RATE OF SEDIMENTATION IN CROPSTON RESERVOIR, CHARNWOOD FOREST, LEICESTERSHIRE

by

W.A. Cummins and H.R. Potter

Summary

Cropston Reservoir was emptied in 1965 for the first time in 95 years of use. The thickness of the mud on the floor of the reservoir was measured and an isopach map constructed. After allowance had been made for the volume of mud cracks and of water in the mud, the total volume of sediment was estimated. The mean annual supply of sediment to the reservoir was found to be 6,214 cubic feet. The reservoir loses capacity at ten times this rate because the mud settling in it incorporates about ninety per cent of water by volume. At this rate the reservoir will be completely silted up in 1,433 years.

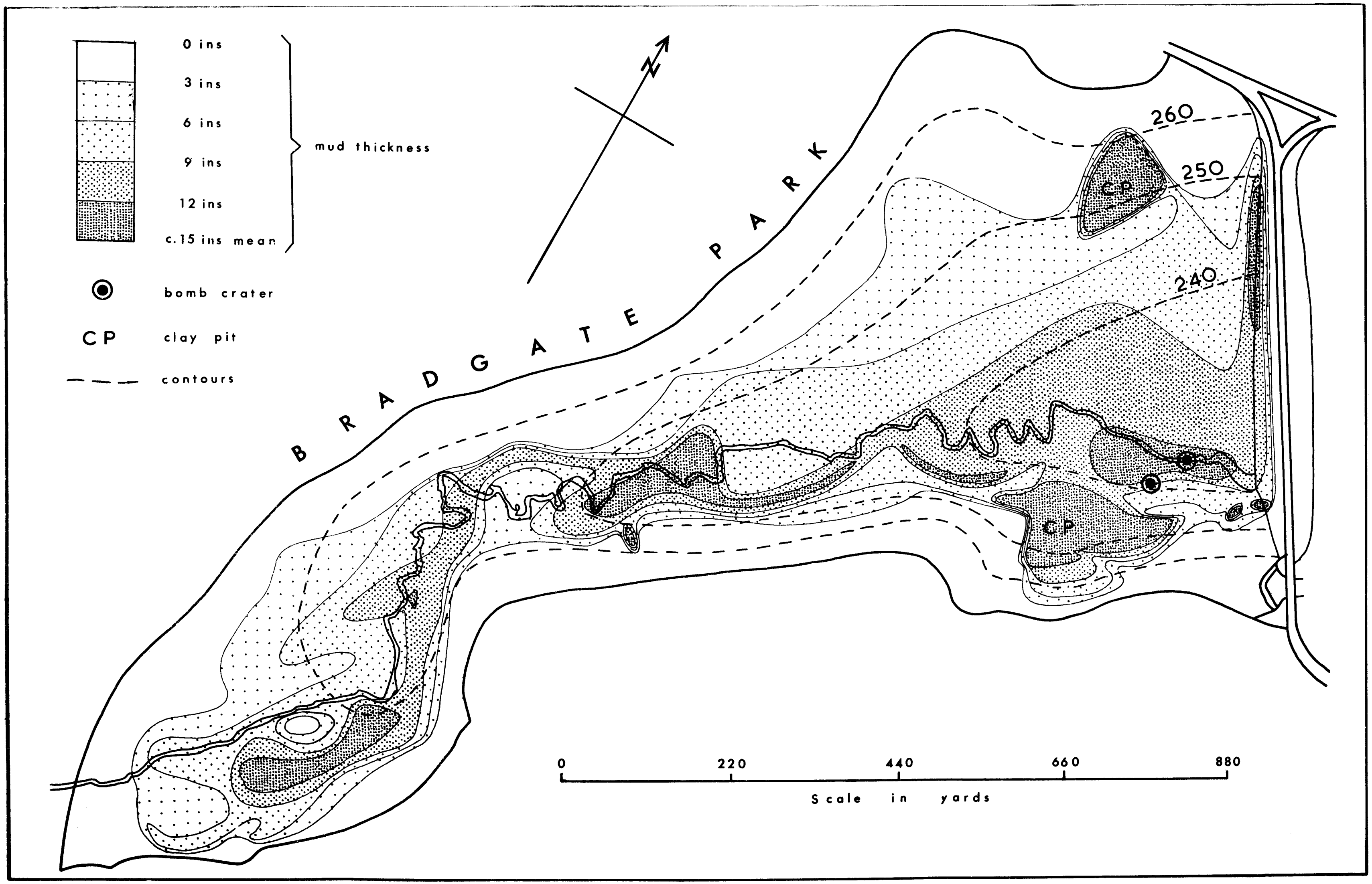
Settling ponds upstream of the reservoir were found to be trapping sediment at the rate of 1,376 cubic feet per annum. Thus the rate of erosion of sediment off the catchment area is 7,590 cubic feet per annum. This may be averaged over the whole area to give a mean annual lowering of the surface by 0.00048 inches.

