Geogr. Fis. Dinam. Quat.
30 (2007), 179-183, 1 fig., 4 tabb.

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GEOMORPHOLOGICAL IMPACT OF EROSION CONTROL MEASURES ON A STEEP COAL-SPOIL EMBANKMENT, PERNIK, BULGARIA

ABSTRACT: HAIGH M. & GENTCHEVA-KOSTADINOVA S., *Geomorphological Impact of Erosion Control Measures on a Steep Coal-Spoil Embankment, Pernik, Bulgaria*. (IT ISSN 1724-4757, 2007).

This geomorphological examination of the effects of two common erosion control strategies on a 17° coal-briquette spoil embankment at Pernik, Bulgaria, finds that while ground losses increase significantly with both slope length and slope angle, the forestation of an unvegetated slope significantly reduced inter-rill erosion (1.9 vs 7.0 mm yr^{-1}) where mechanical protection with contour wattles did not (6.2 vs 7.0 mm yr^{-1}). However, both treatments inhibited the development of rills and gullies. Over 6 years after the trees had been lopped to ground level and the wattles entirely removed, the depth of rill and gully incision remained significantly smaller on the sites that had been protected in previous times. However, despite the presence of roots in the spoil on the former forest site, there was no significant difference between rill development here and on the mechanically protected slope.

KEY WORDS: Erosion control, Contour wattles, Forestation, Pernik (Bulgaria).

INTRODUCTION

The reclamation of land mantled by coal-spoils involves converting a landscape of loose, infertile, usually toxic materials, geomorphologically unstable landforms into stable, sustainable, ideally self-sustaining, landscapes (Haigh, 2000). Despite recent advances in applied physical geography and environmental technology, no-one really knows how to reconstruct the new soils, new hillslopes, and new watercourses into new landscapes that can function effectively without further human intervention. This is the reason that so many «reclaimed» lands and engineered landscapes across Europe degrade rapidly once regular repair and maintenance is neglected (Haigh, 1993).

In 1999, the area affected by coal-mining in Bulgaria was said to exceed 200 km^2, with less than 10% being recultivated, rising from 160 km^2, including 127 km^2 not yet reclaimed in 1993 (McConville & *alii*, 1999; Malakov, 1993). However, the reclaimed area is set to increase following Bulgaria's accession to the European Union. Pernik was singled out for EU-PHARE pre-accession investment in regeneration.

Traditionally, Bulgaria's reclamation of coal spoils has involved the creation of terraces with steep, ideally forested, embankments separating agricultural benches (Haigh & *alii*, 1995). These steeply sloping embankments of reclaimed coal-spoils are vulnerable to erosion by sheet and gully processes, which risks spreading acid and toxic materials into the wider environment. Hence, erosion control is of special interest. In fact, erosion control is a serious issue across Bulgaria for, while rainfall erosivity may be low to moderate (RUSLE: R-factors 48-130), 80% of agricultural land suffers water erosion damage and near 60% of «low productivity» lands are «severely degraded» (Onchev, 1988; Onchev & Kolchakov, 1988; Onchev & Minev, 1988).

This paper examines the geomorphological effects of two common erosion control strategies on a steep coal-spoil embankment in the brown-coal mining area of Pernik. Here, cinder spoils that remain from coal briquette manufacturing are formed into a standard engineering landform, a road embankment on the margins of Pernik city. After initial failure to establish ground surface vegetation on this embankment, adjacent sections were treated with contour wattles, representing mechanical control, and forestation, representing biological control. This study concerns the interaction between the erosion control technology, topographic position, time and the development of gully erosion. The findings emerge from larger studies aimed at achieving the self-sustaining regeneration of soils on coal mine spoils (Filcheva & *alii*, 2000; Haigh, 2000).

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TEST SITE DESCRIPTION

Pernik, 30 km southwest of Sofia, is a traditional industrial and coal mining area, which has large tracts of land mantled by various categories of coal spoil. It has a long history as a reclamation pioneer (Ivanov, 1973). However, large tracts remain that await reclamation and the degraded appearance of these wastelands inhibits inward investment and economic regeneration. Among the most obtrusive of the problem lands is a badly eroded complex of pre-1975 coal-briquette manufacturing tailings on the city margin. These spoils are low in fertility and, despite containing low specific gravity materials such as coal cinders, have relatively high density at depth (tables 1, 2 and Gentcheva-Kostadinova & *alii*, 1994).

