Reprinted from Watershed Management & Operations Management 2000, Proceedings of the Conference American Society of Civil Engineers, Held June 20-24, 2000, Fort Collins, Colorado

Fire and Erosion: Evaluating the Effectiveness of a Post-Fire Rehabilitation Treatment, Contour-Felled Logs

Peter R. Robichaud

Abstract

Recent fires have renewed interest in the effect of fire on flooding, sedimentation and effectiveness of various mitigation techniques. Erosion is a natural process occurring at varying rates and scales depending on soil type, topography, vegetation, climate and type of disturbance. Erosion rates in a forest environment are generally small except when the ground surface is disturbed by human or natural causes. First year surface erosion rates after wildfire can vary from 0.1 to greater than 110 Mg ha^{-1} yr^{-1}, often decreasing by orders of magnitude in subsequent years. Wildfires may consume the forest floor, leaving the soil surface exposed to raindrop impact and overland flow. Additionally, wildfires may leave the soil surface in a water repellent condition, reducing infiltration and increasing overland flow. These highly erosive conditions are temporary, because natural and artificial revegetation occur within first two years after the fire. To control this erosion and flooding potential, post-fire rehabilitation treatments such as contour-felled logs, have increased in use during the last decade.

The 1998, 3240-ha Twenty Five Mile Creek fire on the Wenatchee National Forest, WA provided an opportunity to monitor year-round runoff and erosion from two zero-order watersheds. One watershed (11 ha) was burned-only, the other watershed (9 ha) was burned and contour-felled logs with the capacity to trap 2.3 Mg ha^{-1} were used for a post-fire rehabilitation treatment. Runoff and sediment were measured by 0.3 m H-flumes with attached sediment traps for each watershed. First year results indicate that erosion can be easily triggered by small rain events. Two summer thunderstorm events, produced only 7-mm of rain each but caused 0.3 Mg ha^{-1} and 0.7 Mg ha^{-1} of sediment to leave the contour-felled log watershed whereas the storms did not effect the burned-only watershed. An 11-mm thunderstorm event in August caused 0.1 Mg ha^{-1} of sediment to leave the contour-felled log treated watershed and 0.5 Mg ha^{-1} on the burned-only watershed. By the end of the first year, 1.1 Mg ha^{-1} of sediment left the contour-felled log treated watershed and the contour-felled logs trapped 2.1 Mg Ha^{-1} indicating a trap efficiency of 66 percent whereas the burned-only watershed had 0.7 Mg ha^{-1} leave the watershed. Thus the contour felled log treated watershed had more erosion but the storms did not effect each watershed equally even though they were only 1 km apart. The data to date, however, have not shown any reduction in sedimentation leaving the hillslope from the contour-felled logs treated watershed.

Introduction

Increased awareness of the role of fire in healthy ecosystems has focused attention on some of the effects of fires, wild and prescribed, on soil productivity and watershed health. Precipitation events after forest fires may cause high sediment inputs to streams, destruction of aquatic habitat and downstream flooding, all which may be part of the natural ecosystem response. However, if the fires are more severe due to past fire suppression activities, then the fire effects may be greater than natural. Fire and erosion are both natural processes that have been impacted by forest management activities such as fire suppression, logging, and road building during the last century. Management activities may contribute to increased streamflows and increased sediment supplies to streams and rivers. Additional sediment places streams and rivers at a higher risk for degradation. Sediment adversely affects spawning and rearing sites for anadromous and resident fish species, mobilizes in-stream sediment, and destroys aquatic habitat. Therefore, management and mitigation strategies are often devised to reduce the threat of increased sediment.

Fire is a natural and important part of the disturbance regime for forested terrestrial and aquatic systems especially in the western USA (Agee 1993). However, much uncertainty exists in determining the quantitative assessment of fire effects on ecosystem components such as soil productivity and watershed health.

Surface erosion is the movement of individual soil particles by a force and is usually described by three components: 1) detachment, 2) transport, and 3) deposition. Inherent erosion hazards are defined as site properties that influence the ease which individual soil particles are detached (soil erodibility), slope gradient and slope length. Forces required to initiate and sustain the movement of soil particles are raindrop impact (Farmer and Van Haveren 1971), overland flow (Meeuwig 1971), gravity, wind, and animal activity. Protection is provided by vegetation, surface litter, duff, and rocks that reduce the impact of the applied forces and aid in deposition (Megahan 1986, McNabb and Swanson 1990).