Introduction

Cropston Reservoir (SK 5410 and 5411), supplying water to the City of Leicester, was opened in 1870. It is situated at the south-eastern end of Charnwood Forest, alongside Bradgate Park. The dam at the north-eastern end carries the road (B5330) leading to the nearby village of Cropston (SK 553109). The top water level of the reservoir is 266.7 feet O.D. The highest points in the 4,400 acre catchment area are just over 800 feet O.D. The mean annual rainfall over the period from 1871 to 1964 was 28.06 inches. The main stream feeding the reservoir is Bradgate Brook. A series of five settling ponds (SK 525099 to 528101) in Bradgate Park serve to trap a good deal of the sediment load of Bradgate Brook, which would otherwise be carried on into the reservoir. These ponds are cleared about every ten years.

The catchment area is floored by Pre-Cambrian and Triassic rocks with an extensive cover of Boulder Clay (Text-fig. 4). The Triassic Keuper Marl overlies the Pre-Cambrian Charnian rocks unconformably, the junction between the two being an irregular land surface of Triassic age, which is now being re-excavated. The surface geological composition of the catchment area is as follows:-

Superficial deposits	23%
Keuper Marl	48%
Charnian	29%


0 ins
3 ins
6 ins
9 ins
12 ins
c.15 ins mean
mud thickness
bomb crater
CP clay pit
contours
N
BRADGATE PARK
260
250
240
CP
CP
0
220
440
660
880
Scale in yards

Text-Fig. 1

Cummins and Potter   Cropston Reservoir   Text-Figure captions

Text-Fig. 1. Isopach map of the sediment in Cropston Reservoir. Contours and stream course based on original site survey.

Text-Fig. 2. Data for interpretation of measured mud thicknesses (vertical scale). Each point represents one square yard sample area.

Text-Fig. 3. Top (a) Extract from field note book giving details of a square yard sample area. Bottom (b) Detailed analysis of above sample area (see text, p. 35).

Text-Fig. 4. Simplified geological map of the Cropston Reservoir catchment area.

Text-Fig. 5. Section across old field boundary, showing mud at time of observation (close stipple) and calculated underwater sediment surface (over open stipple).

The area is covered by the Geological Survey one inch sheets 155 and 156, and a general account of the geology may be found in the Geological Survey's "Regional Guide" to the Central England District.

The reservoir was emptied in April 1965 for cleaning and alteration, thus providing an opportunity for measurement of the volume of sediment accumulated over a period of 95 years, from which an estimate of the rate of erosion of the catchment area might be made.

The sediment in the reservoir is uniform black mud. The black colour is due to the presence of ferrous sulphide (c.8% dry weight). The mud also contains ten to fifteen per cent of organic matter. Thin laminae of fine sand and silt occur in the mud at shallow depths in the reservoir, and are related to periods of low water. Similar layers are found in sediment which was re-deposited at greater depths in the reservoir when it was drained. The only other noteworthy example of stratification in the mud is a layer of sand and gravel surrounding the two bomb craters in the lower part of the reservoir (see Note 1 at end).

