NOTE ON A POSSIBLE APPROACH TO THE ASSESSMENT OF SURFACE WATER IN OPENCAST MINES IN THE BRITISH ISLES

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ABSTRACT

An outline is given of the use of the Flood Studies Report to estimate mean and peak surface water flows at a proposed opencast mine site in the British Isles. Whilst this is an empirical method it appears to provide reasonable order of magnitude estimates which can be related to mine life and acceptable levels of risk.

INTRODUCTION

The estimation of quantities of surface-derived water at proposed opencast mines is of considerable importance in project design and costing. It is, however, sometimes neglected and often treated in a superficial manner, despite the costs and problems which may arise if drainage, pollution and flood-protection measures are inadequate. In the past various methods have been used to calculate flood risks in small ungauged catchments typical of surface mine sites in the British Isles. Most widely used is the so-called 'rational method', but other techniques include the 'time-area' and the 'tangent' methods; a summary of these several approaches has been given by Nash (1958) [1]. In 1975 the Flood Studies Report [2], referred to hereafter as FSR, detailed alternative methods based on the statistical assessment of data from throughout the British Isles; this note outlines the use of such techniques to assess likely surface water conditions at a proposed opencast mine in Ireland.

APPROACH

In common with many surface mine settings, there was no stream-gauging within or near the site and consequently no flow records for local streams. *Any* stream flow records, even if only of a year's duration, improve the accuracy of surface water predictions; the FSR recommends that as soon as a potential site is identified a programme of stream-gauging should be established. However, it is possible to obtain reasonable stream discharge figures without flow records. The FSR outlines the analysis of many gauged catchments in Britain and Ireland giving correlations, based on statistical tests, between mean annual flood (MAF) and various catchment parameters. The MAF is the flow rate (dimensions L^3/T) at any particular locality that has a return period of 2.33 yrs. An equation relating MAF to measurable catchment characteristics is presented in the form:

$$\text{MAF (cumecs)} = \bar{Q} = 0.0172\ \text{AREA}^{0.94}\ \text{STMFRQ}^{0.27}\ \text{S1085}^{0.16}\ \text{SOIL}^{1.23}\ \text{RSMD}^{1.03}\ (1 + \text{LAKE})^{-0.85} \qquad 1.$$

This is the equation applicable to Ireland; other regions have different initial constants (instead of 0.0172). The catchment parameters are derived as follows:-

AREA = area of catchment, in km^2
STMFRQ = stream frequency, in junctions km^2
This should be measured by counting channel junctions on a 1:25000 map. For small catchments, however, large scale maps are needed and this tends to give exaggerated estimates. Only the most significant junctions should be counted in these circumstances. In Ireland the combination of man-made and natural channels further complicates the task.
S1085 = 10%-85% slope
This is found by first measuring the length of the main stream in the catchment. The ground elevation is then found at distances of 10% and 85% MSL from the discharge point and S1085 is the difference in these two elevations divided by 0.75 MSL.
SOIL = Soil Index
This is the weighted average of S1, S2, S3, S4 and S5. S1 to S5 represent proportions of the catchment area lying in soil classes 1 to 5, as determined from Table 1 [2], given at the end of this paper. Thus:-

$$\text{SOIL} = \frac{0.15\text{S1} + 0.30\text{S2} + 0.40\text{S3} + 0.45\text{S4} + 0.50\text{S5}}{\text{S1} + \text{S2} + \text{S3} + \text{S4} + \text{S5}}$$

RSMD = 5-year return period 1-day areal rainfall in mm, minus mean soil moisture deficit.
These valuescan be found from maps given in the FSR.
LAKE = Proportion of catchment which drains to a lake.
The area of any lake or impoundment considered must exceed 1% of its own catchment area.

Once MAF has been estimated, stream flood flows for any specified return period can be found using regional growth curves given in the FSR.

In designing drainage facilities it is necessary to assess high flood flow rates commensurate with acceptable engineering risk and the life of the mine. Return flood period, risk and design life of any project are related statistically by the equation:

$$r = 1-(1-\frac{1}{T_D})^L \quad \text{where} \qquad 2.$$

r = risk of failure or exceedance during design life
L = design life
T_D = design return period

PROPOSED MINING SITE

In order to assess surface water flows the parameters outlined above had to be collated for both existing conditions and for conditions that would obtain at various stages during mine development. All surface mines significantly alter the balance between different types of ground during mining *viz.* undisturbed land, excavated void, spoil dumps, regraded material, etc.

Using Equation 2 a design return period of 98 years was calculated for the proposed mine and, for convenience, a 100-year event was used throughout the analysis to assess extreme surface water conditions. This design return period satisfied the requirement for low risk of exceedance during the first five years and a higher acceptable risk over the longer remaining period of mine life.

