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HYDRAULIC BOREHOLE MINING
FOR PITCHING COAL SEAMS

FINAL REPORT

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ABSTRACT

This project was undertaken to extend the vertical borehole mining concept to the new tool configurations needed to economically mine pitching coal seams. The objective was to determine the optimum borehole mining plan and system for mining coal seams less than 10 feet thick that pitch more than 25 degrees. Of the methods considered, the double-drill method was selected for further study. This method uses a larger vertical hole for the pumping tool and a smaller slant hole for the cutting tool. The slanted cutting hole is drilled down-the-dip on the footwall of the seam to intersect the vertical hole at maximum depth. The cuttings thus drain down the cutting hole to its intersection with the pumping hole, from which they are pumped to the surface.

Detailed engineering efforts demonstrated double-drill method technical feasibility and performance capabilities. However, these efforts also revealed two items that require further development: (1) The borehole slurry pump and (2) the means to ensure vertical and slant borehole intersection. Recommendations as to the type of equipments needed and the effort required to develop them for this application are given.

Detailed economic studies of the double-drill method were conducted. These studies indicated that this method has a very favorable economic potential, i.e., potential internal rates of return of about 50 percent per year. This implies that pitching coal seams could be mined more profitably using this method than can level coal seams using conventional underground mining methods.

Based on the success of this project, it is expected that double-drill hydraulic borehole mining will prove to be a valuable tool for recovering pitching coal resources if its development is continued.

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Table of Contents

List of Figures

List of Tables

List of Tables

EXECUTIVE SUMMARY

Conventional hydraulic borehole mining consists of drilling vertical boreholes from the ground surface to the underground coal deposit, removing the coal from the mining face with high-pressure waterjets, crushing the larger coal fragments to a transportable size, and lifting the fractured coal to the surface via a slurry jet pump. All mining equiment is operated from the surface--only the mining tool itself is underground. This mining method allows underground coal deposits to be removed with increased safety and decreased cost compared to other underground mining methods and eliminates the extensive surface disruption associated with strip mining.

During this project, "Hydraulic Borehole Mining for Pitching Coal Seams," Flow Industries, Inc. has extended the vertical borehole mining concept to the new tool configurations needed to economically mine pitching coal seams. The objective was to determine the optimum hydraulic borehole mining plan and system for mining coal seams that pitch more than 25 degrees and are less than 10 feet thick.

The Phase I objectives were to develop mining methods and the corresponding equipment for mining steeply pitching, thin coal seams. A variety of mining methhods were studied to determine the method most likely to succeed economically while providing maximum resource recovery. The results of the preliminary production analysis are summarized in Table 1. The major features distinquishing the various methods are listed across the top of the table. The total investment and mining cost figures were used for economic comparison of the methods. Based on these data, the double-drill method was selected for further study. The down-dip method was determined to be of interest but of secondary importance. The double-drill method, an original concept resulting from this contract effort, uses two boreholes, i.e., a larger vertical hole for the pumping tool and a smaller slant hole for the cutting tool. The slanted cutting hole is drilled down-the-dip at the bottom of the coal seam to intersect the vertical hole at maximum depth. The cuttings thus drain down the cutting hole to the intersecting pumping hole from which they are pumped to the surface.

The Phase II objective was to characterize tool features and verify both the performance and economic feasibility of the selected method (double-drill

Table 1. Economic Comparison

Method	Tool Diameter, in.		Mining Rate, tph	Cavity Radius, ft	Cavity Height, ft	Dip Spacing, ft	Strike Spacing, ft	Effective Availability, %	Drill Cost, $/ft		Total Investment, $ mil	Mining Cost, $/ton
	Pump Tool	Cutting Tool							Pump Holes	Cutting Holes		
Double-Drill Horizontal Cavities	18	6	50	40	40	50	80	82	75	50	26	11.19
Double-Drill Vertical Cavities	18	6	50	20	1344	-	50	81	75	50	28	10.92
Down-Dip Horizontal Cavities	12	-	30	30	40	50	60	83	150	-	32	17.86
Down-Dip Vertical Cavities	12	-	30	20	1344	-	50	83	150	-	34	19.69
Perpendicular-to-the-Dip Rooms	12	-	30	30	10	40	70	52	150	-	110	208.83
Perpendicular-to-the-Dip Tunnels	12	6	30	30	10	28	70	52	150	50	77	89.82
Auxiliary Cutting Jet	18	6	50	40	10	38	50	51	75	15	38	23.67
Diagonal-to-the-Strike	-	6	50	40	10	71	2000	81	-	100	945	60.28
Up-Dip	-	6	50	20	1344	-	50	77	-	100	495	38.53

method). To this end, design and economic analyses were performed and a scale model built to confirm both the attainability of predicted performance targets and the technical feasibility of tool characteristics. The major unproven features of the double-drill method are the slurry pumping and borehole intersection methods. Candidate pumps include a commercially available electric-motor-driven downhole centrifugal slurry pump and a hydraulic-actuated slurry piston pump that is still in the development stage. Either of these pumps would cost approximately $250,000 to prepare for field testing. The borehole intersection approach being considered is to first drill the vertical pumping hole and install a sensor at its bottom. The slant cutting hole is then drilled using a transmitter-equipped tool. The signal from the sensor is used to guide the slant cutting hole drill such that it intersects the vertical hole. This sytem would be backed up with a real-time logging system on the slant drill.

Separate, more detailed economic analyses performed for both the double-drill and down-dip methods showed very favorable internal rates of return (52 and 19 percent, respectively). A double-drill method sensitivity study indicated that the significant parameters are seam thickness, maximum cavity radius, mining rate, mining system availability, and, of course, product value. The detailed economic analysis also showed that the double-drill method can produce coal from pitching seams at less cost than conventional underground equipment mining from horizontal seams. Therefore, it is concluded that the double-drill method is extremely attractive economically and should be developed further for use in the recovery of pitching coal by the mining industry.

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1. Introduction

1.1 Background

The hydraulic borehole mining method includes site selection, mining plan development, site preparation, borehole drilling, equipment setup, mining operations, slurry handling, and, if desired, backfilling operations. A typical borehole mining system setup is shown on Figure 1. The mining tool includes the main swivel, tool sections, mining section, and the independent cutting jet system. The mining trailer carries the mining tool, derrick, hoist controls, and a diesel-powered hydraulic pump. The pump trailer carries diesel-powered high-pressure pumps and an electric-motor-driven slurry pump. For some coal mining locales, an all-electric operation may be advantageous.

The mining tool is lowered into a cased borehole to begin mining operations. Production begins immediately as the mining tool simultaneously cuts the coal with a high-pressure waterjet and transports the resulting coal slurry to the surface via a waterjet pump.

Hoses and temporary pipelines transport the slurry to coal dewatering equipment located within a mile of the extraction site. A large fraction of the water is removed from the coal slurry and returned to the holding pond. The resulting wet coal is then pile dried prior to transportation to a storage and loadout area.

Hydraulic borehole mining is an environmentally attractive method for mining coal. It has the advantage of minimizing surface disruptions, waste shale piles, damage to ground water quality and hydrology, and surface water pollution. Surface disruptions are minimal because no overburden is removed. Waste shale and rock piles are small because a negligible amount of host rock is removed. The quality of local ground water and surface streams remains virtually unaffected since only recycled water is used for the mining process.

Preliminary field tests of the the borehole coal mining method were successfully conducted in bituminous coal by Flow Industries, Inc. (Flow) in 1976[1]. At that time, the technical feasibility of hydraulic borehole coal mining was

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[1]Cheung, J.B., Hurlburt, G.H., Scott, L.E., and Veenhuizen, S.D., "Application of a Hydraulic Borehole Mining Apparatus to the Remote Extraction of Coal," Flow Technology Report No. 97, Final Report for U.S. Bureau of Mines Contract No. H0252007, OFR 117-81, September, 1976.

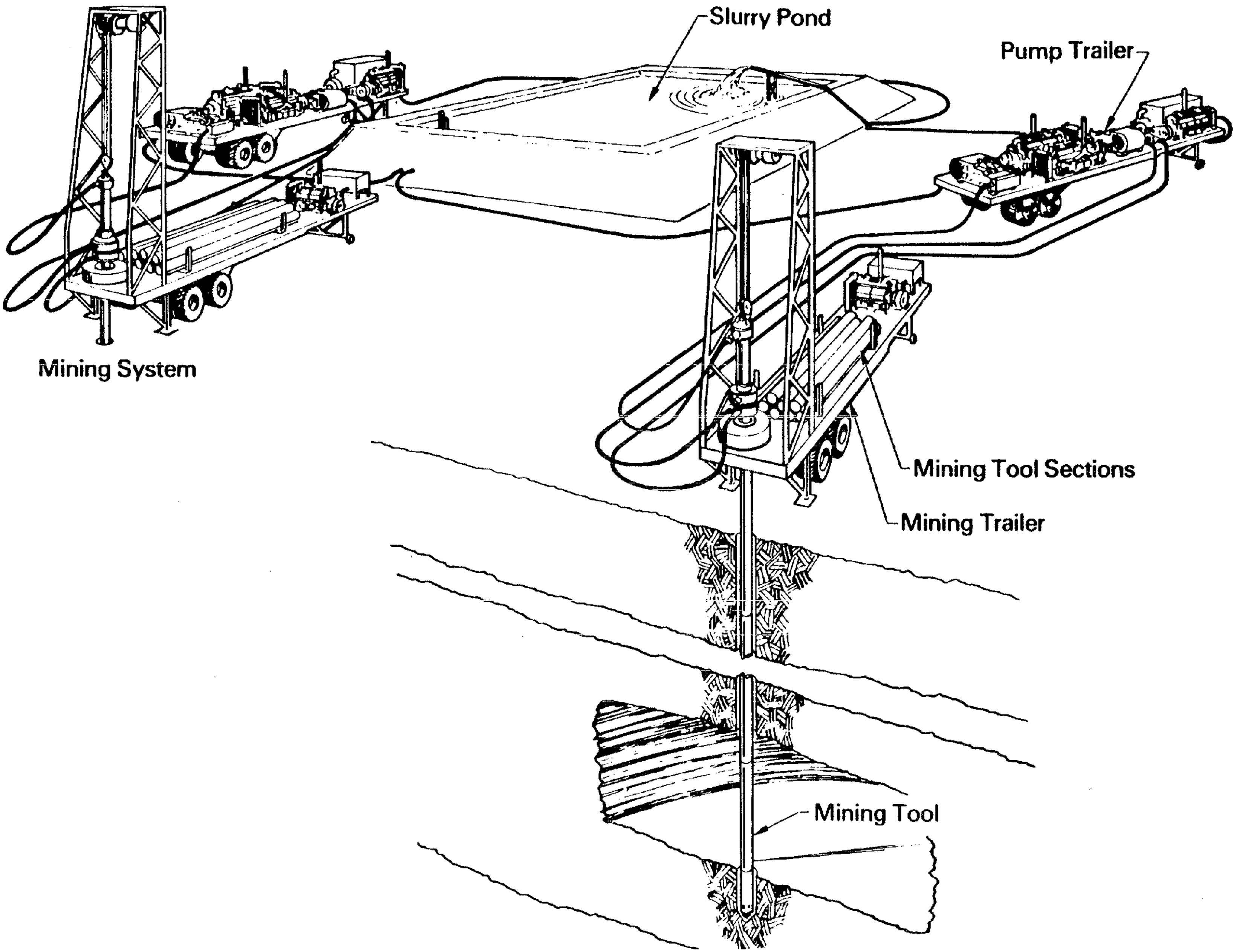

Figure 1. Typical Borehole Mining System Setup

demonstrated by mining 32 tons of coal at a depth of 75 feet over a period of 4 hours. It was discovered during these tests, which involved steeply pitching coal seams, that large shale fragments both from partings in the coal seam and from the hanging wall were plugging the slurry jet pump inlets and reducing the overall mining rate. Accordingly, a hydraulically powered crushing mechanism was developed to reduce such fragments to a transportable size. Field tests of a system incorporating the new crushing mechanism, conducted in 1980 and funded by the U.S. Department of Energy (DOE), demonstrated a combined crushing and pumping rate that intermittently exceeded 30 tons per hour (tph) and averaged 14 tph[2]. The field tests also demonstrated the cutting jet to be capable of rates well in excess of 100 tph. Hence, the overall mining rate of a 12-inch diameter hydraulic borehole mining tool could conceivably average 30 tph.

Concurrent with the DOE-funded coal effort, Flow developed a hydraulic borehole uranium mining system for Rocky Mountain Energy (RME). This is essentially the system shown in Figure 1. This uranium system is scheduled to be retrofitted for coal mining by Flow under contract to the DOE.

1.2 Present Program

During Phase I, the following six mining methods were developed in sufficient detail for a DOE review panel to select one method for further study as part of this contract:

A. Double-Drill Method. Two boreholes are drilled, a vertical hole for the pumping tool and a slant hole down-dip for the cutting tool.

B. Down-Dip Method. A borehole is drilled down the dip of the coal seam. A single tool is then used both to cut the coal and pump it to the surface.

C. Perpendicular-to-the-Dip Method. The borehole is slant drilled perpendicular to the plane of the coal seam.

D. Auxiliary Cutting Jet Method. A single vertical borehole is drilled for the pumping tool and vertical boreholes are drilled for the cutting tools to feed down the dip to the pump.

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[2]Knoke, G.S., "The Application of a Hydraulic Borehole Mining Apparatus to the Remote Extraction of Coal -- Field Test of Borehole Crusher System," U.S. Department of Energy Report No. FE/12483-1 (Flow Technology Report No. 177) for Contract No. DE-AC21-79ET12483, December, 1980.

E. Diagonal-to-the-Strike Method. A large, vertical access shaft is constructed, horizontal tunnels drilled, and the coal is mined via boreholes drilled sloping upward diagonal to the strike.

F. Up-the-Dip Method. A large, vertical access shaft is constructed, horizontal tunnels drilled, horizontal entries drilled in the coal seam, and the coal is mined via boreholes drilled up the dip.

Section 2 provides a detailed description of each mining method, economic parameters, and the results of the preliminary cost analysis.

Based on the preliminary cost analysis results, the double-drill method was selected for detailed analysis during Phase II as reported in Section 3. This detailed analysis included the development of a scale model for the double-drill method, the indentification of unproven features, and a separate, more detailed economic analysis with a parametric sensitivity study. The conclusions and recommendations are given in Section 4.

2. Analysis of Mining Methods

Six mining methods, three with two configurations each, were analyzed for this program. These are discussed in this section in terms of physical configuration and economic viability.

The primary assumption for the economic analysis, based on the production targets, is that 6,000 tons of coal per day will be mined from a 10-foot seam pitching at more than 25 degrees. Secondary assumptions, such as mining a 45-degree pitching seam from 50 to 1,000 feet below the surface, are summarized in Table 2. These assumptions provide a common basis for comparing the economic results. In Table 2, the term "mining system" refers only to the borehole mining tool, the derrick system for tripping the tool, the controls, and the pumps and hoses. Additional operations, such as site work, ore transportation at the mine and loadout, and coal dewatering will require additional labor and supplies, which are included in the operating costs.

These preliminary economic analyses compare the mining cost before taxes, royalties, and profit, which are widely varying, site-specific cost factors. For example, Wyoming extraction taxes amount to 17 percent of the gross while Alabama taxes are only $0.34 per ton. When added to royalty payments, federal income tax, local taxes, and profit to provide a 20-percent return on investment, a $15.00 per ton mining cost corresponds to a selling price of about $25.00 per ton.

2.1 Description of Economics Tables

The economic results for each method studied are presented in tabular form. Each of these tables is divided into three parts: Part A presents the selected initial parameters; Part B lists the calculated parameters based on Part A; and Part C summarizes the capital and operating costs for the particular method.

Part A of each table lists the cavity and borehole dimensions. Cavity height is always defined parallel to the borehole mining tool. Cavity spacing along the strike is the equivalent of borehole spacing. Pump hole extra depth provides a margin for error. Under operating costs, mining rates of 50 tons per hour and 30 tons per hour were selected for units having 18-inch and 12-inch diameter pumping tools, respectively. Moving time is the time lost from mining while the tool is moved from borehole to borehole. The capital

Table 2. Common Basis for Economic Comparison

<u>Ore Body Characteristics</u>	
Seam Thickness	10 feet
Ore Density	83 pounds/cubic foot
Depth to Top of Ore	50 feet
Depth to Bottom	1,000 feet
Dip Angle	45 degrees
<u>Operating Costs</u>	
Total Mine Capacity	6,000 tons/day
Daily Utilization	24 hours/day
Annual Utilization	330 days/year
Mining System:	
Availability	85 percent
Maintenance supplies	10 $/operating hour/unit
Fuel	90 $/operating hour/unit
Miscellaneous supplies	1 $K/year/unit
Operating labor	30 $/hour/unit
Support labor	5 $/hour/unit
Maintenance labor	5 $/hour/unit
Supervisory labor	20 percent of payroll
Payroll benefits	30 percent of payroll
Payroll overhead	40 percent of payroll
Site Preparation	400 $/acre
Ore Transportation	0.87 $/ton mined
Coal Dewatering Plant	0.67 $/ton
Site Reclamation	200 $/acre
<u>Capital Costs</u>	
Exploration	300 $K
Miscellaneous Mining Equipment	300 $K/unit
Coal Dewatering Plant	1,340 $K
Loadout Facility	5,000 $K
Miscellaneous Facilities	2,600 $K
Working Capital	16 percent of annual operating cost
Average Capital Depreciation Period	10 years

cost of a borehole mining system is divided into the mining system (skid-mounted pumps, hoses, derrick, and controls) and the borehole mining tool itself, which is subdivided into its pumping and cutting functions.

Part B of each table lists calculated parametric values based on the selected initial parameters of Part A. Cavity volume is the cross-sectional area times the cavity height. Cavity tonnage is calculated directly from the volume. Borehole tonnage is calculated from the cavity tonnage and the number of cavities that can be accommodated along the dip. Width is defined as the dimension of the seam perpendicular to the strike. This dimension is measured on the surface as the distance from the shallowest end of the dip (50 feet beneath the surface) to the deepest point mined (1,000 feet). Length is the distance along the strike that is mined out each year. Area is calculated from length and width. Ore body density refers to the number of tons of coal beneath a square foot of surface area which, when multiplied by the area, gives the annual ore body requirement. Recovery is then the ratio of annual mined tonnage and ore body requirement. Annual drilling is calculated from the number of holes and the average depth or length of each hole. The effective availability of the mining system is availability (which allows for maintenance down time) less moving time. The effective mining rate is the mining rate per unit adjusted for the number of mining units required to produce the daily production target.

Part C of each table is a summary of capital and operating costs. Exploration includes exploration and development costs prior to equipment buildup. Working capital includes the funds necessary to operate the entire facility to two months, corresponding to the time lag from mining the ore to being paid for it. Borehole mining unit includes the tool, pumps, hoses, controls, and miscellaneous support equipment. Coal dewatering plant includes a sieve-bend, vibrating screen, conveyors, hydrocyclones, and cyclone support equipment. Loadout facilities include trucks, silo, conveyors and elevators, and controls for railcar loadout. Miscellaneous facilities include maintenance facilities and safety equipment.

2.2 Double-Drill Method

This method requires the drilling of vertical pumping holes and slant cutting holes to mine both horizontal and vertical cavities (Figure 2). Seams

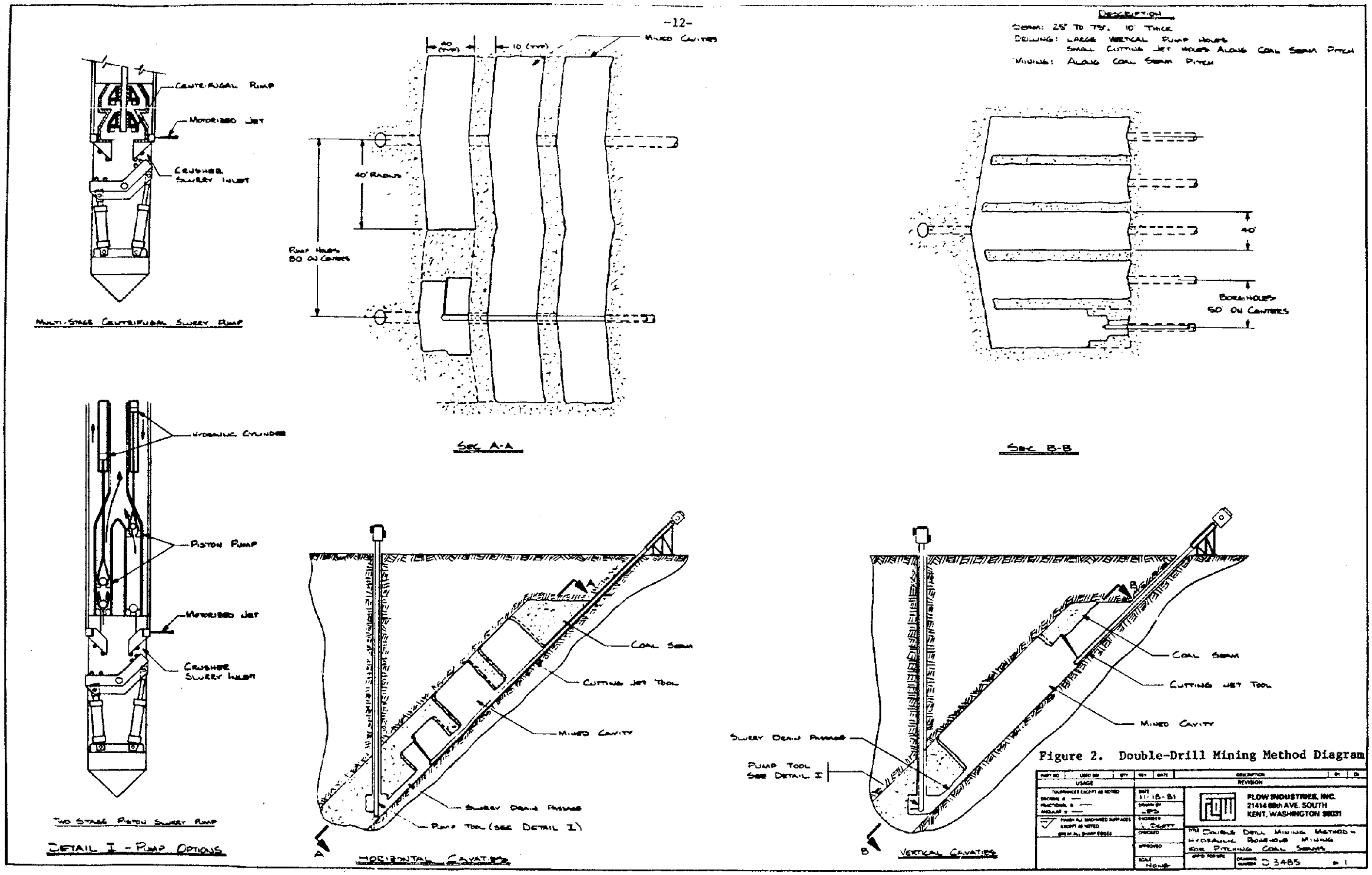


Figure 2. Double-Drill Mining Method Diagram

with dip angles 25 to 75 degrees from the horizontal can be mined using this method. The advantages of this method are low coal recovery costs, high coal recovery percentages, the surface location of all systems and personnel, and the small diameter of the slant-drilled holes. Its disadvantages are the separate pumping and cutting jet tools, difficulty of intersecting two holes, and potential difficulties with interconnecting adjacent vertical cavities.

2.2.1 Horizontal Cavities

The mining of horizontal cavities is initiated by drilling and casing a 24-inch-diameter hole for the 18-inch pumping tool. Next, a 12-inch-diameter hole is drilled for the 6-inch cutting-jet tool along the footwall of the coal seam. The slanted cutting-jet tool hole intersects the vertical pumping-tool hole. The cutting-jet tool is then installed and a small radius (2 to 3 feet) slurry drain passage is formed. Mining begins at the shallow end of the seam and progresses downward along the dip until a cavity 10 feet high, 40 feet long, and 40 feet wide is formed. The cutting jet is directed slightly upward (approximately 3 degrees) and the resulting incline facilitates the flow of slurry down to the slurry drain passage. Cavities overlap along the strike to form an extended horizontal cavity. A 10-foot-thick partition is allowed to remain between cavities along the dip to ensure roof stability.

The basis for economic analysis of the double-drill method horizontal cavity configuration is given in Table 3, Part A. Table 3, Part B, lists the calculated parameters and Table 3, Part C, summarizes the capital and operating costs. Note that Table 3, Part C, shows the borehole mining units to comprise approximately one-half of the total capital cost. Under operating costs, it is interesting that the mining cost, which is not subtotaled separately on the table, of $3.94 per ton is less than the drilling cost. These are the major operating cost components with the other components contributing less than a quarter of the total mining cost, which is significantly below the production target set for cost per ton.

2.2.2 Vertical Cavities

Vertical cavity mining is initiated by drilling and casing a 24-inch-diameter pump hole. A 12-inch-diameter cutting hole is then drilled along the

Table 3. Double-Drill Method with Horizontal Cavities
Part A: Selected Initial Parameters

Cavity Characteristics	
Cavity Height	40 feet
Cavity Radius	40 feet
Cavity Floor Angle	3 degrees
Cavity Spacing Along Dip	50 feet
Cavity Spacing Along Strike	80 feet
Pump Hole Extra Depth	10 feet
Cutting Holes per Pump Hole	1
Operating Costs	
Pumping Tool Diameter	18 inches
Cutting Tool Diameter	6 inches
Mining Rate	50 tons/hour/unit
Borehole Tool Moving Time	16 hours/1,000 feet of tool
Pump Hole Drilling (Vertical)	75 $/foot
Cutting Hole Drilling (Slant)	50 $/foot
Capital Costs	
Borehole Mining System	1,200 $K/unit
Pumping Tool	500 $/foot/unit
Cutting Tool	200 $/foot/unit

Table 3. Double-Drill Method with Horizontal Cavities
Part B: Calculated Parameters

Cavity Volume	28,300 cubic feet
Annual Mined Tonnage	1,980,000 tons
Cavity Tonnage	1,175 tons
Distance Along Dip	1,344 feet
Cavities per Borehole	27
Borehole Tonnage	31,600 tons
Annual Cutting Holes	63
Annual Pump Holes	63
Width	950 feet
Annual Length	5,017 feet
Annual Area	109 acres
Ore Body Density	0.59 tons/square foot
Annual Ore Body Requirements	2,800,000 tons
Ore Recovery	71 percent
Annual Drilling of Cutting Holes	84,300 feet
Annual Drilling of Pumping Holes	63,300 feet
Effective Availability of Mining System	82 percent
Number of Mining Units	6
Effective Mining Rate	51 tons/hour/unit

Table 3. Double-Drill Method with Horizontal Cavities
Part C: Capital and Operating Cost Summary

Capital Cost Summary	$K
Exploration	300
Working Capital	3,179
Borehole Mining Units	13,612
Coal Dewatering Plant	1,340
Loadout Facilities	5,000
Miscellaneous Facilities	2,600
Total	26,031

Operating Cost Summary	$K/yr	$/ton
Site Preparation and Reclamation	66	0.03
Drilling	8,964	4.53
Mining - Payroll	2,281	1.15
- Payroll benefits and overhead	1,597	0.81
- Maintenance supplies	391	0.20
- Fuel	3,516	1.78
- Miscellaneous supplies	6	0.00
Ore Transportation	1,723	0.87
Coal Dewatering Plant	1,327	0.67
Annual Operating Cost	19,868	10.03
Depreciation and Amortization	2,285	1.15
Total Mining Cost	22,153	11.19

seam foot-wall such that it intersects the pump hole. Finally, adjacent cutting holes on 50-foot centers are drilled along the seam strike. These holes, of course, do not intersect the pump hole (Figure 2, Section B-B).

