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Contents

Authors

Brad Sutherland and Clayton Gillies, Western Division

Rehabilitation of temporary forest roads in Alberta and Saskatchewan

Abstract

From September 1998 to May 1999, the Forest Engineering Research Institute of Canada (FERIC) performed short-term case studies of temporary road and landing rehabilitation operations in Alberta and Saskatchewan. Rehabilitation at each location consisted of ripping potentially compacted road and landing surfaces, followed by retrieving roadside berms of topsoil and organic material including large and small woody debris. This report reviews the treatments, productivities and costs of rehabilitation at each location.

Keywords

Rehabilitation, Roads, Landings, Soil compaction, Crawler tractors, Excavators, Productivity, Costs.

Introduction

Many forest companies in Alberta and Saskatchewan are establishing programs for restoring temporary forest roads and landings to productive forest land after logging. Generally, rehabilitation addresses soil compaction and includes the retrieval of displaced topsoil, organic material and woody debris. Soil compaction results in higher soil bulk densities resulting in lower porosity, reduced aeration, slower infiltration rates and greater mechanical impedance to tree roots (Sutton 1991). Compaction, along with displacement of nutrient-rich forest floors and well-structured surface mineral horizons, has led to greatly reduced forest productivity on non-rehabilitated roads and landings (Powers et al. 1990, Sanborn et al. 1999).

Rehabilitation techniques are evolving as the forest industry gains operational experience and as the results of ongoing biological studies are incorporated into practice. FERIC has started a series of case studies to document rehabilitation practices and costs, and to identify areas requiring additional research to improve practice. This report describes four operations in Alberta and Saskatchewan which were monitored from September 1998 to May 1999. The rehabilitation treatments used at each study location were prescribed by the companies involved, based on local experience. An assessment of the suitability of these treatments for reducing soil compaction or otherwise improving soil conditions was not part of this study.

Objectives

FERIC's objectives were to describe four case studies of temporary road rehabilitation, discuss their operating procedures, and provide information and recommendations on treatments, productivity and costs.

Site descriptions

FERIC observed road rehabilitation operations at Drayton Valley and Boyle in Alberta, and Meadow Lake and Big River in Saskatchewan (Figure 1). Harvesting history for all study locations was clearcut summer logging using a full-tree system with leave

Figure 1. General location of study sites.

patches and skidding to roadside. In addition, tree-length harvesting (i.e., limbing and topping at the stump) was used on a portion of the cutblocks at Boyle. Site conditions and silviculture prescriptions at each location are shown in Table 1.

None of the road sections included in the study crossed streams and culvert locations for runoff were dry, so no stream protection measures were required during deactivation and culvert removal. Roads at all locations were constructed using a crawler tractor and blade to remove stumps, topsoil and surface organic layers. At Big River, the log deck or landing area was also cleared at the time of road building to accommodate wheeled loaders when loading log trucks. At the other locations, logs were loaded with tracked butt-and-top loaders that did not require stump removal in the log deck area. Silviculture prescriptions for all locations specified regeneration to conifer-dominated or aspen-dominated mixedwoods. With the exception of Boyle, spruce and in some cases pine were to be planted on the reclaimed roads.

Table 1. Site conditions and silviculture prescriptions

Location and date of treatment	Cutblocks (no.)	Stand composition	Soils and topography	Silviculture prescription
Meadow Lake (Mistik Management Limited) September 1998	1	aspen, pine, spruce	well-drained sandy soils with pockets of silt and clay, flat to gently rolling	natural regeneration of aspen and pine, planting of pine and spruce
Big River (Weyerhaeuser Company Limited) September 1998	1	aspen, minor spruce component	silty clay soils, flat to gently rolling	natural regeneration of aspen
Drayton Valley (Weyerhaeuser Company Limited) October 1998	17	pine, spruce- or aspen-dominated mixedwoods	well-drained, silty clay, sandy loams, gently rolling - a few pitches >18%	natural regeneration of aspen and pine, planting of pine and spruce
Boyle (Alberta-Pacific Forest Industries Inc.) May 1999	2	aspen and poplar, minor spruce component	sand to silty sand and sandy clay, gently rolling	natural regeneration of aspen

