THE CONTROL OF SURFACE EROSION FROM OVERBURDEN AREAS[1]

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Abstract.--Factors effecting soil erosion from overburden areas are discussed; Design procedures to determine the spacing and bedslope of contour drains are presented. An erosion loss model is used to determine the spacing of drains; the results of field trials are used to determine bedslope. Standard hydrological techniques coupled with careful drain construction can limit erosion from overburden areas to acceptable values.

INTRODUCTION

The loss of soil from open cut overburden areas through erosion is perceived to be a problem of increasing environmental concern. Loss of soil hampers rehabilitation operations; consequent increases in settleable and suspended solids reduce the quality of surface runoff. Much of this concern appears to be misplaced: standard hydrologic and hydraulic design practices, coupled with careful drainage construction, can limit erosion losses to acceptable levels.

There are a number of distinct phases in rehabilitation operations: recontouring, top-soiling, soil preparation and revegetation. An essential component of these operations is the reconstitution of a surface drainage network. A properly designed and constructed drainage system is vital for controlling erosion losses. However, in nany cases, surface drainage still receives only token consideration, often as an afterthought during rehabilitation planning.

The author has recently assessed the importance)f rehabilitation planning at an opencut minesite in)ueensland, Australia. The preparation of an .ntegrated rehabilitation plan that incorporates ıurface drainage design as a central component is :ssential for minimizing rehabilitation costs in ;eneral, and erosion losses in particular. As part ıf this investigation a set of erosion control ;uidelines was prepared and 4 contour drains, a drop rain and a number of drop structures were designed, constructed and their performance monitored for 12 months. This paper discusses the various factors affecting erosion and presents design methods for determining the spacing, size and bedslope of contour drains. Difficulties with construction of drains are discussed and methods to overcome these difficulties are suggested.

FACTORS AFFECTING SOIL EROSION

Factors affecting the rate of soil erosion fall into 5 main groups:

- erosion mechanisms,
- soil factors,
- plant cover,
- rainfall intensity and duration, and
- surface drainage factors.

Erosion Mechanisms

Loss of surface soil can occur through 3 mechanisms: sheet erosion, rill erosion, and gully erosion. Sheet erosion is the wearing away of a thin layer of the soil surface through the entrapment and movement of soil particles in sheet flow over the surface. Sheet erosion is the first loss mechanism to occur once surface runoff has commenced. The erosivity of rainsplash is an important mechanism in the loosening and entrainment of soil particles. Because of variations in the topography of the soil surface, water drains into minor preferred flow paths where depths and velocities are greater than in the sheet flow situation. Greater erosion occurs along these preferred flow paths and minor channels or rills are formed. Ultimately, the flow from a number of rills progressively comes together in a major preferred flow path, or gully, with a substantial increase in runoff depth, velocity and erosion potential. According to Komura (1976),

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rills are those channels small enough to be smoothed completely by normal cultivation methods; gullies are those channels that cannot be smoothed in this way (rills are typically less than 5 cm in depth).

Soil Factors

The type, size and characteristics of a soil are major factors that affect its rate of erosion. The smaller the size of soil particles, the easier and more rapidly they can be entrained and transported away by surface runoff. The infiltration characteristics of the soil markedly effect erosion. The greater the surface infiltration, the smaller the volume and rate of surface runoff and the less its erosion potential. Some clay soils are naturally dispersive. On wetting, aggregates of clay particles tend to break down into smaller clumps. This reduces the size of individual 'particles' and increases the erodability of dispersive clays.

