Soil Loss or Gain Soil loss or gain is expressed as the soil surface elevation difference between two successive assessments. To determine this change, a rill meter developed by the American Society of Agricultural Engineers (McCool et al. 1976) was employed. The instrument consists of a portable frame with a graduated chart, a set of 146 aluminum pins, adjustable horizontal bar, supporting poles, rods for positioning the instrument and holding the platform of the recording camera, and levels for alignment. The instrument is positioned, levelled, and the horizontal bar is lowered to a desired setting below the pin heads. The vertical pins fall to ground level and the pinheads with the graduated chart in the background mark the soil profile. (When taking observations on the Enkamat and jute net plots, the netting was slit prior to lowering the pins in order to ensure contact of the pins with the ground instead of the net material. The net was re-stapled after the completion of the observations. This procedure was followed each year.) The setting is photographed with a 35-mm camera mounted on the camera plate, using a 28-mm focal length, wide-angle lens, thus recording the profile.

figure 4 *Recording with the rill meter.*

Photos are enlarged to 20 cm by 25 cm. (Figure 5). Reading the ordinates, (i.e., defined by the distance between the horizontal bar and the pin head) is facilitated with a magnifying glass. The irregular area bounded by the first and last (146th) pin, the horizontal bar, and the irregular line marked by the pin heads is then computed by the standard trapezoidal rule of approximate integration.

This process is repeated in subsequent years with instrument settings on the same permanent iron stakes.

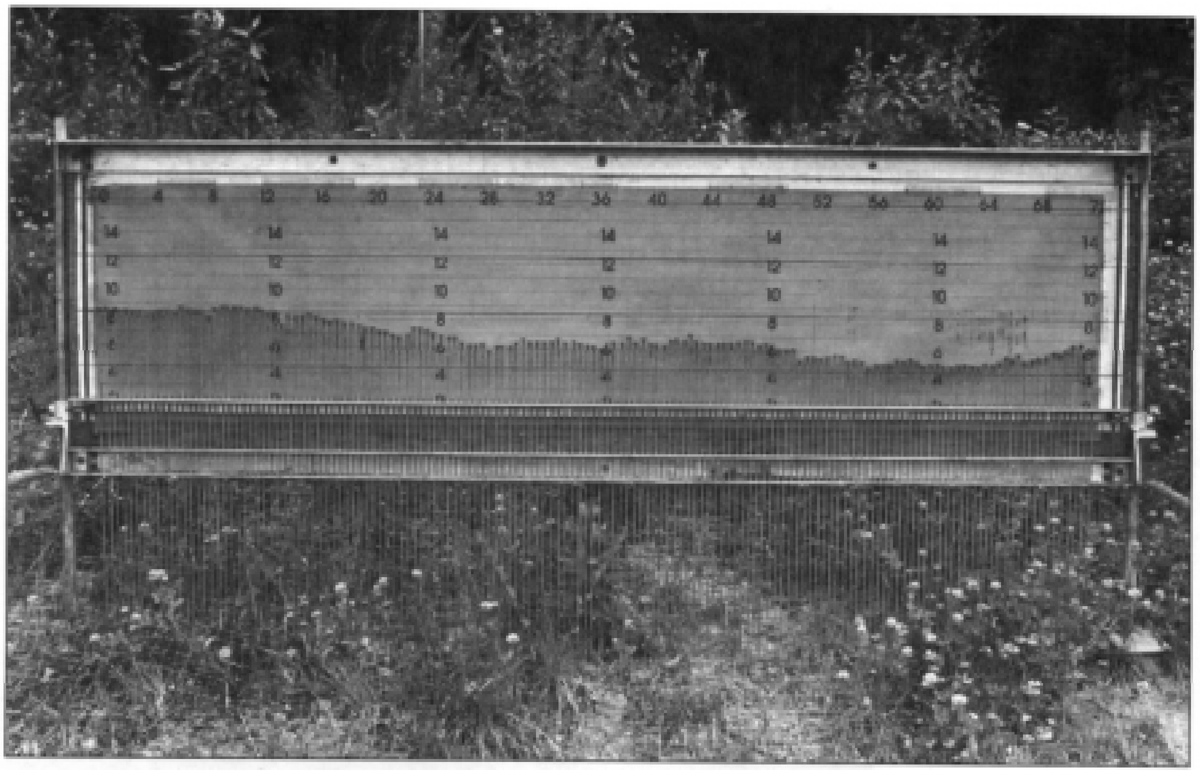

figure 5 *Enlarged photo showing the soil surface profile recorded with the rill meter.*

The difference between computed areas of two consecutive years (“year 1” and “year 2”) will theoretically yield the slope profile change, which can be converted to depth. This would be correct only if the elevation of the horizontal bar during year 2 was identical to that in year 1, but this is never the case. Three factors contribute to the discrepancy:

- **Setting of the horizontal bar** This is the least important problem because in most instances the bar can be positioned at the same whole-numbered line (2", 3", etc.) of the chart during two consecutive years of observations.
- **Vertical displacement of the iron stakes** If the hole widens slightly, the stake slips deeper. If frost heaving acts on it, then it is pushed up. Changes, in most instances, are seemingly small, but, because of fine-tuning of the measurement process, can be significant.
- **Positioning of the frame of the instrument** with respect to the tops of the supporting poles is never the same. Consequently, the elevation of the horizontal bar with respect to the benchmark during the second year always differs from the first year’s horizontal bar elevation. Therefore, these three vertical displacements must be compensated for, to equalize the two horizontal bar elevations.

Furthermore, measurement errors inherent in a set of four data must be compensated for. These are the two stake elevations, and the two pole settings (distance between the top of the frame and the top of the supporting pole). The detailed procedures of compensation for measurement errors and of erosion depth computations are presented in the Appendix.

Data were collected in 1983 ("zero-base"), 1984, 1985, and 1986. Thus, erosion values were computed for 1984, 1985, and 1986, the year when erosion was fully controlled on all treated plots.

5 RESULTS

5.1 Live Vegetation Cover

Late seeding due to time constraints on September 22, 1983 resulted in slow and poor development of the plant cover. Water runoff carried some of the seed downslope, evidenced by dense grass cover along the ditch line. Vegetation distribution within the treated plots was patchy in 1984 and 1985. Normally, an initially sparse grass cover improves sufficiently by the second growing season if seeding is carried out in the proper time frame or "window." In this study, an additional year was needed to improve plant cover to a minimum required standard. Figure 6 illustrates, as an example, the year-to-year development of the plant cover on the Vexar, Enkamat and no-net plots of Replicate II.

