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Résumé de l'article

Le déboisement résultant de divers travaux de génie liés à l'exploitation des champs de pétrole des collines Swan a provoqué un ravinement parfois intense dans des fossés de route, le long des tranchées de pipelines et des lignes de transmission ainsi que sur les sites de puits. L'étude d'un grand nombre de ces ravins dans des argiles ou schistes tendres a permis d'établir un nomogramme pour l'emplacement de barrages de contrôle d'érosion. En plus, l'étude indique une voie de recherche en vue de déterminer la résistance d'un matériel à l'érosion par l'eau courante.

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GULLY EROSION IN THE SWAN HILLS, ALBERTA

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ABSTRACT *Deforestation related to development work in the Swan Hills oilfield has resulted in gullying in road ditches, power lines and pipelines, right-of-ways and on well sites. The study of a large number of these gullies developed in clay and soft shale has made it possible to establish a nomograph to locate erosion control check dams. More importantly, the study suggests research avenues to determine the resistance of poorly consolidated material to erosion by running water.*

RÉSUMÉ *Le déboisement résultant de divers travaux de génie liés à l'exploitation des champs de pétrole des collines Swan a provoqué un ravinement parfois intense dans des fossés de route, le long des tranchées de pipelines et des lignes de transmission ainsi que sur les sites de puits. L'étude d'un grand nombre de ces ravins dans des argiles ou schistes tendres a permis d'établir un nomogramme pour l'emplacement de barrages de contrôle d'érosion. En plus, l'étude indique une voie de recherche en vue de déterminer la résistance d'un matériel à l'érosion par l'eau courante.*

ZUSAMMENFASSUNG *Zersehluchtunq erosion in den Swan Hügeln von Alberta, Kanada.* Abholzen im Zusammenhang mit Ingenieurarbeiten in den Ölfeldern der Swan Hügel hat zur Zerschluchtung von Strassengräben, Strom- und Rohrleitungsbreschen und sogar der Brunnensitze selbst geführt. Eine Erforschung zahlreicher dieser Schluchten, die sich in Lehm und weichem Schiefer entwickelten, hat es möglich gemacht ein Nomogramm herzustellen, das die Lokalisierung von Dämmen zur Erosionskontrolle erlaubt. Ausserdem weist diese Studie einen Weg zu weiterer Forschung, dem Widerstand von verhältnismässig losem Bodenmaterial gegen rinnendes Wasser zu bestimmen.

INTRODUCTION

The immediate cause of widespread erosion and locally intense gullying in the Swan Hills is related to the development of oil fields (ST-ONGE and LENGELLÉ, 1971; LENGELLÉ, 1976). The need to construct roads, well sites, battery stations, right-of-ways for pipelines and power lines, etc. has resulted in the deforestation of between 15% and 18% of the oil field region (LENGELLÉ, 1976, p. 1). The reasons for the rapidly developing gullying lie in the intricate relationships between slopes, surface material, bedrock and vegetation.

Hundreds of kilometres of dirt and gravel covered roads have been constructed since January 1957 when the discovery well of the Swan Hills oil field was brought in. The road network and associated ditches represent a system which has had 10 to 15 years to stabilize. It constitutes an excellent laboratory to evaluate the effectiveness of methods used to control erosion by running water in road ditches.

The removal of vegetation for the right-of-ways exposes soft bedrock which has a very slow revegetation rate (ST-ONGE, 1974; LENGELLÉ, 1976). Detailed surveys of a large number of road ditches show that gullies will develop wherever longitudinal slope exceeds 2°.

Numerous methods were attempted to control gully development, the more common one being: straw bales, plank or log weirs, poles, gabions and gravel pads. Experience made it rapidly obvious that the latter were by far the more effective system. As a result, hundreds of gravel pads were installed across road ditches throughout the various oil fields of the Swan Hills region.

This study concentrates on criteria which should be used to space gravel pads so that maximum efficiency is insured with a minimum number of check dams. The solution to this problem inevitably involves some consideration of the resistance of geologic materials to erosion.

