Proceedings of the 9th Annual British Columbia Mine Reclamation Symposium in Kamloops, BC, 1985.
The Technical and Research Committee on Reclamation

DESIGN OF WASTE DUMPS WITH FLOW-THROUGH ROCK DRAINS

by Peter C. Lighthall, C. David Sellars, and W.D. Burton

ABSTRACT

A number of mines in mountainous regions of British Columbia are being forced by topographic constraints to dump large quantities of waste rock in valley fills. As stream diversions around dumps are often very costly, a flow-through rock drain may be an economical alternative for conveying streamflow, particularly if suitable mine waste rock is available. Aspects to be considered in design of flow-through drains include analysis of the availability and quality of waste rock, the method of waste rock selection and placement, determination of design floods by hydrologie analysis, hydraulic design, stability of the downstream slope, assessment of sediment production, reclamation and abandonment.

At the Teck Bullmoose Coal Project, a valley fill with a flow-through rock drain was an economical solution to waste rock disposal. The rock drain is being constructed by end-dumping selected, good quality sandstone. Construction of the dump began in early 1984 and observations indicate that the drain is functioning well.

INTRODUCTION

A number of surface mines in mountainous regions of British Columbia and Alberta are being forced by topographic constraints to dump large quantities of waste rock in valley fills. As stream diversions around dumps are very costly, flow-through rock drains can be economical alternatives for conveying streamflow, particularly if suitable mine waste rock is available.

Most people familiar with surface mining operations are well aware that dumping waste rock over a face will promote segregation, as coarser particles roll to the bottom of a dump face, and that water will flow readily through the base of a waste pile formed in this manner. For the placement of millions of cubic metres of rock into valleys containing fast-flowing mountain streams, however, engineering design is required based on fundamental principles of mining, geotechnical and hydraulic engineering. The objective of this paper is to present a set of principles which can be used in design of rock drains. By applying these design principles, it is the authors' hope that mine operators will be able to realize the potential economies offered by rock drains and to obtain regulatory approvals more readily.

DESIGN CONSIDERATIONS

Rock Quality

An assessment must be made of the quality and quantity of waste rock available for drain construction. Ideally, rock for drains should consist of large fragments of hard, durable material.

The basic element of rock quality assessment is core logging to inventory the rock types and structural characteristics of the waste. Structural logging is important, since even very hard rock types may not be suitable if they are highly fractured and will form small fragments when blasted.

When potentially suitable material is identified by core logging, tests should be carried out to evaluate the compressive strength of the rock. This may be done on samples of core, either by unconfined compressive testing or by empirical correlation of point load tests. Samples of potential rock types for drain construction should be submitted to a qualified laboratory for evaluation of acid production potential. Any potentially acid-producing materials should be excluded from use in the drain.

Coal measures generally consist of a varying sequence of sedimentary rocks, ranging from hard sandstones and conglomerates through to soft, easily weathered siltstones, mudstones and shales. In metal mines, mineral deposits often occur in highly altered rock types, so waste rock quality may vary considerably.

Waste Rock Selection and Placement

Waste rock selection for drain construction must be integrated into the overall mine plan to ensure that suitable rock will be available when required. The constraints of selecting rock could have considerable impact on the mining plan. Ideally, where a bedding layer, seam or deposit of suitable rock is available in sufficient quantities, drain rock can be obtained by normal mining practice, with no special procedures. It may be necessary to widen drillhole spacings to reduce blast fragmentation. In cases where rock is less available, special procedures such as grizzlying waste material or individual selection of rock fragments may be necessary.

There are two basic methods of constructing rock drains for valley fills, depending on the availability of sufficient quantities of suitable rock to convey the design flow. Ideally, good quality waste can be end-dumped from the top of the valley slopes and the drain be formed by segregation of coarse particles at the toe. A minimum height should be specified for end-dumping to ensure that sufficient segregation occurs. Nichols and Rutledge (1982) noted that better segregation is achieved by dumping directly over the slope rather than pushing over the edge with dozers.

The second method of constructing rock drains is to place the rock directly in the drain. This method is required when limited quantities of suitable rock are available and/or where a high quality drain is desired to limit sediment production. The drain conveying Corbin Creek beneath the waste dump at Byron Creek Collieries is to be constructed by direct placement.

