# RATES OF EROSION IN THE CATCHMENT AREA OF CROPSTON RESERVOIR, CHARNWOOD FOREST, LEICESTERSHIRE

by

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## Summary

The annual load of sediment being transported along Bradgate Brook and deposited in Cropston Reservoir is 7,600 cubic feet (200 $m^3$). The immediate source of this sediment is stream bank erosion along the course of Bradgate Brook and its tributaries. Measurements along these streams led to an estimate of the total area of stream banks undergoing erosion and, from this, the mean annual rate of recession of all eroding stream banks was calculated and found to be 1.2 inches (30 mm). A special study was made of the large cliff of Keuper Marl in Bradgate Park. Here the mean annual rate of recession was found, by direct measurement, to be 1.0 inches (25 mm).

## Introduction

During a recent study of the sediments in Cropston Reservoir (Cummins and Potter, 1967), it was found that the mean annual rate of erosion of the catchment area was about 7,600 cubic feet (200 $m^3$). Averaging this loss over the whole area would mean a general lowering of the surface by about 0.0005 inches (0.006mm) per year. In fact, of course, the erosion is not spread equally over the area but, as far as the immediate source of the sediment is concerned, it is localised along the course of Bradgate Brook, the stream supplying the water for the reservoir.

Erosion along Bradgate Brook is lateral and occurs along the banks, generally round the outside of meanders (see Cummins and Rundle, 1969, fig.3). There is no evidence that the bed of the stream is being eroded and the banks are generally low, cut into the alluvial deposits of the flood plain. Exceptionally, the stream cuts into solid rock along the edge of the flood plain.

The investigation of erosion along Bradgate Brook is recorded here in two parts. In the first part, an attempt is made to estimate the rate of erosion of the large cliff of Keuper Marl (SK 532099) situated between the settling ponds and the reservoir in Bradgate Park (Cummins, 1969, fig.1). In the second part an estimate is made of the total area of stream banks undergoing erosion along the streams flowing into the reservoir.

## The Keuper Marl Cliff

The cliff, about 200 feet (60 m) long at the base, has a surface area of about 8,000 square feet (740 $m^2$). The cliff face is composite and can be divided into several zones composed of different materials, each with a characteristic slope (figs. 1 and 3). These are detailed below, starting at the top of the cliff.

The top soil is somewhat pebbly and forms a small cliff due to the binding action of the overlying turf. The mean slope of this zone is 73° (range 55° - 90°).

The weathered Keuper Marl is soft and crumbly, and forms a slope rather than a cliff. The slope may be fairly uniform (*e.g.* fig.1, profiles 7, 12, 15), or it may consist of an upper gentle slope and a lower steeper slope (*e.g.* fig.1, profiles 10, 17, 18). Where the slope is