GEOLOGY AND GEOMORPHOLOGY

The bedrock of the Swan Hills is composed of shale, poorly consolidated sandstone, coal seams, and bentonite beds (ALLAN, 1918; FENIAL, 1947). These poorly consolidated materials do not contain the necessary nutrients for plant growth, and, when exposed in the process of construction, revegetate very slowly, if at all.

The geomorphology of the Swan Hills has been described earlier and need not be reviewed (*e.g.* ST-ONGE, 1974; ST-ONGE and LENGELLÉ, 1971; LENGELLÉ, 1976). It is important to realize however that:

1) the slopes bordering the Swan Hills are markedly asymmetrical with a fairly gentle slope to the South and a much steeper slope to the North;
2) the thickness of Quaternary deposits varies from 3 metres or more on the South slope to 0.5 metre or less on the North slope (ST-ONGE, 1975).

GULLY EROSION

Detailed surveys of a large number of roadside gully systems was carried out on the north slope of the Swan Hills. In sum, a total of thirty-three gully systems were studied in 18 different sites. Using the unified soil classification system (TERZAGHI and PECK, 1967, p. 39), 17 are in fine grained soils (5 ML, 1 CL, 3 MH, and 8 CH) and 1 is a coarse grained soil (SM); on the soil classification chart, the results are as follows: 15 sites are in clay, 2 in silty clay loam and 1 in sandy loam.

Figure 1 illustrates part of the ditch on the east side of the Swan-Hills-Kinuso highway. The original ditch slope averaged 3°30′ in silty sands. In order to control gully development, gravel pads were spread at varying intervals across the ditch. Three of these are illustrated in Figure 1, a fourth is visible on a photograph of the same site (Fig. 2). In spite of the gravel pads, erosion has worked its way around the two middlepads, and a 66 cm deep gully has been carved (Fig. 3b). In addition, small tributary gullies have eroded backwards to the edge of the road and, unless rapidly controlled, may create problems that would be expensive to repair.

From this and many other sites in the area, the following observations can be made:

1) In road ditches with a longitudinal slope of 2° or more, gullies may develop;
2) If left unchecked, they can create serious damage to roads (ST-ONGE and LENGELLÉ, 1971; LENGELLÉ, 1976);
3) Gullying is a problem at the base of the road ditch and is either minor or non existent on the banks;
4) Gravel pads may be an effective method of control if properly installed and properly spaced;
5) The abundance of gravel on the plateau surface makes this material the best and cheapest with which to control gully development in this region.

GRAVEL PAD SPACING

If the most efficient and economic method of control is to be used, the gravel pad check dams must be properly installed. Experience shows that they should meet the following criteria: 1° a minimum centre thickness of 0.5 metre; 2° a minimum width of 1 metre; 3° the transverse shape should be such that both ends

