Ecological aspects of slimes-dam construction

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SYNOPSIS

This paper gives a brief review of the main environmental and ecological problems of slimes dams, both those created in the immediate vicinity of the dams and those influencing the region or catchment. Methods of dealing with these problems and influences on existing dams are described.

The difficulties encountered in the growing of grass on steep slopes are explained, and, after an analysis of the conditions, a plea is made for flatter slopes on the sides of dams.

SAMEVATTING

Hierdie verhandeling gee 'n kort oorsig oor die vernaamste omgewings- en ekologiese probleme van slykdamme, sowel dié wat in die onmiddellike omgewing van die damme geskep word as dié wat die streek of opvanggebied raak. Metodes om hierdie probleme te hanteer en die invloede daarvan op bestaande damme word beskryf.

Die moeilikhede wat ondervind word met die kweek van gras teen steil hellings word verduidelik en na 'n ontleding van die toestande word daar 'n pleidooi gelewer vir platter hellings teen die kante van die damme.

INTRODUCTION

The word *ecology* is used in one of two senses: either as 'a science concerned with the inter-relationship of living organisms one with another', or it may relate to 'a pattern of such relationships', usually for a particular area.

An ecosystem is an ecological community considered together with its environment as a unit, and the environment consists of the non-living surroundings, conditions, influences, and forces that affect the life and development of living organisms. Thus, when a slimes dam is built on virgin veld, it is the environment of the area that is changed first, and then, because of the changed environment, the dependent ecology changes. This explanation is given because, in this paper, ecological aspects include the associated environmental influences brought about by the building of dams to hold gold-mine tailings, particularly those in the Witwatersrand region.

Slimes, the water-borne tailings from gold-treatment plants, are usually of very small particle size, i.e., a high percentage (usually over 75 per cent) of the material is in the silt and clay categories. The major constituent is silica in the form of quartz, which is present to the extent of 85 to 95 per cent, and the troublesome constituent is pyrite, the concentration of which may be as high as 2,5 to 3,5 per cent, but which is usually about 1,5 to 2,5 per cent. The oxidation of pyrite produces acid and sulphates, and it is mainly the acid that adversely influences the environment and the ecology of the immediate slimes-dam areas. The slimes as deposited are alkaline in reaction, but the oxidation of pyrite causes a gradual accumulation of acidity in the surface layers of the dump, the maximum acidity normally being present in the top 300 mm. When the available pyrite in these surface layers is exhausted, or is deprived of oxygen, the production of acid ceases. It should be noted that the oxidation of pyrite is dependent on the presence of oxygen (air) and moisture assisted by certain bacteria, and that, if oxygen is excluded, oxidation does not occur. As slimes have a very fine particle size (usually holding pore water), the penetration of air into the dump, which has been water-compacted, is limited—normally to less than 2 m.

The designs and the methods of construction of slimes dams that have evolved on the South African goldfields are well known and really need no detailed introduction here. In 1953, the Chamber of Mines entered into a contract with the Council for Scientific and Industrial Research to make an investigation into the structural stability of slimes dams, and in 1959 a report[1] was produced that provided the necessary guide lines for the design of stable dams. During the investigation, the Steering Committee recommended that the most satisfactory method of stabilizing the surfaces of slimes dams would be to establish vegetation on them if this could be achieved. The Chamber of Mines Research Laboratories undertook this task and were successful in determining the necessary principles. It is not intended to give details, for the works of James and Mrost[2, 3] in this field are well known. In 1960 Donaldson[4] presented a paper summarizing the research work done on the stability of slimes dams.

The Chamber issues a 'Code of practice for the construction of slimes dams and the conditions in which they should be left at the time of mine closure'. This 'Code' is a guide to mine managements on how they might construct and close down slimes dams so that they meet their obligations under both the Water Act of 1956 and the Air Pollution Prevention Act of 1965. 'Disposal of Residues', Chapter 6 of a recent book edited by R. J. Adamson[5], is a very useful reference work.