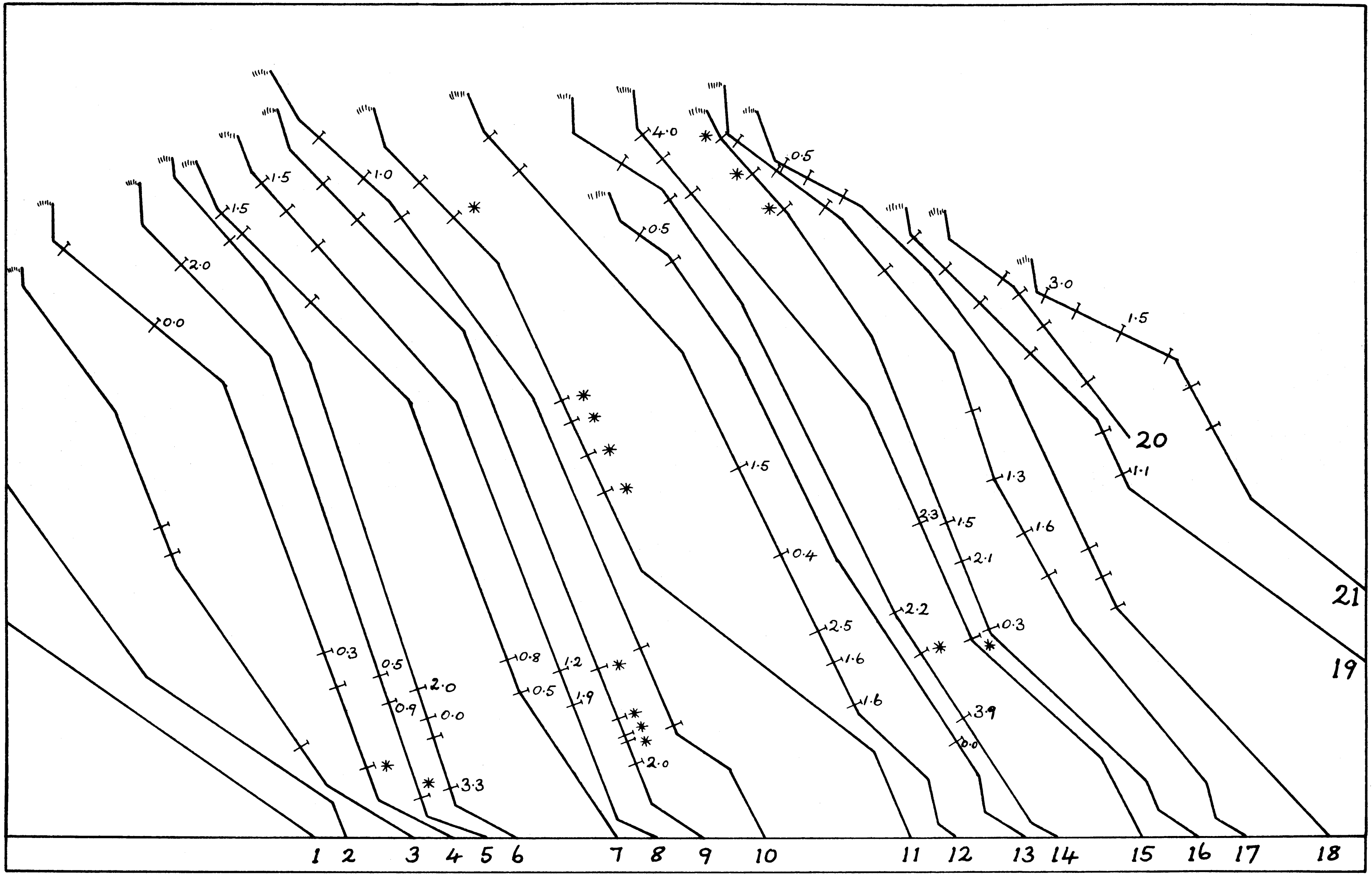

Figure 1. Profiles of the Keuper Marl cliff in Bradgate Park, as measured on the 17th and 19th January 1967 (profile 20 is cut short at the bottom of a gully which runs down the cliff at this point). The profiles are numbered from west to east. The positions of all the nails are shown, together with the measurements (in inches) made on them on the 16th January 1969. Nails lost in areas of obvious recent erosion are marked with an asterisk.

uniform, the mean slope is 46° (range 40° - 50°). Where the break in slope is present, the mean slope above it is 37° (range 26° - 50°) and the mean slope below it is 54½ (range 51° - 57°).

The fresh Keuper Marl forms the main part of the cliff, with a mean slope of 66° (range 58° - 72°).

The scree piled up at the foot of the cliff consists of the accumulated denudation products of the overlying zones. The mean slope of this zone which, unlike the others, has a depositional surface, is 38½° (range 25° - 55°).

The scree cliff is the result of stream erosion cutting into the scree deposits during periods of high water. This zone has a mean slope of 68° (range 62° - 80°). A further deposit of scree material may accumulate at the foot of the scree cliff. Examples of the scree cliff, with or without a lower scree deposit, may be seen in profiles 10 to 17 (fig. 1).

The rapid erosion of the cliff is indicated by the lack of perennial vegetation. The surface of the cliff is bare but for a few scattered annual plants such as willow herb. The soft, weathered Keuper Marl is easily eroded and is washed down over the edge of the cliff in little runnels with every shower of rain. The fresh rock below is worn back by alternate wetting and drying, and freezing and thawing. The debris accumulates in the scree at the foot of the cliff. The amount of sediment being removed by stream erosion at low water is negligible and so scree growth continues through most of the year. During floods, however, the stream erodes the scree in vast quantities, sometimes removing it completely and exposing the fresh cliff face.

## The measurements

One method of measuring the rate of erosion of the cliff would be to measure the amount of sediment being carried by the stream above and below the cliff, and take the difference. To do this adequately would have meant setting up automatic sampling apparatus in the stream above and below the cliff. We decided against this method because we felt (from experience in much less accessible sites) that such apparatus in a public park was almost certain to be interfered with.