The year-to-year assessment results are summarized in Table 1.

table 1 *Percent live vegetation cover by year, treatment, and replicate*

Treatment	Replicate	Year 1984	1985	1986	Treatment mean
			%		
E	I	60	60	70	60.83 AB[a]
	II	40	60	75	
J	I	65	70	70	69.17 A
	II	60	70	80	
V	I	40	50	60	52.50 B
	II	40	50	75	
N	I	50	60	60	60.00 AB
	II	60	65	65	
Year Mean		51.88 C	60.63 CD	69.38 D	

a Means followed by the same letter are not significantly different at $\alpha = 0.05$ (Duncan's multiple range test).

A highly significant difference was found between the 1984 and 1986 means at $\alpha = 0.01$ (Table A2.1 in the Appendix). Treatment mean differences were also highly significant between jute net and Vexar at $\alpha = 0.05$.

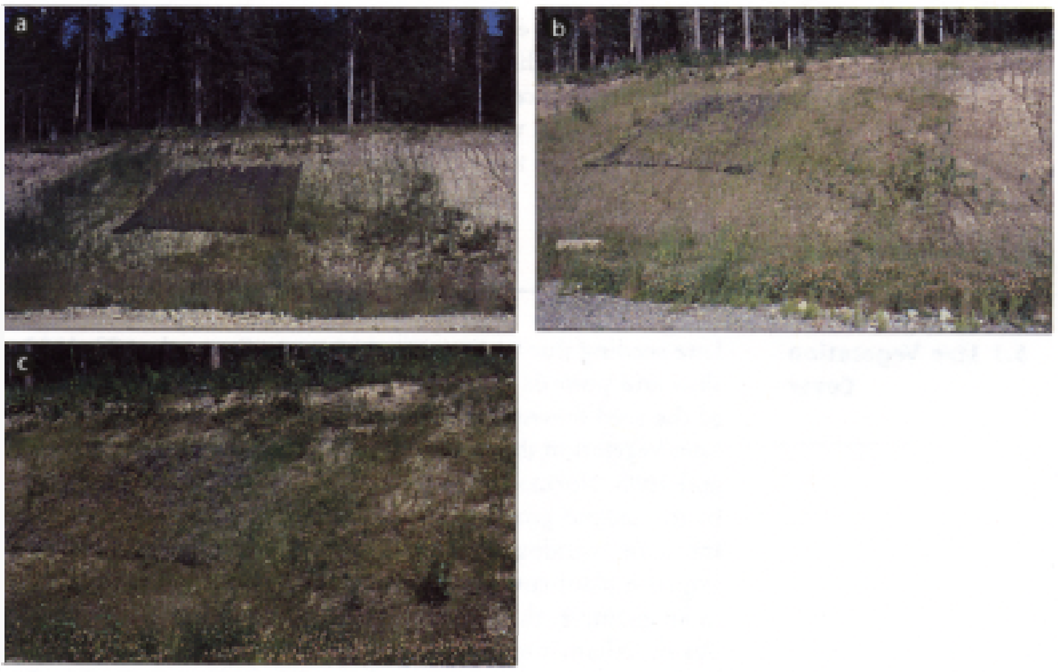

figure 6 Vegetation cover, Replicate II, over three consecutive years; a) 1984 b) 1985 c) 1986.

Examination of the soil surface under Enkamat revealed a nearly continuous cover of moss and algae, indicating the potential of this netting material to trap moisture. Emergence of germinants, however, appeared to be somewhat inhibited. Jute net performed somewhat better than Enkamat but without the moss-algae cover. Enkamat and no-net produced the same level of cover. Vexar was slightly lower that no-net, but the difference was not significant. Vegetation growth was confined mostly to the rills on the J, V, and N plots during 1984, the first year after seeding, but live cover improved on all treatment plots by 1986, the end of the study period.

5.2 Vegetation Composition

Frequency tests of vegetation composition and successional development, summarized in Table 2, show the normal trend experienced on previous trials and assessments (Carr 1977; Carr and Ballard 1980; Homoky 1984 and 1987). The two rye grasses as pioneer species dominated during the first year (1984), receded a year later and were nearly missing during the third year. Red fescue and alsike clover maintained dominance, while intermediate wheat grass, redtop, white clover, alfalfa, and the invader grass, timothy, remained subordinants. Alfalfa and Kentucky bluegrass are late-germinating species. The latter sometimes requires five years to develop adequately, then it achieves dominant status (Homoky 1987).

5.3 Soil Loss and Gain

The merits of treatments were evaluated by computing erosion depths influenced by the functioning of vegetation and netting. These were compared to each other and to erosion depths on the untreated plots.

The process of quantification of surface erosion by soil profile changes is described under “Methods” and in the Appendix. Computed erosion depths in centimetres are presented in Table 3.

table 2 *Species frequency by replicate, treatment, and year*

Species	Treatment/ Replicate	1984				1985				1986			
		E	J	V	N	E	J	V	N	E	J	V	N
Grasses													
Lolium	I	100[a]	80	80	80	40	30		10			10	
multiflorum	II	90	100	90	100	20		30					
Lolium	I	100	80	80	80	40	30		10			10	
perenne	II	90	100	90	100	20		30					
Agropyron	I						10				10		
intermedium	II							10				10	
Festuca	I	70	90	80	50	100	100	70	60	100	100	100	100
rubra	II	70	70	60	80		100	70		100	100	100	100
Poa	I												
pratensis	II												
Agrostis	I												
alba	II	10			10			10		20	30	40	30
Phleum	I	10		10									
pratense[b]	II	10								20			
Legumes													
Trifolium	I		20				10		10		10		10
repens	II							10				20	
Trifolium	I	20	80			50	70	60	40	100	100	100	40
hybridum	II	20	60				70	70	50	100	100	100	
Medicago	I												40
sativa	II						10	10		10		10	20

a Shaded areas indicate dominant status for the species.
b Invader species.

table 3 *Computed erosion depths in centimetres*

Treatment and Line		Replicate I			Replicate II		
		1983–84	1984–85	1985–86	1983–84	1984–85	1985–86
E	1	5.41	-0.25[a]	0.76	4.84	-2.32	-0.15
	2	3.76	-2.77	-1.42	3.48	-1.43	-2.42
J	1	5.60	-0.53	0.00	5.54	2.13	-4.20
	2	1.02	2.32	-5.59	2.74	-0.65	-1.20
V	1	3.65	1.81	-0.82	10.17	0.26	-0.43
	2	3.36	-1.47	-0.46	0.49	0.30	-1.94
N	1	6.22	0.35	-1.87	4.64	-0.98	-0.25
	2	2.65	0.97	-1.89	1.81	2.03	-1.14
C	1	0.04	1.21	0.40	6.15	2.66	1.21
	2	1.49	1.01	0.18	2.03	2.29	0.03

a Minus sign indicates "soil aggradation"; increase in surface elevation.
E = Enkamat 7010 net and hydroseeding
J = jute net and hydroseeding
V = Vexar plastic net and hydroseeding
N = no-net and hydroseeding
C untreated, "control"

The data suggest an irregular pattern of surface erodibility, and indicate some minor "accelerated rill or gully erosion" events at some locations during the first season following establishment, from 1983 to 1984. For instance, 6.22 and 4.64 cm soil losses were recorded in the no-net treatment in both replicates, and 6.15 cm for the "control" in Replicate II. The greatest soil loss of 10.17 cm was computed for the Vexar treatment in Replicate II.