Obviously, the direct placement method is considerably more expensive than construction by end-dumping, as select rock must be hauled to the valley bottom.

Hydrologic Analysis

Design of flow-through waste dump drains requires an assessment of the peak flows which the drain must carry. Normally, basic hydrologie parameters are developed as part of the water management plan for a mining development, so that they need only be applied to the specific catchment upstream of the waste dump. The recommended design flow for flow-through waste dumps is the 200-year return period peak flow. The Probable Maximum Flood must be accommodated if the drain is to function following abandonment.

It has been found that a rock drain has considerable attenuation effect on flood peaks. Detailed hydrologie analysis and flood routing through the rock drain will show that the downstream flows are significantly reduced. This can have cost savings for downstream water management structures.

Hydraulic Design

Design principles for flow through rockfill were developed for civil engineering applications for flow through rockfill dams. The principles were derived from the general equation of flow in a porous medium:

$$v = ki^n \text{ where}$$

where v = the velocity

i = the hydraulic gradient

and n = 1 for Darcy laminar flow

For non-Darcy turbulent flow in rockfall, Wilkins (1965) derived the following empirical formula:

$$v = 0.84m^{0.5}\ i^{0.54} \text{ where}$$

where v = the void velocity in m/s

i = the hydraulic gradient

and m = the hydraulic mean radius

$$= \frac{\text{volume of voids}}{\text{surface area of particles}}$$

$$= \frac{\text{void ratio}}{\text{surface area per unit volume}}$$

A factor of safety should be added to the required drain area to allow for accidental placement of poor quality rock.

It is prudent to design the entrance of the rock drain at the upstream side of the waste dump with extra capacity. This may be accomplished by extending the full drain section up the upstream slope, as illustrated on Figure 1. This will provide a factor of safety against debris blockage or blinding with fines over the long term, and will also provide additional entrance capacity for extreme flood flows.

Slope Stability

The stability of the downstream slope of the dump must be considered, as for any waste dump design. Special attention, however, must be paid to the stability of the rock drain up to the highest point of exit of the design flows. The force of the emerging flow will reduce the stability of the slope. Sliding at the toe could lead to progressive sliding on the downstream slope of the dump. Such sliding could cause large volumes of debris and sediment to be carried downstream.

Stability analyses of the waste dump toe should be carried out to determine a suitable design. The common methods of improving toe stability are flattening the slope and providing large, angular rock fragments.

Sediment Production

Rock drains constructed by end dumping will normally contain some fine materials. These materials will initially be flushed through the drain, causing elevated levels of suspended sediment downstream. This will normally require that a sedimentation pond be constructed downstream to allow settling of suspended solids. Observations of operating flow-through drains by Nichols and Rutledge (1982) have shown that over the long term the sediment concentration downstream will be very low.

In some cases, sediment production may need to be reduced, for example where construction of a sedimentation pond downstream would not be practical. This may require direct placement of clean, select rock.

Reclamation and Abandonment

Valley fills, with flow-through drains, lend themselves readily to reclamation. By placing fill in a valley, the surface area of the dump slopes is considerably reduced. The British Columbia Mine Reclamation Guidelines recommend re-sloping dump faces to 27 degrees or flatter.

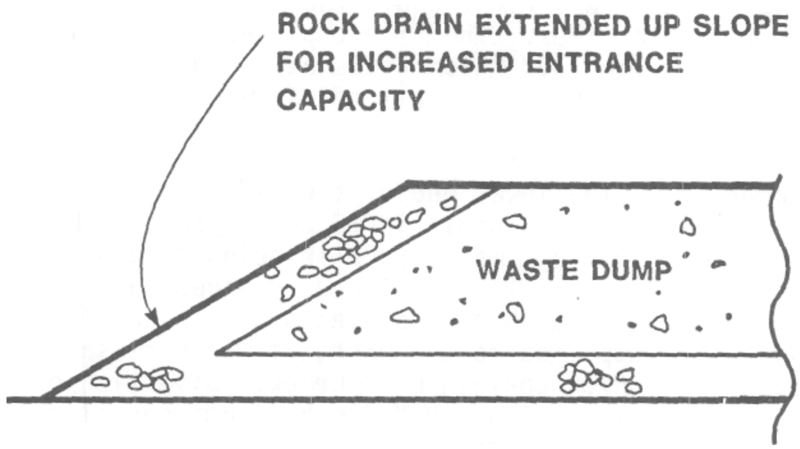
Observations by Nichols and Rutledge (1982) of water draining through waste dumps at Fording Coal indicate that blockage by sediment does not occur in a free-draining dump. Provided that adequate entrance capacity is constructed, flow-through drains should be suitable for abandonment.

