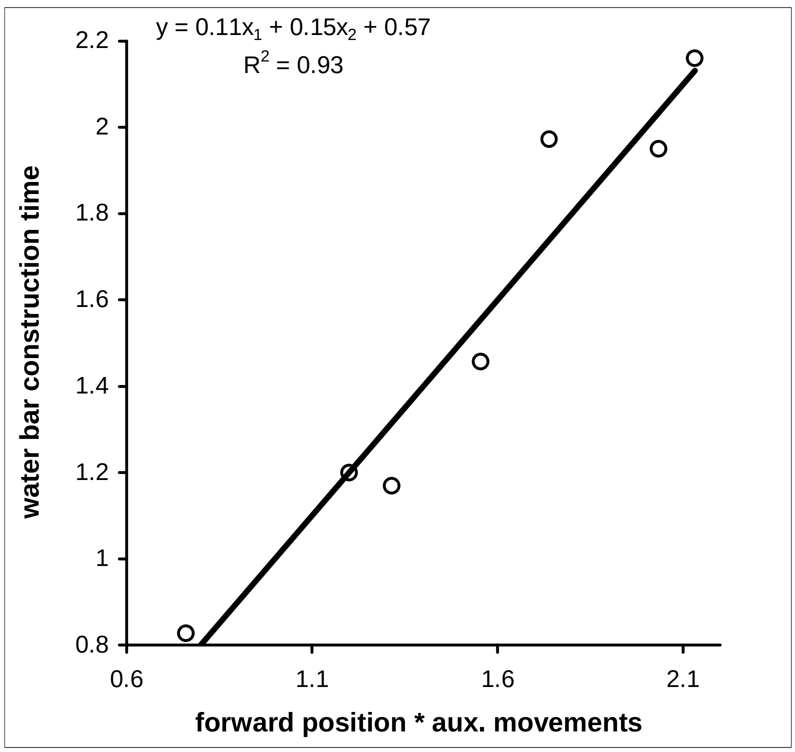

Figure 2.3: Linear regression of water bar construction time vs. forward positioning times auxiliary movements

Table 2.6: Water bar construction method statistics

Method	avg. cons. time (min)[1]	uphill face length (ft)	no. of movements	water bar volume (yd^3)	% slope[2]	trail width (ft)	vol/ mov[3] (yd^3)
Ditching	0.83[a]	2.5[a]	4.4[a]	1.9[a]	10[a]	17[a]	0.55[a]
SBC[4]	1.46[b]	3.4[b]	11.1[b]	5.7[b]	26[b]	15[a]	0.55[a]
SBF[5]	1.97[c]	3.8[c]	13.3[b]	8.4[c]	26[b]	17[a]	0.64[a]

[1]Average construction time per water bar. [2]Average percent slope of skid trail measured above water bar. [3]Ratio of water bar volume to the total number of movements used to construct each water bar. [4]Sucessive berm method of water bar construction implemented from the cut bank side. [5]Sucessive berm method of water bar construction implemented from the fill bank side. Averages within columns with different letters are significantly different ($p < 0.0001$)