Histograms of averaged erosion values of lines and replicates for each treatment for each year were plotted for a quick assessment of the year-to-year trends (Figure 7). Quantities are expressed as rates of erosion in m^3 per hectare (erosion depth in cm times 100). Erosion values in Table 3 and in Figure 7 without the minus sign are associated with "positive erosion," that is, lowering of the soil profile through loss of surface soil. Values with minus sign imply "negative erosion," or "soil aggradation," that is, elevation of the soil profile due to accumulated or trapped sediment and biomass.

Results of the first year (1984) after establishment indicated high positive erosion at all treatment levels. Erosion was still very active on this 3-year-old road, and the weak vegetation either with or without netting was not able to exert any controlling influence on soil movement. Ironically, the "control" produced the least amount of erosion. Sensitivity to erosion on untreated surfaces of differing densities can be highly variable. Since none of the treatments had any influence on erosion processes, all treatment levels were considered "untreated," or "control" in 1984, during the first year following establishment. The weighted average rate of erosion that year amounted to 354 m^3/ha.

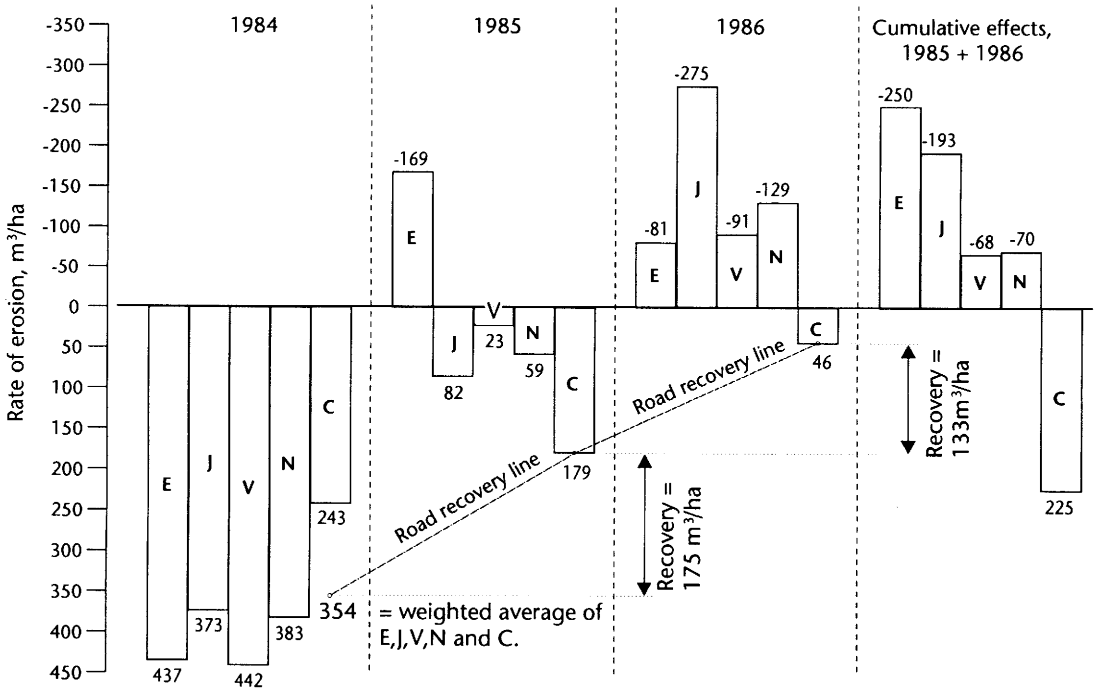

figure 7 *Erosion rates by treatment, year, and cumulative effects.*

The trend of erosion in the following year (1985) was quite different. By this time the vegetation, though weak, started to show some effect. The jute net, Vexar, and no-net treatments still exhibited positive, but substantially diminished erosion compared to the previous year. Enkamat brought about "negative erosion." Combined with the developing vegetation, mosses and algae on the soil surface, and some dead biomass, this three-dimensional material was able to trap sediment in great quantities.

Positive erosion disappeared completely the following year (1986), except on the "control." All treatments had the potential to halt erosion and all raised the surface profile to varying degrees; therefore, monitoring was stopped in 1986.

Most of the erodible surface material is usually lost from the exposed slope during the first few years following road construction. Erosion declines gradually thereafter. The line on Figure 7 connecting the plotted erosion rates of the "control" is the "road recovery line," indicating the decline of erosion on untreated surfaces, since much of the loose material has moved downslope with the passage of time. This line is in very close agreement with the trend first reported by the United States Department of Agriculture Forest Service (1988).

Since treatments started to influence erosion rates only after the second growing season following establishment, the pooled data of the last 2 years were analyzed to evaluate the overall performance of treatments at the end of the study period. Cumulative erosion depths in centimetres from 1984 to 1986 are presented in Table 4. Tabulated data are based on observations that include the compensation factor for measurement errors (see Appendix).

table 4 *Cumulative erosion in centimetres, from 1984 to 1986*

Treatment	**Line**	**Replicate**		**Treatment means**
		I	**II**	
E	1	0.51	-2.46	-2.50 B
	2	-4.19[a]	-3.85	
J	1	-0.53	-2.07	-1.93 B
	2	-3.26	-1.85	
V	1	0.99	-0.16	-0.69 C
	2	-1.93	-1.63	
N	1	-1.51	-1.23	-0.70 C
	2	-0.92	0.89	
C	1	1.61	3.87	2.50
	2	1.19	2.32	
Rep. means		-0.80 A[b]	-0.62 A	

[a] Minus sign indicates "soil aggradation"; increase in surface elevation.

[b] Means followed by the same letter are not significantly different at $\alpha = 0.05$ (Duncan's multiple range test).

E = Enkamat 7010 net and hydroseeding
J = jute net and hydroseeding
V = Vexar plastic net and hydroseeding
N = no-net and hydroseeding
C = untreated, "control"

The analysis of variance in Table A2.2 in the Appendix indicates:

- no significant difference between replicate means,
- highly significant differences between treatment means, and
- no significant interaction between replicates and treatments.