The cutting-jet tool is installed in the hole intersecting the pump hole and the first vertical cavity is formed. The completed cavity will be 20 feet wide by 10 feet high and extend down to the pump hole. As each cavity is begun, the cutting jet is allowed to penetrate through the seam to the adjacent cutting hole. With the first cavity complete, the cutting tool is moved to that hole and the process repeated. The cutting jet is angled upward approximately 3 degrees to provide an incline to facilitate the flow of slurry to the central pump hole. A 10-foot partition is left between cavities for stability.

Table 4, Part A, lists the input parameters for vertical cavities. This table in conjunction with Table 3, Part A, clearly demonstrates the differences between the vertical and horizontal cavity configurations, i.e., continuous cavity (no cavity height and no spacing along the dip), reductions in cavity length and spacing along the strike to support the roof, and the interconnecting of cavities at the bottom (cutting holes per pump). Table 4, Part B, also reflects these changes in terms of cavity volume and tonnage, cavities per borehole, number of cutting and pumping holes, and others. Table 4, Part C, shows the impact of these changes on cost. Increasing the number of mining units by one for the vertical cavity configuration results in higher capital and operating costs. Drilling costs are reduced, however, which results in a slight reduction in overall cost. The total mining cost is below the production target for cost per ton.

2.3 Down-Dip Method

This method requires the slant drilling of 18-inch-diameter boreholes at the seam footwall downward along the dip. Both horizontal and vertical cavities may be mined (Figure 3) in seams with dip angles 25 to 75 degrees from the horizontal. This method's advantages are low recovery costs, high coal recovery percentages, and the surface location of all systems and personnel. Its disadvantages are the handling problems associated with a 12-inch borehole tool in a slant borehole and the high cost of slant drilling 18-inch-diameter boreholes.

Table 4. Double-Drill Method with Vertical Cavities

Part A: Selected Initial Parameters

<u>Cavity Characteristics</u>	
Cavity Radius	20 feet
Cavity Floor Angle	3 degrees
Cavity Spacing Along Strike	50 feet
Pump Hole Extra Depth	10 feet
Cutting Holes per Pump Hole	19
<u>Operating Costs</u>	
Pumping Tool Diameter	18 inches
Cutting Tool Diameter	6 inches
Mining Rate	50 tons/hour/unit
Borehole Tool Moving Time	16 hours/1,000 feet of tool
Pump Hole Drilling (Vertical)	75 $/foot
Cutting Hole Drilling (Slant)	50 $/foot
<u>Capital Costs</u>	
Borehole Mining System	1,200 $K/unit
Pumping Tool	500 $/foot/unit
Cutting Tool	200 $/foot/unit

Table 4. Double-Drill Method with Vertical Cavities
Part B: Calculated Parameters

Cavity Volume	486,000 cubic feet
Annual Mined Tonnage	1,980,000 tons
Cavity Tonnage	20,200 tons
Distance Along Dip	1,344 feet
Cavities per Borehole	1
Borehole Tonnage	20,200 tons
Annual Cutting Holes	98
Annual Pumping Holes	5
Width	950 feet
Annual Length	4,909 feet
Annual Area	107 acres
Ore Body Density	0.59 tons/square foot
Annual Ore Body Requirements	2,740,000 tons
Ore Recovery	72 percent
Annual Drilling of Cutting Holes	132,000 feet
Annual Drilling of Pumping Holes	5,220 feet
Effective Availability of Mining System	81 percent
Number of Mining Units	7
Effective Mining Rate	44 tons/hour/unit

Table 4. Double-Drill Method with Vertical Cavities
Part C: Capital and Operating Cost Summary

Capital Cost Summary	$K
Exploration	300
Working Capital	3,057
Borehole Mining Units	15,881
Coal Dewatering Plant	1,340
Loadout Facilities	5,000
Miscellaneous Facilities	2,600
Total	28,178

Operating Cost Summary	$K/yr	$/ton
Site Preparation and Reclamation	64	0.03
Drilling	6,987	3.53
Mining - Payroll	2,661	1.34
- Payroll benefits and overhead	1,863	0.94
- Maintenance supplies	447	0.23
- Fuel	4,027	2.03
- Miscellaneous supplies	7	0.00
Ore Transportation	1,723	0.87
Coal Dewatering Plant	1,327	0.67
Annual Operating Cost	19,105	9.65
Depreciation and Amortization	2,512	1.27
Total Mining Cost	21,617	10.92

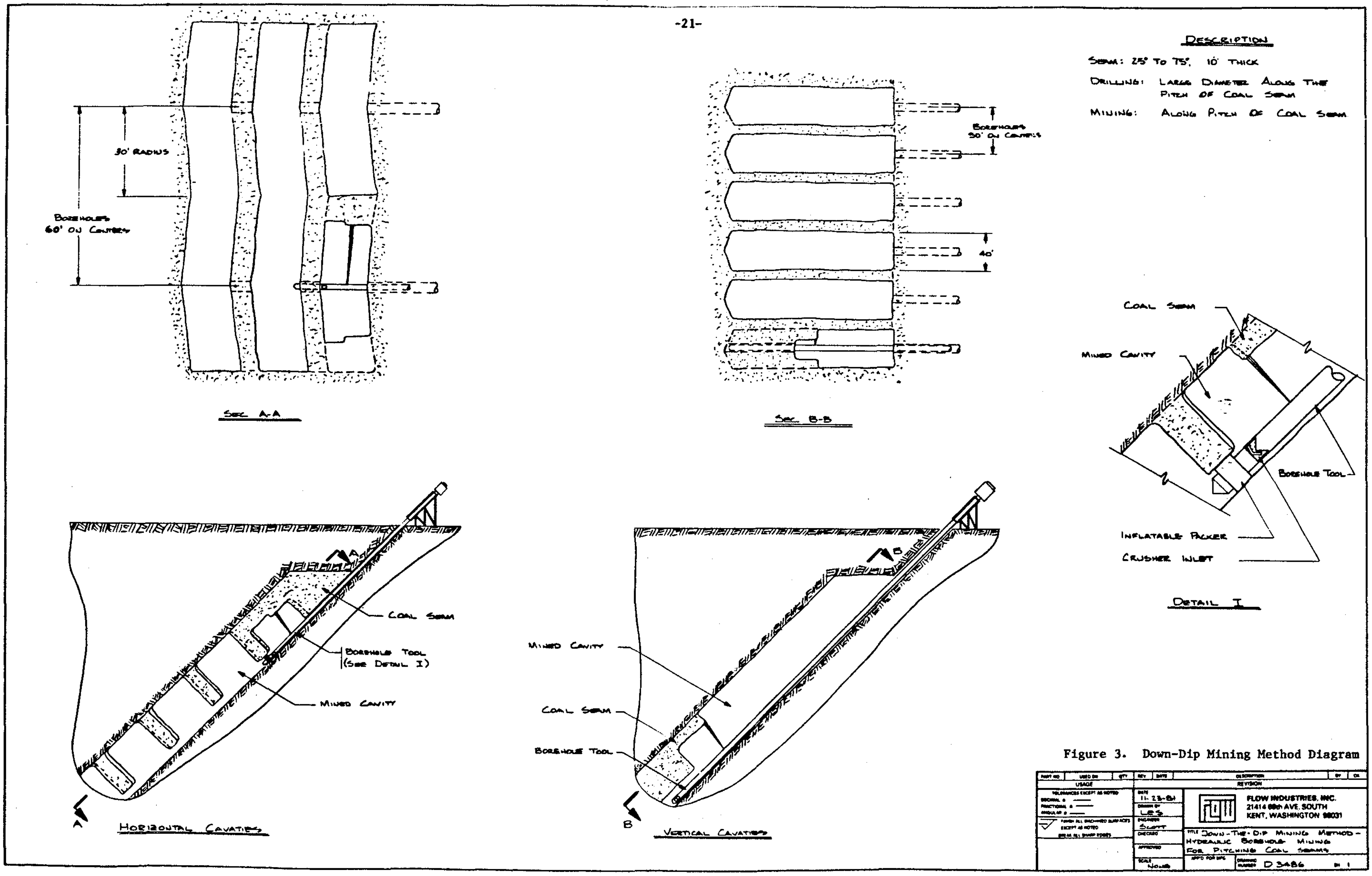


Figure 3. Down-Dip Mining Method Diagram

2.3.1 Horizontal Cavities

The horizontal cavities are mined through boreholes spaced on 60-foot centers. They are 10 feet high, 30 feet wide, 40 feet long, and are begun at the deepest part of the seam. Ten-foot-thick partitions are left between cavities for roof support as the borehole tool mines toward the surface. An inflatable packer on the borehole tool is used to prevent slurry from draining into the lower cavities as mining progresses upward. Adjacent borehole cavities intersect along the strike to form an extended horizontal cavity.

The economic parameters for down-dip horizontal cavity mining are listed in Table 5, Parts A, B, and C. Slant drilling limitations resulted in the selection of a smaller tool for this analysis and, consequently, a lower mining rate than that of the double-drill method. This factor plus the large tonnage to be mined from each borehole will make it necessary for each mining unit to remain more than a month at a single borehole. Table 5, Part C, shows that borehole mining units account for just over half of the capital cost and about a third of the operating cost. Drilling represents about half the total mining cost and is the major operating cost element. It may be seen that the total mining cost is slightly over the production target for cost per ton.

2.3.2 Vertical Cavities

Vertical cavities are mined through boreholes spaced on 50-foot centers. They are formed by mining downward from the top of the coal seam and are 10 feet high, 20 feet wide, and run the length of the seam. A 10-foot-thick partition is left between cavities to provide roof support.

Table 6, Parts A, B, and C, lists the parameters used in the economic analysis of the down-dip vertical cavity mining method. The cavity width has been reduced compared to that of the horizontal cavities in order to prevent failures in the long roof parallel to the borehole. The partition between the cavities is 10 feet thick. The reduced cavity radius decreases the tonnage per borehole (Table 6, Part B), which in turn results in increased drilling cost, reduced mining system availability, and the addition of one more borehole mining unit. These factors combine to make vertical cavity mining more costly than horizontal cavity mining.

Table 5. Down-Dip Method with Horizontal Cavities
Part A: Selected Initial Parameters

Cavity Characteristics	
Cavity Height	40 feet
Cavity Radius	30 feet
Cavity Floor Angle	3 degrees
Cavity Spacing Along Dip	50 feet
Cavity Spacing Along Strike	60 feet
Operating Costs	
Borehole Tool Diameter	12 inches
Mining Rate	30 tons/hour/unit
Borehole Tool Moving Time	16 hours/1,000 feet of tool
Borehole Drilling (Slant)	150 $/foot
Capital Costs	
Borehole Mining System	1,200 $K/unit
Borehole Tool	200 $/foot/unit

Table 5. Down-Dip Method with Horizontal Cavities
Part B: Calculated Parameters

Cavity Volume	21,700 cubic feet
Annual Mined Tonnage	1,980,000 tons
Cavity Tonnage	899 tons
Distance Along Dip	1,344 feet
Cavities per Borehole	27
Borehole Tonnage	24,200 tons
Annual Boreholes	82
Width	950 feet
Annual Length	4,920 feet
Annual Area	107 acres
Ore Body Density	0.59 tons/square foot
Annual Ore Body Requirements	2,740,000 tons
Ore Recovery	72 percent
Annual Drilling of Boreholes	110,000 feet
Effective Availability of Mining System	83 percent
Number of Mining Units	10
Effective Mining Rate	30 tons/hour/unit

Table 5. Down-Dip Method with Horizontal Cavities

Part C: Capital and Operating Cost Summary

Capital Cost Summary	$K
Exploration	300
Working Capital	5,226
Borehole Mining Units	17,687
Coal Dewatering Plant	1,340
Loadout Facilities	5,000
Miscellaneous Facilities	2,600
Total	32,153

Operating Cost Summary	$K/yr	$/ton
Site Preparation and Reclamation	64	0.03
Drilling	16,518	8.34
Mining - Payroll	3,802	1.92
- Payroll benefits and overhead	2,661	1.34
- Maintenance supplies	656	0.33
- Fuel	5,901	2.98
- Miscellaneous supplies	10	0.01
Ore Transportation	1,723	0.87
Coal Dewatering Plant	1,327	0.67
Annual Operating Cost	32,661	16.50
Depreciation and Amortization	2,693	1.36
Total Mining Cost	35,354	17.86

Table 6. Down-Dip Method with Vertical Cavities

Part A: Selected Initial Parameters

<u>Cavity Characteristics</u>	
Cavity Radius	20 feet
Cavity Spacing Along Strike	50 feet
<u>Operating Costs</u>	
Borehole Tool Diameter	12 inches
Mining Rate	30 tons/hour/unit
Borehole Tool Moving Time	16 hours/1,000 feet of tool
Borehole Drilling (Slant)	150 $/foot
<u>Capital Costs</u>	
Borehole Mining System	1200 $K/unit
Borehole Tool	200 $/foot/unit

Table 6. Down-Dip Method with Vertical Cavities
Part B: Calculated Parameters

Cavity Volume	515,000 cubic feet
Annual Mined Tonnage	1,980,000 tons
Cavity Tonnage	21,300 tons
Distance Along Dip	1,344 feet
Cavities per Borehole	1
Borehole Tonnage	21,300 tons
Annual Boreholes	93
Width	950 feet
Annual Length	4,640 feet
Annual Area	101 acres
Ore Body Density	0.59 tons/square foot
Annual Ore Body Requirements	2,590,000 tons
Ore Recovery	77 percent
Annual Drilling of Boreholes	125,000 feet
Effective Availability of Mining System	83 percent
Number of Mining Units	11
Effective Mining Rate	28 tons/hour/unit

Table 6. Down-Dip Method with Vertical Cavities
Part C: Capital and Operating Cost Summary

Capital Cost Summary	$K
Exploration	300
Working Capital	5,779
Borehole Mining Units	19,456
Coal Dewatering Plant	1,340
Loadout Facilities	5,000
Miscellaneous Facilities	2,600
Total	34,475

Operating Cost Summary	$K/yr	$/ton
Site Preparation and Reclamation	61	0.03
Drilling	18,703	9.45
Mining - Payroll	4,182	2.11
- Payroll benefits and overhead	2,927	1.48
- Maintenance supplies	719	0.36
- Fuel	6,469	3.27
- Miscellaneous supplies	11	0.01
Ore Transportation	1,723	0.87
Coal Dewatering Plant	1,327	0.67
Annual Operating Cost	36,121	18.24
Depreciation and Amortization	2,870	1.45
Total Mining Cost	38,991	19.69

2.4 Perpendicular-to-the-Dip Method

This method requires drilling a 24-inch-diameter hole perpendicular to the coal seam, which may dip 5 to 45 degrees from the horizontal. A single borehole mining tool is used to cut and pump the slurry from either room or tunnel cavities (Figure 4). The advantages of this method are that it requires only a single borehole tool, all of its equipment and personnel are on the surface, and it is capable of mining multiple seams at different depths. Its disadvantages are its narrow 30-foot width and the consequent increase in number of cavities required per borehole, the mechanical difficulties of a large tool working at angles to 45 degrees, and the high cost of slant drilling large-diameter holes.

2.4.1 Room Cavities

Room cavities are formed by directing the cutting jet up the dip from the borehole and allowing slurry to run down to the borehole pump. Room cavities are most suitable in areas having unconsolidated roof structures.

The economic results for the perpendicular-to-the-dip room cavity mining method are given in Table 7, Parts A, B, and C. The small cavity width, height, and mining arc (Table 7, Part A) define a small cavity that produces only 567 tons of coal (Table 7, Part B). Such a small cavity results in poor recovery and extremely high drilling costs, which eliminates room cavity mining from consideration as a viable technique.

2.4.2 Tunnel Cavities

Tunnel cavity mining is accomplished in the same manner as with room cavities; however, the individual cavities are connected to form a vertical tunnel. This allows use of smaller diameter cutting-jet holes. This method is suitable for use in areas having consolidated roof materials.

The economic results for the perpendicular-to-the-dip tunnel cavity mining method are given in Table 8, Parts A, B, and C. Tunnel cavity mining allows the majority of the boreholes to be the smaller cutting-jet tool holes, which reduces drilling costs by 60 percent. However, the resulting total mining cost is still unacceptably high.

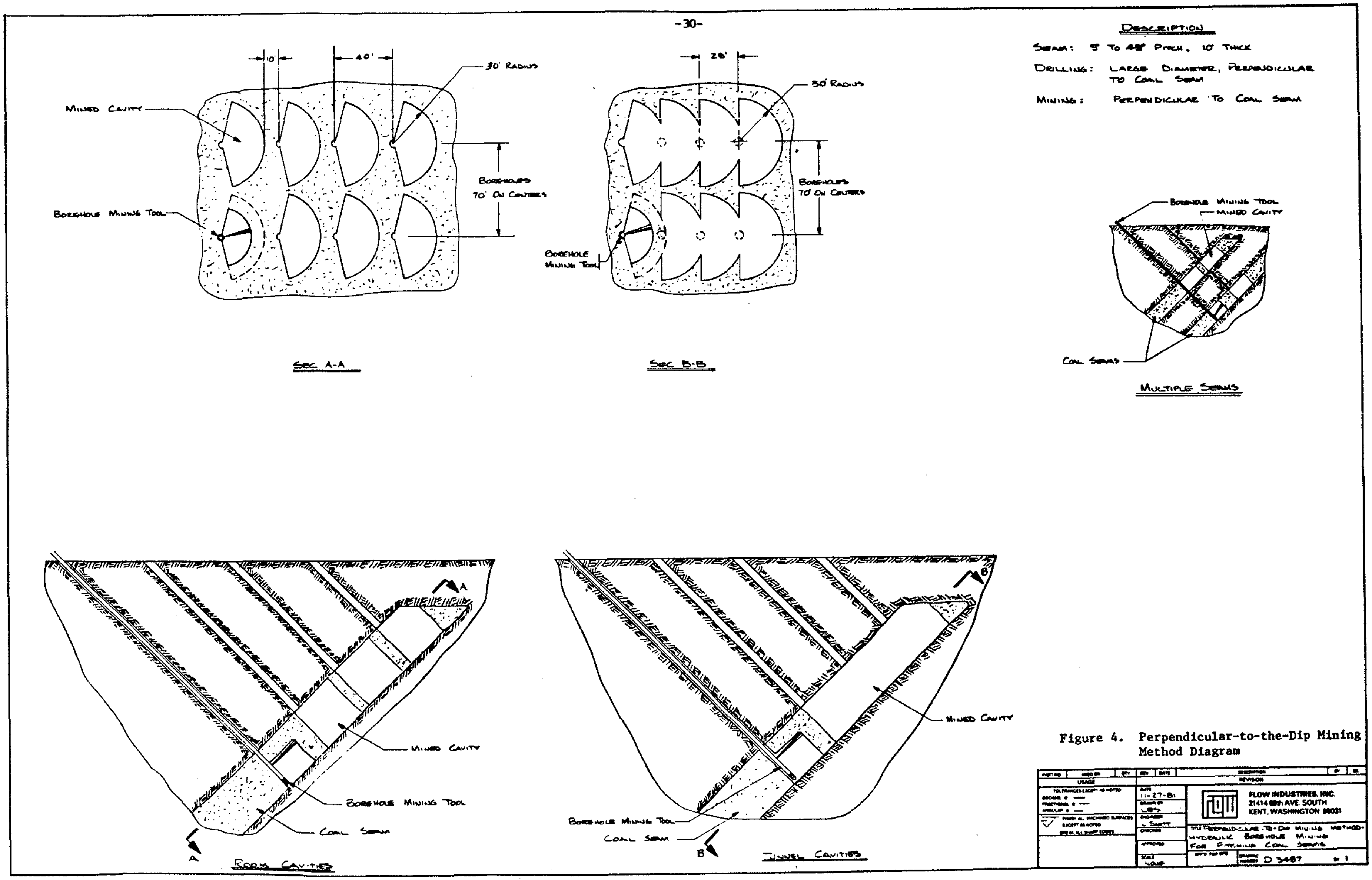


Figure 4. Perpendicular-to-the-Dip Mining Method Diagram

Table 7. Perpendicular-to-the-Dip Method with Room Cavities
Part A: Selected Initial Parameters

Cavity Characteristics	
Cavity Height	10 feet
Cavity Radius	30 feet
Cavity Floor Angle	3 degrees
Mining Arc	180 degrees
Cavity Spacing along Dip	40 feet
Cavity Spacing along Strike	70 feet
Operating Costs	
Borehole Tool Diameter	12 inches
Mining Rate	30 tons/hour/unit
Borehole Tool Moving Time	16 hours/1,000 feet of tool
Borehole Drilling (Slant)	150 $/foot
Capital Costs	
Borehole Mining System	1,200 $K/unit
Borehole Tool	500 $/foot/unit

Table 7. Perpendicular-to-the-Dip Method with Room Cavities
Part B: Calculated Parameters

Cavity Volume	13,700 cubic feet
Annual Mined Tonnage	1,980,000 tons
Cavity Tonnage	567 tons
Distance Along Dip	1,344 feet
Cavities per Borehole	1
Borehole Tonnage	567 tons
Annual Boreholes	3,490
Width	950 feet
Annual Length	14,600 feet
Annual Area	317 acres
Ore Body Density	0.59 tons/square foot
Annual Ore Body Requirements	8,110,000 tons
Ore Recovery	24 percent
Annual Drilling of Boreholes	2,590,000 feet
Effective Availability of Mining System	52 percent
Number of Mining Units	16
Effective Mining Rate	30 tons/hour/unit

Table 7. Perpendicular-to-the-Dip Method with Room Cavities

Part C: Capital and Operating Cost Summary

Capital Cost Summary	$K
Exploration	300
Working Capital	65,444
Borehole Mining Units	35,314
Coal Dewatering Plant	1,340
Loadout Facilities	5,000
Miscellaneous Facilities	2,600
Total	109,998

Operating Cost Summary	$K/yr	$/ton
Site Preparation and Reclamation	190	0.10
Drilling	388,816	196.37
Mining - Payroll	6,083	3.07
- Payroll benefits and overhead	4,258	2.15
- Maintenance supplies	662	0.33
- Fuel	5,953	3.01
- Miscellaneous supplies	16	0.01
Ore Transportation	1,723	0.87
Coal Dewatering Plant	1,327	0.67
Annual Operating Cost	409,026	206.56
Depreciation and Amortization	4,455	2.25
Total Mining Cost	413,481	208.83

Table 8. Perpendicular-to-the-Dip Method with Tunnel Cavities

Part A: Selected Initial Parameters

<u>Cavity Characteristics</u>	
Cavity Height	10 feet
Cavity Radius	30 feet
Cavity Floor Angle	3 degrees
Mining Arc	180 degrees
Cavity Spacing Along Dip	28 feet
Cavity Spacing Along Strike	70 feet
<u>Operating Costs</u>	
Borehole Tool Diameter	12 inches
Mining Rate	30 tons/hour/unit
Borehole Tool Moving Time	16 hours/1,000 feet of tool
Pump Hole Drilling (Slant)	150 $/foot
Cutting Hole Drilling (Slant)	50 $/foot
<u>Capital Costs</u>	
Borehole Mining System	1,200 $K/unit
Pumping Tool	500 $/foot/unit
Cutting Tool	200 $/foot/unit

Table 8. Perpendicular-to-the-Dip Method with Tunnel Cavities
Part B: Calculated Parameters

Cavity Volume	13,400 cubic feet
Annual Mined Tonnage	1,980,000 tons
Cavity Tonnage	557 tons
Distance Along Dip	1,344 feet
Cavities per Borehole	1
Borehole Tonnage	557 tons
Annual Boreholes	3,550
Width	950 feet
Annual Length	10,366 feet
Annual Rows of Boreholes	148
Annual Area	226 acres
Ore Body Density	0.59 tons/square foot
Annual Ore Body Requirements	5,780,000 tons
Ore Recovery	34 percent
Annual Drilling of Cutting Holes	2,430,000 feet
Annual Drilling of Pumping Holes	209,000 feet
Effective Availability of Mining System	52 percent
Number of Mining Units	16
Effective Mining Rate	30 tons/hour/unit

Table 8. Perpendicular-to-the-Dip Method with Tunnel Cavities
Part C: Capital and Operating Cost Summary

Capital Cost Summary	$K
Exploration	300
Working Capital	27,670
Borehole Mining Units	39,839
Coal Dewatering Plant	1,340
Loadout Facilities	5,000
Miscellaneous Facilities	2,600
Total	76,749

Operating Cost Summary	$K/yr	$/ton
Site Preparation and Reclamation	136	0.07
Drilling	152,824	77.18
Mining - Payroll	6,083	3.07
- Payroll benefits and overhead	4,258	2.15
- Maintenance supplies	657	0.33
- Fuel	5,913	2.99
- Miscellaneous supplies	16	0.01
Ore Transportation	1,723	0.87
Coal Dewatering Plant	1,327	0.67
Annual Operating Cost	172,935	87.34
Depreciation and Amortization	4,908	2.48
Total Mining Cost	177,843	89.82

2.5 Auxiliary Cutting Jet Method

This method requires the drilling and casing of a 24-inch diameter vertical pump hole and multiple 12-inch vertical cutting jet holes spaced on 28-foot centers (Figure 5). Cavities 40 feet wide, 10 feet high, and the length of the seam is formed with 10-foot-thick partitions between adjacent cavities. An articulated cutting jet can be used to match the jet angle to the seam dip angle, which may be 5 to 75 degrees from the horizontal. The advantages of this method are vertical boreholes, single large pumping tool, and surface location of all equipment and personnel. Its disadvantage is the relatively small amount of ore that can be recovered per cutting jet hole since the adjacent borehole must be within the cutting radius.

The economic results for the auxiliary cutting jet method are given in Table 9, Parts A, B, and C. A pumping hole large enough to accommodate an 18-inch pumping tool can be drilled and cased since the hole is vertical. The use of a larger pumping tool results in a higher mining rate and cutting jet flow rate than, for example, those of the perpendicular-to-the-dip method. The higher cutting jet flow rate makes possible the use of a larger diameter nozzle capable of a larger cutting radius. This allows rectangular cavity formation and yields a very high recovery percentage. Perpendicular drilling reduces drilling costs by 80 percent since the holes are both shorter and easier to drill. However, the resulting drilling cost is still 64 percent of the total mining cost, which in turn is almost acceptable.