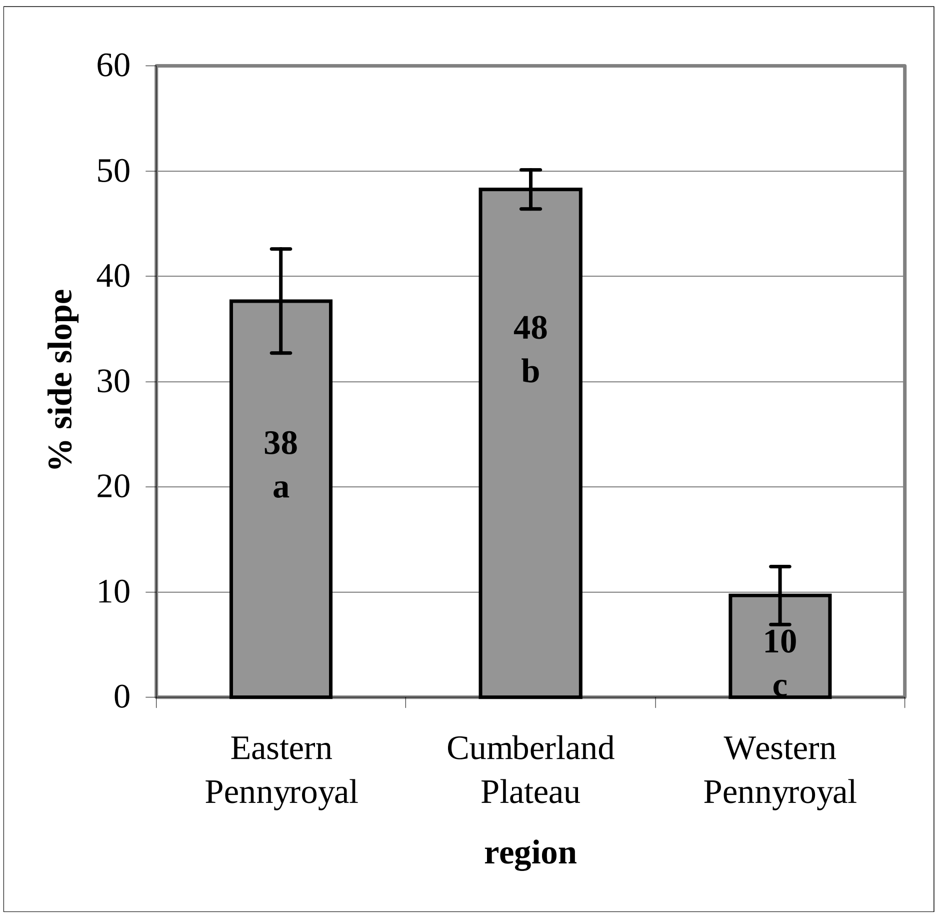

Figure 2.4: Average percent side slope by physiographic region.

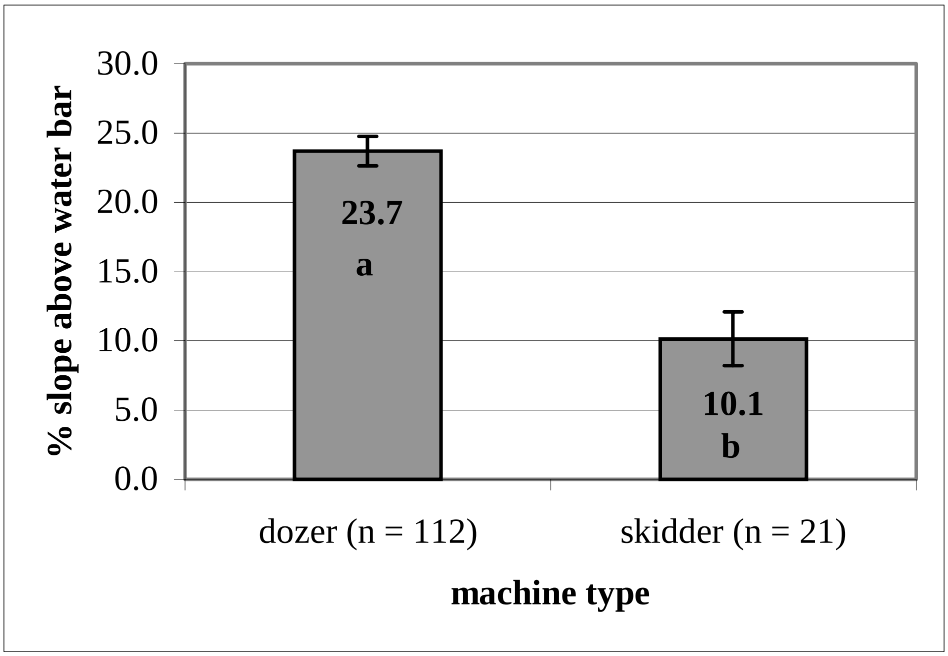

Figure 2.5: Average percent slope of skid trail above measured water bars. Columns with different letters are significantly different ($p < 0.0001$).