CHANGING CONDITIONS

When a slimes dam is built, changes in the ecosystem in the immediate area of the dam are considerable, and in the region (or, more accurately defined, in the catchment) there are usually some much smaller changes.

How does this come about? Consider the surface of a proposed site for a slimes dam—in most cases an area with a comparatively poor top soil (usually with a silt and clay fraction of about 25 per cent), which is slightly acid but with a sufficient nutrient cycle to maintain the normal veld grasses and plants and thus the rest of the ecological

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chain. The grasses and plant-life prevent surface dust from becoming air-borne by wind, or reduce the amount of dust that does become air-borne, and also slow down the rainfall run-off, thus decreasing or preventing water erosion on the surface. Under normal conditions, not many solids are taken into solution in the run-off, but this depends on the local geological formations.

Then a slimes dam is constructed on this site. What happens? The barren, acid-producing water-borne tailings quickly drown and completely destroy any plant life, and the remnants of the ecosystem (small animals and bird life) move to neighbouring areas. Run-off of rain from a slimes dam takes up acid and dissolved solids (mainly sulphates) and then flows into the nearest stream. In the past (prior to 1964), during the operating life of a dam, the discharging of surplus water from the top, especially during storm periods, into a nearby water course was common practice. This put very considerable loads of acid and dissolved solids into the stream, and often completely destroyed the stream ecosystem for some distance. The first major action taken by the Mining Section of the Industrial Water Division of the Department of Water Affairs was to insist on the recycling of water from slimes dams, with the result that surplus top water and rain water are now recycled through the gold-recovery plants. It should be noted that the ecosystem in a stream is affected not only by run-off and silt from the sides of slimes dams, but usually very much more by mine underground water pumped to the surface and discharged to the stream.

PAST AND PRESENT

Mining on the Witwatersrand commenced towards the end of the last century in the catchments of the Klip River (including Natalspruit) and the Suikerbosrand River (including Blesbokspruit), which have combined catchment areas of 5500 km^2, and, since the start of mining, 72 km^2 of slimes dams and sand dumps have been created.

The present practice, which takes ecological aspects into consideration, is to secure the slimes dams and so prevent or reduce run-off of rain by providing water-holding areas for evaporation, on and around the dams, and to prevent or reduce dusty conditions by vegetating the slimes surfaces and minimizing wind erosion. First of all, an outer wall of slime (where this does not exist) is thrown round the top to prevent run-off from the top down the sides, and contour or paddock walls are built in the enclosed top area to make the storage and evaporation of water more effective. Where necessary and feasible, the sides are more suitably shaped, and paddocks are constructed at the bases of the sides to hold run-off from the sides. Vegetation is then established on the surfaces of the slimes dam. Before all this is done, suitable cut-off drains should be constructed round the slimes-dam site so that run-off and other waters from the up-slope side are diverted round the dam to prevent erosion and the up-take of pollutants.

Up to the present, more than 22 km^2 have been grassed, and many slimes dams have been secured by the construction of evaporation areas to reduce or prevent run-off.

It may be asked whether these control measures are proving successful. To answer this, a survey of dissolved solids in the waters from the Benoni Dam and the Geduld Dam was undertaken (Fig. 1). In the catchment between these two dams, there are 10 km^2 (4 square miles) of slimes-dam and sand-dump surfaces and 10 km (6 miles) of slime silt deposited on the valley floors draining to the Geduld Dam. It was therefore assumed that any increase in dissolved solids in the waters between these two dams was due to the dumps and the silt. (Note: Above the Benoni Dams, there are no dumps.)

In mid-1970, the Rand Water Board began a very comprehensive water-pollution survey, which included this catchment. In Fig. 2, the concentrations of dissolved solids (from this survey) in the waters of the Benoni and Geduld Dams (sample points 1 and 2 in Fig. 1) are shown. It will be seen that the concentrations of dissolved solids in the waters of the Benoni Dam are usually in the range of 500 to 600 mg/l, which is practically the same as that in the Benoni sewage effluents that flow into the dam.