Erosion is a natural process occurring on landscapes at different rates and scales, depending on geology, topography, vegetation, and climate. Landscape disturbing activities such as mechanical site preparation, agriculture, and road construction lead to the greatest erosion, which generally exceeds the upper limit of natural geologic erosion (Neary and Hornbeck 1994). Fires and fire management activities (fireline construction and post-fire rehabilitation) can also affect erosion.

Sediment yields one year after prescribed burns and wildfires range from very low, in flat terrain and in the absence of major rainfall events, to extreme, in steep terrain affected by high intensity thunderstorms. Erosion on burned areas typically declines in subsequent years as the site stabilizes, but the rate varies depending on fire severity. Soil erosion after fires can vary from under 0.1 to 6 Mg ha^{-1} yr^{-1} in low severity burns and from 21 to over 110 Mg ha^{-1} yr^{-1} in high severity wildfire burns (Megahan and Molitor 1975, Noble and Lundeen 1971, Robichaud and Brown 1999). For example, Radek (1996) observed erosion of 0.3 to 1.7 Mg ha^{-1} from several large wildfires that covered areas ranging from 200 to 1,770 ha in the northern Cascades mountains. Three years after these fire, large erosional events occurred from spring rainstorms, not from snowmelt. Most of the sediment produced did not leave the burned area. Sartz (1953) reported an average soil loss of 37 mm (about 300 Mg ha^{-1}) after a wildfire on a north-facing slope in the Oregon Cascades. Raindrop splash and sheet erosion accounted for the measured soil loss. Annual precipitation was 1070 mm, with a maximum intensity of 90 mm hr^{-1}. Vegetation covered the site within one year after the burn. Robichaud and Brown (1999) reported first year erosion rates after a wildfire from 21 to 49 Mg ha^{-1} decreasing by one to two orders of magnitude by the second year and to no sediment by the fourth in an unmanaged forest in eastern Oregon.

DeBano et al. (1996) demonstrated that following a wildfire in ponderosa pine, sediment yields from a low severity fire recovered to normal levels after three years, but moderate and severely burned watersheds took 7 and 14 years, respectively. Nearly all fires increase sediment yield, but wildfires in steep terrain produce the greatest amounts 28 to 370 Mg ha^{-1}. Noble and Lundeen (1971) reported an mean annual sediment production rate of 5.7 Mg ha^{-1} from a 365 ha burn on steep river breaklands in the South Fork of the Salmon River, Idaho. This rate was seven times greater than hillslope sediment yields from similar, unburned lands in the vicinity.

Contour-felled logs emergency rehabilitation treatment involves felling logs on burned-over hillsides and laying them on the ground along the slope contour, providing mechanical barriers to water flow and reducing sediment movement, the barriers can also trap sediment. The logs are staked in place and gaps from the soil surface to the log are filled. Logs were contour-felled on 9 ha of the 1979 Bridge Creek Fire, Deschutes NF in Oregon (McCammon and Hughes 1980). Trees 150-300 mm d.b.h. were placed and secured on slopes up to 50 percent at intervals of 3 to 6 m. Logs were staked and gaps underneath were filled. After the first storm event, about 63 percent of the contour-felled logs were judged effective in trapping sediment. The remainder were either partially effective or did not receive flow. Nearly 60 percent of the storage space behind contour-felled logs was full to capacity, 30 percent was half-full, and 10 percent had insignificant deposition. Common failures were flow under the log and not placing the logs on contour. Over 1,225 m^3 of material was estimated trapped behind contour-felled logs on the 9 ha, or about 135 m^3 ha^{-1}. Only 0.7 m^3 of sediment was deposited in the intake pond for a municipal water supply below. Miles et al. (1989) monitored contour-felling on the 1987 South Fork Trinity River fires, Shasta-Trinity NF in California. The treatment was applied to 80 ha within a 20,240 ha burned area. Trees 250 mm d.b.h. spaced 4.5 to 6 m apart were felled at rate of 200-250 trees ha^{-1}. The contour-felled logs trapped 0 to 0.05 m^3 of soil per log, retaining 3 to 13 m^3 ha^{-1} of soil on site. Miles et al. (1989) considered sediment trapping efficiency low and the cost high for this treatment. Sediment deposition below treated areas was not measured, however.