The isopach map

When the reservoir was emptied the stream quickly returned to its old channel and, as the mud dried and contracted, many of the old field boundaries were revealed as slight irregularities on the surface of the mud. Thus a copy of the original survey of the site made at the time of construction of the reservoir served as a useful base map for the present study.

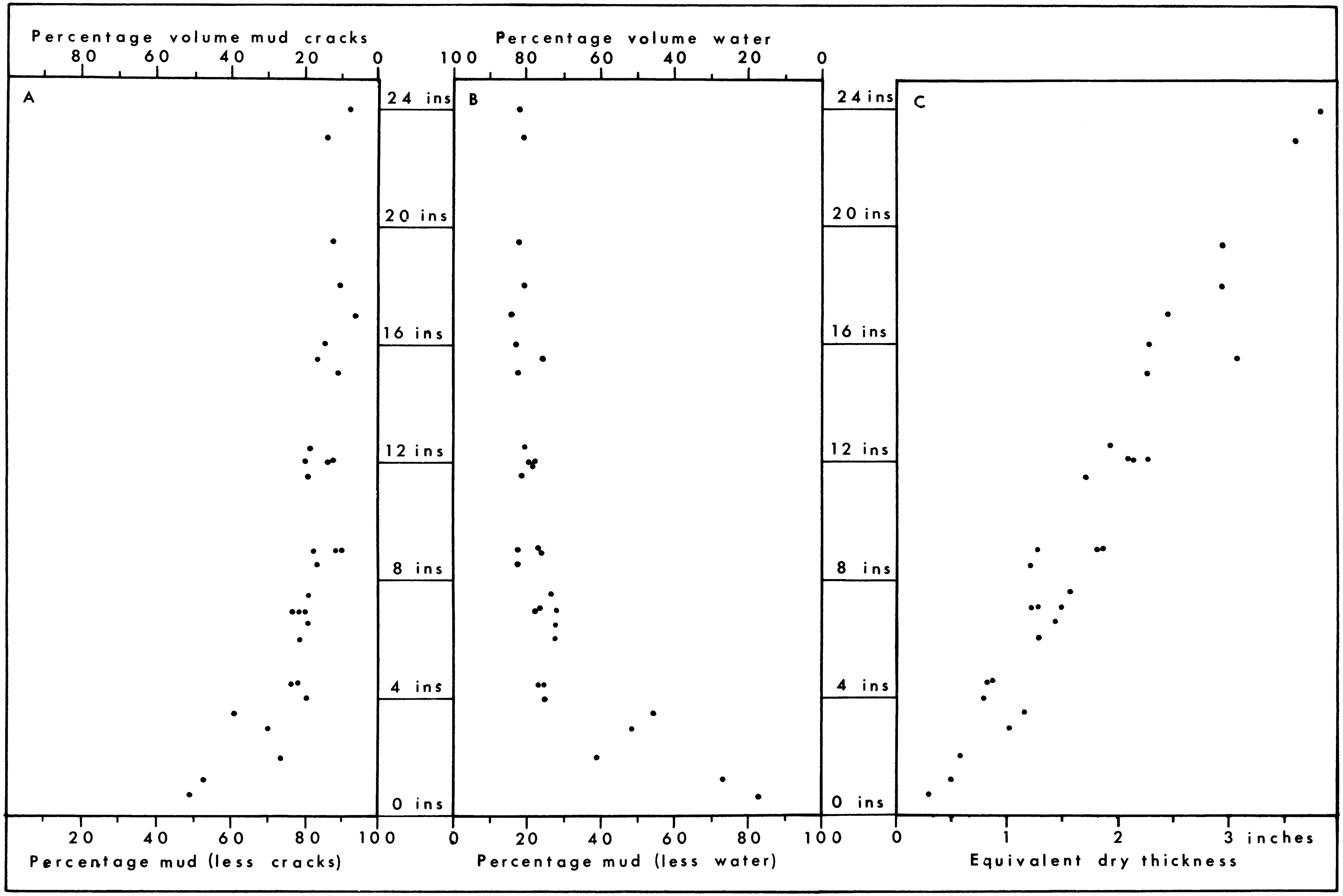
Determination of the volume of sediment in the reservoir was made from an isopach map based on measurements taken during late May and June 1965, by which time the surface of the mud had dried sufficiently to permit walking with reasonable safety over most of the area. The depth of the sediment was determined by digging and measuring with a ruler. The black cohesive mud parted readily from the substratum along the porous mat of dead roots which represented the old turf.