Prior to 1970, when underground mine water was being pumped into the catchment, the dissolved solids content of the Geduld Dam discharge was about 5000 mg/l. Unfortunately, there are no continuous records for conditions prior to 1970. At the beginning of 1970, the pumping of mine water had practically ceased, and a great deal of work (grassing and securing of dumps) to control pollution had been and was being undertaken. It will be seen that the concentrations of dissolved solids in the Geduld Dam discharges dropped from over 3000 mg/l in mid-1970 to within the range of 500 to 600 at the beginning of 1972, and have continued to remain there.

During 1972, the Chamber of Mines made a survey of the concentrations of sulphates in the waters of these two dams and the same pattern was noted, i.e., there was not much difference between the two waters. The sulphate concentration in the Geduld Dam discharge is now less than 200 mg/l, whereas prior to 1970 it had been between 2000 and 3000 mg/l. (For domestic water supplies, the South African Bureau of Standards' recommended limit is 250 mg/l and the maximum allowable limit is 400 mg/l.)

Apart from the mining industry, the Government Departments of Water Affairs, of Health, and of Mines have been financing work on pollution control measures in the catchment, and, judging by the results the survey has shown so far, a considerable measure of success in pollution control is being achieved.

Samples of silt taken from stream beds indicate that, according to the normal erosion pattern of the past, the silts that are washed off slimes dams lose (by oxidation) practically all the available pyrite content within a distance of 5 km downstream.

To sum up the situation at present, the conditioning (by vegetation) of the surfaces of slimes dams and the reduction of the rainfall run-off by the construction of water-holding paddocks have so far shown