Since no literature was available to determine how effective contour-felled logs are on reducing sediment at the base of hillslopes, a study was designed and initiated in the fall of 1998 to compare two high severity burned watersheds (paired) with and without contour-felled logs as an emergency rehabilitation treatment.

Methods and Site Description

The study was conducted on the Chelan Ranger District, Wenatchee National Forest, near Chelan, WA in the northern Cascade Mountains (47°58' N, 120°20' W). The topography is rugged with an altitude range of 330 to1800 m above sea level with most sub-watersheds facing east-west. Slopes within the study area varied from 30 to 70 percent. The predominant soil type is a Palmich cindery sand loam (volcanic ash and pumice over colluvium or glacial till) and is 250 to 550 mm thick. Mean annual precipitation is 760 mm with much of that occurring as snow. Vegetation of the area was typical of the grand fir, ocean-spray habitat type (Williams and Smith 1991). The overstory was dominated by grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*), and ponderosa pine (*Pinus ponderosa*). The understory was relatively sparse because of the high stand density but did contain some medium shrubs such as ocean spray (*Holodiscus discolor*), Douglas maple (*Acer glabrum var. douglasii)* and elderberry (*Sambucus cerulea*). Herbaceous plants include heart leaf arnica (*Arnica cordifolia*), pinegrass (*Calamagrostis rubescens*), and elk sedge (*Carex geyeri*). The 1998 3240-ha North Twenty Five Mile Creek fire was a lighting strike fire started on August 4, 1998. Most of the area burned in two days with a fast moving fire which cause over 40 percent of the area to be classified as high severity burn. Two south-easterly exposed high severity burned zero-order watersheds (1 air-km apart) were selected for a paired watershed study (Table 1).

Contour-Felled Log Treatment

Logs were cut from burned trees 4.5 to 6 m in length with diameters of 100 to 305 mm. The logs were placed on the contour, and staked or existing stumps were used to prevent them from being moved downslope. The logs were backfilled with soil to increase ground contact. The storage capacity of each log was determined by calculating storage volume from on site measurements (Figure 1). Log measurements included total length, three measurements for volume calculations, and the log slope. Volume measurements consisted of a horizontal distance from top of log to soil level and depths from this line to the soil surface every 0.2 m. These were taken at the log centers and 0.5 m from each end. An ocular estimate for log soil contact was also made. Volumes were calculated using the average depths and lengths then discounted for poor ground contact and slope placement. There were an average of 45 logs ha^{-1}. Average initial individual log storage was 0.11 m^3. Watershed total storage from contour felled logs was 44 m^3.

Sub-Watersheds Instrumentation

At the outlet of each sub-watershed, a cut off wall was installed that diverts all runoff and sediment into a sediment trap and a 0.3 m H- flume (Figure 2). All sediment stored in the sediment trap is weighed after each storm event at the site (Figure 3). Sub-samples were taken for moisture contents, organic matter content, particle size analysis and nutrient contents. Organic materials such as ash was removed from the sediment weight. A complete remote weather station measuring wind speed and direction, solar radiation, humidity, ground water level, flume discharge, and rainfall intensity and amounts was located at each site. This information is transmitted daily via cell phone to the Rocky Mt. Research Station in Moscow, ID.

Results

Winter precipitation resulted in 1.1 m of snow with a snow water content of 406 mm by 22-March-1999. During the spring melt season, daily temperature fluctuations resulted in relatively slow melt season (Figure 4). Snowmelt-driven runoff occurred only from the burned-only watershed on 18-May-1999 which caused a rill to form about 30 m from the outlet of the watershed. Runoff amounted to 290 m^3. Sediment derived from the rill was 0.01 Mg ha^{-1} that was collected in the sediment box (Table 2). No runoff occurred from the contour-felled log treated watershed.