The other approach is to make direct observations on the cliff itself. The method we finally adopted was suggested to one of us by a student, Miss S. Rutter, during a discussion of the problem in the Geology Department, Nottingham University. In essence, it consists of hammering nails into the cliff face and returning at a later date to measure the length of nail exposed.

On the 17th and 19th January 1967 we measured twenty two profiles of the cliff from stout wooden pegs hammered in at 12 foot (4.2 m) intervals along the cliff top. Along these profiles we hammered in a hundred 6 inch (152 mm) nails, forty eight in the weathered Keuper Marl of the upper (slope) zone of the cliff, and fifty two in the solid rock of the main cliff face. The distribution of these nails (fig.1) was controlled partly by accessibility and partly (on the main cliff face) by the difficulty of finding a place where a nail could be hammered in securely without causing the erosion it was intended to measure.

We had intended to return a year later but, owing to the restrictions on access during the epidemic of foot and mouth disease, we were unable to do this. We therefore postponed our return until two years had elapsed, and made our measurements on the 16th January 1969. By this time, the wooden pegs had long since disappeared, but the holes in which they had stood were easily found. After careful searching, we were able to find and measure only ten out of the forty eight nails in the upper weathered zone, and twenty six out of the original fifty two in the main cliff face. The measurements are shown against the profiles (fig. 1).

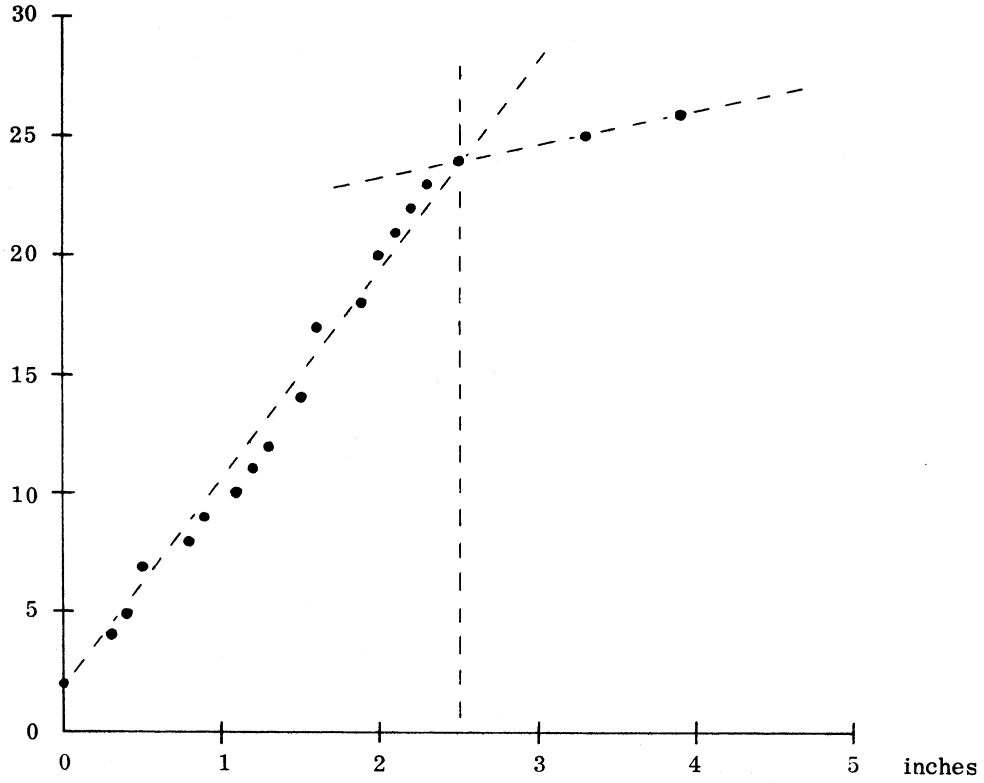

Figure 2. Cumulative curve showing the frequency distribution of exposed lengths of nails in the main cliff zone (see figs. 1 and 3) after two years erosion.