Forest Engineering Research Institute of Canada (FERIC)

Find us Online!
www.feric.ca

Eastern Division and Head Office
580 boul. St-Jean
Pointe-Claire, QC, H9R 3J9
☎ (514) 694-1140
(514) 694-4351
admin@mtl.feric.ca

Western Division
2601 East Mall
Vancouver, BC, V6T 1Z4
☎ (604) 228-1555
(604) 228-0999
admin@vcr.feric.ca

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Equipment and treatments

Rehabilitation was conducted in two stages: ripping road and landing surfaces followed by retrieving topsoil and organic material including small and large woody debris. A description of the equipment and treatments is provided in Table 2. Variations in the shape and function of ripper implements used were evident at each location (Figures 2–4).

The objective of ripping was to till potentially compacted road surfaces. The ripper shanks with modified tips produced narrow furrows and shattering of subsurface soil layers. The amount of soil shatter decreases as the moisture content and clay component of the soil increases. The V-plow produced a wider furrow and displaced soil layers into berms, resulting in a more irregular surface and greater overall soil disturbance.

At Drayton Valley and Meadow Lake, retrieval was done exclusively by the excavator. At Drayton Valley, the standard bucket was replaced with a chuck blade that could be pivoted from side to side up to a 45-degree

Figure 2. Ripping with two modified ripper shanks.

Table 2. Rehabilitation equipment and treatments

Treatment	Prime mover	Attachment
Meadow Lake		
Rip	Caterpillar D7G crawler tractor	angled blade and ripper shank with half-circle plate (57 cm wide with small wings on either side) welded just above thumb
Retrieve	Samsung SE210W wheeled excavator	standard bucket (with no teeth) and live thumb
Big River		
Rip/retrieve	Caterpillar D7H crawler tractor	straight blade and ripper shank with wings welded to the tip
	Hitachi EX200 excavator	six-toothed site preparation rake 1.5 m wide and 1 m ripper tooth with wings welded just above tip
Drayton Valley		
Plow	Caterpillar D8K crawler tractor	moldboard V-plow, 150 cm wide and 90 cm high
Retrieve	Komatsu PC250LC excavator	chuck blade, 210 cm wide and 138 cm high with tilt capability up to 45 degrees
Boyle		
Rip/retrieve	Caterpillar D7G crawler tractor	angled blade and two ripper shanks with plates (30 cm high and 30 cm wide) welded to each tip
Retrieve	Komatsu PC200LC excavator	standard bucket (with teeth) and live thumb

Intermittent breaks

V-plow

Figure 3. Ripping with moldboard V-plow at Drayton Valley.

angle (Figure 5). For retrieval, the chuck blade was used as an excavating tool to scoop and deposit material, similar to the use of an excavator bucket. The chuck blade was also used to construct 11 cross-drains. At Big River, retrieval was done by the crawler tractor and straight blade and by the excavator using a 1.5-m-wide site preparation rake (Figure 6). At Boyle, retrieval was done primarily with an excavator-mounted standard bucket and live thumb, and partially using a crawler tractor with an angled blade.

Operating technique

Figure 4. Excavator using modified tooth.

Operations were planned so that road sections furthest from the cutblock entrance were treated first to maintain road access for service and emergency vehicles. At Drayton Valley, however, all of the roads on several cutblocks were ripped prior to any retrieving activity and access to the cutblocks was limited during the retrieval phase.

At Meadow Lake, the crawler tractor ripped the road surface on the cutblock in a series of four passes. This was followed by light blading (approximately three passes) of the ripped surface into the ditchline and levelling the surface for the wheeled excavator. Following ripping of a short spur or portion of road, the excavator started retrieving at the furthest point and retreated along the road centreline, swinging to either side (7.3 m maximum) to reach retrievable material. The excavator was stationary while reaching for material, supported by lowering two hydraulic out-riggers and a small front dozer blade.

Figure 5. Chuck blade used for retrieval at Drayton Valley.