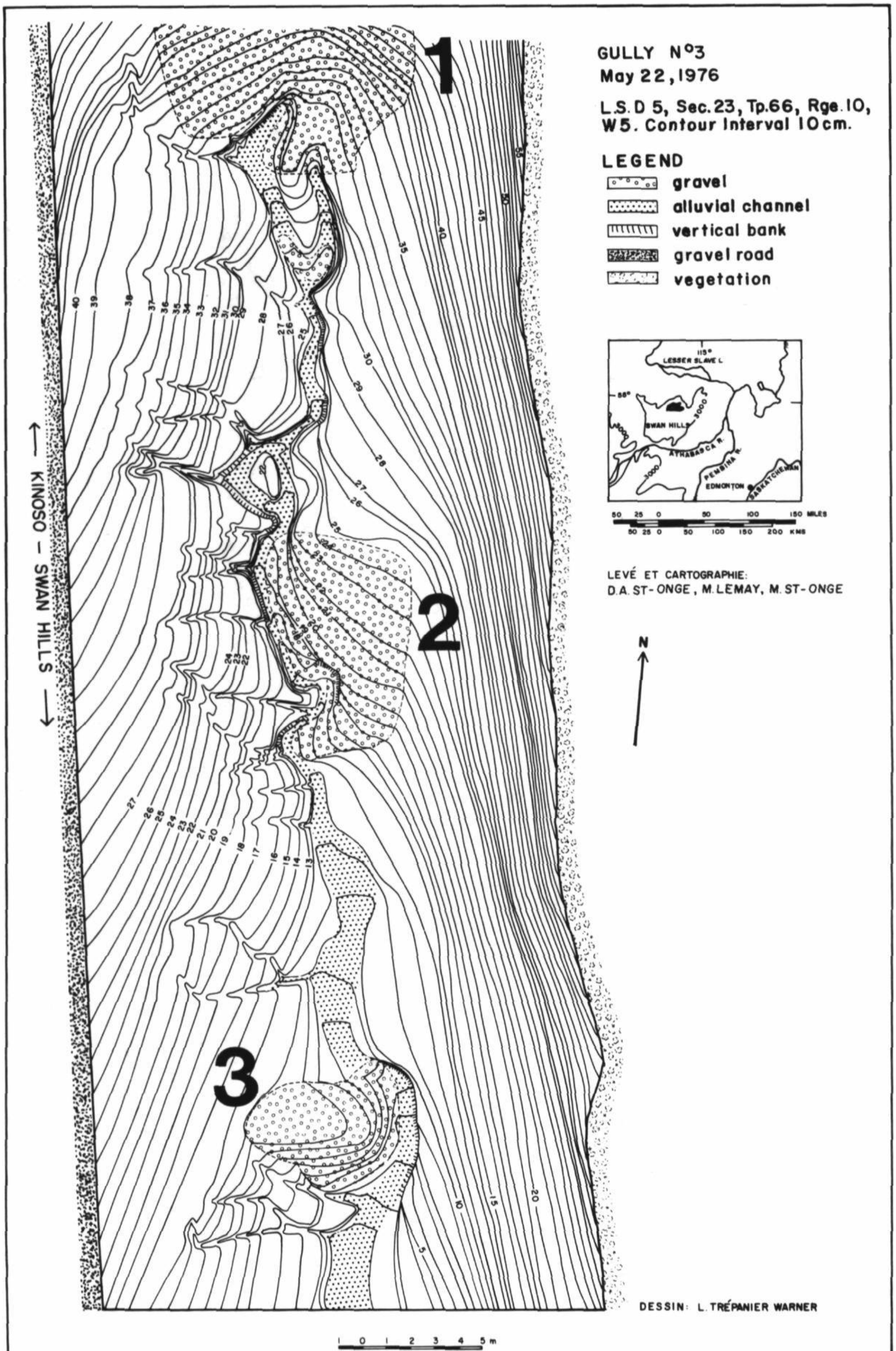

FIGURE 1. Detailed map of a section of the road ditch of the East side of the Swan Hills-Kinuso highway. Large numbers identify gravel pads (also visible on Fig. 2.)

Carte détaillée d'une section du fossé est de la route Swan Hills-Kinuso. Les gros chiffres indentifient les tas de gravier.

FIGURE 2. Section of road ditch mapped in Figure 1. Numbers identify gravel pads.

Photo du fossé de la figure 1. Les chiffres identifient les tas de gravier.