Chapter three: Thesis summary

Skid trail retirement

Skid trail condition prior to retirement

Measurement of average cross-sectional profiles allowed the development of a simplified method to quantitatively describe skid trail condition. The measurement of the depth of the deepest rut from a straight line established from the base of the cut bank to the opposite side of the skid trail allows the use of the developed regression equation. Although skid trail condition did not appear to have any affect total machine times or it's components in this study (likely due to a small amount of variation in skid trail condition among sites), the measurement may still be useful in other situations where a quantitative value is needed. Since the equation encompasses only a small amount of variation in skid trail condition, it could not be used on sites with more extensive rutting or outside embankments. A separate study might be conducted that would include a wider range of skid trail conditions as well as post retirement measurements of selected points so as to measure the effect of reshaping activities rather than assuming what effect reshaping has on the skid trail surface.

Reshaping and water bar construction

Sites that used bulldozers to conduct retirement operations averaged 52 minutes of machine time per 1000 feet of skid trail while sites that used skidders averaged 51 minutes. Although skidders used much more of their time constructing water bars than dozers (60% vs. 32%) and the same amount of time traveling to the work location (10%), they spent much less of their time reshaping (29% vs. 58%). The difference in average reshape time between the two machine types lies in the tendency of skidders to reshape as they build water bars. Since skidders cannot dig as well as dozers, they must back up much further from the desired location of the water bar and scrape dirt from the surface of the skid trail to build the water bar levee. Dozers, on the other hand, reshape on their way down to the end of the skid trail and then build water bars on the way back up. Also, dozers build water bars by cutting a dip from the skid trail on the uphill side of the water bar to build the levee which creates a channel that is compacted and less erodible than a levee of loose fill created by a skidder. Differences in retirement methods between the two machine types raises a couple of questions:

1. Can dozer operators reduce their retirement times by combining reshaping and water bar activities?

2. Are water bars constructed with a skidder as effective as those constructed with a dozer?

These are questions best answered with separate studies.

Revegetation

The average time required to apply seed, fertilizer, or lime to 1000 feet of skid trail was 23 minutes, regardless of the amount of material applied. None of the loggers that applied seed had a clear idea of how much they were sowing or how much should be sowed. A simple rule of thumb methodology to calculate seeding rates should be incorporated into logger education programs.

Costs

Perhaps the most valuable result of this study is the range of machine and/or labor times required per length of skid trail retired (time to length ratio). Time to length ratios may be used in conjunction with skid trail density values in simple formulas to calculate per acre retirement costs. While this study generated per acre costs for participating logging firms, these firms are probably not representative of the average logging firm in Kentucky. More accurate state averages for skid trail retirement times may be developed by coordinating with foresters across the state. Each participating forester could observe retirement operations and report basic information such as total machine and/or labor time required, total length retired, and the county in which the retirement occurred. This type of data collection is easy to obtain, low cost, and allows development of more reliable state averages in a relatively short period of time.

Time and motion analysis

Reshaping

Reshaping activities did not lend themselves to time and motion analysis. Time and motion analysis usually requires that identifiable processes exists which can be divided into component parts and scrutinized to determine the most influential factors in process completion times. No common process or methodology was observed during reshaping activities. Generally, operators did not seem to have a clear idea of what needed to be done during reshaping. Reshaping objectives should be thoroughly addressed during logger education programs.

Water bar construction

The average water bar construction time for sites that used dozers was 1.5 minutes while sites that used skidders averaged 3.5 minutes. A significant positive relationship was established between water bar construction time and the number of forward and reverse movements used to construct each water bar for both dozers and skidders. Two other important factors that had significant positive relationships with water bar construction time were the number of forward positioning movements and the number of forward auxiliary movements. Forward positioning and auxiliary movements occur when operators make small adjustments to the water bar that have little or no effect on the shape or size of the water bar levee. Loggers may be able to reduce water bar construction times and thus reduce retirement costs by limiting unnecessary movements.