Conditions before mining

During exploration and geotechnical site investigations, walkover surveys were carried out to locate watersheds, ditches and areas of standing water. Combined with a review of available maps and plans, these surveys enabled the watersheds around and within the site to be identified, together with major stream channels. Equal attention was given to areas *outside* the mine from which runoff might enter the site. In common with many British mines, much of the drainage was effected by hedgerow ditches, with relatively few natural channels, most of which had been locally deepened and straightened to increase flow rates. There was a large peat bog in the centre of the site, through which much of the area drained. The site and its related environs comprised 1.4 km^2 and was divided into three catchments, one major and two minor, which were analysed separately. Within each catchment, the available maps and plans were used to estimate stream frequency, ground slope and areas of 'lake'. The peat bog was modelled as a 'lake' since it was expected to have a similar effect on flood peaks passing the catchment discharge point; such a 'lake' in the system generally tends to reduce and attenuate flood peaks. Soil and rainfall parameters were derived from maps and tables in the FSR.

The empirical equation given above (Equation 1) was used to obtain the mean annual flood for the principal catchment within the site; predicted flows from the two minor catchments were negligible. A figure of 18m^3/min was obtained for the mean annual flood. Using growth curves in the FSR, the 100-year return period flood was found to be 34m^3/min. These figures both represent flood *peaks* - *i.e.* of instantaneous duration. By extrapolation, and using tables for factors of low return periods given in FSR supplements, the 30-day duration 6-month return period 'flood' was found to be c 1.3m^3/min. This value was taken to represent the mean monthly discharge which occurs on average twice a year.

The mean monthly discharge could be checked using a 'theoretical' method based on local climatological data. This data was obtained from two sources. Rainfall information was available for stations 10-12 km away and since rainfall patterns were not likely to vary significantly over this distance, this data was used without alteration. Other meteorological information on wind, sunshine, frost, snow and relative humidity were only available for a station 25 km from the mine, but being the only data available these figures were used without alteration. The monthly evapotranspiration from the site was then calculated using Serra's simplification of Thornthwaite's Method 3 . For each month, evapotranspiration losses were subtracted from the monthly precipitation to give a 'net' rainfall figure. Assuming no infiltration, the *mean* monthly discharge was found to be c 0.7m^3/min, within a range of 0-2.3m^3/min. Whilst the upper part of the range was slightly higher than the empirical figure, possibly due to the fact that storage in the peat and infiltration were both ignored in the 'theoretical' analysis, the results compared favourably.

Conditions during mining

Since the character of ground surfaces are substantially altered by mining operations, patterns of surface water runoff will be affected. Two principal categories of land were considered: firstly land outside the excavation, most of which will be either unaffected or covered with vegetated low angle spoil heaps, and secondly, the excavation area itself. The plant yard/processing area was treated as a subsection of the excavation area.

Land outside the excavation area was treated empirically, using the FSR method outlined above. Clearly, since this is based on catchment characteristics, catchment boundaries and characters had to be redefined. Thus, general drainage patterns had to be assumed for the mine site. Essentially this consisted of continuing natural drainage where relevant plus cut-off ditches around the crest of the excavation, at the base of the out-of-pit spoil heaps, and along haul roads. Siltation lagoons and pumps were located as necessary. With the pattern of mine drainage thus defined, empirical calculations were carried out as previously for each catchment so as to derive the mean annual and 100-year flood flows, and to estimate the size of various lagoons.

Whilst the excavation area was a well-defined catchment it proved difficult to select appropriate parameters for empirical analysis. Excavated and spoil slopes were considerably steeper than natural slopes, there was no 'main stream' within excavation, and it was difficult to quantify soil moisture deficit or winter rain acceptance potential. It was therefore considered appropriate to use 'theoretical' methods, similar to that employed for the pre-mining stage. Instead of subtracting evapotranspiration, only evaporation was considered, there being no vegetation in the excavation area. Evaporation was calculated using Penman's equation, for which a nomogram is available [3]. It was also assumed that 20% of the net rainfall would infiltrate into the surface. This is an arbitrary but commonly quoted figure [4] for a bare rock or low permeability surface soils, and is often used for hydrological assessments of reclamation sites in Britain. A design chart, such as that used by the N.C.B. in estimating tip drainage, may be used to determine the runoff coefficient, and hence infiltration, by reference to ground slope, surface composition and vegetation cover [5].