TABLE 1 - Site description: climate, hydrology, soils

- Location: Bulgaria, Pernik, (42° 36'N, 23° 03'E).
- Site: Road embankment: 15-20° slope by up to 50-m length.
- Geology: Spoil from a coal-briquette processing plant, mainly low-density coal cinders formed from medium quality brown coals, admixed with some coal shale and marls.
- Bulk density of spoils: (0-40 cm depth) 0.97-1.43 g.cm3. Total porosity: 64%.
- Field capacity: 48 mm.m^2, maximum available water capacity: 40 mm.m^2, wilting coefficient 7 mm.m^2, hydroscopic capacity: 6 mm.m^2; all calculated for the depth of 1metre and the growing period April-September. The moisture in the layer 0-20 cm is counted «dead reserve» i.e. plant unavailable.
- Precipitation 550-650 mm/a^{-1}; maximum rainfall - May and June (together 148 mm) minimum - August and September (together 73 mm).
- Temperature: mean annual air temperature is 8-10°, but soil surface temperatures on south facing (TB170°) spoils can reaching 50°-70° in summer (Donov & *alii*, 1978).
- A special feature is that the site straddles an environmental threshold for the re-establishment of vegetation - it can support trees but not ground vegetation due to adverse microclimate, poor soil structure and fertility. Planted trees survive because there is free soil moisture at depths >1 m into the spoils.

TABLE 2 - Chemical characteristics of briquette spoils, Pernik

	Depth (cm)	pH	pH (KCl)	C%	N%	P%	K%	Ca%
Control plot	00-05	2.44	2.20	6.21	0.40	0.05	0.95	0.51
	05-10	2.55	2.30	5.81	0.40	0.05	0.94	0.41
	10-50	2.43	2.20	8.34	0.42	0.05	0.84	0.44
Forest plot	00-05	4.03	3.22	7.54	0.40	0.06	0.92	0.32
	05-10	3.20	2.70	8.02	0.40	0.05	1.00	0.61
	10-50	2.95	2.51	8.02	0.32	0.19	0.91	1.94

In table 2, high levels of carbon on the control site reflect the presence of mineral carbon in coal. Its depletion in the surface layer may reflect a selective removal of low density materials by surface wash. The low pH of the forest site may reflect a moderating effect of the trees (Filcheva & *alii*, 2000). However, elevated calcium records in the root zone under forest may also have something to do lime applied during planting, but there are no records.

Several factors have prevented the establishment of herbaceous vegetation: microclimate, spoil characteristics and, until recently, an absence of human interference. At Pernik, most rain falls in May (71 mm/a) and June (77 mm/a) while the driest months are August (39 mm) and September (34 mm). In the warmest months, July and August, average air temperatures at Pernik exceed 19 °C and dark coloured soil surfaces may suffer severe overheating with those on the briquette spoils embankment (2.5YR 3/2-2.5/0) reaching 50 °C, and exceptionally 70 °C. The spoils can have a high total porosity of 64% but their fine texture and poor aggregation allow little capillary rise. Between April and September, there is virtually no plant available moisture in the 0-20 cm layer, but at 40-50 cm, the spoils may be moist and at 60-80 cm, there may be free moisture. Deep rooting trees survive by exploiting these reserves where surface vegetation dies.

EXPERIMENT DESIGN AND TECHNIQUE

This field study involved setting out three plots on three adjacent slope segments (angle: 17° sd.7.6) of the same unvegetated, south facing, embankment. In 1978-1979, the test slope was part-forested with *Betula pendula* on the embankment and some *Pinus nigra* at the crest. The three monitoring zones, set up 10-years later, differ only in that while one (the control) had received no treatment, a second had been planted to trees and the third defended with contour wattles (Haigh & Gentcheva-Kostadinova, 2002).

