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Borehole Hydraulic Coal Mining System Analysis

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Space Administration

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Sections of this document were extracted from publications written by the following authors who are members of the JPL Advanced Coal Extraction Systems Definition Project Team:

Jay Chen: Soil Mechanics

Paul Gordon: Equipment Selection

Syd Ireland: Environmental Analysis

Bill Mabe: Mine Design & Extraction Sequence (Pitching Seam) - Health and Safety

Peter Poon: Economic Analysis

Bob Weaver, Don Starkey: Flow Diagrams, Timing Charts

ABSTRACT

As a portion of an Advanced Coal Extraction Project at the Jet Propulsion Laboratory, an evaluation method was developed to analyze underground coal extraction systems. The evaluation method was designed to analyze, both technically and economically, underground mining systems to compete with existing coal mining systems. The borehole hydraulic mining system, under development by a Bureau of Mines' Research Center, is considered an advanced extraction system, and may be analyzed by this method. As a result of the coal extraction project work in the evaluation area, JPL was directed to perform an evaluation of the proposed advanced system.

The borehole hydraulic coal mining system accesses the coal seam through a hole drilled in the overburden. The mining device is lowered through the hole into the coal seam where it fragments the coal with high pressure water jets. The fragmented coal is pumped to the surface as a slurry by a jet pump located in the center of the mining device. The coal slurry is then injected into a slurry pipeline for transport to the preparation plant.

The system was analyzed for performance in the thick, shallow coal seams of Wyoming, and the steeply pitching seams of western Colorado.

The evaluation considered all the aspects of the mining operation for a 20-year mine life, producing 2.64×10^6 tons/yr. The mine was planned from geologic data for the region, and the expected extraction efficiency. Capital equipment to support the operation was determined and costed. Effects on the environment and the cost of restoration, as well as the concerns for health and safety, were studied.

This report details the assumptions for the design of the mine, the analytical method, and the results of the analysis.

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SECTION I

SUMMARY OF RESULTS

A. COST ANALYSIS

A computer program was devised to calculate the selling price of coal for a variety of mining and economic conditions. A range of geologic conditions, as well as variations in capital invested, manpower requirements, and other economic parameters can be accommodated in the computer program. The resulting selling price for these conditions can be computed. Table 1-1 is a summary of selling prices for a variety of flat seam mining conditions as a function of discounted cash flow rate of return.

Appendix E details the assumptions and methodology for deriving selling price and a complete set of results for a wider range of variations. The analysis performed on the thick flat seam was also applied to pitching seams. A summary of the resulting selling prices for various pitching seam conditions is displayed in Table 1-2. The details of the pitching seam analysis are included in Appendix E, as for the thick flat seam situation.

As discussed previously, the analysis can accommodate a range of conditions. To better understand the sensitivities of the hydraulic borehole system, plots of selected parameters as a function of selling price were generated. Figure 1-1 illustrates the effect of increasing the system mining rate on selling price. The nominal case of the cost analysis assumed a mining rate of 40 tons/hr. The effect of seam thickness for a thick flat seam, on selling price, is shown in Figure 1-2. Seam thickness of the coal deposit selected in Wyoming ranges to 220 ft in some areas. However, pump capacity limits the extraction depth. If the seam thickness is held to 30 ft, the effect of increasing overburden thickness is shown in Figure 1-3. The variation of three other parameters — field equipment cost, manpower and supply costs — were investigated, and the results are illustrated in Figures 1-4, 1-5, 1-6.

B. ENVIRONMENTAL RESTORATION

A value of $5,000/acre environmental restoration cost was assumed for the analysis in Appendix E. As the investigation in Appendix F indicates, this value may be very optimistic if certain geologic conditions or legislative requirements prevail. The major reoccurring restoration costs throughout the mine life are the cost of waste pile removal and extracted cavity backfill. For the flat seam situation, mine waste removal is estimated to cost approximately $3,580,000 over the mine life, and cavity backfill would cost $106,000,000. Waste pile removal for the steeply pitching seam situation is estimated to be $5,280,000 with a cavity backfill cost of $106,000,000. In addition, other major items for the pitching seam situation are regrading of site excavations and the restoration of drainage control facilities. These items are expected to cost

Table 1-1. Coal Cost Resulting From Various Flat Seam Conditions

Mining Rate, tons/hr	Seam Thickness, ft	Borehole Diameter, ft	Overburden Thickness, ft	Selling Price $/ton Discounted Cash Flow Rate of Return 20%	15%	10%	Comments
40	30	25	200	30.56	27.11	23.88	Nominal Case
40	60	25	200	19.23	16.88	14.70	Effects of Seam Thickness
40	90	25	200	16.35	14.26	12.31	Effects of Seam Thickness
40	30	25	100	21.7	19.07	16.63	Effects of Overburden Thickness
40	30	25	300	36.61	32.82	29.28	Effects of Overburden Thickness

Table 1-2. Coal Cost Resulting From Various Pitching Seam Conditions

Pitch, deg	Mining Rate tons/hr	Borehole Diameter, ft	Borehole[a] Depth, ft	Overburden Thickness, ft	Selling Price $/ton Discounted Cash Flow Rate of Return 20%	15%	10%
75	40	30	300	30	15.92	13.45	11.16
85	40	30	250	50	17.59	14.74	12.09

[a]Measured along the pitching seam.

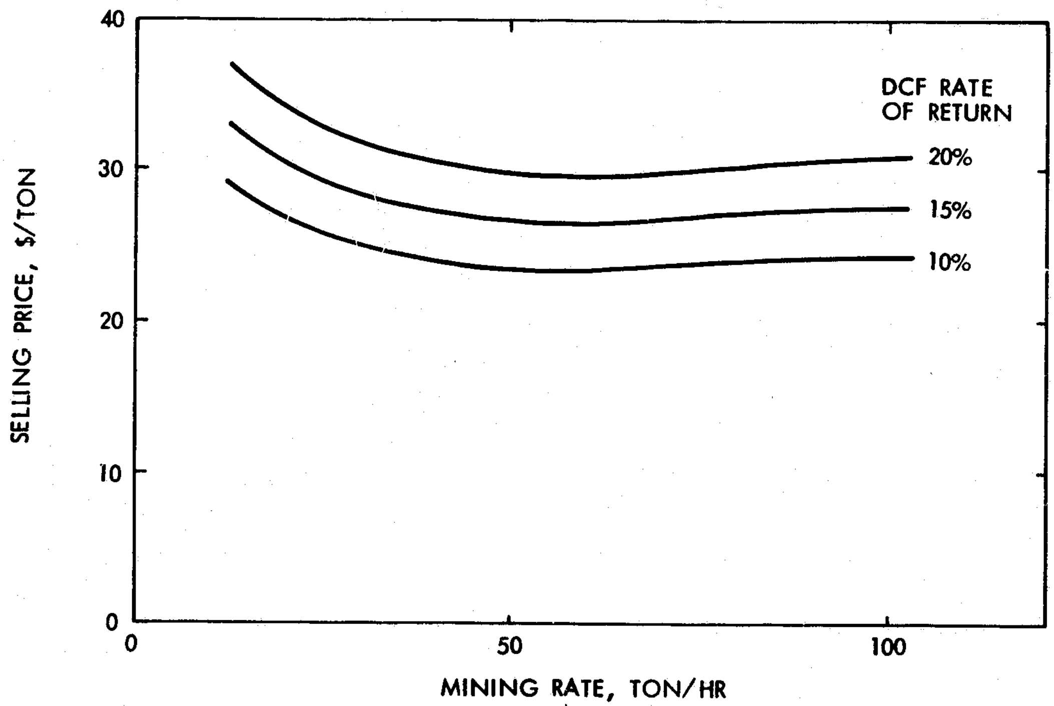


Figure 1-1. Selling Price as a Function of Mining Rate (30-ft Seam, 200-ft Overburden, 50% Recovery)

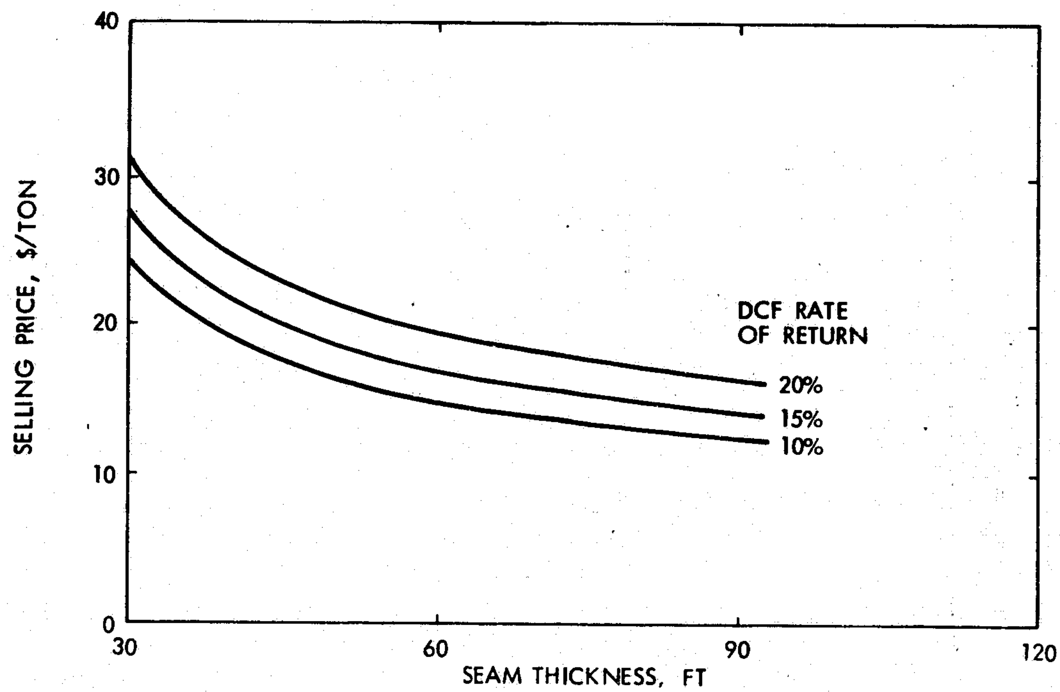


Figure 1-2. Selling Price as a Function of Seam Thickness (40 tons/hr, 200-ft Overburden)

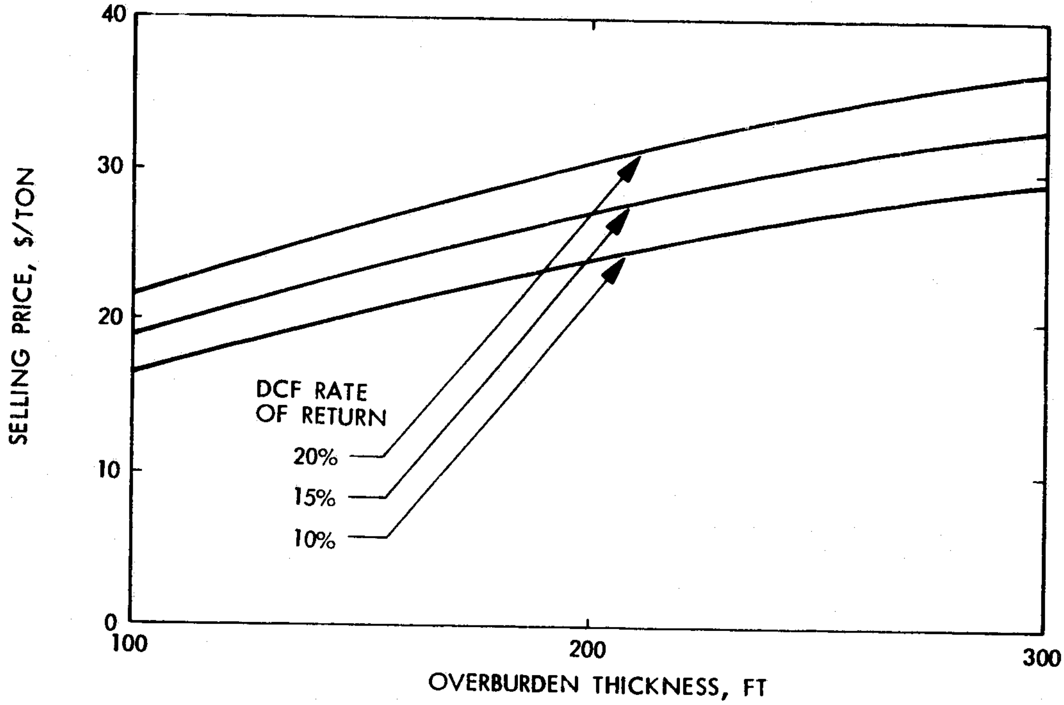


Figure 1-3. Selling Price as a Function of Overburden Thickness (40 tons/hr, 30-ft Seam)

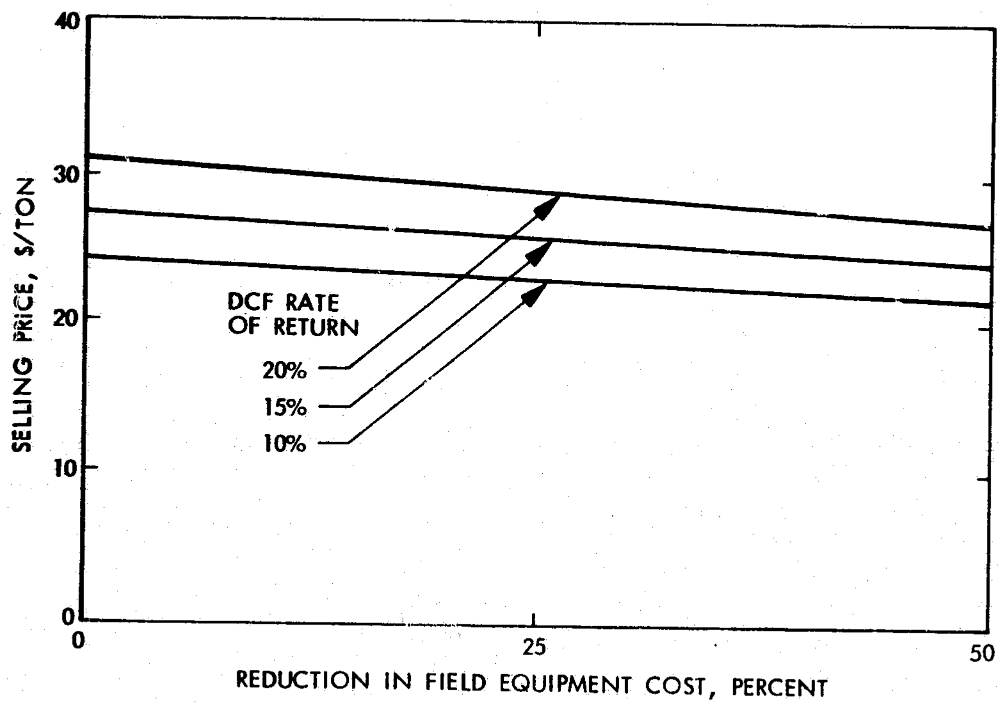


Figure 1-4. Sensitivity to Reduction in Field Equipment Cost (40 tons/hr, 30-ft Seam, 200-ft Overburden)

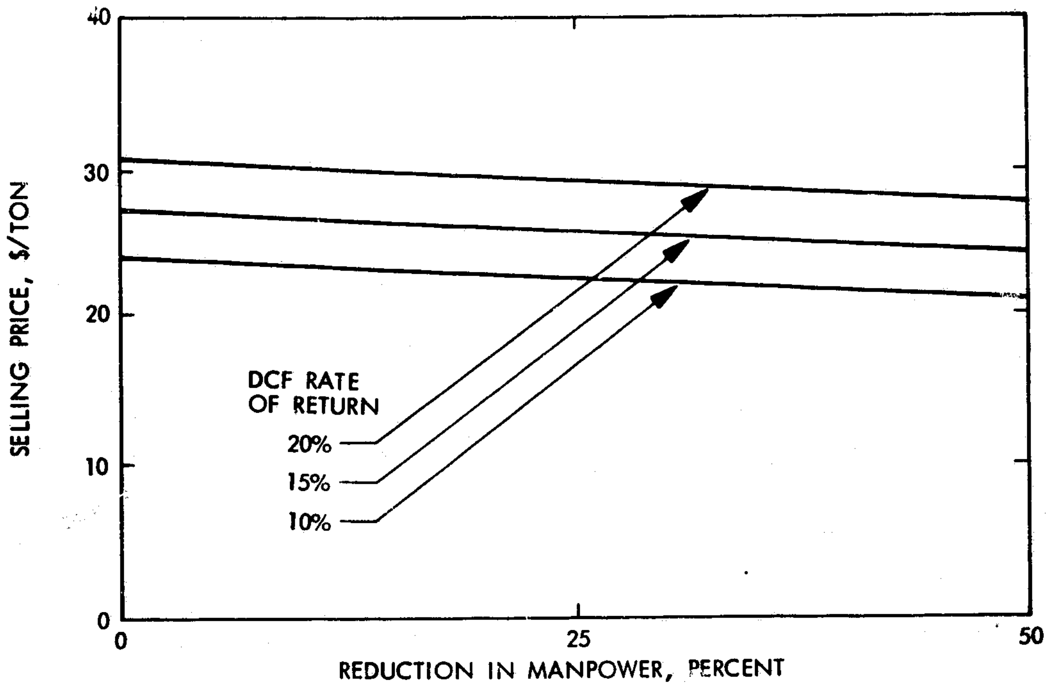


Figure 1-5. Sensitivity to Reduction in Manpower (40 tons/hr, 30-ft Seam, 200-ft Overburden)

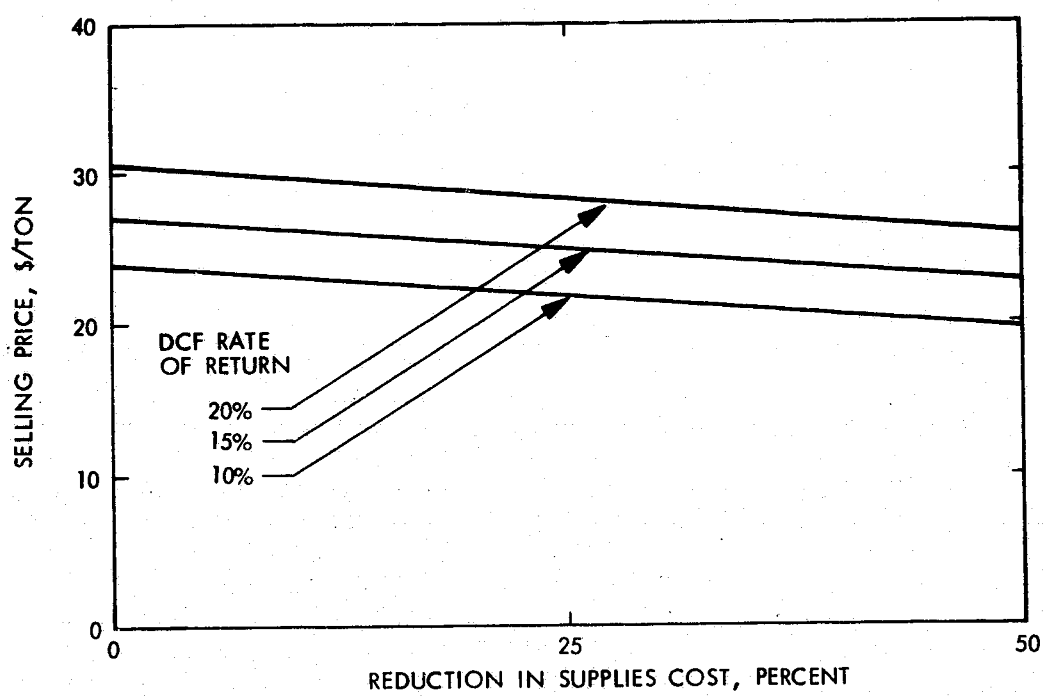


Figure 1-6. Sensitivity to Reduction in Operating Supplies Cost (40 tons/hr, 30-ft Seam, 200-ft Overburden)

$17,000,000 and $4,950,000, respectively. The costs sited above are only the major items of cost. These costs exceed the $5,000/acre assumed for the analyses by a wide margin. The increase in the cost of coal for the flat seam 30-ft thick, under 200 ft of overburden, assuming backfilling and full restoration, was $1.70/ton for a total of $28.81/ton. The increase in cost for the pitching seam situation of a 30-ft diameter cavity, 250 ft deep with a 50-ft overburden thickness, is $2.20/ton for a total of $16.94/ton.

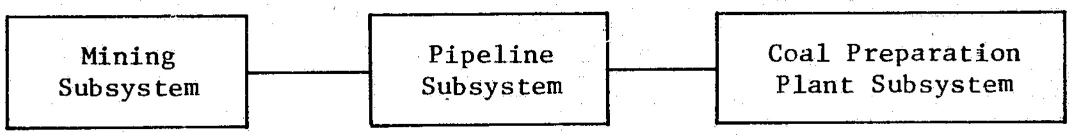
C. HEALTH AND SAFETY

In the discussion of health and safety in the text, costs for these items are not indicated separately. The data available at this stage of the design do not provide cost information. The analysis does provide a comparison with the existing mining systems. This comparison is the average severity of lost time accidents in lost time days per accident. For longwall mining the statistic is 24.2 days lost per lost time accident. The hydraulic borehole statistic is estimated to be 20.45 lost days per lost time event.

D. SYSTEM AVAILABILITY

The cost analysis is based on 100% availability of the total system. If either the total system or some element is unavailable to produce coal when required, then three things are possible. Either the total capacity of the mine will decrease, the existing equipment will somehow have to make up for the loss at some additional cost, or spare capital equipment is brought in to replace the failed unit. Figure 1-7 shows the effect of total system availability on price for the second option, assuming constant capacity without additional capital equipment.

For availability considerations, the system is assumed to be composed of three major subsystems:



Given this system definition, if the preparation plant or pipeline subsystem is unavailable due to failure, the mining subsystem will be unable to produce coal. The immediate effect of these failures has been alleviated somewhat in the system design by incorporating holding ponds at each subelement installation (four extraction units for flat seam and two extraction units for pitching seams). These ponds were sized to hold approximately the equivalent of one-shift production from the mining location. In essence, then, the maintenance crew has approximately one shift to repair and restart the system before the mining operation must be shut down.

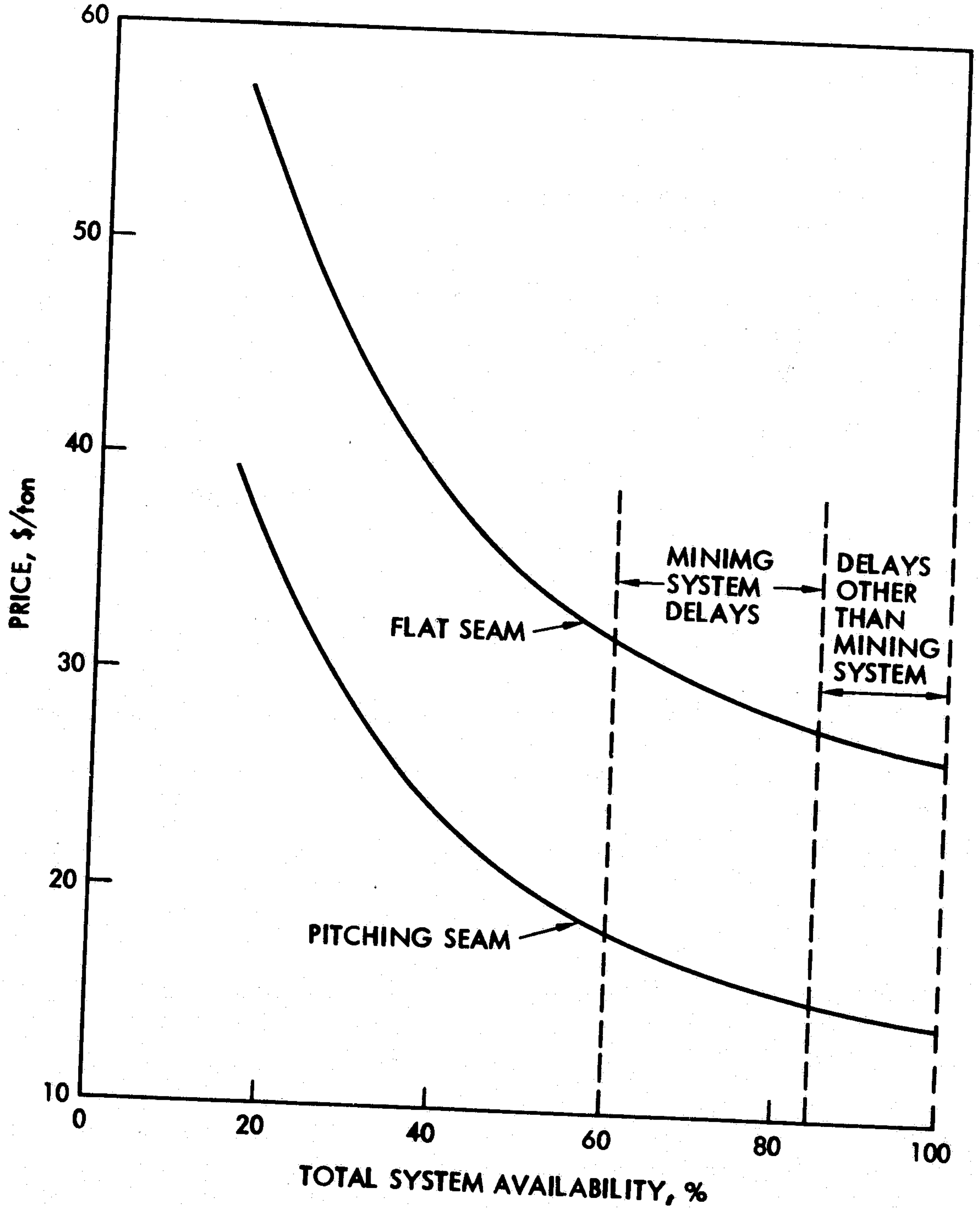


Figure 1-7. Flat and Pitching Seam Availability as a Function of Total System Availability

Typically, conventional preparation plants provide two-shift coal storage in silos with the added possibility of simply storing mine output in piles. This option is not available for the borehole without additional capital expense. However, the cost of slurry holding ponds is relatively small — $1600 each, and therefore, the additional amount required to approximate current practice (two shifts) is within the accuracy of the overall analysis. If it is assumed the borehole system may be approximated by current practices, then a fair comparison for pipeline and preparation plant downtime would be to use current experience.

Recent findings (References 1-1 and -2) have shown that delays, other than the mining subsystem, account for approximately 15% of total downtime. This value is shown on Figure 1-7, and should be used only as a guide to compare with current industry practices.

The availability of the mining system is somewhat more complicated in that four boreholes are mined in each setup. As previously stated for the flat seam, 36 extraction units are working at once on 4-hole patterns, 1 hole at a time, while the pitching seam is being worked by 16 extraction units on 2-hole patterns. In either case, should a cavity fail for geological reasons, the unit would be removed and inserted in the next hole, thereby minimizing the loss of production. If a mining unit is lost, the system will lose 1/36 of the production capacity for the flat seam, and 1/16 of the production capacity for the pitching seam. Both of these are within the accuracy of the cost analysis. The problem arises when more than one of the units, or its support system, fails.

These types of failures may be viewed as generic design defects or natural mortality. An example of a generic design defect would be the failure of the down hole crusher to properly break the coal for transport, thus requiring the extraction unit to be backflushed, etc. The effect on cost of such a defect would be reflected in capacity sensitivity curves (Figure 1-1), i.e., 40 tons/hr reduced to 30 tons/hr, etc.

The natural mortality of equipment effect may be seen on the availability figure. Recent findings (References 1-1 and -2) have shown that a current long-wall mining system is available 75% of the expected mining time. Figure 1-7 shows the effect on price if the borehole were to experience this kind of mortality.

SECTION II

BACKGROUND

As a result of the Jet Propulsion Laboratory's effort on the Advanced Coal Extraction Project, a method was developed to evaluate underground coal extraction systems. The evaluation method was designed to analyze, both technically and economically, underground mining systems to compete with existing coal mining systems. One such mining method is under development by the Twin Cities Bureau of Mines Research (BOM) Center, and early technical evaluation has been completed by this BOM office. As a result of JPL's system evaluation effort, JPL was directed to perform an analysis on the proposed advanced method.