Consideration was given to the question of runoff and infiltration, from in-pit spoil. The permeability of this spoil was estimated to be in the range of 10^{-4} to 10^{-6} m/s; travel times of infiltrating rain water through a 20m high in-pit spoil dump could therefore vary from a few hours to a few days. Consequently, during periods of 'normal' rainfall, water was considered to flow continuously through spoil piles with a time lag of up to several days. However for longer periods most of the rain falling on any in-pit spoil pile will seep out of its base and the residence time of water within the spoil pile may be ignored. A 20% allowance was made for net infiltration, to represent water held in the partially-saturated spoil. During storms, which are usually of less than a day's duration, there will be virtually no evaporation, and considerable quantities of water, estimated at 80%, will runoff into the pit. Of the 20% that infiltrates, any that seeps through the in-pit spoil and out at its base will probably enter the pit some days later, after the end of the storm. The net result will be to slightly attenuate the effects of the storm within the excavation, however for the purposes of calculating depths of pit flooding *during storms*, water seeping through in-pit spoil may be ignored.

A similar analysis was carried out for proposed areas of hard-standing to be used for a plant yard and for mineral processing. These areas were very small and could not be sensibly modelled using empirical methods.

Whilst the general principles of site drainage were likely to remain the same throughout the life of the mine, the relative proportions of water coming from within and outside an excavation would change as the size of the excavation increased. The total amount of water discharged from site would increase with time, as more land was cleared and excavated. Analyses were therefore carried out for the site during 'early' and 'late' stages of mine development. At this stage in the calculations groundwater components were added to the surface water flows. It was found that in addition to the main siltation lagoon two subsidiary lagoons were required, one at the plant yard which would form a pumping reservoir, and one as a flood-protection measure to prevent large volumes of flood water entering the excavation. Whilst the main siltation lagoon was designed to carry the normal discharge from the site, it would have been impractical if designed to carry flood flows, which would be permitted to bypass the lagoon system. However, *all* ditches were designed to carry flood water, and in-pit pump capacity was specified such that during times of flooding, water in the pit could be kept to acceptable levels. Flow charts shown in Figures 1 and 2 illustrate the water routing proposed for the mine site; they illustrate the size of discharge figures obtained, and the differences between flood and normal conditions.

SUMMARY

A preliminary approach to the quantification of surface water flow on small ungauged catchments, such as are commonly found at British opencast mines has been described. It should be appreciated, however, that the methods used, especially the empirical FSR method, rely heavily on statistics and when applied to very small catchments are at the limit of their reliability. These methods cannot be directly employed outside the British Isles. Extensive results are not yet available to determine the accuracy of the predictions although similar methods appear to have been useful in small civil engineering projects [6]. Figures deduced from such calculations are best regarded as order of magnitude estimates. As such, however, they are more soundly based than many current estimates used in the extractive industries.

REFERENCES

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TABLE 1

Drainage class	Depth to impermeable layer (cm.)	Slope classes								
		0 - 2°			2 - 8°			> 8°		
		Permeability rates above impermeable layers								
		(1) Rapid	(2) Medium	(3) Slow	(1) Rapid	(2) Medium	(3) Slow	(1) Rapid	(2) Medium	(3) Slow
1	> 80	1	1	2	1	2	2	1	2	3
	40-80	1	1	2	2	2	3	3	3	4
	< 40	—	—	—	—	—	—	—	—	—
2	> 80	2	2	3	3	3	4	—	4	5
	40-80	2	3	3	3	4	4	4	4	5
	< 40	3	4	4	4	4	4	4	5	5
3	> 80	4	4	5	5	5	5	—	5	5
	40-80	4	5	5	5	5	5	—	5	5
	< 40	5	5	5	5	5	5	5	5	5

Winter rain acceptance indices: 1, very high; 2, high; 3, moderate; 4, low; 5, very low. Upland peat and peaty soils are in Class 5. Urban areas are unclassified.

The classification of soils by winter rain acceptance rate from soil survey data.
From: Flood Studies Report [2].