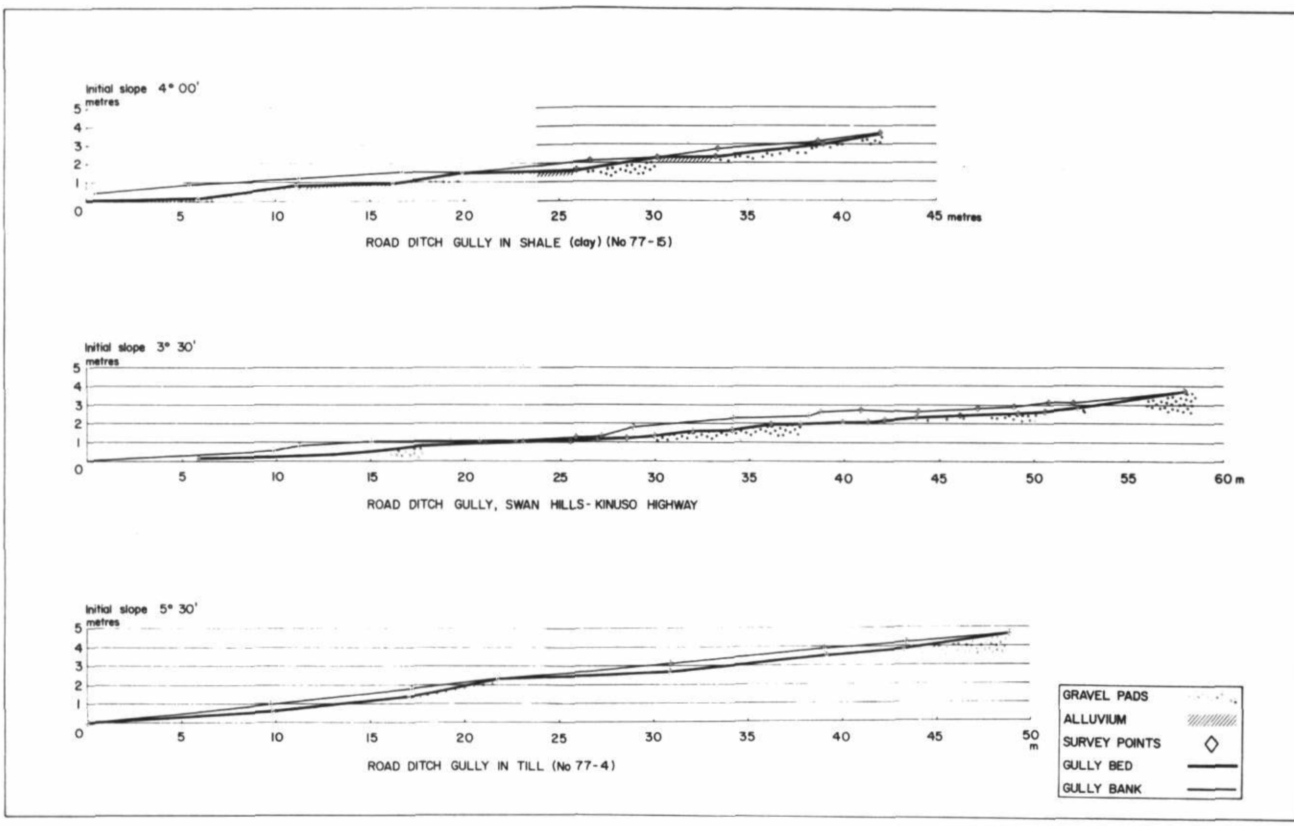

FIGURE 3. Longitudinal profiles along road ditch gullies indicating gravel pads and depth of incision. «Gully Bank» profile corresponds approximately to original ditch trough.

Profils longitudinaux de ravins de fossés de routes. Les barrages de gravier et les profondeurs de ravins sont indiqués. Le profil de la berge du ravin correspond à peu près au fond original du fossé.

must stand at least 0.3 metre above the central through. This avoids gullying around the pad as in Figure 1.

Spacing of the gravel pads is the next most obvious problem. One solution is to design pad spacings to "zero erosion" in which the top of the downslope pad is roughly at the same elevation as the base of the next upslope pad (Fig. 4a adapted from Fig. 7, Anonymous, 1976, p. 48). The geometry of such a design can be approximated by the following equation:

$$D = \frac{g}{\sin\alpha} \quad \text{----------} \quad (1)$$

where g = thickness of gravel pad (m)
D = distance between pads (m)
α = longitudinal ditch slope (°)

Solution to the above equation can be presented in a nomograph (Fig. 5) which is similar to the one proposed by HEEDE and MUFICK (1973, p. 324).

Such a system represents a maximum number of useful check dams and therefore a maximum cost. However an effective gully control system can be constructed with far fewer dams if the gravel pad spacing is designed to allow a certain amount of gullying in this road ditch. This value (I) represents the amount of incision which can take place in the bottom of a road ditch without triggering small slumps or side gullies. Empirical data for the gullies studied indicate that an incision of up to 50 cm between gravel pads creates no problems. Depending on the nature of the material, there are two possibilities:

a) the material is so easily erodible that the longitudinal bed profile will be very nearly horizontal (Fig. 3a and 4b).