At Big River, both ripping and retrieving treatments were done by the crawler tractor and the excavator, with each machine operating on a separate portion of road. On the segment treated by the crawler tractor, roads and landings were ripped in a series of continuous passes. Retrieval consisted of blading roadside berms onto the ripped surfaces. On the road segment treated by the excavator, a series of short rips was completed in a pattern radiating away from the excavator. Retrieval was accomplished while positioned on the ripped surface and within reach of the roadside berm material. Using the site preparation rake and fixed thumb, soil and organic material were retrieved and shaken or sprinkled across the ripped surface. For both machines conducting retrieval, a 2-m-wide path was left on the ripped surface for future access to the cutblock by all-terrain vehicles.

At Drayton Valley, two passes were made with the V-plow, each one centred in the wheel path on either side of the road centreline (Figure 3). On relatively flat grades, plowing was continuous. When steeper road gradients (approximately 18%) were encountered, the operator would intermittently lift the plow, creating a 1-m break to prevent channelling of runoff water that could lead to erosion or downcutting along the furrow (Figure 3). Following V-plowing of a spur, the excavator started retrieving at the furthest point and retreated along the road centreline, reaching available soil and organic material from either side (7.8 m maximum reach). Drainage and ephemeral seepage sites were excavated down to natural flow depth. Drainages ranged in size from 6 m wide and 1 m deep to 19 m wide and 2–3 m deep. Logs from drainage structures were excavated and distributed on the surface. On steeper gradients, skewed berms were constructed by the excavator to divert runoff into the cutblock and prevent channelling along the road.

At Boyle, the operations of the crawler tractor and excavator complemented each other. The crawler tractor first ripped a short portion of road using two to four passes. Next, retrieval of soil and organic material was conducted by both the excavator and the crawler tractor and blade. The crawler tractor and blade were used primarily to reprofile road prisms and to retrieve large berm piles, while the excavator was used primarily to retrieve and place soil and organic material. Reprofiling consisted of blading fill material out of depressions to restore the natural drainage patterns and/or partially backfilling cuts through knolls. To promote aspen regeneration in areas with high concentrations of woody debris from roadside processing, the debris was concentrated into either small piles to expose the ground surface, or into large piles to facilitate disposal by burning. Both machines, but primarily the excavator, were used for debris piling. Smaller amounts of woody debris were either flung from the processing area using the excavator bucket, or retrieved to spread across the deactivated road surface.

Figure 6. Excavator using site preparation rake during retrieval.

Study methods

At each location, FERIC timed ripping and retrieving activities on a sample of the road systems and noted relevant operating techniques. Machine time data and productivity were analyzed for each treatment using standard work-study methods (Bérard et al. 1968), and hourly machine ownership and operating costs were calculated using FERIC's standard costing procedures (Appendix I). For the purposes of this study, only productive activities, ripping roads and landings, retrieving soil and organic material, reprofiling and constructing cross-ditches, piling or redistributing roadside debris piles, and within-block travelling, were timed. Thus, the productivities presented in this report represent maximum values and minimum costs. Ripping and retrieving rates would be lower and costs would be higher when adjusted to account for normal operating circumstances. To facilitate the comparison of equipment and treatment costs, machine costs and productivities were combined and presented as $/1000 m^2 of area treated for each machine. In addition, machine costs and harvested volume from the treated blocks were combined and presented as $/m^3 for each machine. At Big River, within block travel was not included in productive time due to the small portion of road system sampled. As a result, only ripping and retrieving were included in productive time.

Results

Table 3 shows cutblock, road and landing attributes and a summary of productive times for ripping and retrieving at each of the four locations. Average road width treated varied between locations. At Big River, landings were constructed along much of the road length so that the average treated width was higher than at the other locations where landings were not constructed. Variations in treated width and configuration of ripper teeth (single versus double) between locations influenced the number of machine passes required for ripping. The spacing between furrows varied from less than 1 m at Boyle to 2.9 m at Drayton Valley.

The average depth of organic material retrieved varied from 20 to 23 cm at Big River (excavator) and Boyle, respectively, to over 40 cm at the other locations.