During the summer months, four thunderstorm events occurred that cause rills to form from the tops of each watershed and in some cases continue throughout the watersheds. Rills were observed after the 15-June-1999 event on the treated watershed only because the storm track missed most of the untreated watershed. The storm had a maximum 10-min intensity of 33.5 mm hr^{-1} at the top of the watershed, produced only 10.4-mm of rainfall and delivered 0.28 Mg ha^{-1} of sediment at the outlet of the contour-felled log treated watershed. The contour-felled logs trapped 0.57 Mg ha^{-1} of sediment on site. The second storm (21-July-1999) also only affected the contour-fell log treated watershed with 10-min max intensity of 29 mm hr^{-1}, producing 6.6-mm of rainfall and 0.7 Mg ha^{-1} of sediment at the outlet. The cumulative trapped sediment was 1.12 Mg ha^{-1}.

The third rainfall event (3-August-1999) affected both watersheds with 10-min max intensity of 21.3 mm hr^{-1} on the untreated burned-only watershed and 13.7 mm hr^{-1} on the contour-fell log treated watershed. Sediment yields on the untreated burn-only watershed were 0.46 Mg ha^{-1} and 0.12 Mg ha^{-1} on contour-fell log treated watershed with a cumulative 2.09 Mg ha^{-1} trapped by the contour-felled logs.

The fourth and final rainfall event affected the untreated burn-only watershed more that the contour-felled log treated watersheds. The 10-min max intensity was 9 mm hr^{-1} mm on the untreated burn-only watershed and 6.1 mm hr^{-1} on the contour-felled log treated watershed. Only 0.19 Mg ha^{-1} of sediment was collected on the untreated burn-only watershed and no sediment was collected on the contour-felled log treated watershed. Cumulative sediment yield totals were 0.66 Mg ha^{-1} on the untreated burn-only watershed and 1.10 Mg ha^{-1} on the contour-felled log treated watershed with 2.09 Mg ha^{-1} trapped by the contour-felled logs.

Discussion and Conclusions

A paired watershed design is being used to evaluate the use of contour-felled logs on reducing flooding threats and sediment yield. The results show more sediment came from the contour-felled log treated watershed but the rainfall events did not affect each watershed the same, therefore caution must be used in evaluating the results. Some of the thunderstorms were traveling from the southwest to the northeast and only affected one watershed as evident by the 10-min rainfall intensity and total rainfall amounts.

After the first rainfall event, rills were evident from within 5 m of the ridge line and continued throughout the watershed. Often the rills would be parallel along the flow paths, until an obstruction (contour felled log, tree, rock) occurred then the rills would converge at the location. The rills were generally enlarged with each successive rainfall event. There were large amounts of ash in the sediment, especially during the first two rainfall events. Due to the large ash component in the viscous flow, runoff measurements by the H-flume were unreliable.

The first two rainfall events produced more rainfall and two to ten times higher 10-min maximum rainfall intensities on the contour-felled log treated watershed than the untreated burn-only watershed. These short duration high intensity thunderstorms are common in the area. By the third rainfall event, 3-August1999, the untreated burn-only watershed produced four times the amount of sediment as the contour-felled log treated watershed. Since no erosion had occurred on the untreated burn-only watershed by that time, the site had easily transportable ash-laden sediment readily available. The last rainfall event only affected the untreated burn-only watershed even though storm duration and amounts were similar.

The contour-felled logs trapped sediment from the first three rainfall events with a cumulative total of 2.09 Mg ha^{-1}. The maximum capacity of the contour-felled logs is 2.34 Mg ha^{-1}, thus after the third event about 345 logs out of a possible 389 had trapped sediment with most filled to capacity. Since they are near capacity, little additional sediment can be held on site by the contour-felled logs. If the contour-felled logs were not there, would all of the trapped sediment been transported to the outlet of the watershed, probably not. Natural obstructions (trees, rocks, grass, etc.) would have trapped some of the sediment.

Sediment trap efficiency of contoured felled logs can be defined in several ways (Table 2). One method defines it as sediment stored by the contour-felled logs for each rainfall event divided by total possible storage. The results show that the contour-felled logs are efficient since they trapped 25 percent after the first storm and 91 percent of their capacity by the fourth rainfall event. Another method divides cumulative sediment trapped by the contour-felled logs (2.09 Mg ha^{-1}) by the cumulative sediment yield and sediment trapped (3.19 Mg ha^{-1}) which indicates a 66 percent trap efficiency. Thus, one might conclude that the contour-felled logs treated watershed were effective in reducing sediment, but sediment yield from the contour-felled treated watershed was greater than the untreated burn-only watershed.