Formula (1) then becomes:

$$D = \frac{g + I}{\sin\alpha} \quad \text{----------} \quad (2)$$

where I = tolerable depth of gully incision.

b) the material is resistant to erosion and the longitudinal profile of the gully bed will be steeper.

To attain a given value of "I", a greater reach (*i.e.* distance between gravel pads) is required (Fig. 3c and 4c).

A nomograph constructed from the 33 gully systems surveyed in detail (Fig. 6) allows for a far greater spacing than is the case with Figure 5, particularly if it is possible to design for a fairly important depth of incision. This would be the case, for instance, in soil with properties that would make rapid revegetation possible. The relatively widespread distribution of points on both sides of the original slope lines probably reflects the nature of the material or the presence of debris of all sorts in some of the ditches. Given the available data

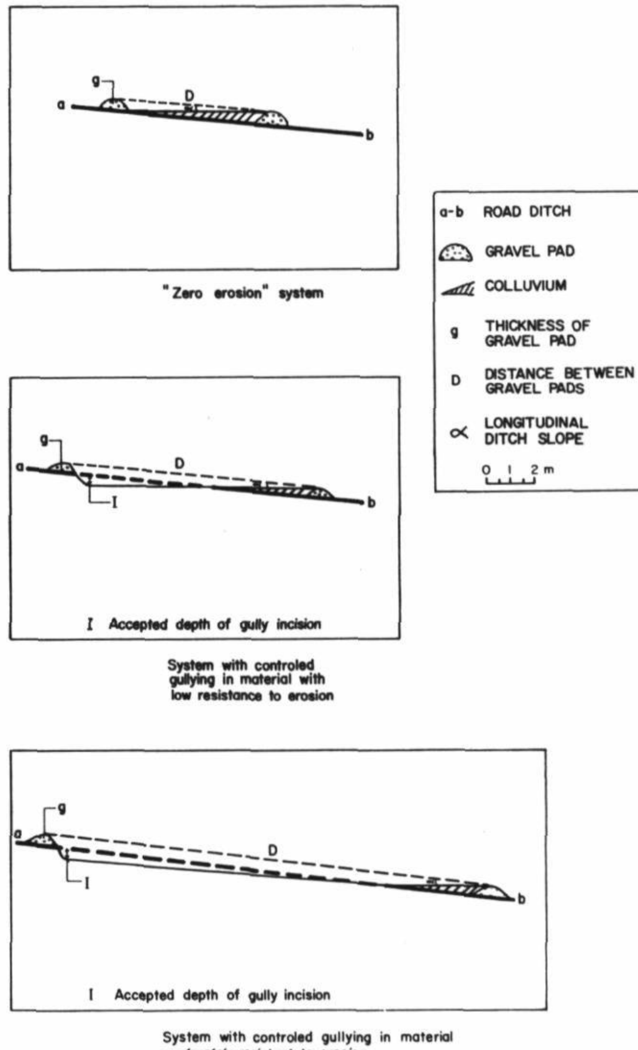

FIGURE 4. Amount of gully incision related to gravel pad spacing and to materials' resistance to erosion.

Importance du ravinement en relation avec l'espacement de barrages de gravier et avec la résistance du matériel à l'érosion.

the nomograph represents an excellent field tool which would allow a road engineer to determine rapidly the best spacing of gravel pads in road ditches excavated in a silt-clay material.