The systems evaluation method consists of a number of detailed analyses of specific disciplines. This report shall consist of a narrative explaining the method, and a summary of the results supported by detailed analyses, in specific areas, in the appendixes.

The JPL evaluation method was designed to evaluate mining systems, thus a mining method, such as the one presented by the Twin Cities Research Center, must be expanded from a method which is concerned only with extraction into a system which includes the effort prior to extraction through preparation for market. Requirements for the system must be established, and a system design generated. Requirements for production and mine life were selected such that a direct comparison with earlier system investigations could be performed. The system design requirements are discussed in Section IV of this Report.

Operational requirements on the mining device were obtained from the machine development contractor's final report. Appendix A is extracted directly from the final report on the mining method detailing the machinery's capabilities and projected capacity.

The capability of the machinery is the principle input for selecting extraction sites. For the analysis of this mining method, two types of mining conditions were investigated: (1) thick horizontal seams under thin overburden, and (2) steeply pitching seams. To provide authenticity to the analysis, coal reserves were reviewed and sites in existing reserves were chosen. The process for site selection is discussed in part A-1 for thick flat seams, and in part B-1 for steeply pitching seams.

The selection of existing coal reserves provides the geologic, topographic, meteorological, and environmental data required to influence a mine design. An evaluation of the influence of the soil mechanics is discussed in Appendix B. The design of the mines for the two sites is discussed in parts A-2 and B-2. To analyze the types of support equipment required for the mining method, the utilization of equipment, and the number of units required, flow diagrams and timing charts were generated for each site. A discussion of the flow diagrams and their use is presented in Appendix C.

The details of the mine design, which includes the method of coal transport, the extraction sequence, the types of equipment required, and the facilities, are discussed in parts A-2a, b and c for horizontal seams, and in B-2a, b and c for pitching seams. Appendix D investigates the equipment requirements in much greater depth, and lists specific pieces of equipment to meet the requirements of the mining conditions.

Following the selection of the requirements and goals, the selection of sites, the design of the mine, and the selection of equipment, an economic analysis of the mines was performed. A summary of the results of the analysis appears in Section I. The details of the method and a greater spectrum of variations on the parameters are discussed in Appendix E. Included in the analysis is a cost which is derived from environmental considerations. The magnitude of this figure is based on a number of geologic and legislative considerations. A summary of the range of potential costs credited to environmental restoration is stated in Section I, and a thorough analysis of the environmental factors is explained in Appendix F.

Although there are no costs attributed to health and safety at this stage of the mine design, a preliminary study was performed. A summary of those results is sited in Section I, and the details of the study are discussed in Appendix G.

SECTION III

DESCRIPTION OF MINING METHOD

The mining method, which shall be referred to as the hydraulic borehole method, accesses the coal seam through a hole drilled from the surface. The mining device, which consists of a system of high pressure hydraulic jets to cut the coal and a jet pump to lift the cut coal to the surface, is lowered to the top of the coal seam. High pressure water is pumped from the surface, through the mining device, to be discharged through high pressure jet nozzles near the lower end of the device. The jets fragment the coal, and form a slurry in the underground cavity which is then drawn into the mining device, and pumped to the surface. The slurry pump is a downhole jet pump which is supplied with high pressure water from a second system of pumps on the surface. The mining device, as presently designed, is a system of chambers and conduits, within a 12-in. tubular housing, which channels the water to the cutting nozzles and the jet pump. The coal slurry is lifted to the surface through a tube which is also within the mining device cylindrical housing.

A working prototype model of the hydraulic borehole mining device has been designed, fabricated, and tested by Flow Research, Inc., under contract to the Twin Cities Bureau of Mines Research Center. JPL elected to analyze the device as it is presented in the Flow Technology Report No. 3 entitled "Application of a Hydraulic Borehole Mining Apparatus to the Remote Extraction of Coal" — Final Report.

Appendix A is the description of the unit as described in the Flow Technology Report No. 3.

SECTION IV

SYSTEM DESIGN

The borehole mining method, as presented, is concerned only with the extraction process and is not a system as is a conventional mine. The evaluation method developed by JPL is based on a comparison with the current technology of conventional mines, and is designed to evaluate mining systems which have a production goal on the order of 2.64×10^6 tons/yr, and have a life of 20 yr. This production goal was selected such that a straight-across comparison could be made with existing BOM analytical models of conventional systems scaled to this production value and mine life. The equipment, labor, supplies, and support facilities required to meet the mine life for the borehole system at the required production goal were determined.

For the purpose of system design and analysis, JPL has divided the life of the mine into three functional phases: (1) development, (2) production, and (3) mine closing. The functions under each of these phases are illustrated in Figure 4-1. The mine design also uses the functional diagram by further detailing the functions to the level of construction costs, equipment costs, operating costs, supplies, manpower requirements, and estimated time to perform specific functions.

As discussed in the previous text, the borehole mining method does not constitute a system without its required support equipment. The support equipment will vary somewhat with the conditions under which it must operate. JPL analyzed the borehole mining system for two situations — thick flat coal seams, and steeply pitching coal seams. The coal extraction unit will be the same for both operational conditions. However, the details of the mine design and support equipment will vary somewhat. The description of the mine design and analysis of each of the two conditions, pitching and flat seams, will be discussed.

A. THICK FLAT SEAM MINE

1. Site Selection

The initial effort in the mine design, for the flat seam application, was to select a suitable coal reserve for the proposed operation. The operational characteristics of the borehole miner are provided in the Flow Research Report, and site selection was based on those criteria. A trade-off which compared preliminary estimates of overburden drilling costs (to access the coal seam) to the expected yield of coal from a range of coal seam thicknesses, was conducted. The object of the comparison was to perform a very preliminary analysis of mining conditions which yield coal of adequate quantity and quality to recoup the overburden drilling costs. The total depth of the combined overburden and coal seam thickness is limited by the mining device pump lifting capacity to approximately 300 ft. A graph which plots overburden depth against coal seam thickness was generated, and is shown in Figure 4-2. Overburden thickness, on the ordinate, and coal seam thickness, on the abscissa, may be added together to illustrate the 300-ft lift capacity of the pump. The resulting limit line is labeled

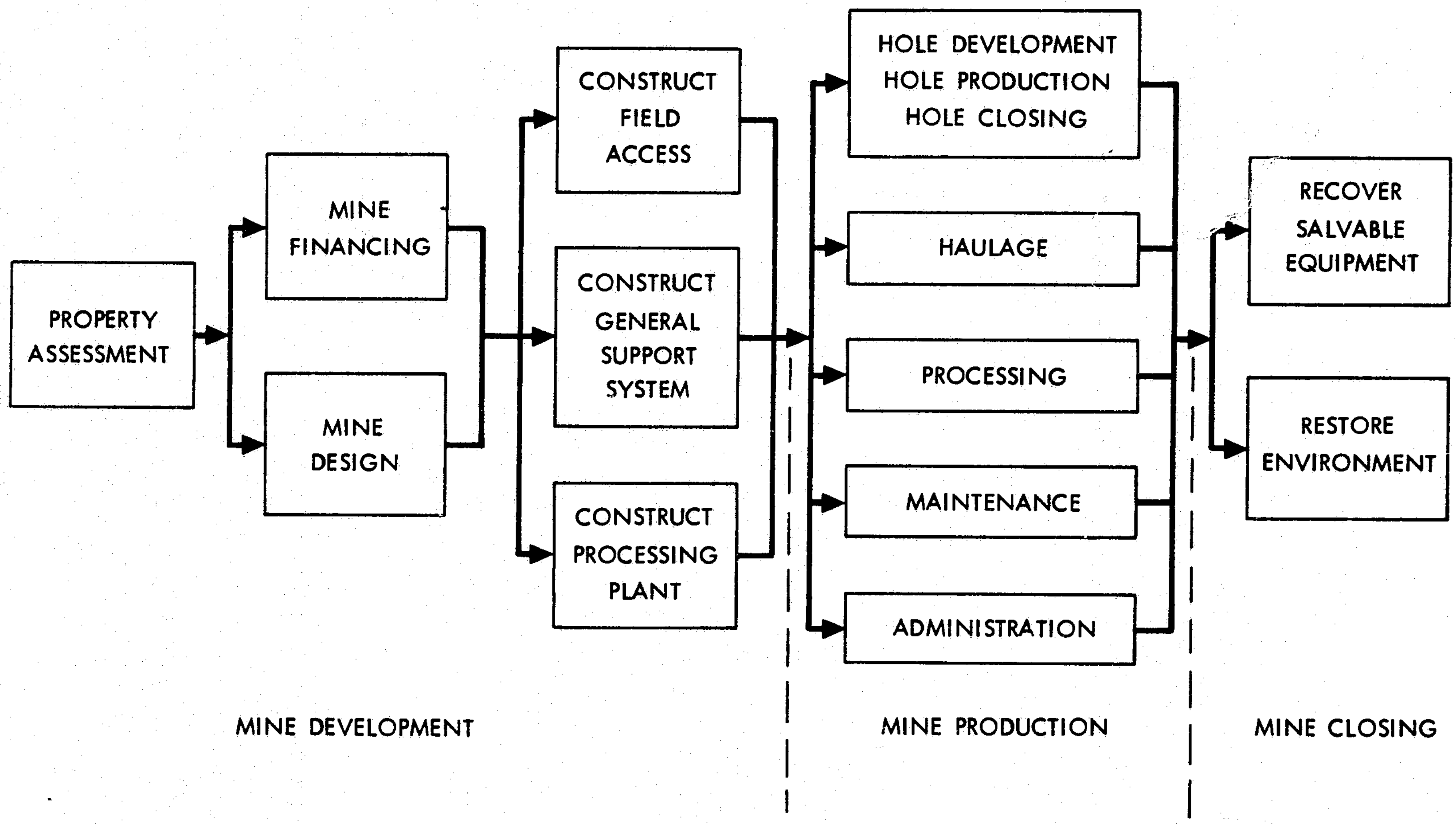


Figure 4-1. Mine Life Functional Diagram

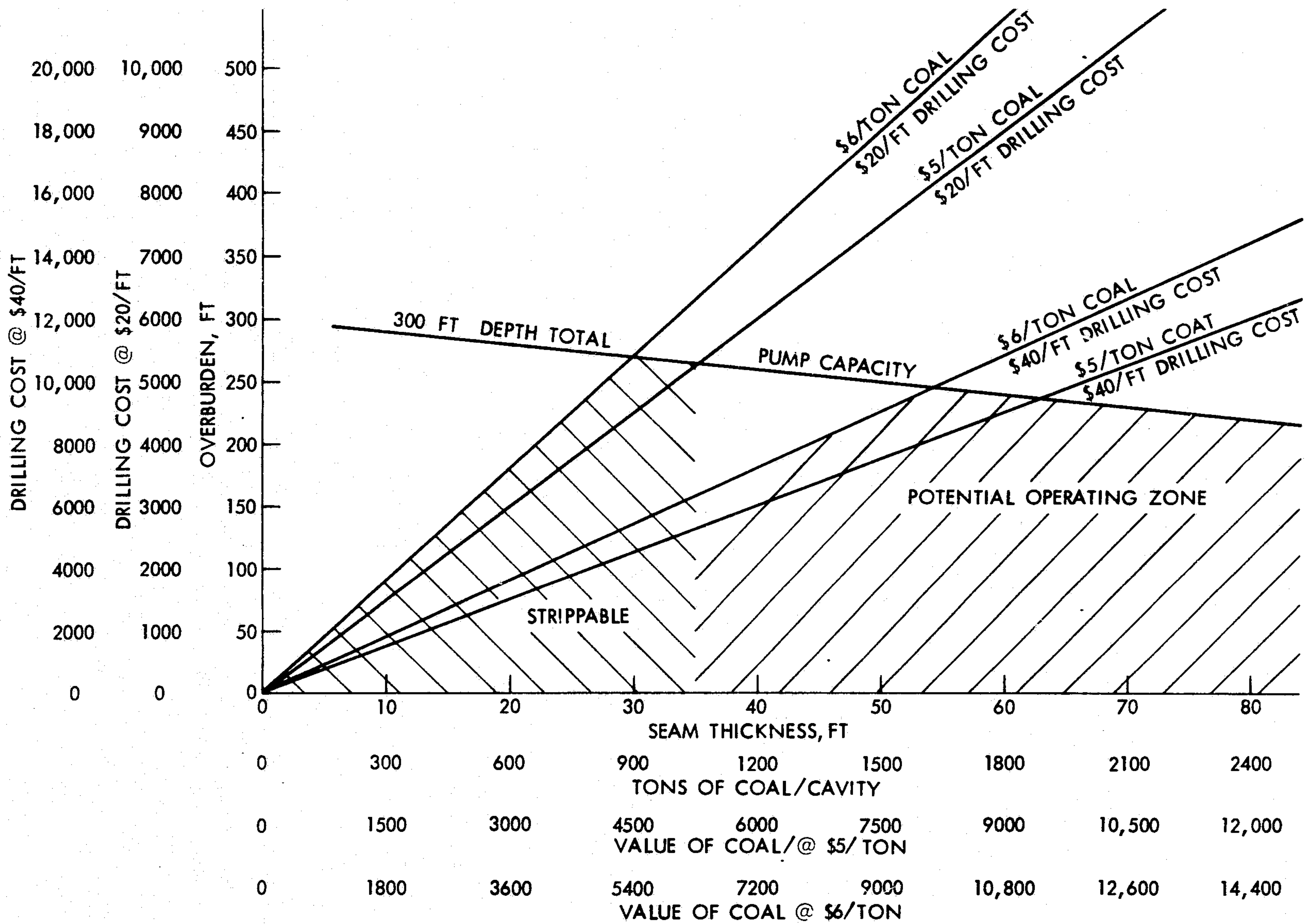


Figure 4-2. Borehole Mining Potential Operating Conditions

300-ft Total Pump Capacity in Figure 4-2. Two drilling costs, which are roughly the range of drilling costs for varying conditions, were assumed for accessing the coal seam: $20 and $40/ft. The resulting overburden drilling costs for the range of overburden depths are shown on the ordinate of the Figure 4-2. Assuming a cavity of 25 ft in diameter, the tons of coal extracted from each seam thickness is shown on the abscissa of Figure 4-2. The total value of the extracted coal at $5 and $6/ton is shown below the Tons of Coal/Cavity. With the assumed costs of drilling through the overburden, and the value of the coal extracted, break-even lines may be shown on Figure 4-2 for the assumed variations.

Using the coal seam thickness and overburden conditions indicated in the preceding discussion as a selection criteria, a search was conducted for a significant reserve. The western edge of the Powder River Basin in northern Wyoming, which contains thick flat coal seams under shallow overburden, was selected as a suitable example. Figure 4-3 illustrates the geology of the region and depicts the coal seams out cropping. The selection of the site provided a set of conditions which were then factored into the mine design and the system analysis. The geology and topography data were used to determine the machinery required to support the borehole extraction method. Geology data were also used to analyze the soil mechanics for stability. Hole placement, roof stability and extraction efficiency are a function of the soil mechanics.

The site selection also provided data on the availability of support resources, such as water, power, construction materials, etc., which are all unique to specific regions. In addition, environmental conditions and requirements can be analyzed realistically using the conditions presented by the selected region.

2. Mine Design

The sizing of the mine is a function of the following elements:

(1) Annual production goal and mine life

(2) Borehole miner performance

(3) Coal seam thickness

(4) Geology of site.

The 25-ft diameter of the extracted cavity in the coal seam was determined from the performance data of the mining device. A production value for each cavity was estimated conservatively by assuming a 30-ft seam thickness (see Figure 4-2). Seam thickness exceeds 200 ft in portions of the selected coal reserve. The relative placement of the holes was determined from geologic considerations, such as overburden strength and thickness, coal strength and cavity diameter. Details of the analysis are contained in Appendix B.

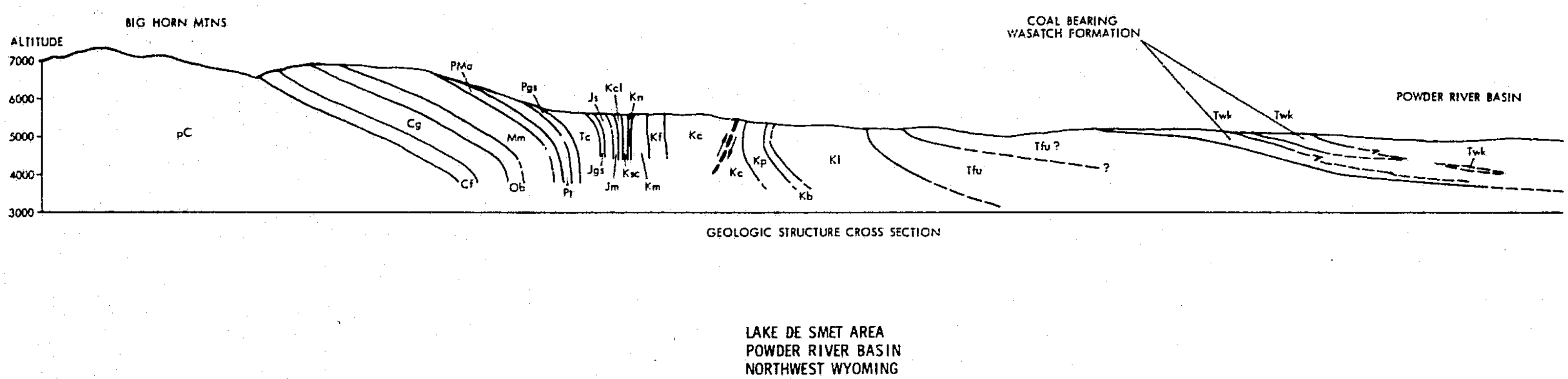


Figure 4-3. Geologic Cross Section of Northwest Wyoming
Powder River Basin

As the analysis in Appendix B indicates, more accurate geologic data would yield more conclusive results. For the purpose of this system evaluation, 25-ft diameter cavities, in a close packed hexagonal pattern with a 50% coal recovery, were used. This recovery factor locates the holes on 33.65-ft centers. A coal density of 87.3 lb/ft^3 was assumed to calculate a yield of 642 tons per cavity extracted. With the hole spacing indicated above, 92 acres of mine area are required per year of operation, or a total of 1,856 acres for the 20-yr life of the mine. Figure 4-4 illustrates the area of the mine and the proposed layout.

a. Coal Transportation. Another assumption, which is basic to the mine design, is the mode of coal transportation to be used internal to the mine. Since the coal is pumped to the surface in slurry form, water extraction facilities would be required at each drill site if other than slurry transport was chosen for the transport mode. Although an in-depth trade-off of the options (conveyors, trucks, and rail) was not performed, a brief investigation into the required investment, maintenance, and manpower indicated the slurry transport was a reasonable choice for this system. To conserve water, and provide a transport system for returning the mine waste from the coal preparation plant to the drill site cavities, a return line system was assumed also. Figure 4-5 illustrates the slurry line routing for the mine.

An investigation into the slurry line expected life indicated plastic pipe could be presumed to last approximately 5 yr without requiring rotation for wear. The decision to divide the mine into 5-yr segments was based on the slurry line life data. The assumption was made that a major relocation of the principle slurry and water supply line would be performed every 5 yr. The coal preparation plant would be centrally located, such that relocation would not be required for the 20-year life of the mine.

Each 5-yr mine segment was then divided further into subelements which are provided with spur slurry and water supply lines. Four coal extraction units equip each subelement, and are supported by the spur water and slurry lines. In addition, each subelement has its own slurry pump station and water surge pond. Figure 4-6 illustrates the subelement area and equipment.

Water and slurry lines, which extend from the subelement spur lines to the four extraction units, are temporary installations. To provide flexibility, the last 200 ft from the temporary line to the extraction units are hoses.

b. Extraction Sequence. The extraction procedure of the borehole mining system is as follows:

(1) Holes, 15 in. in diameter, are drilled through the overburden to the upper surface of the coal seam. The access hole is then cased (with 13-3/8-in. diameter casing) as is required by the Wyoming environmental laws, and the casing

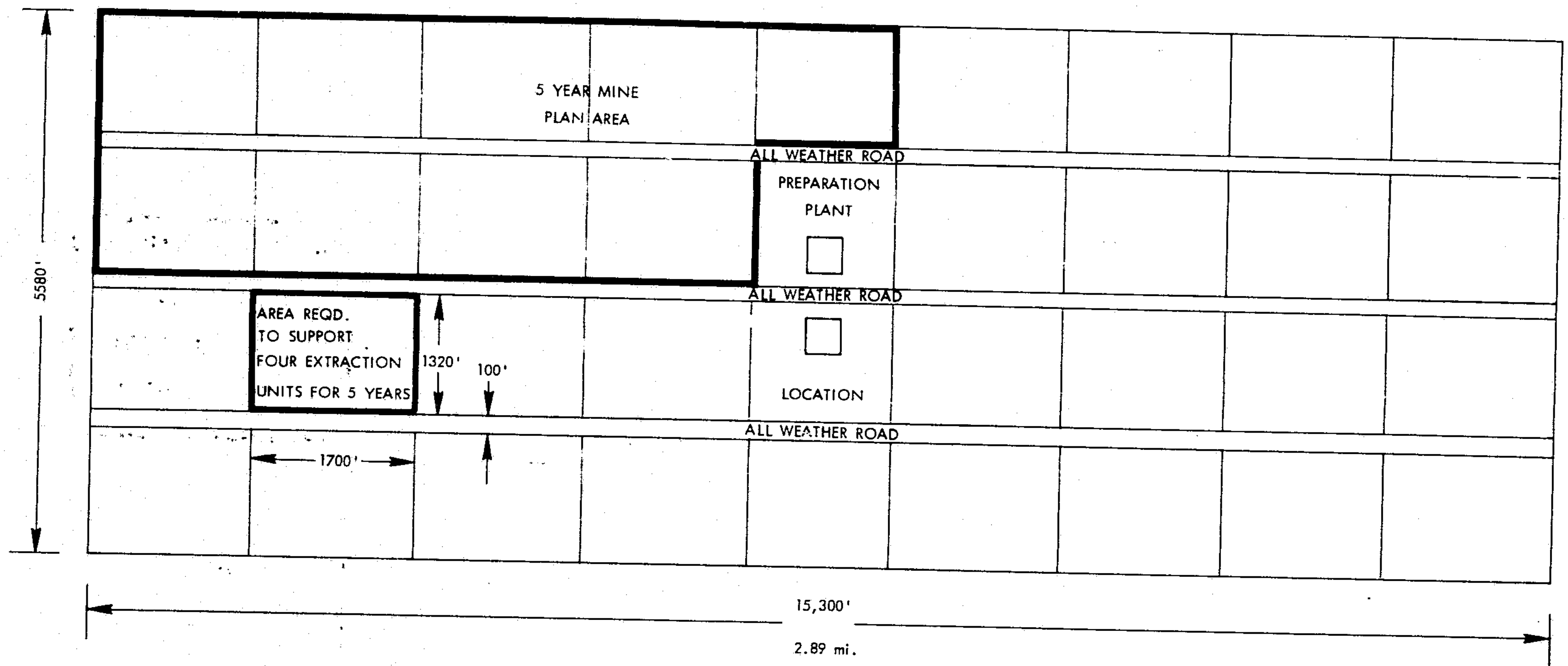


Figure 4-4. Area Required for 20-yr Mine Plan (50% Recovery)

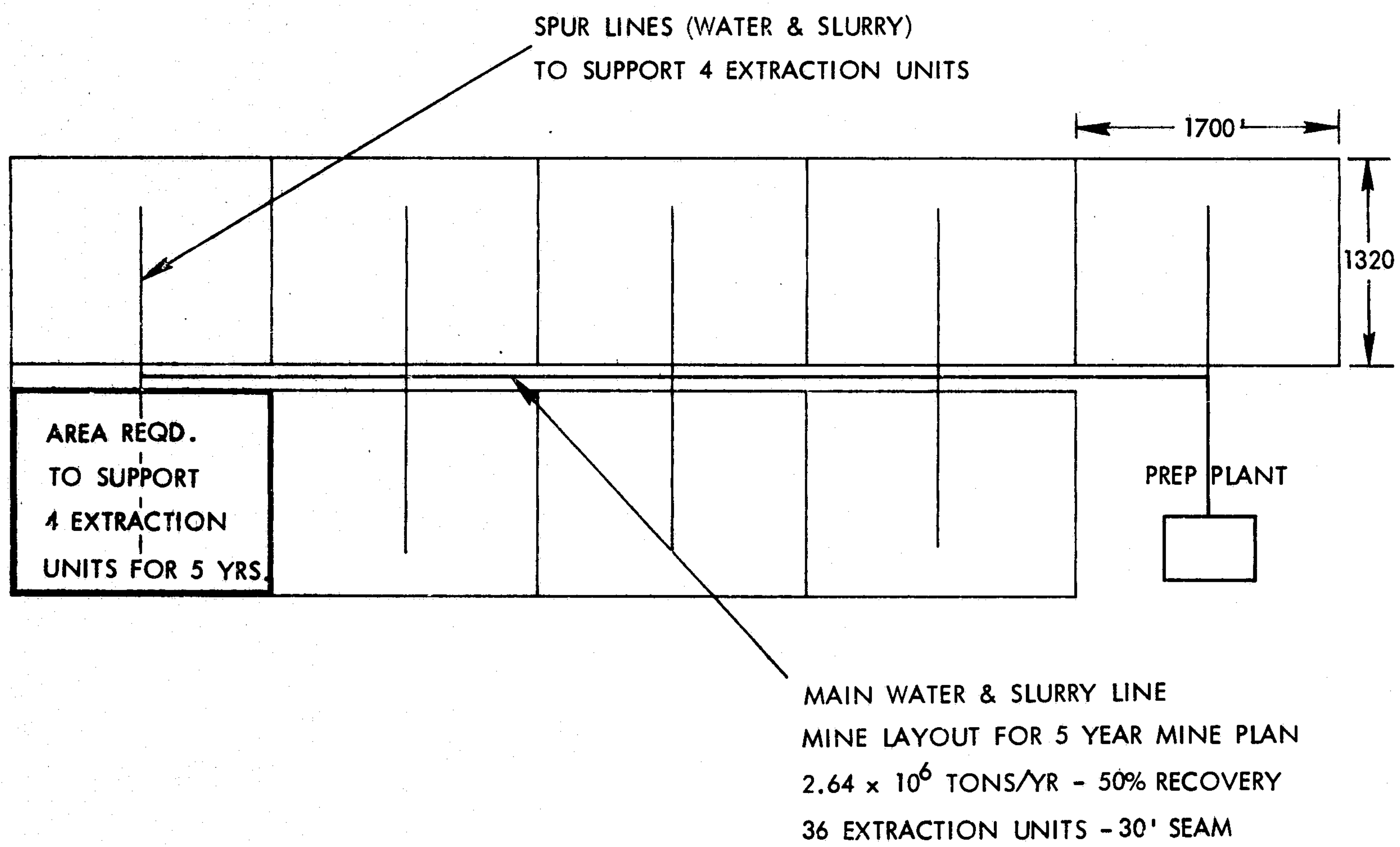


Figure 4-5. Five-year Section of Mine Plan

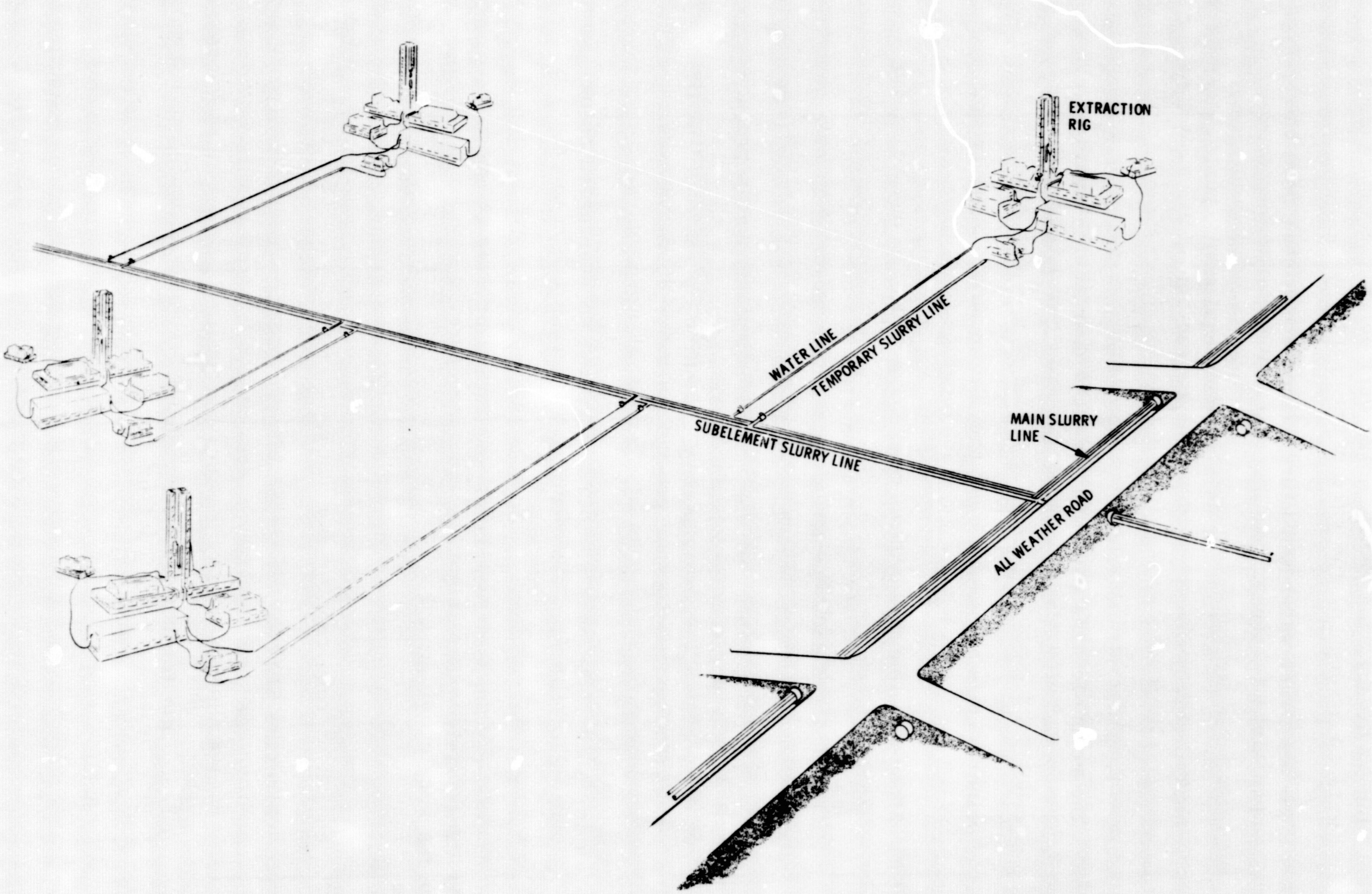


Figure 4-6. Subelement, Four Rigs Operating on 5-yr Plot

is cemented in place and capped. To best utilize the drilling machinery, the access holes will be drilled and capped well in advance of the extraction operation.