Soil treatment also affects the erodability of soil. Mechanical equipment compacts surface layers and can dramatically reduce surface infiltration. Tests conducted on run-of-mine overburden cast from a dragline indicated that recontouring by D-10 bulldozers resulted in a 10-15 fold reduction in surface infiltration. During revegetation operations, acid soils are often limed prior to sowing. The application of lime to dispersive soil reduces their dispersiveness and erodability. Mulching protects the surface from rainsplash and reduces the rate and volume of surface runoff by trapping and delaying surface water and by providing a greater opportunity for surface infiltration. A comparison between infiltration rates for cultivated soils and mulched soils indicated that straw mulched soils (6 tones/ha - "just enough to hide most of the ground") absorbed 3-5 times as much rainfall as bare soils and had infiltration rates 3-4 times greater than the that of bare soil. In additon, there was practically no soil lost in the runoff from the mulched plots (Jacks et al, 1955).

Plant Cover

The denser and more uniform the plant cover, the less the erodability of the soil. Plant cover protects the soil and reduces the effects of rainsplash; plant roots help bind the surface soil together; plants and plant litter retard surface runoff and increase infiltration. In addition, by 'drying out' the soil through evapotranspiration, plants increase the infiltration potential of the soil.

Rainfall Intensity

The greater the rainfall intensity, the more severe are rainsplash effects and the greater rate of surface runoff. Higher rates of runoff will be reflected in faster and deeper surface flows and greater erosion potential. Intense rains tend to 'surface seal' some soils, thereby greatly reducing their infiltration capacity. This increases the rate of surface runoff and its erosion potential.

Surface Drainage Factors

The rate of soil loss increases progressively from sheet erosion to rill erosion to gully erosion. According to Komura (1976), sheet erosion with major rill formation results in 5 times the soil loss of sheet erosion with minor rills; sheet erosion with gullies results in 10 times the soil loss of sheet erosion with minor rills. Important factors determining whether rill or gully erosion develops are soil characteristics, surface slope and length of overland flow. The steeper the surface slope, the greater the velocity and erosion potential of sheet flows, and the more likely the formation of major rills and gullies. The longer the overland flow path, the greater the depth and erosion potential of sheet flow. To reduce the tendency of surface runoff to form rills and gullies, it is necessary to limit surface slopes and/or lengths of overland flow.

CONTOUR DRAINS

The object of overburden drainage management is to convey surface runoff off the overburden area in a controlled manner that minimizes soil erosion and prevents the formation of major erosion gullies. To achieve this, it is generally necessary to construct contour drains to carry runoff either to the edge of the overburden area, or to convey the runoff to a central 'drop drain' that discharges down the slope. The topgraphy of the overburden area and surrounding natural area determines the feasibility of these two alternatives. Without contour drains of some type, gully erosion will inevitably develop at the surface slopes characterizing many overburden areas. Gully erosion can also develop if contour drains have been poorly designed or constructed. A major difficulty with contour drains is their tendency to silt-up. Silting or inadequate capacity can lead to overtopping and washout, so allowing water to discharge downslope and create a gully. Although the following discussion is limited specifically to contour drains, it is emphasized that they are but one part of an integrated drainage system for recontoured overburden areas. We can identify 2 design problems associated with the use of contour drains to control erosion:

(i) determination of the contour drain spacing necessary to limit soil erosion to some prescribed acceptable value, and

(ii) determination of the cross-section, longitudinal slope and construction techniques necessary to ensure that contour drains do not silt-up

The development and application of design procedures for each of these design areas is now discussed.

SPACING OF CONTOUR DRAINS

Design Considerations

An overburden area is most vulnerable to erosion loss immediately after seeding: the soil surface is bare; topsoil, seeds and fertilizer are poised to be washed downslope. Once an initial strike of grass cover has been established to protect and bind the soil, the erosion potential is greatly reduced. For design purposes, it is assumed the overburden area is in the 'bare soil' condition immediately after seeding.

When discussing the rate of erosion of soils, it is important to distinguish between the rate of erosion during a specific isolated storm (event erosion) and the long term annual rate of erosion that occurs over a period of years (average annual erosion). In assessing the long term effectiveness of rehabilitation operations, the 'annual rate of erosion' is the appropriate measure. The best known annual loss model is the 'Universal Soil Loss Equation' (USLE) of Weischmier and Smith (1978). However, when designing erosion control measures to minimize erosion during the initial strike of grass, the 'event rate of erosion' is the appropriate measure. In essence, it is necessary to choose a design rainfall event and an acceptable rate of erosion for this event, and then establish the surface slopes and spacing of contour drains to meet these targets.