The isopach map (Text-fig. 1) shows a close relationship between mud thickness and topography, such that the mud is generally thicker in the deeper parts of the reservoir. Superimposed on this general pattern are areas of thick mud in local topographic depressions such as old abandoned river meander channels and the clay pits (not shown on the old map) from which boulder clay was dug for the construction of the dam. This local topographic effect is also apparent on a scale smaller than can be shown on the map. The mud is thin on banks and ridges and thick in ditches and furrows. Examples of such small scale variations are found along old field boundaries and across the ridges and furrows resulting from medieval strip cultivation, traces of which were visible over a large part of the floor of the reservoir and can also be seen in many of the fields nearby.

The variations in mud thickness, as measured in the field and shown on the map, are not necessarily directly related to variations in the amount of sediment present. Before the map can be interpreted, allowance must be made for the water content of the muds at the time of measurement, and also for the lateral contraction on drying as reflected in the pattern of mud cracks.

Interpretation

In order to allow for the volume of mud cracks, the following procedure was devised. A square yard was marked out on the ground with string and nails. The pattern of cracks in this area, hereafter referred to as a sample area, was sketched in the field notebook (Text-fig. 3a) and the length and width of every crack measured and recorded. The surface area of the cracks was totalled and recorded as a percentage of the sample area. The percentage volume of mud cracks in the sample area was calculated, generally on the assumption that the cracks were triangular in cross-section and extended to the bottom of the mud. Where the mud was very thin and dry, the cracks were found to be rectangular or trapezoidal in cross-section and the calculation of percentage volume was adjusted accordingly. The results of these


Percentage volume mud cracks
80
60
40
20
0
Percentage volume water
100
80
60
40
20
0
A
B
C
24 ins
20 ins
16 ins
12 ins
8 ins
4 ins
0 ins
24 ins
20 ins
16 ins
12 ins
8 ins
4 ins
0 ins
20
40
60
80
100
Percentage mud (less cracks)
0
20
40
60
80
100
Percentage mud (less water)
0
1
2
3 inches
Equivalent dry thickness

Text–Fig. 2

measurements are summarised in Text-figure 2a, in which each point represents one sample area. Over most of the thickness range there is little variation in the percentage of mud cracks, but below about six inches, there is a marked increase of mud crack volume with decreasing mud thickness.

After the mud crack measurements, part of a mud polygon was dug out for sampling. The samples, approximately inch cubes, were cut from different levels in the mud with a thin wire and placed in small self-sealing polythene bags. The water content of these samples was then determined by heating to constant weight in a drying oven. It was found that the polythene bags withstood the temperature of the oven, so the procedure was as follows:- The wet samples were weighed in the polythene bags; the bags were opened and the samples dried in the oven; they were then reweighed and the weight loss calculated as percentage water. It was found, as expected, that the upper crust of the mud was a good deal drier than the rest; and also, rather less expectedly, that the water content at the bottom was invariably less than higher up. Presumably, water was squeezed out at the bottom by the weight of the overburden (no longer supported by the reservoir water) and drained along the old turf layer. This old turf layer was an excellent example of an aquifer, and digging through the mud down to this level in a hollow generally resulted in a sudden inrush of water.