CASE HISTORY - BULLMOOSE COAL MINE

To illustrate how the above design criteria can be applied, the

FIGURE 1

UPSTREAM SLOPE OF WASTE DUMP



development of a large rock drain at the Bullmoose Coal Project is described. The Bullmoose Coal Mine is located in the northeast coal development of British Columbia. Waste dump plans were submitted to government as part of the development plan and these were granted approval with delay. The mine commenced production on schedule and under budget in November 1983 and has operated profitably since that time. Figure 2 shows a plan of the development.

The mine is located on a ridge above the confluence of West Bullmoose Creek and Bullmoose Creek. The five coal seams to be mined lie nearly parallel to the ridge top, which rises at a slope of about 10° to the south. The sides of the ridge fall off toward stream valleys to the east, north and west.

Mining commenced at the lower end of the ridge and will proceed uphill to complete mining at the summit in 16 to 18 years. During pre-production and early years of mining, waste rock is being disposed in sidehill waste dumps, after which waste will be placed in mined-out areas of the pit as well as waste dumps at higher elevations. To develop a large, relatively level dump area to the west, it was necessary to place waste in *a* steep-sided canyon containing Y Creek. Diversion of Y Creek would have been very costly. Although Y Creek is not normally a large stream and dries completely in winter, it carries large flows during spring runoff and heavy rainstorms. Rigorous design procedures were required to develop a drain which would carry the flow of Y Creek.

Design Aspects

Through examination of exploration drill logs and logging of core from two additional diamond drill holes, an inventory of rock types was developed. Fortunately, the waste materials at Bullmoose are of good quality, with the approximate proportions during initial mining stages being 40% hard, durable sandstone, 40% medium strength siltstone and 20% lower strength, degradable mudstone/shale. Point load index tests performed on selected sandstone samples indicated an unconfined compressive strength of 125 to 165 MPa. Both slake durability tests and magnesium sulphate soundness tests were carried out on sandstone samples, both of which indicated the material was resistant to weathering and chemical breakdown.

As ample quantities of waste rock were determined to be available, it was possible to design the drain conservatively.

The design data for the Y Creek rock drain are listed in Table 1.

A typical section through the waste dump is shown in Figure 3. The waste dump is about 100 m high, but the maximum water level in the rock drain during the 200-year peak flow will be only 12 m above the creek bed. The drain section is extended entirely up one side of the valley and will provide a flow area of about 4 times the required area of 400 m^. This generous drain section will provide a considerable factor of safety for

Proceedings of the 9th Annual British Columbia Mine Reclamation Symposium in Kamloops, BC, 1985.
The Technical and Research Committee on Reclamation