Water bar construction method analysis

Three methods of water bar construction using a dozer were identified and analyzed to determine which method was the most efficient. The ditching method had the lowest average (0.83 min.) water bar construction time while the SBC method (successive berms beginning on the cut bank side) had the second lowest average (1.46 min.) and the SBF method (successive berms beginning on the fill bank side) had the highest average (1.97 min.). However, the ditching method also had lower average water bar volumes and lower average percent slopes than the other two methods. The data suggest that the differences in water bar construction times may have more to do with skid trail percent slope than the method used. These methods should be studied further so that differences among methods may be clearly defined.

Appendices

Appendix A: Logger's cost analysis

Skid Trail and Landing Retirement Cost Report:

A confidential cost analysis of skid trail and landing retirement costs

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What Is In This Report

SECTION 1 - "Production Loss" retirement costs

Retirement operations are usually carried out either during the regular 40 hour work week or on the weekend when only part of the normal crew would be paid to do retirement work. Using crew member time for retirement work during normal operating hours causes a loss of production or a decrease in the amount of timber that would normally be available to ship to the mill on an average work day. Section 1 of this report provides costs based on the amount of "Production Loss" incurred as a result of retirement work plus the cost of any materials used for retirement purposes (i.e. seed, fertilizer, mulch, lime). These costs **are not** to be added to Section 2 costs.

Page 1: Tables 1 and 2 estimate total costs for skid trail and landing retirement as a result of production loss

Page 2: Tables 3 and 4 provide a detailed breakdown of skid trail retirement costs due to production loss.

Page 3: Tables 5 and 6 provide a detailed breakdown of landing retirement costs due to production loss.

SECTION 2 - "Contract" retirement costs

While weekend retirement or "Contract" retirement does not cause any production loss, it does incur machine and labor costs not included in the normal work week. Section 2 estimates costs as if you had contracted yourself to do the retirement work which is based on machine and labor costs you provided as well as the cost of any materials used for retirement purposes (i.e. seed, fertilizer, mulch, lime). This section also includes two tables that compare of the cost per acre between production loss costs and contract costs. It is important to note that these costs do not include any profit margin. These costs **are not** to be added to Section 1 costs.

Page 4: Tables 7 and 8 estimate total costs for skid trail and landing retirement from a "Contract" perspective.

Page 5: Tables 9 and 10 provide a detailed breakdown of contract skid trail retirement costs.

Page 6: Tables 11and 12 provide a detailed breakdown of contract landing retirement costs.

Page 7: Tables 13 and 14 provide a comparison of production loss costs and contract costs for the measured area.

SECTION 3 - Other information

This section provides a site description, statistics on the measured area, a description of the calculation of hourly crew production rates, recommendations and comments.

Page 8: Provides a brief description of the measured area and a table of statistics for the same area .

Page 9: Lists crew information and a description of the calculation of production loss.

Page 10: Provides a description of the retirement work and recommendations that may help reduce costs.

IMPORTANT: The costs provided in this report are based on machine and labor time recorded during the site visit and operating cost information you provided. It is important to remember that these costs are specific to the site where the information was collected and the crew information you provided; when any of these change it will affect your BMP retirement costs.

Section 1: Production Loss Cost Summary

Table 1 - Skid trail summary cost estimates

cost:	per mile of trail	per acre of woodland	% of total cost
Water Bars			
Reshape			
seed			
fertilize			
mulch			
lime			
other			
misc. Costs			
totals			
Skid trail retirement costs for 0 acres:			

Table 1: This table is a summary of costs for skid trail retirement work on a per mile and per acre basis. The per mile costs were determined by taking the costs for the length of trails that were actually measured for this analysis and adjusting the cost to equal one mile of trail. For example, if the time analysis was conducted on retirement work over ½ mile of skid trail then the cost would be doubled to provide the per mile cost. The per acre cost was determined by applying the cost per mile determined in this analysis to the average length of retirable skid trails per acre for typical timber harvests in your area. The table also provides a percent breakdown for each of the activities involved in skid trail retirement.