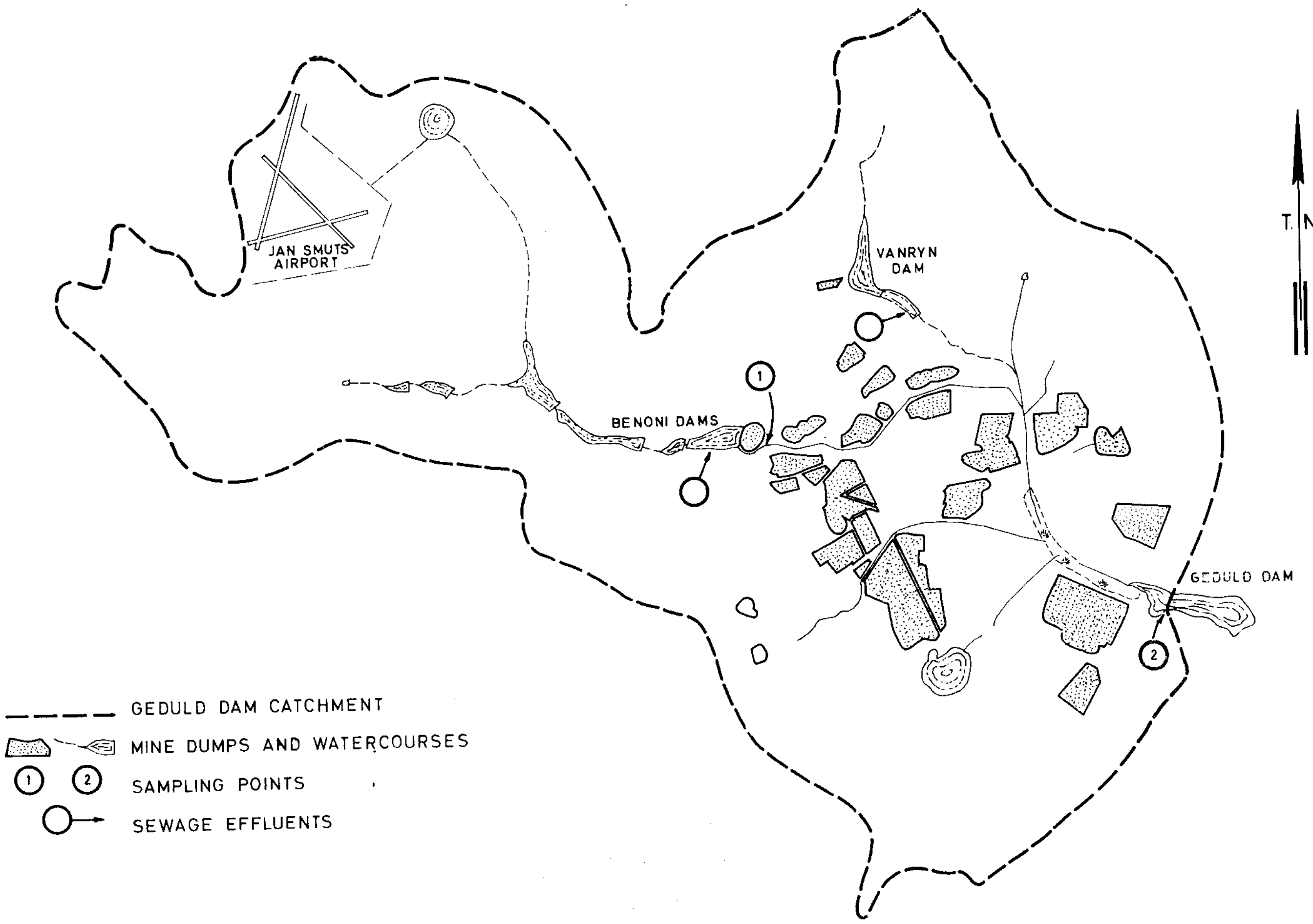

Fig. 1

that ecological restoration requirements are being met.

FUTURE

The establishment of vegetation on the surfaces of existing slimes dams has in most instances proved to be successful, except for the sides of the dams, especially when they are steep. Side slopes steeper than 1 in 1 (45°) have sometimes been found on old existing dams. Acid conditions (due to evaporation and capillary action) have recurred and caused the failure of vegetation growth, but it appears that the major problems in maintaining growth are the physical conditions created by the slopes.

When the gradient is 1 in 1, the slope length is 1,41 times the horizontal, which thus reduces the effective annual rainfall on the Witwatersrand from 750 mm to 530 mm. On the other hand, when the gradient is 1 in 3, the slope length is 1,05 times the horizontal and the effective rainfall is reduced to 712 mm.

Soil erosion is dependent on run-off velocity for that particular run-off volume, and run-off velocity is dependent on the slope of the sides so that, the steeper the slope, the greater the velocity of run-off and the greater the amount of erosion.

As the oxidation of sulphides tends to cause particles to become cemented together, the permeability of oxidized slime is low, and this, coupled with high run-off velocity, causes the absorption of rain water on the sides to be very low.

The Government Mining Engineer originally suggested, as a guide to Mine Inspectors, that the slope of the outside walls of slimes dams should be between 30° and 45°, depending on the type of slime, conditions of ground, and rate of rise, and that, where the stability of the wall was in doubt, stepping-in at intervals to form ledges from 3 to 15 m or more wide should be resorted to.

In the Chamber's 'Code' of 1968, a gradient for the sides of 1 in 2 (27°) was recommended for the following reasons.

(a) The flatter the slope, the less difficult and less costly it would be to establish and maintain vegetation on the slope.
(b) It is just possible for a crawler tractor to work on a slope of 1 in 2.
(c) A general review of embankment construction revealed that motorway embankments in Europe were in the 1 in 2 range, but that there was a tendency to make these less steep where possible.

Incidental benefits include the following.

(1) The flatter the slope, the greater the permissible slimes-dam height and therefore the greater volume of slime per unit area of land (for dams of reasonable size).
(2) The flatter the slope, the greater

the structural and surface stabilities, and the less critical the ground foundation conditions become.