2.6 Diagonal-to-the-Strike Method

This method is an underground borehole mining application. A 20-foot by 20-foot access shaft is connected to a 10-foot by 10-foot vent shaft with slightly sloping tunnels (Figure 6). Ten-inch-diameter boreholes are drilled horizontally and slightly upward diagonal to the strike (approximately 5 degrees). A cutting jet tool is installed in the borehole to form cavities 10 feet wide, 40 feet high, and up to 1,000 feet long in seams that may dip 25 to 75 degrees from the horizontal. The resulting slurry flows to and then down the tunnel to a sump at the bottom of the access shaft. A slurry pump installed in the access shaft pumps the slurry to the surface. Roof support coal is left between the different levels of cavities. The advantages of this method are its large cavities and its suitability for mining at great depths

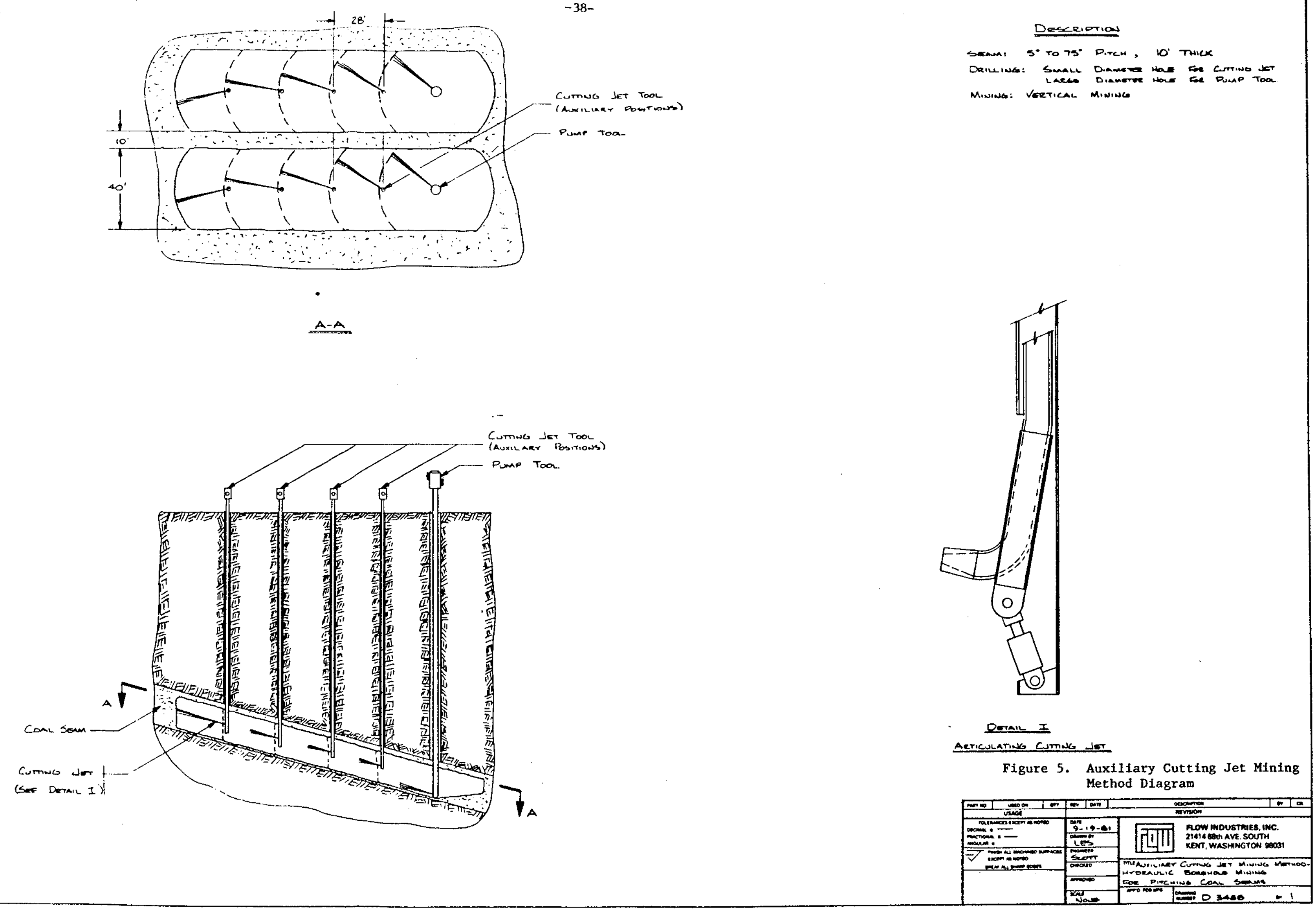


Figure 5. Auxiliary Cutting Jet Mining Method Diagram

Table 9. Auxiliary Cutting Jet Method

Part A: Selected Initial Parameters

Cavity Characteristics	
Cavity Width	40 feet
Cavity Length	40 feet
Cavity Overlap	2 feet
Cavity Spacing Along Strike	50 feet
Pump Hole Extra Depth	10 feet
Operating Costs	
Pumping Tool Diameter	18 inches
Cutting Tool Diameter	6 inches
Mining Rate	50 tons/hour/unit
Borehole Tool Moving Time	16 hours/1,000 feet of tool
Pump Hole Drilling (Vertical)	75 $/foot
Cutting Hole Drilling (Vertical)	15 $/foot
Captial Costs	
Borehole Mining System	1,200 $K/unit
Pumping Tool	500 $/foot/unit
Cutting Tool	200 $/foot/unit

Table 9. Auxiliary Cutting Jet Method
Part B: Calculated Parameters

Cavity Spacing Along Dip	38 feet
Cavity Volume	15,200 cubic feet
Annual Mined Tonnage	1,980,000 tons
Cavity Tonnage	631 tons
Distance Along Dip	1,344 feet
Cavities per Borehole	1
Borehole Tonnage	631 tons
Annual Boreholes	3,140
Width	950 feet
Annual Length	4,440 feet
Annual Area	97 acres
Annual Rows of Boreholes	89
Ore Body Density	0.59 tons/square foot
Annual Ore Body Requirements	2,470,000 tons
Ore Recovery	80 percent
Annual Drilling of Cutting Holes	1,560,000 feet
Annual Drilling of Pumping Holes	89,700 feet
Effective Availability of Mining System	51 percent
Number of Mining Units	10
Effective Mining Rate	49 tons/hour/unit

Table 9. Auxiliary Cutting Jet Method
Part C: Capital and Operating Cost Summary

Capital Cost Summary	$K
Exploration	300
Working Capital	6,997
Borehole Mining Units	22,000
Coal Dewatering Plant	1,340
Loadout Facilities	5,000
Miscellaneous Facilities	2,600
Total	38,237

Operating Cost Summary	$K/yr	$/ton
Site Preparation and Reclamation	58	0.03
Drilling	30,112	15.21
Mining - Payroll	3,802	1.92
- Payroll benefits and overhead	2,661	1.34
- Maintenance supplies	404	0.20
- Fuel	3,637	1.84
- Miscellaneous supplies	10	0.01
Ore Transportation	1,723	0.87
Coal Dewatering Plant	1,327	0.67
Annual Operating Cost	43,733	22.09
Depreciation and Amortization	3,124	1.58
Total Mining Cost	46,857	23.67

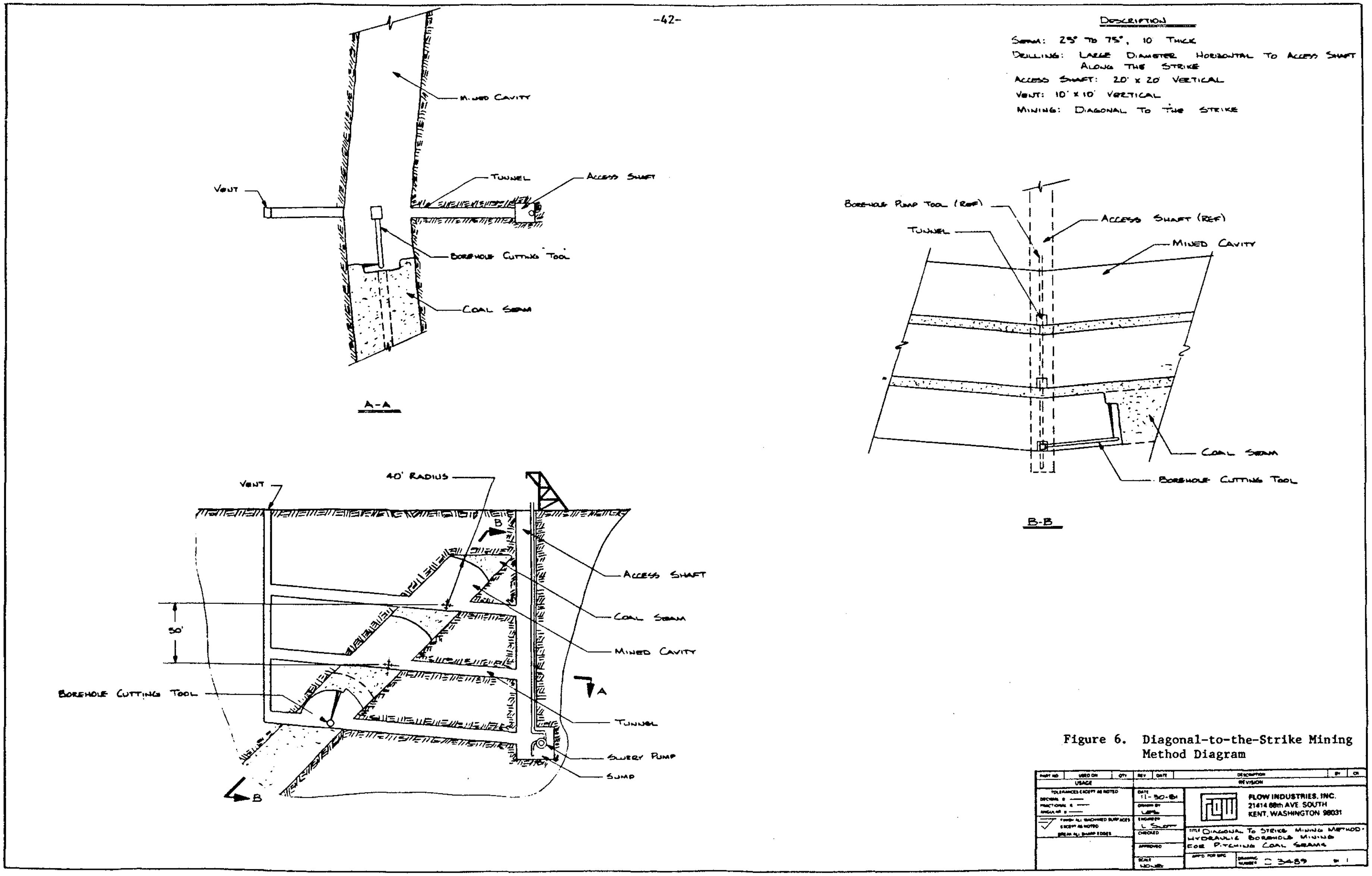


Figure 6. Diagonal-to-the-Strike Mining Method Diagram

along the seam. Its disadvantages include high cost, the safety precautions required for underground operations, and the long development lead time required before production begins.

The economic results for the diagonal-to-the-strike method are given in Table 10, Parts A, B, and C. The cost of sinking an access shaft or a ventilation shaft every 1,000 feet along the strike is enormous compared to normal borehole mining costs. This factor, which appears under depreciation and amortization in Table 10, Part C, dominates the total mining cost.

2.7 Up-the-Dip Method

This method is an underground borehole mining application. A 20-foot by 20-foot access shaft is connected to a 10-foot by 10-foot vent by a tunnel along the strike (Figure 7). Twelve-inch-diameter boreholes are drilled at the footwall on 50-foot centers from the tunnel upward along the dip. A cutting-jet tool is used to mine vertical cavities 10 feet high, 40 feet wide, and the length of the seam, which may dip 5 to 75 degrees from the vertical. A 10-foot partition is left between cavities for roof support. The slurry flows back to the sump at the bottom of the access shaft where a slurry pump pumps it to the surface. The advantages of this method are its small diameter slant-drilled boreholes and large number of cavities per access shaft. Its disadvantages include high cost, the safety precautions required for underground mining operations, and the long development lead time before production begins.

The economic results for the up-the-dip method are given in Table 11, Parts A, B, and C. As in the diagonal-to-the-strike method, installing almost a half-million dollars worth of shafts is the biggest cost factor and makes the total mining cost of this method completely unacceptable.

2.8 Summary of Analysis

We have studied six mining methods and their associated equipment for mining steeply pitching thin coal seams. For comparison purposes, economic performance estimates for these methods were made based on mining a 10-foot

Table 10. Diagonal-to-the-Strike Method
Part A: Selected Initial Parameters

Cavity Characteristics	
Cavity Radius	40 feet
Vertical Spacing of Tunnels	50 feet
Access Shaft Spacing along Strike	2,000 feet
Operating Costs	
Cutting Tool Diameter	6 inches
Mining Rate	50 tons/hour/unit
Cutting Tool Moving Time	16 hours/1,000 feet of tool
Hoist	60 $/hour
Cutting Hole Drilling (Slant)	100 $/foot
Pumps to Surface	100 $/hour
Capital Costs	
Access Shafts	8,000 $/foot
Ventilation Shafts	2,000 $/foot
Borehole Mining System	2,000 $K/unit
Cutting Tool	300 $/foot/unit
Shaft Headframe Facility	10,000 $K/shaft
Pumps to Surface	2,000 $K

Table 10. Diagonal-to-the-Strike Method
Part B: Calculated Parameters

Distance along Strike	1,000 feet
Cavity Volume	400,000 cubic feet
Annual Mined Tonnage	1,980,000 tons
Cavity Tonnage	16,600 tons
Number of Mining Levels	20
Number of Access Shafts	29
Cavities per Borehole	1
Borehole Tonnage	16,600 tons
Width	950 feet
Annual Length	5,964 feet
Annual Area	130 acres
Ore Body Density	0.59 tons/square foot
Annual Ore Body Requirements	3,330,000 tons
Ore Recovery	60 percent
Annual Drilling of Boreholes	119,000 feet
Effective Availability of Mining System	81 percent
Number of Mining Units	7
Effective Mining Rate	44 tons/hour/unit

Table 10. Diagonal-to-the-Strike Method
Part C: Capital and Operating Cost Summary

Capital Cost Summary	$K
Exploration	300
Working Capital	5,006
Access and Ventilation Shafts	580,000
Tunnels	330,600
Pumps	2,000
Borehole Mining Units	18,200
Coal Dewatering Plant	1,340
Loadout Facilities	5,000
Miscellaneous Facilities	2,600
Total	945,046

Operating Cost Summary	$K/yr	$/ton
Site Preparation and Reclamation	78	0.04
Hoist	475	0.24
Drilling	11,928	6.02
Mining - Payroll	2,661	1.34
- Payroll benefits and overhead	1,863	0.94
- Maintenance supplies	450	0.23
- Fuel	4,046	2.04
- Miscellaneous supplies	7	0.00
Pumping	792	0.40
Ore Transportation	1,723	0.87
Coal Dewatering Plant	1,327	0.67
Annual Operating Cost	25,349	12.80
Depreciation and Amortization	94,004	47.48
Total Mining Cost	119,353	60.28

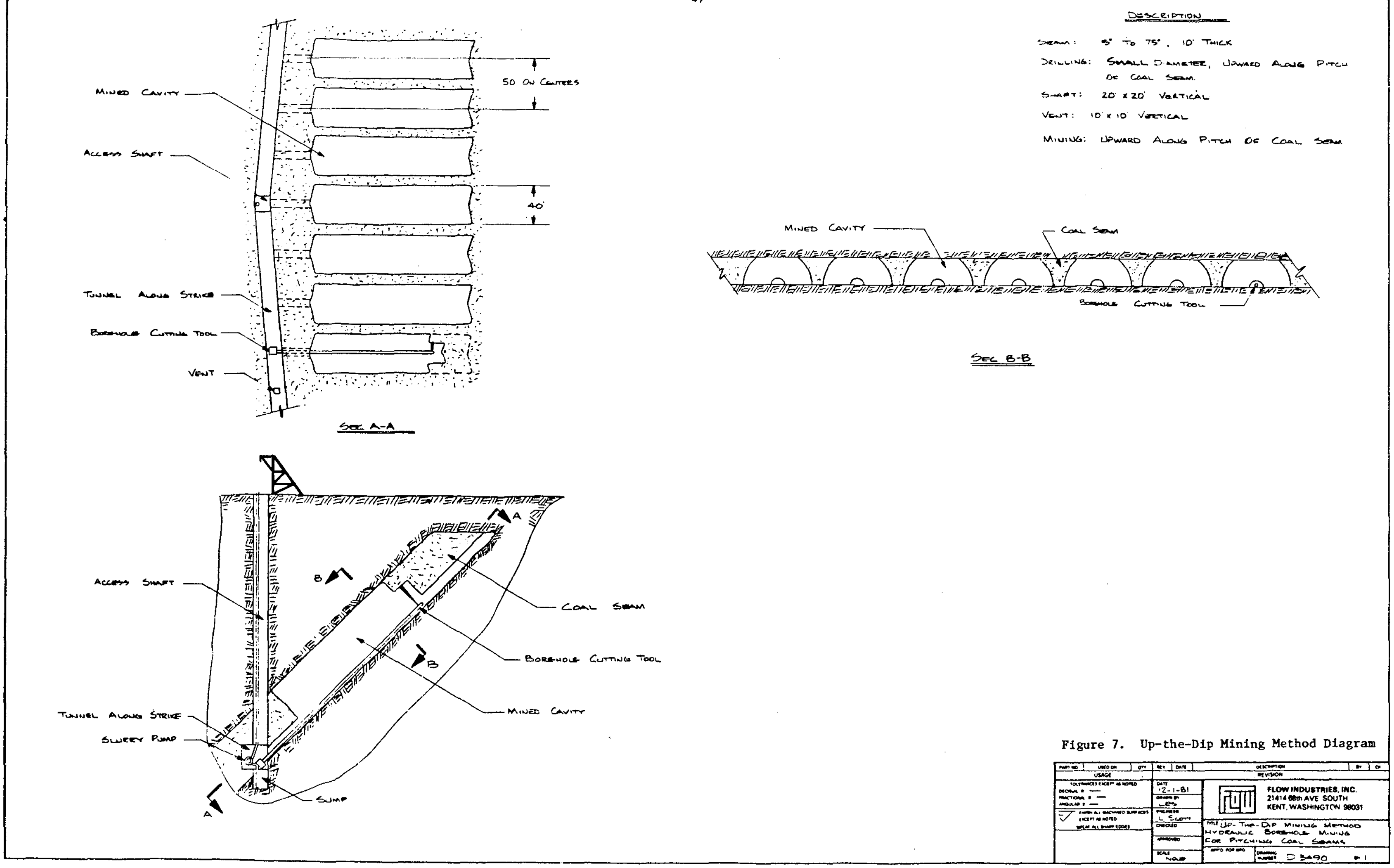


Figure 7. Up-the-Dip Mining Method Diagram

Table 11. Up-the-Dip Method

Part A: Selected Initial Parameters

Cavity Characteristics	
Cavity Radius	20 feet
Cavity Spacing Along Strike	50 feet
Access Shaft Spacing Along Strike	2,000 feet
Operating Costs	
Cutting Tool Diameter	6 inches
Mining Rate	50 tons/hour/unit
Cutting Tool Moving Time	32 hours/1,000 feet of tool
Hoist	60 $/hour
Entry Drilling	300 $/foot
Slurry Pipe in Entry	50 $/foot
Cutting Hole Drilling (Slant)	100 $/foot
Pumps to Surface	100 $/hour
Capital Costs	
Access Shafts	8,000 $/foot
Ventilation Shafts	2,000 $/foot
Borehole Mining System	2,000 $K/unit
Cutting Tool	300 $/foot/unit
Shaft Headframe Facility	10,000 $/shaft
Pumps to Surface	2,000 $K

Table 11. Up-the-Dip Method

Part B: Calculated Parameters

Number of Access Shafts	23
Cavity Volume	514,000 cubic feet
Annual Mined Tonnage	1,980,000 tons
Cavity Tonnage	21,300 tons
Distance Along Dip	1,344 feet
Cavities per Borehole	1
Borehole Tonnage	21,300 tons
Annual Boreholes	93
Width	950 feet
Annual Length	4,640 feet
Annual Area	101 acres
Ore Body Density	0.59 tons/square foot
Annual Ore Body Requirements	2,590,000 tons
Ore Recovery	77 percent
Annual Drilling of Boreholes	125,000 feet
Effective Availability of Mining System	77 percent
Number of Mining Units	7
Effective Mining Rate	46 tons/hour/unit

Table 11. Up-the-Dip Method

Part C: Capital and Operating Cost Summary

Capital Cost Summary	$K
Exploration	300
Working Capital	5,316
Access and Ventilation Shafts	460,000
Pumps	2,000
Borehole Mining Units	18,921
Coal Dewatering Plant	1,340
Loadout Facilities	5,000
Miscellaneous Facilities	2,600
Total	495,477

Operating Cost Summary	$K/yr	$/ton
Site Preparation and Reclamation	61	0.03
Hoist	475	0.24
Entry	1,392	0.70
Piping	232	0.12
Drilling	12,469	6.30
Mining - Payroll	2,661	1.34
- Payroll benefits and overhead	1,863	0.94
- Maintenance supplies	428	0.22
- Fuel	3,853	1.95
- Miscellaneous supplies	7	0.00
Pumping	792	0.40
Ore Transportation	1,723	0.87
Coal Dewatering Plant	1,327	0.67
Annual Operating Cost	27,282	13.78
Depreciation and Amortization	49,016	24.76
Total Mining Cost	76,298	38.53

thick coal seam pitching at 45 degrees to a depth of 1,000 feet (see Table 1). These methods are listed in order of their economic acceptability as follows:

Method	Total Investment ($ mil)	Mining Cost ($ ton)
Double-Drill	26	11
Down-Dip	32	18
Auxiliary Cutting Jet	38	24
Up-the-Dip	495	39
Diagonal-to-the-Strike	945	60
Perpendicular-to-the-Dip	77	90

The double-drill method is economically acceptable and the down-dip method is marginal. While the auxiliary cutting jet method might be economically feasible in certain high-quality coal seams, the up-the-dip, diagonal-to-the-strike, and perpendicular-to-the-dip methods result in unacceptably large operating costs due mainly to either the number of boreholes or the large shafts they require.

In conclusion, the double-drill and down-dip methods should be capable of economically mining steeply pitching thin coal seams. However, both methods will necessarily involve the use of slant drilling techniques, the development of slant-borehole mining equipment, and possibly the development of improved slurry pumping equipment.

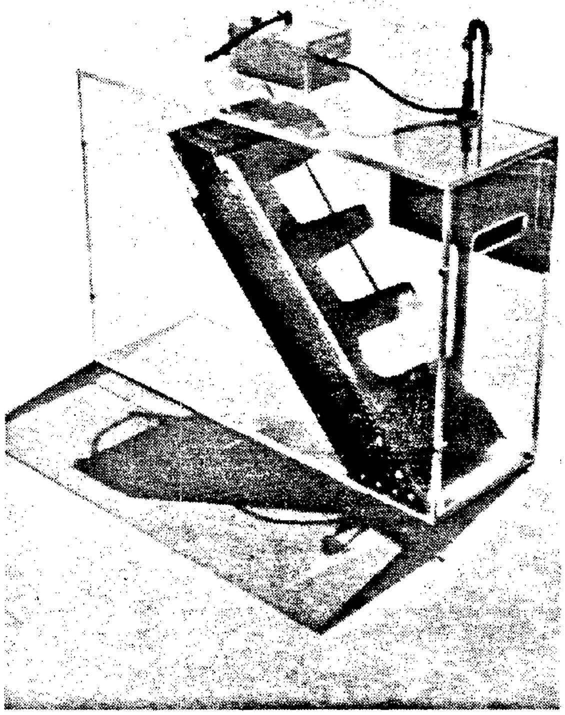
3. Detailed Analysis of Double-Drill Method

Based on the technical and economic considerations discussed in the previous section, the double-drill method with horizontal cavities was selected for detailed analysis during Phase II of this program. The down-dip method was deemed to be of secondary importance and all others were dropped from further consideration. As a result of this selection, a scale model of equipment required to implement the double-drill method was fabricated, further engineering design work was performed, and a more detailed economic analysis with sensitivity study was made. A similar economic analysis was performed for the down-dip method for comparison purposes.

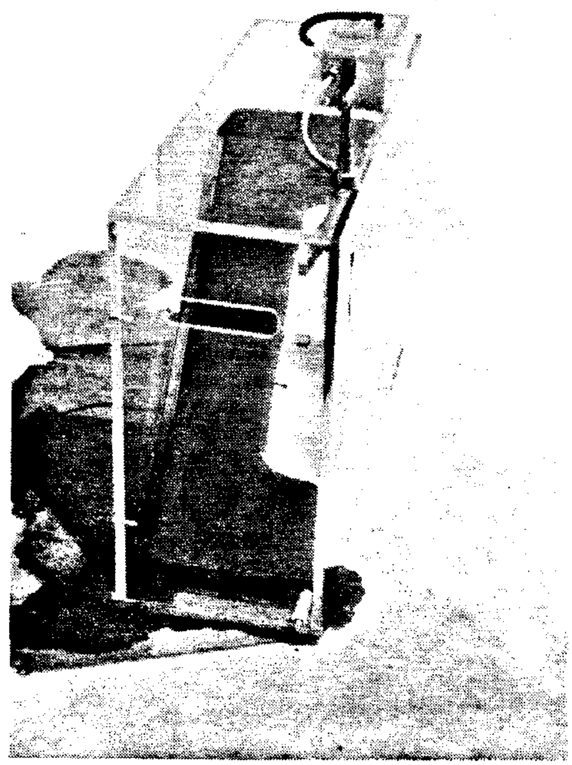
3.1 Technical Description and Scale Model

The double-drill method, previously described in Section 2.2 and shown on Figure 2, was further conceptualized by the fabrication of a scale model (shown in Figure 8). This scale model depicts a coal seam pitching at 45 degrees with the double-drill borehole mining tool installed. The coal seam piece is interchangeable to allow demonstration of horizontal or vertical cavities. The vertical tool includes a hand-operated piston pump to pump water to a reservoir and so pressurizes it. The reservoir then feeds the cutting jet, which can be moved to illustrate cavity cutting.

The double-drill borehole mining method requires equipment to drill the vertical pumping and slant cutting holes in addition to the downhole waterjet pumping and cutting tools and their aboveground support equipment. The vertical hole is drilled with a 24- or 26-inch mud-circulation tricone drill bit or equivalent to just below the intersection with the coal seam. It is then cased with 22-inch casing to just above the coal seam and cemented, unless it is later deemed feasible to recover 1000 feet of 22-inch casing. The pumping tool, illustrated in Figure 9 with the centrifugal pump, is lowered into the cased hole. A small cutting jet, about 0.2-inch in diameter, is required to open up a sump area large enough to intersect the cutting hole. This jet will also serve as an agitation jet during regular mining. The pumping tool has a capacity of 50 tons per hour of solids in 800 gallons per minute (gpm) of slurry, corresponding to about 23 percent solids by weight. The 800 gpm is supplied by the agitation jet (100 gpm), ground water (50 gpm), solids (150 gpm), and the cutting jet (500 gpm).