The storm events appropriate for design purposes will vary from minesite to minesite. In outback Queensland, resowing may be required for several years in succession before adequate grass cover is established. Under these conditions, the 5 year rainfall event of critical duration (i.e. with duration equal to the time of concentration of overland flow) appears appropriate for determining the spacing of contour drains. (In any one year, there is an 80% chance that the peak rainfall intensity of the critical duration storm event will be less than the 5 year value). At the particular minesite studied in North Queensland, it was the recommended that erosion loss be limited to 5 mm for the 5 year storm event occurring under 'bare soil' conditions. Once adequate grass cover is established, the loss of soil for this event would be much less (¼ 1 mm).

Erosion Model

After a comprehensive literature review, the event loss model of Komura (1976) was adopted for predictive purposes. Komura used Kalinske's bed load function to derive theoretical expressions for the transport of sediment in laminar and turbulent flow over a soil surface. The relative proportions of sheet, rill and gully erosion processes are incorporated in an empirical erodability index. Komura's model is simple, its parameters are self-explanatory and it has been verified against test results that reflect the surface slopes (9-45%), flow lengths (7-25 m), rainfall intensities (2-500 mm/hr) and sediment sizes (average size 0.1 - 7.0 mm) likely to be encountered on many overburden areas. In addition, the simple nature of the model makes it a readily applicable management tool.

Komura's event erosion loss model is given by:

$$E = \frac{0.0011\ C_A\ C_E}{D}\ (fI)^{15/8}\ L^{3/8}\ S_o^{3/2} \qquad (1)$$

where E is the average rate of soil loss during the event ($kg/hr/m^2$),
C_A is the bare soil ratio (unitless: $C_A = 1$ for bare soil),
C_E is the erodability coefficient (unitless),
f is the runoff coefficient (unitless),
I is the average rainfall intensity during the event (mm/hr),
L is the length of overland flow (m),
S_o is the slope of the soil surface in the direction of runoff (unitless ratio), and
D is the mean sediment size (mm).

Equation (1) includes the various factors affecting erosion that were discussed previously. The erodability coefficient, C_E, incorporates the effects the different erosion mechanisms. (Komura recommends a value of 1 for sheet erosion or sheet erosion with small rills, a value of 5 for sheet erosion with major rills and value of 10 for sheet erosion with gullies). Soil factors are incorporated through the mean sediment size, D; the bare soil ratio, C_A, represents the effects of plant cover; infiltration effects are embodied in the runoff coefficient, f. The rainfall intensity, I, appears directly in the equation. Surface drainage factors are incorporated in L and S_o. Note that the only empirical parameter is C_E.

Table 1 Sensitivity of Erosion Estimates to Paramater Values, Komura's Equation

Parameter	Effect on Original Erosion Rate if Parameter Doubled
I	+3.7
S_o	+2.8
C_A, C_E and D	+2.0
L	+1.3

Table 1 shows the effect on erosion estimates of a two-fold increase in the various parameters of equation (1). The effect of doubling the surface slope is to increase the original erosion rate some 2.8 times the original value. The least sensitive parameter is seen to be length of overland flow.

Design Method

Komura's equation provides a convenient vehicle for bringing together the various factors that influence erosion. The equation will provide consistent estimates of erosion at a minesite. Moreover, as experience is gained with its use, the equation can be 'tuned' to conditions at a specific minesite via the erodability index, C_E. Komura's equation forms the basis of the design method for spacing contour drains.