Erosion pins were set into three slope profiles on each test plot. On the control and forested slope, pins were located at 5-m intervals from slope crest to slope foot. On the wattle protected slope, pins were located at 1-m intervals on a single mid-slope terrace between two contour wattles. Erosion pins are thin metal rods driven deep into the soil to the point where they cannot be moved by either frost or trampling. A small length of each pin is left exposed above the surface and this exposed head is counted a fixed benchmark. Changes in its exposure (mm) are counted changes in ground surface elevation (Haigh, 1977). These may be due to erosion, deposition or changes in soil packing around the erosion pin. Pin exposure will increase if the soil is removed or compacted and decrease if soil is deposited around the pin or if there is loosening through frost action. The pins also provide fixed reference points for other records. So, leaf litter cover and evidence of trafficking was collected for a metre square about each pin. In addition, rill incision was recorded whenever a rill passed within 0.5-m of a pin. Rill depth was recorded by placing a flat board across the rill and measuring its depth, the distance from the base of the board to the deepest point in the rill (cm).

Monitoring started on September 9th, 1988, with a plan to collect data annually each September, and whenever possible in April. Unfortunately, in the turbulent times since 1988, two September records were lost, one through theft from a field vehicle and another through access problems. These are replaced with records from April visits. Ultimately, the erosion-pin project was cut short by the complete destruction of the experimental plots. In the hard winter of 1994/5, the trees were cut to ground level, the wattles taken for firewood and the pins pulled out by scavengers.

However, the project continued and a morphometric survey was undertaken in May 2001. This collected records of rill incision measured along the former erosion pin rows on three parts of each slope, the convex upper third, the steep linear central third, and the concave lower third. The survey proceeded by recording the deepest incision (cm) in each metre of a survey line stretched across the contour on sites of the former test plots. The aim was to discover if the remains of the trees or the former presence of the wattles had any long-term geomorphological effects.

RESULTS

Some 85% of the erosion pins survived from 1988-1994. Crude averages indicate mean annual increases in the erosion pin exposure of 5.86 mm (sd 5.89) overall, 6.91mm (sd 6.14) on the control plot, 7.29 mm (sd 6.13) on the terrace, and 2.50 mm (sd 3.55) in the forest. Erosion pins disappeared from different parts of each plot but especially the slope-foot of the forested plot. Additionally, the sample wattle terrace is mid-slope where, on the control plot, ground loss rates are maximal. So, these raw results distort the effects of both contour wattles and forestation.

This problem is overcome by comparing ground loss rates on data standardised by slope angle. In 1994, the average slope at each surviving pin was 17.9 degrees (sd 7.62) (32.6%, sd 14.8) so, here, comparisons are based on data from pins on slopes that lie within one standard deviation of this site mean, (i.e. 18° +/– 8) (Haigh & Gentcheva-Kostadinova, 2002). These corrected results confirm that inter-rill ground losses on the wattle-protected slope differ little from those on the control plot (table 3).

TABLE 3 - Corrected erosion pin results - losses of surface elevation (mm yr^{-1})

Test Plot	**Mean Annual Ground Loss (mm)** (+/– Standard Error of the Mean (Sample n=))	Range (Max : Min)
Control	7.01 +/– 0.93 (n = 360)	23.17 (21.67: –1.50)
Sample Terrace	6.17 +/– 1.26 (n = 214)	21.83 (18.67: –3.17)
Forest	1.86 +/– 0.61 (n = 204)	10.83 (07.67: –3.33)

T-test comparison confirms that there is a significant difference between mean annual ground loss on the control and forest plot (p<0.0005; 7.01 vs 1.86 mm yr^{-1}, ratio: 3.77:1) and on the forest and terrace plot (p=0.004; 6.17 vs 1.86 mm yr^{-1}, ratio: 3.32:1) but no significant difference between the control and terrace plots (p=0.59). In sum, forestation significantly reduces inter-rill ground losses but slope protection by contour wattles makes no significant difference.

On table 4, correlation analysis on ancillary variable on the six complete slope transects, forest and control, finds that ground loss increases significantly with slope angle and distance from the slope crest on both profiles. It is correlated with rill incision on the control plot and with trafficking on the forest plot. Here, there is a close relation with the negative correlation between surface leaf litter and ground loss.