A. DOUBLE—DRILL MODEL WITH HORIZONTAL CAVITIES



B. DOUBLE--DRILL MODEL WITH VERTICAL CAVITY

Figure 8. Double-Drill Scale Model

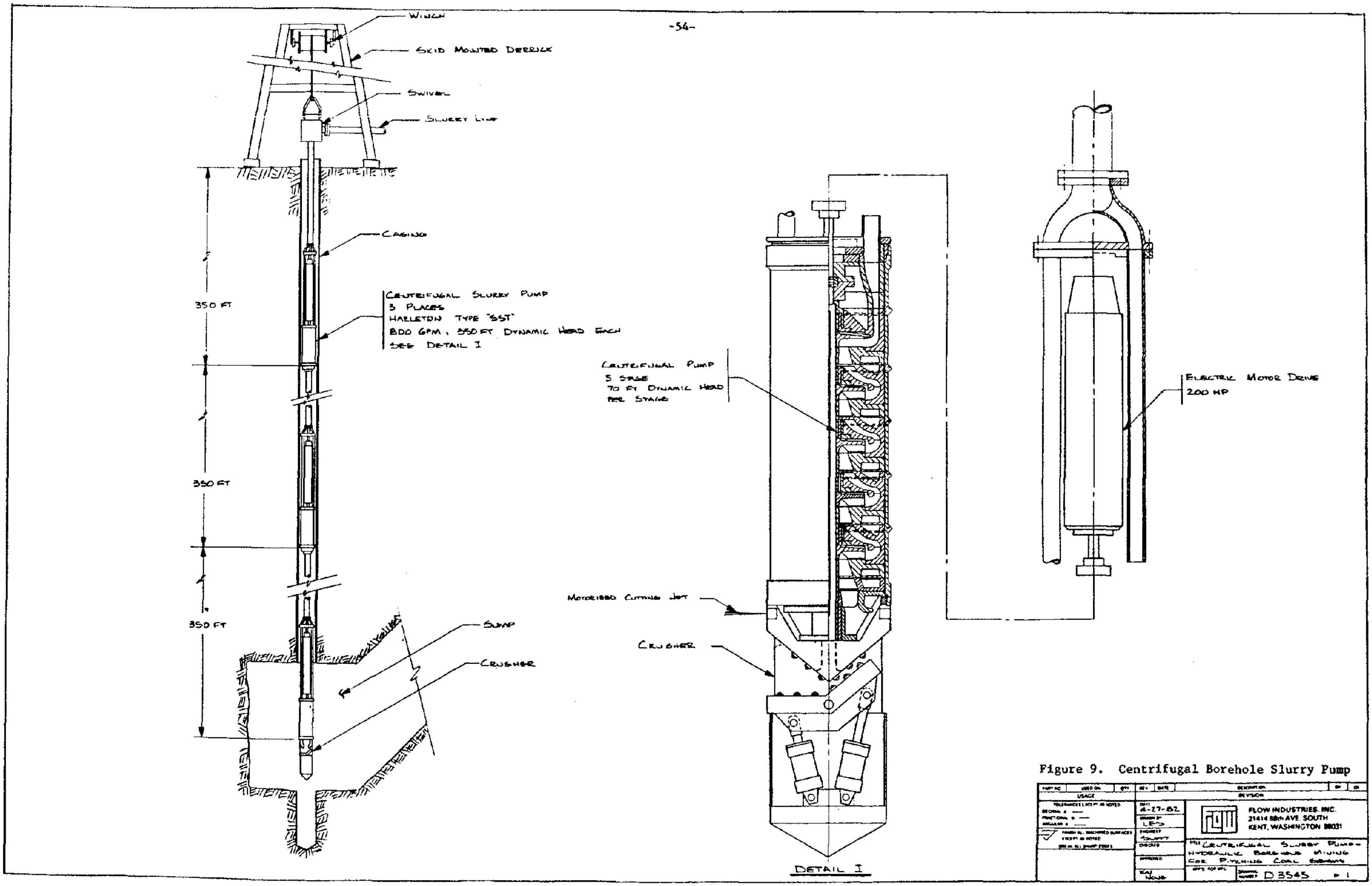


Figure 9. Centrifugal Borehole Slurry Pump

One of the unproven features of this system is the pump. Figure 9 shows a commercially-available electric-power-driven centrifugal slurry pump. Additional information and a manufacturer's quote for this pump is included in Appendix A. The quoted price of a pump to lift 350 feet is $45,000. Three such units will be required to lift 1000 feet, as shown in Figure 9. An additional development effort is required to couple a coal crusher to the bottom pump, bringing the total development cost of this system to approximately $250,000.

A competing hydraulically-actuated pump system is illustrated in Figure 10 and described in Appendix A. This system includes a double-acting slurry piston pump to lift the slurry much as oil is pumped from an oil well. This system would also require development at a cost of possibly $250,000. Much of the technology needed to develop this pump is available at Flow. However, a field test program would be required. A 300-horsepower hydraulic system would be required aboveground to support this pump.

Other aboveground equipment to support the pumping tool is a 125-ton hoist on a derrick, electric power, controls and instruments for the pumps, and slurry pipes and hoses to carry the coal slurry to the coal dewatering area.

The cutting jet hole is drilled with a 10-inch-diameter slant drill with a mud-recirculation bit. This hole is drilled down-the-dip at the bottom of the coal seam until it intersects the pump hole. The exact method to be used for making the holes intersect is the second unproven feature of the double-drill method, as described in Appendix B. Methods under consideration utilize electro-magnetic fields generated on the drill bit and received at the target point. That is, an electro-magnetic field sensor (three-axis) is installed at the bottom of the vertical hole (the target) and the slant hole is drilled with a transmitting antenna mounted coaxially in the drill tool. The transmitter generates the field received at the sensor, which, in turn, creates a signal that increases with the degree of drill misalignment and can be used to guide the slant drill. A back-up method combines drill guidance with real-time position logging such that the drill position can be compared with the logged location of the vertical hole.

No casing is installed in the slant hole except down through the overburden to the coal seam. The 6-inch cutting tool will therefore rest on the coal in

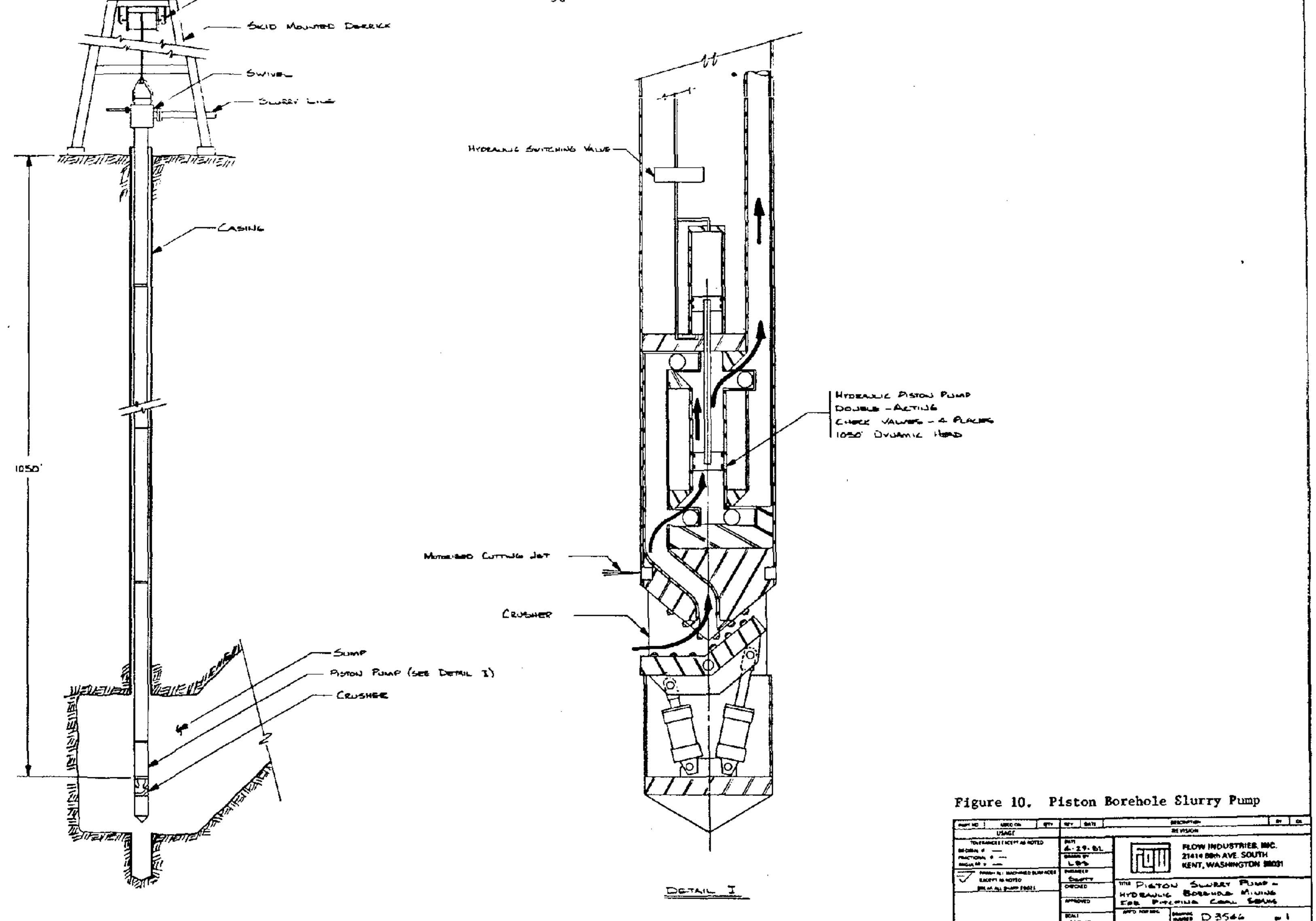


Figure 10. Piston Borehole Slurry Pump

the drilled hole. This cutting tool is lowered to the bottom of the hole and used to ream a 5-foot-diameter drainage hole up to the bottom of overburden. Horizontal cavities are then formed one at a time from the top down, leaving 10-foot intervals, or "pillars" to support the roof. With the hole completely mined in this fashion, it may then be feasible to remove the pillars. Pillar removal would begin from hole bottom and proceed to the top, leaving a continuous 40-foot span to subside while the cutting tool is protected by the remaining pillars in its upward course. However, this technique would be useful only in areas where subsidence is acceptable.

The coal is dewatered on the surface and the water returned to a holding pond where the remaining fines are allowed to settle out. The pond supplies water to a charge pump that drives it through filters to reduce pump and nozzle erosion. The filtered water is then supplied to the cutting tool via large, 5000-psi triplex pumps. Approximately 1300 kw of electric power are required to pump 500 gpm at that pressure.

3.2 Economic Analysis

A detailed economic analysis was performed to determine the potential benefit of developing the double-drill mining system. This analysis predicts the costs of all phases of the mining operation through delivery onto a unit train. Based on reported site selection efforts[3], it was assumed that the pitching coal seam used as a test case would be located either in the Hams Fork Region or the Hanna Basin of Wyoming. (Known reserves of pitching coal in Wyoming exceed 200 million tons.) Several of the input data assumptions are based on a Wyoming mine site.

Subsection 3.2.1 presents the baseline case description of the double-drill mining method. This baseline case is used for the sensitivity study presented in Subsection 3.2.2, which allows the importance of individual cost elements and mining parameters to be established. The issue of subcontracting

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[3]Knoke, G.S. and Archibald, W.R., "Test of Hydraulic Borehole Coal Mining, Site Selection, Phase I Review," Flow Technology Report No. 202 for DOE Contract No. DE-AC01-81FE14212, September, 1981.

or buying the drilling equipment is addressed in Subsection 3.2.3. Subsection 3.2.4 compares the double-drill mining method with the down-dip method, conventional borehole mining of horizontal seams, and standard underground mining of horizontal seams.

3.2.1 Baseline Case Description

The double-drill remote hydraulic mining economic analysis presented here is based on an eight-task division of the mining operation: pre-mining, site preparation, borehole development, production mining, production transportation, production processing, site reclamation, and safety.

Pre-mining activities include land acquisition, site exploration, and mining method selection. It is assumed that the mining company owns neither the surface nor the mineral rights and that there will be land and royalty costs during mining. There are also initial exploration costs to determine where and how much coal is at the site.

Site preparation includes developing the property to the point where the drilling crew can begin preparing boreholes. Access roads are first prepared and then the area around each borehole is cleared, leveled, and made contiguous with the access roads. A large dozer and grader are used to prepare the access roads and level the borehole sites. The equipment requires one operator each and a shared support man on the ground. A dump truck would assist by hauling gravel for the roads.

The borehole development operation includes drilling and casing the boreholes. The primary borehole development equipment consists of the 24-inch vertical and 10-inch slant drill rigs, both provided with conventional mud-circulation drills. The procedure is to drill the hole, install casing as required, and cement it into place. We assume that the casing is delivered directly to the site by the supplier and that the cementer costs are included with those of the drill rig. As each borehole is completed, the drill rig is moved to the next borehole location. A three-man crew is required to operate each drill rig. The existence of numerous drilling subcontractors makes it possible to subcontract the drilling operations as opposed to the mining company itself owning and operating the equipment. We have selected the subcontracting option for the purposes of this analysis in order to reduce the total initial investment. (A comparison of the subcontracting and equipment buying options is made in Subsection 3.2.3.)

Production mining consists of delivering the coal to the surface. The equipment required includes the pump tool and its aboveground support equipment, the cutting tool and its aboveground support equipment, and the cutting jet supply pumps and filters. The mining tools are broken out separately in the cost analysis to properly account for the effect of maximum depth in the sensitvity study. The cost of the pumping tool reflects the cost of the centrifugal pumps installed in the tool every 350 feet. The pumping and cutting systems have one operator each and share the services of a support man. Thus, the crew of each pumping-cutting system comprises three persons. Support and maintenance personnel are available from neighboring systems to assist with tripping the tools for maintenance or moving the system to a new borehole, the latter being required approximately once per month. The pumping system delivers a de-aired coal slurry to the slurry pipeline network.

Production transportation consists of delivering the coal slurry from the boreholes to the coal processing area, returning the clarified water to the cutting tool, trucking the coal to the silo, and loading the unit trains. The processing area may be as much as a mile away from the mining tools. A network of slurry pumps, hoses, and pipes is used to transport the slurry from each pumping tool to their common coal processing area for dewatering. The water is recycled into a holding pond from which it may be filtered and pumped back to the cutting tool as required. The dewatered coal is piled on draining pads from which it is loaded onto 35-ton off-road ore trucks by means of a 6-yard front-end loader. These trucks haul the coal an average of 2 miles across the mine area to the rail loadout facility. This facility consists of a rail loop, a truck dumping facility, a conveyor, a 12,000-ton coal silo or equivalent, and a silo discharge to load the trains. The coal is dumped by the haul trucks and lifted by conveyor into the silo, where it is stored until 10,000 tons have been accumulated (which takes approximately 40 hours). A 100-car unit coal train is then loaded (taking about 3 hours). Only two men are required to operate this facility.

Coal processing consists of coarse separation, fine separation, fine drying, and a holding pond to settle out the remaining fines. Coarse separation is accomplished with a sieve bend, a vibrating screen, and a conveyor to pile the coarse dewatered coal on a draining pad. The fine separation process consists of a cyclone feed tank, cyclone feed pump, a bank of hydrocyclones, and a tank level control system. The fine drying process is accomplished by a continuous-feeding centrifuge and a conveyor to carry the dry coal fines to a storage pile. The fines remaining in the water are recovered in the holding pond, to which a flocculent is added to accelerate the deposition rate. Two operators are needed for this coal processing system.

Site reclamation consists of borehole abandonment and land reclamation. Borehole abandonment is performed in accordance with standard oil well abandonment procedures. Land reclamation includes using a dozer to recontour the land to approximately its original state and replanting the soil with native vegetation, as required by the local environmental agencies. The dozer and its operator are shared with the site preparation task.

Various health and safety equipment will be provided, including a four-wheel-drive ambulance, large fire extinguisher carts, numerous hand-held fire extinguishers, first aid kits on every moving vehicle and in facilities, general safety equipment, and personal safety equipment. General safety equipment includes stretchers, signs, and tags; personal safety equipment includes hardhats, goggles, safety glasses, safety-toed boots, and ear protectors. One full-time person will be available for minor medical assistance and for first aid in emergencies. A health and safety administrator will be part of the office staff paid from overhead.

A complete cost package prepared for the use of the double-drill system in Wyoming consists of the following:

A. Borehole inputs
B. Financial inputs
C. Borehole operating parameters
D. Individual equipment cost inputs
E. Individual equipment cost outputs
F. Equipment investment schedule
G. Summary of capital, operating, depreciation, and amortization costs
H. Cash flow calculation for typical years
I. Cash flow calculation for the first year
J. Cash flow and investment schedule with return on investment

These data tables are listed and discussed in Appendix C. A unified summary of the costs is shown in Table 12. This table lists the costs associated with each item of equipment and the indirect costs in terms of annual cost and dollars per ton of product. The bottom line shows the internal rate of return (IROR) available with the selling price of coal indicated. Note that there is no drilling equipment depreciation allowance since it is assumed that drilling has been subcontracted.

3.2.2 Sensitivity Study

A study of the sensitivity of IROR (discounted cash flow) to various parameters was performed to provide insight into the economic feasibility of the double-drill mining method and to establish the potential benefits obtainable from subsystem development. The parameters considered include seam thickness, maximum depth, cavity radius, dip angle, mining rate, mining system availability, slant drilling cost, pipeline transportation distance, selling price, extraction tax rate, and royalty rate. The sensitivity study was performed by individually varying each parameter by approximately a factor of two from its baseline value. The resulting IROR of investment curves are plotted on identical ordinate scales in Figures 11 through 21 for ease of comparison.

Figure 11 shows that seam thickness is a very important parameter when it is less than 10 feet. Greater thicknesses bring little improvement in IROR. The maximum depth is the lowest point of the coal seam that is mined from the overburden down.

Figure 12 shows that the amount of coal removed from each borehole becomes uneconomically small at shallow depths. At great depths, drilling and pumping dominate the costs.

Cavity radius is relatively insensitive within the range of 30 to 50 feet but becomes increasingly important at smaller values, as shown in Figure 13. As with shallow depth, the amount of coal removed from each borehole is economically small at smaller cavity radii.

In contrast, dip angle (Figure 14) is insensitive over a wide range. At low dip angle, the long slant drill is compensated for in high yield per borehole, and vice versa for high dip angle.

Table 12. Double-Drill Baseline Cost Summary

Item/Equipment	Depreciation, $K/yr	Operating, $K/yr	Total, $K/yr	Unit Cost $/ton of Product
GRADER	32	220	252	0.13
DOZER	34	160	194	0.10
DRILL-18	0	4,242	4,242	2.20
MINER-18	60	4,473	4,533	2.35
PIPELINE	25	372	397	0.21
COAL PREP-CRSE	24	416	440	0.23
COAL PREP-FINE	12	450	462	0.24
COAL PREP-DRY	3	69	72	0.04
LOADER	80	331	411	0.21
ORE TRUCK 35T	57	556	613	0.32
LOADOUT	225	856	1,081	0.56
SAFETY EQUIP.	8	190	198	0.10
DUMP TRUCK	4	103	107	0.06
SLANTDRILL-6	0	3,960	3,960	2.05
PUMPTOOL	720	78	798	0.41
CUTTOOL	254	34	288	0.15
MINER-6	420	5,965	6,385	3.31
Depreciation & Amortization				
Miscellaneous	156		156	0.08
Exploration	15		15	0.01
Miscellaneous Operating				
Land Cost		146	146	0.08
Ponds		12	12	0.01
Utilities		1	1	0.00
Other Costs				
Royalty Payments			3,860	2.00
Extraction Taxes			8,204	4.25
Income Taxes			3,217	1.67
Profit				
Net Income After Taxes			8,218	4.23
Gross Revenue				
Total			48,262	25.00
IROR				41.0%