The goal was to compare trap efficiency by comparing sediment at the outlet of each watershed, but since the rainfall events did not affect each watershed equally, caution must be used in that comparison. After one year, the data have not shown any reduction in sedimentation leaving the hillslope from the contour-felled log treated watershed. The study is ongoing and will be monitored for at least two more years. Thus a better evaluation of the sediment trapping ability of contour-felled logs and sediment yield effects may provide additional information for comparison.

Acknowledgment

The National Forest Systems Burned Area Emergency Rehabilitation (BAER) program; and the USDI, Bureau of Land Management-USDA, Forest Service Joint Fire Science program contributed funds for this study. The author would like to acknowledge the assistance of Randy Niman, Forester, Chelan R. D., Wenatchee National Forest and Robert Brown, Hydrologist, Rocky Mountain Research Station for installation, maintenance and data collection.

References

Agee, J. K. (1993). *Fire ecology of Pacific northwest forests.* Island Press, Washington, D.C., 493 p.

DeBano, L. F., Ffolliott, P. F. and Baker, M. B. Jr. (1996). "Fire severity effects on water resources." In: Ffolliott, P. F., DeBano, L. F., Baker, M. B. Jr., Gottfried, G. J., Solis-Garza, G., Edminster,C. B., Neary, D. G., Allen, L. S. and Hamre, R. H., tech. coords. Effects of Fire on Madrean Province Ecosystems - A Symposium Proc. *Gen. Tech. Rep. RM-289.* U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO, 77-84.

Farmer, E. E. and Van Haveren, B. P. (1971). "Soil erosion by overland flow and raindrop splash on three mountain soils." *Gen. Tech. Rpt. INT-100.* U. S. Department of Agriculture, Forest Service, Intermountain Research Station, Odgen, UT, 14 p.

McCammon, B. P. and Hughes, D. (1980). "Fire rehab in the Bend Municipal Watershed." In: Proc. Watershed Management Symposium, July 21-23, 1980, Boise, ID. ASCE, 252-259.

McNabb, D. H. and Swanson, F. J. (1990). "Effects of fire on soil erosion." In: Walstad, J. D., Radosevich, S. R. and Sandberg, D. V., eds. Natural and Prescribed Fire in Pacific Northwest Forests. Oregon State University Press, Corvallis, OR, 159-176.

Meeuwig, R. O. (1971). "Soil stability on high-elevation rangeland in the intermountain area". *Res. Paper INT-94*. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT, 10 p.

Megahan, W. F. (1986). "Recent studies on erosion and its control on forest lands in the United States." In: Richard, F., ed. Range Basin Sediment Delivery: Proc., 1986 August; Albuquerque, NM. *IAHS Pub. 159*, Wallingford, Oxon, United Kingdom, 178-189.

Megahan, W. F. and Molitor, D. C. (1975). "Erosion effects of wildfire and logging in Idaho." In: Watershed Management Symposium, 1975 August, Logan, UT. ASCE Irrigation and Drainage Division, 423-444.

Miles, S. R., Haskins, D. M. and Ranken, D. W. (1989). "Emergency burn rehabilitation: cost, risk, and effectiveness." In: Berg, N. H., technical coordinator. Proc. Symposium on Fire and Watershed Management, October 26-28, 1988, Sacramento, CA. *General Technical Report PSW-109.* U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA, 97-102.

Neary, D. G. and Hornbeck, J. W. (1994). "Chapter 4: Impacts of harvesting and associated practices on off-site environmental quality." In: Dyck, W. J., Cole, D. W. and Comerford, N. B., eds., Impacts of forest harvesting on long-term site productivity. Chapman & Hall, London, 81-118.

Noble, E. L. and Lundeen, L. (1971). "Analysis of rehabilitation treatment alternatives for sediment control." In: Symposium on forest land uses and stream environment. Oregon State University, Corvallis, OR, 86-96.