Table 4 shows the productivities and costs for ripping and retrieving as separate activities and total costs for both activities

Table 3. Cutblock and road/landing attributes and productive machine time [a]

	Meadow Lake	Big River: Crawler tractor	Big River: Excavator	Drayton Valley	Boyle
Volume harvested attributed to sample (m^3)	7 473	12 145		51 686/18 039 [b]	11 672
Road length ripped/retrieved (m)	1 987/1 938	925	820	12 053/4 918	4 133/4 363
Average treated width (m)	4.9	21.9	19.4	5.9	5.7 [c]
Number of equipment passes for ripping	4	10	-	2	2–4
Road area ripped/retrieved [d] (m^2)	9 364/8 972	20 258	15 939	71 243/29 147	25 488/27 383 (27 513) [e]
Ripping depth (cm)/spacing (m)	48–50/1.1	45–50/2.1	50/2.0	50–70/2.9	35–40/<1
Average retrieval depth/range (m)	42/3–116	44/0–98	20/0–60	41/1–118	23/0–50
Crawler tractor productive time [f] (min)					
Rip	649 [g]	202	-	644	371
Retrieve	-	624	-	-	830 [h]
Excavator productive [f] (min)					
Rip	-	-	341	-	-
Retrieve	910	-	317	1 556	1 163 [i]

[a] Productive time excludes delays for repairs, maintenance and breaks.
[b] Volume harvested from cutblocks ripped/retrieved.
[c] Does not include turnarounds and landings.
[d] Includes landings and turnarounds.
[e] Road area retrieved by excavator only.
[f] Productive times at Big River do not include travel within a cutblock.
[g] Includes time for blading of ripped surface (3 passes).
[h] Includes reprofiling, piling and walking.
[i] Includes piling, spreading and walking.

Table 4. Productivity in m/PMH, m²/PMH and cost in \$/1000 m² and \$/m³ of harvested volume

	Productivity				Cost [a]					
	Crawler tractor		Excavator		Crawler tractor		Excavator		Combined (rip & retrieve)	
	m/PMH	m^2/PMH	m/PMH	m^2/PMH	\$/1000 m^2	\$/m^3	\$/1000 m^2	\$/m^3	\$/1000 m^2	\$/m^3
Meadow Lake										
Rip or retrieve [b]	184	866	128	592	137	0.17	142	0.17	279	0.34
Big River										
Rip	275	6 018	144	2 805	20	0.03	34	0.04	-	-
Retrieve	89	1 948	155	3 017	61	0.10	32	0.04	-	-
Combined	-	-	-	-	81	0.13	66	0.08	-	-
Drayton Valley										
Rip or retrieve [b]	1 123	6 638	190	1 124	20	0.03	93	0.15	113	0.18
Boyle										
Rip	668	4 122	-	-	29	0.06	-	-	-	-
Retrieve	315	1 979	225	1 419	60	0.14	68	0.16	-	-
Combined	-	-	-	-	89	0.20	68	0.16	157	0.36

[a] Total ownership and operating costs based on FERIC's standard methodology. Costs do not include supervision, profit or overhead, and are not the actual costs incurred by the contractor or company.
[b] At this site, the crawler ripped only and the excavator retrieved only.

combined. Productivities and costs varied between location, treatment and equipment. Productivity and costs for ripping ranged from 866 m²/productive machine hour (PMH) and \$137/1000 m² at Meadow Lake (4 passes with blading), to 6638 m²/PMH and \$20/1000 m² at Drayton Valley (2 passes). At all locations, a greater proportion of productive time was used for retrieving than for ripping (Table 3), which is reflected in the productivities for each activity.

For retrieving, productivity and cost ranged from 592 m²/PMH and \$142/1000 m² at Meadow Lake, to 3017 m²/PMH and \$32/1000 m² at Big River (excavator).

The combined costs for ripping and retrieving ranged from \$113/1000 m² at Drayton Valley to \$279/1000 m² at Meadow Lake. At Big River, where the crawler tractor and excavator were used for both activities on separate portions of road, the combined cost when ripping and retrieving were done by the crawler tractor was \$81/1000 m² and \$66/1000 m² when both treatments were done by the excavator.

Discussion

Factors affecting productivity

Machine configuration, variations in the amount of soil and organic material retrieved, and differences in the tasks performed between study locations influenced ripping and retrieving productivities. For retrieving at Big River, excavator productivity of 3017 m²/PMH was much higher than the 1948 m²/PMH for the crawler tractor (Table 4). However, the average retrieval depth for the excavator of 20 cm was less than half that of the crawler tractor of 44 cm (Table 3).