(2) The temporary water and slurry lines are routed from the spur lines to the extraction site.

(3) The borehole extraction unit support equipment (pumps, tanks, etc.,) are located at the extraction site, such that their placement can service four extraction cavities with the relocation of the borehole miner rig only.

(4) The borehole miner is then inserted down the casing, and the coal below the casing is cut and fragmented into a slurry and pumped into the slurry line. Following the extraction of all the coal from one cavity, the borehole miner rig is relocated over the second hole in the group, which can be reached from this location.

(5) After all four holes have been extracted, the entire mining unit is relocated and the procedure is repeated. Appendix C details the operations of extraction and unit relocation, the times of each operation, and the manpower required. These items are costed for the production phase cycle.

Designers of the borehole mining method indicated that a production rate of 40 tons/hr was an achievable goal for a unit the size of the prototype. Assuming a 220-day work yr, 3 shift operation, 8 hr of operation per shift, and 40 tons/hr production rate, 36 units were required to produce 2.64×10^6 tons/hr.

Assuming a drilling rate of 16.7 ft/hr, and an overburden thickness of 200 ft, 24 drill rigs are required to access the seam prior to extraction.

c. General Support Facilities and Equipment. As shown in Appendix C, a detailed investigation into the operations was conducted. All aspects were considered down to the details of supplies delivery and crew transport. The equipment to support these activities was also considered.

The equipment required for each borehole miner extraction unit is:

Pipeline Rig
Miner Rig
Mining Device
Water Supply Tank
Feed Pump for High Pressure Pumps
High Pressure Pump (Cutting Jet Supply)
Low Pressure Pump (Slurry Jet Pump Supply)
Suction Pump
Maintenance Truck
Crew Bus

Drilling units will drill and case the access holes in advance of the extraction units to minimize the number of drilling rigs required. The equipment required for drilling and casing is:

Drilling and Casing Rig
Mud Pump and Tank
Drill Bits and Stem
Casing Truck

A cement mixing plant and truck will also be required to support the drill casing installations.

The slurry transport system will be sized to an area which will support extraction for 5 yr as described in the text. The equipment required for the slurry system is:

Slurry Pump Station
9000 ft 8-in. Line
6000 ft of Connecting Line
44 8-in. Valves

Support facilities, such as accumulation ponds for surge control at each of the subelement sites, drainage ditches, all weather roads, and construction yards are required. The following are facilities and miscellaneous equipment required for construction projects:

16 mi of Gravel Road
Supply Yard
Coal Preparation Plant
Office and Crew House
Water Treatment Plant
Shop and Warehouse
Portable Toilets
8 Well Pumps
Oil Storage Tank
Fuel Tanker
Pickup Trucks
Dump Truck
Bulldozer

The quantities of the items listed above are somewhat a function of the mining conditions overburden and seam thickness, etc. A tabulation of the equipment and facilities required for the prototype borehole unit extracting 40 tons/hr from a 30-ft seam under 200 ft of overburden is contained in Appendix D. Other cases were analyzed using variations of the parameters.

Following the mine planning exercise and the determination of the equipment, manpower, facilities, and time functions, the economic analysis of the mine was performed. The details of the analysis are contained in Appendix E, as well as the results with several variations of the sensitive parameters.

The method for examining mining systems (which are in the preliminary design phases) for health and safety considerations, has been developed as a portion of the systems evaluation. The initial investigation into health and safety does not reflect costs, thus direct health and safety expenses will not be reflected in the economic analysis (Appendix E). As the design progresses, a reexamination may be required and costs extracted. Appendix G discusses the method for analyzing health and safety and the areas of concern for the hydraulic borehole mining system.

In addition to health and safety, environmental considerations may not be reflected fully in the economic analysis. The analysis in Appendix E uses a cost of $5,000/acre for restoration of the environment. Appendix F is an in-depth investigation into the elements of environmental restoration and the associated costs. These values represent the cost if the projected environmental requirements are enforced, and are considerably higher than the $5,000/acre. The most significant cost is the backfilling of the borehole extracted cavities. The geology is not fully understood, thus the need for backfilling has not been validated. Should backfilling be required, the costs quoted would be expected, and the mining costs would be increased significantly.

B. PITCHING SEAM MINE

1. Site Selection

Evaluation of the borehole hydraulic mining device in a thick, flat coal seam indicated that the cost of mining a ton of coal decreases as the thickness of the coal seam increases. Since the thickness of most coal seams in the United States is less than 100 ft, it was suggested by the Twin Cities Mining Research Center that an investigation be performed of the hydraulic borehole system operating in pitching seams. Extraction from the up-turned edge of the pitching seam would then be limited by seam thickness and machine depth capacity. The Grand Hogback in Colorado was suggested as a likely location for such a mine. The hydraulic mining device, as presently designed, requires near vertical positioning to insure proper operation. Therefore, the section of pitched seam located in Rio Blanco County (T1S - R94W) was specifically selected as applicable for this mining analysis effort. The coal seam in this area is nearly vertical (Figure 4-7). The topography presented by this site is rugged, with elevation changes from 1,000 to 1,500 ft/mi, with a general elevation of 7,000 to 8,000 ft above sea level. The summers are warm and dry, while the winters are cold with heavy snowfall. The climate, elevation and elevation changes all have an affect on the mine design.

2. Mine Design

The hydraulic borehole mining system is assumed to be used to mine coal from a near vertical seam that outcrops in the Grand Hogback of Colorado. The production rate for the mine was again selected to be 2.64×10^6 tons/yr, and the mine would have a projected life of 20 yr.

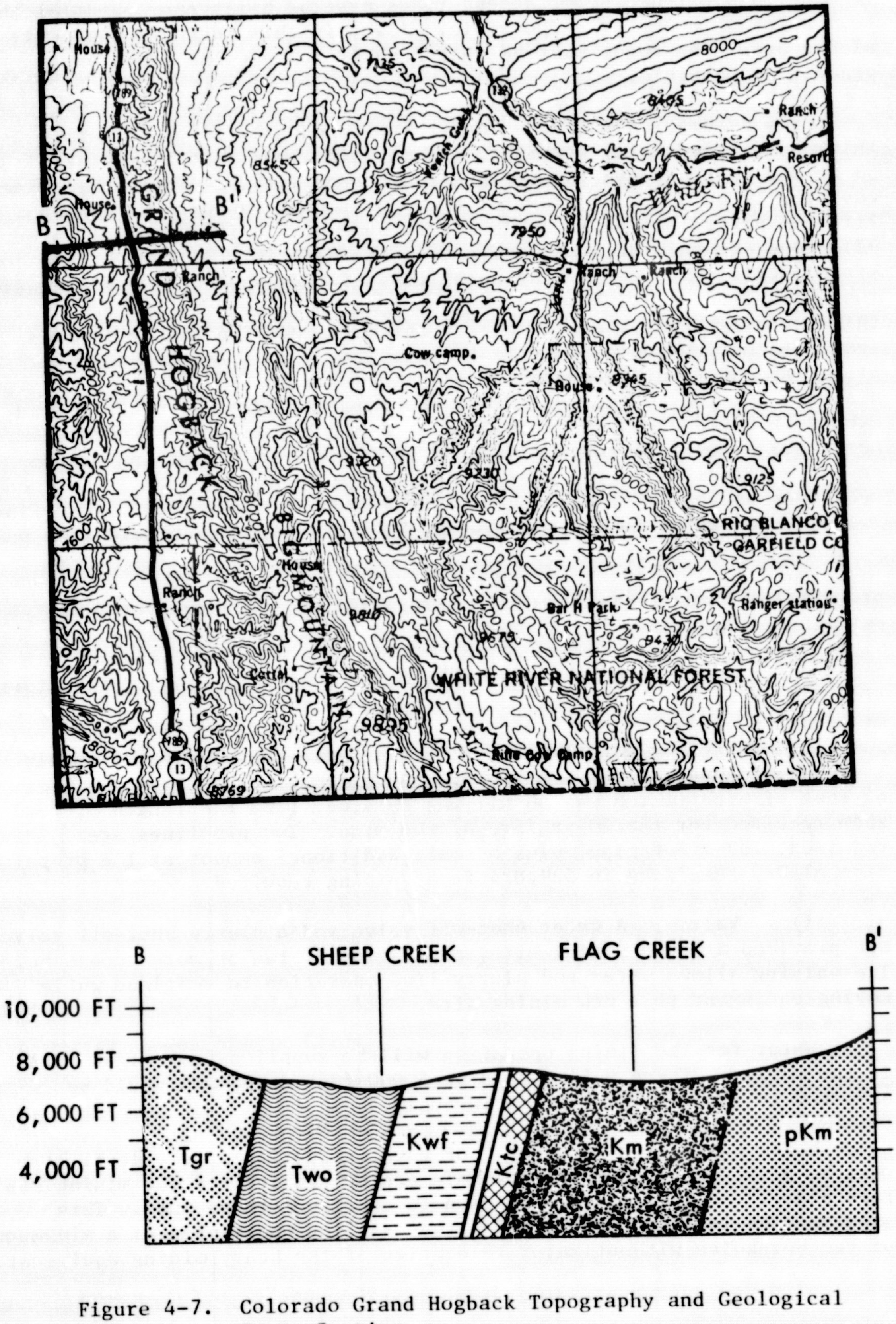


Figure 4-7. Colorado Grand Hogback Topography and Geological Cross Section

To mine this pitched seam, access roads must be built that parallel the seam outcrop in-so-far as possible. Also, in this rugged and steeply sloped area, the roads must be switch backs to keep the grade as gradual as possible.

The assumption was made that the pitched seam is of uniform thickness, essentially straight, without dips, and that a barrier of 50 ft was left between the surface and the coal to be mined. The mined cavity will be 30 ft in diameter and 250 ft deep (assuming a maximum lift capability in the downhole slurry pump of 300 ft), and will produce 7718 tons of coal for each cavity (density 87.3 lb/ft^3, 100% extraction efficiency). Mining the 2.64×10^6 tons of coal each year would require the extraction of 342 cavities. It was assumed, for the purpose of this analysis, that the same pillar thickness used in the horizontal seam application could apply to the pitching seam. The 6.8-ft-thick piller and 30-ft-diameter cavity established a 36.8-ft center-to-center distance for the holes. With this spacing, the 342 cavities required each year would consume approximately 12,549 linear feet of coal seam per year, or 47.5 mi for the life of the mine. In the mining of the nearly vertical seam, the extraction is from the upper edge of the seam requiring up to 100 ft of land on either side of the seam's center line. Two or more extraction cavities would be worked from each work site pad.

a. Coal Transportation. Transportation of the coal to the preparation plant from the mining sites will be a slurry system as described in the analysis of the thick flat seam mining system. A slurry transport system was chosen to avoid the on-site equipment required to dewater the coal slurry (20-30% coal by weight). The slurry line design would be complex, due to the requirement for maintaining a minimum flow velocity and a minimum flow pressure loss. This, however, was circumvented by assuming the slurry pipeline and the water supply line was of constant 8-in. diameter. An estimate of the total number of feet of pipe (which was 50 mi) was obtained from the length of coal seam required for the 20-yr life of the mine. Two pipelines are required, 100 mi of pipe, plus a small additional amount at the preparation plant, resulting in 529,824 ft of piping required.

1) Valves. A water shut-off valve and a slurry shut-off valve are provided at each mining site, consisting of two or more access holes The valving allows water and slurry line operation to continue while moving equipment to a new mining site.

Water for the mining operation will be supplied from eight wells in the valley. These wells would be 5,000 feet deep, and would be expected to produce 400 gpm continuously.

b. Extraction Sequence. At each extraction site a level area must be provided so that the borehole can be drilled and the mining can take place. Bulldozers will be used to construct these pads. This area must be large enough to allow the drilling and mining of a minimum of two boreholes without major relocation of the heavy mining equipment.

The 15-in. diameter borehole will be drilled to a depth of 50 ft below the surface, and then cased with 13-3/8 in. diameter casing to that depth. It is assumed that this depth will terminate in the coal seam.

The access hole to the coal seam will be drilled 15-in. in diameter in a single drill pass. A drilling rate of approximately 16 ft/hr is expected. The casing will be set in conjunction with the drilling operation. The 15-in. hole will require drilling mud, rather than compressed air or foam, since the air requirements become very large. At the expected drill rate, approximately 3 hr would be required to drill the 50-ft hole. Casing is lowered into the holes and cemented into place and capped. The drill rig is then free to proceed to the next hole drilling site. Since the 15-in. diameter access hole can be drilled at a much faster rate than the coal can be mined, only two such drill rigs and their support elements are needed for the entire mine. The drilling rig consists of the following elements: heavy duty drill rig, cement truck, mud pump and tank, and drill bits and steam. Figure 4-8 illustrates the operation of the equipment on a pitching seam. Detailed information on the equipment selected and the cost data are presented in Appendix D.

The elements of the drill rig were selected to be complete self-contained and crawler-mounted because of the elevation change expected between mining sites. Care must be observed when constructing the roads to assure the grades are within the capability of the crawler-mounted equipment.

After the coal seam is accessed to the proper depth by the drill rig, a mining rig will be brought in to extract the coal. This rig will consist of the following equipment:

(1) A light duty truck-mounted rotary rig, with draw works capable of handling 300 ft of the hydraulic mining device

(2) A truck-mounted, high pressure, triplex pump for supplying the 4500 psi water flow to the coal cutting jets

(3) A truck-mounted, low pressure triplex pump to supply low pressure water supply to the slurry pump and stirring jets

(4) A feed pump used to supply water at sufficient pressure to the high pressure pump to suppress cavitation

(5) A suction pump used to assist the coal slurry out of the hole, and boost its pressure sufficiently to inject it into the slurry transport system to the preparation plant

(6) Water supply tank to provide the mining site with a small independent water supply to eliminate the surge affects from the water supply system.

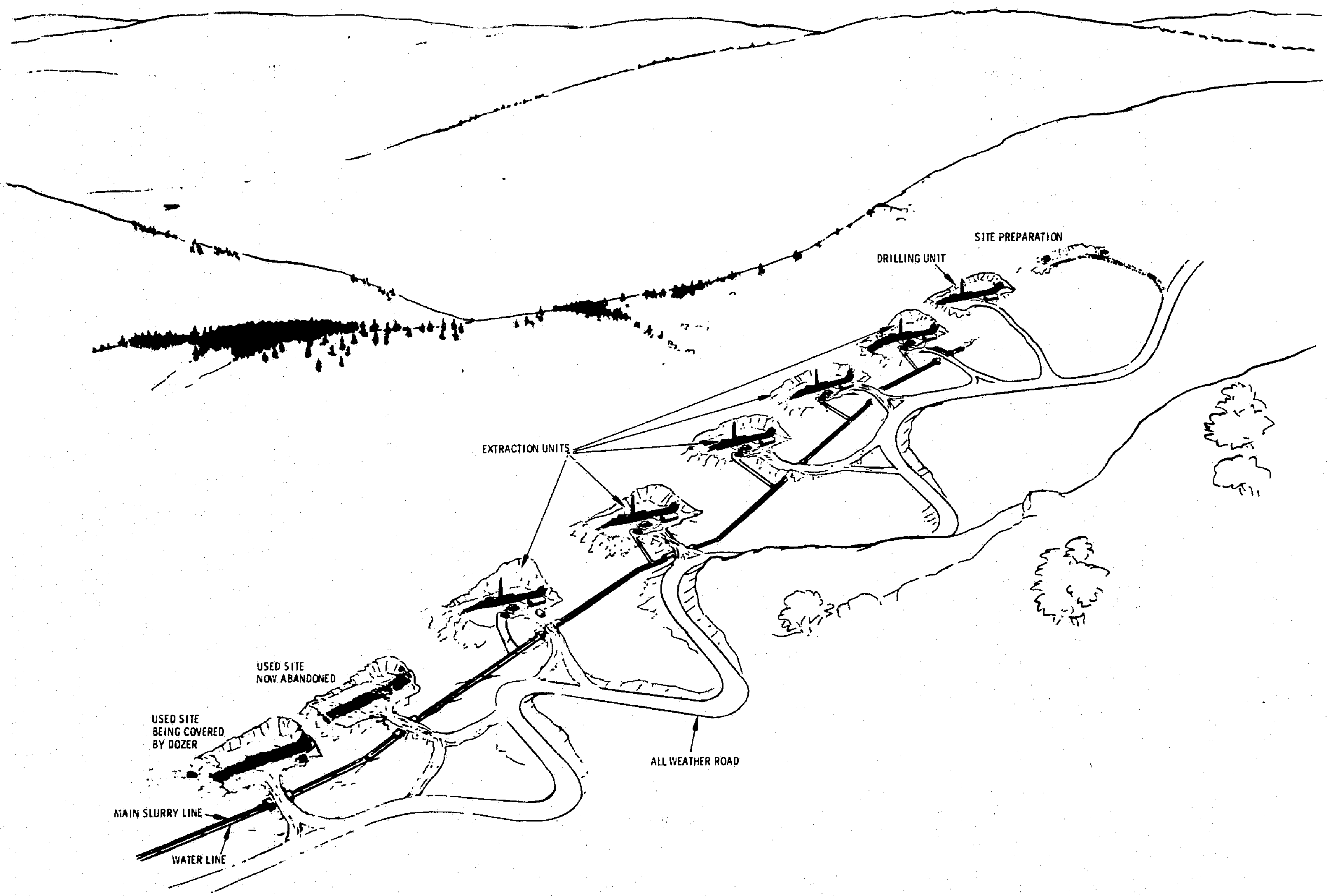


Figure 4-8. Equipment Operating on a Pitching Seam

A determination of the number of mining systems required to maintain the 2.64 x 10^6 tons/yr production rate was made by estimating the time required to accomplish each element of the flow diagram (Figure C-3 in Appendix C). An example of one element is the time necessary to completely mine one of the cavities. The mining device is assumed to be capable of mining a 30-ft diameter cavity with a height of 250 ft in a pitching seam. As discussed earlier, these dimensions provide a total of 7718 tons of coal at a density of 87.3 lb/ft^3, and with a 100% extraction efficiency. The time required to mine the cavity would thus be 7718 tons/40 tons/hr, or 192.95 hr. This value was then inserted into its appropriate element in the functional flow diagram. Similar assumptions were made for all other elements, and then the number of mining devices was calculated. Using these critieria, 16 mining devices are required in order to maintain the desired production rate.

c. General Support Facilities and Equipment. As can be seen in Figure 4.7, this mine will be long and narrow, stretching over the top of the rugged Grand Hogback. Construction of roads and mining sites will be a problem. If all 16 mining elements were located in close proximity, some equipment would have to be passing other equipment from time to time, and possibly incurring delays. Therefore, the length of seam required for a 20-yr mine life should be divided into 16 lengths, allowing each mining element to mine out its own portion over the 20-yr mine life. This would eliminate congestion and equipment delays caused by traffic. A mine lay-out of this type would require multiple access roads (in this case, four roads were included) to shorten supply routes as much as possible. The construction of 105 mi of gravel road was assumed and costed for this analysis.

1) Water Well Pumps. Eight water wells will be needed to supply the water requirements for the mine, and each must have its own water pump.

2) Earth Moving Equipment. The individual mining sites require a nearly level area so that the drilling and mining equipment will operate properly. It is anticipated that five bulldozers will be needed to prepare these sites, and will be required to maintain the road system, and for snow removal.

3) Trucks. Transportation of supplies and men to the mining sites will be by truck as follows:

(1) Casing truck — one truck will be devoted entirely to the distribution of borehole casing to mining sites

(2) A diesel fuel tanker will be required to supply fuel to mining sites

(3) Two crew busses will be required to transport crews to their work stations

(4) Two roving maintenance crew trucks are required to keep equipment operating

(5) Ten pickup trucks and two dump trucks are also required to support construction activities

(6) The general coal mine support facilities which must also be provided are: coal preparation plant, office and crew change room, repair shop and warehouse, supply yard, oil storage tank, and water treatment plant.

The above text describes the hydraulic borehole mining system as used to mine coal from a near vertical coal seam. The cost of this equipment, manpower to operate it, and the supplies, were used to perform an economic analysis to determine the cost per ton of coal mined using the hydraulic borehole system. Appendix E addresses the method of analysis, and the resultant costs, for the borehole systems operating in pitching seams.

REFERENCES

1-1. Longwall Mine Availability and Delay Analysis Phase II - JPL Internal Document 5030-46.

1-2. Shortwall Mine Availability and Design Analysis Phase II - JPL Internal Document 5030-47.

APPENDIX A

BOREHOLE MINER OPERATIONAL CHARACTERISTICS
VERBATIM EXTRACTION FROM FLOW
TECHNOLOGY REPORT NO. 3 — APPLICATION
OF A HYDRAULIC BOREHOLE MINING
APPARATUS TO THE REMOTE EXTRACTION
OF COAL — FINAL REPORT

3.2 HYDRAULIC BOREHOLE MINING DEVICE DESIGN

From the results of the above-mentioned studies and the requirements of the program, the following design requirements were established.

(1) The hydraulic borehole mining device shall consist of three systems:

a. A hydraulic jetting system, including pumps to generate the flow of water (200 gpm), high-pressure conduits to convey water to the nozzles, and nozzle assemblies to form two water jets at 4,500 psi.

b. A jet pump slurry system (operating at 670 psi and 260 gpm), including a suction device to pick up cuttings and a conduit to carry cuttings to the surface from a depth of at least 100 feet to a maximum of 300 feet.

c. A tricone bit to reduce the oversize coal lumps to a size suitable for the slurry pump, and, in addition, water jets emanating from the tricone bit that agitate the cuttings to facilitate pick up.

(2) The pilot borehole shall have a diameter of 16 inches or less.

(3) The device shall be designed to cut coal in full 360 degree rotations, or to oscillate about the central axis of the borehole.

(4) All conduits are to occupy the same borehole.

The design of the hydraulic borehole mining device satisfied all of the above requirements. The entire system for hydraulic borehole mining is shown in Figure A1*. It includes:

a. The hydraulic borehole mining device,

b. A rotary table to rotate and oscillate the hydraulic borehole mining device,

c. A drilling rig to support the hydraulic borehole mining device,

*These figures are excluded from this report. Refer to original document for this data.

d. High-pressure pumps and motors to generate water pressures and flow rates of 4,500 psi and 200 gpm, 700 psi and 300 gpm, and 700 psi and 100 gpm for coal cutting, jet pump and coal agitation, respectively,

e. A supply water reservoir to hold water,

f. A slurry pond to retain the coal slurry, and

g. Flexible hoses to conduct water and slurry.

In the following sections, the detailed descriptions of each component are given.

3.2.1 The Hydraulic Borehole Mining Device (HBMD)

The HBMD is the heart of the hydraulic coal mining system, and it is shown in Figure A1*. It forms the water jets that fragment the coal, and contains the jet pump for coal-slurry transport. The HBMD has a tricone bit (not shown), and water jets to reduce the over-size coal, and to agitate the coal for pickup by the jet pump. From top to bottom, it includes a three-passage swivel, a kelley section, standard sections, and the mining section. Three passages are provided: 4,500 psi for water, 700 psi for water, and the coal slurry.

3.2.1.1 The Three-Passage Swivel. The three-passage swivel is shown in Figure A2*. The outer part of the swivel is stationary, and is supported by the drilling rig. The inner part of the swivel can rotate relative to the outer part. The swivel allows for rotation and for passage of 4,500 psi water, 700 psi water, and coal slurry. The swivel can be connected to the kelly section, the standard section, or the mining section by a ring of bolts.

3.2.1.2 The Kelly Section. Figure 13* shows the kelly section. The torque to rotate the HBMD is transmitted from the rotary table to the HBMD through the kelly section. The kelly section is 22 feet long, has a 12-inch outer diameter, and has two 0.75-inch webs along its length for drive. The arrangement of the conduits inside is the same as that of the standard sections.

3.2.1.3 The Standard Section. A typical standard section is shown in Figure 14*. The standard sections provide the length to reach the underground coal seam, and carries the three previously mentioned passages. The outer diameter is 12 inches. It has a 4-inch pipe for coal slurry, and a 2-inch pipe for the 4,500 psi water, enclosed within a tube with a 12-inch outer diameter. The space between the three pipes contains the 700 psi water. All sections are connected by a ring of bolts, and all sections can be interchanged. In each standard section

*These figures are excluded from this report. Refer to original document for this data.

and the kelly section is a wrench gove near the upper end for support during section connect and disconnect. Each standard section is 20-feet long.

3.2.1.4 The Mining Section. The mining section is the bottom-most section of the HBMD, and is shown in Figure 15*. It is approximately 6-feet long and 12-inches in diameter. It is connected to the last standard section by a ring of bolts. The mining section containing two replaceable nozzles form the high-pressure water jets for cutting coal. It also contains a jet pump, intake ports, and screen for coal-slurry pickup and transportation of the surface. The screens have 3 1/2-inch vertical slots that are 0.400-inches wide to filter out large particles that might plug the jet pump. A valve is mounted on the slurry output of the swivel so that back-flushing can be used to clean the screens. The mining section also has a 12 5/8-inch tricone rock bit to reduce oversize coal lumps, and includes a water jet (700 psi, 100 gpm) to agitate the coal for easier pickup. We later removed the bricone rock bit, and installed a conical auger in its place.

*These figures are excluded from this report. Refer to original document for this data.