FIGURE 2

PLAN OF BULLMOOSE COAL MINE

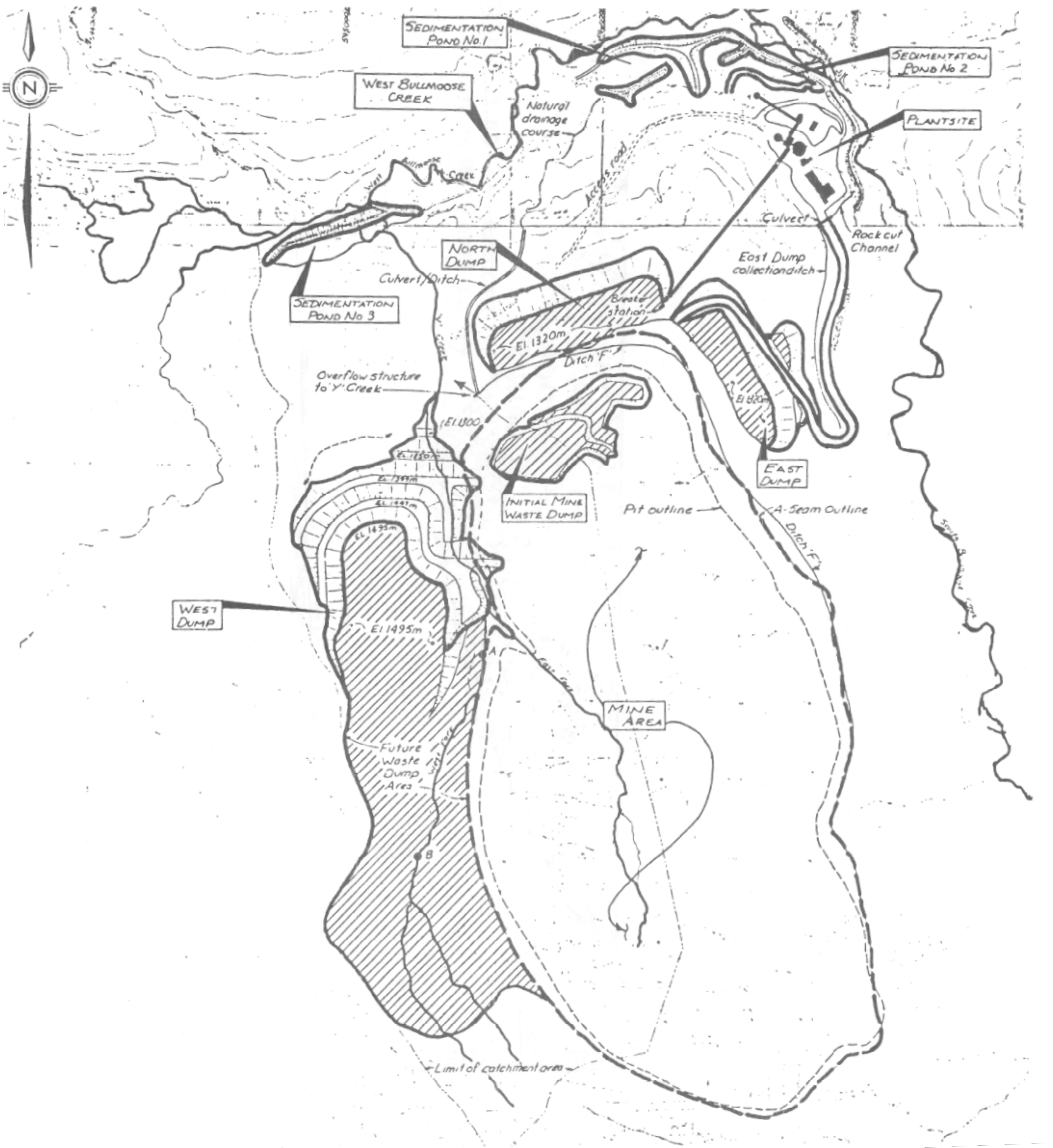


FIGURE 3

FLOW-THROUGH ROCK DRAIN

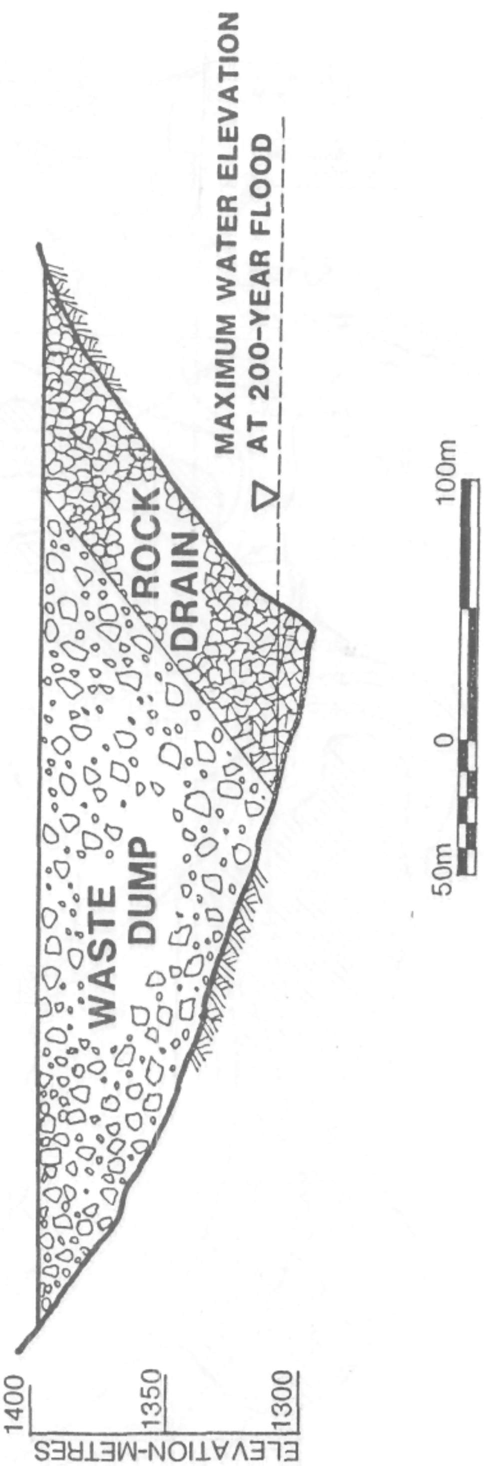


TABLE 1

ROCK DRAIN DESIGN DATA

Average rock size:	300 mm
Rock size after breakage:	240 mm
Initial void ratio:	0.7
Final void ratio:	0.6
Hydraulic gradient:	0.08
Design flow:	25.7 m^3/s (200 year flood)
Void velocity:	0.17 m/s
Mean velocity:	0.064 m/s
Cross-sectional area:	400 m^2
Typical flow depth:	12 m^2
Minimum drain height:	20 m

the entrance at the upstream end, in case of ice or debris blockage or the placement, in error, of finer material during dump construction. As the select material is readily available there is no cost: penalty in providing a large safety factor.

Figure 4 shows a typical design section of the downstream slope of the waste dump along the alignment of Y Creek. The creek section was designed with a toe berm to accommodate the high water levels at the outlet during peak flow. The slope was designed to be flattened to 3.5 horizontal to 1 vertical, with a riprap toe. The overall waste dump slopes are laid out to allow resloping for reclamation. Berms are left at 50 m intervals to allow the slope to be flattened to 27 degrees overall.

In addition to the advantages of convenience, flexibility in dump construction and lower costs, the flow-through rock drain on Y Creek was found to have a significant flood routing effect which reduced the construction costs of the spillway on Settling Pond No. 3 downstream of the dump. (Sellars, Lighthall and Robertson, 1984). Figure 5 is a diagram of the catchment areas contributing to Settling Pond No. 3. The 200-year inflow to the rock drain was derived for Catchment 301 (3.08 km^). The hydrograph from Catchment 301 was routed through the rock drain, and then added to the hydrograph from Catchment 302 (2.64 km^). The combined hydrograph was the inflow to the settling pond.

The inflow design hydrographs to Settling Pond No. 3 are shown in Figure 6. The routing effect of the rock drain not only reduced the peak flow from Catchment 301 but also delays the timing of the peak. When the outflow hydrograph from the rock drain is added to the hydrograph from Catchment 302, the total peak inflow to the pond is reduced by a factor of about two. This hydrologie analysis allowed a reduction in the size of the spillway design for Settling Pond No. 3, which is located downstream of the waste dump, just above the confluence of Y Creek with West Bullmoose Creek. As the dumps are extended to cover more of the Y Creek catchment