Apart from surface treatment, the only other design parameters that can be manipulated on site are the length and slope of overland flow (length of overland flow defines the spacing of contour drains). If the design method is used prior to recontouring, various combinations of surface slope and drain spacing can be investigated. If the design method is used subsequent to recontouring, the only parameter available for design purposes is drain spacing.

The design process consists of the following:

1. Select a drain spacing/surface slope combination.
2. Estimate the time of concentration of overland flow.
3. Estimate the rainfall intensity corresponding to a storm event of this duration and the adopted design storm severity.
4. Use Komura's equation to estimate the depth of soil loss corresponding to this event.
5. If the soil loss is unacceptable, adjust the drain spacing/surface slope conditions and repeat the analysis.

The design process is based on standard hydrological procedures. The determination of time of concentration and rainfall intensity is very similar to 'Rational Method' analyses of peak flood flows. Two charts were prepared to aid in this design process. Figure 1 shows a chart for estimating the time of concentration of overland flow and the corresponding rainfall intensity. Figure 2 is a graphical solution of Komura's equation. Note that the rainfall intensity data shown on Figure 1 is specific to the minesite in north Queensland.

CROSS SECTION AND LONGITUDINAL SLOPES OF CONTOUR DRAINS

Field Investigation

A series of 4 contour drains, 1 drop drain and a number of drop structures were designed, constructed and monitored over 12 months to check their performance. The total overburden area commanded by these drains was 4.5 ha. The 4 contour drains conveyed water to the central drop drain which discharged directly down a steep face of the overburden area. This face had a slope of 25%. Details of the 4 contour drains are shown in Table 2. Drain No. 3 was a 'terrace drain' cut by 'dozer' along the steep face. With the exception of the terrace drain, the other 3 contour drains have lengths of 110-220 m and command catchment areas of 1-2 ha with overland slopes of 4-8% and overland flow lengths of 60-100 m.

Table 2 Characteristics of Contour Drains

Drain	Catch. Area (ha)	Drain Length (m)	Overland Flow (m)	Overland Slope (%)
1	1.32	220	60	7.5
2	1.90	190	100	4.3
4[a]	0.22	110	20	20.0
5	1.05	140	75	4.0 & 12.0

[a] Terrace Drain

Design Considerations

Important factors in the design of contour drains are ease of construction, non-silting behaviour, and adequate freeboard. Graders will generally be used to construct contour drains, and a symmetrical 'V-shaped' cross-section with the channel side slopes of 30^{o} to the horizontal was adopted (see Figure 3). The 'Rational Equation' was used to estimate the drain discharge for the design event. (The time of concentration equals the time of overland flow plus the travel time for the water to move down the drain). Manning's equation, in the form of simple design chart, was used to determine the hydraulic characteristics of the drain. For a given discharge and bedslope, the depth and velocity of flow can be determined (see Figure 3). Also shown on Figure 3 is the self scouring limit for the drain (Hughes, 1980), which indicates that for bedslopes greater than 1%, the drain is likely to be self-scouring.

The overburden at the study area contains rocks hanging in size from footballs to boulders, and it was anticipated that the accurate construction of a contour drain to a given bedslope might be difficult. One way of overcoming this problem is to cut the channel to a steeper slope and use a series of drop structures to provide hydraulic controls and