The mean water content of the mud was thus found for each sample area and converted to a mean percentage volume of water. For this purpose, a specific gravity of 2.6 was taken for dry sediment and it was assumed that the samples as collected were completely water saturated (an assumption checked in the first few sample areas by cutting cubic inch samples as accurately as possible). The results of these determinations are shown in Text-figure 2 b, in which each point represents one sample area. The percentage volume of water in the muds shows little variation down to a mud thickness of about six inches, below which the muds become drier with decreasing thickness.

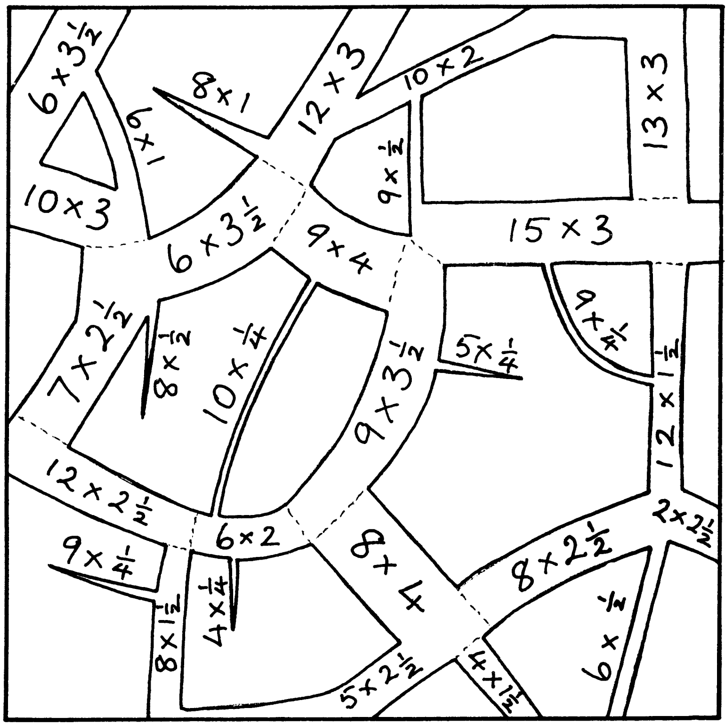
It is now possible to determine the equivalent dry thickness of the mud, that is to say the thickness of solid sediment which would spread evenly over a sample area if all the water were removed. This is given by the formula:-

$$\frac{MST}{10,000}$$

where M is the perecentage volume of mud (less cracks) in the sample area, S is the mean percentage volume of sediment (less water) in the mud, and T is the thickness of mud measured in the field.

Since the water content of the mud and the width of the mud cracks both vary with depth, a few sample areas were analysed in greater detail to check the effects of these variations. For these detailed analyses, samples were taken throughout the thickness of the mud. A cross section of such a sample area is shown diagrammatically in Text figure 3b. The blank part to the left represents the mud cracks. The first column of figures shows the percentage volume of mud (less cracks) at each sample level. The next column of figures gives the percentage volume of sediment (less water) in each mud sample. The third column gives the percentage volume of sediment (less cracks and water) for each sample level. The final column gives the equivalent dry thickness for each sample level. The sum of these gives a total equivalent dry thickness for the mud, which differs but little from the equivalent dry thickness based on the formula given in the preceding paragraph.

Time available for measurements was limited. The contractors were working on the floor of the reservoir; plants were springing up all over the place and a thick jungle of vegetation was advancing over the mud from the sides of the reservoir with surprising rapidity; finally, the condition of the mud itself was changing at an unknown rate. The general procedure adopted therefore was to take samples at intervals through the thickness of the mud in each sample area. From these a mean water content was obtained, saving much valuable time in the field and in the laboratory.



Locality	15a
Mud thickness	$12\frac{1}{2}$ ins.