Obviously the "I" factor is going to vary with the nature of the material. A gully depth of a given value will develop rapidly on a short, gentle slope in very soft material but the same value will require more time, a longer reach and a steeper slope in more resistant material. In other words, the "resistance to erosion" of the material should be taken into consideration when attempting to control gullies. Although often used, either intuitively or empirically, there is no satisfactory

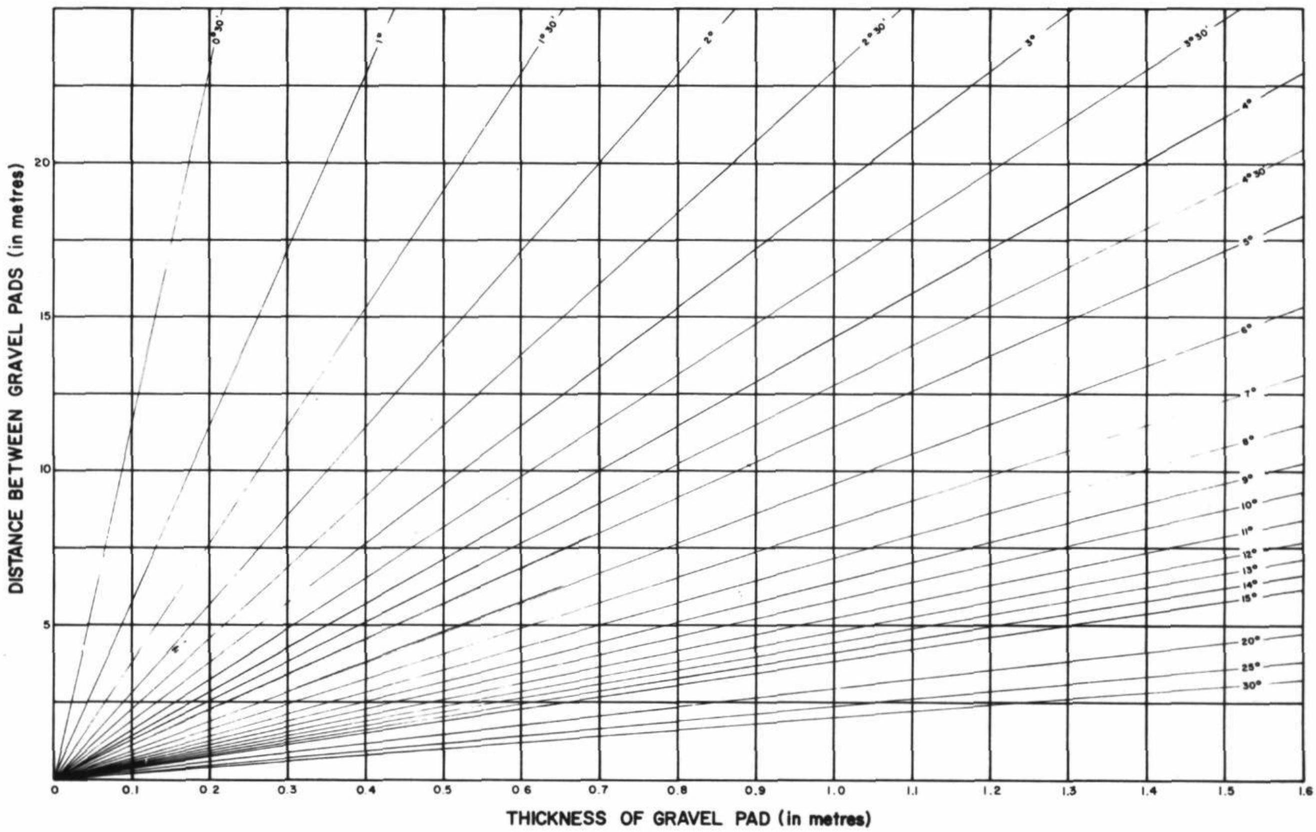

FIGURE 5. Nomograph indicating maximum spacing possible between gravel pads if «zero erosion» is a requirement. Thickness of gravel pad and initial longitudinal ditch slope combine to determine spacing.

Nomogramme qui indique la distance maximale possible entre les barrages de gravier si on veut empêcher tout ravinement. L'épaisseur du tas de gravier et la pente initiale déterminent l'espacement.

method for determining a material's resistance to erosion by running water.

The road engineers and "cat skinners" who have laid down the gravel pads in the road ditches of the Swan Hills during the past 15 years were instinctively spacing them according to the slope and to the material's resistance to erosion. In Figure 6, there is an empirical value related to the same factor built into the graph. If this concept is to be incorporated into the design of check dams in road ditches, a reliable method of defining the resistance factor must be determined.