FIGURE 4

DOWNSTREAM SLOPE OF WASTE DUMP

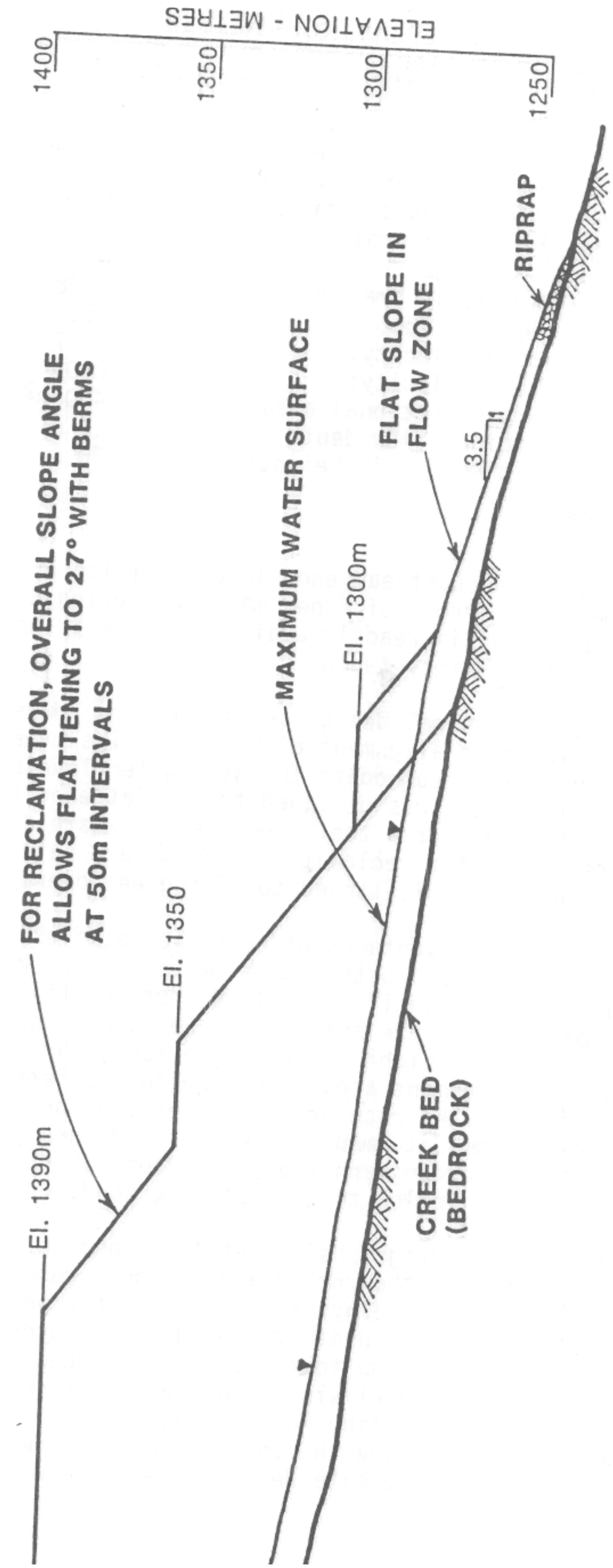


FIGURE 5