TABLE 4 - Correlations between mean annual ground loss and test-plot parameters

Variable	Forest	Control
Slope angle (degrees)	0.518 (p=0.001)	0.541 (p<0.0005)
Distance from slope crest (m)	0.608 (p<0.0005)	0.347 (p=0.003)
Rill incision	No rill incision	0.406 (p=0.001)
Trafficking	0.361 (p=0.015)	0.138 NS
Litter Cover %	–0.553 (p<0.0005)	No litter cover

However, in 1994, 31% of the pins had rills within 0.5m. The average depth of the deepest rill incision within 0.5 metres of each pin on the control plots was 121.8 mm (sd 255.0; max 1100 mm, min 0 mm) and on the sample terrace plot: 34.1 mm (sd. 49.3; max 140 mm, min 0 mm). Independent sample T-tests finds that this difference is highly significant (p>0.0005). There were no rills recorded on the forested plot. This result differs significantly from those in the two other tests (p>0.0005).

Spearman rank correlation tests find that, on the untreated control plot rill incision is positively and significantly associated with slope angle (*rho*: 0.579, p<0.0005) and with distance from the slope crest (*rho*: 0.586, p< 0.0005) but negatively associated with inter-rill ground loss (erosion) (*rho*: –0.467, p<0.0005). This negative correlation reflects the concentration of runoff in rill channels and consequent reduction of wash-erosion on inter-rill areas. There were no significant correlations between rill incision and any of these three variables on the terrace sample plot, although the negative correlation with mean annual erosion came close (*rho:* –0.267, p=0.58).

When, in 1995, the test plots were cleared of trees and wattles, the impact of the erosion control treatments became clearly visible. The wattle-protected areas showed significantly less rill incision than the unprotected control plot and, in this respect, more resembled the forest-protected plot. The final question was - would this situation persist now that the erosion control protection was removed? In September 2001, a detailed survey of rill and gully development on the three inter-rill test areas recorded the deepest incision in each metre of a survey line stretched across the contour on the upper, mid and lower slopes of the site.

In t-tests, it was found that there remained significant differences between the rill incision recorded on the control compared to that on the forest (t: –4.48, p<0.0005) and terrace protected slopes (t: –4.79, p<0.0005). The differences between the forest and terraced plot were not significant. There was, however, a weakly significant positive correlation between the rill incision records on these two slopes (rho: 0.31, p=0.43).

Figure 1 displays the pattern of rill development in 2001; six years after the erosion control structures were destroyed. The graph shows the average maximum per metre incision at three slope locations – a quarter of the distance from the crest on the slope's upper convexity, at the mid-slope, and three quarters of the distance down slope on the slope's lower concave region.

Rills are now recorded on all three slopes and, in all cases, the depth of rill incision increases down slope (cf. Govindaraju & Kavvas, 1992). Further, the amount of incision is around three times greater three quarters of the way down slope than it is one quarter of the way down slope. However, at each three stations, the amount of rill incision on the control slope remains more than four times greater than that on the other two. Indeed, the mean depth of the maximum rill in each metre on the lower control slope (49 cm) is almost 14 times that of the rill incision on the upper quarter of the forest and terrace slope (3.5 cm). Average rill incision on the three slopes is forest: 6.6 cm, terrace: 8.0 cm and control 33.0 cm.

DISCUSSION

Rill and gully formation often occurs very rapidly, within weeks of land disturbance on newly constructed embankments. Of course, it is well known that the erodibility of disturbed land is greatest immediately after disturbance and declines thereafter (Hudson, 1992). However, examined in 2001, >6 years after the destruction of their erosion control works, the formerly protected plots remain clearly visible. Trees and wattles may be gone but rill activity remains minor compared to the control plot. Several factors may slow the development of these rills, which include settlement, changes in packing density or aggregate stability, surface armouring by crusting, the selective removal of fines and/or the development of a coarse surface layer, the development of soil fissures and macropores that facilitate drainage, as well as increasing human disturbance (cf. Poesen & *alii*, 1999; Guebert & Gardner, 2001; Kilmartin, 2000). Since many of these changes could accelerate gully formation, it is likely that increased runoff infiltration through macropores is the key. However, the textbook notion that tree root systems, which remain in the spoil even after the felling of the trees on the forest plot, contribute to gully suppression must be discounted. There is no significant difference in the degree of rill development on the forest and wattle-protected plot, which never had vegetation.