Ripping and retrieving were the only activities included in productive time at Big River. Within-block travel time was included at the other three locations. At Drayton

Valley and Boyle, additional tasks involved construction of cross-drains. At Boyle, reprofiling and piling/redistributing of woody debris were performed. The higher productivity of the excavator retrieving at Big River compared to other locations was due in part to the larger average road width. This resulted in more efficient operation of the excavator, as more area could be treated before repositioning than on the narrower roads at the other locations. The higher productivity should be viewed with caution, however, due to the relatively short road length sampled at Big River (820 m versus greater than 4900 m at Drayton Valley and Boyle).

At Meadow Lake, the crawler tractor was required to blade the ripped surfaces to improve the travel surface for the wheeled excavator. The stabilizers on the wheeled excavator needed to be raised and lowered following repositioning. These requirements adversely affected the productivity of both machines compared to other locations. The wheeled excavator is not typically used by the company for rehabilitation work, but proved useful for comparison with tracked excavators used at the other locations. Use of wheeled rather than tracked excavators for road deactivation offers the potential of faster travel speeds when repositioning and travelling within a cutblock. However, this advantage is offset by the need to employ stabilizers at each working position and by the limited trafficability of wheeled versus tracked undercarriages on rough surfaces or wet roads.

The configuration of ripper shanks (single or double) and the prescribed spacing between furrows affected machine productivity. At Meadow Lake and Boyle, the spacing between furrows was approximately 1m. At Meadow Lake, ripping with a single shank required four passes and resulted in an average productivity of 866 m^2/PMH. Included in productive time for ripping was the additional blading work done to fill in the ditchline and improve access for the wheeled excavator. At Boyle, ripping with two shanks required two to four passes and resulted in an average productivity of 4122 m^2/PMH. Productivity for ripping was higher at Big River (crawler tractor) and Drayton Valley where the spacing between furrows was increased to approximately 2.9 m.

Other observations and recommendations

Additional observations and recommendations regarding site impacts and operational efficiency follow:

- **Minimize additional travel on the ripped surface and adjacent cutblock whenever possible to avoid soil compaction.** At Big River and Boyle, retrieving soil and organic material with a crawler tractor and blade resulted in additional off-road traffic. At Meadow Lake, blading of ripped road material into the ditchlines was expected to be minimal and done only when necessary. Any equipment movement over a cutblock has the potential to injure aspen roots and has a negative impact on regeneration (Greenway 1999). Retrieving with an excavator was conducted from the road or landing surface without travelling on the adjacent cutblock. At Boyle, where woody debris was piled using both the excavator and crawler tractor, piling was accomplished with less off-road travel with the excavator. The excavator, unlike the crawler tractor, can retrieve or fling woody material away from roadside piles. To avoid machine traffic on the cutblock, rescheduling slash dispersal or piling to the harvesting phase may avoid equipment passage in the spring when soil moisture tends to be higher (i.e., soils more prone to compaction), and vegetative reproduction of aspen is active and more prone to damage.
- **Utilize the best machine for the job**. The crawler tractor with blade was more efficient for moving large volumes of material than the smaller-sized

excavator with bucket, rake, or blade. At Boyle, blading of deeper fills and initial rough-in of cross-drains was accomplished quickly with the crawler tractor. The excavator was used more effectively to complete the construction of cross-drains, to retrieve roadside berm piles within reach while positioned on the road, and to distribute woody debris to blend the final rehabilitated surface in with the surrounding cutblock. The chuck blade used at Drayton Valley had a larger volume capacity than a standard bucket and was more efficient for cross-drain work. However, as demonstrated at Boyle, the crawler tractor and blade was a more efficient tool for the initial rough-in of cross-drains. At Meadow Lake, the excavator bucket was used without teeth. For retrieval of woody debris, teeth improve the effectiveness of a bucket in penetrating somewhat matted woody debris and raking material towards the excavator.