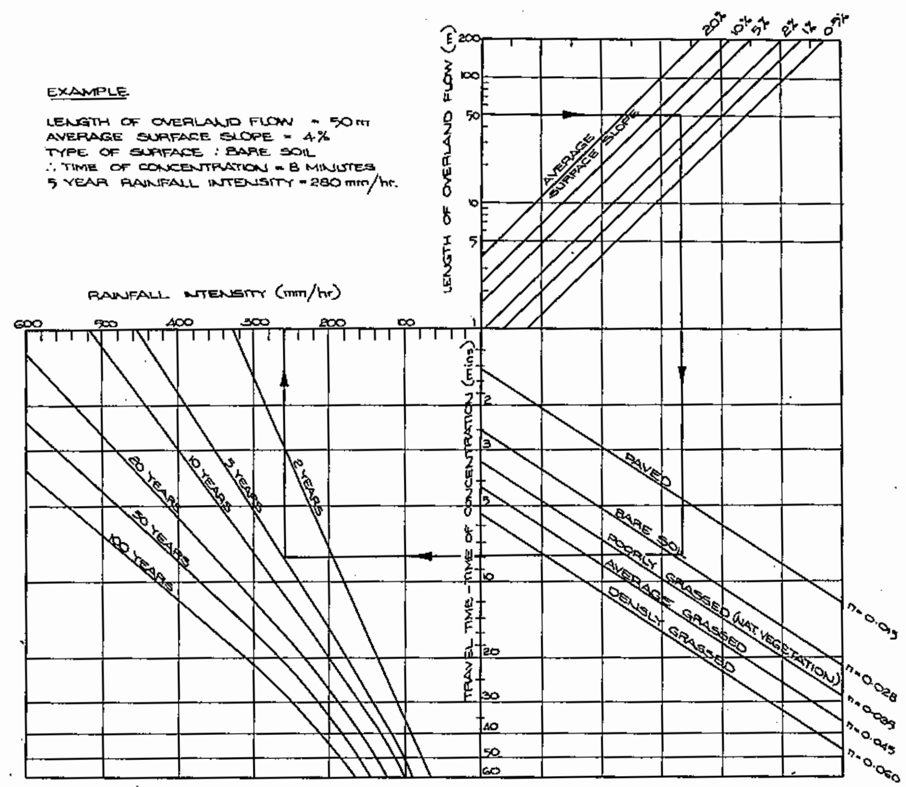

Figure 1.--Estimation of travel time and rainfall intensities, North Queensland.