In time, most rill and gully systems stabilise (Sidorchuk, 1999; Harvey, 1992). Often, gully expansion trends on a new embankment may be conceived as a logistic growth process. The pattern may be masked in the short term by sporadic cut and fill sequences but, on average, there is a phase of rapid proportional growth followed by a long period of decelerating expansion toward stability. It could be that changes in the soil have slowed down gully growth and expansion. Equally, since gullies tend to proportional growth and that this occurs during high intensity, low frequency events, that the situation in 2001 represents a developmental phase and that, ultimately, there will be a convergence in the gully dimensions of the test and control slopes. However, the possibility remains that the temporary suppression of erosion has made a permanent difference to the degree of gully development, even in the absence of vegetation.

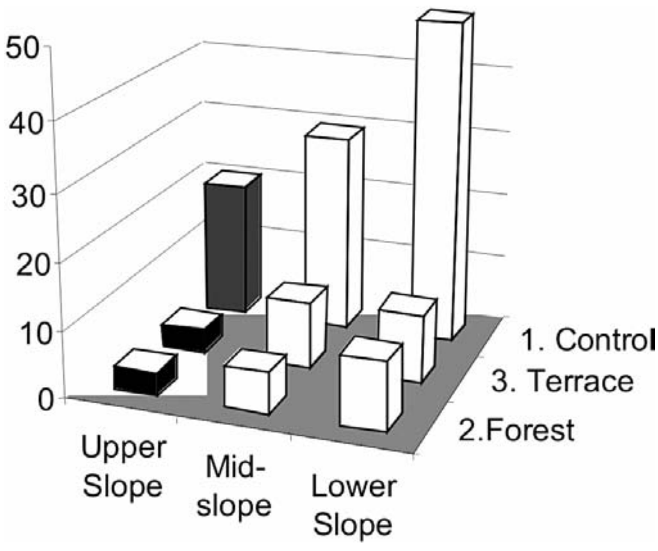

FIG. 1 - Maximum rill incision (cm per m): Pernik 2001.

CONCLUSION

This study has examined three test plots established on a single, steeply sloping (ca.17°), 30-50 m long, south-facing road embankment, which has been constructed from coal-briquette manufacturing spoils on the edge of Pernik, Bulgaria. Due to the poor water holding capacity of the spoil's surface layers and the water stress that develops on these dark coloured spoils during the summer, the site supports no ground surface vegetation. Trees survive because there is plant-available water at depth. In 1978, different areas of this spoil embankment were treated with erosion control works. Part was planted to trees, mainly *Betula pendula*, and part was protected with contour wattles. For six years between 1988 and 1994, inter-rill and rill erosion was compared on three test plot areas. Results from 1994 show that interrill erosion increases with slope angle, distance from the slope crest and the presence of rills and decreases with the surface cover of leaf litter, where this is not disturbed by trafficking. In addition, it was found that while forestation reduced inter-rill soil losses compared to the control plot, mechanical protection with wattles had little effect.

However, both wattles and forestation suppressed the development of surface flow pathways; rills were entirely absent from the forest plot and significantly smaller on the wattle protected plot than on the control area. The wattles and tree were destroyed in 1995/96. In 2001, the team resurveyed the site and found that, while there was now rill development on both the former forest and wattle protected plots, the amount remained very significantly smaller than that on the control plot but there was no significant difference between rill development on the wattle protected or forest plot, showing that the effects or roots remaining in the soil on rilling were minor. However, the study proved that the effects of a temporary suppression of gully erosion, by forestation and mechanical protection with contour wattles, persisted >6 years after the removal of the erosion control structures, even in the absence of surface stabilisation by vegetation.

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(Ms. received 10 February 2007; accepted 30 November 2007)