Mud crack areas:-

$\frac{1}{4}$ X (14, 9, 4, 10)	9.25
$\frac{1}{2}$ X (9, 6, 8)	11.5
1 X (6, 8)	14
$1\frac{1}{2}$ X (8, 4, 12)	36
2 X (6, 10)	32
$2\frac{1}{2}$ X (12, 7, 5, 8, 2)	85
3 X (12, 10, 13, 15)	150
$3\frac{1}{2}$ X (6, 6, 9)	73.5
4 X (8, 9)	68
Total mud crack area	479.25 sq. ins.
Percentage area mud cracks	37%
Percentage volume mud cracks	18.5%

65% mud	28.0% solids	18.2% of 1.25 ins.	0.227 ins.
68% -	24.7% -	16.8% of 1.00 ins.	0.168 -
71% -	19.5% -	13.9% -	0.139 -
74% -	18.3% -	13.5% -	0.135 -
77% -	17.8% -	13.7% -	0.137 -
80% -	17.8% -	14.3% -	0.143 -
83% -	16.4% -	13.6% -	0.136 -
86% -	16.6% -	14.3% -	0.143 -
89% -	16.9% -	15.0% -	0.150 -
92% -	17.8% -	16.4% -	0.164 -
95% -	17.8% -	16.9% -	0.169 -
98% -	19.2% -	18.8% of 1.25 ins.	0.235 -

Text-Fig. 3

The equivalent dry thickness is plotted against measured thickness of the mud in Text-figure 2c, in which each point represents one sample area. The two opposing factors of large crack volume and low water content in the thinner muds cancel each other out, and it can be seen that, right down to the smallest thickness measured, there is a direct linear relationship between the equivalent dry thickness and the thickness measured in the field. Thus the patterns on the isopach map reflect a real relationship between sedimentation and topography which has to be accounted for (see Note 2 at end).

Conclusions

The total volume of sediment in the reservoir can be determined from the isopach map. The areas between the isopachs were measured, multiplied by the mean equivalent dry thickness between each one, and totalled. It was found that 590,367 cubic feet of sediment had been deposited in the reservoir in a period of 95 years. The mean annual accumulation of sediment is thus 6,214 cubic feet. This figure refers to dry sediment and is of interest in a study of erosion of the catchment area. The reservoir actually fills up with sediment at ten times this rate, because the mud which settles on the bottom incorporates about ninety per cent of water by volume. At this rate the reservoir would be completely silted up in a period of 1,433 years.