APPENDIX B

ROCK MECHANICS STUDY

PRELIMINARY STUDY OF ROCK MECHANICS FOR HYDRAULIC BOREHOLE SYSTEMS

A preliminary investigation of the underground structure for hydraulic borehole systems was performed using the limited data available for the Wyoming Powder River Basin coal deposits. The assumptions and results of the study are briefly summarized in the following:

(1) Geological Strata

A three-layer rock strata is considered, namely alluvium top layer, roof rock and coal.

(2) Extraction Pattern

Circular boreholes are arranged in a hexagonal closed-packed pattern. The panel diameter (cavity), d, and the center-to-center distance, s, determine the recovery factor.

(3) Pillar Stability

For a given depth of overburden, the stress distribution of the pillar can be calculated. Due to the borehole arrangement, the circumferential stress at the borehole surface is higher than the hydrostatic pressure. This stress concentration factor is calculated as a function of d/s ratio (Figure B-1). The analysis is performed by a finite element method using the general purpose computer code NASTRAN. Due to the cyclic symmetry nature, only a 60^{o} section has to be modeled (Figure B-2).

(4) Coal Properties

After the stress distribution in a pillar is determined, the stability is examined by using Coulomb-Mohr failure envelopes for different coals (Figure B-3). The maximum d/s ratio is calculated as a function of the overburden depth, h, whose density is assumed to be 127.92 lb/ft^3 (Figure B-4). Since the pillar is under compressional stress, a safety factor of 4.0 has been used.

(5) Roof Stability

Since the overburden depth is in the order of 200 ft, the roof will most likely fail due to the tensile stress from bending. In the present analysis, it is assumed that the roof is rigidly supported by the pillar. Again finite element method is used to calculate the maximum tensile stress as a function of d/h ratio, where h is the roof thickness. A safety factor of 8.0 is employed due to the nature of tensile stress (Figure B-5).

(6) Sample Case

(a) Overburden depth h - 200 ft

(b) Roof thickness h - 100 ft, rupture stress 0.8×10^3 psi (sandstone).

(c) Powder river sub-bituminous coal

From Figure B-4, max. d/s is d/s = 0.975.

From Figure B-5, for the roof with 0.8×10^3 psi tensile stress (115.2 lb/ft^2), and h = 200 ft max. d/h is d/h = 0.4.

The results can be summarized as follows:

(i) Panel diameter, d = 0.4 h = 40 ft.

(ii) Center-to-center distance: s = d/0.975 = 41.03 ft

(iii) Recovery factor $\eta_\infty = 0.907 \times (d/s)^2 = 86.2\%$.

Concluding Remarks

The analysis which was conducted for the Wyoming site is of a preliminary nature. Some of the assumptions postulated, such as the roof which is rigidly supported by the pillars, may not reflect reality. The geologic data available from the proposed mining site is quite incomplete. The finite elements models also somewhat crude, and the accuracy of the computed results could be improved. Nevertheless, the qualitative trend has been established.

The sample case above indicates that 40-ft-diameter holes on 41.03-ft center-to-center distances are feasible under the stated conditions. Presently, the borehole mining device is design-limited to creating only a 25-ft diameter cavity. For the Wyoming site example, a close-packed hexagonal pattern was selected, and a recovery factor of 50% was assumed. From these assumptions, a 33.65-ft center-to-center distance was calculated which provides a more conservative example than the example above.

A center-to-center distance of 36.8 ft was used for the pitching seam situation, and an optimistic cavity size of 30-ft diameter was assumed. This provided a pillar thickness of 6.8 ft — the same as was used in the horizontal seam situation. A limited amount of geologic data were available on the Colorado pitching seam site. The pillar size was assumed to be adequate for most geologic conditions.

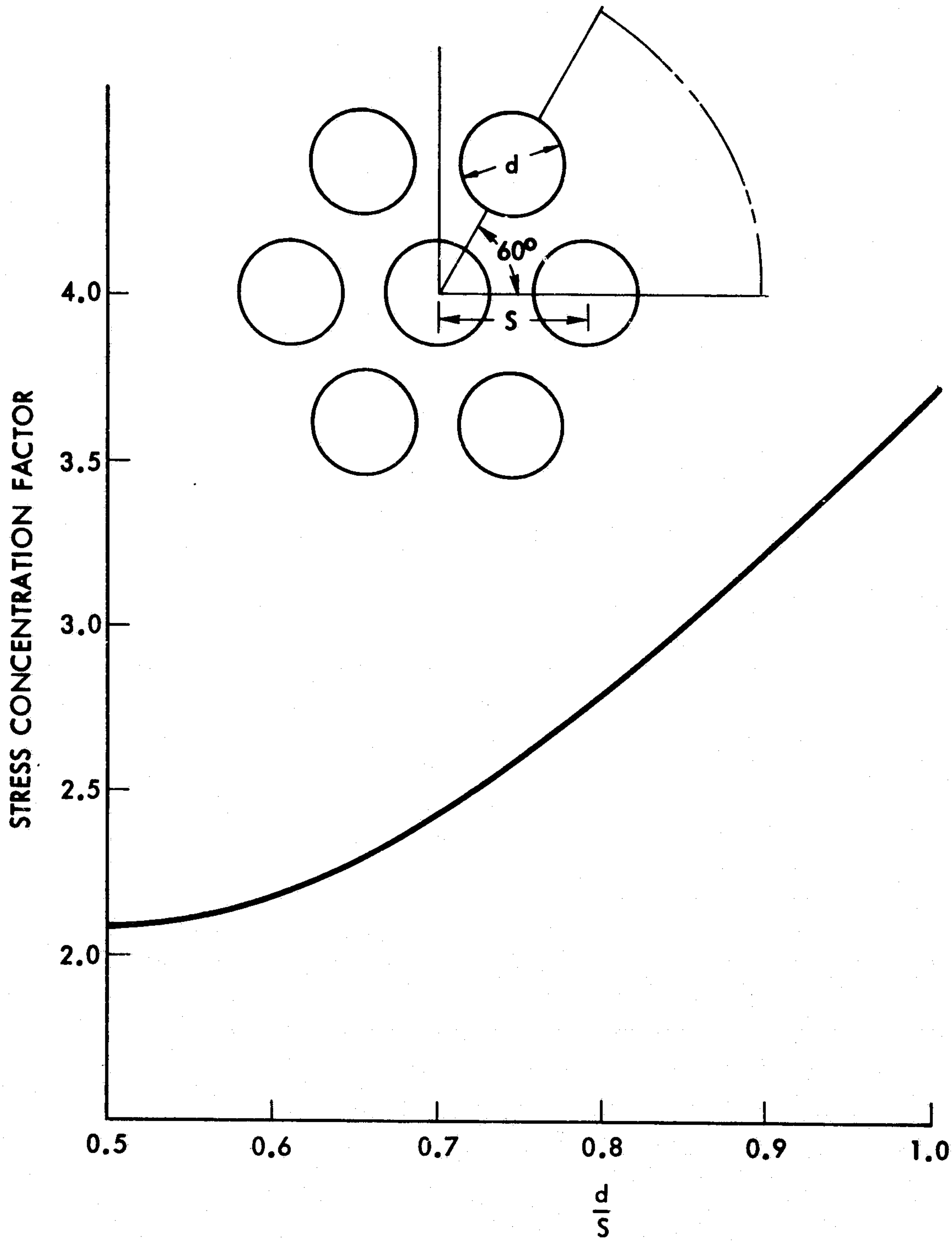


Figure B-1. Stress Concentration in Pillar

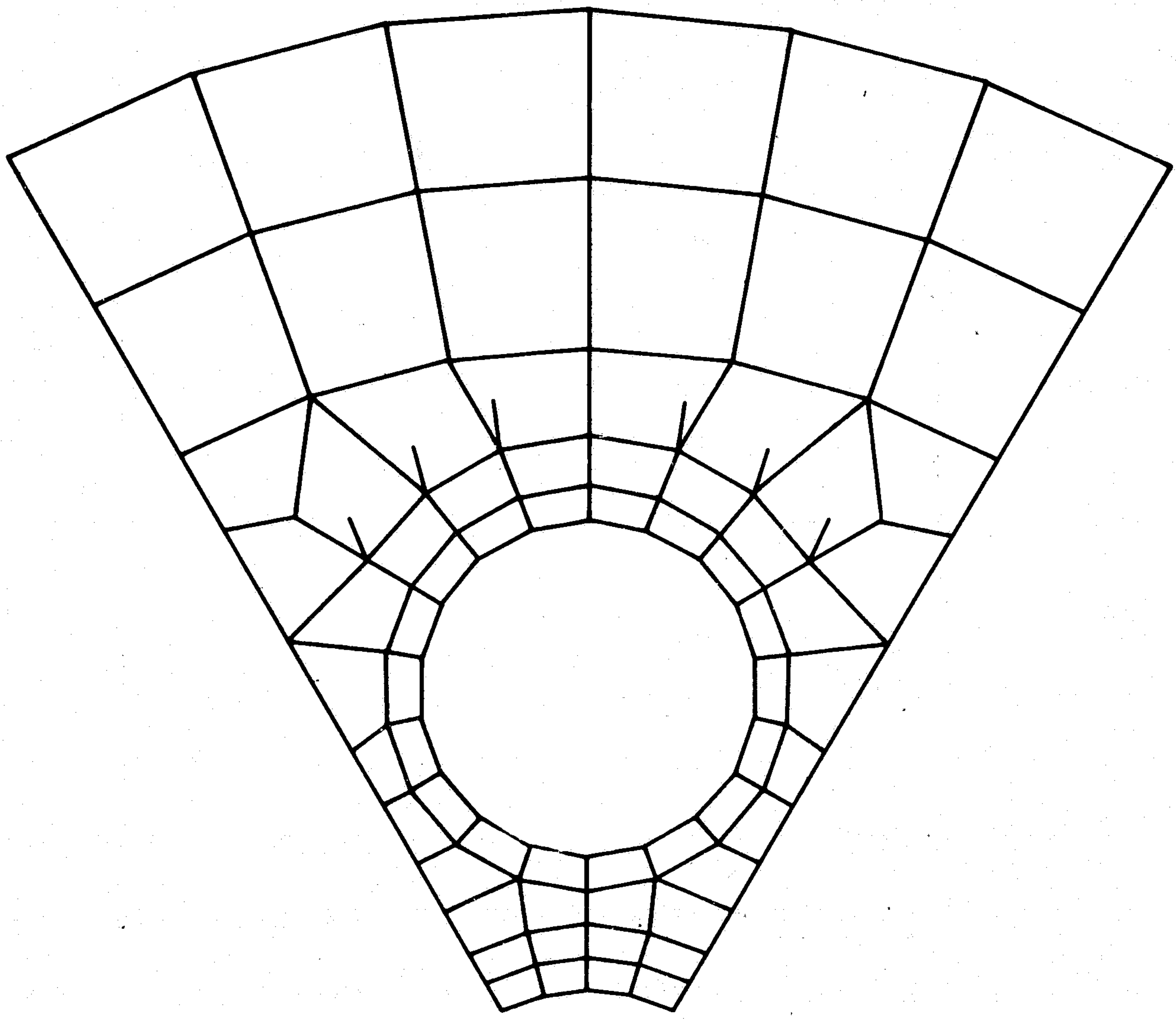


Figure B-2. Finite Element Model for Pillar

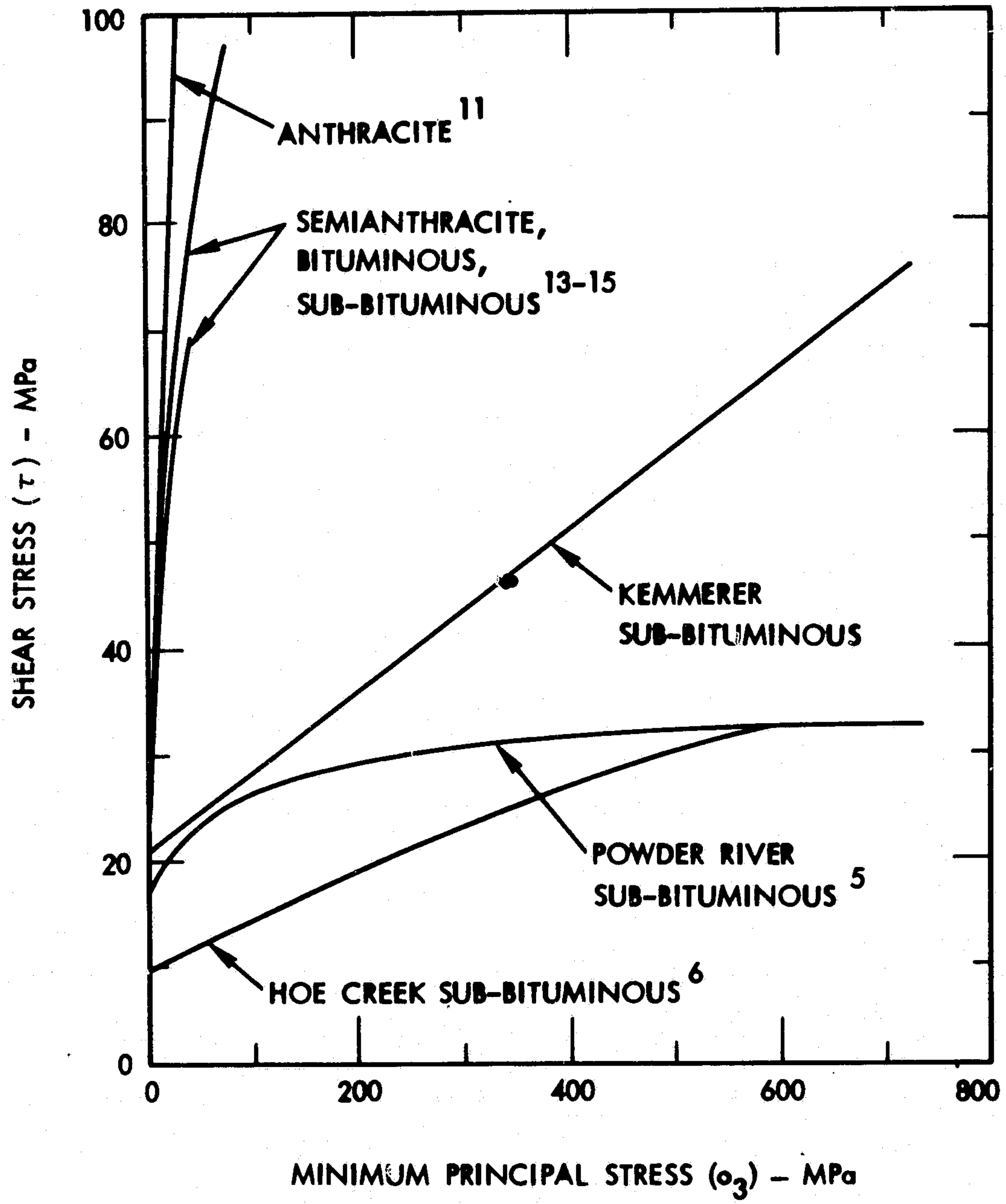


Figure B-3. Coulomb-Mohr's Failure Envelopes for Coals

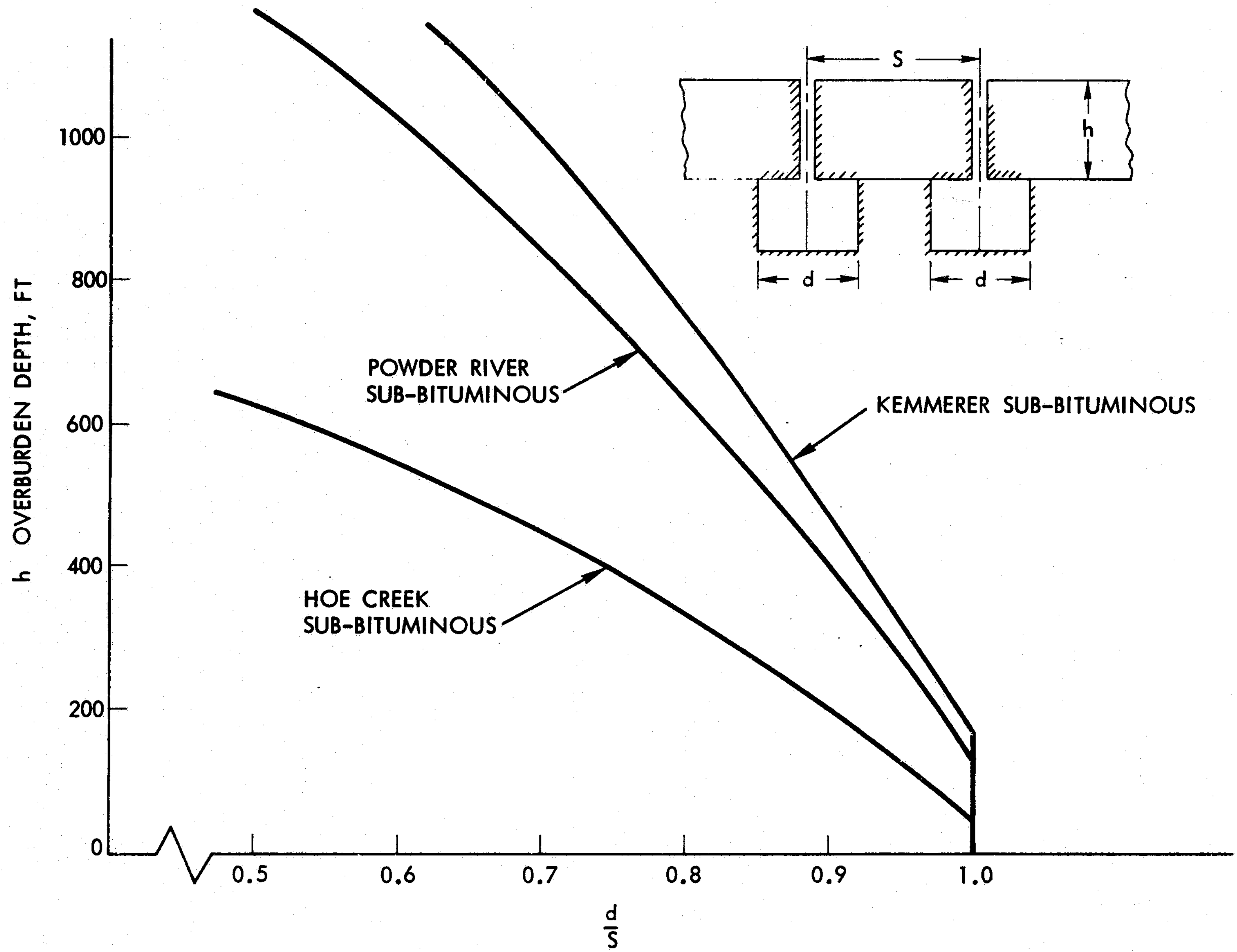


Figure B-4. Pillar Stability

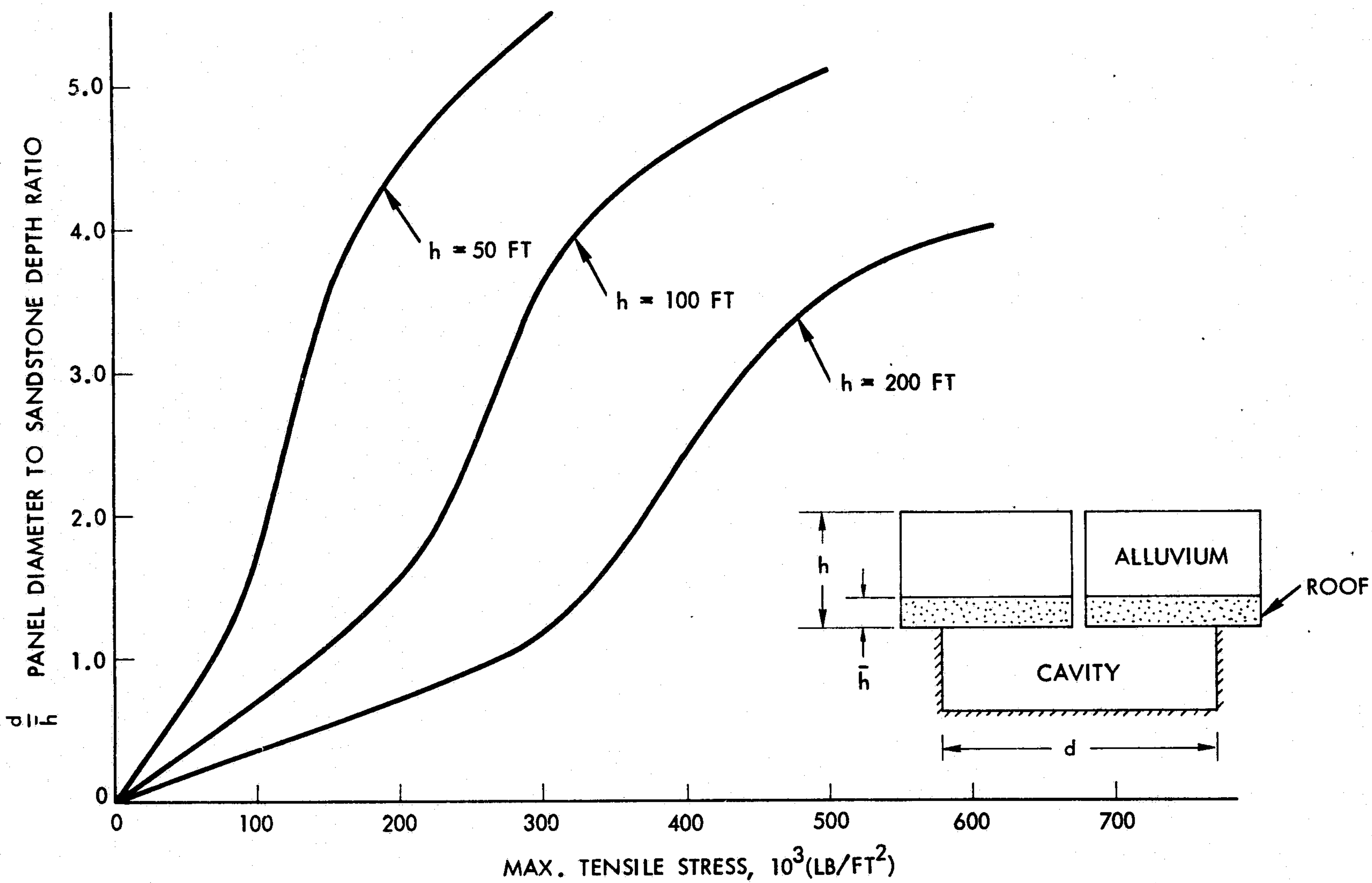


Figure B-5. Roof Stability

APPENDIX C

FUNCTIONAL DIAGRAMS

The method employed in the analysis of underground mining was to express the operations as functions in a graphic presentation known as a functional diagram. The functional diagram breaks the operations into levels of detail with the most detailed level resembling a time-motion tabulation of the activities. The top level of the underground coal mining functions can be expressed in three functions: (1) mine development, (2) mine production, and (3) mine closure. These functions are general enough to be consistent with all underground coal mining operations. Each level of function becomes more explicit and more directly oriented toward a specific method of coal extraction as levels progress down from the top level. Figure C-1 illustrates the second level functions as they relate to the top level functions, and are oriented to the hydraulic borehole method. For other extraction processes, such as room and pillar or longwall mining, the activities vary in the more detailed levels. As an example, the mine development activity "Construct Field Access", shown in Figure C-1, would be replaced with "Construct Entry Shaft" for a longwall or room and pillar mine. Lower functional levels become more method-specific, yet the overall format remains the same.

The "mine production" function contains the major part of the activity for any mining method. Figures C-2, C-3, and C-4 illustrates a further breakdown of the mine production phase as it occurs in the hydraulic borehole mining method. Each of the functions (hole development, hole production, and hole closing) are cyclic for this mining method. When the functional diagram is carried to the next lower level, the number of cavities which may be extracted from a pump and support equipment relocation would be detailed. At this level, the differences in flat seam and pitching seam extraction would be illustrated. The volumes of coal extracted in a cycle, and the utilization of time, would appear at the lower level. From the functional diagrams, times for the operations are determined and tabulated into charts. Figure C-5 illustrates the timing chart for flat seam operation. Note that two times are quoted in the chart, one for a single function and another for four cycles of the operation. In the flat seam operation, four holes may be extracted from a single pump and support equipment position, thus four cycles are performed at each site. Figure C-6 is a timing chart for the pitching seam situation, where the geometry of the seam permits only two holes to be extracted from a single pump-support equipment position.

The functional diagrams are also used as a working medium for determining labor force size, utilization of labor, and equipment requirements. From the diagrams, the number of drilling and extraction units was determined to achieve the desired production goal.