Cumulative effects plotted in Figure 7 suggest differences between the "control" and all other treatments. Further, the Enkamat and jute net treatments indicate higher values of negative erosion than Vexar and no-net. These differences were evaluated with the contrast test, shown in Table A2.3 in the Appendix.

The analysis indicates that in applying any of the four treatments, erosion can be controlled primarily by establishment of vegetation cover. The significance of the difference between any treatment and no action at all (Control) is enormous. Soil-building potential of either Enkamat or jute net is significantly greater than that of no-net or Vexar. Jute net has the same potential as Enkamat, and no-net is just as effective as Vexar with regards to soil-building potential.

6 DISCUSSION

- The slow development of the live vegetation and the sparse cover 1 and 2 years after establishment confirm earlier empirical results with late summer and early fall seeding in the British Columbia interior. Adverse effects can be mitigated by mulch application and a protective mature forest cover along roadsides. Seeding very late in the season (i.e., before the onset of frost and snowfall) is a strategy used in the Boreal White and Black Spruce biogeoclimatic zone in the Peace River region. Seeds overwinter under the protective snow cover and get an early start next spring after snowmelt. Recovery of the vegetation does materialize, but it takes an additional year. Under normal operating conditions, vegetation maintenance in the form of refertilization enhances the slowly developing or receding vegetation cover. This simple practice is the re-application of the full rate of fertilizer 2 to 4 years after establishment, when the declining natural regeneration is evidenced by few new shoots associated with greater accumulation of dead vegetation matter. Refertilization is a boost to the existing vegetation, restoring the vigour of grasses and legumes. There is usually no need for a repeated application thereafter because the agronomic vegetation then can maintain its vigour and in the interim period the indigenous vegetation slowly starts to recolonize the treated slope (Homoky 1987).

  In this study, vegetation could have been enhanced with refertilization; however, the aim was to study the impact of treatments on vegetation development without any further aid. Another factor that inhibited the growth and natural regeneration of the agronomic cover was the unusually dry season during 1985. Total precipitation from April to July was only 201.1 mm, the lowest recorded in 13 years (188.9 mm in 1972) at the Dome Creek weather station, 53°44' North and 120°59' west at 648 m above sea level.

  Density of cover increased progressively during the study period. Improvement was significant from the first to the last year, but the year-to-year differences were insignificant (Table 1). Jute net produced the highest density. No-net was equal to Enkamat and produced slightly higher cover percent than the Vexar treatment. It appears that Enkamat does not enhance vegetation cover development as much as jute net does. It is better merited for its potential to trap sediment and moisture, as indicated by the mosses and algae under the mat.

- Species distribution was fairly normal except for the paucity of redtop (*Agrostis alba*). In wet and moist biogeoclimatic zones this species often achieves dominance. The low-frequency representation of this species can be explained by the factors noted under the discussion of slope cover development, especially the dry season of 1985. Among the legumes, alsike clover (*Trifolium hybridum*) maintained dominance throughout the study period and by 1986 its vigour was quite prominent (Figure 6) on all but the no-net plots.

  Indigenous species recorded on the plots were fireweed (*Epilobium angustifolium*), horsetail (*Equisetum arvense*) as a hydrophite on wet spots, and some white spruce germinants (*Picea glauca*). Two deciduous species, black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) and paper birch (*Betula papyrifera*) were most abundant. A few willow shoots (*Salix* ssp.) were also counted. The spread of indigenous species by 1986 was still modest.

- Soil erosion and aggradation data show dramatic year-to-year changes, but the cumulative effects sort out the treatments in an orderly fashion. The first year's data again indicate strongly the previously mentioned deficiency of late-season seeding, where none of the treatments exerted any significant influence on erosion control and all acted as untreated plots. Treatment behaviour seemed erratic during the following 2 years. Enkamat produced negative erosion (soil aggradation) quite early, but the rate of this aggradation declined because the netting was already filled with trapped sediment and vegetation matter by 1986. Jute net acted in 1986 as Enkamat did in 1985, but 1 year later. By then, moss cover started to develop under the "thatch," the layer of dead vegetation matter. Data of soil loss or gain cannot be correlated properly with percent slope cover: it must be remembered that as well as the live vegetation cover, the dead cover or "thatch" contributes significantly to erosion control. The overall performance of the various treatments can be best appreciated when the cumulative effects of the last 2 years are viewed. Enkamat and jute net contributed significantly more to sediment trapping and biomass accumulation than no-net and Vexar, which were almost identical in this respect. Erosion continued on the "control," however, at a decreasing rate due to road recovery. These findings focus attention on two aspects: a) the control or arrest of surface soil movement, and b) the enhancement of the soil by trapping sediment and biomass, thus building up the organic component of the top soil layer. It appears from the results of cumulative effects that all treatments can achieve both objectives but certain netting materials can enhance soil improvement more significantly than others. The questions are: how much additional improvement is needed? how much extra cost is involved? and where is the extra cost justified? Therefore, the control of surface erosion should be viewed in terms of these two objectives.

The decreasing rate of erosion or "road recovery" on the untreated plots is a natural phenomenon, because the volume of the loose material continues to diminish at varying rates with the passage of years (United States Department of Agriculture Forest Service 1988). In this study, the rate of decrease from 1984 to 1985 was 175 m^3/ha, and from 1985 to 1986, 133 m^3/ha altogether 308 m^3/ha in 2 years. This seems to mask the effect of erosion control treatments, yet it is part of the total erosion control process. In this study, the average cumulative erosion on the "control" was calculated as 225 m^3/ha. Without road recovery, the rate would have been 708 m^3/ha, maintaining the rate of 354 m^3/ha/year of 1984. Although erosion rate decreased to 46 m^3/ha/year by 1986, soil loss still continued in the form of rill and sheet erosion.

It is also noteworthy that the rate of erosion on the untreated slope surfaces of this 3-year-old forest road, found to be 354 m^3/ha, is in close agreement with similar figures reported by other workers in diverse geographical locations, climates, and slopes. Carr (1977) reported 2.3 cm (230 m^3/ha) over a period of 7 months between September and April on south Vancouver Island. Extrapolated to a 12-month period, this figure would be increased to 394 m^3/ha. The extrapolation is not entirely correct, but the 10% difference can be explained, since the rate of erosion is somewhat lower between April and September than during the fall and winter months. Dyrness (1970) found 234 m^3/ha soil loss in 1 year, but under a drier climate in Oregon. Five years after road construction, the rate was still 51 m^3/ha on that same forest road. This figure approximates very closely the 46 m^3/ha rate on the Walker Creek Road, also 5 years after road construction.