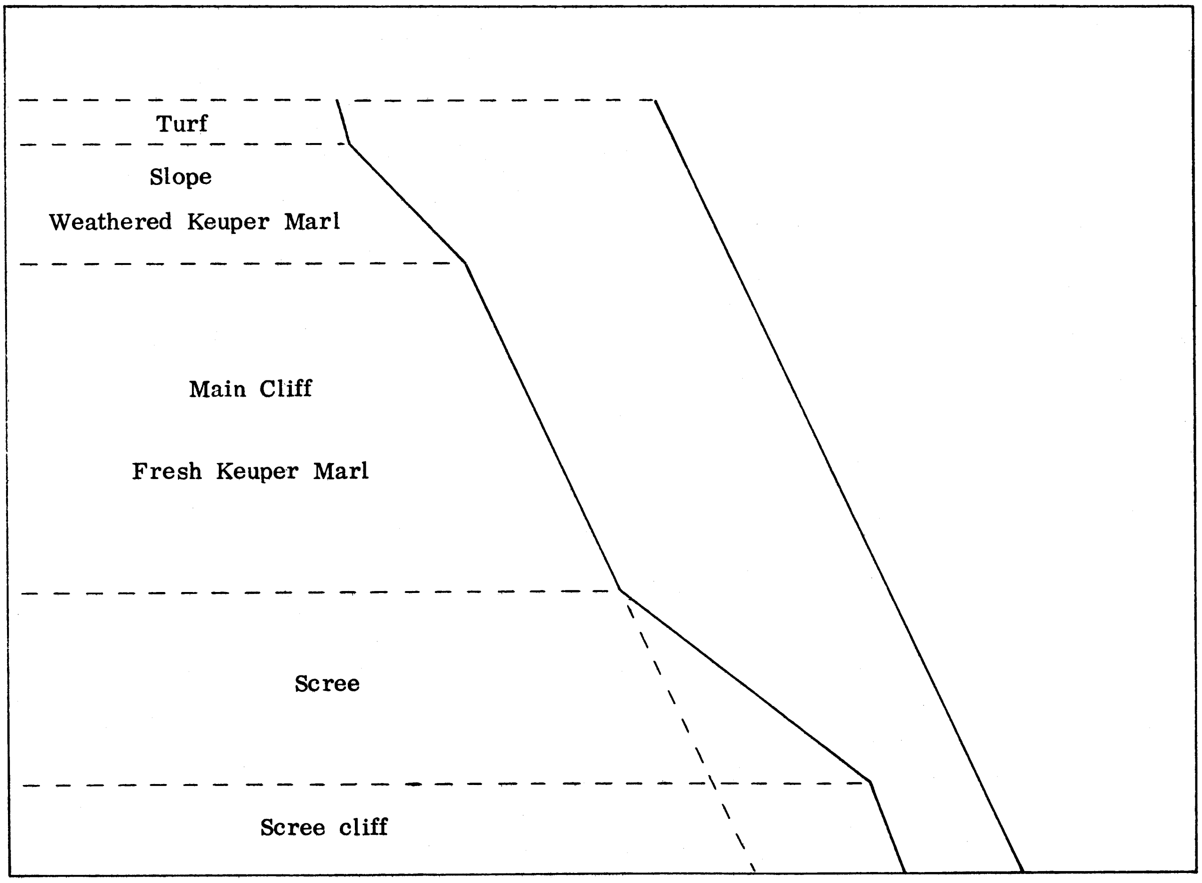

Figure 3. Profile No. 11 of the Keuper Marl cliff (see fig. 1) with the several zones of the cliff named. The model profile, used in calculating the volume of sediment removed from the cliff (p.153), is shown to the right of the measured profile.

## Rate of Erosion

The rate of erosion of the weathered upper zone of the cliff is impossible to determine with any degree of certainty from the results obtained. The mean exposed length of the ten nails measured was 1.55 inches (40 mm), which would represent a rate of erosion of 0.775 inches (20mm) per annum. Of the remaining thirty eight nails, one was found lying on the surface and three had clearly been washed away in a newly eroded gully. Thirty four, nearly three quarters of the total, could not be accounted for. Some may have been covered by material washed down from above; some may have been washed out of position or disturbed by the deer, which often scramble over this part of the cliff; and some we may simply have failed to re-locate.