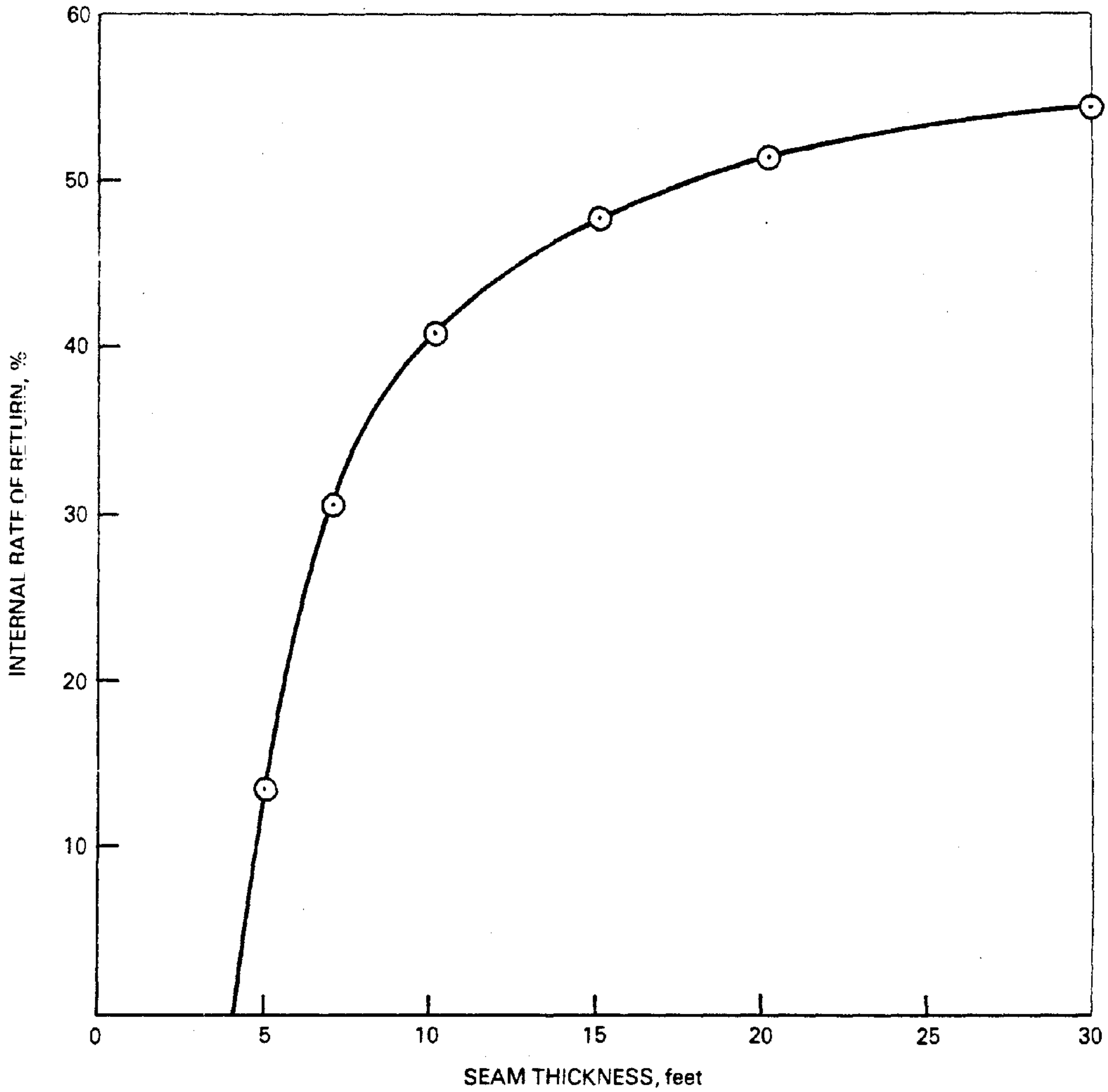

Figure 11. Seam Thickness Sensitivity Study Results

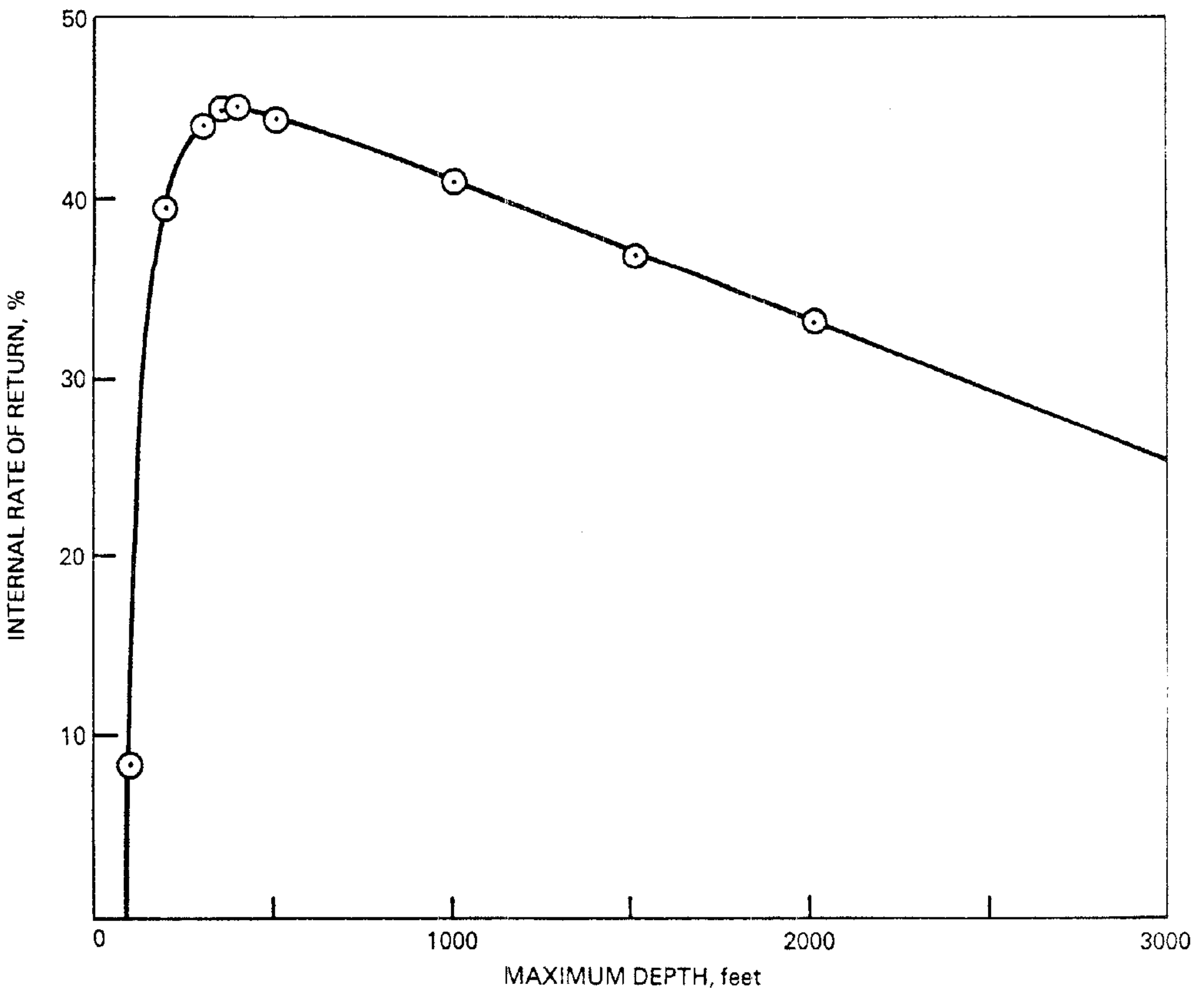

Figure 12. Maximum Depth Sensitivity Study Results

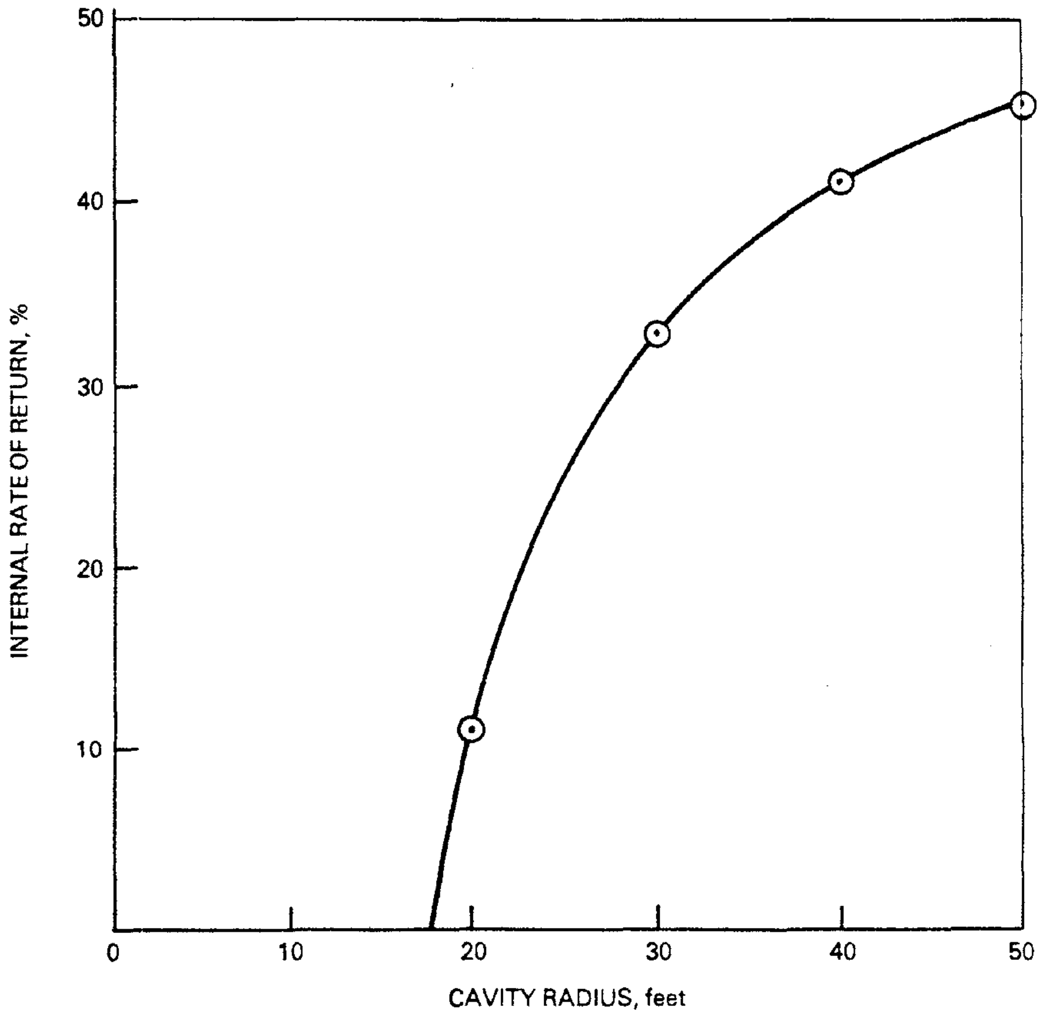

Figure 13. Cavity Radius Sensitivity Study Results

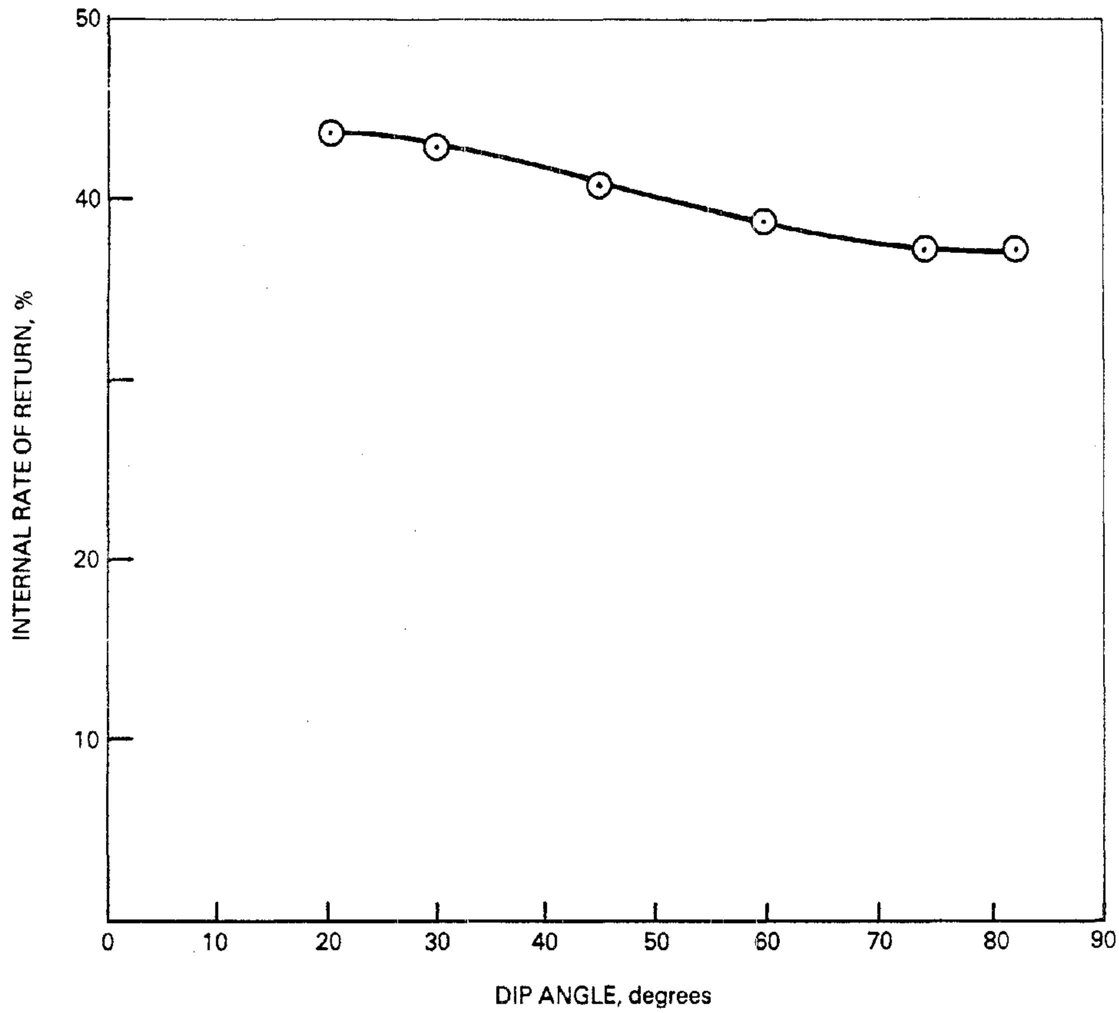

Figure 14. Dip Angle Sensitivity Study Results

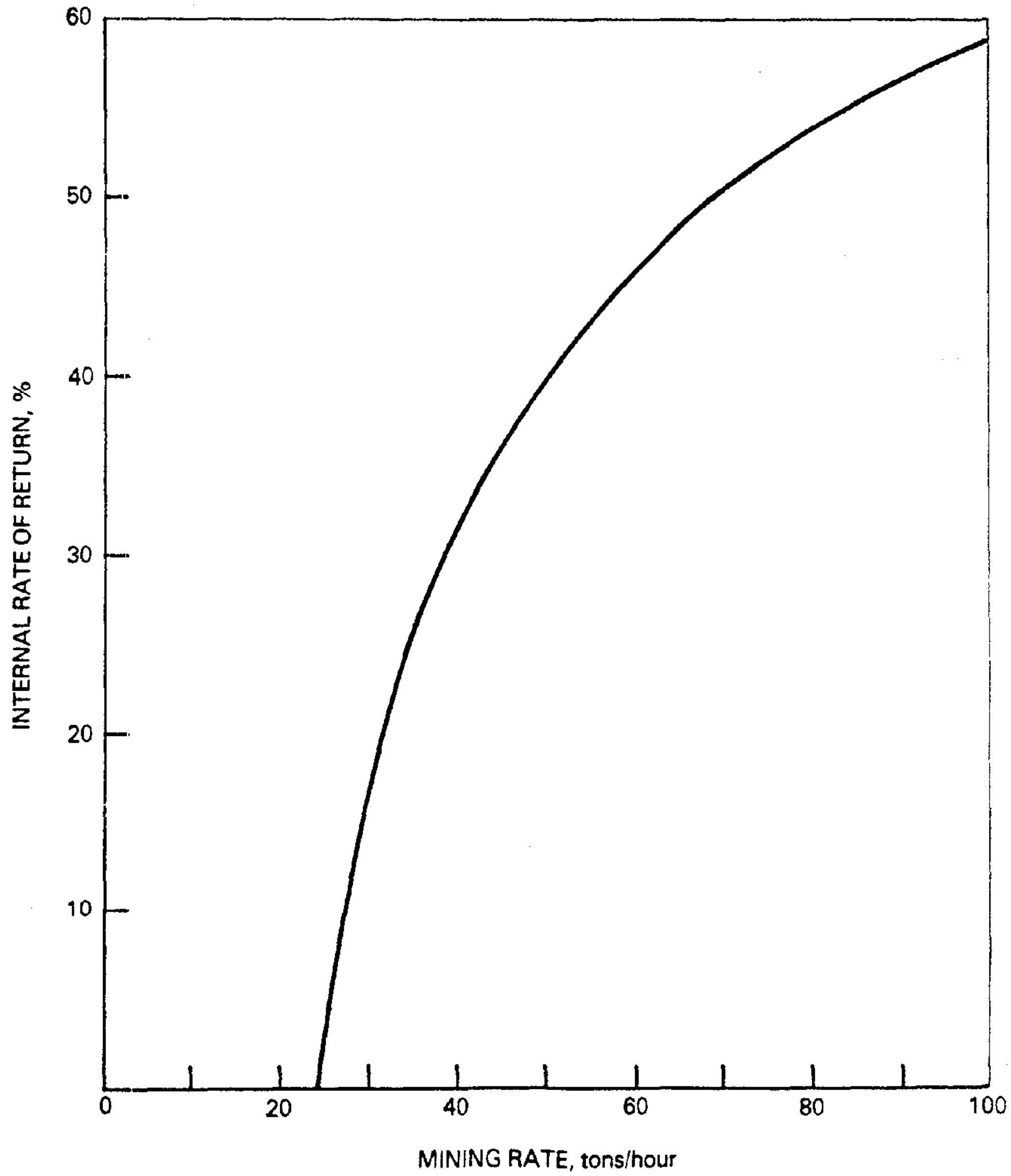

Figure 15. Mining Rate Sensitivity Study Results

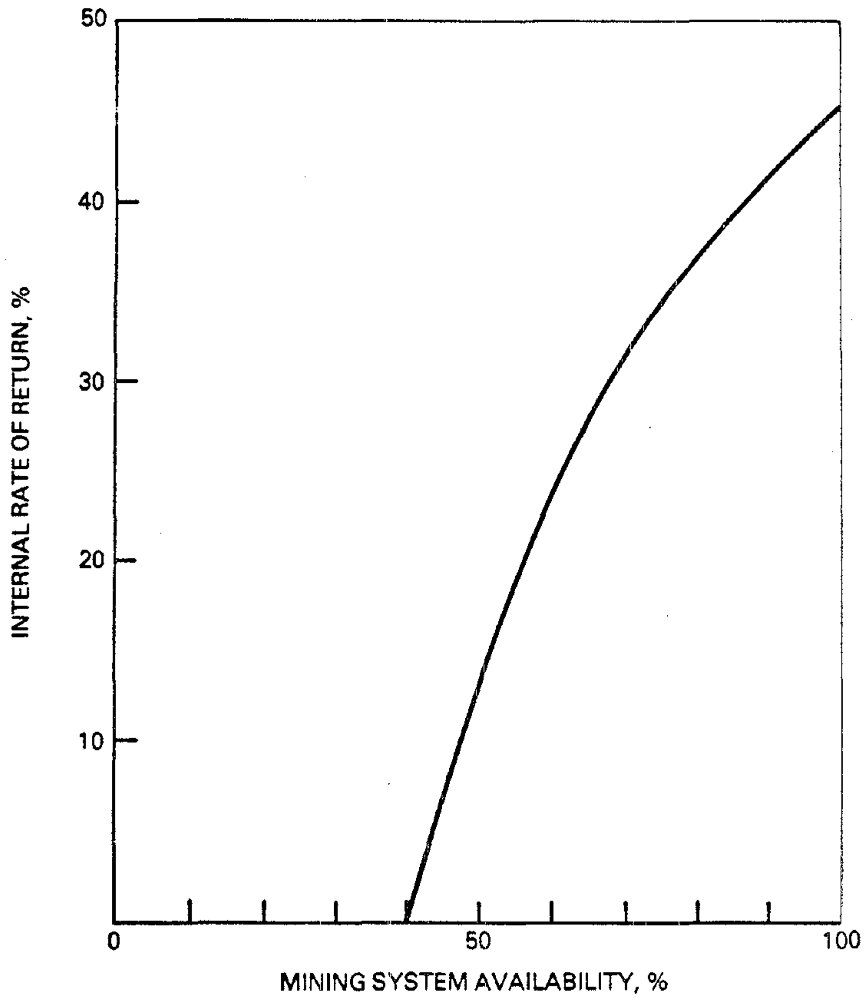

Figure 16. Mining System Availability Sensitivity Study Results

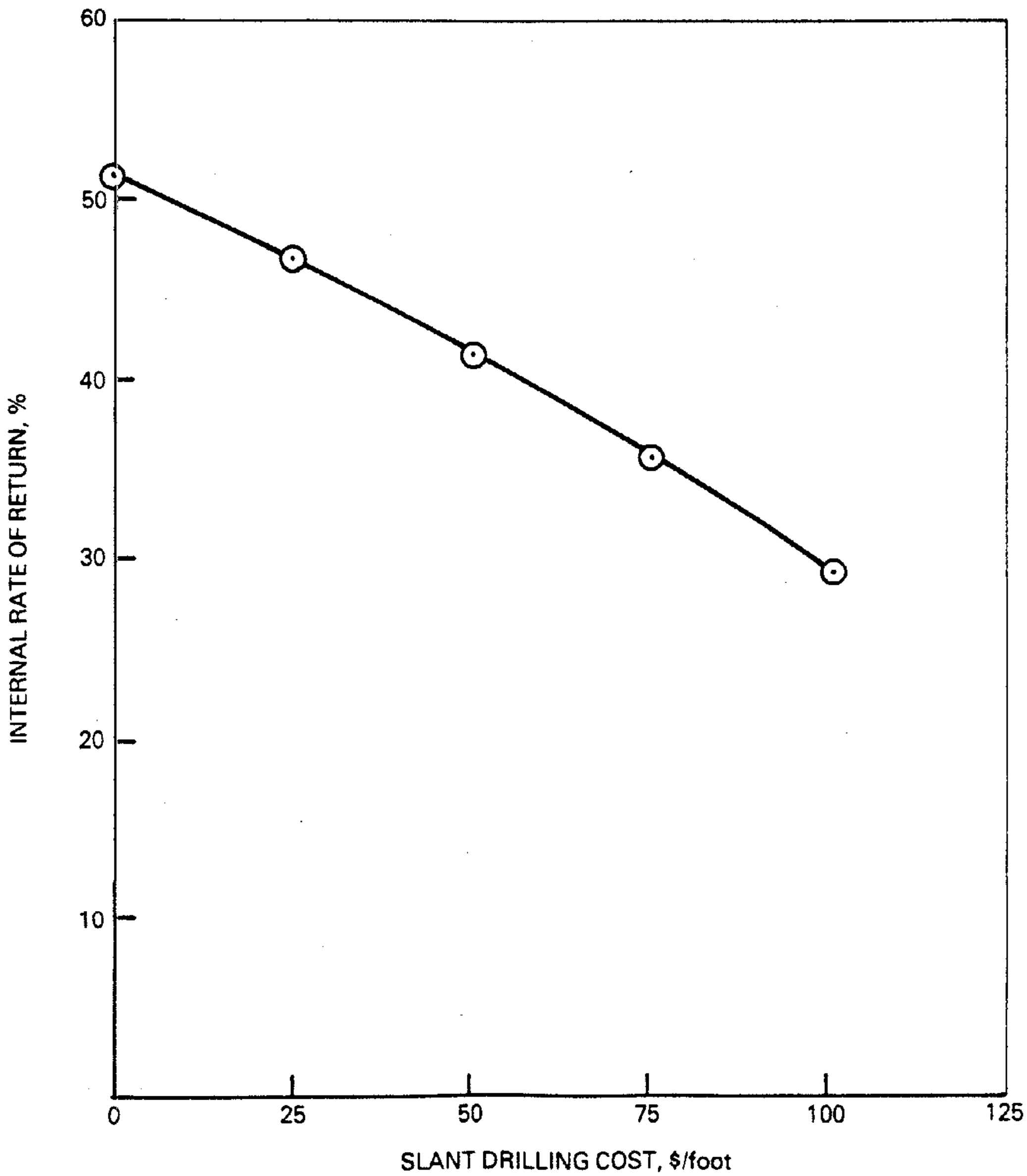

Figure 17. Slant Drilling Cost Sensitivity Study Results

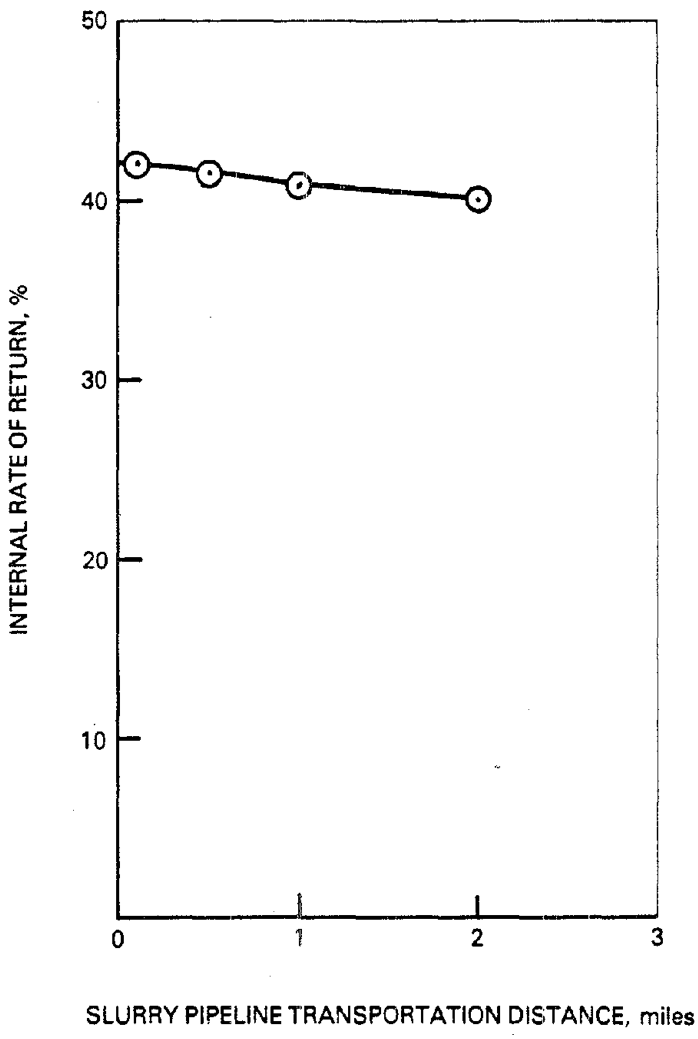

Figure 18. Pipeline Transportation Distance Sensitivity Study Results

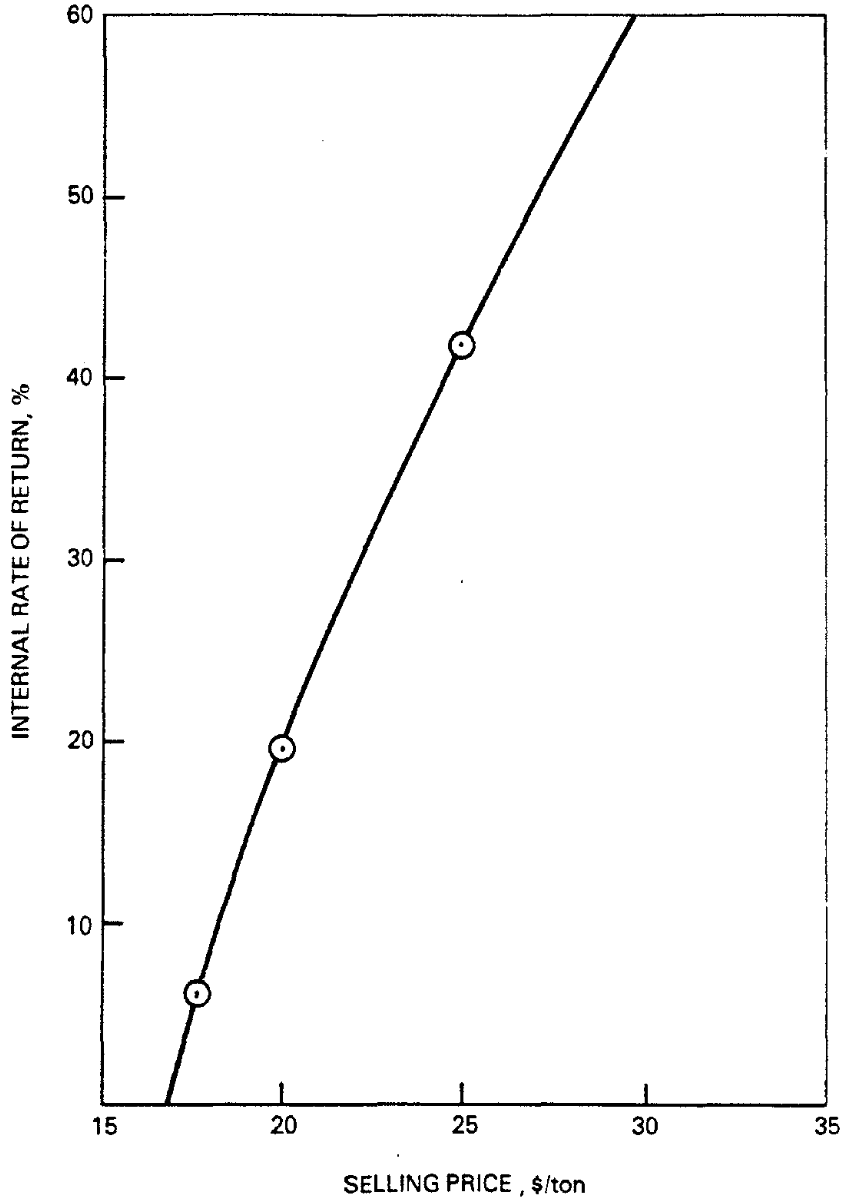

Figure 19. Selling Price Sensitivity Study Results

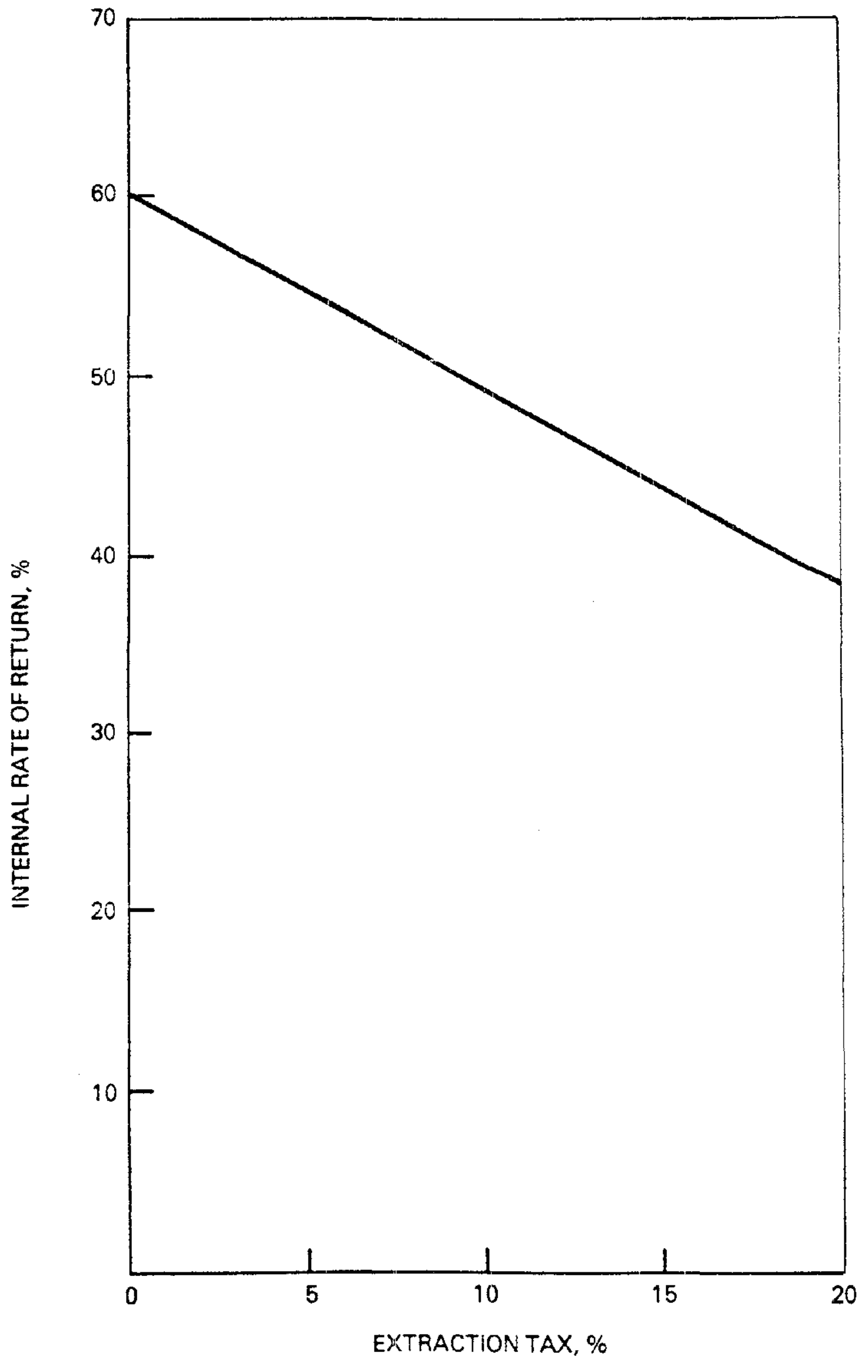

Figure 20. Extraction Tax Rate Sensitivity Study Results

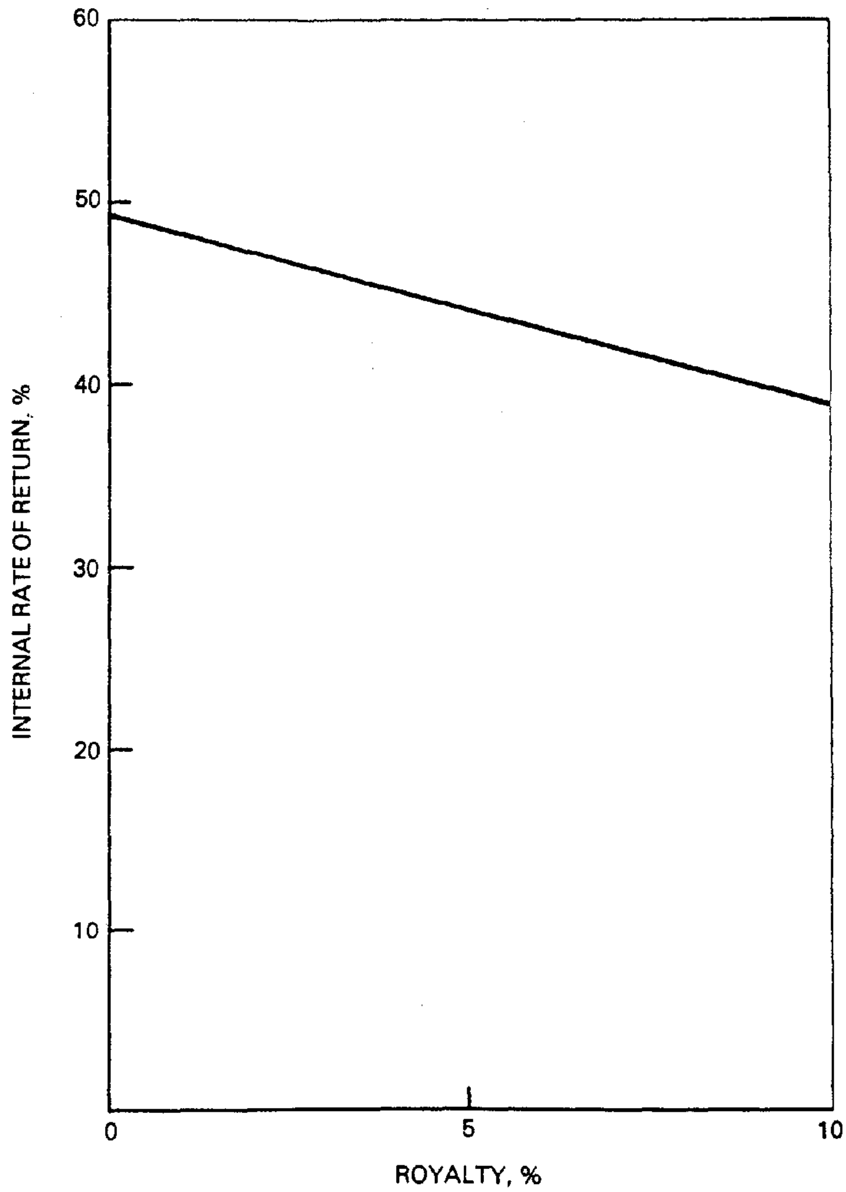

Figure 21. Royalty Rate Sensitivity Study Results

The mining rate is the single most important parameter considered. The curve shown in Figure 15 is actually a smooth representation of a stepped shape, with steps at each change in the number of mining systems required to provide the daily tonnage.