The successful control of surface soil erosion by vegetation, with and without netting, is demonstrated even with a somewhat sparse vegetation cover. In comparison, the absence of any treatment leads to substantial soil loss.

- The justification of using erosion control netting on forest road slopes for accelerated and improved soil build-up with associated costs is largely a management decision. Comparative cost/benefit ratios of erosion control nettings can be used as indicators of economic feasibility.

  The unit costs per square metre of Vexar plastic netting, jute net, and Enkamat 7010 were respectively, \$0.64, \$1.49, and \$13.20. The question is, what benefit was gained by applying one or another netting material? Or, more specifically, how much did it cost to prevent 1 m^3 of soil erosion?

Hydroseeding costs being equal on all treatments, the comparison between cost/benefit ratios of these three nettings can be viewed as follows:

Netting	Unit Cost $/m^2	Soil aggradation as benefit cm	Cost/benefit ratio $/m^3
Vexar	0.64	-0.69	92.75
Jute net	1.49	-1.93	77.20
Enkamat	13.20	-2.50	528.00
No-net	0.08	-0.70	11.93

Accumulating 1 m^3 of soil with jute net was more economical by 17% than with Vexar netting. In other words, building up 1 m^3 of soil with Vexar cost 1.21 times as much as with jute net. The cost of soil aggradation of 1 m^3 of soil with Enkamat was 6.83 times greater than with jute net, and 5.66 times greater than with Vexar. The ratios of cost-effectiveness of these three nettings are:

V: J: E = 1.00: 0.83: 5.66, when comparisons are based on Vexar, and

V: J: E = 1.21: 1.00: 6.83, when comparisons are based on jute net.

It appears that jute net is the most cost-effective of the three nettings tested, Soil aggradation with the no-net treatment was found to be -0.6951 cm, almost identical to that of Vexar. This means that the same benefit as with Vexar can be realized without using any netting. Enkamat seems to be prohibitively expensive, but again, this is a management decision, where the high cost of treatment may be warranted by the demand for quick soil aggradation: sensitive slopes near large drainage structures, bridge abutments, and problematic sections of other road slopes.

- There are other materials besides these three, and presumably several others will appear on the market in the near future. As stated earlier, flexibility is a key criterion in selecting a netting for use on forest road slopes. It is advisable to test other nettings in the future to determine their technical performance and economic feasibility on forest roadside slopes. So far, it appears that the Curlex Blanket by American Excelsior Company (1990) is a good candidate. It is about as cost-effective as jute net[2] with the added feature of being made of shredded aspen, a biodegradable substance, held together with a nylon net, similar to Vexar.

  In future tests, slopes and their treatments should more closely resemble operational conditions. Thus, the slopes should be fully covered with netting. Therefore, the number of lines or subsamples on treated plots should be increased to four (or five, if the slope is long). This would further increase the reliability of computations if the rill meter is used. The technique, though cumbersome in some ways, is a fairly accurate one. If the erosion bridge is used, the number of sample lines should be at least double the number of rill meter lines.

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[2] Personal communications with Frank S. Atkinson, Atkinson-McDougal Corporation, 980 Montroyal Boulevard, North Vancouver, B.C., Canada v7r 2h2.

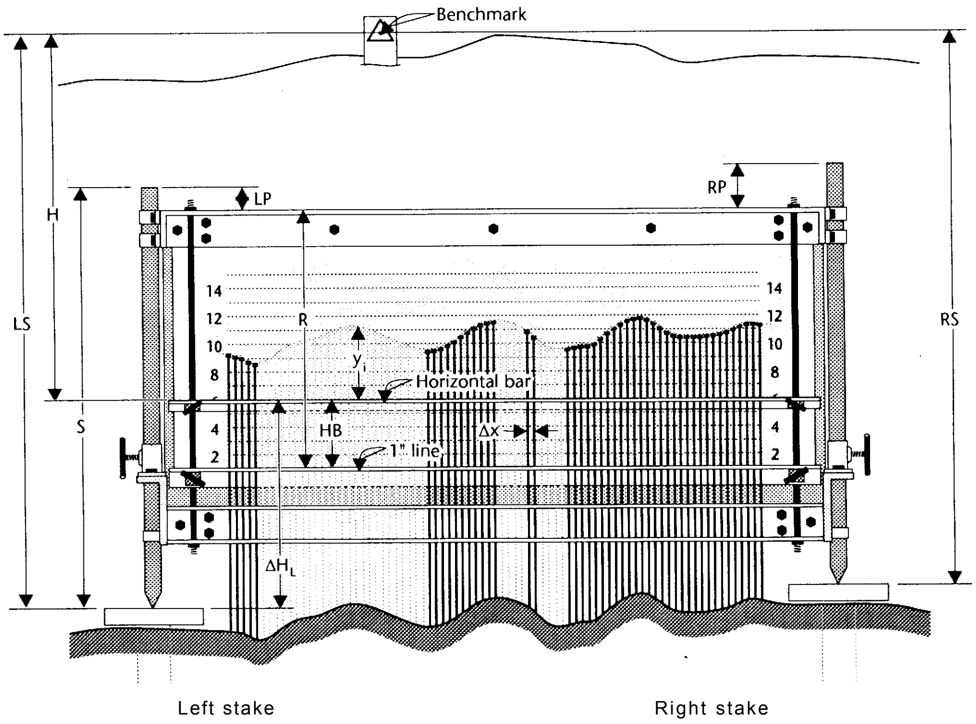
- Live vegetation cover increased progressively from year to year but development was slow. The preferred timeframe for seeding in the British Columbia interior extends from late April to mid-July in most biogeoclimatic zones, depending on the seeding window in a particular region. This timeframe can be extended if cool, moist weather prevails. If seeding is done in late summer or early fall, mulch should be included with the hydroseeding mix to protect germinants from desiccation and frost. The seeding window can be extended also at sites where a mature forest cover along roadsides serves as a buffer against weather extremes. Seeding very late in the season immediately before frost and snowfall can be successful in the Peace River region.
- Jute net produced the highest, Vexar netting the lowest percent of vegetation cover. Enkamat did not perform significantly better than the no-net treatment. Enkamat, however, conserved more soil surface moisture and trapped more sediment than other treatments.
- Species distribution was normal, but redtop remained retarded on this west-facing slope due to the dry season of the second year. Creeping red fescue and alsike clover maintained dominant status. Paper birch and black cottonwood along with white spruce germinants were the most prominent indigenous species, but the spread of these native plants was still low at the end of the study period.
- Since late seeding produced a less-than-satisfactory initial cover, erosion both on treated and untreated plots was high during the first year after seeding. Erosion decreased the second year on the jute net, Vexar, and no-net plots, influenced by vegetation establishment. Enkamat produced substantial soil aggradation; that is, trapped sediment and accumulated biomass. Erosion disappeared completely on all but the untreated plots, and aggradation developed on all treated plots by the third year. Jute net produced the highest rate of aggradation. Cumulative erosion figures of the second and third year, as a measure of treatment performance, sorted out the treatment levels: Enkamat and jute net formed a distinct group indicating the highest rate of soil build-up, while Vexar plastic netting and no-net constituted the other class. Difference between these two groups was highly significant at $\alpha = 0.05$. No significant difference in performance was found between Enkamat and jute net, and Vexar and no-net were almost identical. Erosion on the untreated plots was greater than on any of the treated plots at $\alpha = 0.005$, indicating the beneficial effects of any treatment even at less-than-perfect cover, versus no treatment at all. The established vegetation is the most important contributing factor in surface erosion control.