In the main cliff of fresh rock, the results were rather better. The mean exposed length of the twenty six nails measured was 1.44 inches (37 mm), which would represent a rate of erosion of 0.72 inches (18.5 mm) per annum. Of the remaining twenty six nails, seventeen were lost in parts of the cliff showing obvious signs of recent erosion. Only nine remain unaccounted for. The frequency distribution of the twenty six measurements from the main cliff have been plotted on a cumulative curve (fig.2). It can be seen from these plots that measurements are evenly distributed through the range 0 to 2.5 inches (63 mm) and that, furthermore, measurements over 2.5 inches (63 mm) are quite exceptional. From these observations it can be inferred that nails with over 2.5 inches exposed by erosion are generally unstable and liable to be loosened and fall out. This provides some basis for assessing the value of the lost nails.

The mean annual rate of erosion of the main cliff can now be calculated on a variety of assumptions about the value of the twenty six lost nails. The first assumption is that the nine nails, which are unaccounted for, would have shown no erosion and the seventeen, lost in areas of new erosion, would have shown between 2.5 inches (63 mm) and 4.0 inches (102 mm) erosion. On this assumption, the mean rate of erosion of the cliff would be 0.89 inches (23 mm) per annum. The second assumption is that all twenty six lost nails would have shown between 2.5 and 4.0 inches erosion. On this assumption, the mean rate of erosion would be 1.17 inches (30 mm) per annum. The third assumption is that all fifty two nails would have shown measurements evenly distributed through the range from 0 to 4.0 inches. On this assumption, the mean rate of erosion would be 1.0 inches (25 mm) per annum. It is of course possible that some of the lost nails would have shown more than 4.0 inches erosion, since this upper limit is merely the greatest measurement made on any of the nails which remained in position. In this case, the mean rate of erosion, on all three assumptions, would be slightly raised.

From the above discussion, a round figure of 1.0 inches (25 mm) would seem to be a fair estimate of the mean annual rate of erosion of the main cliff of fresh Keuper Marl. This, of course, controls the rate of recession of the upper, weathered zone and, thus, the rate of erosion of the whole cliff. For the purpose of calculation, a model cliff is used, which has the height of the real cliff, but the slope of the main cliff zone, uniformly from top to bottom. The mean annual rate of erosion of 1.0 inches for the main cliff zone can be applied to the whole surface of the model cliff, to calculate the volume of material removed annually from the real cliff (fig.3). The annual volume of detritus removed from the cliff is found to be about 560 cubic feet (15.5 $m^3$). This represents about 7½ percent of the total erosion from the whole catchment area.

## The streams

Bradgate Brook and its trubutaries supply the water (and the sediment) to Cropston Reservoir. The streams are floored with sediment, generally gravel except along the smaller tributaries. There is no evidence of downcutting and the bulk of the stream erosion must therefore be lateral. An attempt is here made to estimate the total area of stream banks undergoing erosion in the catchment area of the reservoir. For this purpose, eroding banks are taken as all steep or vertical, vegetation-free banks, including the parts above as well as