Table 2 - Landing summary cost estimates

activity	average cost per landing	cost per acre of disturbed ground	% of total cost
reshape			
seed			
fertilize			
mulch			
lime			
other			
totals			
Estimated landing retirement costs for 0.0 acres:			

Table 2: The "cost per acre" column estimates the cost for each activity per acre of disturbed ground. If the time analysis was completed on one landing occupying 1/4 acre then the costs estimated for this 1/4 acre would be multiplied by 4 to get the cost per acre of disturbed ground.

Skid Trail Retirement Costs Due To Production Loss

Table 3 (same as Table 1)

cost:	per mile of trail	per acre of woodland	% of Total
Water Bars			
Reshape			
seed			
fertilize			
mulch			
lime			
other			
misc. Costs			
totals			

Table 3: This is exactly the same table as table one in the beginning of this report. It is repeated here so that all skid trail information may be viewed on a single page.

Table 4: This table provides costs for the skid trail that was measured and video-taped. For each retirement activity, time (in minutes) is listed under each cost category, except for "materials" where pounds per acre is listed. The times listed are summed across each activity and then multiplied by the hourly production rate per employee under the "total production loss" cost category.
You will notice that the length is included in the table's title. This is the length of skid trail that applies to the total cost figure in this table.

Table 4 - Activity costs for measured skid trail (0 ft)

Activity	**machine** (minutes)	**labor** (minutes)	**purchase** (minutes)	**materials** lbs/acre	cost	**total production loss** time	cost	**totals** cost
Water bars (0)								
Reshape (0 ft)								
Seed (0 ft)								
Fertilize (0 ft)								
Mulch (0 ft)								
Lime (0 ft)								
other								
misc. Costs								
culvert removal								
totals (minutes)								
total costs								
% of total cost								

Reshape refers to any earthwork that isn't a water bar; **Misc. Costs** refers to machine travel and delay; **Production Loss** refers to crew member time spent on retirement work; **Purchase** refers to time required to purchase and deliver materials to the job site.

Landing Retirement Costs Due To Production Loss

Table 5 (same as Table 2)

activity	average cost per landing	cost per acre of disturbed	% of total cost
reshape			
seed			
fertilize			
mulch			
lime			
other			
totals			

Table 5: This is exactly the same table as table two in the beginning of this report. It is repeated here so that all landing information may be viewed on a single page.

Table 6: This table provides costs for the landings that were measured and video-taped. For each retirement activity, time (in minutes) is listed under each cost category, except for "materials" where pounds per acre is listed. The times listed are summed across each activity and then multiplied by the hourly production rate per employee under the "total production loss" cost category. You will notice that the landing acreage is included in the table's title. This is the acreage that applies to the total cost listed in this table.

Table 6 - Activity costs for retired landing area (0.0 acres)

activity	machine (minutes)	labor (minutes)	purchase (minutes)	materials lbs/acre	materials cost	total production loss time	total production loss cost	totals
reshape								
seed								
fertilize								
mulch								
lime								
other								
totals (time)								
totals (costs)								
% of Total cost								

Reshape refers to any earthwork that isn't a water bar; **Misc. Costs** refers to machine travel and delay; **Production Loss** refers to crew member time spent on retirement work; **Purchase** refers to time required to purchase and deliver materials to the job site.