Radek, K. J. (1996). "Soil erosion following wildfires on the Okanogan National Forest - initial monitoring results." In: International Erosion Control Association symposium, February 27 - March 1, 1996, Seattle, WA. International Erosion Control Assoc., Steamboat, CO, 7 p.

Robichaud, P. R. and Brown, R. E. (1999). "What happened after the smoke cleared: onsite erosion rates after a wildfire in eastern Oregon." In: Olsen, D. S. and Potyondy, J. P. eds., Proc., Wildland Hydrology Conference, June 1999, Bozeman, MT. American Water Resource Association, Hernon, VA, 419-426.

Sartz, R. S. (1953). "Soil erosion on a fire-denuded forest area in the Douglas-fir region." *J. Soil and Water Conservation* N/A, 279-281.

Williams, C. K. and Smith, B. G. (1991). Forest plant associations of the Wenatchee National Forest, draft. Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Wenatchee National Forest, WA, 226 p.

Corresponding Author
Peter R. Robichaud, Ph.D., P.E., Research Engineer, U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forestry Science Laboratory, 1221 South Main St., Moscow, ID 83843. Phone: 208-883-2349. Fax 208-883-2318. E-mail: probichaud@fs.fed.us

Table 1. Site characteristics for the two forested burned over watersheds indicating storage capacity of the contour-felled logs.

Site Characteristics	Untreated Burn-Only	Treated Contour-Felled Logs
Area (ha)	11	9
Outlet elevation (m)	1580	1545
Slope (%)	50-60	45-55
Contour felled logs (#)	0	389 (43 logs ha^{-1})
Max. storage vol. of logs (m^3)	0	44 (4.9 m^3 ha^{-1})
Max. storage mass of logs (Mg)	0	21 (2.3 Mg ha^{-1})

Table 2. Rainfall, runoff and sediment measured on two zero-order burned over watersheds. Rainfall values were from measurements at watershed outlet; values in parenthesis are from upper watershed boundary. Flows from watershed were heavily sediment laden making flow measurements unreliable.

Storm Date	Storm Rainfall (mm)	Storm Duratn. (min)	10-min Max. Intensity (mm hr^{-1})	Sed. Yield (Mg ha^{-1})	Cum. Sed. Stored by Contour-Felled Logs (Mg ha^{-1})	Trap Method A[1] (%)	Efficiency Method B[2] (%)
			Untreated Burn-only Watershed				
18-May-99	snowmelt			0.01			
15-Jun-99	4.1 (3.3)	88 (87)	9.1 (9.1)	0.00			
21-Jul-99	1.0 (1.2)	41 (49)	3.1 (1.5)	0.00			
3-Aug-99	8.0	48	21.3	0.46			
30-Aug-99	15.0	956	9.0	0.19			
Totals	28.1			0.75			
			Contour-felled log treated Watershed				
18-May-99	snowmelt			0.00	0.00		
15-Jun-99	7.6 (10.4)	87 (88)	22.9 (33.5)	0.28	0.57	25	67
21-Jul-99	6.9 (6.6)	24 (82)	39.6 (29.0)	0.70	1.12	49	53
3-Aug-99	7.4	83	13.7	0.12	2.09	91	66
30-Aug-99	11.7	907	6.1	0.00	2.09	91	66
Totals	33.6			1.1	2.09		

[1] Trap efficiency: method A is the storm sediment amounts divided by the total storage capacity of the contour-felled logs.

[2] Trap efficiency: method B is the cumulative sediment trapped by the contour-felled logs divided by the cumulative sediment trapped by the contour-felled logs and the cumulative sediment yield at the outlet of the contour-felled logs treated watershed.

Figure 1. Measuring storage capacity of the contour-felled logs.