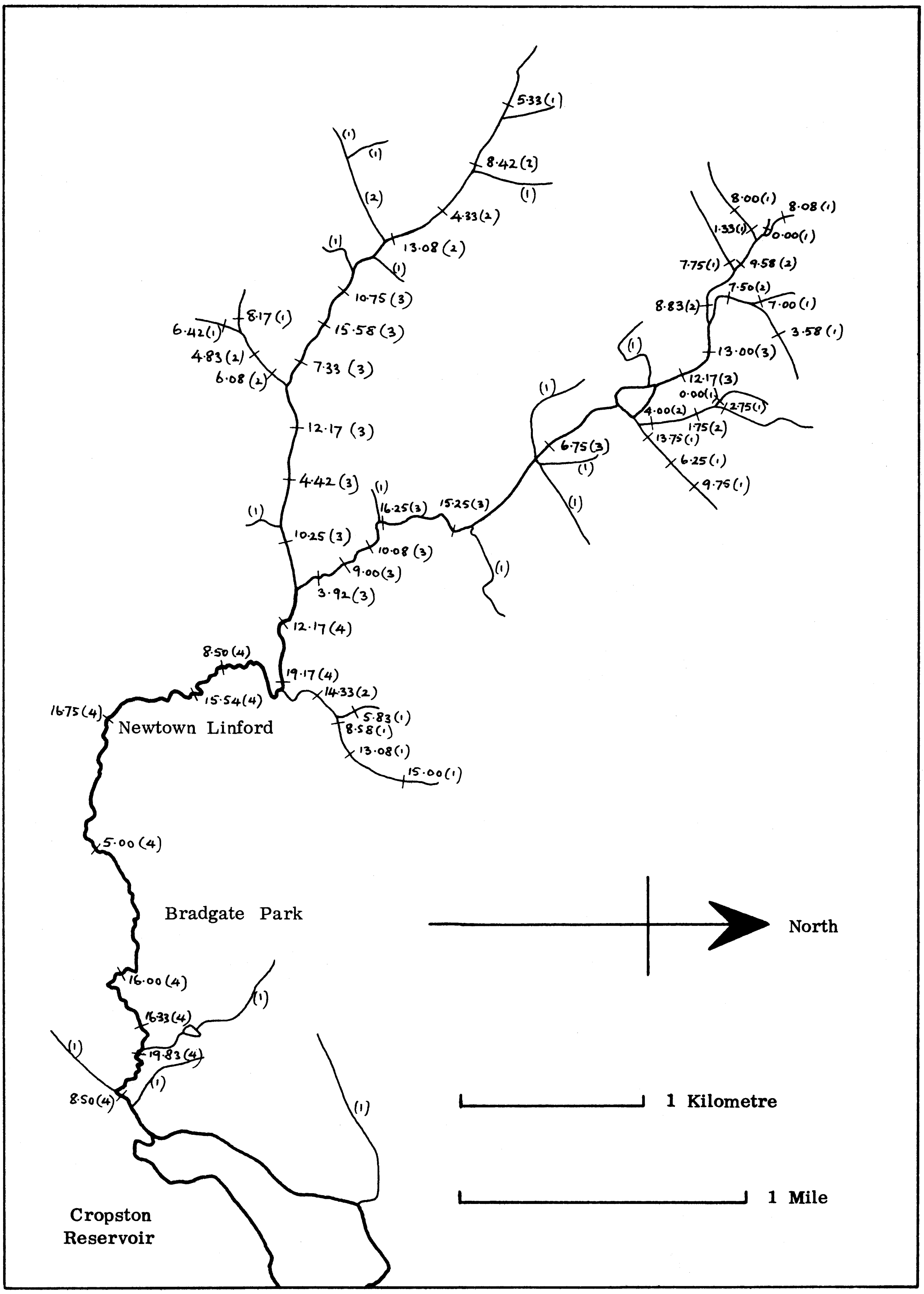

Figure 4. Map of the stream system flowing into Cropston Reservoir. Mean cross sections of erosion (arithmetic) are shown (in inches) for each series of ten cross sections measured. The figures in brackets denote the stream order (Strahler, 1957).

below water level. This definition excludes depositional stream margins, such as point bars of gravel, and all banks protected from erosion by walls, trees, shrubs, reeds, sedges, etc.

At any point along a stream, the cross-section of erosion represents the sum of the heights of eroding banks (and the widths of eroding beds, if any) at that point. The total area of banks (and beds) undergoing erosion in the stream is the product of the stream length and the mean cross section of erosion, which can be determined from a sufficient number of measurements made along the length of the stream. It was felt that the mean cross section of erosion of the main stream might be significantly different from that of the minor tributaries, so Bradgate Brook and its tributaries were classified by stream orders (fig.4), according to the system of Strahler (1957). The main stream flowing into the reservoir is a 4th. order stream and is 3½ miles (5.6 km) long. The two 3rd. order branches have a total length of 3½ miles (5.6 km), and there are 2½ miles (4 km) of 2nd. order streams and 8 miles (13 km) of 1st. order streams in the catchment area.

## The measurements

The measurements were made in the following manner. First, a point on the stream was selected and marked on the six inch map. The banks at this point were examined and the observations recorded in a field note book. If a bank was eroding, its height was measured and noted. If a bank was not eroding, a note was made of the nature of the stream margin. The width of the stream was also recorded. Similar observations were made at another point, ten paces from the first, and at another, ten paces from the second, and so on, until a series of ten cross sections of erosion had been recorded. Thus, while there may have been a subjective element in the choice of the first point (ease of access, quality of the banks, etc.), this was certainly not true of the other nine points at which measurements were made. Cross sections of erosion were measured in similar series of ten throughout the catchment area of Cropston Reservoir, and the mean cross section of erosion for each series is shown on a map of the area (fig.4).