Section 2: Contract Retirement Cost Summary

Table 7 - Skid trail summary cost estimates

activity	per mile of trail	per acre of woodland	% of total cost
Water Bars			
Reshape			
seed			
fertilize			
mulch			
lime			
other			
misc. Costs			
totals			
Skid trail retirement costs for 0 acres:			

Table 7: This table is a summary of costs for skid trail retirement work on a per mile and per acre basis. The per mile costs were determined by taking the costs determined for the length of trails that were actually measured for this analysis and adjusting the cost to equal one mile of trail. For example, if the time analysis was conducted on retirement work over ½ mile of skid trail then the cost would be doubled to provide the per mile cost. The per acre cost was determined by applying the cost per mile determined in this analysis to the average length of retirable skid trails per acre for typical timber harvests in your area. The table also provides a percent breakdown for each of the activities involved in skid trail retirement.

Table 8 - Landing summary cost estimates

activity	average cost per landing	cost per acre of disturbed ground	% of total cost
reshape			
seed			
fertilize			
mulch			
lime			
other			
totals			
Estimated landing retirement costs for 0.0 acres:			

Table 8: The "cost per acre" column estimates the cost for each activity per acre of disturbed ground. If the time analysis was completed on one landing occupying 1/4 acre then the costs estimated for this 1/4 acre would be multiplied by 4 to get the cost per acre of disturbed ground.

Contract Skid Trail Retirement Costs

Table 9 (same as Table 7)

	cost:	per mile of trail	per acre of woodland	% of Total
Water Bars				
Reshape				
seed				
fertilize				
mulch				
lime				
other				
misc. Costs				
totals				

Table 9: This is exactly the same table as table one in the beginning of this report. It is repeated here so that all skid trail information may be viewed on a single page.

Table 10: This table provides costs for the skid trail that was measured and video-taped. For each retirement activity, time (in minutes) and costs are listed under each cost category, except for "materials" where pounds per acre is listed. You will notice that the length is included in the table's title. This is the length of skid trail that applies to the total cost figure in this table.

Table 10 - Activity costs for measured skid trail (0 ft)

	machine		labor		purchase		materials		totals
Activity	time	cost	time	cost	time	cost	lbs/acre	cost	cost
Water bars (0)									
Reshape (0 ft)									
Seed (0 ft)									
Fertilize (0 ft)									
Mulch (0 ft)									
Lime (0 ft)									
other									
misc. Costs									
culvert removal									
totals (minutes)									
total costs									
% of total cost									

Reshape refers to any earthwork that isn't a water bar; **Misc. Costs** refers to machine travel and delay; **Purchase** refers to time required to purchase and deliver materials to the job site

Contract Landing Retirement Costs

Table 11 (same as Table 8)

activity	average cost per landing	cost per acre of disturbed ground	% of total cost
reshape			
seed			
fertilize			
mulch			
lime			
other			
totals			

Table 11: This is exactly the same table as table two in the beginning of this report. It is repeated here so that all landing information may be viewed on a single page.

Table 12: This table provides costs for the landings that were measured and video-taped. For each retirement activity, time (in minutes) and costs are listed under each cost category, except for "materials" where pounds per acre is listed. You will notice that the landing acreage is included in the table's title. This is the acreage that applies to the total cost listed in this table.

Table 12 - Activity costs for retired landing area (0.0 acres)

	machine		labor		purchase		materials		totals
activity	time	cost	time	cost	time	cost	lbs/acre	cost	
reshape									
seed									
fertilize									
mulch									
lime									
other									
totals (time)									
totals (costs)									
% of Total cost									

Reshape refers to any earthwork that isn't a water bar; **Misc. Costs** refers to machine travel and delay; **Purchase** refers to time required to purchase and deliver materials to the job site

Production Loss vs. Contract Retirement

Table 13 - Skid Trail Contract Costs vs. Production Loss Costs

	cost per acre of woodland		% of total cost	
Activity	Contract	Production Loss	contract	Production Loss
Water Bars				
Reshape				
seed				
fertilize				
mulch				
lime				
other				
misc. Costs				
totals				

Table 13: This table provides skid trail retirement costs for both "Contract" and "Production Loss" so that you may compare the difference in costs more easily.