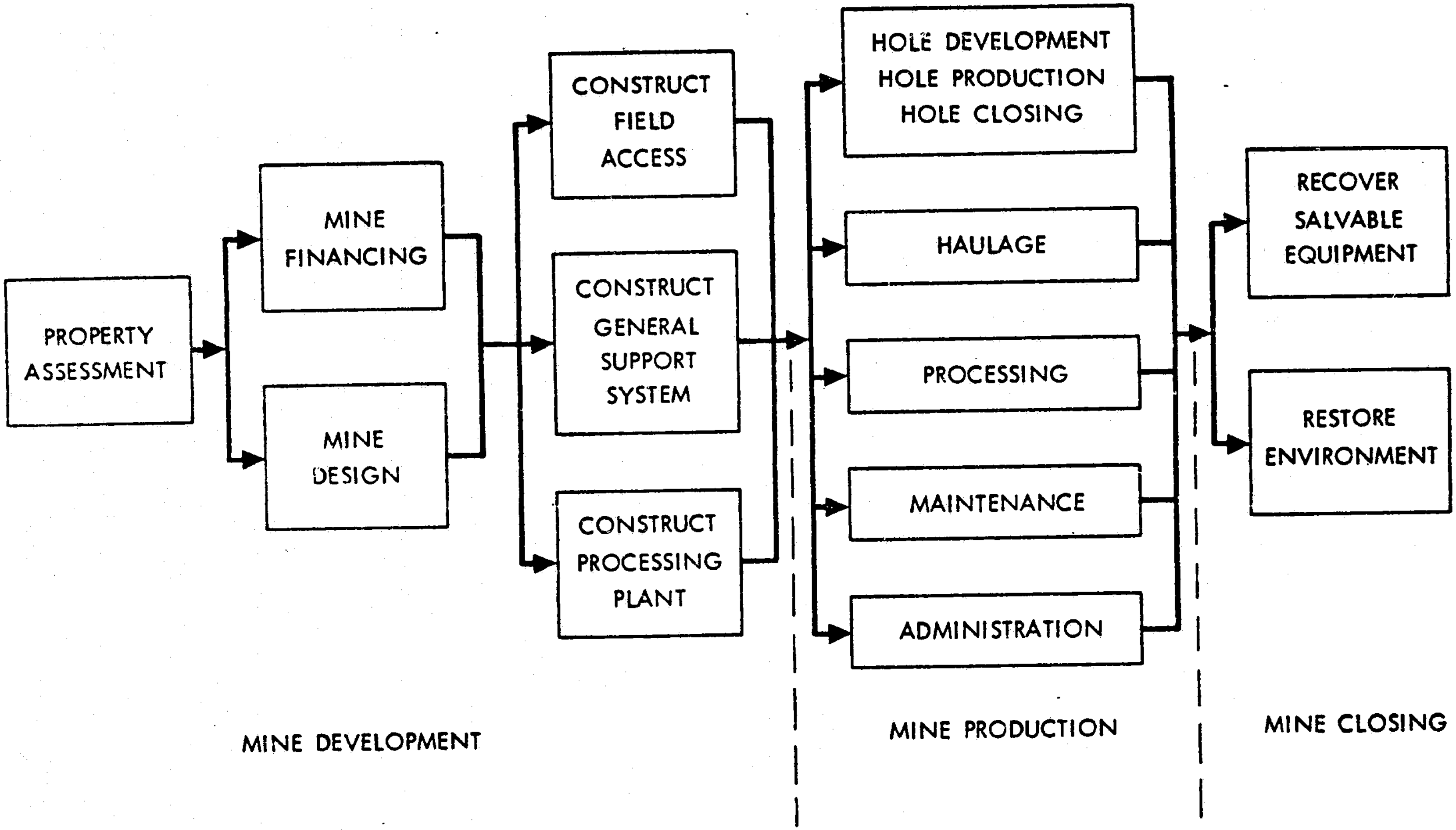


Figure C-1. Mine Life Functional Diagram

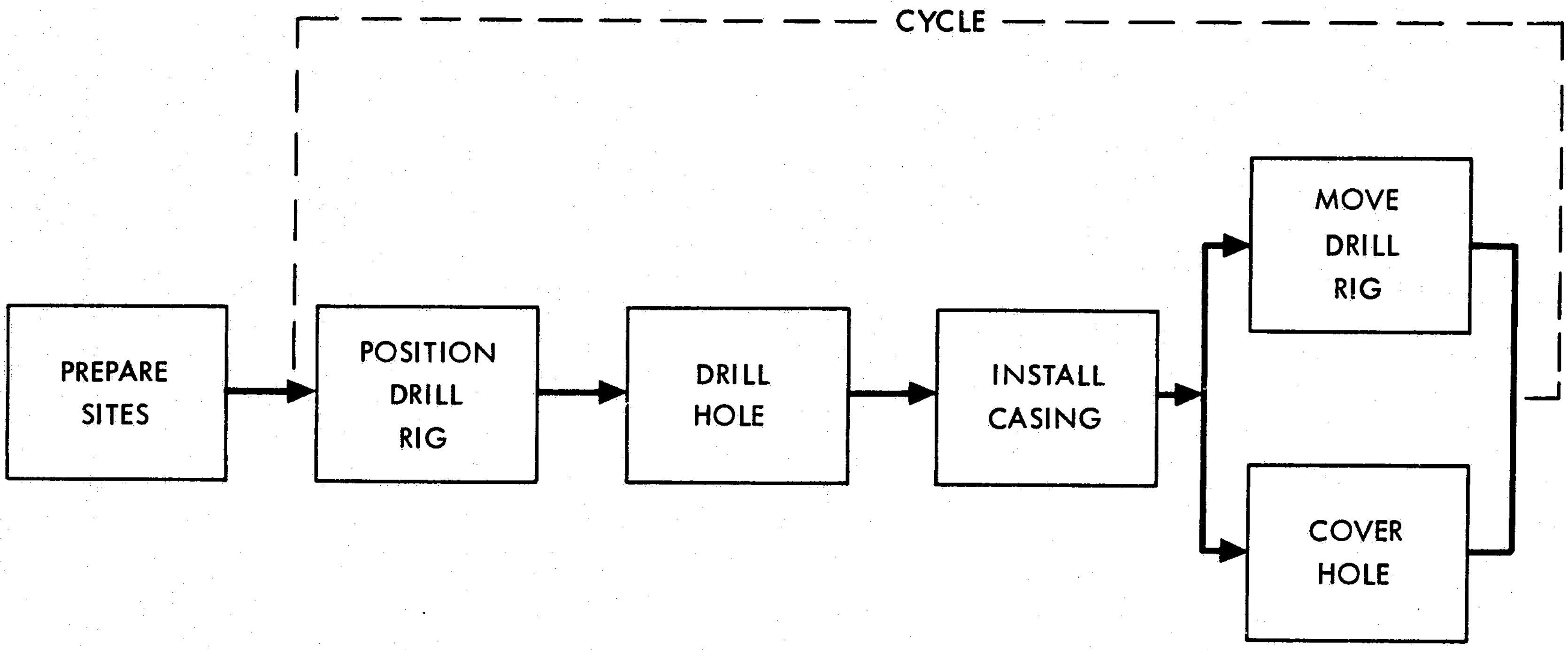


Figure C-2. Development Phase Functional Diagram

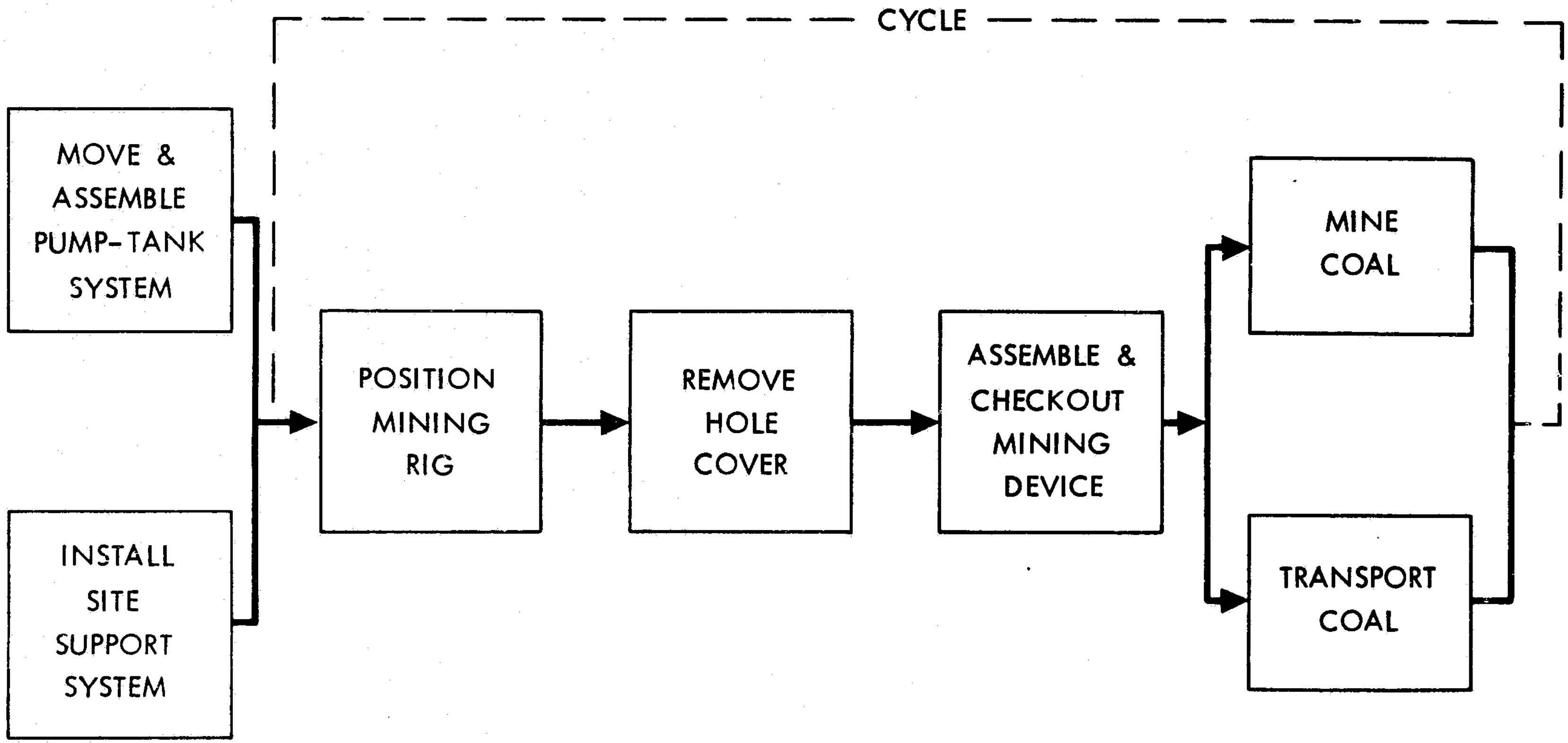


Figure C-3. Production Phase Functional Diagram

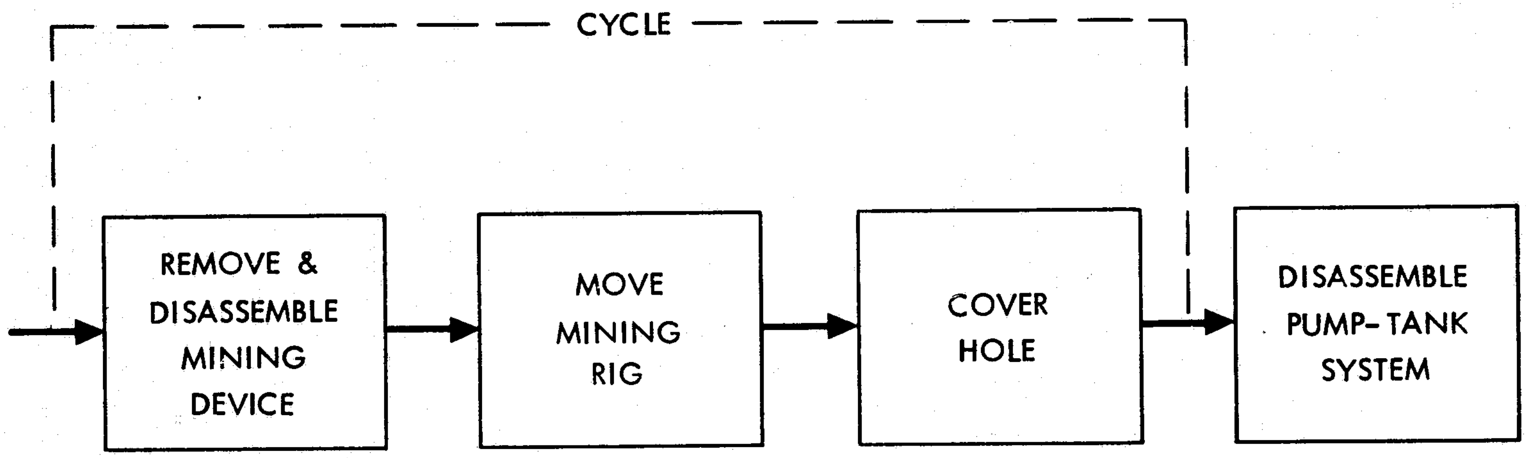


Figure C-4. Closing Phase Functional Diagram

THIRD LEVEL FUNCTIONAL ANALYSIS

TIMING CHART

	FUNCTION TIME	4 CYCLE TIME	
HOLE DEVELOPMENT:			
SITE PREPARATION	3.0		
POSITION DRILL RIG	8.0	32.0	
DRILL HOLE	12.0	48.0	
CASE HOLE	6.0	24.0	
MOVE DRILL RIG	4.0	16.0	
COVER HOLE	.5		
TOTAL TIME			123.0
HOLE PRODUCTION:			
MOVE & ASSEMBLE PUMP-TANK SYSTEM	10.0		
INSTALL SUPPORT SYSTEM	10.0		
POSITION MINER RIG	3.0	12.0	
REMOVE HOLE COVER	.2	.8	
ASSEMBLE & CHECKOUT MINING DEVICE	12.0	48.0	
MINE COAL	4.0	16.0	
PUMP COAL	16.0	64.0	
TOTAL TIME			134.8
HOLE CLOSING:			
REMOVE & DISMANTLE MINING DEVICE	10.0	40.0	
MOVE MINING RIG	1.0	4.0	
COVER HOLE	.5	2.0	
DISMANTLE PUMP-TANK SYSTEM	4.0		
TOTAL TIME			50.0

Figure C-5. Timing Chart for Flat Seam Operation for a 40-ton/hr System

THIRD LEVEL FUNCTIONAL ANALYSIS

TIMING CHART

	FUNCTION TIME	2 CYCLE TIME	
HOLE DEVELOPMENT:			
SITE PREPARATION	..0		
POSITION DRILL RIG	8.0	16.0	
DRILL HOLE	6.0	12.0	
CASE HOLE	3.0	6.0	
MOVE DRILL RIG	2.0	4.0	
COVER HOLE	.5		
TOTAL TIME			38.0
HOLE PRODUCTION:			
MOVE & ASSEMBLE PUMP-TANK SYSTEM	12.0		
INSTALL SUPPORT SYSTEM	2.0		
POSITION MINER RIG	3.0	6.0	
REMOVE HOLE COVER	.1	.2	
ASSEMBLE & CHECKOUT MINING DEVICE	16.0	32.0	
MINE COAL	48.0	96.0	
PUMP COAL	192.9	385.8	
TOTAL TIME			436.0
HOLE CLOSING:			
REMOVE & DISMANTLE MINING DEVICE	12.5	25.0	
MOVE MINING RIG	1.0	2.0	
COVER HOLE	.5	1.0	
DISMANTLE PUMP-TANK SYSTEM	4.0		
TOTAL TIME			32.0

Figure C-6. Timing Chart for Pitching Seam Operation for a 40-ton/hr System

APPENDIX D

EQUIPMENT LISTS

A. INTRODUCTION

The analysis which discussed the text of this report was oriented toward particular coal deposits and the conditions which exist in these reserves. Two sets of conditions were considered in the evaluation of the borehole mining method — thick, flat lying seams and steeply pitching seams. The example selected for thick, flat lying seams was the northwestern portion of the Wyoming Powder River Basin. The Grand Hogback region in Colorado was chosen as the example of a steeply pitching seam. The approach to equipment selection for the flat seam application, with the unique problems created by the selected region, is discussed in Section A. Section B discusses the equipment required to operate on the selected pitching seam.

B. GENERAL SYSTEM DESCRIPTION

The hydraulic borehole mining concept is a method whereby underground coal can be mined remotely from the surface. A small diameter (~15 in.) hole is drilled to the coal seam and casing is installed to protect ground water from contamination and to prevent the hole from caving during the mining operation. The mining device, consisting of a high pressure nozzle and a slurry pumping device, is lowered through the small hole to the coal seam. The high pressure water stream hydraulically erodes the coal from the seam as the device is rotated and lowered producing a coal slurry. This slurry is pumped to the surface for transfer to a pipeline to processing facilities. The resultant mined cavity is generally a cylindrical shape.

The equipment required is:

(1) Drilling rigs to drill the small diameter holes to the coal seam and set the casing in the hole

(2) Smaller rigs with derricks to handle the operation of the mining device. This includes pipe handling and connections, a method of rotating the device and drawworks to suspend the drill string.

(3) Pumps to supply high pressure water to the mining nozzles and medium pressure water for bringing the slurry to the surface. In addition to the pumps, connecting hoses and piping, fluid storage tank, and possibly equipment to separate coal from the slurry fluid would be required.

This concept would be especially useful in applications where current mining technology cannot be used to extract the coal, such as steeply pitched seams. Careful selection of site will probably be necessary to make the concept economically feasible. This is because recent large increases in capital and operating cost of oilfield-type machinery may result in cost-per-ton of coal mined exceeding the current market price. However, it should be noted that the feeling was expressed by various oilfield men that the concept has merit and that with good engineering design and operation planning the borehole mining of coal might become competitive.

C. FLAT SEAM BOREHOLE MINING EQUIPMENT DESCRIPTION

1. Background

The borehole mining concept could be applied to mining horizontal (flat) coal seams located up to 200 ft underground. This technique would be especially applicable to thick coal seams located in the Western United States. Coal located in the Powder River Basin of Wyoming is a good example of a candidate area. The surface of the land is gently rolling, used for cattle grazing. The coal seam dips about 2°, is 30 ft thick and is located about 200 ft below the surface. The advantage of the borehole mining method over conventional strip mining would be minimum disturbance of the surface.

2. Equipment

(a) Drilling the pilot hole: The pilot hole would be a 15-in.-diameter hole drilled about 230 ft deep through surface alluvium, shale and limestone and finally through the coal bed. This hole would be cased to the top of the coal bed with 13-3/8 in. O.D. API grade K-55 pipe.

(b) Pilot hole drilling rig: There are a number of commercially-available drilling rigs which are suitable for the drilling of the pilot holes. Several of these rigs, designed for blasthole drilling, utilize compressed air for removal of debris from the hole while it is being drilled. The depth and size of these holes is larger than normal blastholes (usually 50 ft deep) and therefore a large volume of compressed air is needed. After discussion with several suppliers and drilling contractors, it was concluded that a more economical approach would be to use a lightweight and mud system. Mud would also provide hole control which would help prevent caving in the unconsolidated formations. This would mean that the "standard" compressed air system for blastholes would have to be replaced with a "standard" oilwell mud system; but, considering that a relatively large number of rigs would be required over the 20-yr life of the coal mining operation, custom designed rigs built for the specific area would provide the most economical operations. Manufacturers producing equipment large enough for this job are as follows.

Manufacturer	Model No.	Hole Dia. Range, in.	Approx. Cost,[a] $
Bacyrus-Erie	2400-R	6 – 30	200,000
Gardner-Denver	GD 120	9-7/8 – 17-1/2	715,000
Joy (Robbins Div.)	PR15-E	10-5/8 – 15	N/A (New Product)
Marion Power	M-5	15	800,000
Smith International (Portadrill Div.)	522	7-1/2 – 12	130,000
Challenger Rig & Mfg. Co.	Custom	15	200,000
Chicago Pneumatic	T-8000	12-1/4	300,000

[a]These are cost estimates based upon standard units. Actual cost may differ because of required modifications.

All of the rigs listed except the challenger rig are self-propelled, either on rubber tires or crawler tracks. The Challenger rig consists of standard oilfield-type skid-mounted modules which can be moved by Caterpillar tractor or truck. They can be easily skidded from one location to another provided the terrain is not too rugged. The self-propelled unit can be driven over roughly graded roads. Most are self-leveling and drilling can be accomplished over slopes to about 10°. After analyzing the various units, the skid-mounted unit appeared to be the most economical from the standpoint of initial and operating costs, flexibility, rapid drilling rate. Since it consists of standard oilfield equipment maintenance should be easily accomplished in most locations.

The equipment to drill the 15-in. diameter hole would be divided into 4 modules, each mounted on skids with solid flooring on the bottom. The drill rig skid would be 10 ft wide and 30 ft long providing a stable base which would allow movement without lowering the 45-ft-high derrick. A second skid of about the same dimensions would contain the necessary drill pipe and a supply of hole casing. The third skid would contain the mud pump and diesel engine. Mud would be supplied from a tank mounted on a fourth skid which would be located to supply several holes before moving would be required. The weight of the equipment would allow movement to locations with a Caterpillar tractor and it was recommended that the rig and pipe skids be moved together. The specifications are:

i. Drilling Rig: Mounted on mud boat-type skids using 18-in. WF beam as main skids, flooring bottom with 1/2 in. plate. Rig to be mounted on 12 in. WF beam with legs to skid. Floor area to be 10 ft wide (with wide floor area it will be very easy to winterize entire rig).

GMC-471N series engine with Allison CLT-3341-4 speed powershift transmission driving to right angle drive to drawworks, which will be a Challenger Model M-128. Clutches on drawworks are full air operated 2 plate 16 in., clutch to rotary is 2 plate 11 in. full air. Rotary table is heavy duty with 18 in. opening which is large enough to pass 15 in. bits. Casing slips are available to run casing through table.

Derrick will be a Challenger 45 ft clear height and equipped with kelly guide and retract pull down system, hydraulic drive to raise and lower derrick as well as running the pulldown. Kelly will have full 3 in. opening. Both drums on rig will be equipped with 2 sheave blocks making a smoother operation. Catheads will be installed to manually make up and break out pipe. (Automatic equipment is available at additional cost.) The estimated price for a complete package ready to drill will be approximately $115,000.

ii. The drill pipe and casing skid as proposed will be approximately $13,500.

iii. The mud pump package proposed will have a Gardner-Denver pump 7-1/2 in. x 8 in. powered by 471 GMC diesel engine (pump will be controlled from drillers position on rig). Price will vary some depending on length of pressure hose (this is so pump will not have to be moved to drill 3 to 6 wells). Estimated price: $37,500.

iv. The mud storage tank would be skid mounted with dimensions of 10 ft long, 8 ft wide and 6 ft high. Estimated price is $10,000.

v. Miscellaneous equipment including 200 ft of 5-1/2 in. OD drill pipe slips, elevators, hoses, derrick lighting, winterizing rig floor, etc., is $34,000. Total price for pilot hole drilling system is $210,000.

3. Pilot Hole Drilling Operations

a. Preparations. Depending upon the topography, a pad may have to be prepared to set the drilling rig. A minimum of grading and surface preparation work should be required because of the skid-mounted units. Water and access roads will have to be provided as well as parking and storage facilities. Personnel sanitary facilities and a typical oilfield "dog-house" will be required. A sketch of a typical drill site is shown on Figure D-1. It is intended that up to six holes be drilled in one site to reduce moving and setup costs. The holes will be drilled on approximately 50-ft centers.

b. Rig Moving. The initial setup will involve delivery of all equipment by truck to the site, locating the units, "rigging up" the drill rig, plumbing hookup. Subsequent moves in that immediate area

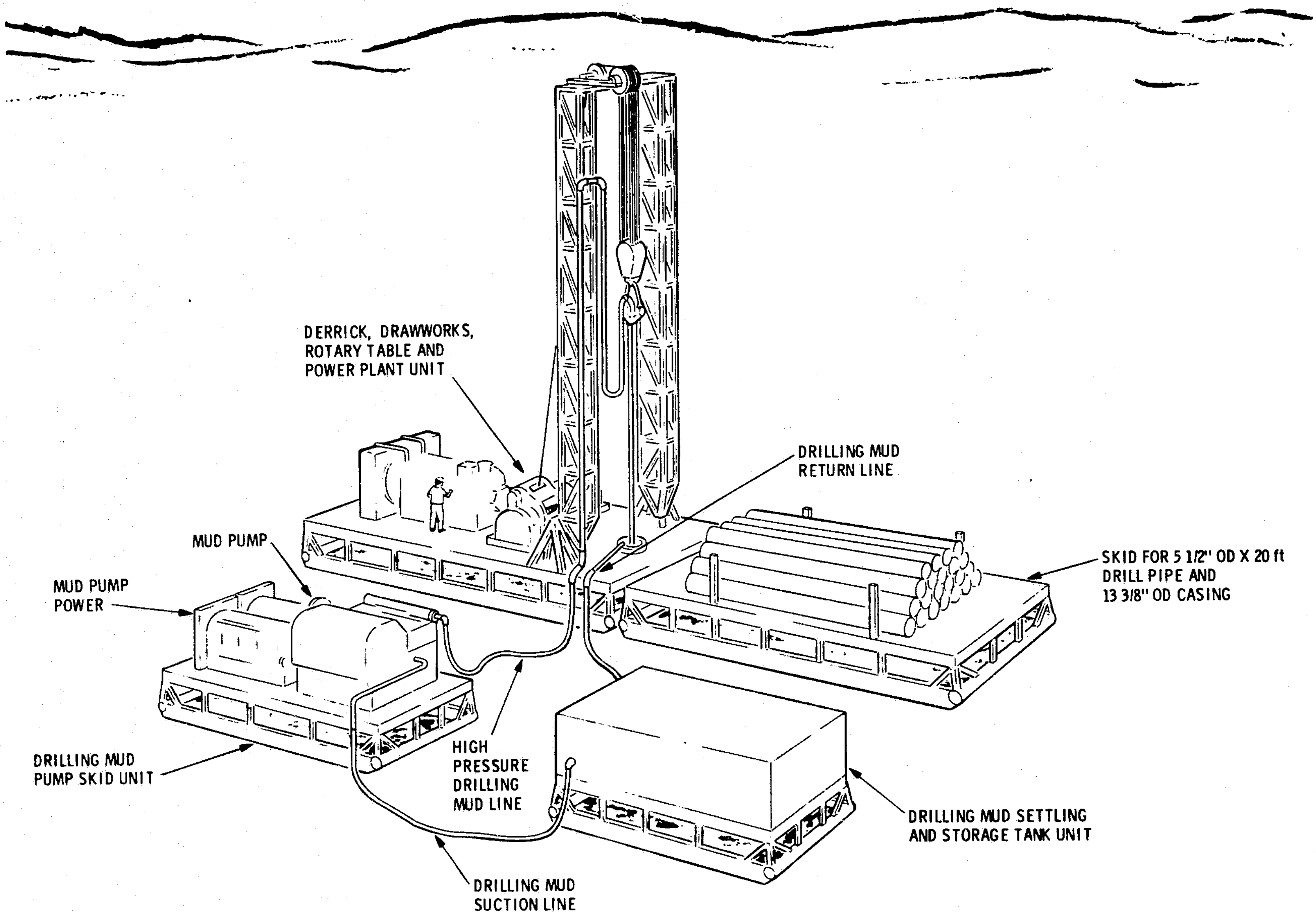


Figure D-1. Borehole Drilling System (Flat Coal Seam) would involve only drill rig and pipe carrying skids using a "Caterpillar" for sliding the units. Such "skidding" can be continued until distance or terrain requires truck movement. Initial setup could require 1-2 days and the skidding operation would require 8 to 12 hr. Both operations would require about 5 to 6 men.

c. <u>Drilling and Casing</u> - The actual drilling operation could require 3 men working 12 hr with 4 to 5 men working about 4 to 8 hr to place the casing in the hole and pump the cement in place. (As soon as the cement is in place the rig can be moved.)

4. Hydraulic Mining Operation

a. <u>Assumptions</u>:

1) 40 tons/hr mining rate

2) Horizontal coal seam, 30 ft thick, under 200 ft of overburden

3) The hydraulic device can mine a circular area 25 ft in diameter.

4) The hydraulic device is 12 in. O.D. requiring two water supplies of gpm at 710 psi for slurry jet pump operation.

5) The hydraulic device is lowered into the pilot hole using 20-ft-long sections of pipe. The pipe has conduits for fluid supply and slurry return. This drilling string is suspended in a small "workover"-type oilfield drill rig having necessary equipment to handle pipe and rotate the mining device at approximately 1 rpm.

6) Fluid requirements would be supplied by separate pumping units. A reserve tank would be provided.

b. <u>Mining Rig</u>: Small truck-mounted drilling rigs would be satisfactory for this operation. However, standard blasthole units are not especially suited because they are supplied with fluid pumps which do not have sufficient capacity for the mining operation and the fluid requirements are large so the necessary pumping units cannot be mounted on the same rig truck. It is therefore recommended that a special skid mounted rig be designed as follows:

1) Rig to rotate tools for coal recovery. This unit will be mounted on a mud skid for ease in moving. Rig will have the Challenger 128 drawworks, 471 GMC with Allison transmission, hydraulic system to raise derrick and also to rotate power sub.

- Derrick will be 45 ft with double block arrangement
- Kelly retract to retract tool while making a connection
- Provisions to make up and break 9-in. pipe

- Spider and slips to set pipe to make up and break out
- One set 9-5/8 elevators
- Two traveling blocks for four-line string up
- One Challenger power sub special built with 9-5/8 pipe quill, rotating speed 1 to 5 rpm to rotate mining tool
- All unitized on skid with equipment as listed but does not include special swivel, pipe or mining tool
- Cost of rig as listed would be approximately $68,000
- Hoses, rig winterizing, miscellaneous equipment: $30,000

Total for complete rig is approximately $98,000.

c. Fluid Pumps: In order to arrive at an accurate cost estimate for pumps, power units, and associated equipment, Mid-Continent Supply was contacted regarding their engineering solution to this fluid problem. This company is a major supplier of equipment to the petroleum industry as well as owner of a major drilling contracting company (Loffland Brothers Co.). They have recommended three separate skid mounted units which they feel would be easy to slide from location to location.

1) High Pressure Mining Pump:

- Gardner-Denver PZ-8 Triplex Single Acting Pump, 6-1/4 in. maximum bore, 8 in. stroke, 750 maximum input hp at 165 rpm of pump. Complete with pistons, liners, and all standard accessories.
- Required hp for 200 gpm at 4500 lb: 583 hp.
- Gardner-Denver 5 in. x 6 in. centrifugal charging pump assembly, V-belt driven from jackshaft of PZ-8 with Koomey suction dampener, low press safety relief valve and piping of centrifugal discharge to suction of PZ-8. Weight 1200 lb.
- Hydril Model K-10-5000 pulsation dampener, 10-gal capacity, 5000 lb WP with 4 in. 5000 lb bottom connection.

Furnish three-runner oilfield-type master skid for pump and engine with oiltight chain case, bearing mounted layshaft with 1-1/2 in. pitch quintuple roller chain and sprockets, Fawick clutch and assemble with above as one unit.

Subtotal: $120,899.00

- One Caterpillar Model D379 turbocharged after-cooled, Series B diesel industrial engine, four cycle, V-8, 6.25 in. bore × 8 in. stroke, counter-clockwise rotation (as viewed from flywheel end) including accessories.

  Subtotal: $46,113.00

  Total Price, High Pressure Mining Pump: $167,012.

  Approximate dimensions of complete unit: length - 27 ft, width - 10 ft (skid 8 ft), height - 9 ft.
  Total weight: 48,138 lb.