  Sheet and rill erosion, though substantially decreased from the first year, was still in progress at the end of the study period on untreated surfaces. The natural decrease of erosion on untreated surfaces followed the trend of the "road recovery line" at rates from 354 to 175 to 46 m^3/ha/year, 3, 4, and 5 years after road construction, respectively, showing close agreement with similar figures reported elsewhere. Cumulative erosion of the last 2 years on the untreated plots amounted to 225 m^3/ha. Without road recovery, it would have been as high as 708 m^3/ha.

- Two objectives can be considered in surface erosion control: the basic goal to halt erosion, and, in addition, increased or accelerated soil improvement by trapping sediment and dead biomass to upgrade soil quality. The first objective can be achieved with any of the treatments as long as the vegetation is established (with or without netting), therefore netting with its attendant cost is not a requirement. The second objective can be accomplished with high-quality netting such as Enkamat and jute net.
- The economic feasibility of the three types of nettings tested in this study can be viewed in terms of the cost of 1 m^3 of accumulated soil (and biomass). The cost-benefit comparison of Vexar, jute net, and Enkamat, respectively, indicate ratios of 1.00:0.83:5.66 when comparisons are based on Vexar, and 1.21:1.00:6.83 when based on jute net. The same benefit without the cost of netting can be gained with straight hydroseeding as with Vexar and hydroseeding. Jute net proved to be the most cost-effective of the three nets tested. Enkamat seems to be prohibitively expensive, except where the high cost is justified at specified locations for enhanced soil aggradation. Generally, erosion control netting on forest roads should be applied to slopes around bridge abutments, major drainage structures, and sensitive segments of forest road slopes where accelerated soil improvement is needed to enhance the functions of established live vegetation cover.
- The Curlex Blanket, and other flexible netting material yet to be produced and marketed, should be tested on forest roads. Operational conditions should be closely approximated in future testing projects: seeding should be carried out within the safe time frame during the growing season; refertilization should be applied when the established vegetation shows stagnation or declining vigour; the net should blanket the full width of the slope, and therefore the number of measurement lines (or subsamples) should be increased from two to four, or five on long slopes. Recording with the rill meter, computation of erosion figures and analysis of data should follow the methodology used in this study.
- Other, less time-consuming techniques may perform just as well: sediment traps at the base of the slope, or erosion bridges tied in to a permanent benchmark. The latter would increase confidence in checking road slope stability, and correction could be made for displacement.

APPENDIX 1 Method of Computation of Erosion Depth, and Compensation for Measurement Errors

Parameters used for computing erosion depth are illustrated and listed in Figure A1.1. Stake elevations LS and RS, and pole settings LP and RP are observations, while S, R, and ΔX are instrument constants for computing horizontal bar elevation and profile area. The horizontal bar setting HB is chosen arbitrarily.



LP = left pole setting (cm)
RP = right pole setting (cm)
LS= left stake elevation (cm)
RS = right stake elevation (cm)
S = length of pole (cm)
HB = horizontal bar setting (in)
H= horizontal bar elevation (cm)

ΔH_L= distance between left stake and top of horizontal bar (cm)
y_i = distance between horizontal bar and top of i^{th} pin (in)
R = distance between top of frame and 1" line (cm)
Δx = distance between adjacent pins

FIGURE A1.1 *Schematic illustration of the rill meter with parameters used for the computation of erosion.*

The irregular area delineated by the rill meter is computed in square inches by the trapezoidal method of approximate integration, as

$$A = \frac{\Delta X}{2}\left[y_0 + 2(y_1 + y_2 + \ldots + y_{144}) + y_{145}\right], \quad \text{where } y_0, y_1, \ldots \text{etc.}$$

are ordinates read from the graduated chart of the rill meter. This area is equivalent to the area of a parallelogram having a base of 73.054 inches, the distance between the first and last (146th) aluminum pin. The height is computed as $\bar{y} = \frac{A}{73.054}$ in. Converted to centimetres

$\bar{y} = A\left(\frac{2.54}{73.054}\right)$cm, or $\bar{y} = AK$, where $K = 0.034769$.

The difference between the computed heights (or mean ordinates) of two periods would yield the erosion depth, $\overline{\overline{y}} = y_1 - \bar{y}_2$, theoretically. This is not the case, however, because the elevation of the horizontal bar during the second year (H_2) is not the same as that of the first year (H_1). Therefore, $\bar{y}_2$ should be modified to $\bar{y}_{2c}$, as if all ordinates would have been measured from the first year's horizontal bar elevation. The correction for horizontal bar elevation is $\delta = H_1 - H_2$, in centimetres.

From Figure Al.1, $H = LS - \Delta H_L$, where LS is known from levelling, as an observation. The ΔH_L term can be expressed from an algebraic identity, $S = LP + R - 2.54\ HB + \Delta H_L$. From this, $\Delta H_L = (S - R) + 2.54\ HB - LP$. The constant term $(S - R)$ is denoted as T, thus $\Delta H_L = T + 2.54\ HB - LP$. Therefore, $H = LS - T - 2.54\ HB + LP$. The difference between the first and second years' elevations, $H_1 - H_2 = LS_1 - T - 2.54\ HB_1 + LP_1 - LS_2 + T + 2.54\ HB_2 - LP_2$, or $\delta = (LS_1 - LS_2) + (LP_1 - LP_2) - 2.54(HB_1 - HB_2)$, when stake elevations and pole settings from the left end of the rill meter are used. With right-end data, $\delta = (RS_1 - RS_2) + (RP_1 - RP_2) - 2.54(HB_1 - HB_2)$. Left- and right-side data should yield the same result, theoretically. In reality, results are not equal because all stake-elevation and pole-setting data are loaded with measurement errors, even with the most careful observation procedures. The observations first must be compensated for measurement errors before erosion depth computations can proceed.