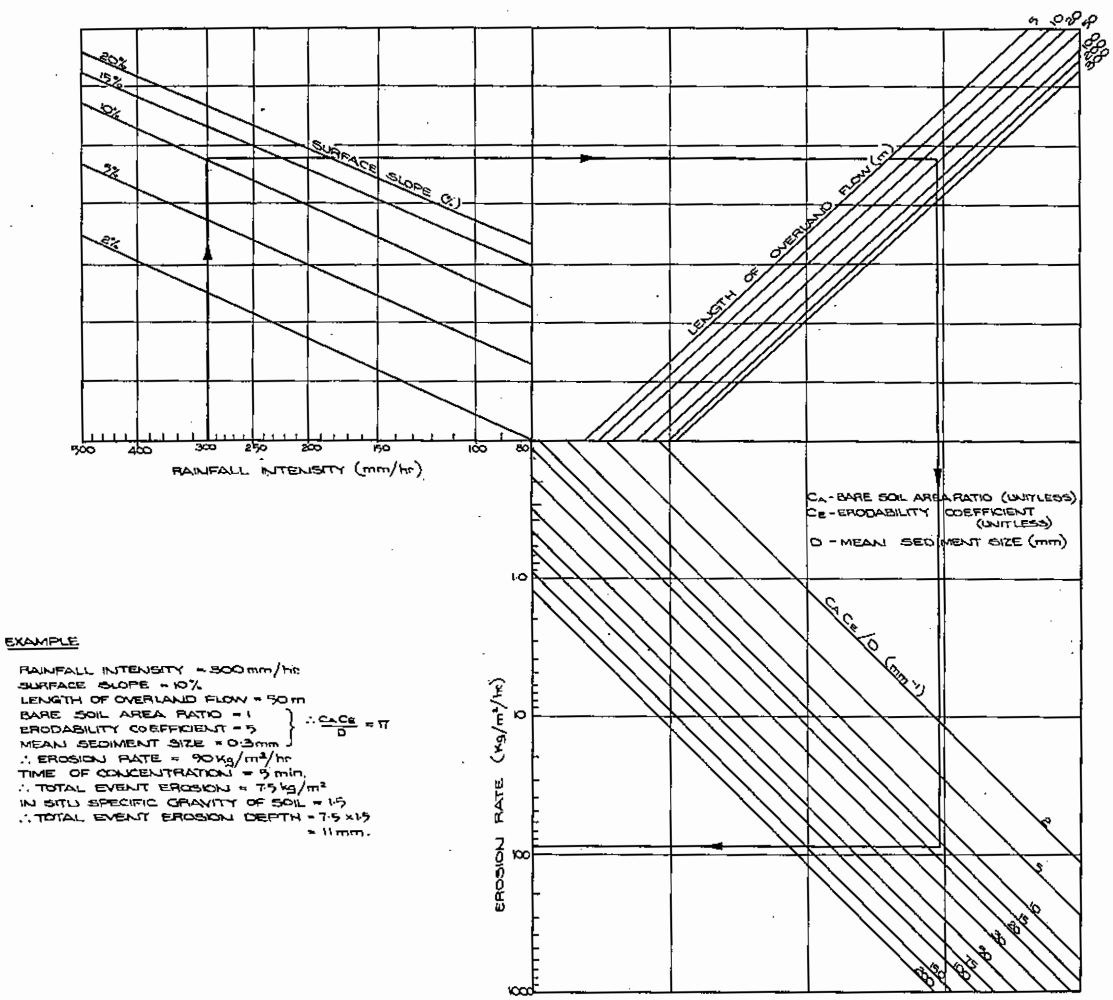

Figure 2.--Estimation of soil loss through erosion (Komura's Equation).

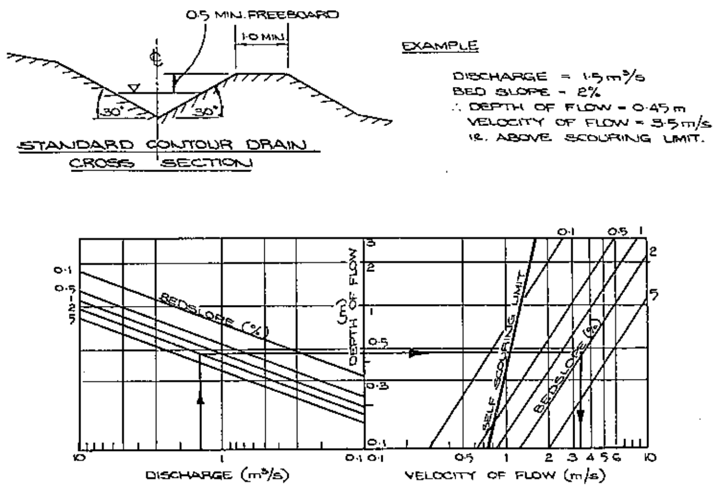

Figure 3.--Depth and velocity of flow, standard contour drain section.

stabilize the bed. Such structures initially act as sediment traps and allow the upstream bed slope to automatically adjust itself to the discharge of water and sediment down the drain. A number of drop structures constructed from dumped rock were installed in the contour drains to test their effectiveness.

Construction Difficulties

Several problems became apparent during the construction of the drains. The first concerned the setting out of the contour drains. A level and staff were used to peg the centreline at 20 m intervals. This distance proved to great. Because of the unevenness of the overburden surface, it was impossible to cut a satisfactory channel with the grader between marks with this spacing. Lime was then used in conjunction with the level and staff to mark the centreline between pegs, and this proved satisfactory.

The presence of rocks in the overburden material added to construction difficulties. When cutting contour drains, the grader was stopped on numerous occasions by the blade striking large rocks. Some of these rocks could be removed by the grader but others required the 'dozer. The removal of large rocks left 'pot holes', which when subsequently filled, resulted in 'low points'. Figure 4 shows the 'as constructed' profile of Drain No. 1. Table 3 shows the specified design bedslopes and the as constructed bedslopes. Satisfactory agreement between the design bedslope and 'as constructed' bedslope was only achieved for Drain 2.