ERODIBILITY FACTOR

Although the problems related to erosion by running water have preoccupied geomorphologists and other earth scientists for over a century, there is still no satisfactory method of defining the erodibility of a given geological material. This point is stressed in a report by a task committee of the American Society of Civil Engineers: «A great deal of research has been conducted into the basic aspects of scour resistance of cohesive sediments. Still, the properties which control erosion resistance of cohesive sediments have not been conclusively defined. The Task Committee considers that a major research effort must be undertaken to define those properties, whether chemical, physical, or environmental, that determine the resistance of a cohesive sediment to flowing water. The properties of these sediments which influence their ability to resist erosion need to be understood.» (MASH *et al.*, 1968, p. 1045). A more recent article suggests that progress is astonishingly slow in solving this very basic problem: «A generally applicable method of estimating the rate of soil loss on roadsides has not yet been developed. The main problem is that it is still not possible to classify the erodibility of a soil from a knowledge of its physical or chemical properties. One suspects that the relationship is so complex that when it is eventually better understood, it will be of little practical value to the highway engineer» (DUNN, 1975, p. 118).

The «Universal Soil Loss Equation» incorporates an erodibility factor «K» based on selected grain size

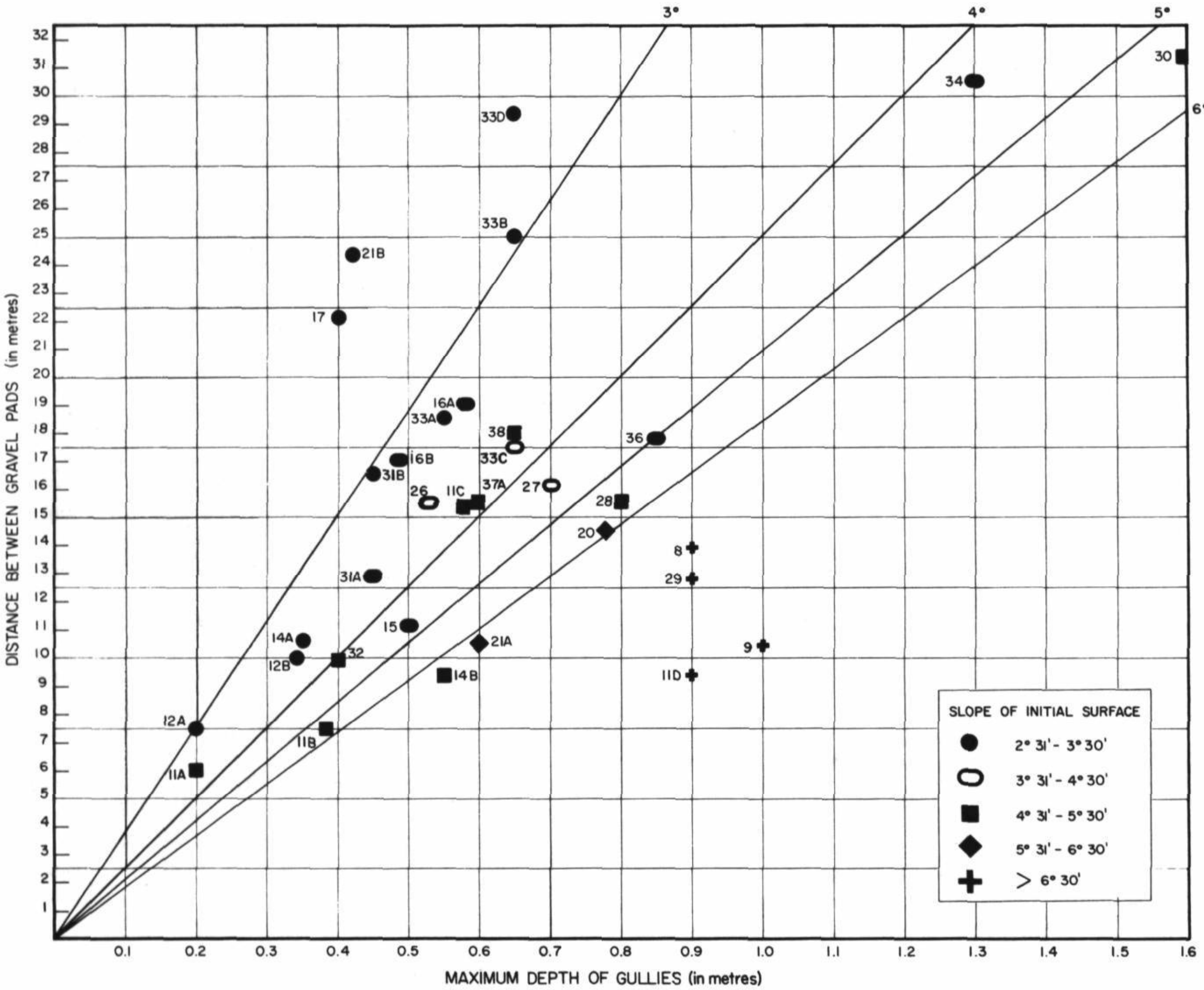

FIGURE 6. Nomograph relating distance between gravel pads to initial longitudinal ditch slope and an acceptable depth of gully incision.

Nomogramme qui met en rapport la distance entre les barrages, la pente longitudinale initiale du fossé et l'incision maximale tolérable.

properties, soil structure and soil permeability (WISCHMEIER, 1965, 1971, 1973, 1974 and 1976). The equation is designed to measure soil loss related to sheet wash not to gully erosion (WISCHMEIER, 1974, pp. 15-21).

The difficulty of dertemining an erodibility factor stems from attempts based on theoretical considerations with no clear indication of the relationship between the values or ratios obtained and the resulting gully form. This problem may be circumvented if the initial study is concerned with controlled gullies for which an erodibility factor is calculated. It would then be possible to determine which soil properties best define the observed erodibility.