If error-free data (the absolute values of observations) were available, the computed elevation of the horizontal bar would be the same with left-side and right-side data:
$H = \overline{\overline{LS}} - T - 2.54\ HB + \overline{\overline{LP}} = \overline{\overline{RS}} - T - 2.54\ HB + \overline{\overline{RP}}$. Therefore,
$\overline{\overline{LS}} + \overline{\overline{LP}} = \overline{\overline{RS}} + \overline{\overline{RP}}$. Reduced to zero, $\overline{\overline{LS}} + \overline{\overline{LP}} - \overline{\overline{RS}} - \overline{\overline{RP}} = 0$.

If observed values are used in the equation, the right side is not zero but, instead, a + or – real number, the sum-total of errors of the terms on the left side of the equation: $LS + LP - RS - RP = /$.

Since the observations are of different orders of magnitude (stake elevations are much larger than pole settings), the corrections applicable to individual observations will correspond to the weights of those observations.

The method of compensating for measurement errors for indirect observations with unequal weights dependent on each other is adapted from land survey techniques (Sébor 1949).

Observations can be dependent on each other if a certain condition is satisfied. The condition, a + or – real number can be a mathematical statement. For instance, the sum of the internal angles of a triangle equals 180°. The relationship between the observations and the condition can be expressed with an equation, termed as *the equation of condition.*

This equation is characterized by the absolute values of the observations on the left side, and the condition on the right side of the equation.

In general form, $a_1L_1 + a_2L_2 + a_3L_3 \ldots + a_nL_n =$ A. Reduced to zero, $a_1L_1 + a_2L_2 + a_3L_3 \ldots + a_nL_n - A = 0$, where $a_1, a_2, a_3, \ldots a_n$ are known coefficients in the equation. The "L" terms are the absolute values and "A" is the condition. If the relationship can be expressed in this linear fashion, the computations are easy, which is the case in this study. (Otherwise, the relationship would appear as an implicit non-linear function, which would have to be converted into a linear form.)

By substituting observed values for absolute values, the resulting "/" constant on the right side will contradict zero, the right side of the equation of condition. Therefore, this equation is termed as *the equation of contradiction.*

In general form, $a_1o_1 + a_2o_2 + a_3o_3 + \ldots + a_no_n - A = /$, where $o_1, o_2, o_3, \ldots o_n$ are the measured, observed values.

Absolute values consist of two components, the observed values and the corrections: $L_1 = o_1 + v_1, L_2 = o_2 + v_2, L_3 = o_3 + v_3, \ldots L_n = o_n + v_n$. Substituting these algebraic expressions into the equation of condition, $a_1(o_1 + v_1) + a_2(o_2 + v_2) + a_3(o_3 + v_3), + \ldots + a_n(o_n + v_n) - A = 0$. From this, $a_1v_1 + a_2v_2 + a_3v_3 + \ldots + a_nv_n + (a_1o_1 + a_2o_2 + a_3o_3 + \ldots + a_no_n - A) = 0$. The term in the bracket is the contradiction, "/." Therefore, $a_1v_1 + a_2v_2 + a_3v_3 + \ldots + a_nv_n + / = 0$.

This is the third type of equation, termed as *the equation of correction.* (There can be not one, but two or any r number of relationships among n number of observations; therefore, writing equations of condition, contradiction, and correction would be required for all possible relationships. In this study only one relationship exists between observations, [i.e., r = 1], which greatly simplified computations.)

The formula for the "minimum sum" or "sum of squares" for indirect observations with unequal weights is [pvv] = Smin. Expanded, $p_1v_1^2 + p_2v_2^2 + p_3v_3^2 + \ldots + p_nv_n^2 = \text{Smin}$, where $v_1, v_2, v_3, \ldots v_n$ are all different variables. The symbols $p_1, p_2, p_3, \ldots p_n$ are the weights of the individual observations. The weight of the largest observation is the smallest and equals 1, since larger observations are associated with larger errors, and therefore, with smaller weights. Weights of the other observations are greater than 1, in proportion to their respective sizes compared to the largest observation. For instance, if o_3 is the largest observation, $p_3=1$. Weights of the other observations will be $p_1 = \frac{o_3}{o_1}, p_2 = \frac{o_3}{o_2}, \ldots p_n = \frac{o_3}{o_n}$. Figures are rounded up or down to the nearest whole number. Partially differentiating the function, $p_1v_1(dv_1) + p_2v_2(dv_2) + p_3v_3(dv_3) + \ldots + p_nv_n(dv_n) = 0$.

In order to compute the corrections of the individual observations, the equation of correction is partially differentiated: $a_1(dv_1) + a_2(dv_2) + a_3(dv_3) + \ldots + a_n(dv_n) = 0$. This equation is multiplied with a constant, "k," the correlation coefficient, yet unknown: $a_1k(dv_1) + a_2k(dv_2) + a_3k(dv_3) + \ldots + a_nk(dv_n) = 0$.

Compared to the above equation of the partially differentiated equation of the minimum sum, the multipliers of the respective dv terms in the two equations are equal:

$p_1v_1 = a_1k$ The corrections are expressed as $v_1 = \frac{a_1}{p_1}k$

$p_2v_2 = a_2k$ $v_2 = \frac{a_2}{p_2}k$

$p_3v_3 = a_3k$ $v_3 = \frac{a_3}{p_3}k$

....

$p_nv_n = a_nk$ $v_n = \frac{a_n}{p_n}k$

To compute k, these algebraic expressions of the corrections are substituted in the equation of correction:

$\frac{a_1a_1}{p_1}k + \frac{a_2a_2}{p_2}k + \frac{a_3a_3}{p_3}k + \ldots + \frac{a_na_n}{p_n}k + \ell = 0$, or

$\left[\frac{aa}{p}\right]k + \ell = 0$. From this, the correlation coefficient, $k = \frac{-\ell}{\left[\frac{aa}{p}\right]}$.

Now the above equations for the corrections of the individual observations can be used for computing the v values. Following these steps, the minimum sum, [ppv] = Smin can be computed.

A simple "control equation" is used for checking the computations for v values and Smin. The derivation is as follows:

The "pv" equations above are multiplied, respectively, with $v_1, v_2, v_3, \ldots v_n$, and summed. The equation of correction is multiplied with k.

$p_1v_1v_1 = a_1v_1k$ $a,v,k + a_2v_2k + a_3v_3k + \ldots + a_nv_nk + k\ell = 0$, or

$p_2v_2v_2 = a_2v_2k$ $[av]k + k\ell = 0$.