- **Prescribed minimum and optimum depths of organic material to recover from roadside berms are needed to improve retrieval efficiency**. At Big River, where both the excavator and crawler tractor were used for retrieval, differences in the depth and composition of retrieved product were evident. The bladed product was a fairly heterogeneous mix of soil and organic material of uniform depth, while the product from the excavator rake was hummocky and more stratified with the heavier soil at the lowest levels and lighter woody debris on top. Visually, the irregular surface of the excavated product blended in better with the surrounding cutblock than the smoother bladed surface. Other less visual but important differences may exist in terms of microclimate for planted seedlings and availability of soil nutrients. Excavator productivity is more sensitive to the amount of material retrieved due to the comparatively small volume capacity of excavator attachments.
- **Modifications to road building techniques can improve the efficiency of deactivation**. Segregating the stumps and large woody debris from the topsoil and organic layers at time of road building would facilitate retrieval of these materials by the excavator. Narrow road widths would mean that berm piles were within the typical reach of excavators. At Drayton Valley, at the turnarounds, the soil and organic material were stored primarily in the centre. Distributing this material more evenly between the centre and periphery of the turnaround would minimize the swing distance for the excavator during retrieval. Landings and turnarounds should be no larger than necessary to minimize maneuvering of excavators to reach and distribute material.
- **The timing of road rehabilitation should be coordinated with the silvicultural activities or natural regeneration on the block**. Rehabilitating the roads as soon as possible following harvesting, for example, would minimize the disturbance of roadside aspen regeneration. However, leaving roads open temporarily is desirable to provide access for planting crews. At Drayton Valley, the cutblock including the roadside berm piles, had been site-prepared by mounding, and planted prior to road rehabilitation. When the roadside berm piles were retrieved, much of this regeneration was lost or heavily disturbed. A compromise would be to rehabilitate prior to planting and leave an all-terrain vehicle access trail as was done at Big River.

Conclusions and implementation

For ripping, both the spacing between furrows, number of passes and depth varied between locations. For retrieving, the amount of material retrieved, tasks performed and equipment used (crawler tractor and blade or excavator and bucket/blade/rake) also varied between locations. At Drayton Valley and Boyle, rehabilitation included drainage control measures such as construction of cross-drains, and recontouring and construction of deflector berms to prevent erosion. At Boyle, piling and dispersing of woody debris from roadside processing was also part of the rehabilitation process documented in this study.

Productivity and costs of rehabilitation varied between study locations as a result of differences in treatment prescription, nature of the ground being treated, machine configuration, and suitability of the equipment for the task. Productivity was lower and costs higher for retrieving versus ripping. However, with the exception of Big River, retrieving at each location encompassed several tasks and required a proportionally greater amount of time than did ripping. Productivity for ripping was highest at 6638 m^2/PMH and costs lowest at \$20/1000 m^2 at Drayton Valley using a crawler tractor making two passes with a moldboard V-plow. Productivity for retrieving was highest at 3017 m^2/PMH and costs lowest at \$32/1000 m^2 at Big River for an excavator and rake retrieving roadside berms only. At Big River, productive time was based on a comparatively short length of treated road and did not include travel time or tasks other than soil and debris retrieval. As a result, the high productivities and low costs for both ripping and retrieving at Big River are not comparable to other locations. Ripper productivity was higher when the spacing between furrows was greater (e.g., 2.9 m at Drayton Valley) and/or when there were two ripper teeth mounted on the crawler tractor. The combined costs for ripping and retrieving ranged from \$113/1000 m^2 at Drayton Valley to \$279/1000 m^2 at Meadow Lake.

Rehabilitation of roads with a crawler tractor and excavator working cooperatively can be effective when each implement is used appropriately. The crawler tractor and blade appeared most effective for ripping the road surface, retrieving large volumes of topsoil, and roughing in cross ditches. The excavator with a bucket, blade or rake was better suited to retrieving surface organic material and woody debris, and blending in the deactivated surface with the surrounding cutblock. Additional ground compaction from equipment conducting rehabilitation treatments should be avoided whenever possible. Use of an excavator rather than a crawler tractor for activities such as retrieving and piling/spreading of debris piles will reduce machine travel over treated areas.