Table 3 Design and As-Constructed Bedslopes, Contour Drains

Drain	Design Bedslope (%)	As Constructed Bedslope (%)
1	1.0%	0.3% - 2.0%
2	1.5% & 4.0%	1.4% & 4.0%
4	0.5%	0.2%
5	1.0%	0.7% - 4.6%

Monitoring

The adopted monitoring program was simple and limited in scope. Rainfall intensity and duration were measured at an automatic raingauge located about 1 km from the study area. A series of white painted wooden pickets with a cm scale marked on them were driven into the bed of the drains at 20 m intervals and used to record the bed level of sediments before and after storm events.

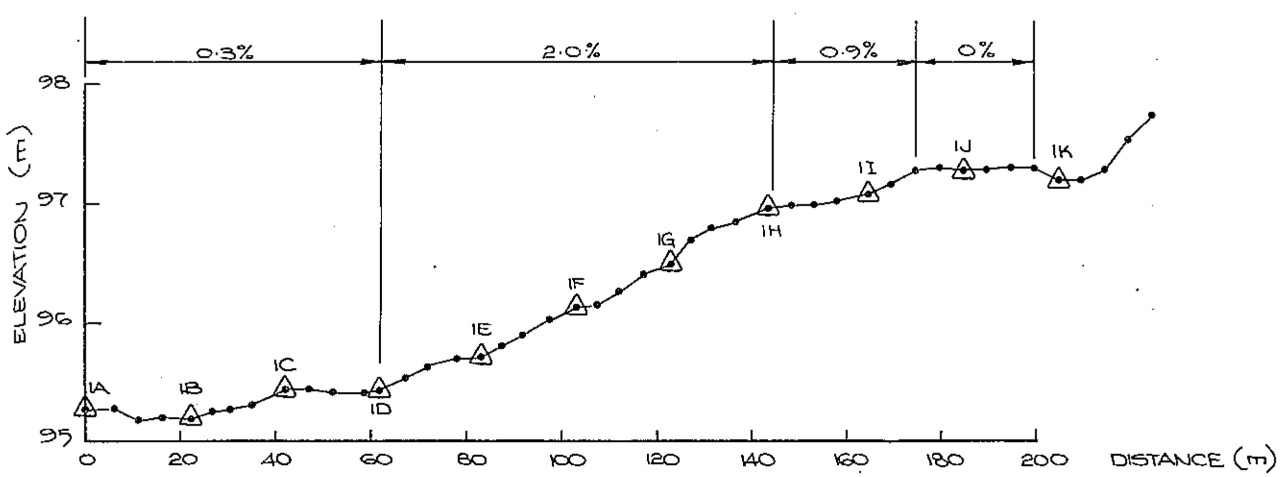

Figure 4.--Longitudinal section, contour drain no. 1

Results

Rainfall Events

Unfortunately, the 12 month monitoring period was drier than usual. The annual rainfall for the period was 344 mm; the median annual total is 700 mm. Table 4 shows the monthly rainfall for the study period December '84 to December '85. (The wet season in North Queensland runs from November to March). Greater than 10 mm of rain per day fell on 15 occassions; the highest daily rainfall was 56 mm in December '85. Several moderate storm events occurred throughout the test period; the peak hourly rainfall intensity had a return period of about 2 years. Although no major storm events occurred, useful results were obtained.

Table 4 Monthly Rainfalls, December '84 to December '85, Study Area

Month	D	J	F	M	A	M	J	J	A	S	O	N	D
mm	17	78	28	44	0	2	2	56	0	26	30	51	122

Erosion and Deposition in Contour Drains

Erosion and Deposition in the contour drains showed marked changes after storm events. Results obtained after a moderate storm event are shown in Figure 5. The measured erosion and deposition of the bed of the drain correlates well with the 'as-constructed' slope of the drains. The relationship indicates that for the rainfall conditions experienced during the test period, a channel slope of about 2%-2.5% would result in 'balanced' self-scouring design. Note that this value is considerably <u>higher</u> than the 1% value indicated by Hughes (1980).