The results of these measurements are shown in Table 1. As expected, there is a relationship between stream order and erosion. Higher order streams have a greater mean cross section of erosion than lower order streams. In detail however, the figures for the first order streams are rather anomalous. The percentage of the measured sections showing some erosion is significantly higher for first order streams than for second order streams; thus, in spite of the fact that the mean of the eroding cross sections is smaller for first order streams, there is very little difference between the mean cross sections of erosion (taking account of all sections, whether eroding or not) of the first and second order streams.

The reason for this anomaly is that many of the first order streams are artificially cut and maintained field drainage channels. Such streams might have been unable to cut their own channels and, if the present artificial cuts were not maintained, would choke with vegetation and the adjacent fields would revert to marshland. The fact that these ditches retain their straight courses shows that lateral erosion can not be rapid. On the other hand, the freshly cut sides of such ditches are probably more easily eroded than the natural stream margins would have been and they have therefore been measured as eroding banks, unless overgrown. This study is concerned with the streams as they are now and not as they might have been in the absence of human interference.

The total area of eroding stream banks in the catchment area of Cropston Reservoir (see Table 1) is found to be about 71,000 square feet (6,600 m$^2$). The mean annual rate of erosion of the catchment area is 7,600 cubic feet (200 m$^3$), of which 560 cubic feet (15.5 m$^3$) are supplied by the Keuper Marl cliff (p.153). If the remaining 7,040 cubic feet (184.5 m$^3$) are eroded from the stream banks, then the mean rate of erosion of these banks is 1.2 inches (30 mm) per annum. The actual rate of erosion is likely to be considerably greater for the higher order streams than for the lower order streams, but it is none-the-less interesting that the mean rate of stream bank erosion is of the same order as the rate of erosion of the Keuper Marl cliff (p.153).

Table 1. Data for calculation of area of eroding stream banks

| Stream order | 4th | 3rd | 2nd | 1st |
|---|---|---|---|---|
| Number of sections measured | 100 | 140 | 110 | 190 |
| Percentage of banks eroding | 43 | 44 | 36 | 44 |
| Percentage of sections eroding | 68 | 73 | 56 | 64 |
| Arithmetic mean cross section of erosion, in inches (eroding sections only). | 24.14 | 17.65 | 16.74 | 13.35 |
| Standard deviation | 13.78 | 9.15 | 10.12 | 7.64 |
| Mean of log. distribution of cross sections of erosion, in inches (eroding sections only). | 19.34 | 15.23 | 13.98 | 11.26 |
| Standard deviation | 2.08 | 1.76 | 1.85 | 1.85 |
| Mean cross section of erosion, in inches (all sections). | 13.09 | 11.20 | 7.88 | 7.17 |
| Length of streams, in miles. | 3.5 | 3.5 | 2.5 | 8.0 |
| Area of bank erosion, in square miles (to nearest thousand). | 20,000 | 17,000 | 9,000 | 25,000 |

Notes on Table 1.

1. The percentage of sections showing some erosion is roughly fifty percent greater than the percentage of banks (two per section) eroding. The reason is that the number of sections showing no erosion on either side is about double the number with both banks eroding.

2. The arithmetic mean is a poor average value (large standard deviation), due to the strong positive skewness of the data distribution. A logarithmic transformation of the data resulted in a more nearly normal distribution and a mean which gives a much better average value (smaller standard deviation). This (geometric) mean is used to find the mean cross section of erosion of all sections (including those showing no erosion) and, from this, the area of stream banks undergoing erosion.

## Conclusions

1. The mean annual rate of recession of the Keuper Marl cliff (SK 532099) in Bradgate Park is 1.0 inches (25 mm). This figure is based on direct measurement.

2. The mean annual rate of recession of all stream banks undergoing erosion in the catchment area of Cropston Reservoir is 1.2 inches (30 mm). This figure depends on a knowledge of the annual rate of sedimentation in the reservoir and on measurements leading to an estimate of the total area of stream banks undergoing erosion.