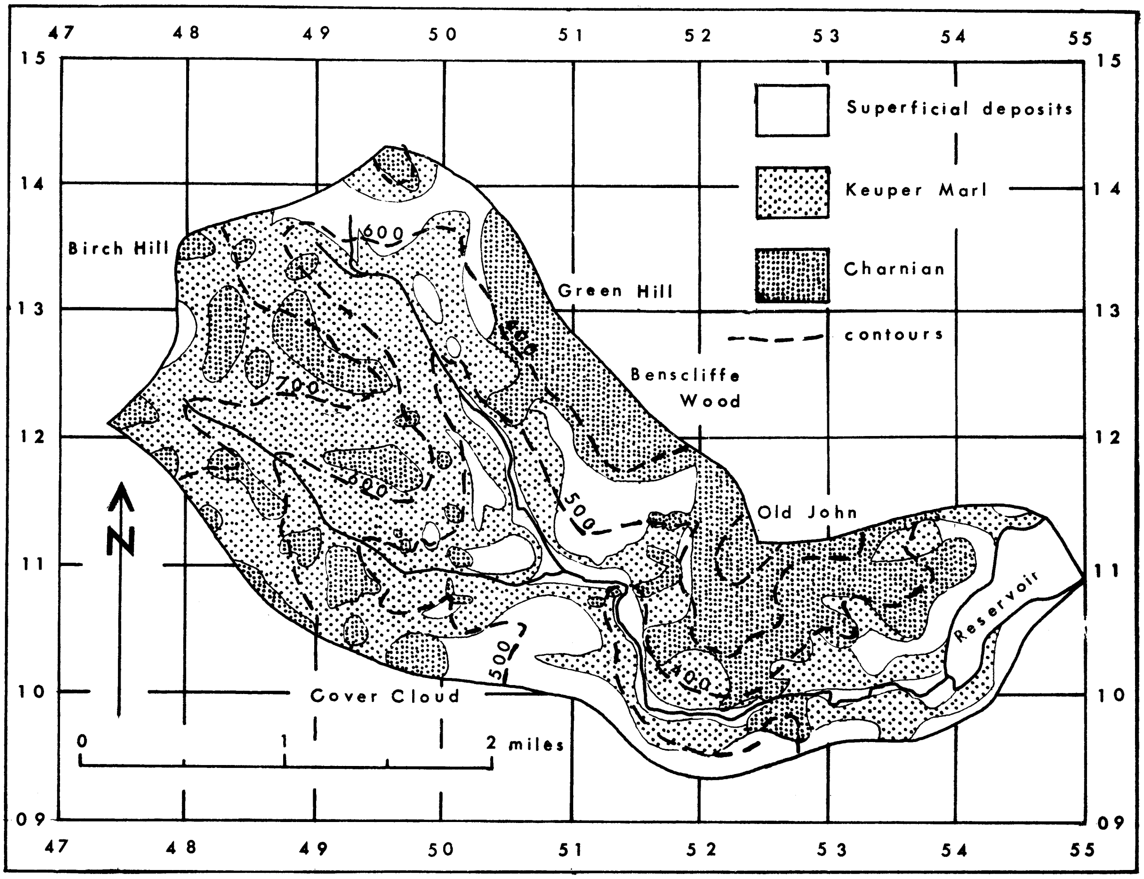
Before the rate of erosion of the catchment area can be determined, allowance must be made for the sediment which is deposited in the settling ponds in Bradgate Park. They were cleaned out during the summer of 1965 and the sediment dumped nearby. The last clearance of the ponds had been in 1955, so, assuming that the 1955 and 1965 cleanings were done in the same manner and to the same extent, the sediment in the dumps represents ten years accumulation. A rapid survey of the surface of the dumps was made; pits were dug to find the thickness of the dumped sediment; and samples were collected for water determination. The water content of the dumped sediment was considerably less than in the undisturbed reservoir muds, and dessication cracks had not developed. The total volume of dry sediment represented by the dumps from all five ponds was 13,758 cubic feet, which gives an annual rate of accumulation of 1,376 cubic feet. This is rather less than a quarter of the rate of sedimentation in the reservoir and means that the ponds are trapping 18 per cent of all the sediment coming down Bradgate Brook before it reaches the reservoir.

The rate of erosion of the catchment area, taken as the sum of the rates of accumulation in the reservoir and the settling ponds, is 7,590 cubic feet per annum. If this loss is averaged over the whole surface of the area, the annual rate of erosion may be represented as a general lowering of the surface by 0.00048 inches. Discussion of these figures and comparison with other areas will be deferred for a later publication, pending completion of research already in hand.