A similar stepped shape results from varying mining system availability -- the percentage of time the units actually spend mining. The smoothed curve shown on Figure 16 also represents a fair amount of sensitivity.

Another parameter known to be important in borehole mining is the drilling cost (Figure 17). The slant drilling cost has been selected because its cost is less reliably known than vertical drilling. Fortunately, even a factor of two increase in drilling cost does not make a major change in IROR.

A minor cost element that is important to the mine plan is the impact of the slurry pipeline transportation distance. As can be seen in Figure 18, a great deal of latitude is available to the mine planner.

Figure 19 illustrates the influence of coal quality and demand, reflected in selling price, on the IROR. This sensitivity is also reflected in such parameters as the state's extraction tax rate and the mineral rights owner's royalty rate, but to a lesser degree (Figures 20 and 21).

3.2.3 Drilling Equipment Purchase/Rental Comparison

The largest piece of equipment that is readily available for subcontracting is the drilling equipment. The question being addressed here is whether the mine operator should buy his own drilling equipment and operate it himself, or subcontract the drilling. In order to reduce the capital investment and because experienced drilling subcontractors are available to the extent that we obtained quotes from them to use in the analysis, the baseline case subcontracts the drilling. The contrasting case is summarized in Table 13. The depreciation is higher than in Table 12, reflecting the increased capital investment, but the operating costs are lower, reflecting the difference between the estimated drill operating costs and the subcontracting quotes. The net effect is reduced costs, higher profit, more taxes, and higher IROR. The conclusion is that the additional investment for the drilling equipment would be justified.

Table 13. Double-Drill Cost Summary with No Subcontracted Drilling

Item/Equipment	Depreciation, $K/yr	Operating, $K/yr	Total, $K/yr	Unit Cost $/ton of Product
GRADER	32	220	252	0.13
DOZER	34	160	194	0.10
DRILL-1[illegible]	60	970	1,030	0.53
MINER-1	60	4,473	4,533	2.35
PIPELINE	25	372	397	0.21
COAL PREP-CRSE	24	416	440	0.23
COAL PREP-FINE	12	450	462	0.24
COAL PREP-DRY	3	69	72	0.04
LOADER	80	331	411	0.21
ORE TRUCK 35T	57	556	613	0.32
LOADOUT	225	856	1,081	0.56
SAFETY EQUIP.	8	190	198	0.10
DUMP TRUCK	4	103	107	0.06
SLANTDRILL-6	40	1,673	1,713	0.89
PUMPTOOL	720	78	798	0.41
CUTTOOL	254	34	288	0.15
MINER-6	420	5,965	6,385	3.31
Depreciation & Amortization				
Miscellaneous	156		156	0.08
Exploration	15		15	0.01
Miscellaneous Operating				
Land Cost		146	146	0.08
Ponds		12	12	0.01
Utilities		1	1	0.00
Other Costs				
Royalty Payments			3,860	2.00
Extraction Taxes			8,204	4.25
Income Taxes			5,728	2.97
Profit				
Net Income After Taxes			11,166	5.76
Gross Revenue				
Total			48,262	25.00
IROR				51.8%

3.2.4 Double-Drill Method/Alternate Methods Comparison

This subsection compares the economics of mining a 10-foot-thick seam using the double-drill, down-dip, conventional borehole, and standard underground mining methods. For these comparisons, the former two methods necessarily involve pitching seams while the latter two methods involve non-pitching seams. A comparison of Tables 12 and 14 shows that the down-dip method has a higher mining cost (includes equipment and miscellaneous operating and depreciation and amortization costs) than the double-drill method ($16.04 versus $12.85). With royalty payments, extraction tax, and income tax, the resulting IROR is 19 percent as compared to 41 percent for the double-drill method. When this factor is combined with the additional complexity of drilling a larger diameter slant hole for the down-dip method, the double-drill method is seen to be distinctly preferable.

Employing conventional borehole mining systems that use vertical boreholes to mine shallow (300 foot), nearly horizontal (11-degree), 15-foot thick seams also results in a mining cost slightly higher ($15 per ton) than that of the double-drill method. Table 15 summarizes conventional borehole mining costs using assumptions comparable to those of the double-drill case given in Table 12. Although drilling costs are very similar for the two methods, mining costs are considerably less for the double-drill method due to its higher mining rate and greater availability (85 percent versus 70 percent for conventional borehole mining equipment).

Standard underground mining, whether with conventional or continuous mining equipment, costs in the range of $15 to $35 per ton, depending upon the amount of shaft development work required to access the 6,000 tons per day of production[4,5]. The lower figure represents mining costs where the seam outcrops and no development is required; the higher figure corresponds to the cost of mining at depths of approximately 2,000 feet. In the former case, coal selling prices of approximately $25 per ton will produce an acceptable return; in the latter case, the coal value must be approximately $55 per ton to be acceptable. By comparison, the double-drill economics appear very favorable.

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[4]Private Communication, Rocky Mountain Energy Corp., 1981.

[5]Brezovec, D., "Conventional Output Falls in U.S.," Coal Age, Vol. 87, No. 5, pp. 82-89, May, 1982.

Table 14. Down-Dip Cost Summary with Horizontal Cavities

Item/Equipment	Depreciation, $K/yr	Operating, $K/yr	Total, $K/yr	Unit Cost $/ton of Product
GRADER	32	220	252	0.13
DOZER	34	160	194	0.10
PIPELINE	2	392	394	0.20
COAL PREP-CRSE	24	416	440	0.23
COAL PREP-FINE	12	450	462	0.24
COAL PREP-DRY	3	69	72	0.04
LOADER	80	331	411	0.21
ORE TRUCK 35T	57	556	613	0.32
LOADOUT	225	856	1,081	0.56
SAFETY EQUIP.	8	190	198	0.10
DUMP TRUCK	4	104	108	0.06
CUTTOOL	424	57	481	0.25
SLANTDRILL-12	0	17,352	17,352	8.99
SLANTMINER-12	900	7,655	8,555	4.43
Depreciation & Amortization				
Miscellaneous	156		156	0.08
Exploration	15		15	0.01
Miscellaneous Operating				
Land Cost		160	160	0.08
Ponds		13	13	0.01
Utilities		1	1	0.00
Other Costs				
Royalty Payments			3,860	2.00
Extraction Taxes			8,204	4.25
Income Taxes			1,205	0.62
Profit				
Net Income After Taxes			4,035	2.09
Gross Revenue				
Total			48,262	25.00
IROR				19.3%

Table 15. Conventional Borehole Cost Summary

Item/Equipment	Depreciation, $K/yr	Operating, $K/yr	Total, $K/yr	Unit Cost $/ton of Product
GRADER	36	220	256	0.13
DRILL	150	6,619	6,769	3.42
FLATBED	5	102	107	0.05
FORKLIFT	32	123	155	0.08
CEMENTER	26	318	344	0.17
MINER	2,160	14,900	17,060	8.62
PIPELINE	25	397	422	0.21
COAL PREP-CRSE	24	416	440	0.22
COAL PREP-FINE	14	450	464	0.23
COAL PREP-DRY	3	69	72	0.04
LOADER	90	331	421	0.21
CAT TRUCK	65	556	621	0.31
LOADOUT	225	856	1,081	0.55
CRANE	32	204	236	0.12
RECL. GRADER	36	220	256	0.13
SAFETY	8	190	198	0.10
Depreciation & Amortization				
Miscellaneous	156	0	156	0.08
Exploration	15	0	15	0.01
Miscellaneous Operating				
Land Cost	0	192	192	0.10
Ponds	0	15	15	0.01
Utilities	0	1	1	0.00
Other Costs				
Royalty Payments			3,960	2.00
Extraction Taxes			8,415	4.25
Income Taxes			1,804	0.91
Profit				
Net Income After Taxes			6,040	3.05
Gross Revenue				
Total			$49,500	25.00
IROR				21.3%

4. Conclusions and Recommendations

Six remote hydraulic mining methods for mining steeply pitching thin coal seams have been studied. These six methods were developed in sufficient detail to permit preliminary mining cost estimates to be made. The most economically favorable method was shown to be the double-drill method, i.e., the method by which coal is mined via a slanted cutting jet borehole and pumped to the surface through a vertical pumping borehole. The down-dip method, wherein a single large slanted borehole is drilled down-the-dip and a combined cutting and pumping tool is used to extract the coal, was determined to be economically feasible but of secondary interest relative to the double-drill method.

The double-drill method was then subjected to more detailed engineering and economic analysis. Two unproven features were identified: The pumping method and the method to ensure borehole intersection underground. The recommended pump is a centrifugal slurry pump commercially available for installation in boreholes. This pump would be combined with a coal crushing device. The recommended drilling method utilizes a low-frequency electromagnetic homing device to guide the slant drill to the vertical borehole.

The more detailed economic analysis of the double-drill method indicated a very favorable IROR (52 percent). A similar analysis of the down-dip method showed that it might provide a respectable 19 percent IROR. A cost comparison of double-drill mining in pitching seams versus standard underground mining in level seams shows that the former offers the greater potential IROR.

In conclusion, the double-drill method, and possibly the down-dip method, should be capable of economically mining steeply pitching thin coal seams. However, both methods involve the use of slant drilling and mining equipment and will require further development of specific features.

APPENDIX A

PUMP SPECIFICATIONS

A.1 Centrifugal Pump

The following information describes a commercially available, electric-driven centifugal submersible slurry pump and includes the manufacturer's cost estimate and specifications for a five-stage, 6-inch-diameter pump capable of generating 350 feet of dynamic head. Three such pumps, spaced at 350-foot intervals from the bottom of the string, are required to pump from a 1000-foot depth.

A water-powered, reciprocating jaw crusher will be installed at the bottom pump's slurry inlet. This crusher will reduce oversize coal fragments to particles 1/2 inch in diameter.

A motorized cutting jet at the base of the centrifugal pump will be used both to generate the sump and to break up pieces of coal too large to enter the crusher.

BARRETT, HAENTJENS & CO.

HAZLETON Pumps

. . . TELEPHONE AREA CODE 717 455-7711 · TWX 510-655-7255 TELEX

March 16, 1982

Mr. Michael McDonald
Flow Industries
21414 68th Ave., South
Kent, WA 98035

RE: Our Proposal Q-17808

Dear Mr. McDonald,

On November 25th, we spoke about an application involving the possible use of our submersible slurry pump. I had promised to send information and pricing, however, shortly after our conversation, I learned of some difficulty with our test unit. I should have corresponded with you, however, we were expecting to have the pump returned to us for examination. The pump did not arrive until approximately one week ago at which time it was disassembled for inspection. From the telephone report, we had expected to find considerable damage as a drop in capacity had been intended. What we found was simply that the shaft seals had not functioned satisfactorily and that considerable wear occured on the shaft sleeves. This permitted a recirculating flow between the stages which accounted for the drop off in capacity. We are uncertain as to the adequacy of flushing water which was supplied during the test, however, plan to make some improved seals and to request a renewed test period. The condition of the impellers and casings is excellent and we are, therefore, quite optimistic.

For your planning purposes, we are enclosing some general literature and a cross section of the pumping unit. The motor is a conventional submersible well pump motor, however, has a thrust bearing reversed to take a down thrust when the motor is located above the pump. The motor is cooled and flushed by an independent supply line and thus does not need to be submerged for cooling.

We regret the delay in submitting this information, however, we trust you can appreciate our concern.

Very truly yours,.

BARRETT, HAENTJENS & CO.

W. D. Haentjens

W. D. Haentjens

TO Mr. M. McDonald, Flow Ind., Q-17808 DATE March 16, 1[illegible]2

CC: (Dist. Representative)
M.E.Kline Company
10205 Grand Lake Sta.,
Oakland, CA

VERTICAL PUMP SPECIFICATIONS

BARRETT, HAENTJENS & CO., - HAZLETON, PENNSYLVANIA

CUSTOMER: Flow Ind., Q-17808
SERVICE:

One (1) "HAZLETON" 6" 5 Stage TYPE "SST" PUMP(S)

800	Gallons per minute (~~Each~~)
350	Total dynamic head (~~Each~~) 70'/stage (9 stages max. this unit)
1725	Revolutions per minute (Drive)
48%	Efficiency
147	BHP—Clear water
-	BHP including sp. gr. of slurry
200	HP motor recommended (1725 RPM) 460V,3 phase, 60 Hertz
6"	Discharge— # ANSI flange
-	Length from bottom of mounting plate to bottom of pump
-	Center bearings
-	Max. spherical size solids thru impeller
-	Max. spherical size thru standard screen
-	Tons per hour of
-	% Insoluble solids by weight
-	Sp. gr. of dry solids
-	NPSH required
-	NPSH available
1.5	GPM of bearing water required at atmos. pressure /bearing plus 10 GPM for motor cooling.
-	Pumping temperature
-	pH/Corrosives
-	Viscosity at P.T.
-	Elevation above sea level
-	Dia. bid impeller (min./ max)
-	GPM minimum recommended flow

CONSTRUCTION:

Temp. "SST" bulletin; P-1117; Bull. 450 for motor construction.

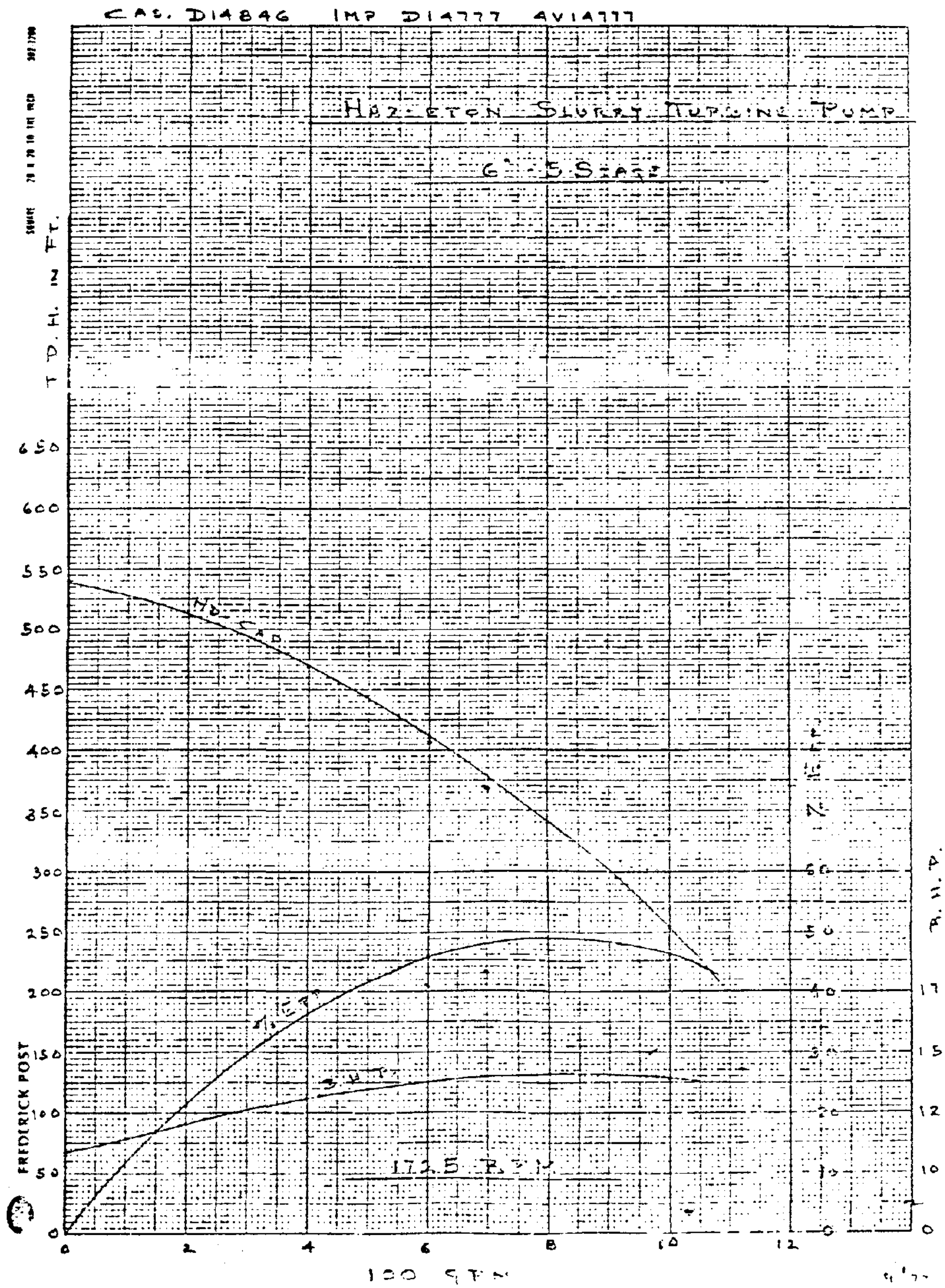
MATERIAL:

Internal casings and impellers of Type 4 NiHard,
housing (supports NiHard casing) aluminum bronze;
17-7 shaft; 28% Cr. heat treated shaft sleeves.

WEIGHT: Approx. lbs. without motor

PRICE: $ 44,557 complete with motor, FOB, Hazleton, PA

SHIPMENT: Approx. 20-22 weeks after receipt of formal purchase order, finalization of technical or other pertinent details, and return of prints or data submitted for customer approval.

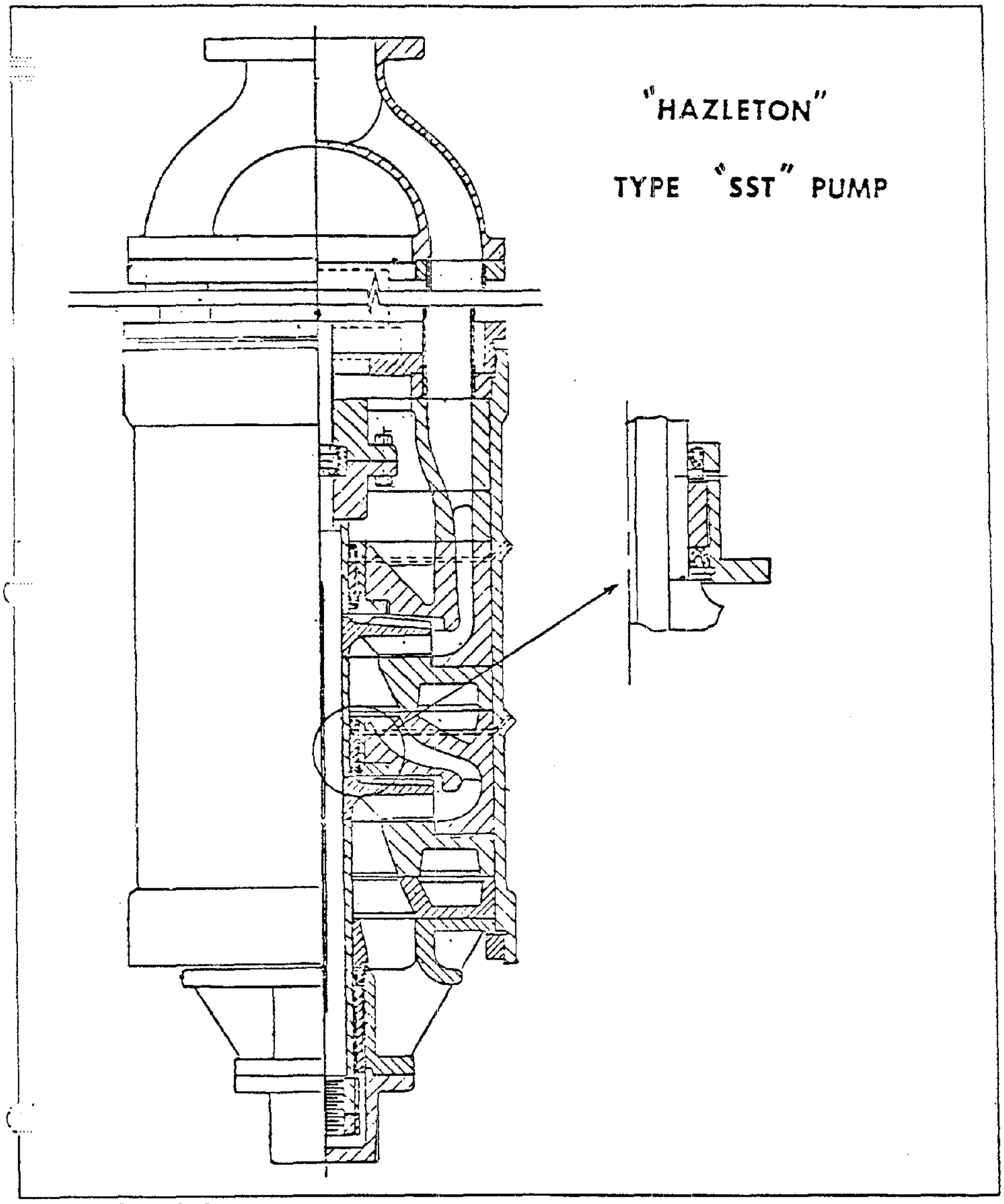

CAS. D14846 IMP D14777 4V14777
HAZLETON SLURRY TURBINE PUMP
6" - 5 STAGE
T.D.H. IN FT.
HD. CAP.
% EFF.
B.H.P.
B.H.P.
1725 R.P.M.
100 GPM
FREDERICK POST

BARRETT. HAENTJENS & COMPANY

HAZLETON, PENNSYLVANIA

BULLETIN

PAGE #



DRAFTING 2C 4/70

BARRETT, HAENTJENS & CO. – HAZLETON, PENNSYLVANIA

A pioneering development by HAZLETON — a submersible turbine type slurry pump with all wea[illegible] parts of NiHard or other abrasion resisting alloy. Special water cooled motor can operate e[illegible] submerged or in air. Motor is located between the three discharge pipes. For heads to 600'. [illegible] shown is for 700 GPM, 340' 1770 RPM, 140 HP motor. Unit designed for mining through borehol[illegible] such services of shaft bottom piping. Larger capacities and heads available.

A.2 Piston Pump

The piston pump design incorporates a double-acting piston. A previously developed four-way hydraulic control valve uses two inlet and two outlet check valves to control the action of the piston. As the piston moves upward, an upper outlet check valve opens, an upper inlet check valve closes, and slurry flows from the upper piston chamber into the slurry line. At the same time, a bottom inlet check valve opens, a bottom outlet check valve closes, and slurry flows through the crusher into the lower piston chamber. The action is reversed when the piston moves in the downward direction.

A water-powered, reciprocating jaw crusher will be installed at the pump's slurry inlet. This crusher will reduce oversize coal fragments to particles 1/2 inch in diameter.

A motorized cutting jet at the base of the pump will be used both to form the sump and to break up pieces of coal too large to enter the crusher.

The basic operating parameters of this pump are as follows:

Pumping capacity	800 gpm
Piston diameter	10 inches
Slurry line diameter	6 inches
Slurry velocity	9.1 feet/second
Piston velocity	3.3 feet/second
Piston pressure	500 psi
Total dynamic head	1050 feet

APPENDIX B

DRILL GUIDANCE SPECIFICATIONS

B.1 Conventional Drill Guidance Method

A drill guidance system is employed to ensure the intersection of the two holes drilled for the double-drill coal mining method. Various commercially available devices have been developed to determine and control the direction of the drill. For example, conventional magnetic survey devices (magnetometers) are used to determine drill azimuthal direction while its inclination is determined with accelerometers or bubble devices. Direction is checked as each new drill section is added and the course plotted manually. This guidance method is accurate to within 30 feet per 1,000 feet of drilling.

B.2 Advanced Drill Guidance System

A state-of-the-art system available only from Develco, Inc., Sunnyvale, California, might be used as a homing system to guide the drill for the last several hundred feet of drilling. This method employs a ferro-magnetic-core-solenoid transmitting antenna mounted coaxially in the drill head to generate low-frequency (approximately 10 Hz) quasi-static dipole magnietic fields. A single vector field sensor (three-axis) is placed at the target point and aligned with the drill approach direction. Perfect alignment of drill and sensor results in a null signal, i.e., the transverse fields components will be zero. Imperfect alignment resulting from drill deflection produces error signals at the sensor that can be translated into steering commands to bring the drill back on course.