Table 14 - Landing Contract Costs vs. Production Loss Costs

	cost per acre of disturbed ground		% of total cost	
Activity	contract	production loss	contract	production loss
Reshape				
seed				
fertilize				
mulch				
lime				
other				
totals				

Table 14: This table provides landing retirement costs for both "Contract" and "Production Loss" so that you may compare the difference in costs more easily.

Site Information

Site description:

Table 7 - Site Statistics

tract acreage	average trail width (ft)
region	average slope %
length of trail retired (ft)	Avg. In-slope/Out-slope
total length in heavy ruts	measured trail area (acres)
total length in high berms	% of road in heavy ruts
estimated acres per mile of trail	% of road in high berms
soil moisture	average rut depth (inches)
average cut area (sq. ft)	total number of water bars

Table 7: This table provides descriptive measurements of the measured skid trail.

Logging Crew Information and Production Loss Calculation

Data supplied by logger

Crew Information:	**Machine and Labor Costs**	
	average hourly wage for:	**hourly machine cost for:**
crew size	seeding	water bar cons.
hours per day	fertilizing	reshaping
work days/week	mulching	seeding
workers comp rate	lime application	mulching
annual premium	other	lime application

Production loss calculation

weekly production of:		**dollars per hour per employee**	**hourly production**
saw logs	price per		
hardwood pulp	price per		
softwood pulp	price per		

total dollar amount produced per employee per hour →

Calculation of Production Loss:

$$crew\ member\ production\ per\ hour = \frac{average\ weekly\ crew\ production}{\#\ of\ scheduled\ work\ hours\ per\ week} \times \frac{1}{crew\ size} =$$ *hourly crew member production rate*

Recommendations and Comments

Recommendations:

Comments:

Appendix B: Data collection sheets

Crew and site information

weekly production of:

	units	volume		units	price
saw logs			price per		
hardwood pulp			price per		
softwood pulp			price per		

Site and Crew Info:

tract acreage		Average Wage to:		
region			seed	
crew size			fertilize	
hours per day			mulch	
work days/week			lime	
workers comp rate			other	
annual premium				

Operator Experience (years)

With equip. used	logging exp.	bmp installation	master logger (y,/n)

Measurements

length of trail retired	
total length in heavy ruts	
total length in high berms	

Machinery Description and hourly cost

make	**model**	**horse-power**	**hourly cost**	**hours**

Skid trail profile data sheet

Total Length of Road Segment:	# of Measurment points:	Site Number:

Point #	H. dist.	Height

Point #	H. dist.	Height

Point #	H. dist.	Height

Water bar construction video data sheet

Date: ______________

Road section start time: ________________

Road section stop time: ___________________

Site			Time		forward				reverse				WB cons. method (sb, d)	Delay (m/o)
Site #	Road Sec	WB #	start (hh:mm:ss)	stop (hh:mm:ss)	main	auxiliary	position	travel	main	auxiliary	position	travel		

Reshaping data sheet

Date: ______________ Road section start time: ________________ Road section stop time: ___________________

Site			Time		forward			reverse			WB cons. method (sb, d)	Delay (m/o)
Site #	Road Sec	WB #	start (hh:mm:ss)	stop (hh:mm:ss)	moves earth	moves brush	position	moves earth	moves brush	position		

Post retirement water bar and skid trail measurement data sheet

Operator experience				Machine				
bmp installation	lifetime	logging	Master Logger (yes, no)	Make/ model	blade width	total machine hours	rented Yes/No	cost per hour

Segment #	WB id#	road width	%slope of road	%side slope	Uphill face height	Uphill angle	Down-hill face height	Down-hill angle	WB Length	layout method (for, op.-go, op.-stop)	layout time
	1										
	2										
	3										
	4										
	5										
	6										
	7										
	8										
	9										
	10										
	11										
	12										
	13										
	14										
	15										
	16										
	17										
	18										
	19										
	20										
	21										

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