## Acknowledgements

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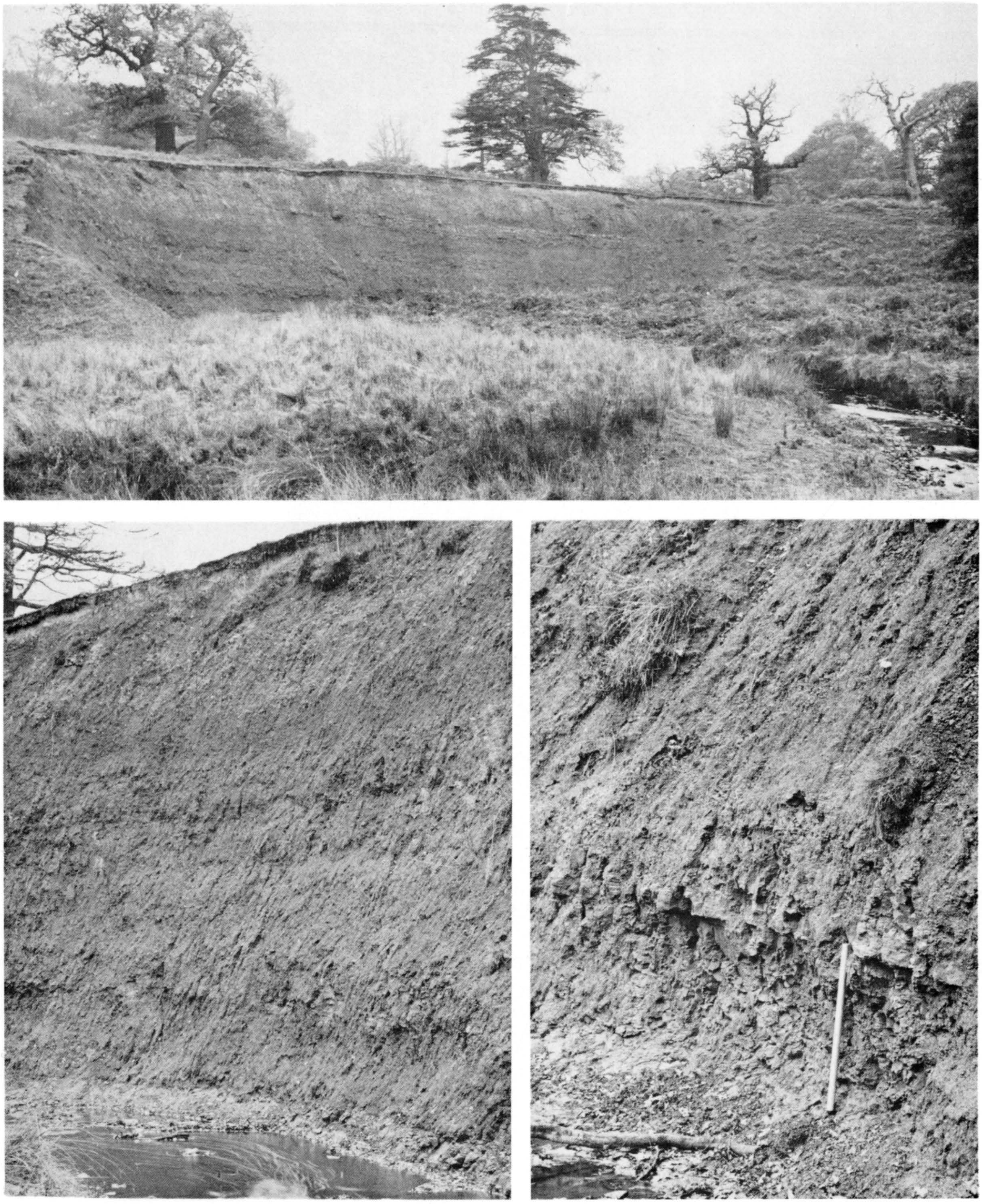

**Top**: General view of the Keuper Marl cliff in Bradgate Park, as seen from the north. The main cliff of fresh Keuper Marl is slightly darker than the weathered zone above.

**Lower left**: The cliff face. The prominent drag marks are caused by masses of wet sediment and turf sliding down the cliff face. Note the detached masses of turf near the top of the cliff. The scree at the foot of the cliff has been entirely removed by recent erosion.

**Lower right**: Close up of the base of the cliff. The erosion which removed the scree has also cut back into the solid rock, forming a new, nearly vertical cliff at the base of the main cliff. Note the material beginning to accumulate at the foot of this new cliff. Note also the masses of turf (with grass), which have slid down the cliff but not quite reached the bottom. The metal rod is 2 feet (31 cm) long.

Photos by Mr. D. Jones, 11th November 1971