B.3 Technical Information

An example of commercially available directional drilling services for borehole mining is presented in the remaining portion of this appendix. This information describes the Baker Energy Resources Corporation's approach to drilling holes for both the double-drill and down-dip borehole mining methods. This company now uses conventional drill guidance methods but may soon begin using the low-frequency magnetic homing system described above.

BAKER
ENERGY RESOURCES CORPORATION
DIRECTIONAL DRILLING SPECIALISTS

November 25, 1981

Mr. Lester Huffman
Flow Industries, Inc.
21414 - 68th Avenue South
Kent, WA 98301

Dear Mr. Huffman:

We are pleased to submit preliminary costs for directional drilling services at the coal project in Wyoming. These costs are only estimates; a firm proposal may be prepared once a more definitive lithology is reviewed, a time is set for drilling and contract terms are set.

Our costs reflect the three different mining methods you described. Briefly, these methods are:

> Mining Method One: A vertical bore hole large enough to install 18" casing to 1000 feet.
>
> Mining Method Two: A slant bore hole 25°+ from vertical large enough for 18" casing to 1000 feet.
>
> Mining Method Three: A slant bore hole 25°+ from vertical large enough for 7" casing to 1000 feet.

The first two methods are very similar in terms of cost and time. The rig would be mobilized to Wyoming and set at its initial angle, vertical for Method One and 25°+ from vertical for Method Two. A 9 5/8" diameter hole is then drilled to the full depth using a downhole motor and special directional drilling techniques. The hole is opened to 20" diameter using two passes. A 18" dia. Schedule 30 steel line pipe to be used for casing is then cemented into place. A project like this could be completed within 15 days per hole after being rigged up and ready to drill. The costs for Mining Method One and Two are attached.

Mining Method Three would require less time and money. In this situation, a 9 5/8" diameter hole is drilled to the total depth. A 7" diameter threaded steel casing is run in the bore hole and then cemented into place. It would take approximately nine days to complete this project once the rig is ready to drill. The costs for Mining Method Three are also attached.

BERCO manufactures and operates slant drilling rigs with various capabilities; and some rigs by others currently on the market could be modified for this type of application. For the vertical bore in Mining Method One, we could use our equipment or a conventional rig could be used employing directional drilling techniques to maintain a straight vertical hole.

We appreciate the opportunity to help you on this project. If you have any questions or if we may be of further help. please do not hesitate to call. We look forward to working with Flow Industries on this work.

Very truly yours,

BAKER ENERGY RESOURCES CORPORATION

Hugh W. O'Donnell

Hugh W. O'Donnell, P.E.
President

HWO/gd
Enclosures

PRELIMINARY COST ESTIMATE

DIRECTIONAL HOLES FOR COAL SLURRY MINING

1. Mobilization/Demobilization Cost

Mobilization and Rig Up (14 days).	$70,000
Rig Down & Demobilize (2 days)	50,000
Sub Total	$120,000

2. Mining Method One

Drill a 9 5/8" bore hole vertically to 1000 feet. Open hole to 20 inches using two passes. Weld and run 18" diameter schedule 30 line pipe and cement in place.

Contractor Cost

Drill & Ream Hole, Rig Time to Run Casing and Cement (13 days).	$ 91,000

Third Party Cost

Casing (Per U.S. Steel).	$ 6,000
Cement (Per Halliburton)	24,000
Miscellaneous (Mud, Bits, Reamers, Diverter,et.al.)	33,000
Sub Total - Third Party Cost	$ 63,000
Sub Total - Method One	$154,000

3. Mining Method Two

Drill a 9 5/8" bore hole at 25°+ from vertical to 1000 feet. Open hole to 20 inches using two passes. Weld and run 18" diameter Schedule 30 line pipe and cement in place.

Contractor Cost

Drill & Ream Hole, Rig Time to Run Casing and Cement (13 days).	$91,000

Third Party Cost

Casing (Per U.S. Steel).	6,000
Cement (Per Halliburton)	24,000
Miscellaneous (Mud, Bits, Reamers, Diverter,et.al.).	33,000
Sub Total - Third Party Cost	$ 63,000
Sub Total Method Two	$154,000

4. Mining Method Three

Drill a 9 5/8" bore hole at 25°+ from vertical to 1000 feet. Run 7" diameter threaded casing and cement in place.

Contractor Cost

Drill Hole, Rig Time to Run Casing and Cement (7 days)	$ 49,000

Third Party Cost

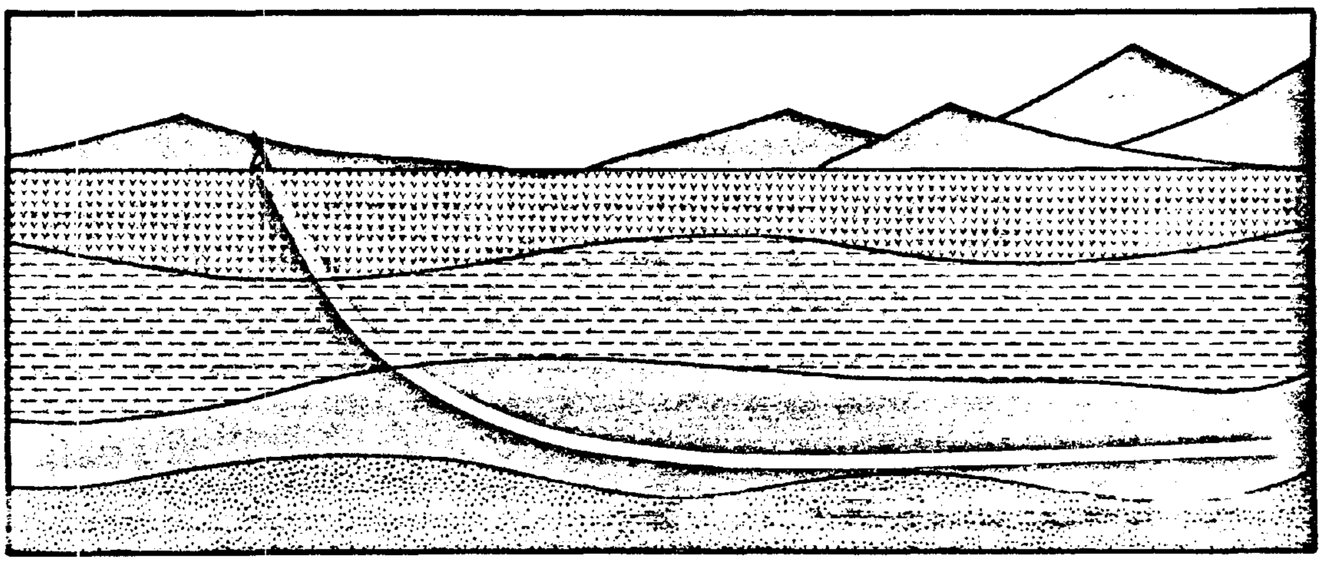
Casing (Per National Supply)	$ 12,000
Cement (Per Halliburton)	7,000
Miscellaneous (Mud, Bits, Diverter, et.al.).	23,000
Sub Total - Third Party Cost	$ 42,000
Sub Total Method Three	$ 91,000
GRAND TOTAL	$519,000

Horizontal Directional Drilling

Directionally Controlled Horizontally Drilled Underground Pathways for Resource Transport, Recovery and Exploration

Baker Energy Resources Corporation entered the directionally controlled horizontal drilling industry to provide an alternative to digging through or building over natural and man-made obstructions. BERCO offers the finest equipment, personnel and technology currently available to provide a safe, economic and environmentally acceptable means in which to pass conduits for resource transport, resource transmission, energy transmission and communications.

Energy resource recovery is another area in which BERCO has the edge. As earth's natural resources continue to dwindle, the search for new supplies of energy will intensify. Directionally controlled horizontal drilling can aid in the recovery of natural gas from shallow veins of coal and the removal of oil from insitu, tar, and oil sands. In addition to the already mentioned uses, exploration of minerals, transportation tunnels and rescue tunnels are other areas in which BERCO's advanced technology can be used to help man.



ENERGY & RESOURCE TRANSPORT

Waterway/Obstacle Crossing
- Rivers
- Canals
- Beaches
- Bluffs
- Environmental Areas
- Congested Areas
- Roads/Railroads
- Airfields

Communications
- Telephone
- Television

Resource Transmission
- Natural/Manufactured Gases
- Liquids, Unrefined Hydrocarbons, Water

Energy Transmission
- Electricity
- Refined Hydrocarbons
- Gases
- Fuels
- Slurry

ENERGY RESOURCE RECOVERY

Coal
- Insitu Gassification
- Degassification

Tar/Oil Sands
Oil Shale
Thin Seam Mining

EXPLORATION/SPECIALTY
Minerals
Energy Resources
Pennstocks/Outfalls
Transportation Tunnels
Rescue

Waterway and Obstacle Crossings — A Typical Application

Safety — Drilled crossings provide the utmost in safety for the pipeline and for the environment in which it is placed. The great depth of cover beneath the waterway bottom and the long distances into the banks normally provided in a drilled crossing virtually eliminated fears of future exposure of the line by natural or man-made activities.

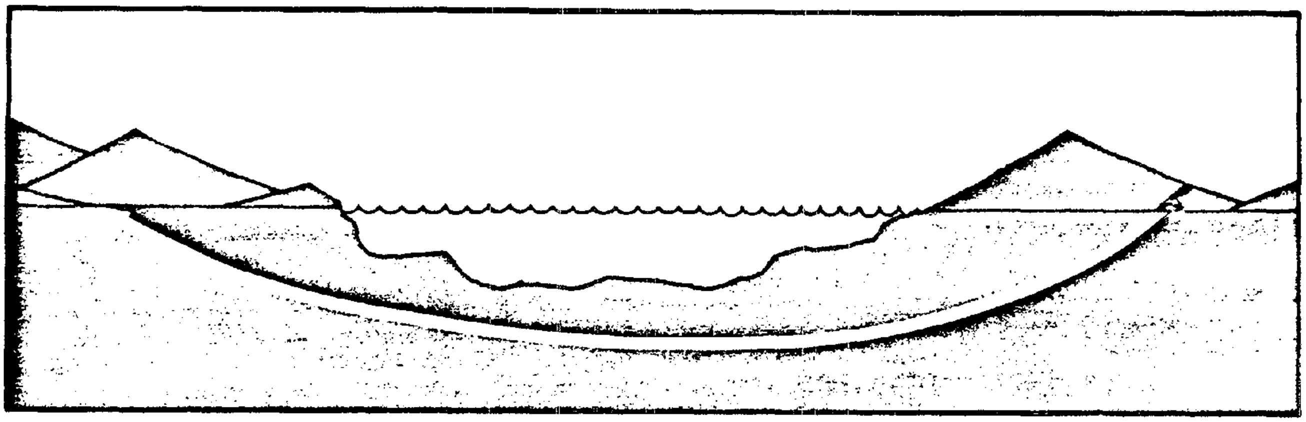
The Environment — A drilled crossing is made with little or no effect on the ecology of the waterway or of the adjacent land. A crossing normally starts and is completed well back of the river banks. The natural vegetation is not disturbed. The drilled crossing requires a minimum of land area on each bank. This significantly reduces the amount of clearing required for job completion. The bed of the stream or river is not disturbed. Harmful effects on fish, vegetation and the natural ecology of the waterway are eliminated.

Usage — The use of directional drilling can be applied in numerous ways depending upon the diameter of the conduit or line and the geological conditions of the site.

Economics — Drilled crossings provide the utmost in economic advantages for the pipeline. Advantages that start with the preliminary cost and continue the life of the line.

Initial Cost — Construction of the drilled crossing lends itself to cost savings from the beginning of the project. Route select-ions for a pipeline can be expedited and existing utility corridors can be used. Less land is required during construction, making acquisition of the right-of-way less costly and easier to negotiate. No additional areas are needed for disposal of spoil. Drilled crossings can normally be constructed at less cost than the conventional dredged or aerial crossings. No bank protection construction such as bulkheads or rip rap are required since the banks are not disturbed.

Annual Cost — Since the drilled crossing is placed so deep beneath the banks and bed of the waterway, periodic survey and maintenance cost at the crossing can be reduced. Since no structures are required for bank protection, no future repair is required. This unique feature of the drilled crossing will represent a significant savings of operational funds.



Schedules — Man's activities such as marine traffic are not impeded by a drilled crossing. Work can be conducted when waterway or weather conditions would prevent conventional work to proceed. Such conditions include high water, winter weather and in some areas fish spawning seasons. With today's emphasis on ecology and the environment, pipeline engineers and contractors are having to be more aware of the earth around us.

Sizes — Diameter of lines from 2 to 60 inches can be accom-modated by this method in distances from 300 feet to 5000 feet. Soil conditions for drilled crossings vary from silt and sands to soft rock such as shale. The actual geologic conditions will determine the feasibility of installing a crossing and its maximum diameter and length.

APPENDIX C

DOUBLE-DRILL ECONOMIC ANALYSIS

C.1 Double-Drill Cost Package

A complete cost package has been prepared for a double-drill system deployed in Wyoming. The package consists of the following:

A. Borehole inputs
B. Financial inputs
C. Borehole operating parameters
D. Individual equipment cost inputs
E. Individual equipment cost outputs
F. Equipment investment schedule
G. Summary of capital, operating, depreciation, and amortization costs
H. Cash flow calculation for typical years
I. Cash flow calculation for the first year
J. Cash flow and investment schedule with return on investment

C.2 Double-Drill Economic Analysis

The borehole and financial inputs (Tables C-1 and C-2) summarize the starting assumptions concerning a mining operation. The borehole operating parameters (Table C-3) result directly from the starting assumptions. The individual equipment cost inputs (Tables C-4 through C-21) specify the pertinent capital and operating cost information for every major equipment item calculation. Having inserted an annual equipment productivity requirement from the borehole operating parameters, the results for the individual equipment costs can be calculated (Tables C-22 through C-38). Included in the results is a comparison of the operating cost for equipment owned by the mining company and the potential subcontractor's cost. In the case of equipment actually subcontracted (the drill rigs), a verifiable bid rate is shown on the table and used in the calculation.

The equipment investment, depreciation, and operating costs are summarized in Table C-39. The various equipment units are sold for their salvage value at the end of their useful life and replaced, as indicated by the investments in later years of the schedule. Table C-40 adds the miscellaneous costs to the basic equipment costs. The cash flow in a typical operating year is summarized in Table C-41, the upper half of which is the income tax computation, including a depletion allowance, and the lower half the cash flow and net income calculation. Table C-42 shows the same information for year 1, which has 84 percent as much production as the normal year due to a two-month start-up delay in coal deliveries.

The cash flow and investment schedule (Table C-43) shows the operating (pre-investment) cash flow, the investment, the investment tax credit, and the resulting annual cash flow for each year. Note that the investment is the difference between the new equipment capital and the salvage value of the equipment sold whereas the tax credit is based solely upon the value of the new equipment purchased. The annual cash flows are converted to a net cash flow internal rate of return (IROR) on investment, which can be directly compared to other financial investment IROR.

Table C-1. Borehole Inputs

Daily Mining Capacity	6,000 tons/day
Seam Thickness	10.0 feet
Cavity Height	40.0 feet
Maximum Depth	1,000 feet
Minimum Depth	50 feet
Ore Density	83.0 lb/cubic foot
Ore Grade	0.975 tons/ton mined
Dip Angle	45 degrees
Cavity Radius	40 feet
Cavity Bottom Slope	0 degrees*
Cavity Spacing Along Dip	50 feet
Cavity Spacing Along Strike	80 feet
Mining Tool Move Time	0.016 hours/foot
Cutting to Pumping Tool Ratio	1
Trucking Distance	2.0 miles
Slurry Pipeline Length	1.0 miles
Coarse Recovery	92 %
Fine Recovery	69 %
Casing Recovery	0 %

*Indicating parallel surfaces cut in the roof and floor coal, although sloped to allow drainage to the center.

Table C-2. Financial Inputs

Exploration	300	$K
Mine Life	20	years
Product Value	25.00	$/ton-of-product
Royalty	8.0	% of gross
Extraction	17.0	% of gross
Federal Income Tax Rate	46.0	% of taxable income
Depletion Allowance	10	% of depletion base
Payroll Benefits	30.0	% of total labor
Payroll Overhead	40.0	% of total labor
Property Taxes and Insurance	2.0	% of total capital
Miscellaneous Capital	3120	$K
Land Cost	1500	$/acre
Pond Construction	30	$K
Utilities	1	$K
Working Capital for Project	16.0	% of first year costs
Investment Tax Credit	10.0	% of equipment investment

Table C-3. Borehole Operating Parameters

Arcsin of Thickness/Radius	0.2527	radians
Cavity Volume	31,665.6	cubic feet
Annual Tonnage	1,980,000	tons/year
Cavity Tonnage	1,314.1	tons
Depth Along Dip Borehole	1,414.2	feet
Mined Distance Along Dip	1,343	feet
Number of Cavities Along Dip	26.9	
Borehole Tonnage	35,349.3	tons/borehole
Annual Slant Boreholes	56.0	boreholes/year
Annual Vertical Boreholes	56.0	boreholes/year
Total Annual Boreholes	112.0	boreholes/year
Site Width Along Dip	950.0	feet
Annual Length Along Strike	4,480.0	feet/year
Annual Site Area	97.7	acres/year
Ore Body Density	0.5869	tons/square-foot
Annual Ore Body Requirement	2,497,736	tons/year
Ore Body Recovery	79.3	%
Annual Dip-Borehole Feet	79,195	feet/year
Annual Vertical Borehole Feet	56,560	feet/year
Annual Truck Ore Transportation	3,960,000	ton-miles/year
Annual Production	1,930,500	tons-of-product/year
Annual Pipeline Transportation	1,980,000	ton-miles/year
Annual Tonnage of Fines Processed	158,400	tons/year
Annual Tonnage of Fines Dried	109,296	tons/year
Annual Feet of Vertical Casing	55,208	feet/year
Annual Casing Recovered	0	feet/year
Hours Safety Protection	7,920	hours/year

Table C-4. Equipment Analysis Inputs
for Grader (Site Preparation)

Production-Units (P-U) are: BOREHOLES

Item	Value
Annual or Maximum Capacity	112 P-U/year
Utilization Rate	0.250 P-U/hour
Daily Utilization Rate	12.0 hours/day
Annual Utilization Rate	330 days/year
Availability	80 % of operating time
Maintenance Supplies	0.70 $/hour/unit
Power Cost	10.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	0.00 $K/year/unit
Operating Labor	15.00 $/hour/unit
Support Labor	6.00 $/hour/unit
Maintenance Labor	1.50 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	200 $K/unit
Salvage Value per Unit	40 $K/unit
Life Time	5.0 years
Local Property Taxes and Insurance	2.0 % of capital

Subcontractor Inputs

Working Capital	20.0 % of annual operati
Interest Rate on Loan	15.0 % /year
Loan Term	5 years
Profit Margin	25.0 % of total annual
Subcontractor Quote	400.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-5. Equipment Analysis Inputs
for Dozer (Site Preparation)

Production-Units (P-U) are: BOREHOLES

Item	Value
Annual or Maximum Capacity	112 P-U/year
Utilization Rate	0.250 P-U/hour
Daily Utilization Rate	8.0 hours/day
Annual Utilization Rate	330 days/year
Availability	80 % of operating time
Maintenance Supplies	0.70 $/hour/unit
Power Cost	15.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	0.00 $K/year/unit
Operating Labor	15.00 $/hour/unit
Support Labor	6.00 $/hour/unit
Maintenance Labor	1.50 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	270 $K/unit
Salvage Value per Unit	100 $K/unit
Life Time	5.0 years
Local Property Taxes and Insurance	2.0 % of capital

Subcontractor Inputs

Working Capital	20.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	5 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	400.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-6. Equipment Analysis Inputs for Dump Truck (Site Preparation)

Production-Units (P-U) are: STR-FEET

Item	Value
Annual or Maximum Capacity	4,480 P-U/year
Utilization Rate	10.000 P-U/hour
Daily Utilization Rate	8.0 hours/day
Annual Utilization Rate	330 days/year
Availability	80 % of operating time
Maintenance Supplies	0.30 $/hour/unit
Power Cost	5.00 $/hour/unit
Operating Supplies	0.50 $/P-U
Miscellaneous Supplies	0.00 $K/year/unit
Operating Labor	15.00 $/hour/unit
Support Labor	0.00 $/hour/unit
Maintenance Labor	1.50 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	50 $K/unit
Salvage Value per Unit	10 $K/unit
Life Time	10.0 years
Local Property Taxes and Insurance	2.0 % of capital
Subcontractor Inputs	
Working Capital	10.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	10 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	10.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-7. Equipment Analysis Inputs
for 18-inch Drill (Borehole Development)

Production-Units (P-U) are: BH-FEET

Item	Value
Annual or Maximum Capacity	56,560 P-U/year
Utilization Rate	20.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	40 % of operating time
Maintenance Supplies	10.00 $/hour/unit
Power Cost	50.00 $/hour/unit
Operating Supplies	2.00 $/P-U
Miscellaneous Supplies	5.00 $K/year/unit
Operating Labor	24.00 $/hour/unit
Support Labor	12.00 $/hour/unit
Maintenance Labor	4.00 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	800 $K/unit
Salvage Value per Unit	200 $K/unit
Life Time	10.0 years
Local Property Taxes and Insurance	2.0 % of capital
Subcontractor Inputs	
Working Capital	20.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	10 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	75.00 $/P-U
Subcontracted effort (Y or N)?	Y

Table C-8. Equipment Analysis Inputs
for 6-inch Slant Drill (Borehole Development)

Production-Units (P-U) are: DIPBHFT

Item	Value
Annual or Maximum Capacity	79,195 P-U/year
Utilization Rate	15.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	40 % of operating time
Maintenance Supplies	10.00 $/hour/unit
Power Cost	10.00 $/hour/unit
Operating Supplies	3.00 $/P-U
Miscellaneous Supplies	2.00 $K/year/unit
Operating Labor	24.00 $/hour/unit
Support Labor	12.00 $/hour/unit
Maintenance Labor	4.00 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	300 $K/unit
Salvage Value per Unit	100 $K/unit
Life Time	10.0 years
Local Property Taxes and Insurance	2.0 % of capital
Subcontractor Inputs	
Working Capital	20.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	10 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	50.00 $/P-U
Subcontracted effort (Y or N)?	Y

Table C-9. Equipment Analysis Inputs
for 18-inch Miner (Production Mining)

Production-Units (P-U) are: TONS-MINED

Item	Value
Annual or Maximum Capacity	1,980,000 P-U/year
Utilization Rate	50.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	85 % of operating time
Maintenance Supplies	5.00 $/hour/unit
Power Cost	45.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	1.00 $K/year/unit
Operating Labor	15.00 $/hour/unit
Support Labor	5.00 $/hour/unit
Maintenance Labor	5.00 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	200 $K/unit
Salvage Value per Unit	100 $K/unit
Life Time	10.0 years
Local Property Taxes and Insurance	2.0 % of capital
Subcontractor Inputs	
Working Capital	25.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	10 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	10.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-10. Equipment Analysis Inputs
for Pumping Tool (Production Mining)

Production-Units (P-U) are: DEPTH-FEET

Item	Value
Annual or Maximum Capacity	1,000 P-U/year
Utilization Rate	20.000 P-U/hour
Daily Utilization Rate	16.7 hours/day
Annual Utilization Rate	1 days/year
Availability	1 % of operating time
Maintenance Supplies	0.00 $/hour/unit
Power Cost	0.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	0.00 $K/year/unit
Operating Labor	0.00 $/hour/unit
Support Labor	0.00 $/hour/unit
Maintenance Labor	0.00 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	13 $K/unit
Salvage Value per Unit	1 $K/unit
Life Time	5.0 years
Local Property Taxes and Insurance	2.0 % of capital

Subcontractor Inputs

Working Capital	10.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	5 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	1,500.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-11. Equipment Analysis Inputs
for 6-inch Miner (Production Mining)

Production-Units (P-U) are: TONS-MINED

Item	Value
Annual or Maximum Capacity	1,980,000 P-U/year
Utilization Rate	50.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	85 % of operating time
Maintenance Supplies	5.00 $/hour/unit
Power Cost	80.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	1.00 $K/year/unit
Operating Labor	15.00 $/hour/unit
Support Labor	5.00 $/hour/unit
Maintenance Labor	5.00 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	850 $K/unit
Salvage Value per Unit	150 $K/unit
Life Time	10.0 years
Local Property Taxes and Insurance	2.0 % of capital

Subcontractor Inputs

Working Capital	25.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	10 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	10.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-12. Equipment Analysis Inputs for Cutting Tool (Production Mining)

Production-Units (P-U) are: DIP-FEET

Item	Value
Annual or Maximum Capacity	1,414 P-U/year
Utilization Rate	20.000 P-U/hour
Daily Utilization Rate	16.7 hours/day
Annual Utilization Rate	1 days/year
Availability	1 % of operating time
Maintenance Supplies	0.00 $/hour/unit
Power Cost	0.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	0.00 $K/year/unit
Operating Labor	0.00 $/hour/unit
Support Labor	0.00 $/hour/unit
Maintenance Labor	0.00 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	4 $K/unit
Salvage Value per Unit	1 $K/unit
Life Time	5.0 years
Local Property Taxes and Insurance	2.0 % of capital
Subcontractor Inputs	
Working Capital	10.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	5 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	500.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-13. Equipment Analysis Inputs for Pipe Line (Production Transportation)

Production-Units (P-U) are: PIPE-TM

Item	Value
Annual or Maximum Capacity	1,980,000 P-U/year
Utilization Rate	30.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	90 % of operating time
Maintenance Supplies	0.10 $/hour/unit
Power Cost	3.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	0.00 $K/year/unit
Operating Labor	0.00 $/hour/unit
Support Labor	0.60 $/hour/unit
Maintenance Labor	0.30 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	30 $K/unit
Salvage Value per Unit	5 $K/unit
Life Time	10.0 years
Local Property Taxes and Insurance	2.0 % of capital

Subcontractor Inputs

Working Capital	20.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	10 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	0.03 $/P-U
Subcontracted effort (Y or N)?	N

Table C-14. Equipment Analysis Inputs for Loader (Producton Transportation)

Production-Units (P-U) are: TONS-MINED

Item	Value
Annual or Maximum Capacity	1,980,000 P-U/year
Utilization Rate	300.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	90 % of operating time
Maintenance Supplies	2.50 $/hour/unit
Power Cost	12.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	0.00 $K/year/unit
Operating Labor	12.00 $/hour/unit
Support Labor	0.00 $/hour/unit
Maintenance Labor	1.50 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	500 $K/unit
Salvage Value per Unit	100 $K/unit
Life Time	5.0 years
Local Property Taxes and Insurance	2.0 % of capital

Subcontractor Inputs

Working Capital	10.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	5 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	0.30 $/P-U
Subcontracted effort (Y or N)?	N

Table C-15. Equipment Analysis Inputs
for 35-ton Ore Truck (Production Transportation)