Y-CREEK CATCHMENT AREAS

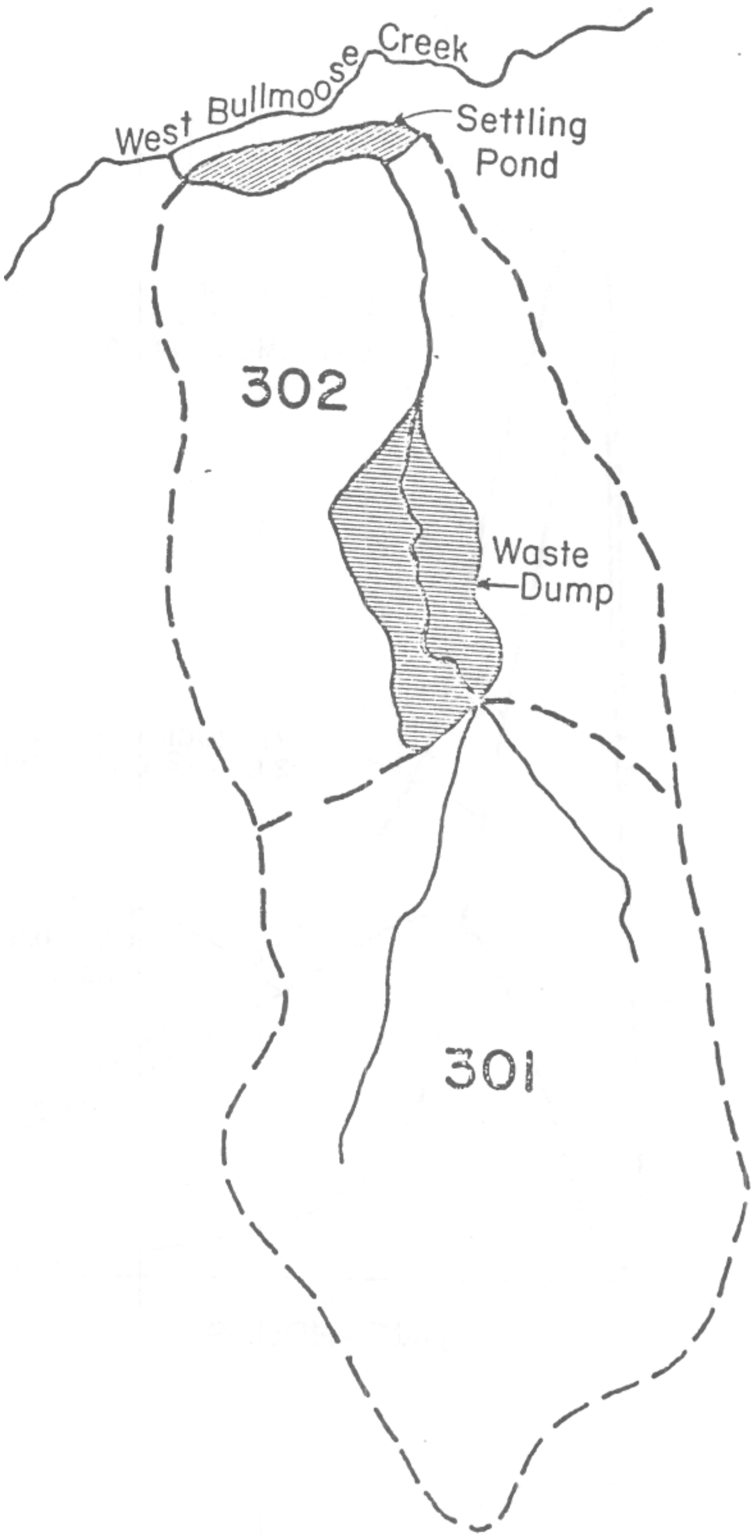
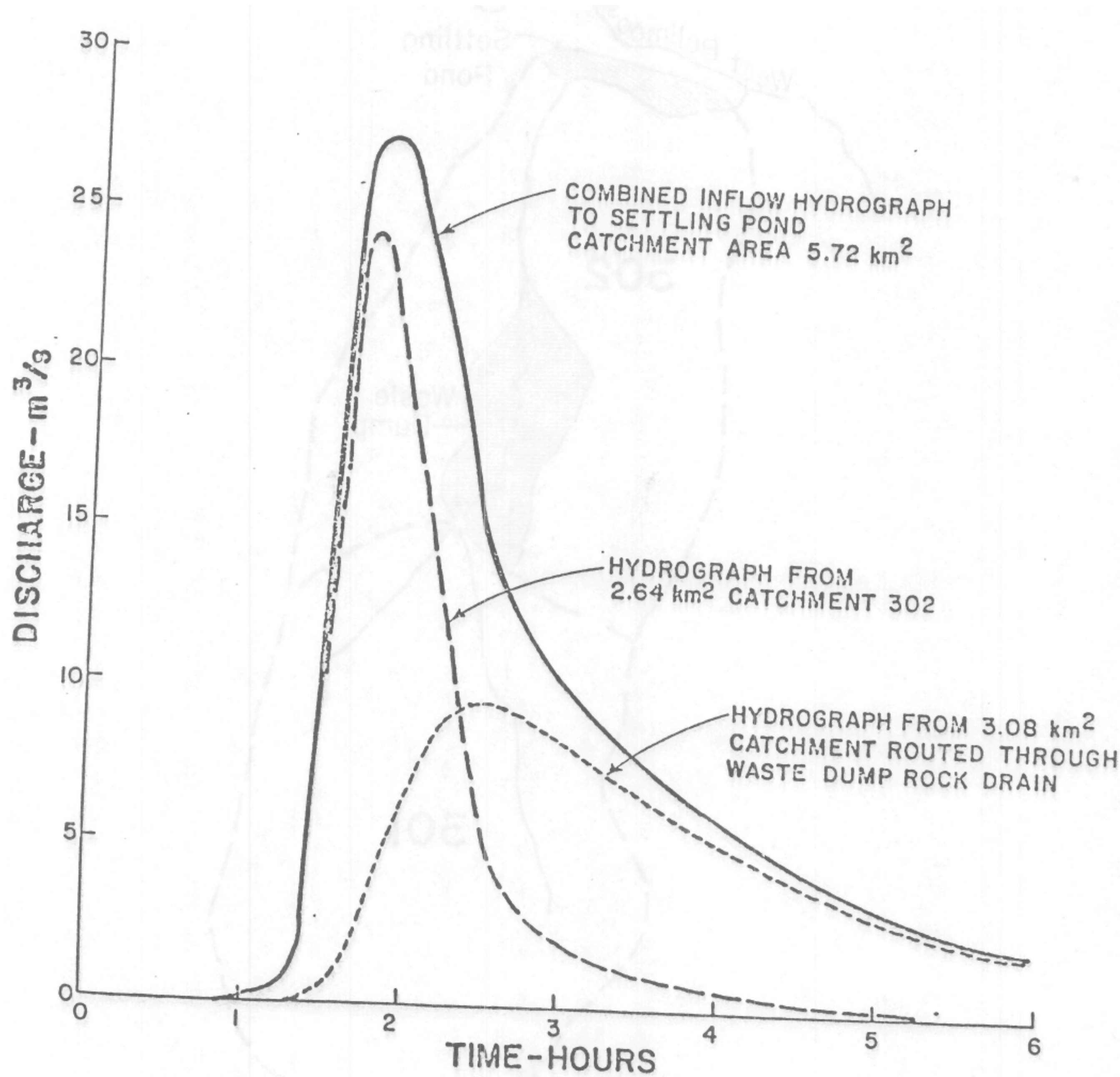