2) <u>Low Pressure Jet Pump Fluid Supply Pump:</u>

- Gardner-Denver Model PZ-7 Triplex Single Acting Pump, 7 in. maximum bore, 7 in. stroke, 550 maximum input HP at 165 rpm of pump. Complete with pistons, liners, and all other standard accessories.

  Required hp for 400 gpm at 710 lb psi: 184 hp.

- Gardner-Denver 5 in. × 6 in. centrifugal charging pump assembly, V-belt driven from jackshaft of PZ-7 with Koomey suction dampener, low press safety relief valve and piping of centrifugal discharge to suction PZ-7.

  Weight 1200 lb.

- Hydril Model K-10-5000 pulsation dampener, 10-gal capacity, 5000-lb WP with 4 in.-5000-lb bottom connection. Weight 950 lb. Furnish three-runner oilfield-type master skid for pump and engine with oiltight chain case, bearing mounted layshaft with 1-1/2 in. pitch quintuple roller chain and sprockets, Fawick clutch and assemble with above as one unit.

  Subtotal: $105,748.00

- One Caterpillar Model 3406 turbocharged after-cooled diesel industrial engine, four-cycle, six-cylinder, 5.4-in. bore-x 6.5-ft stroke, counter-clockwise rotation (as viewed from flywheel end) including accessories and radiator, 4N3016, blower fan, 4N3093, fan drive, 4N6378.

  Subtotal: $14,931.00

  Total price, Low Pressure Jet Pump: $120,679.

  Approximate dimensions: length, 23 ft, width, 10 ft (skid 8 ft), height, 8 ft. Total weight: 35,086 lb.

3) Fluid Storage Tank. Houston Systems slurry pit, 200 bbl capacity, 7 ft wide × 6 ft deep × 28 ft long, mounted on a 30-ft-long two-runner oilfield-type skid, complete with two partitions with bottom gates, cleanout gates, and two slurry pump suction outlets.

Weight: approximately 14,000 lb.

Total: $10,250.00

The cost of the complete system of all three fluid units totals approximately $300,000. The total cost for one borehole hydraulic mining system including mining rig and fluid units is estimated to be $400,000. Figure D-2 illustrates a typical mining site.

D. STEEPLY PITCHING SEAM BOREHOLE MINING EQUIPMENT DESCRIPTION

1. Background

There are many areas in the western United States that contain large coal reserves in seams that are nearly vertical. Examples of such structures are found in the Grand Hogback area of Western Colorado where several coal seams are found having dips of 60° to 90°. The coal is contained in rock formations which outcrop on the edge of the Piceance Basin in the Grand Hogback structure. The conventional mining methods using continuous mining machines, shuttle cars, and rapid conveying equipment cannot be applied easily to such vertical seams. However, the borehole mining concept appears to be suited to this type of coal seam as it can mine the coal by moving down the seam to a depth limited by the head capacity of the downhole pump to lift the slurry up the hole. The equipment used in a borehole system operating in steeply pitching seams is similar to that used in the horizontal seams with some changes required to adapt to different surface topography and to guide the mining device so that it will remain in the coal seam.

2. Equipment

a. Drilling the Pilot Hole. The drill rig used in conventional oilwell drilling is designed primarily to produce a vertical hole. When holes other than vertical are desired, special equipment is utilized. Present practice is to use a mud-driven downhole motor to turn the drill bit while the rest of the drill pipe is used as a conductor for the drilling fluid, to provide a reaction force against the torque developed by the rock bit as it drills, and to orient the drilling direction in the horizontal plane (azimuth). The angle from vertical that is drilled, referred to as inclination, is accomplished by use of an adjustable jointed pipe located near the drill bit. Recent developments in electronic equipment provide surface read-out of the hole direction during drilling and allow corrections to be made without removing the drill string from the hole. A typical example of directional drilling was a well completed in a formation about 4700 ft deep from a drilling location about 10,000 ft away (measured horizontally). This hole was drilled vertically for 100 ft and then deviated at a rate of 5° per 100 ft until a 70° from vertical angle was obtained. Another recent example of state-of-the-art directional drilling was a 6-in.-dia

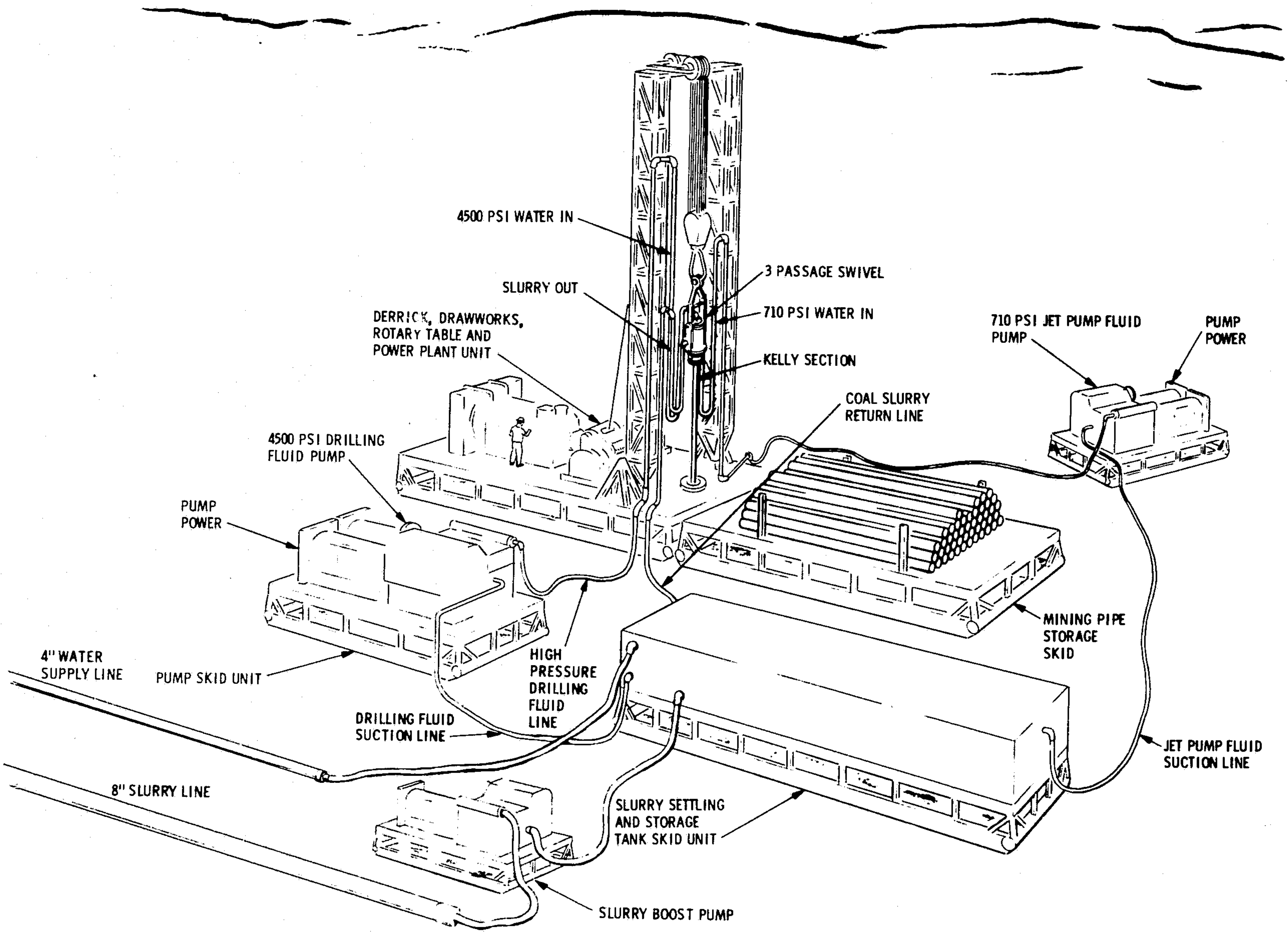


Figure D-2. Borehole Mining System (Flat Coal Seam) horizontal hole 1800 ft long which was drilled using these same directional drilling techniques. Considering the availability of the off-the-shelf equipment, the problem of guiding the drill bit whould be largely solved. Of course, being able to guide the drill does not completely solve the problem of drilling down a coal seam. An accurate method of determining the direction and thickness of the coal seam is also needed. This problem is being addressed and the hardware and techniques will eventually be developed.

In analyzing the borehole mining device applied to pitched seams, only the vertical seam will be considered since there will be no R&D breakthrough necessary to assure a feasible system.

3. Pilot Hole Drilling Rig

a. <u>Assumptions</u>:

- Since the vertical seams usually occur in very rugged mountainous regions the drill rig should be mounted on a truck. This would allow relatively easy movement from one drilling site to another although a road would be needed.
- The rig should be capable of drilling a 15-in.-dia hole to 300 ft deep in a vertical coal seam 30-ft thick which outcrops at the surface.
- The top 50 ft of the pilot hole would be cased with 13-3/8 in. O.D. pipe to prevent caving at the top while mining operations continue on down the hole for up to 250 ft.
- Drilling would be done with water or water-mud drilling fluid to prevent caving, and to carry the cuttings up the hole. Flow rates, mud tank capacities would be similar to the equipment used for the flat seam.

b. <u>Drill Rig</u>. Drilling rigs similar to the requirements for this job are manufactured by the companies listed in part C-2 of this Appendix. Since most of the units are for drilling blast holes, they utilize air compressors. These units could possibly be modified by removing compressors and installing mud pumps, but a survey of the manufacturers has indicated only mild interest in this modificaiton. A unit such as Bucyrus-Erie Model 2400-R is already fitted to do fluid rotary drilling and is a good example of the type of unit required. The unit base cost is about $200,000. The following are specifications:

Bucyrus-Erie Model 2400-R Rotary Drill

1) <u>Drill Ratings</u>: Maximum depth (6-in. hole): 2500 ft
Hole size: 6-30 in.
Drill torque: 75,000 in.-lb
Pull down force: 50,000 lb
Hoist force: 65,000 lb

2) Mud Pump: Gardner Denver Model FY-FXD providing 487 gpm at 255 psi

3) Dimensions: (see figure below) Approximately 38 ft long, 12 ft high, 8 ft wide (Mast down)
Weight: 52,000 lb

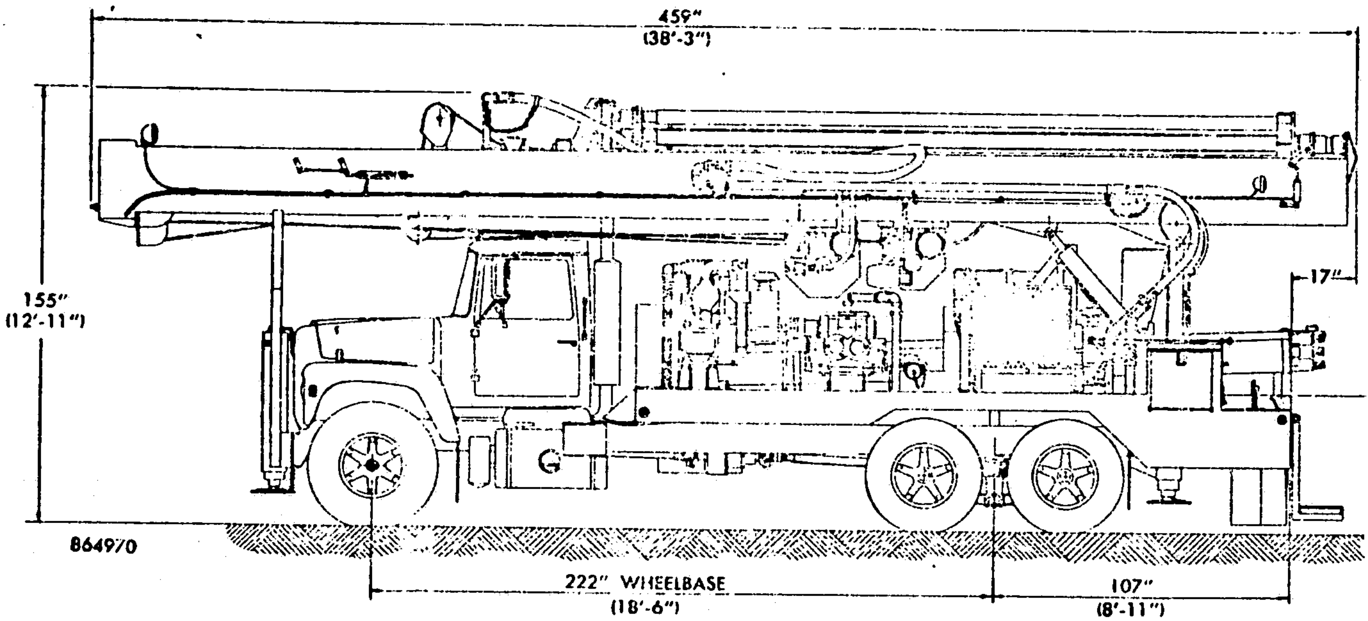


Figure D-3. Bucyrus-Erie Model 2400-R

4) Pipe Rack: A carousel-type rack that holds six 20-ft pipe sections mounts to mast. Rack pivots into position hydraulically. Manual indexing for locating drill pipe. Optional deck-mounted pipe rack holds ten pipe sections (320 ft of pipe total).

5) Controls: Controls located to rear of drill, directly in front of driller's platform. The operator's and helper's platform extends from rear of drill for ease of operation. (Unit normally operated by two men.)

6) Hydraulic Leveling Jacks: One front with 36-in. stroke. Two rear with 26-in. stroke. Cylinders are equipped with double lock valves to prevent drift either up or down. Controls for leveling jacks located at driller's platform. Bubble level is standard.

Figure D-4 illustrates the drill rig in a pitching seam installation.

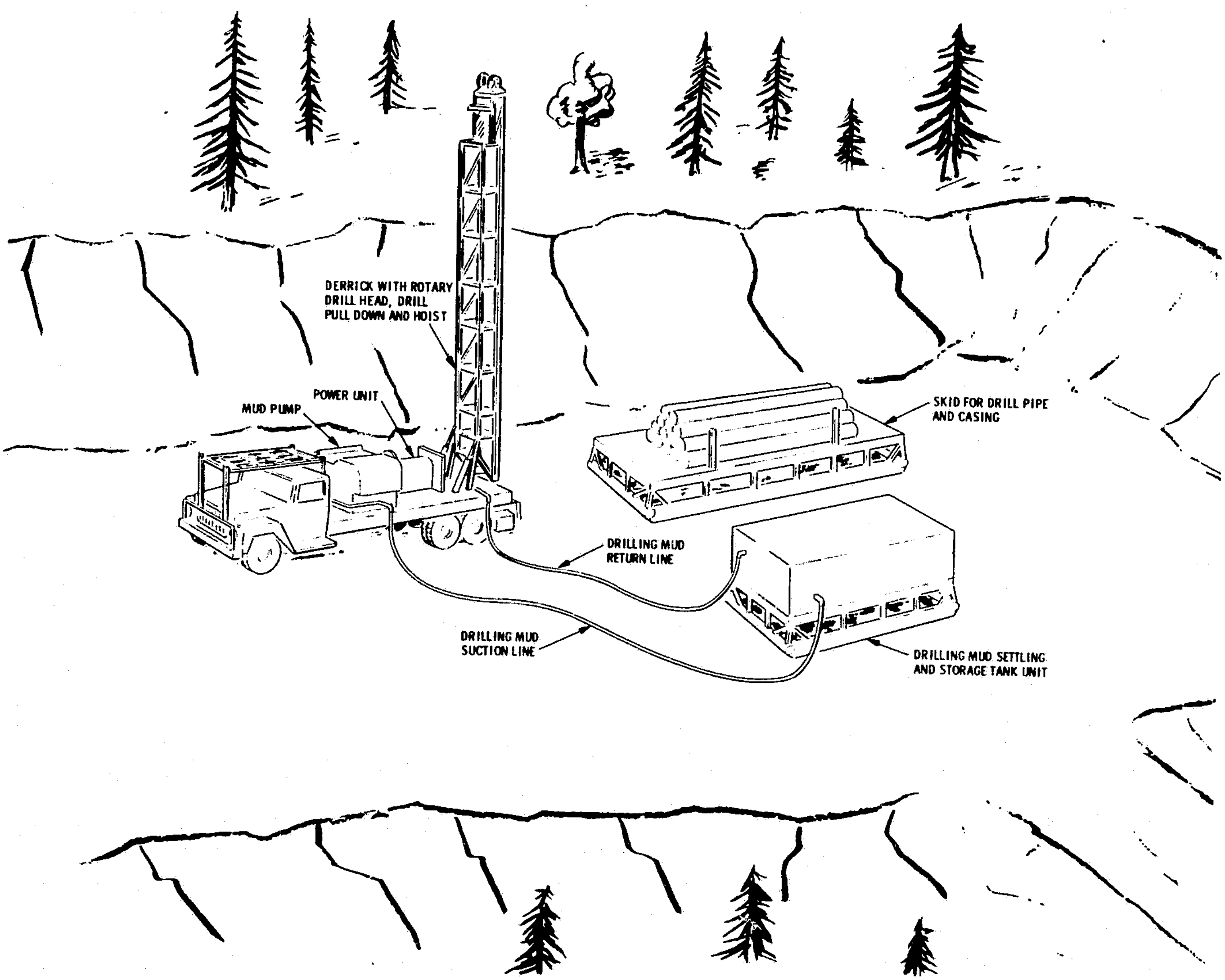


Figure D-4. Drill Rig in a Pitching Seam Installation

3. Hydraulic Mining Operation

a. Assumptions:

1) 40 tons/hr mining rate.

2) Vertical coal seam 30 ft thick, outcropping a surface of ground.

3) The hydraulic device will mine a cavity having a diameter equal to seam thickness starting 50 ft below the surface and continuing to a total depth of 300 ft.

4) The hydraulic device is 12 in. O.D. requiring two water supplies of 200 gpm at 710 psi for slurry jet pump operation.

5) The hydraulic device is lowered into the pilot hole using 20-ft-long sections of pipe. The pipe has conduits for fluid supply and slurry return. This drilling string is suspended in a small "workover"-type oilfield drill rig having necessary equipment to handle pipe and rotate the mining device at approximately 1 rpm.

6) Fluid requirements would be supplied by separate pumping units. A reserve tank would be provided.

b. Mining Rig: Small, truck-mounted drilling rigs referred to as workover rigs in the oilfield industry would be suitable for the operation of the hydraulic mining tool. The rig should be capable of supporting approximately 40,000 lb which is the estimated weight of the hydraulic mining tool, pipe, and swivel joint. An example of a suitable unit is manufactured by Bucyrus-Erie, Model 12-RH.

Specifications:

1) Overall dimensions: Length — mast lowered: 32 ft, 9 in.
Height — mast lowered: 11 ft, 4 in.
Width: 8 ft

2) Mast (with truck): Overall height-mast raised: 40 ft
Working height above rotary table: 31 ft, 8 in.
Mast capacity: 40,000 lb

3) Mounting: Selection of various makes of approved trucks available; also will mount on truck furnished by the purchaser that meets required capacities and minimum specifications.

4) 12-R Top Drive Machine Top Drive Unit:

(1) Oil bath spur gear type

(2) Driven by four low speed high torque hydraulic motors

(3) Rotary speeds 0-80 rpm

(4) Torque range to 43,000 in. lb

(5) Variable volume piston hydraulic pump supplies oil to gear case motors

5) Pipe Rack: Capacity — 10 lengths, 2-3/8 in. shouldered or 3-1/2 in. flush O.D. drill pipe

6) Leveling Jacks: Quick-setting triple hydraulic leveling jacks or dual screw-type jacks available.

7) Cost: Approximately $80,000 as equipped above, including truck.

Some modifications to the standard unit will no doubt be necessary to provide efficient handling and operation of the hydraulic mining tool.

c. The high pressure mining pump and low pressure jet supply pump would be similar to those used in the flat seam operation but would be truck-mounted which would add about $100,000 total to the estimated cost for a total of $500,000 for each mining rig. The fluid storage tank would be skid-mounted but could be easily moved by truck or "Cat" when empty.

Figure D-5 illustrates the mining equipment as it would operate in a pitching seam installation.

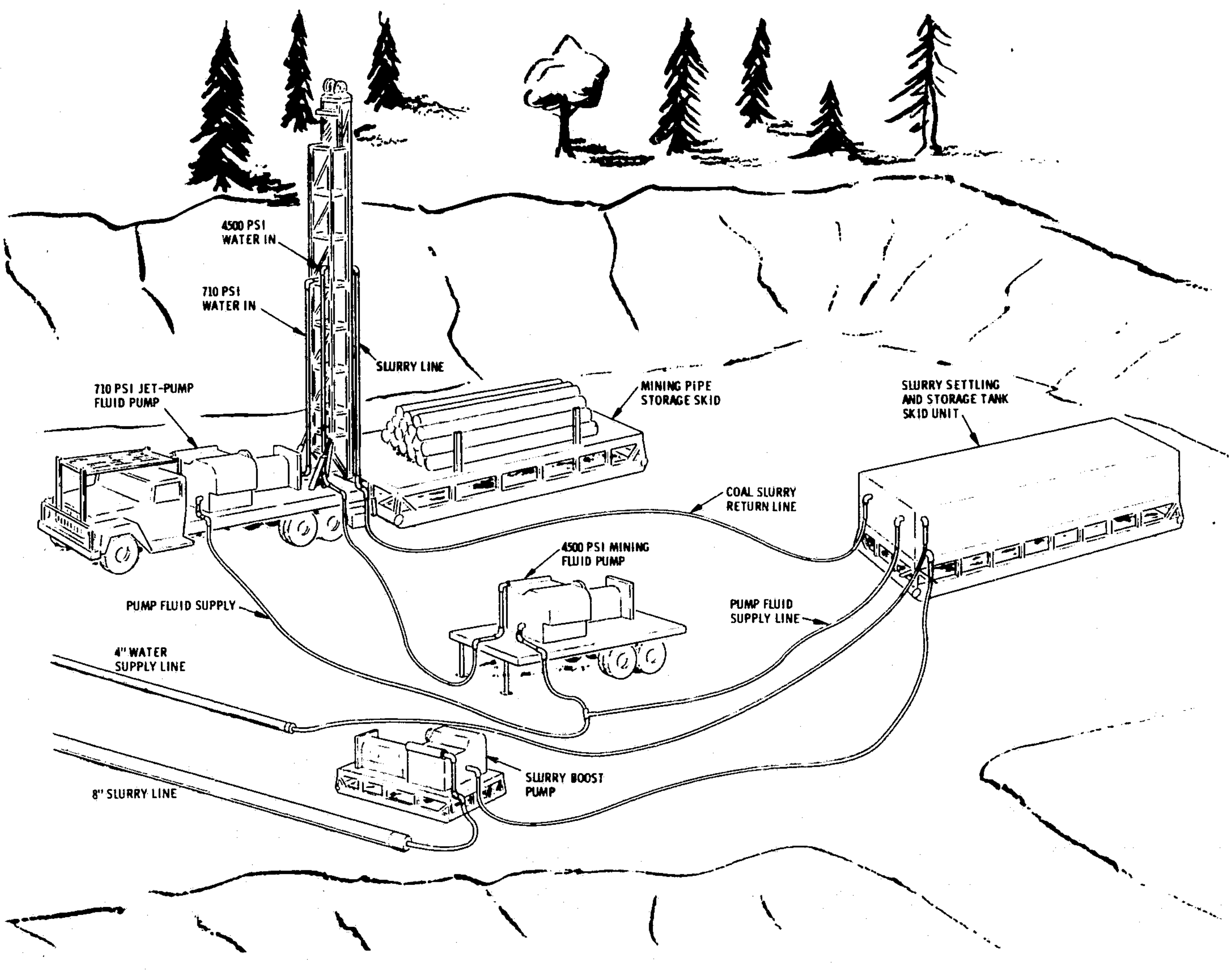


Figure D-5. Mining Equipment as it Would Operate in a Pitching Seam Installation

APPENDIX E

ECONOMIC ANALYSIS
- Method and Results -

PRODUCTION/COST ANALYSIS FOR 2.64 mm-tons/yr HYDRAULIC BOREHOLE COAL MINING SYSTEMS FOR FLAT AND PITCHING SEAMS

A. INPUTS AND OUTPUTS

Based on the inputs from the members of the analysis team in the form of costs or charges pertaining to:

- Field equipment
- Other capital equipment
- Operating supplies
- Land acquisition
- Reclamation
- Labor and supervision
- Depreciation

The following outputs are generated using the present value analysis computer program COCOST (see Reference E-1):

- Selling price
- Annual sales
- Annualized cash flow
- Depletion allowance
- Gross profit
- Taxable income
- Federal income tax
- Annual net profit

Furthermore, sensitivity analysis has been carried out for variations with respect to the following parameters:

- Mining rate
- Discounted cash flow rate of return
- Field equipment cost
- Manpower

- Seam thickness
- Overburden thickness
- Other parameters such as cost of operating supplies, etc.

B. ASSUMPTIONS AND METHODOLOGY

The basic assumptions and methodology of the first version of the cost analysis program are generally similar to those employed in a series of information circulars issued by the United States Bureau of Mines (Refs E2-E4) based on widely accepted principles of capital budgeting and engineering economics.

1. Assumptions

The basic assumptions are:

(1) The start-up transient in production is neglected, i.e. there is no extended development.

(2) The mine operates 3 shifts per day, 220 days per year and has a 20-yr life.

(3) The mine operates at full capacity throughout its life.

(4) The cost of acquisition of land is $2500/acre.

(5) The reclamation cost of the land is $5000/acre and 20% of the cost occurs in the final year while the rest spreads evenly throughout the other years.

(6) Inflation in various costs is not addressed by the model.

(7) The computation of depreciation is based on a straight-line rule and the economic life of each item of plant and equipment is equal to its service life.

(8) The depletion allowance is a constant fraction f_ℓ of the annual sales in the model; f_ℓ has been set equal to 0.1 in the computations.

(9) The federal income tax is a constant fraction f_t of the taxable income which is the annual gross profit reduced by the depletion allowance; f_t has been set to the value 0.5.

(10) State, local taxes and insurance amount to 2% of the mine cost which is the net estimate of the initial capital investments reduced by interest during development.

(11) The contingency cost in the initial capital investment is 10% of the total cost of construction, engineering, overhead and administration.

(12) The payroll overhead is 40% of payroll while the indirect cost is 15% of labor, supervision and operating supplies.

(13) The union welfare payments are computed with a portion being proportional to the tonnage, and the rest, to the hours worked, in accordance with the current Bituminous Wage Agreement.

2. Methodology

First of all, the aggregate of the present values of all capital investments occurring at different times of the mine life is obtained, which includes initial capital equipment, construction, land acquisition, working capital and interim equipment replacement, etc. With a desired discounted cash flow rate of return, the annual cash flow, which consists of net profit, depletion and depreciation, can be calculated. Assuming depletion allowance to be a constant fraction of the sales and the Federal Income Tax to be a constant fraction of the taxable income, and keeping the selling price and annual operating cost constant, the annual sales are determined by the following relationship (Ref. E-1).

Annual sales

$$= \frac{(1 - \text{tax fraction}) \times \text{operating cost} + \text{cash flow} - \text{depreciation}}{1 - \text{tax fraction} + \text{tax fraction} \times \text{depletion fraction}}$$

The selling price is simply the annual sales divided by the annual tonnage capacity. The present analysis has been carried out for the nominal conditions as well as for various conditions that deviate from the nominal ones so that a sensitivity analysis can be performed.

C. NOMINAL CASE

The following nominal conditions are assumed for the flat seam:

- 2.64 million tons of coal per year
- 200 ft overburden
- 30 ft seam thickness
- 87.3 lb/ft^3 for coal density
- 30% coal by weight for slurry density
- 532 gpm per hole for water flow rate
- 4106 holes per year
- 1860 acres of coal field
- 40 tons per hour mining rate

- 25-ft borehole diameter
- 20-year lifetime of mine
- 50% recovery factor
- 731 persons working
- 15% discounted cash flow rate of return

Table E-1 gives the capital investments and costs incurred in the 2.64-mm-tons/yr borehold mining system for nominal conditions. A pro forma profit and loss statement is presented in Table E-2, while the outputs of the computer program which gives the year-by-year discounted cash flow and the summary of the outputs of the cost analysis are included in the appendix.