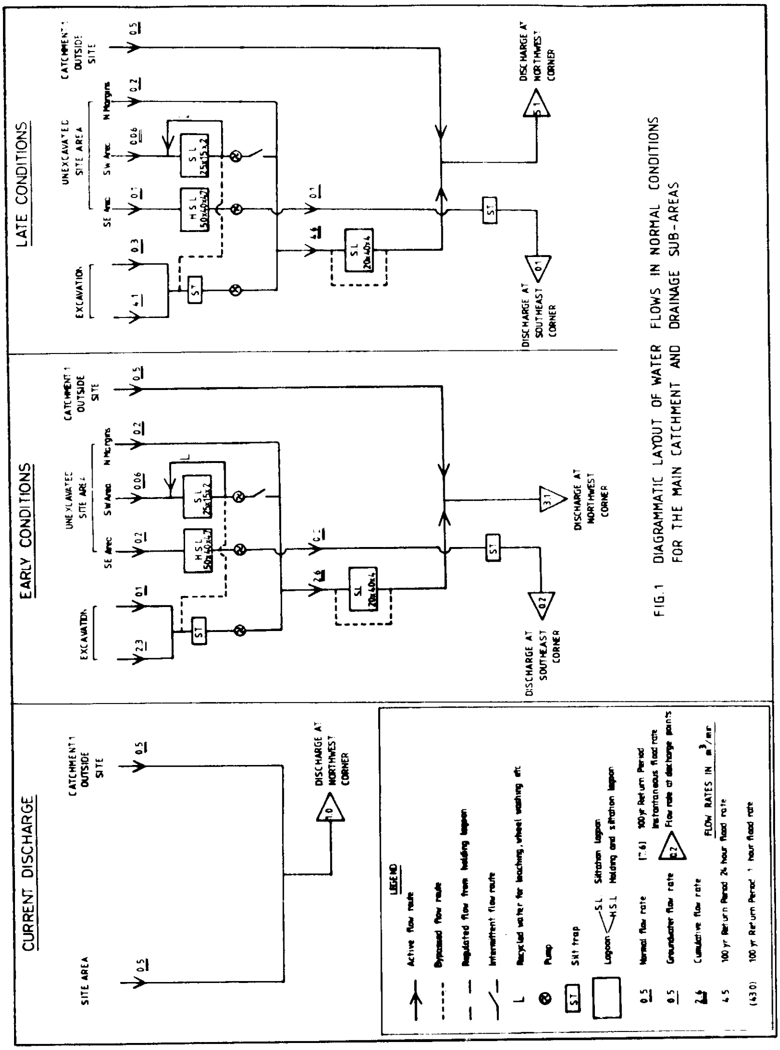
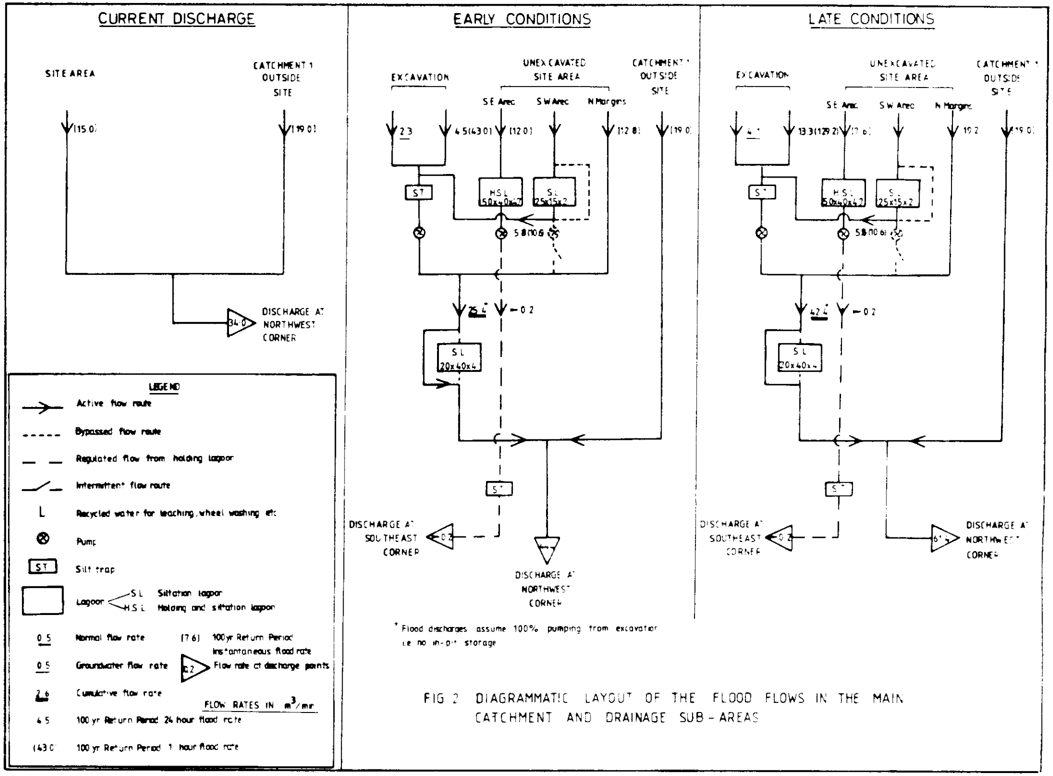


FIG.1 DIAGRAMMATIC LAYOUT OF WATER FLOWS IN NORMAL CONDITIONS FOR THE MAIN CATCHMENT AND DRAINAGE SUB-AREAS



* Flood discharges assume 100% pumping from excavator i.e. no in-pit storage

FIG 2 DIAGRAMMATIC LAYOUT OF THE FLOOD FLOWS IN THE MAIN CATCHMENT AND DRAINAGE SUB-AREAS