FIGURE 6

SETTLING POND NO. 3
200-YEAR INFLOW DESIGN HYDROGRAPHS



area, the flood peaks will be further attenuated as runoff infiltrates into the dumps.

Construction and Performance.

Construction of the waste dump drain began in early 1984, with placement of a high lift at elevation 1390 m near the downstream end of the Y Creek drain. Subsequently, in late 1984 and early 1985, berms were added at elevations 1350 m and 1300 m. Partial drain sections were also placed as creek crossings at several locations upstream.

Prior to the spring freshet in 1984, very little flow was observed in Y Creek and Bullmoose personnel were concerned whether the drain was functioning properly. However, as snowmelt began, the rock drain carried all of the flow with no blockages observed even at the highest flows. As expected, a considerable amount of sediment was flushed from the drain initially. By summer, however, flows appeared free of sediment.

One design modification has been agreed upon since construction of the downstream slope. The flattening berm at the toe of the dump has been eliminated. The toe area is so well confined by the canyon walls and by a bend in the stream alignment that no instability would be expected during high flows, other than minor ravelling at the toe.

CONCLUSIONS

In summary, the advantages of the flow-through rock drain at Bullmoose Coal Mine are:

- convenient waste disposal location in valley fill;
- avoids costly stream diversion and erosion control measures;
- allows flexibility in dump construction;
- constructed at no cost to the mine other than requirement for selective disposal of waste rock;
- has significant flood routing effect which reduces downstream spillway construction costs.

By the application of sound engineering principles, waste dumps can be designed to safely carry significant streamflow, both during mine operation and following abandonment. The rock drain at Bullmoose has operated successfully to date and is an excellent example of the use of these principles to develop a safe and economical design.

LITERATURE CITED

Nichols, R.S. and Rutledge, A.L. (1982) Water Drainage Through Waste Dumps at Fording Coal Ltd. CIM Bulletin Vol. 75, No. 844-

Wilkins, J.K. (1956) Flow of Water Through Rockfill and its Application to the Design of Dams. Proceedings of the Second Australian Soil Mechanics Conference.

Sellars, C.D., Lighthall, P.C. and Robertson, J. (1984) Cost-Saving Water Management Strategies for Control of Runoff from Mine Developments. Canadian Water Resources Association 37th Annual Conference, May 16-18, 1984.