A report[6] by a committee set up in October 1971 by the Institution of Civil Engineers, London, states:

25. Vegetation on tips is closely linked to the gradients on the side slopes.
26. Planning authorities, in their conditions of consent to the construction of tips, in most cases require that the surfaces of tips be given some form of treatment and lay down the shapes of tips in the form of restrictions on heights and gradients.

In 1972, a report of the Canadian Department of Energy, Mines and Resources[7] states:

there has been no case of stable reclamation where the original slope is over 28 °.
(Note: *Stable* here refers to surface stability—not structural stability.)

From present general world-wide information it appears that, for surface stability and aesthetic reasons, it is preferable to construct (where economically feasible) embankments with a slope in the 1 in 3 range (18 °).

In the CSIR report[1] on the structural stability of slimes dams, it is stated that, for any given strength and factor of safety, the permissible height will increase as the angle of the slope is decreased. Donaldson considers a cohesive strength of 96 kN/m² (2000 lb/ft²) suitable for slime, and a factor of safety of 1,5 as safe for a structure such as a slimes dam. On the basis of these two premises, and by extrapolation of his results, the permissible slimes-dam heights for the angle of wall slope can be derived. These are shown in Fig. 3: for a 1 in 1 (45 °) slope, the permissible height is 20 m; for a 1 in 2 (26 ° 30′) slope, the height is 26 m; and, for a 1 in 3 slope (18 ° 30′), the height is 33 m.

For purposes of comparison, consider hypothetical cases of square slimes dams (on level ground) with bases of 500 m and 1000 m, and with side slopes of 1 in 1, 1 in 2, and 1 in 3. Cross-sections of these are shown in Fig. 4. Table I gives details of volumes of slimes and slime surface areas for these, and it will be seen that, within the range of slopes, the volume of slimes per ground unit area and per unit of slimes dam