Figure E-1 shows the breakdown of the computed selling price for a DCF rate of return of 15% for the nominal case. The direct cost amounts to slightly more than half of the selling price. Approximately half of the direct cost is attributed to the cost of the operating supplies, while labor-related costs such as labor and supervision, payroll overhead and union welfare payments make up almost all of the rest of the direct cost. The high cost of the operating supplies can be traced back primarily to the cost of casing for the boreholes and, secondarily, to the diesel fuel supply cost. The annualized cash flow per ton consisting of the depletion allowance, the depreciation charge and the net profit reflects the cost of money and is approximately one-fourth of the selling price.

D. SENSITIVITY ANALYSIS

The selling price of coal for a desired DCF rate of return is dependent on various parameters such as the seam thickness, mining rate, field equipment cost, labor-related costs, etc. How does the selling price respond to the change of each individual parameter? Knowing the trend and magnitude of variation will enable the mine operator to rank the importance of the parameters and to select those options which will lower the selling price for a desired rate of return. Based on the inputs from various members of the Coal Team, a number of cases have been studied and are displayed in Table E-3 for flat seams where the selling price determined from the present value analysis from the COCOST program for three DCF rates of return is given.

1. Flat Seams

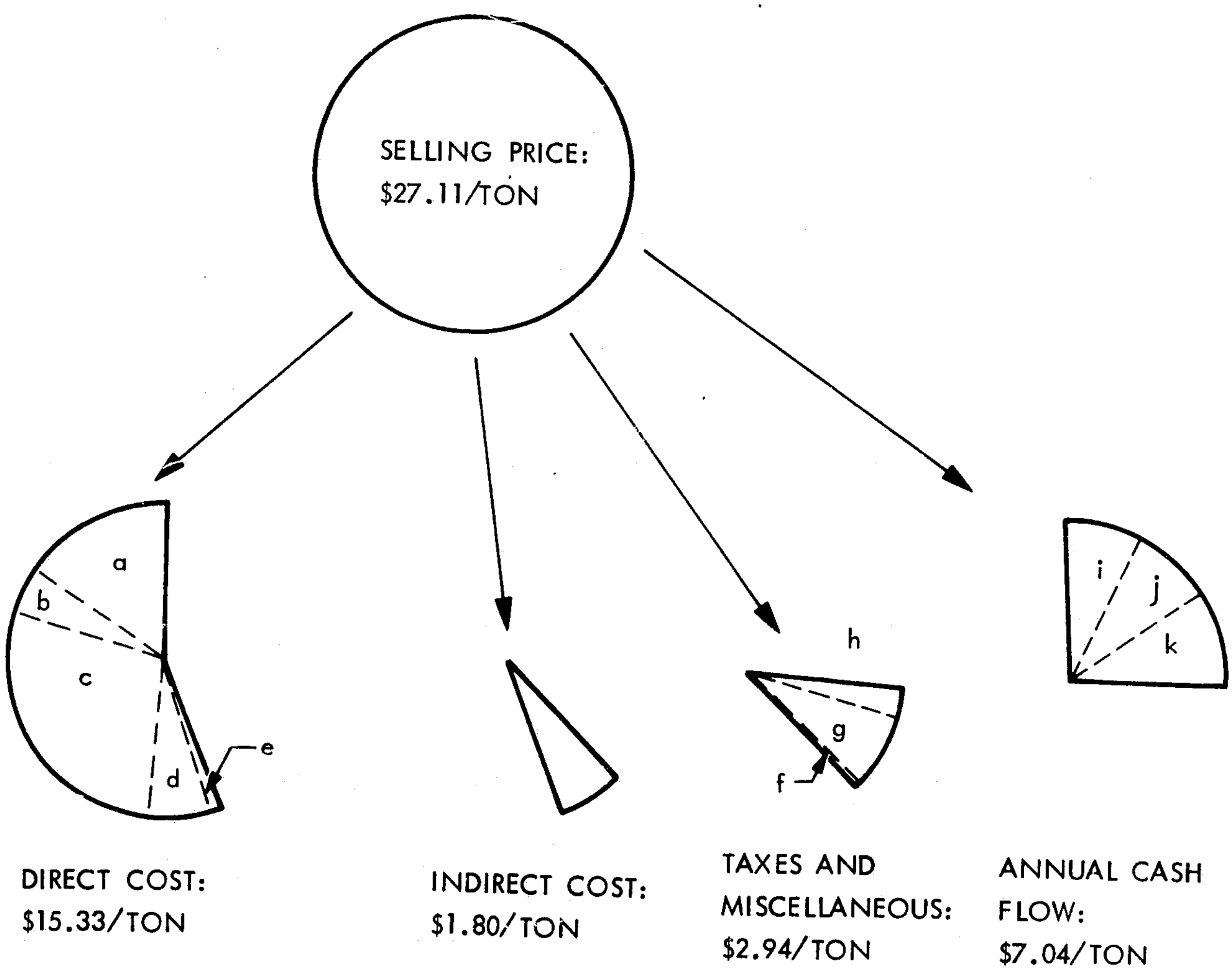
a. Mining rate. From Figure E-2, for a fixed seam thickness of 30 ft and fixed overburden thickness of 200 ft, the selling price decreases as the mining rate increases from 14 ton/hr to around 50 ton/hr.

Table E-1. Capital Investments and Costs Incurred in Borehole Mining System for Nominal Conditions

Capital Investments	Dollars
Field equipment	45,240,000
Other capital equipment	22,807,800
Total direct	68,047,800
Field indirect	1,361,000
Total construction	69,408,800
Engineering	1,388,200
Overhead and administration	3,470,400
Contingency	7,426,700
Fee	1,633,900
Estimated development cost	7,000,000
Interest during development	4,516,400
Gross estimate	94,844,400
Land acquisition at $2,500/acre	4,650,000
Net estimate	99,494,400
Estimated working capital	11,103,600
Estimated initial capital investment	110,598,000
Estimated deferred capital investment	24,693,400
Estimated initial and deferred capital investment	135,291,400
Annual depreciation	
Field equipment	2,982,000
Other capital equipment	1,207,800
Interim equipment replacement	447,300
All other depreciation	1,339,800
Total annual depreciation	5,976,900
Annual operating cost	
Labor and supervision	11,210,100
Power and water	618,800
Operating supplies	20,482,000
Payroll overhead	4,484,100
Union welfare fund	3,666,100
Indirect cost	4,753,800
Taxes and insurance	1,899,600
Depreciation	5,976,900
Reclamation cost	391,600
Total annual operating cost	53,483,000

Table E-2. Pro Forma Profit and Loss Statement for 2.64-mm tons/yr Borehole Mining System for Nominal Conditions

		$(000's)		$/Ton		Percent
Annual Sales:		71,583.4		27.11		100.0
Less Other Costs						
Direct Cost:		40,461.1		15.33		56.5
Labor and supervision	11,210.1		4.25		15.7	
Payroll overhead	4,484.1		1.70		6.3	
Union welfare	3,666.1		1.39		5.1	
Oper. supplies	20,482.0		7.76		28.6	
Power and water	618.8		0.23		0.8	
Indirect Cost:		4,753.8		1.80		6.6
Taxes and Miscellaneous:		7,762.2		2.94		10.9
Local tax and insurance	1,899.6		0.72		2.7	
Federal tax	5,471.0		2.07		7.6	
Annual reclamation cost	391.6		0.15		0.6	
Subtotal		52,977.1		20.07		74.0
Annual Cash Flow:		18,606.3		7.04		26.0
Depletion	7,158.3		2.71		10.0	
Depreciation	5,976.9		2.26		8.3	
Net profit	5,471.1		2.07		7.7	
		71,583.4		27.11		100.0



a = LABOR AND SUPERVISION
b = UNION WELFARE
c = OPERATING SUPPLIES
d = PAYROLL OVERHEAD
e = POWER AND WATER
f = ANNUAL RECLAMATION COST
g = FEDERAL TAX
h = LOCAL TAX AND INSURANCE
i = NET PROFIT
j = DEPRECIATION
k = DEPLETION

Figure E-1. Breakdown of Selling Price of Coal for 15% DCF Rate of Return

Table E-3. Case Description Table (Flat Seams)

Mining Rate, Tons/hr	Seam Thickness, ft	Borehole Diameter, ft	Overburden Thickness, ft	Selling Price $/Ton DCF Rate of Return 20%	15%	10%	Comments
14	30	25	200	36.39	32.42	28.73	
40	30	25	200	30.56	27.11	23.88	Nominal Case
40	60	25	200	19.23	16.88	14.70	Effects of Seam Thickness
40	90	25	200	16.35	14.26	12.31	
40	30	25	200	28.63	25.65	22.88	- 25% Field Equipment Cost
40	30	25	200	26.66	24.13	21.77	- 50% Field Equipment Cost
40	30	25	200	28.87	25.48	22.33	- 25% Manpower
40	30	25	200	27.23	23.88	20.76	- 50% Manpower
40	30	25	200	28.35	24.99	21.85	- 25% Supplies Cost
40	30	25	200	26.11	22.79	19.70	- 50% Supplies Cost
40	30	25	100	21.7	19.07	16.63	Effects of Overburden Thickness
40	30	25	300	36.61	32.82	29.28	
100	30	25	200	31.06	27.56	24.30	Effects of Seam Thickness
100	60	25	200	20.63	18.04	15.61	
100	90	25	200	17.21	15.03	13.00	
100	120	25	200	15.49	13.49	11.63	
100	30	100	200	12.08	10.31	8.67	Borehole Diameter Effect

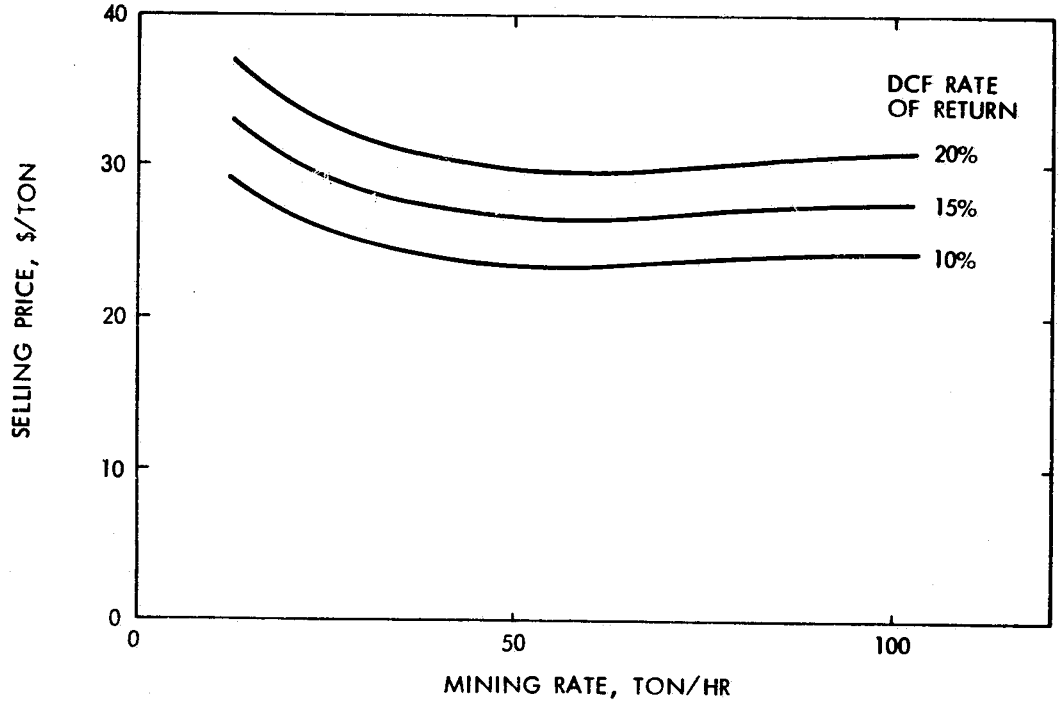


Figure E-2. Selling Price as a Function of Mining Rate (30-ft Seam, 200-ft Overburden, 50% Recovery)

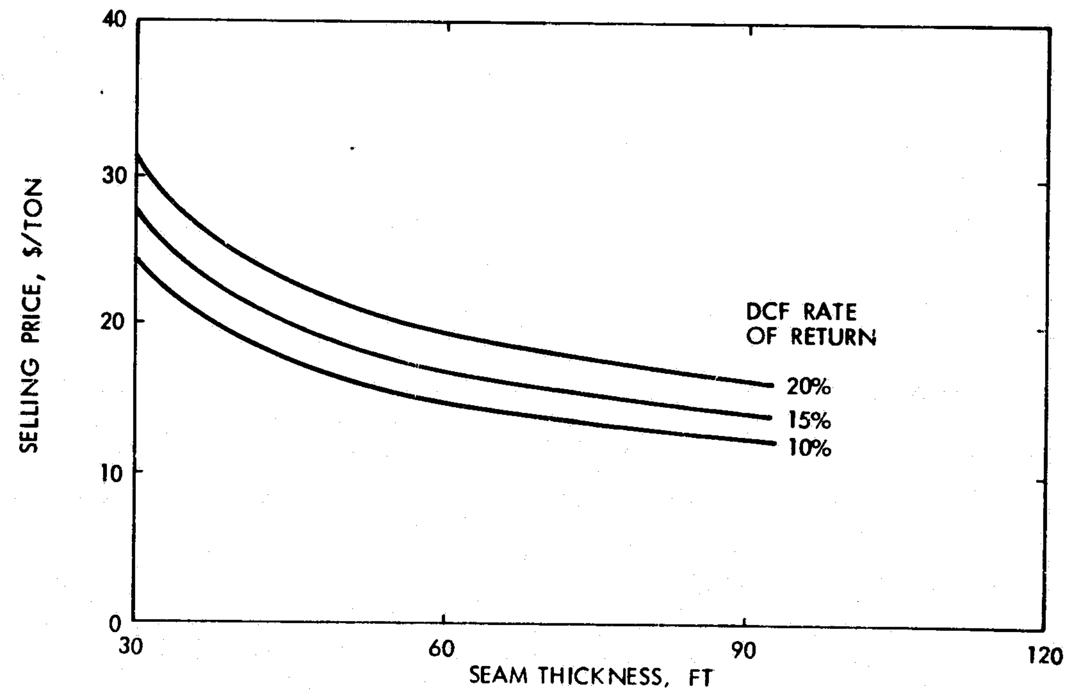


Figure E-3. Selling Price as a Function of Seam Thickness (40 tons/hr, 200-ft Overburden)

Somewhat beyond 50 tons/hr of mining rate, the selling price actually increases slightly due to an increase in equipment and supplies cost which more than offsets the decrease in labor costs.

b. Seam Thickness. From Figure E-3, at a mining rate of 40 ton/hr and a fixed overburden thickness of 200 ft, the selling price decreases as the seam thickness increases. The decrease is less rapid as the seam thickness increases. For example, at 15% rate of return, the selling price drops 38% from the nominal as the seam thickness increases from 30 ft to 60 ft while a further increase of seam thickness from 60 ft to 90 ft causes the selling price to drop a further 10% from the nominal. At a higher mining rate of 100 ton/hr as shown in Figure E-4, the trend is similar to that for 40 ton/hr.

c. Overburden Thickness. The selling price increases as the overburden thickness increases (Figure E-5), as expected. At 15% rate of return and mining rate of 40 ton/hr, increasing the overburden thickness by 100 ft from the nominal causes an increase in selling price of 21%, while decreasing it by 100 ft from the nominal causes a drop in selling price of 30%.

d. Field Equipment Cost. Figure E-6 shows the response of the selling price due to hypothetical reduction in the field equipment cost. The decrease in selling price is 11% from the nominal at 15% rate of return and for a 50% reduction in the field equipment cost from the nominal.

e. Manpower. The sensitivity of the selling price to the manpower reduction is similar to that pertaining to the field equipment cost. The decrease in selling price is 12% for a 50% reduction in manpower at 15% rate of return, as shown in Figure E-7.

f. Operating Supplies Cost. The selling price is slightly more sensitive to the operating supplies cost than to the previous two items. The corresponding decrease in selling price for 50% reduction in annual operating supplies cost is 16% (Figure E-8).

2. Pitching Seams

Three cases of pitching seams have been studies so far, as listed in Table E-4. The first case with a depth of 500 ft measure along the pitching seam represents a rather deep hole. A more realistic hole depth would be 250 ft as in the third case for the Wheeler pitched seam in Colorado. Figure E-9 shows the selling price for the three cases as a function of the DCF rate of return.

E. DISCUSSIONS

Results of the production/cost analysis for a 2.64 mm-ton/yr hydraulic borehole mining system have been presented. The trend and behavior of the estimated selling price for flat seams as a function

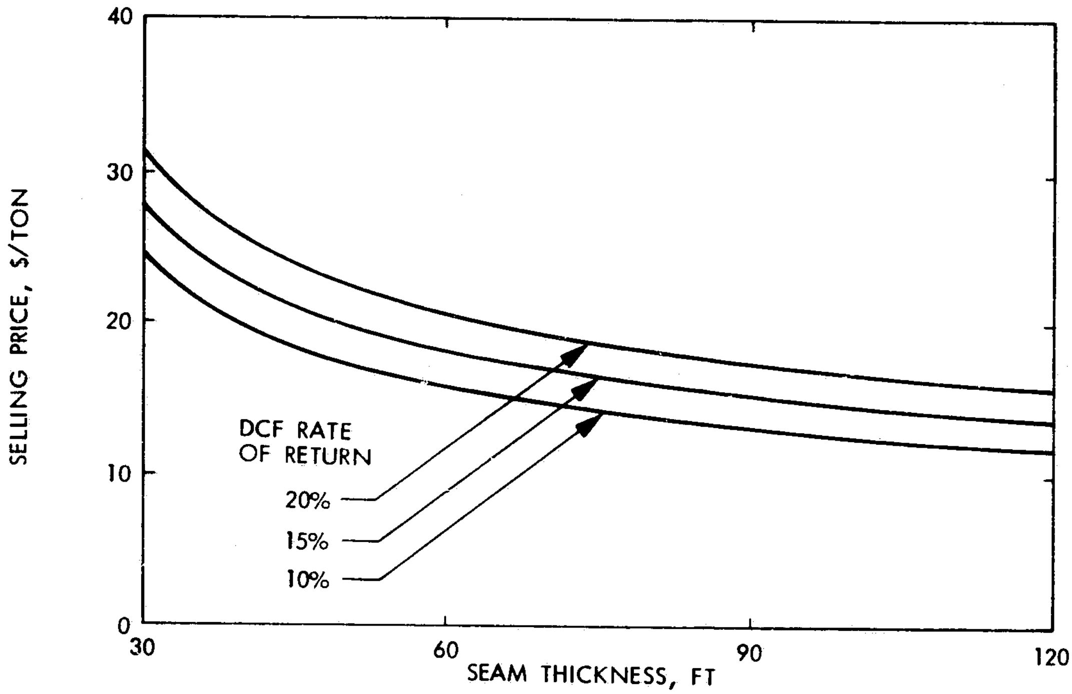


Figure E-4. Selling Price as a Function of Seam Thickness (100 tons/hr, 200-ft Overburden)

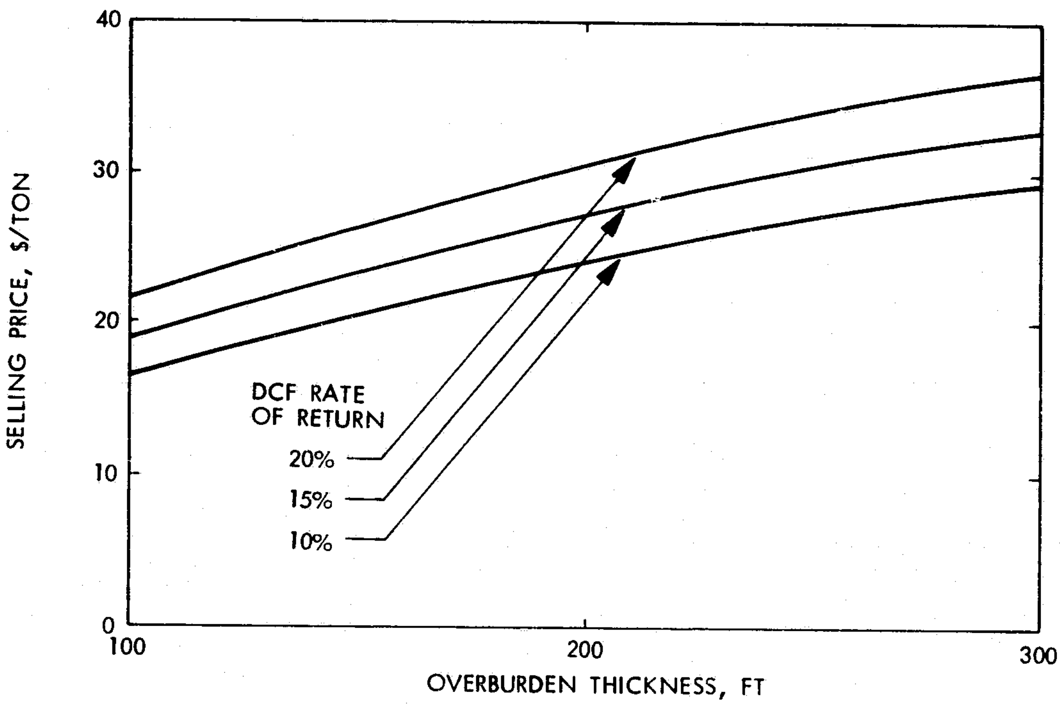


Figure E-5. Selling Price as a Function of Overburden Thickness (40 tons/hr, 30-ft Seam)

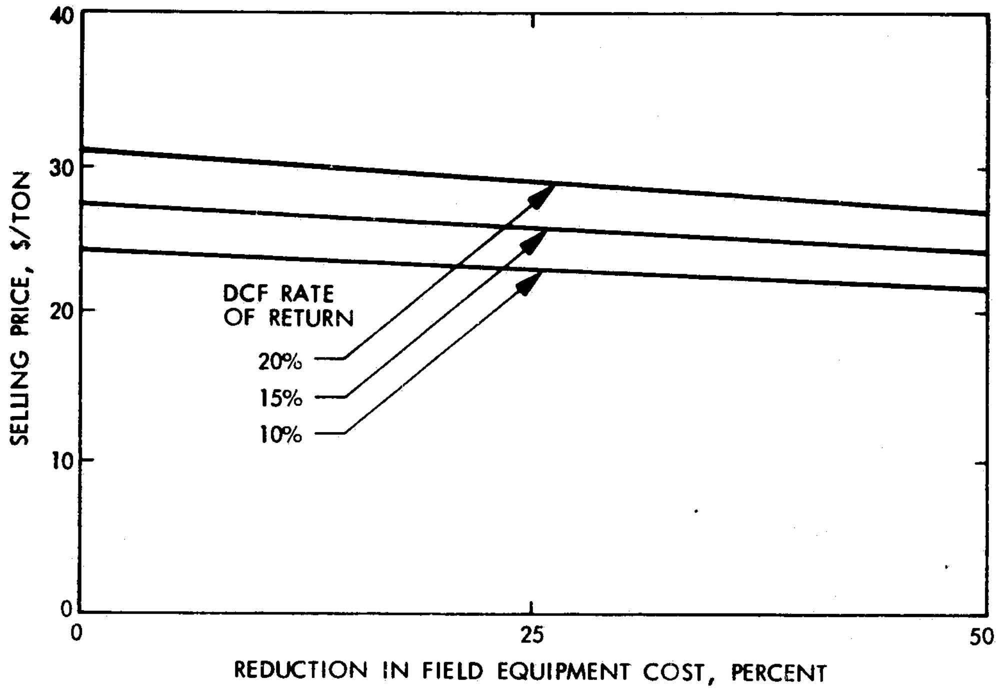


Figure E-6. Sensitivity to Reduction in Field Equipment Cost (40 tons/hr, 30-ft Seam, 200-ft Overburden)

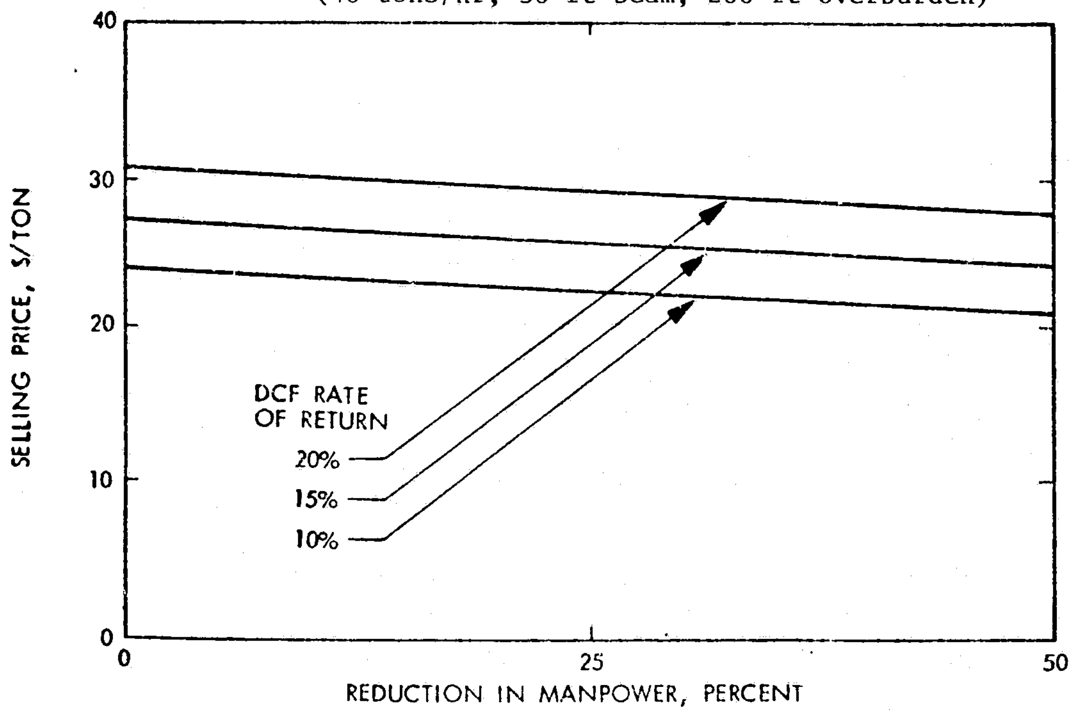


Figure E-7. Sensitivity to Reduction in Manpower (40 tons/hr, 30-ft Seam, 200-ft Overburden)

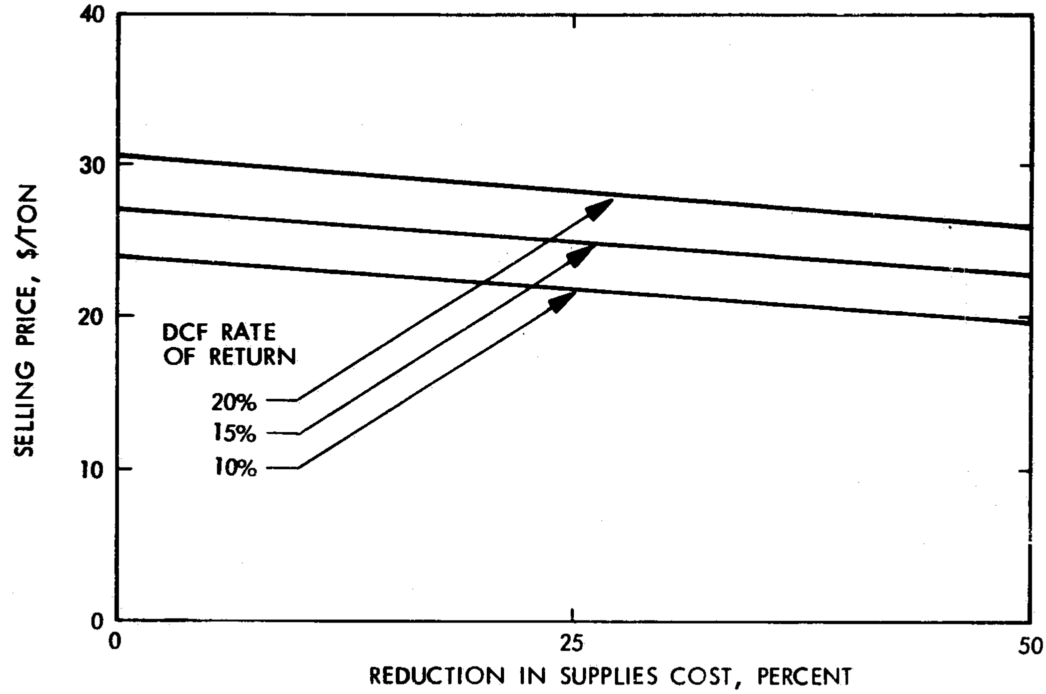


Figure E-8. Sensitivity to Reduction in Operating Supplies Cost (40 tons/hr, 30-ft Seam, 200-ft Overburden)