In this study if the value of « D » as defined by formula 2 is compared to the actual distance between gravel pads, a ratio reflecting resistance to erosion is thus defined. The following example is taken from a ditch on the west side of a road located on the south-facing slope of a ridge between the Swan and Moose Horn Rivers (L.S.D. 11, Sec. 19, Tp. 67, Rge 10W5):

Initial slope: (α): 4°30′

Distance between pads (D): 19m

g + l: 0.906m

D (calculated with formula (2)): 11.55

Resistance factor $\frac{19}{11.55} = 1.65$

Formula (2) then becomes (3) $D = \frac{g + l}{\sin \alpha} \times Re$,
where Re = Resistance factor

As mentioned above all the surveyed sites except one are in fine-grained soils (inorganic silts and clays). Resistance factor values for these sites vary from a low of 1.04 to a maximum of 2.93 with an average of 1.67.

If these results from a relatively small sample can be accepted, a resistance factor (Re) of 1.7 can be used to determine the distance between check dams in areas where ditches are constructed in non fertile clays and silts. This covers large regions of Saskatchewan and Alberta.

Although a great deal more work needs to be done in order to determine a resistance factor, not from observed erosion forms, but from basic soil properties, formula (3) provides a very useful mean of spacing check dams to insure effective control at minimum cost.

CONCLUSION

The study of gullies developed in road ditches constructed in poorly consolidated bedrock has made it possible to determine a resistance to erosion factor. Using this factor in a formula which incorporates original slope values and a tolerated depth of gully incision, the spacing of check dams can be calculated so that effective control is insured with a minimum number of dams.

Present results suggest that it should be possible to determine a resistance to erosion factor that could be used in engineering practice. Previous studies (MASH *et al.*, 1968; DUNN, 1975) which stressed the complexity of the problem were largely based on theoretical considerations. In this study, it was possible to empirically define a resistance factor because of the large amount of field data available.

To expend this concept to other lithologic types, it would be necessary to define a resistance to erosion factor from soil properties rather than from actual gullies. This has not yet been done but this study indicates that it could be done by performing a series of standard tests on material in which gullies have developed and for which an empirical Re factor has been determined.

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