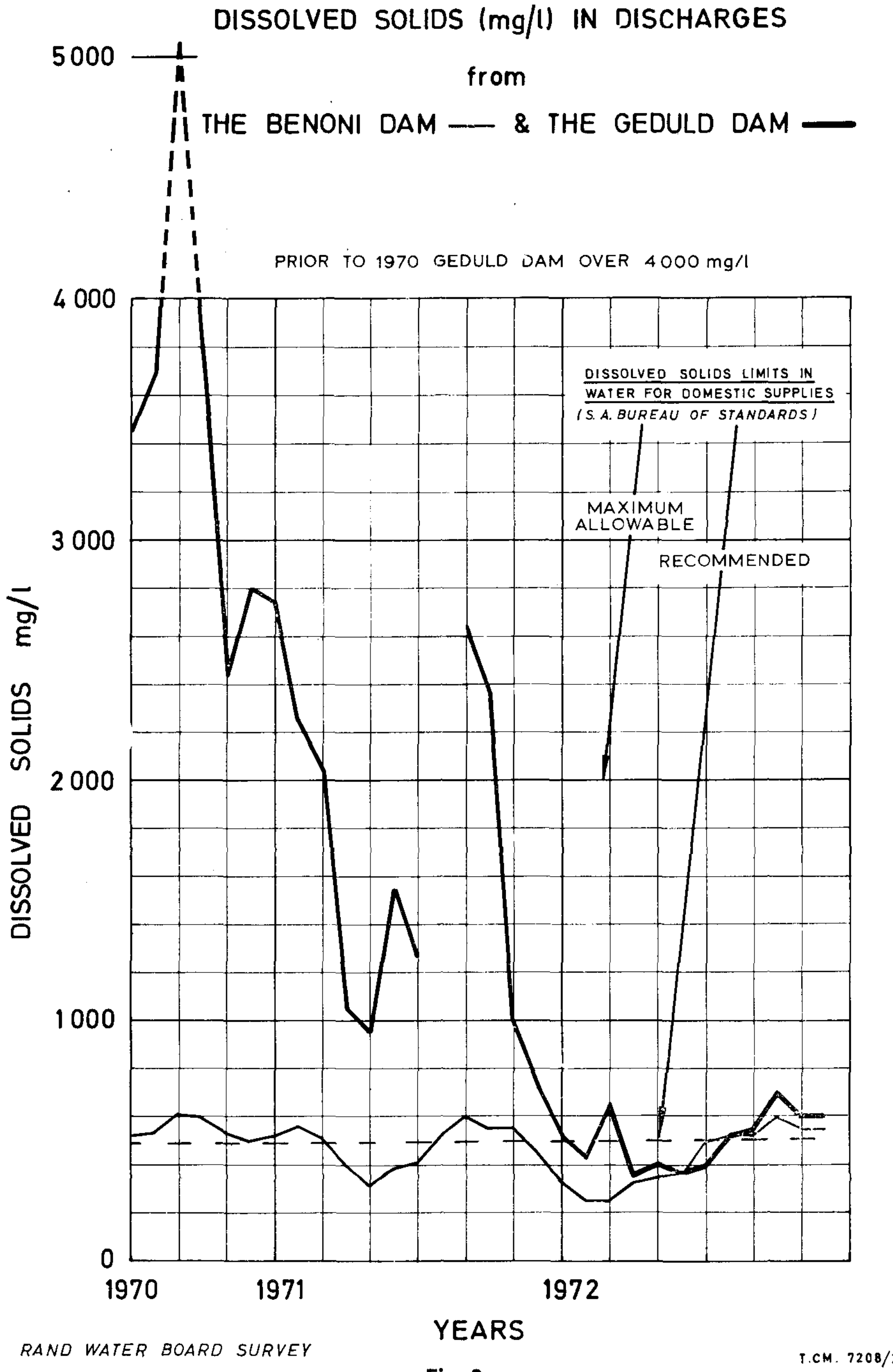

Fig. 2

TABLE I
DETAILS OF HYPOTHETICAL SLIMES DAM

Wall slope	1 in 1 (45 °)	1 in 2 (26 ° 30′)	1 in 3 (18 ° 30′)
Permissible height, m	20	26	33
Slime volume, m³			
500 m side	4 616 000	5 288 608	5 629 866
1000 m side	19 216 000	23 436 608	27 112 866
Dam surface area, m²			
500 m side	265 898	260 966	258 575
1000 m side	1 032 458	1 023 268	1 019 267
m³ slime under m² dam surface			
500 m side	17,4	20,3	21,8
1000 m side	18,6	22,9	26,6
m³ slime on m² ground surface			
500 m side	18,5	21,2	22,5
1000 m side	19,2	23,4	27,1