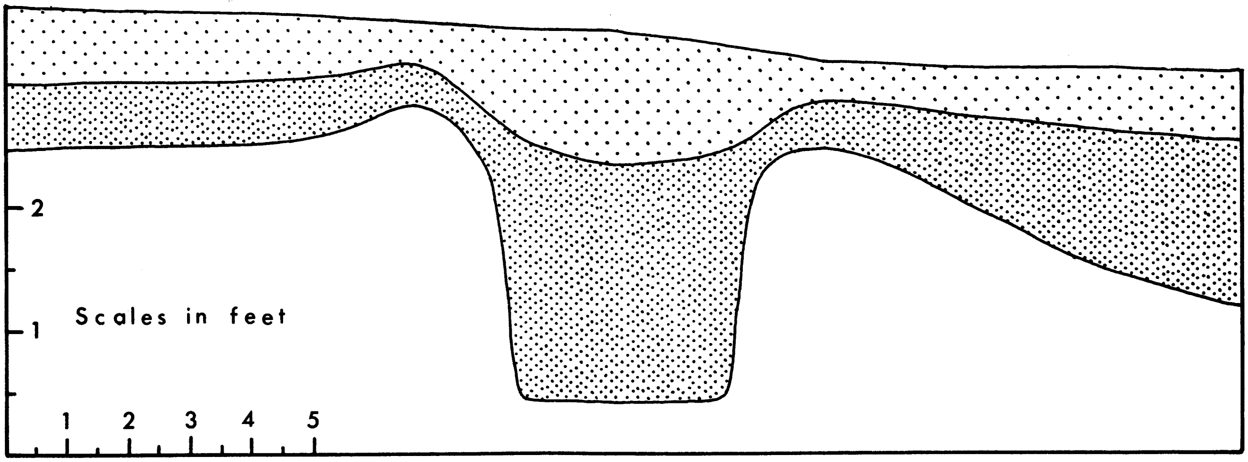
Note 1

Two bombs fell in the reservoir during the war. One fell in the old stream course about a hundred yards from the dam and the other fell between this and the southern clay pit (Text-fig. 1). The bombs had exploded below the reservoir mud and formed circular craters, about 30 feet in diameter, with rims of upcast boulder clay. The crater of the one which had dropped in the old stream course was very imperfectly preserved. A layer of pebbly sand in the mud extended for a distance of about 30 yards from each of the craters, and the thickness and pebble content gradually decreased away from the craters. These bomb sands differed from the layers of sand associated with the emptying of the reservoir in their coarser grain size, poorer sorting, and lack of current structures such as parting lineation.

The bomb sands suggested a test for constancy of rate of sedimentation by determining the equivalent dry thickness of sediment above and below. The exact date of the bombs has not been discovered, but they must divide the history of sedimentation in the reservoir into two unequal periods, an earlier one of about 70 years and a later one of about 25 years. Two sample areas with bomb sand were analysed by the detailed method (p. 35). The results of both showed that the rate of sedimentation after the bombs were



Text-Fig. 4



Text-Fig. 5

dropped was apparently about fifty per cent greater than before. This anomaly is almost certainly due to an unknown thickness of mud being redeposited in this part of the reservoir when it was drained in the Spring of 1965.

Note 2

The relationship between sedimentation and topography extends to the deepest parts of the reservoir, beyond the reach of erosion and wave action, and seems likely to have resulted from some process on the floor of the reservoir unrelated to movements in the water above. There is no evidence of sediment deposition from turbidity currents. It is suggested that the relationship has resulted from a gradual downslope flow of the watery sediment accumulating on the floor of the reservoir. Such a process would result in the accumulation of extra sediment in hollows at the expense of that on the adjacent higher ground, producing a general smoothing off of the underwater topography.

A section across an old field boundary is shown in Text-figure 5. Five sample areas were studied along this section and their relative levels measured. The equivalent dry thickness was determined for each of them and multiplied by ten to give an equivalent thickness of underwater sediment (90% water by volume for the underwater sediment is taken as being a round figure a little in excess of the highest water content of any sample collected during the present study). The underwater sediment surface, thus reconstituted, has a considerably smoother profile than either the original underlying ground surface or the surface of the mud at the time of measurement. The results of this traverse are consistent with the idea of gentle downslope flow of the watery sediment deposited on the floor of the reservoir.

Acknowledgements

The authors wish to express their thanks to the following:- Mr. Marshall Nixon, Engineer to the Trent River Authority, and Professor W. D. Evans, Head of the Geology Department in the University of Nottingham, suggested the project to us. Facilities for working in the reservoir were given by officers of the City of Leicester Water Department, Mr. Hal Wallhouse, Engineer and Manager, Mr. R. West, Project Engineer, and Mr. A.R. Leaf, Station Superintendent of Cropston Reservoir. Analyses were carried out by Mr. D. Mather and Mr. I. Beaumont in the Geology Department.

W.A. Cummins, B.Sc., Ph.D., F.G.S.
Department of Geology,
The University,
Nottingham

H.R. Potter, Esq.,
Hydrologist,
Water Resources Section,
Trent River Authority,
West Bridgford,
Notts.
Manuscript received 19th October, 1966