Production-Units (P-U) are: TRUCK-TM

Item	Value
Annual or Maximum Capacity	3,960,000 P-U/year
Utilization Rate	350.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	80 % of operating time
Maintenance Supplies	1.50 $/hour/unit
Power Cost	7.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	0.00 $K/year/unit
Operating Labor	12.00 $/hour/unit
Support Labor	0.00 $/hour/unit
Maintenance Labor	1.50 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	290 $K/unit
Salvage Value per Unit	60 $K/unit
Life Time	8.0 years
Local Property Taxes and Insurance	2.0 % of capital

Subcontractor Inputs

Working Capital	10.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	8 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	0.25 $/P-U
Subcontracted effort (Y or N)?	N

Table C-16. Equipment Analysis Inputs
for Load Out Facility (Production Transportation)

Production-Units (P-U) are: TONS-MINED

Item	Value
Annual or Maximum Capacity	1,980,000 P-U/year
Utilization Rate	300.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	90 % of operating time
Maintenance Supplies	25.00 $/hour/unit
Power Cost	6.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	2.00 $K/year/unit
Operating Labor	30.00 $/hour/unit
Support Labor	0.00 $/hour/unit
Maintenance Labor	3.00 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	5,000 $K/unit
Salvage Value per Unit	500 $K/unit
Life Time	20.0 years
Local Property Taxes and Insurance	2.0 % of capital
Subcontractor Inputs	
Working Capital	25.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	20 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	1.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-17. Equipment Analysis Inputs
for Coarse Coal Preparation (Production Processing)

Production-Units (P-U) are: TONS-MINED

Item	Value
Annual or Maximum Capacity	1,980,000 P-U/year
Utilization Rate	400.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	80 % of operating time
Maintenance Supplies	20.00 $/hour/unit
Power Cost	10.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	1.00 $K/year/unit
Operating Labor	12.00 $/hour/unit
Support Labor	0.00 $/hour/unit
Maintenance Labor	1.50 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	340 $K/unit
Salvage Value per Unit	100 $K/unit
Life Time	10.0 years
Local Property Taxes and Insurance	2.0 % of capital
Subcontractor Inputs	
Working Capital	25.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	10 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	0.50 $/P-U
Subcontracted effort (Y or N)?	N

Table C-18. Equipment Analysis Inputs for Fine Coal Preparation (Production Processing)

Production-Units (P-U) are: TONS-FINES

Item	Value
Annual or Maximum Capacity	158,400 P-U/year
Utilization Rate	25.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	80 % of operating time
Maintenance Supplies	1.00 $/hour/unit
Power Cost	35.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	1.00 $K/year/unit
Operating Labor	12.00 $/hour/unit
Support Labor	0.00 $/hour/unit
Maintenance Labor	1.50 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	160 $K/unit
Salvage Value per Unit	40 $K/unit
Life Time	10.0 years
Local Property Taxes and Insurance	2.0 % of capital
Subcontractor Inputs	
Working Capital	25.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	10 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	5.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-19. Equipment Analysis Inputs
for Coal Drying (Production Processing)

Production-Units (P-U) are: TONS-DRIED

Item	Value
Annual or Maximum Capacity	109,296 P-U/year
Utilization Rate	20.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	330 days/year
Availability	90 % of operating time
Maintenance Supplies	3.15 $/hour/unit
Power Cost	3.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	0.00 $K/year/unit
Operating Labor	0.00 $/hour/unit
Support Labor	0.00 $/hour/unit
Maintenance Labor	1.50 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	40 $K/unit
Salvage Value per Unit	10 $K/unit
Life Time	10.0 years
Local Property Taxes and Insurance	2.0 % of capital
Subcontractor Inputs	
Working Capital	25.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	10 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	1.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-20. Equipment Analysis Inputs for Dozer (Site Reclamation)

Production-Units (P-U) are: BOREHOLES

Item	Value
Annual or Maximum Capacity	112 P-U/year
Utilization Rate	0.500 P-U/hour
Daily Utilization Rate	8.0 hours/day
Annual Utilization Rate	330 days/year
Availability	80 % of operating time
Maintenance Supplies	0.70 $/hour/unit
Power Cost	15.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	0.00 $K/year/unit
Operating Labor	15.00 $/hour/unit
Support Labor	6.00 $/hour/unit
Maintenance Labor	1.50 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	270 $K/unit
Salvage Value per Unit	100 $K/unit
Life Time	5.0 years
Local Property Taxes and Insurance	2.0 % of capital

Subcontractor Inputs

Working Capital	20.0 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	5 years
Profit Margin	25.0 % of total annual cost
Subcontractor Quote	400.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-21. Equipment Analysis Inputs
for Safety Equipment (Health and Safety)

Production-Units (P-U) are: HRS-SAFETY

Item	Value
Annual or Maximum Capacity	7,920 P-U/year
Utilization Rate	1.000 P-U/hour
Daily Utilization Rate	24.0 hours/day
Annual Utilization Rate	365 days/year
Availability	100 % of operating time
Maintenance Supplies	0.00 $/hour/unit
Power Cost	0.00 $/hour/unit
Operating Supplies	0.00 $/P-U
Miscellaneous Supplies	10.00 $K/year/unit
Operating Labor	10.00 $/hour/unit
Support Labor	0.00 $/hour/unit
Maintenance Labor	0.00 $/hour/unit
Supervisory Labor	20 % of direct labor
Payroll Benefits	30.0 % of total labor
Payroll Overhead	40.0 % of total labor
Capital Cost per Unit	85 $K/unit
Salvage Value per Unit	5 $K/unit
Life Time	10.0 years
Local Property Taxes and Insurance	2.0 % of capital

Subcontractor Inputs

Working Capital	8.3 % of annual operating
Interest Rate on Loan	15.0 % /year
Loan Term	10 years
Profit Margin	20.0 % of total annual cost
Subcontractor Quote	40.00 $/P-U
Subcontracted effort (Y or N)?	N

Table C-22. Equipment Analysis Output for Grader (Site Preparation)

Number of Units	1.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	0.035
Annual Operating Hours	3,960.000
Total Equipment Capital ($K)	200.000
Total Residual Value ($K)	40.000
Annual Depreciation ($K/yr)	32.000
Working Capital ($K)	43.932
Maintenance Supplies ($K/yr)	2.218
Fuel ($K/yr)	31.680
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	0.000
Payroll ($K/yr)	106.920
Payroll Benefits ($K/yr)	32.076
Payroll Overhead ($K/yr)	42.768
Local Taxes and Insurance ($K/yr)	4.000
Operating Cost ($K/yr)	219.662
Working Capital Interest ($K/yr)	6.590
Loan Payment ($K/yr)	57.096
Operating Income ($K/yr)	70.837
Gross Revenue ($K/yr)	354.185
Normalized Operating Cost ($/P-U)	1,961.26
Estimated Subcontractor Price ($/P-U)	3,162.36

Table C-23. Equipment Analysis Output for Dozer (Site Preparation and Reclamation)

Number of Units	1.000
Number of Tasks Using Units	2.000
Effective Utilization (P-U/hr)	0.106
Annual Operating Hours	2,640.000
Total Equipment Capital ($K)	270.000
Total Residual Value ($K)	100.000
Annual Depreciation ($K/yr)	34.000
Working Capital ($K)	31.947
Maintenance Supplies ($K/yr)	1.478
Fuel ($K/yr)	31.680
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	0.000
Payroll ($K/yr)	71.280
Payroll Benefits ($K/yr)	21.384
Payroll Overhead ($K/yr)	28.512
Local Taxes and Insurance ($K/yr)	5.400
Operating Cost ($K/yr)	159.734
Working Capital Interest ($K/yr)	4.792
Loan Payment ($K/yr)	77.080
Operating Income ($K/yr)	60.402
Gross Revenue ($K/yr)	302.008
Normalized Operating Cost ($/P-U)	713.10
Estimated Subcontractor Price ($/P-U)	1,348.25

Table C-24. Equipment Analysis Output
for Dump Truck (Site Preparation)

Number of Units	1.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	2.121
Annual Operating Hours	2,640.000
Total Equipment Capital ($K)	50.000
Total Residual Value ($K)	10.000
Annual Depreciation ($K/yr)	4.000
Working Capital ($K)	10.330
Maintenance Supplies ($K/yr)	0.634
Fuel ($K/yr)	10.560
Operating Supplies ($K/yr)	2.240
Miscellaneous Supplies ($K/yr)	0.000
Payroll ($K/yr)	52.272
Payroll Benefits ($K/yr)	15.682
Payroll Overhead ($K/yr)	20.909
Local Taxes and Insurance ($K/yr)	1.000
Operating Cost ($K/yr)	103.296
Working Capital Interest ($K/yr)	1.549
Loan Payment ($K/yr)	9.680
Operating Income ($K/yr)	28.631
Gross Revenue ($K/yr)	143.157
Normalized Operating Cost ($/P-U)	23.06
Estimated Subcontractor Price ($/P-U)	31.95

Table C-25. Equipment Analysis Output for 18-inch Drill (Borehole Development)

Number of Units	1.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	17.854
Annual Operating Hours	7,920.000
Total Equipment Capital ($K)	800.000
Total Residual Value ($K)	200.000
Annual Depreciation ($K/yr)	60.000
Working Capital ($K)	194.094
Maintenance Supplies ($K/yr)	31.680
Fuel ($K/yr)	158.400
Operating Supplies ($K/yr)	113.120
Miscellaneous Supplies ($K/yr)	5.000
Payroll ($K/yr)	380.160
Payroll Benefits ($K/yr)	114.048
Payroll Overhead ($K/yr)	152.064
Local Taxes and Insurance ($K/yr)	16.000
Operating Cost ($K/yr)	970.472
Working Capital Interest ($K/yr)	29.114
Loan Payment ($K/yr)	154.883
Operating Income ($K/yr)	288.617
Gross Revenue ($K/yr)	1,443.085
Normalized Operating Cost ($/P-U)	17.16
Estimated Subcontractor Price ($/P-U)	25.51
Subcontractors Operating Cost ($K/yr)	4,242.000

Table C-26. Equipment Analysis Output for 6-inch Slant Drill (Borehole Development)

Number of Units	2.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	12.499
Annual Operating Hours	15,840.000
Total Equipment Capital ($K)	600.000
Total Residual Value ($K)	200.000
Annual Depreciation ($K/yr)	40.000
Working Capital ($K)	334.570
Maintenance Supplies ($K/yr)	63.360
Fuel ($K/yr)	63.360
Operating Supplies ($K/yr)	237.585
Miscellaneous Supplies ($K/yr)	4.000
Payroll ($K/yr)	760.320
Payroll Benefits ($K/yr)	228.096
Payroll Overhead ($K/yr)	304.128
Local Taxes and Insurance ($K/yr)	12.000
Operating Cost ($K/yr)	1,672.849
Working Capital Interest ($K/yr)	50.185
Loan Payment ($K/yr)	116.162
Operating Income ($K/yr)	459.799
Gross Revenue ($K/yr)	2,298.995
Normalized Operating Cost ($/P-U)	21.12
Estimated Subcontractor Price ($/P-U)	29.03

Table C-27. Equipment Analysis Output
for 18-inch Miner (Production Mining)

Number of Units	6.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	49.020
Annual Operating Hours	47,520.000
Total Equipment Capital ($K)	1,200.000
Total Residual Value ($K)	600.000
Annual Depreciation ($K/yr)	60.000
Working Capital ($K)	1,118.280
Maintenance Supplies ($K/yr)	201.960
Fuel ($K/yr)	1,817.640
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	6.000
Payroll ($K/yr)	1,425.600
Payroll Benefits ($K/yr)	427.680
Payroll Overhead ($K/yr)	570.240
Local Taxes and Insurance ($K/yr)	24.000
Operating Cost ($K/yr)	4,473.118
Working Capital Interest ($K/yr)	167.742
Loan Payment ($K/yr)	232.324
Operating Income ($K/yr)	1,218.296
Gross Revenue ($K/yr)	6,091.479
Normalized Operating Cost ($/P-U)	2.26
Estimated Subcontractor Price ($/P-U)	3.08

Table C-28. Equipment Analysis Output for Pumping Tool (Production Mining)

Number of Units	300.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	19.960
Annual Operating Hours	5,009.999
Total Equipment Capital ($K)	3,900.000
Total Residual Value ($K)	300.000
Annual Depreciation ($K/yr)	720.000
Working Capital ($K)	7.800
Maintenance Supplies ($K/yr)	0.000
Fuel ($K/yr)	0.000
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	0.000
Payroll ($K/yr)	0.000
Payroll Benefits ($K/yr)	0.000
Payroll Overhead ($K/yr)	0.000
Local Taxes and Insurance ($K/yr)	78.000
Operating Cost ($K/yr)	78.000
Working Capital Interest ($K/yr)	1.170
Loan Payment ($K/yr)	1,113.380
Operating Income ($K/yr)	298.138
Gross Revenue ($K/yr)	1,490.688
Normalized Operating Cost ($/P-U)	78.00
Estimated Subcontractor Price ($/P-U)	1,490.69

Table C-29. Equipment Analysis Output
for 6-inch Miner (Production Mining)

Number of Units	6.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	49.020
Annual Operating Hours	47,520.000
Total Equipment Capital ($K)	5,100.000
Total Residual Value ($K)	900.000
Annual Depreciation ($K/yr)	420.000
Working Capital ($K)	1,491.210
Maintenance Supplies ($K/yr)	201.960
Fuel ($K/yr)	3,231.360
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	6.000
Payroll ($K/yr)	1,425.600
Payroll Benefits ($K/yr)	427.680
Payroll Overhead ($K/yr)	570.240
Local Taxes and Insurance ($K/yr)	102.000
Operating Cost ($K/yr)	5,964.839
Working Capital Interest ($K/yr)	223.681
Loan Payment ($K/yr)	987.376
Operating Income ($K/yr)	1,793.974
Gross Revenue ($K/yr)	8,969.869
Normalized Operating Cost ($/P-U)	3.01
Estimated Subcontractor Price ($/P-U)	4.53

Table C-30. Equipment Analysis Output for Cutting Tool (Production Mining)

Number of Units	424.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	19.969
Annual Operating Hours	7,080.798
Total Equipment Capital ($K)	1,696.000
Total Residual Value ($K)	424.000
Annual Depreciation ($K/yr)	254.400
Working Capital ($K)	3.392
Maintenance Supplies ($K/yr)	0.000
Fuel ($K/yr)	0.000
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	0.000
Payroll ($K/yr)	0.000
Payroll Benefits ($K/yr)	0.000
Payroll Overhead ($K/yr)	0.000
Local Taxes and Insurance ($K/yr)	33.920
Operating Cost ($K/yr)	33.920
Working Capital Interest ($K/yr)	0.509
Loan Payment ($K/yr)	484.178
Operating Income ($K/yr)	129.652
Gross Revenue ($K/yr)	648.258
Normalized Operating Cost ($/P-U)	23.99
Estimated Subcontractor Price ($/P-U)	458.46

Table C-31. Equipment Analysis Output for Pipe Line (Production Transportation)

Number of Units	10.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	27.778
Annual Operating Hours	79,200.000
Total Equipment Capital ($K)	300.000
Total Residual Value ($K)	50.000
Annual Depreciation ($K/yr)	25.000
Working Capital ($K)	74.476
Maintenance Supplies ($K/yr)	7.128
Fuel ($K/yr)	213.840
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	0.000
Payroll ($K/yr)	85.536
Payroll Benefits ($K/yr)	25.661
Payroll Overhead ($K/yr)	34.214
Local Taxes and Insurance ($K/yr)	6.000
Operating Cost ($K/yr)	372.379
Working Capital Interest ($K/yr)	11.171
Loan Payment ($K/yr)	58.081
Operating Income ($K/yr)	110.408
Gross Revenue ($K/yr)	552.039
Normalized Operating Cost ($/P-U)	0.19
Estimated Subcontractor Price ($/P-U)	0.28

Table C-32. Equipment Analysis Output for Loader (Production Transportation)

Number of Units	1.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	277.778
Annual Operating Hours	7,920.000
Total Equipment Capital ($K)	500.000
Total Residual Value ($K)	100.000
Annual Depreciation ($K/yr)	80.000
Working Capital ($K)	33.147
Maintenance Supplies ($K/yr)	17.820
Fuel ($K/yr)	85.536
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	0.000
Payroll ($K/yr)	128.304
Payroll Benefits ($K/yr)	38.491
Payroll Overhead ($K/yr)	51.322
Local Taxes and Insurance ($K/yr)	10.000
Operating Cost ($K/yr)	331.473
Working Capital Interest ($K/yr)	4.972
Loan Payment ($K/yr)	142.741
Operating Income ($K/yr)	119.796
Gross Revenue ($K/yr)	598.982
Normalized Operating Cost ($/P-U)	0.17
Estimated Subcontractor Price ($/P-U)	0.30

Table C-33. Equipment Analysis Output
for 35-ton Ore Truck (Production Transportation)

Number of Units	2.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	312.500
Annual Operating Hours	15,840.000
Total Equipment Capital ($K)	580.000
Total Residual Value ($K)	120.000
Annual Depreciation ($K/yr)	57.500
Working Capital ($K)	55.555
Maintenance Supplies ($K/yr)	19.008
Fuel ($K/yr)	88.704
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	0.000
Payroll ($K/yr)	256.608
Payroll Benefits ($K/yr)	76.982
Payroll Overhead ($K/yr)	102.643
Local Taxes and Insurance ($K/yr)	11.600
Operating Cost ($K/yr)	555.545
Working Capital Interest ($K/yr)	8.333
Loan Payment ($K/yr)	124.901
Operating Income ($K/yr)	172.195
Gross Revenue ($K/yr)	860.974
Normalized Operating Cost ($/P-U)	0.14
Estimated Subcontractor Price ($/P-U)	0.22

Table C-34. Equipment Analysis Output for Load Out Facility (Production Transportation)

Number of Units	1.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	277.778
Annual Operating Hours	7,920.000
Total Equipment Capital ($K)	5,000.000
Total Residual Value ($K)	500.000
Annual Depreciation ($K/yr)	225.000
Working Capital ($K)	214.036
Maintenance Supplies ($K/yr)	178.200
Fuel ($K/yr)	42.768
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	2.000
Payroll ($K/yr)	313.632
Payroll Benefits ($K/yr)	94.090
Payroll Overhead ($K/yr)	125.453
Local Taxes and Insurance ($K/yr)	100.000
Operating Cost ($K/yr)	856.142
Working Capital Interest ($K/yr)	32.105
Loan Payment ($K/yr)	790.076
Operating Income ($K/yr)	419.581
Gross Revenue ($K/yr)	2,097.903
Normalized Operating Cost ($/P-U)	0.43
Estimated Subcontractor Price ($/P-U)	1.06

Table C-35. Equipment Analysis Output
for Coarse Coal Preparation (Production Processing)

Number of Units	1.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	312.500
Annual Operating Hours	7,920.000
Total Equipment Capital ($K)	340.000
Total Residual Value ($K)	100.000
Annual Depreciation ($K/yr)	24.000
Working Capital ($K)	103.999
Maintenance Supplies ($K/yr)	126.720
Fuel ($K/yr)	63.360
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	1.000
Payroll ($K/yr)	128.304
Payroll Benefits ($K/yr)	38.491
Payroll Overhead ($K/yr)	51.322
Local Taxes and Insurance ($K/yr)	6.800
Operating Cost ($K/yr)	415.997
Working Capital Interest ($K/yr)	15.600
Loan Payment ($K/yr)	65.825
Operating Income ($K/yr)	124.355
Gross Revenue ($K/yr)	621.777
Normalized Operating Cost ($/P-U)	0.21
Estimated Subcontractor Price ($/P-U)	0.31

Table C-36. Equipment Analysis Output for Fine Coal Preparation (Production Processing)

Number of Units	1.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	25.000
Annual Operating Hours	7,920.000
Total Equipment Capital ($K)	160.000
Total Residual Value ($K)	40.000
Annual Depreciation ($K/yr)	12.000
Working Capital ($K)	112.603
Maintenance Supplies ($K/yr)	6.336
Fuel ($K/yr)	221.760
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	1.000
Payroll ($K/yr)	128.304
Payroll Benefits ($K/yr)	38.491
Payroll Overhead ($K/yr)	51.322
Local Taxes and Insurance ($K/yr)	3.200
Operating Cost ($K/yr)	450.413
Working Capital Interest ($K/yr)	16.890
Loan Payment ($K/yr)	30.977
Operating Income ($K/yr)	124.570
Gross Revenue ($K/yr)	622.849
Normalized Operating Cost ($/P-U)	2.84
Estimated Subcontractor Price ($/P-U)	3.93

Table C-37. Equipment Analysis Output for Coal Drying (Production Processing)

Number of Units	1.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	15.333
Annual Operating Hours	7,920.000
Total Equipment Capital ($K)	40.000
Total Residual Value ($K)	10.000
Annual Depreciation ($K/yr)	3.000
Working Capital ($K)	17.218
Maintenance Supplies ($K/yr)	22.453
Fuel ($K/yr)	21.384
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	0.000
Payroll ($K/yr)	14.256
Payroll Benefits ($K/yr)	4.277
Payroll Overhead ($K/yr)	5.702
Local Taxes and Insurance ($K/yr)	0.800
Operating Cost ($K/yr)	68.872
Working Capital Interest ($K/yr)	2.583
Loan Payment ($K/yr)	7.744
Operating Income ($K/yr)	19.800
Gross Revenue ($K/yr)	98.999
Normalized Operating Cost ($/P-U)	0.63
Estimated Subcontractor Price ($/P-U)	0.91

Table C-38. Equipment Analysis Output for Safety Equipment (Health and Safety)

Number of Units	1.000
Number of Tasks Using Units	1.000
Effective Utilization (P-U/hr)	0.904
Annual Operating Hours	8,760.000
Total Equipment Capital ($K)	85.000
Total Residual Value ($K)	5.000
Annual Depreciation ($K/yr)	8.000
Working Capital ($K)	15.804
Maintenance Supplies ($K/yr)	0.000
Fuel ($K/yr)	0.000
Operating Supplies ($K/yr)	0.000
Miscellaneous Supplies ($K/yr)	10.000
Payroll ($K/yr)	105.120
Payroll Benefits ($K/yr)	31.536
Payroll Overhead ($K/yr)	42.048
Local Taxes and Insurance ($K/yr)	1.700
Operating Cost ($K/yr)	190.404
Working Capital Interest ($K/yr)	2.371
Loan Payment ($K/yr)	16.456
Operating Income ($K/yr)	41.846
Gross Revenue ($K/yr)	251.077
Normalized Operating Cost ($/P-U)	24.04
Estimated Subcontractor Price ($/P-U)	31.70
Subcontractors Operating Cost ($K/yr)	3,959.750

Table C-39. Equipment Investment Schedule ($K)

Equipment	No. Units	Year 0	Year 5	Year 8	Year 10	Year 15	Year 16	Year 20	Annual Deprec.	Oper. Cost
GRADER	1	200	160	0	160	160	0	40	32	220
DOZER	1	270	170	0	170	170	0	100	34	160
DRILL-18	0	0	0	0	0	0	0	0	0	4,242
MINER-18	6	1,200	0	0	600	0	0	600	60	4,473
PIPELINE	10	300	0	0	250	0	0	50	25	372
COAL PREP-CRSE	1	340	0	0	240	0	0	100	24	416
COAL PREP-FINE	1	160	0	0	120	0	0	40	12	450
COAL PREP-DRY	1	40	0	0	30	0	0	10	3	69
LOADER	1	500	400	0	400	400	0	100	80	331
ORE TRUCK 35T	2	580	0	460	0	0	460	350	57	556
LOADOUT	1	5,000	0	0	0	0	0	500	225	856
SAFETY EQUIP.	1	85	0	0	80	0	0	5	8	190
DUMP TRUCK	1	50	0	0	40	0	0	10	4	103
SLANTDRILL-6	0	0	0	0	0	0	0	0	0	3,960
PUMPTOOL	300	3,900	3,600	0	3,600	3,600	0	300	720	78
CUTTOOL	424	1,696	1,272	0	1,272	1,272	0	424	254	34
MINER-6	6	5,100	0	0	4,200	0	0	900	420	5,965
		19,421	5,602	460	11,162	5,602	460	3,529	1,958	22,475

Table C-40. Equipment and Miscellaneous Costs

Capital Costs ($K)

Total Equipment	$ 19,421
Miscellaneous Capital	3,120
Exploration	300
Total Investment	$ 22,841

Operating Costs ($K/yr)

Total Equipment	$ 22,475
Miscellaneous Operating	
Land Cost	146
Ponds	12
Utilities	1
Total Operating	$ 22,634

Depreciation Schedule ($K/yr)

Total Equipment	$ 1,958
Miscellaneous Capital (20 yrs)	156
Exploration Amortization (20 yrs)	15
Total Depreciation & Amortization	$ 2,129

Table C-41. Typical Operating Year Cash Flow

<u>Cash Flow Calculation ($K/yr)</u>

Gross Revenue ($25/ton)	$ 48,262
Royalty (8%)	-3,860
Depletion Base	44,402
Extraction Taxes (17%)	-8,204
Total Operating Cost	-22,634
Operating Income	13,564
Total Depreciation & Amortization	-2,129
Taxable Income Before Depl. Allow.	11,435
50% of TIBDA = 5717	
10% of Depl. Base = 4440	
Depletion Allowance*	-4,440
Taxable Income After Depl. Allowance	6,995
Income Tax (46%)	3,217
Operating Income	13,564
Income Tax	-3217
Cash Flow Before Investments	10,347
Total Depreciation & Amortization	-2,129
Net Income After Taxes	$ 8,218

*Lesser of 50% TIBDA or 10% of Depletion Base.

Table C-42. Year 1 Cash Flow

Cash Flow Calculation ($K/yr)

Gross Revenue ($25/ton)		$ 40,540
Royalty (8%)		-3,243
Depletion Base		37,297
Extraction Taxes (17%)		-6,891
Total Operating Cost		-22,634
Operating Income		7,772
Total Depreciation & Amortization		-2,129
Taxable Income Before Depl. Allow.		5,643
50% of TIBDA =	2821	
10% of Depl. Base =	3730	
Depletion Allowance*		-2,821
Taxable Income After Depl. Allowance		2,822
Income Tax (46%)		1,298
Operating Income		7,772
Income Tax		-1,298
Operating Cash Flow		$ 6,474

*Lesser of 50% TIBDA or 10% of Depletion Base.

Table C-43. Cash Flow/Investment Schedule ($K/yr)

Year	Oper. Cash Flow	New Equipment	Salvage value	Tax Credit*	Cash Flow
0	-300	-22,541	0	0	-22,841
1	6,474	0	0	2,254	8,728
2	10,347	0	0	0	10,347
3	10,347	0	0	0	10,347
4	10,347	0	0	0	10,347
5	10,347	-6,566	964	656	5,401
6	10,347	0	0	0	10,347
7	10,347	0	0	0	10,347
8	10,347	-580	120	58	9,945
9	10,347	0	0	0	10,347
10	10,347	-13,841	2,679	1,384	569
11	10,347	0	0	0	10,347
12	10,347	0	0	0	10,347
13	10,347	0	0	0	10,347
14	10,347	0	0	0	10,347
15	10,347	-6,566	964	656	5,401
16	10,347	-580	120	58	9,945
17	10,347	0	0	0	10,347
18	10,347	0	0	0	10,347
19	10,347	0	0	0	10,347
20	10,347	0	3,529	0	13,876

IROR = 41.0 percent

*Includes 10% investment tax credit in years 1 through 19 on New Equipment.