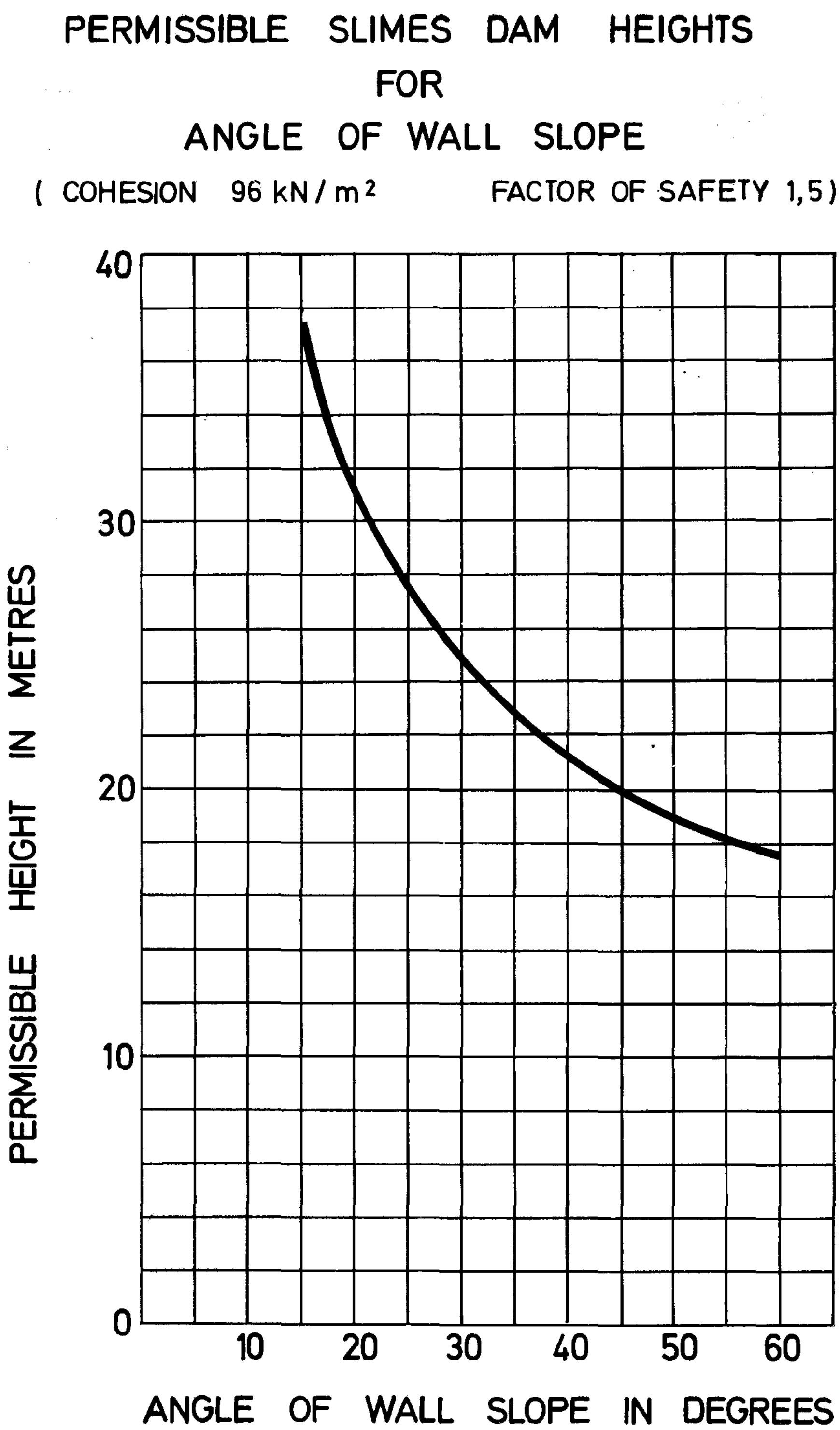

Fig. 3

surface (including sides) becomes greater as the side slope angle decreases and the permissible height increases.

For the greatest chance of achieving a self-sustaining maintenance-free grass cover for new slimes dams, it is suggested that the side slopes should have a gradient of approximately 1 in 3. Each slimes dam has to be designed to suit local requirements and topography. Unless the site is fairly level, the dam should be built with its long dimension on the contour, and it has been suggested that, for aesthetic reasons, the use of right angles or acute angles at the corners should be avoided, and the corners and top edges should be rounded. When land is acquired for slimes dams, these requirements should be borne in mind.

It is debatable whether expenditure is justified on attempts to establish vegetation on the surfaces of old abandoned slimes dams with steep sides and hard surfaces, and with paddocks to hold run-off water at the base of the walls.

COSTS

A broad overall cost picture is given in Table II.

TABLE II
ESTIMATED RANGES OF COST AT PRESENT (PER TONNE MILLED)

Total reduction costs (including slimes-dam costs)	Cents 90 to 110
Slimes-dam costs	
Preliminary construction	1 to 2
Operating costs	1 to 2
Securing and grassing	1 to 2

From these it will be seen that the cost of dealing with the ecological aspects of slimes dam construction (securing and grassing) increases slimes-dam costs by about 50 per cent, and represent between 1 and 2 per cent of the total reduction costs. These figures are for existing well-designed dams. For dams on old existing mines on which problem conditions have been created in the past, the costs of grassing are usually higher, and the old mines find these additional charges very burdensome.