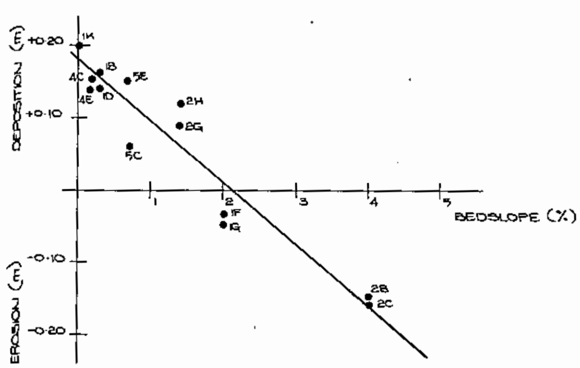

Figure 5.--Relationship between depth of erosion/deposition and bedslope, contour drains, storm event of March, 1984.

Drop Structures

The drop structures performed well in stabilizing the bed of contour drains and in trapping sediment. In 2 cases 'breakthrough' occurred around the sides of drop structures because the blanket of rocks had not been extended a sufficient distance up the banks of the drain.

CONCLUSIONS

Komura's equation provides a simple and convenient means of estimating the erosion loss from overburden areas for isolated storm events. The equation incorporates the major factors affecting erosion and provides a basis for determining the slope/contour drain spacing/soil treatment combinations necessary to limit erosion to prescribed levels for the design storm event. The equation incorporates an empirical factor, the erodability index, C_E. However, the equation has been verified against test data that reflect overburden conditions. The equation is expected to provide consistent estimates of erosion losses and contour drain spacing. If a limited monitoring program is instituted, covering 1 or perhaps 2 wet seasons, the equation can be 'tuned' to specific conditions at a minesite through the adjustment of C_E.

There appears to be little published data concerning the minimum bedslope necessary to achieve self-scouring conditions in contour drains on overburden areas. (These drains are characterized by generally shallow flows). Breakthrough of the downstream bank of the drain, whether caused by siltation or inadequate channel capacity, inevitably leads to the formation of a major erosion gully. The field tests reported here demonstrate how the self-scouring bedslope can be determined with inexpensive and simple monitoring equipment. (A single drain with variable bedslopes will provide the necessary information after 1 or 2 moderate storm events).

The presence of large rocks in the overburden makes it difficult to accurately construct a contour drain to a given bedslope. Results in north Queensland indicate that the bedslope can only be expected to be within $\pm$ 1% of the specified bedslope. In such situations, it is recommended that drains be cut to a steeper slope (self-scouring bedslope plus 1%) and that drop structures of dumped rock or other suitable materials be constructed at regular intervals (30-50 m) to act as hydraulic controls and sediment traps.

The results and techniques reported here indicate that with careful design and construction, contour drains can be successfully used to limit erosion losses from overburden areas to acceptable levels.

REFERENCES CITED

Hughes, W.C. 1980. 'Scour Velocities in Ephemeral Channels', J. Hyd. Div., ASCE, 106(HY9):1435-1441.

Jacks, G.V., W.D. Brind and R. Smith, 1955. '<u>Mulching</u>'. Technical Communication No. 49 of the Commonwealth Bureau of Soil Science. Commonwealth Agricultural Bureaux, Bucks, England: 1955).

Komura, S. 1976. 'Hydraulics of Slope Erosion by Overland Flow', J. Hyd. Div., ASCE, 102(HY10):1573-1586.

Wischmeier, W.H. and D.D. Smith 1978. 'Predicting Rainfall Erosion Losses - A Guide to Conservation Planning'. Agric. Handb. No. 537, USDA. Govt. Printing Office, Washington, DC.