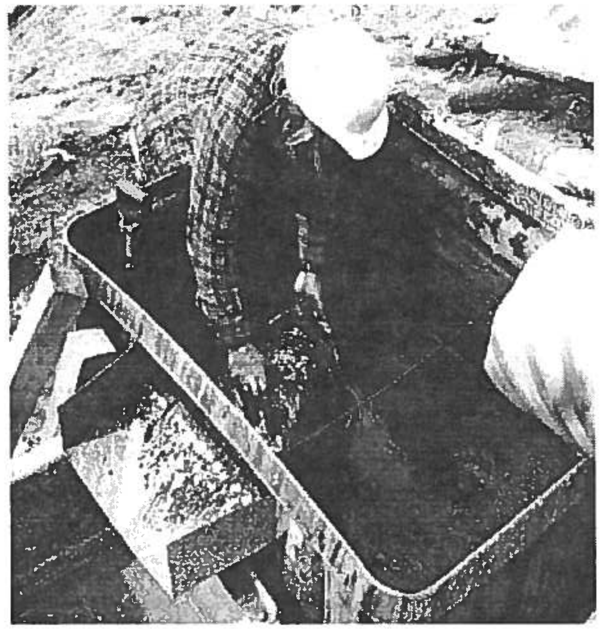

Figure 2. Cleaning the sediment trap at the outlet of the contour-felled log watershed.

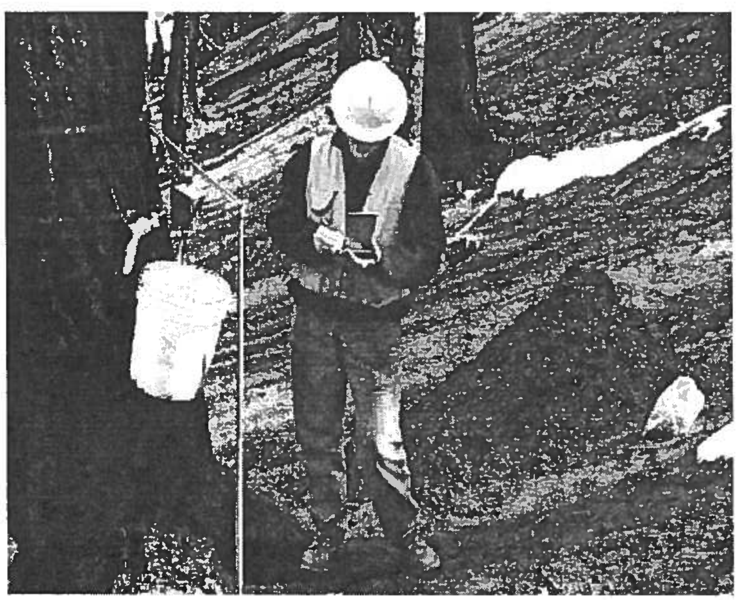

Figure 3. Weighing the sediment after clean out at the outlet of the burn-only watershed.

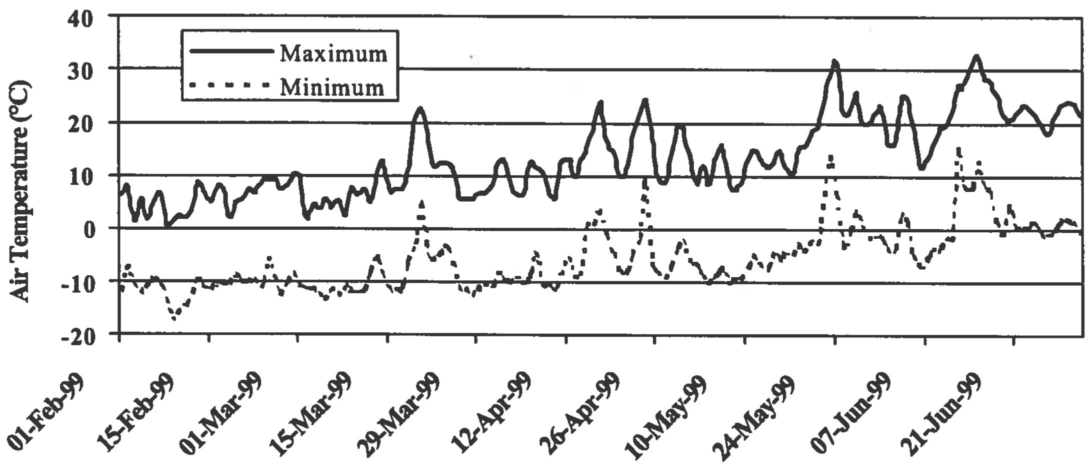

Figure 4. Maximum and minimum air temperatures for the spring melt season indicating daily diurnal fluctuations below 0 °C that promoted slow runoff response.