Practically all costs incurred on slimes dams (including securing and grassing) can be charged to working costs. It should be remembered that, as it is not possible to grass slime surfaces in the early stages of dam construction because of formation of acid, it is permissible for mines to set aside, in approved trust funds, monies chargable to present working costs but to be used on this work at a later stage. Paying for higher standards cannot be considered inflation; higher costs for the same standards create inflation.

An alternative title for this short paper could have been 'Slimes dams and the environment'. Today, when conservation of the environment is uppermost in people's minds, the concluding paragraph of an article

HYPOTHETICAL SLIMES DAMS

CROSS SECTIONS

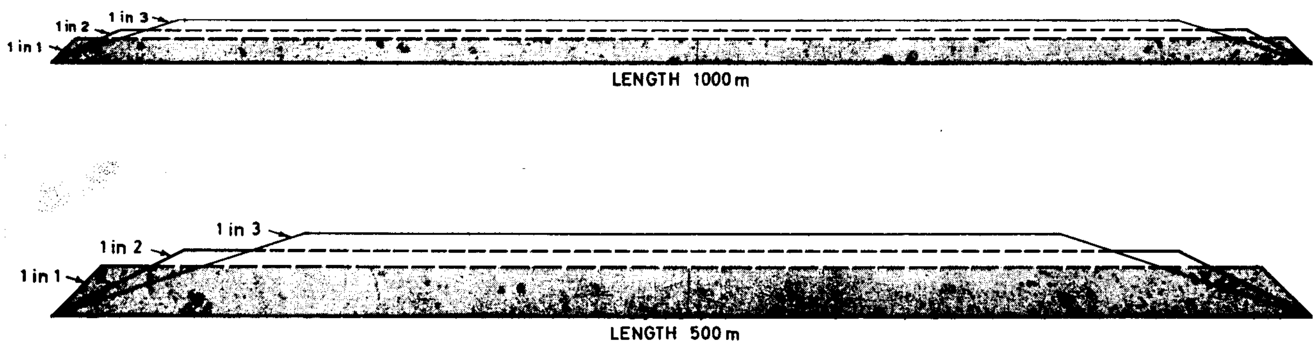

Fig. 4

by Dr M. G. Atmore[8] is most relevant and is worth quoting:

> What is important is that today, all over the world, man has come to realise that the pursuit of material prosperity ought not to be achieved at the cost of sacrificing to any considerable degree the other qualities of life. How society is to value the degree of impairment, in relation to the degree of economic advance, is really what the argument is all about. It is surely not beyond our ingenuity to learn how to weigh the various factors objectively and find solutions that are broadly acceptable to the society concerned.

SUMMARY

Seeing that slimes destroy the surface environment on the site of a dam, the aim should be to recreate as nearly as possible a similar environment on the superimposed slimes surface. This is done by making it possible to grow vegetation on the slimes.

Plant life on the slimes surface reduces or prevents dust becoming air-borne by wind, and so prevents air pollution in the surrounding area.

To reduce rainfall run-off from slimes dams and so reduce water pollution, water-evaporation paddocks are constructed on and around slimes dams. Vegetation on the slimes surfaces also helps to reduce water pollution by slowing run-off velocity and so reducing erosion.

The establishment of vegetation on the surfaces of slimes dams has in most instances proved successful except on steep sides, owing mainly to the physical conditions created by the gradients. A side gradient of 1 in 3 is now recommended for new dams. It is debatable whether expenditure is justified in attempting to establish vegetation on the surfaces of old abandoned dams having steep sides, hard surfaces, and run-off paddocks at the base of the sides.

The cost range for the securing and grassing of slimes surfaces on existing dams, many of which were not constructed to optimum dimensions, is 1 to 2 cents per tonne milled. By good design, considerable savings can be made both in the area of land used and in the cost of establishing vegetation, and these savings will possibly offset any additional slimes-pumping charges that may be incurred.

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