$p_3v_3v_3 = a_3v_3k$ since $[av]k = [pvv]$,

$p_nv_nv_n = a_nv_nk$ $[pw] + k\ell = 0$. From this, the control equation is

$[pvv] = [av]k$ $[pvv] = -k\ell$

The mean error of the unit-weight observation is given as $m_0 = \pm\sqrt{\frac{[pvv]}{r}}$, where r is the number of relationships between the observations. When $r = 1, m_o = \pm\sqrt{[pvv]}$.

The mean errors of the individual observations can be computed as $m_1 = \pm \frac{m_0}{\sqrt{p_1}}$ Thus, the corrected observations within their respective ± m error bands will be,

$$m_2 = \pm \frac{m_0}{\sqrt{p_2}} \qquad 0_1 = o_1 + v_1$$

$$m_3 = \pm \frac{m_0}{\sqrt{p_3}} \qquad 0_2 = o_2 + v_2$$

$$0_3 = o_3 + v_3$$

$$m_n = \pm \frac{m_0}{\sqrt{p_n}} \qquad 0" = o_n + v_n$$

Substituting the corrected observations into the equation of condition, $a_1 0_1 + a_2 0_2 + a_3 0_3 + ... + a_n 0_n - A = 0$.

Following the steps in the above analogy, measurements for stake elevations and pole settings can be corrected.

- *Equation of condition* $\overline{\overline{LS}} + \overline{\overline{LP}} - \overline{\overline{RS}} - \overline{\overline{RP}} = 0$

  In this equation a, $= a_2 = 1$, $a_3 = a_4 = -1$, $L_1 = \overline{\overline{LS}}, L_2 = \overline{\overline{LP}}, L_3 = \overline{\overline{RS}}, L_4 = \overline{\overline{RP}}$ and $A = 0$.

- *Equation of contradiction* LS + LP - RS - RP = ℓ. In this equation $o_1 = LS, o_2 = LP, o_3 =$ RS and $o_4 =$ RP.

- *Weights* Since stake elevations are much larger than pole settings, the respective weights for LS, LP, RS, and RP will be p_1, p_2, p_3, and p_4 where $p_1 = p_3 = 1$, because LS and RS are the observations of the largest order of magnitude. Consequently, p_2 and p_4 are each greater than 1. Thus,

$$\left[\frac{aa}{p}\right] = \frac{1}{p_1} + \frac{1}{p_2} + \frac{1}{p_3} + \frac{1}{p_4} = \frac{1}{p_2} + \frac{1}{p_4} + 2$$

- *Correlation coefficient*

$$k = \frac{-\ell}{\left[\frac{aa}{p}\right]}$$

- *Corrections of individual observations*

$$v_1 = k$$

$$v_2 = \frac{k}{p_2}$$

$$v_3 = -k$$

$$v_4 = -\frac{k}{p_4}$$

Appendix 1 Concluded.

- *The Minimum Sum (or sum of squares)*

  $$p_1v_1^2 + p_2v_2^2 + p_3v_3^2 + p_4v_4^2 =$$
  $$= v_1^2 + p_2v_2^2 + v_3^2 + p_4v_4^2 = [pvv] = -k/$$

- *Mean error of the unit-weight*

  $$m_0 = \pm\sqrt{[pvv]}$$

- *Mean errors of individual observations*

  $$m_1 = m_3 = m_0$$
  $$m_2 = \pm\frac{m_0}{\sqrt{p_2}}$$
  $$m_4 = \pm\frac{m_0}{\sqrt{p_4}}$$

- *Corrected observations*

  $$\overline{LS} = LS + v_1$$
  $$\overline{LP} = LP + v_2$$
  $$\overline{RS} = RS + v_3$$
  $$\overline{RP} = RP + v_4$$

- *Substitution into the equation of condition*

  $$\overline{LS} + \overline{LP} - \overline{RS} - \overline{RP} = 0$$

- *Stake elevations and pole settings are corrected in this manner for year 1 and year 2.*

- *Correction for* $\overline{y}_2$

  $$\delta = \left(\overline{LS}_1 - \overline{LS}_2\right) + \left(\overline{LP}_1 - \overline{LP}_2\right) - 2.54\left(HB_1 - HB_2\right)$$

  Check for "right-side" data:

  $$\delta = \left(\overline{RS}_1 - \overline{RS}_2\right) + \left(\overline{RP}_1 - \overline{RP}_2\right) - 2.54\left(HB_1 - HB_2\right)$$

  Corrected mean ordinate for second year,

  $$\overline{y}_{2c} = \overline{y}_2 + \delta$$

- *EROSION DEPTH in centimetres WITH CORRECTED OBSERVATIONS*

  $$d = \overline{y}_1 - \overline{y}_{2c} = \overline{y}_1 - \overline{y}_2 - \delta = (A_1 - A_2)K - \delta.$$

  Since $(A_1 - A_2)K = \overline{\overline{y}}$,

  $$\mathbf{d} = \overline{\overline{y}} - \delta$$

APPENDIX 2 Statistical Analyses of the Results

table a2.1 *Analysis of variance for percentive vegetation cover*

Source of variation	**SS**	**d.f.**	**MS.**	**F**	**P**
Year (Y)	1225.0000	2	612.5000	12.6000	0.0071
Treatment (T)	836.4583	3	278.8194	5.7357	0.0339
Y x T	291.6667	6	48.6111	1.2613	0.3478
Sampling error	462.5000	12	38.5417		
Total	2815.6250	23			

Year	1984	1985	1986
Mean	51.88	60.63	69.38

Any two means not underscored by the same line are significantly different at $\alpha = 0.01$.

Treatment	J	E	N	V
Mean	69.17	60.83	60.00	52.50

Any two means not underscored by the same line are significantly different at $\alpha = 0.05$.

table a2.2 *Analysis of variance for cumulative erosion*

Source of variation	**SS**	**d.f.**	**MS.**	**F**	**P**
Replicate (R)	0.1748	1	0.1748	0.1225	0.7440
Treatment (T)	53.7643	4	13.4411	9.4218	0.0236
Interaction (R x T)	5.7064	4	1.4266	0.5751	0.2947
Sampling error	24.8051	10	2.4805		
Total	84.4506	19			

table a2.3 *Analysis of variance with contrast tests for cumulative erosion*

Source of variation	**SS**	**d.f.**	**MS.**	**F**	**P**
Treatment	53.7643	4	13.4411	6.5702	0.0029
Contrast, C vs. all others	43.8333	1	43.8333	21.4265	0.0003
Contrast, E & J vs N & V	9.2780	1	9.2780	4.5352	0.0502
Among samples, E vs. J and N vs. V	0.6530	2	0.3265	0.1596	0.1499
Error	30.6863	15	2.0458		
Total	84.4506	19			

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