Ripping and retrieving are common rehabilitation treatments for roads and landings in Alberta and Saskatchewan. Currently, road rehabilitation practices are evolving while research is ongoing to better understand and define the biological objectives that lead to treatment prescriptions. Having clear objectives or prescriptions on the extent of decompaction and depth and composition of organic material to reclaim will help to refine rehabilitation practice. Steps taken during road construction prior to rehabilitation can ease the retrieval process and reduce additional ground compaction and disturbance following harvesting. Together, these improvements will lead to proper equipment selection and cost-efficient, low-impact treatment options.

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Appendix I

Equipment costs [a]

	Caterpillar D7G crawler tractor	Caterpillar D8K crawler tractor	Samsung SE210W excavator	Hitachi EX200 excavator	Komatsu PC200LC excavator	Komatsu PC250LC excavator
OWNERSHIP COSTS						
Total purchase price (P) $	500 000	550 000	225 000	265 000	270 000	360 000
Expected life (Y) y	8	8	8	8	8	8
Expected life (H) h	16 000	16 000	16 000	16 000	16 000	16 000
Scheduled h/y (h)=(H/Y) h	2 000	2 000	2 000	2 000	2 000	2 000
Salvage value as % of P (s) %	30	30	30	30	30	30
Interest rate (Int) %	8.8	8.8	8.8	8.8	8.8	8.8
Insurance rate (Ins) %	3.0	3.0	3.0	3.0	3.0	3.0
Salvage value (S)=(P•s/100) $	150 000	165 000	67 500	79 500	81 000	108 000
Average investment (AVI)=((P+S)/2) $	325 000	357 500	146 250	172 250	175 500	234 000
Loss in resale value=((P-S)/H) $/h	21.88	24.06	9.84	11.59	11.81	15.75
Interest=((Int•AVI)/h) $/h	14.30	15.73	6.44	7.58	7.72	10.30
Insurance=((Ins•AVI)/h) $/h	4.88	5.36	2.19	2.58	2.63	3.51
Total ownership costs (OW) $/h	41.05	45.16	18.47	21.76	22.17	29.56
OPERATING COSTS						
Fuel consumption (F) L/h	30	30	30	30	30	30
Fuel cost (fc) $/L	0.48	0.48	0.48	0.48	0.48	0.48
Lube & oil as % fuel cost (fp) %	15	15	15	15	15	15
Annual tire consumption (t) no.	-	-	0.3	-	-	-
Tire replacement (tc) $	-	-	3 600	-	-	-
Track & undercarriage replacement (Tc) $	30 000	43 000	-	27 000	27 000	28 000
Track & undercarriage life (Th) h	5 000	5 000	-	5 000	5 000	5 000
Annual operating supplies (Oc) $	1 500	1 500	1 500	1 500	1 500	1 500
Annual repair and maintenance (Rp) $	40 000	55 000	25 000	34 000	34 000	34 000
Shift length (sl) h	10	10	10	10	10	10
Wages (W) $/h	22.78	23.54	23.14	23.14	23.14	23.54
Wage benefit loading (WBL) %	38	38	38	38	38	38
Fuel (F•fc) $/h	14.40	14.40	14.40	14.40	14.40	14.40
Lube & oil ((fp/100)•(F•fc)) $/h	2.16	2.16	2.16	2.16	2.16	2.16
Tires ((t•tc)/h) $/h	-	-	0.54	-	-	-
Track & undercarriage (Tc/Th) $/h	6.00	8.60	-	5.40	5.40	5.60
Operating supplies (Oc/h) $/h	0.75	0.75	0.75	0.75	0.75	0.75
Repair & maintenance (Rp/h) $/h	20.00	27.50	12.50	17.00	17.00	17.00
Wages & benefits (W•(1+WBL/100)) $/h	31.44	32.49	31.93	31.93	31.93	32.49
Prorated overtime (((1.5•W-W)•(sl-8)•(1+WBL/100))sl) $/h	3.14	3.25	3.19	3.19	3.19	3.25
Total operating costs (OP) $/h	77.89	89.14	65.48	74.84	74.84	75.64
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	118.94	134.30	83.95	96.59	97.00	105.20

[a] The costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs. These costs do not include supervision, profit, or overhead, and are not the actual costs incurred by the contractor or company.