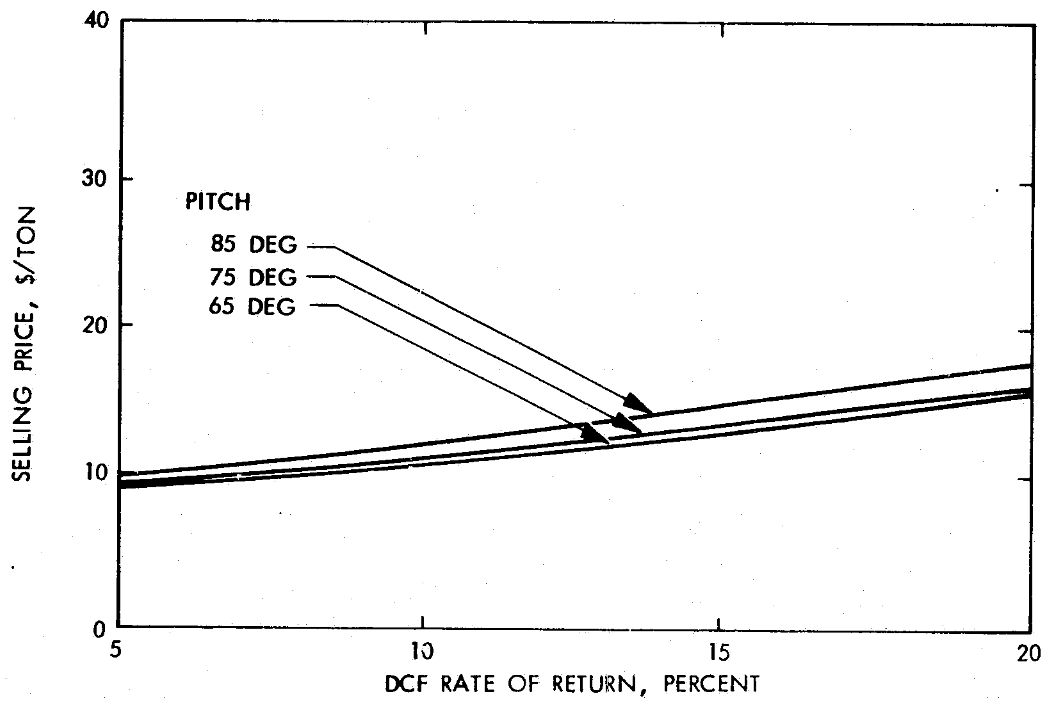


Figure E-9. Selling Price as a Function of Rate of Return for Three Cases of Pitching Seams

Table E-4. Case Description Table (Pitching Seams)

Pitch, deg	Mining Rate, ton/hr	Borehole Diameter, ft	Borehole[a] Depth, ft	Overburden Thickness, ft	Selling Price $/Ton DCF Rate of Return		
					20%	15%	10%
65	40	25	500	0	15.50	13.09	10.86
75	40	30	300	30	15.92	13.45	11.16
85	40	30	250	50	17.59	14.74	12.09

[a]Measured along the pitching seam.

of individual variables should be interpreted with considerations of technical and economic feasibility. To give examples, a reduction of 50% in the cost of the operating supplies or field equipment may not be economically feasible, the mining rate of 100 tons/hr does not appear technically feasible and is not economically desirable, and a small overburden thickness will have to include mine stripping as a competitor to the borehole mining system. Based on the sensitivity analysis results, a mine operator planning the borehole mining system on a flat seam ought to work with a thick seam, a mining rate of around 50 tons/hr (if technically feasible), an overburden which is as thin as possible but not so thin as to compete with strip mining and, as a first step of economizing, should look for ways of cutting down the operating supplies cost. For the three cases of pitching seams which have been studied, the results compare favorably with flat seams — the selling price is about half that of the nominal case. The economic viability of the system will depend on the quality of coal that is extracted. Our next effort will be to carry out more thorough studies on the pitching seams.

REFERENCES

E-1. Poon, P., "Computer Program for Present Value Analysis on Advanced Coal Extraction Systems: First Version," IOM 3530-76-028, JPL Internal Document, Oct. 6, 1976

E-2. Katell, S., Hemingway, E. L., and Berkshire, L. H., "Basic Estimated Investment and Operating Costs for Underground Bituminous Coal Mines: Mines with Annual Production of 1.03 to 3.09 Million Tons from a 48 Inch Coalbed," U.S. Bureau of Mines, Information Circular 8689, 1975.

E-3. Katell, S., Hemingway, E. L., and Berkshire, L. H., "Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines: Mines and Annual Production of 1.06 to 4.99 Million Tons from a 72-Inch Coalbed," U.S. Bureau of Mines, Information Circular 8682, 1975.

E-4. Duda, J. R., and Hemingway, E. L., "Basic Estimated Capital Investment and Operating Costs for Underground Bituminous Coal Mines Developed for Longwall Mining: Mines with Annual Production of 1.32 and 2.64 Million Tons by Longwall Mining from a 48 Inch Coalbed," U.S. Bureau of Mines Draft Information Circular, 1976.

APPENDIX F

ENVIRONMENTAL ANALYSIS

A. ENVIRONMENTAL IMPACT ANALYSIS

The environmental analysis for the borehole mining system involved the investigation of the environmental elements, the legislation regulating environmental protection, and the associated costs. The following text details the areas of concern for borehole mining the thick flat coal seams of the Wyoming Powder River Basin, and for a representative pitching seam situation. Costs are detailed for each restoration item, assuming the most costly situation when the required action is not well defined.

1. Flat Seam

Part of the analysis of the proposed borehole coal extraction system is an environmental evaluation. Not a complete environmental impact statement, only the primary environmental impacts are considered. The following reclamation plan suggests methods by which these impacts may be mitigated.

The primary environmental impact of the borehole coal extraction system is subsidence. In Wyoming, subsidence has occurred in abandoned underground mines at Sheridan and Rock Springs. Operations are under way attempting to halt all further subsidence at Rock Springs by employing a backfilling method. So far this method has met with success. However, the regulatory agencies which have authority over coal mine development in Wyoming are very wary of issuing mining permits to operations which will cause further subsidence.

The borehole coal extraction system also necessitates the use of 2 billion gal of water. In Buffalo, there are only 10 to 14 in. of precipitation a year. The coal seam itself is the best aquifer, and a well produces water at the rate of 1 to 7 gal/min. The possibility exists of depleting Buffalo's water reserve by utilizing the borehole system here.

Although water treatment is traditionally considered a reclamation activity, in this study water treatment is included in the analysis of the mine system itself. Because of short supply, water used in the mining process will be treated and recycled through the system via a water treatment plant. This mitigates the potential water pollution problem.

The Wyoming Environmental Quality Act of 1973 states that reclamation shall begin on mined land within 30 days after mining operations have ceased, unless the operator intends to further utilize the mine. The borehole system utilizes 465-acre parcels of land every 5 yr. Once all the coal extractable by the borehole method is mined out of one section, the mining operation moves to the next 465-acre parcel. The result is that 465 acres must be reclaimed every 5 yr. Operations and structures affected by the necessity to reclaim the land in 5-yr intervals are drainage ditches, pipeline removal, road removal, fencing, regrading and revegetation.

a. Debris Basin and Drainage Ditches. The Buffalo, Wyoming area only receives 10 to 14 in. of rainfall a year making a complex drainage and storage system for runoff water unnecessary. One 11,111 yd^3 debris basin will be constructed with an earthen outflow flume. The basin will cost $17,000 to construct and the outflow flume, $14,000.00.[1] These costs will occur during the year of mine site development before mining begins. Removal of the debris basin and outflow flume will cost $8,000 and $7,000, respectively. Removal will occur in the year of deactivation after mining operations have ceased.[2]

Twenty drainage ditches are required, altogether equalling a length of 10 mi. The dimensions of the ditches are 3 ft by 4 ft. Drainage ditches will be constructed and removed every 5 years as the mining operation progresses. The cost of ditch construction is $8,800 and its removal $4,400.

b. Waste Pile Removal. It is estimated that the borehole coal extraction system will generate 264,000 tons of waste shale and sandstone a year. At a cost of 80¢ per yd^3 moved 2,000 ft or less, removal of this waste material will cost $179,000 a year. For every additional 1,000 ft the material is moved, the cost increases 15¢/yd^3.[3]

c. Backfill. The borehole coal extraction system is limited to coal seams no deeper than 300 ft. The overburden in the Buffalo area is composed of sandstones, shales and clay and will collapse over excavated coal seams, causing subsidence on the surface. The strength of the overburden is undetermined as is the length of time between coal extraction and roof collapse. Backfilling should occur soon after mining is complete, therefore the costs of backfilling will occur yearly.

Backfilling underground mines is a fairly new technology. Hydraulic backfill has been demonstrated in Scranton, Pennsylvania and more recently in Rock Springs, Wyoming. Cost estimates for these operations include the costs of site preparation, water wells, backfill material, pipeline, injection boreholes, mixing plant, site restoration and some miscellaneous costs such as electricity, fuel usage and equipment maintenance. Most of these costs are included in the borehole coal extraction system itself. Their inclusion under backfill costs would portray a higher reclamation cost than that which actually exists.

In Rock Springs, Wyoming, sand was used as the backfill material. Mr. Gary J. Colaizzi of the Bureau of Mines in Denver indicated the

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[1] The cost of moving earth is $1.50/$yd^3$ according to Mr. Barratta of the Green Construction Company near Lake DeSmet, Wyoming.

[2] Mr. Barratta, Green Construction Company-removal cost equals approximately half the cost of construction.

[3] Mr. Barratta, Green Construction Company.

price per ton of backfill was $3.48. In Scranton, Pennsylvania crushed mine waste was used for backfill. There are several advantages to using mine waste for backfill. The mine waste piles are disposed of, the potential air and water pollution from exposed mine wastes are eliminated, as well as the fire hazard. The cost of the total backfill operation including mine waste crushing was $4.80/yd^3. In Buffalo, Wyoming, the site of the borehole mining method, there are no sand and gravel deposits available for use as backfill; therefore, crushed mine waste will be the backfill material here also.

To avoid double counting costs included in the coal extraction system itself and to account for the fact that the number of capital expenditures will decrease over the 20-yr mine life, backfill costs in this analysis will be $2.00/ton or $2.36/yd^3. The yearly cost of backfill using 2,640,000 tons a year is $5,300,000. The total cost of backfill over the entire life of the mine is $106,000,000.

d. Removal of Pipeline. The mining system will require 15,000 ft of pipeline. At $100/day/man[4] working 10 man-years, the cost of pipeline removal is $140,000. Pipeline will be installed as the mining operation progresses, and will be removed every 5 yr as it is left behind.

e. Removal of Roads. The mining process requires 16 mi of two-lane all weather road. Wyoming law defines a mining operation as including all routes of ingress and egress, therefore the removal of roads is included in this reclamation plan. As the mining operation moves, the roads which service each section must be reclaimed. The cost of removing sections of the required 16-mi road every 5 yr is $120,000. This allows $30,000/mi.[5]

f. Removal of Buildings. There will be five buildings to house the water treatment plant, the coal processing plant, office building and crew house, warehouse and shop and a backfill mixing plant. At $5,000 per building[6] for removal, the total cost of removing all buildings will be $25,000. These buildings are necessary throughout the whole life of the project and will not be removed until the deactivation year.

g. Fencing. The Wyoming Environmental Quality Act of 1973 requires that all areas disturbed by mining operations be fenced to prevent danger to the surface owner of the land. This requires approximately 18,000 ft of "cattle" fence at 80¢/ft[7] every 5 yr. Total cost

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[4]Mr. Barratta, Green Construction Company.

[5]Bill Mabe, Jet Propulsion Laboratory

[6-9]Mr. Baratta, Green Construction Company.

for fencing will be $57,600. Fence removal will cost $28,800. In addition 500 yd of chain link fence is required at $8.00/ft, or $12,000. Removal of this fence will cost $6,000. These costs will be incurred in 5-yr intervals.

h. Regrading to Natural Contours. It is required by Wyoming law that the land be returned to its "highest previous use," after a mining operation. The borehole coal extraction system will not have the effect on the land that strip mining does, however, it will still constitute a major disturbance. To comply with the law, the entire area must be regraded upon complete removal of all mining equipment and support faciliteis. The nature of this mining method requires regrading of a 465-acre area every 5 yr. The cost of regrading 465 acres at $400/acre is $186,000.

i. Revegetation. The final step in reclaiming mined land is revegetation. The borehole system will cause soil compaction and disturbance but does not involve the removal of topsoil. Once the mine area has been regraded, the land is ready for revegetation. Don Bailey the plant ecologist with the Land Division of the Wyoming Department of Environmental Quality described revegetation in Wyoming as consisting of these activities.[10]

Activity	Price	Cost per acre
Straw mulch (2 tons per acre)	$30-35 a ton	$ 60
Fertilizer (30 pounds per acre)	$176 a ton	$ 26.4
Seeds	$20-30 per acre	$ 25
Seeding	$10 per acre	$ 10
Weed control	$5 per acre	$ 5
		$126.4

The cost of revegetation every 5 yr on 465 acres is $59,000.

A 15% contingency fund was included in the total cost of reclamation for unexpected expenditures. A factor which has not been included in this evaluation is the effect the weather could have on operations. Buffalo, Wyoming receives snow in the winter, ans its effect on the borehole coal extraction system as well as on reclamation activities is undetermined.

The total cost of reclamation over 20 yr is $127,650,000. These costs are all in 1976 dollars and the total cost is a summation of cash flows (Figure F-1). A present value analysis was done using several escalation and discount rates (Figure F-2).

[10]Don Bailey, Plant Ecologist-Lands Division of the Wyoming Department of Environmental Quality.

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Reclamation Cost Pro
Coal Extr

F

Year 0

Life Cycle Stage		Development	PRO									
Years		0	1	2	3	4	5	6	7	8	9	10
Reclamation Activities	Debris Basins and Outflow Flume	31,000	0	0	0	0	0	0	0	0	0	0
	Drainage Ditches	8,800	0	0	0	0	13,200	0	0	0	0	13,2
	Waste Pile Removal	0	179,000	179,000	179,000	179,000	179,000	179,000	179,000	179,000	179,000	179,0
	Backfill	0	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,0
	Removal of Pipelines	0	0	0	0	0	35,000	0	0	0	0	35,0
	Removal of Roads	0	0	0	0	0	120,000	0	0	0	0	120,0
	Removal of Buildings	0	0	0	0	0	0	0	0	0	0	0
	Fencing Chain Link	12,000	0	0	0	0	0	0	0	0	0	0
	"Cattle Fence"	14,400	0	0	0	0	21,600	0	0	0	0	21,6
	Regrading Entire Area	0	0	0	0	0	186,000	0	0	0	0	186,0
	Revegetation	0	0	0	0	0	59,000	0	0	0	0	59,0
	Sub Total											
	15% Contingency Fund											
	Annual Totals	66,200	5,479,000	5,479,000	5,479,000	5,479,000	5,913,300	5,479,000	5,479,000	5,479,000	5,479,000	5,913,

FOLDOUT FRAME 2

Reclamation Cost Projection for the Borehole Coal Extraction System

Flat Seam

Year 0 Nominal Dollars

PRODUCTION													Deactivation	Total Action Cost
8	9	10	11	12	13	14	15	16	17	18	19	20	21	Summation of Cash Flows
0	0	0	0	0	0	0	0	0	0	0	0	0	15,000	46,000
0	0	13,200	0	0	0	0	13,200	0	0	0	0	0	4,400	52,800
79,000	179,000	179,000	179,000	179,000	179,000	179,000	179,000	179,000	179,000	179,000	179,000	179,000	0	3,580,000
00,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	0	106,000,000
0	0	35,000	0	0	0	0	35,000	0	0	0	0	35,000	0	140,000
0	0	120,000	0	0	0	0	120,000	0	0	0	0	0	120,000	480,000
0	0	0	0	0	0	0	0	0	0	0	0	0	25,000	25,000
0	0	0	0	0	0	0	0	0	0	0	0	0	6,000	18,000
0	0	21,600	0	0	0	0	21,600	0	0	0	0	0	7,200	86,400
0	0	186,000	0	0	0	0	186,000	0	0	0	0	0	186,000	744,000
0	0	59,000	0	0	0	0	59,000	0	0	0	0	0	59,000	236,000
														111,000,000
														16,650,000
9,000	5,479,000	5,913,800	5,479,000	5,479,000	5,479,000	5,479,000	5,913,800	5,479,000	5,479,000	5,479,000	5,479,000	5,514,000	422,600	127,650,000

Figure F-1. Reclamation Cost Projection for the Borehole Coal Extraction System, Flat Seam

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- Flat Seam
- Year Zero Dollars

Escalation Rate	0	0.05	0.05	0.05
Discount Rate	0.15	0.10	0.15	0.20
Present Value of Capital Expenditures	35,000,000	71,000,000	49,000,000	36,000,000

Figure F-2. Present Value of Capital Expenditures, Flat Seam

2. Pitched Seam

As well as evaluating the borehole coal extraction system in a flat seam, it was evaluated in a pitched seam. This evaluation was derived in part from a reclamation study of the Tabby Mountain area in Utah. The coal extraction system in the Tabby Mt. study is also a borehole extraction system, but involves the use of a solvent to aid in the fracturing of coal. The coal seam at Tabby Mt. is pitched, and the study included the mitigation of impacts relative to steeply sloping topography, fair amounts of precipitation and the necessity to stockpile topsoil. The system at Tabby Mt. was never evaluated at the level the Buffalo coal extraction method as been; therefore, many of the assumptions made for the Buffalo study will be used in this analysis.

The same overall system requirements were assumed for the pitched seam study as in the Buffalo analysis. During a total mining life of 20 yr, the mining operation itself will move every 5 yr. There will be a year of mine site development before the first year of mining, and a year of deactivation in which mining equipment and support facilities will be removed and the mine site will be returned to a natural state.

a. Topsoil Stockpiling. In the study of Tabby Mt. it was necessary to stockpile topsoil in order to provide an appropriate medium for revegetation. In Utah, the price of moving earth is one dollar a cubic yard.[11] An estimated 25,000 yd^3 of topsoil will be moved a year making the cost of topsoil stockpiling $25,000 a year.

b. Drainage Ditches. The number and capacity of drainage ditches is determined by the amount of precipitation received by the proposed mine site. At Tabby Mt. two ditches are required to hold $696,960 ft^3 of water in 1 hr of rainfall. Their cost will be $1,360,000 or $340,000 every 5 yr. Removal of the ditches is assumed to equal half the construction cost as in the Buffalo analysis.[12] The inclusion of removal cost brings the cost of drainage ditches to $20,400,000.

[11] Ross Construction Company, Utah.
[12] Green Construction Company, Wyoming.

FOLDOUT FRAME 1

Reclamation Cost P
Coal Ex

Pi

Year

Life Cycle Stage	Development										
Years	0	1	2	3	4	5	6	7	8	9	
Reclamation Activities											
Topsoil Stockpiling	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25
Drainage Ditches	340,000	0	0	0	0	5,100,000	0	0	0	0	5,100
Debris Basins and Outflow Flume	825,000	0	0	0	0	1,237,500	0	0	0	0	1,237
Waste Pile Removal	0	264,000	264,000	264,000	264,000	264,000	264,000	264,000	264,000	264,000	264
Backfill	0	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300
Removal of Pipeline	0	0	0	0	0	150,000	0	0	0	0	150
Removal of Roads	0	0	0	0	0	120,000	0	0	0	0	120
Removal of Buildings	0	0	0	0	0	0	0	0	0	0	
Rechanneling Streams	0	0	0	0	0	0	0	0	0	0	
Regrading Area	0	0	0	0	0	4,250,000	0	0	0	0	4,25
Revegetation	0	0	0	0	0	31,000	0	0	0	0	3
Sub Total											
15% Contingency Fund											
Annual Totals	1,190,000	5,589,000	5,589,000	5,589,000	5,589,000	11,837,500	5,589,000	5,589,000	5,589,000	5,589,000	11,

Reclamation Cost Projection for the Borehole Coal Extraction System

Pitched Seam

Year 0 Nominal Dollars

PRODUCTION													Deactivation	Total Action Cost
8	9	10	11	12	13	14	15	16	17	18	19	20	21	Summation of Cash Flows
25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000		0	500,000
0	0	5,100,000	0	0	0	0	5,100,000	0	0	0	0	170,000	0	2,040,000
0	0	1,237,500	0	0	0	0	1,237,500	0	0	0	0	412,500	0	4,950,000
264,000	264,000	264,000	264,000	264,000	264,000	264,000	264,000	264,000	264,000	264,000	264,000	264,000	0	5,280,000
,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	5,300,000	0	106,000,000
0	0	150,000	0	0	0	0	150,000	0	0	0	0	0	150,000	600,000
0	0	120,000	0	0	0	0	120,000	0	0	0	0	0	120,000	480,000
0	0	0	0	0	0	0	0	0	0	0	0	0	250,000	250,000
0	0	0	0	0	0	0	0	0	0	0	0	0	9,600	9,600
0	0	4,250,000	0	0	0	0	4,250,000	0	0	0	0	0	4,250,000	17,000,000
0	0	31,000	0	0	0	0	31,000	0	0	0	0	0	31,000	124,000
														137,000,000
														20,550,000
,589,000	5,589,000	11,887,500	5,589,000	5,589,000	5,589,000	5,589,000	11,887,500	5,589,000	5,589,000	5,589,000	5,589,000	6,146,500	4,585,600	157,550,000

Figure F-3. Reclamation Cost Projection for the Borehole Coal Extraction System, Pitching Seam

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c. Debris Basins. Six debris basins are required, each one requiring the removal of 500,000 yd^3 of earth. An outflow flume is needed for every one at a cost of $5,000. The cost of each basin is $55,000. Removal cost is $165,000, bringing the total cost to $495,000. This cost too will be incurred every 5 yr throughout the 20-yr mine life.

d. Waste Pile Removal. The mining system is estimated to generate 264,000 $tons^3$ of waste material a year. At a cost of $1.00/$yd^3$ to move, the yearly cost associated with mine wastes will be $260,000.

e. Backfill. The cost of backfilling was not included in the study of the Tabby Mt. area. It will be assumed, therefore, that the same amount of backfill will be required at the same price as in the Buffalo study, making the cost of backfill $5,300,000 a year.

f. Removal of Pipeline. Pipeline removal in Utah was estimated to cost $600,000 over 20 yr. The slurry line will be a two-way system involving 34 mi of pipes and will cost $10.00 a yard to remove. The cost of removing the pipeline every 5 yr is $150,000.

g. Removal of Roads. Sixteen miles of two-way all weather road is assumed to be required at the Tabby Mt. site. At a cost of $30,000 a mile to remove, road removal will cost $120,000 every 5 yr.

h. Removal of Buildings. The same number of buildings will be required at the Tabby Mt. site as in Buffalo, a water treatment plant, a coal processing plant, office building and crew house, warehouse and shop, and a backfill mixing plant. At a cost of $5,000 each, total removal cost is $25,000 and will occur in the deactivation year.

i. Rechanneling Streams. The topography and the amount of precipitation in Utah create streams. The Tabby Mt. area includes four streams, which must be rechanneled during mine operation. Upon the completion of all mining, the streams will be returned to their natural beds. This is estimated to cost $9,600.

j. Regrading. In the analysis of Tabby Mt. it was estimated that 1.7 million yd^3 of material need to be moved during regrading. At a cost $1.00/$yd^3$, to return the mine site to its natural contours will cost $17,000,000.

The total cost of reclamation in this analysis is $137,000,000. The cost including a 15% contingency fund is $157,550,000 (Figure F-3).

A present value analysis was done for the pitched seam case as well as the flat seam (Figure F-4).

- Pitched Seam
- Year Zero Dollars

Escalation Rate	0	0.05	0.05	0.05
Discount Rate	0.15	0.10	0.15	0.20
Present Value of Capital Expenditures	42,000,000	86,000,000	59,000,000	44,000,000

Figure F-4. Present Value of Capital Expenditures, Pitched Seam

APPENDIX G

HEALTH AND SAFETY

1. Design Assumptions

The borehole hydraulic mining system gains access to the coal seam through a borehole from the ground surface. A mining device, which contains hydraulic cutting jets and a water jet, coal-slurry pump, is lowered into the borehole to seam height. The hydraulic cutting jets are rotated and cut a circular hole in the coal seam (25-ft diameter) which is made to cover the entire thickness of the seam by slowly lowering the mining device through the seam (average seam thickness assumed to be 30 ft). Coal is extracted at approximately 40 tons/hr by the slurry pump. The coal slurry coming from the borehole enters a boost pump on the surface, is injected into a main slurry line, and transported to a central preparation plant for cleaning and dewatering. To obtain 2.64×10^6 tons of coal per year, 18 boreholes must be mined out each day to a diameter of 25 ft, assuming a seam thickness of 30 ft. This will require 24 drilling rigs and 36 mining rigs to be working in the field at any given time.

2. Health and Safety Design Review

The evaluation methodology, developed previously for health and safety, requires that a group of safety experts be convened to evaluate the mining system's conceptual design and generate a list of "areas of concern" for health and safety issues. A panel was convened for a borehole solvent mining system to generate the evaluation methodology, and was not repeated for this borehole system due to system similarities. Therefore, the "area of concern" list, generated for the borehole solvent mining system, is considered valid if the concerns associated with the solvent are removed, and there are substituted concerns for the check-out of the high velocity water jets. This new list of areas of concern is as follows:

a. Areas of Concern

1) Subsidence of evacuated coal seam under mining rig

2) Stability of the mining and drill rigs while moving over undulating terrain

3) Protection of the operating crew from high velocity water jets

4) Diesel fuel storage and handling

5) Methane gas control and disposal

6) Protection of crew from noise

7) Protection of crew from winter elements and slippery surfaces (road, walkways, hanging icicles)

8) Protection of crew while handling and assembling large, heavy pipe and mining equipment sections

9) Ground support for heavy equipment during wet weather

10) Protection of crew from moving vehicles

11) Electrical hazards

12) Crew safety training

13) Operating crew exposure to SiO_2 dust

14) Medical dispatch and rescue from remote area, especially during bad weather

15) Protection of the crew from abandoned, worked out holes.

This list of concerns are then grouped in accordance with the severity of their occurance.

b. Catastropic Areas of Concern

1) Subsidence of the excavated coal seam under the mining rig.

2) Stability of the mining and drill rigs while moving over undulating terrain.

3) Protection of the operating crew from high velocity water jets during check-out of the hydraulic mining system.

4) Protection of the crew from abandoned worked out holes.

Engineering counter-measures for these concerns must be developed prior to considering this system for further evaluation.

c. Serious Areas of Concern

1) Diesel fuel storage and handling

2) Methane gas control and disposal

3) Protection of the crew from winter elements, and slippery surfaces (roads, walkways, hanging icicles)

4) Crew protection while handling and assembling large heavy pipe and mining equipment sections

These concerns can be resolved during the preliminary design phase, if the system is selected for further design effort.

d. Moderate Areas of Concern

1) Protection of the crew from noise

2) Ground support for heavy equipment during wet weather

3) Protection of crew from moving vehicles

4) Electrical hazards

5) Crew safety training

6) Operating crew exposure to SiO_2 dust

7) Medical dispatch and rescue from remote area, especially during bad weather.

These areas of concern must be provided with proper countermeasures, however, this can occur during the latter stages of the detail design.

Additional evaluation of the hydraulic borehole mining system involves the development of health and safety statistics for comparison with the standard mining system. In this case, the standard mining system is the longwall system. Only one statistic has been developed at this time for the longwall. This is the average severity of lost time accidents in lost time days per accident. The statistic for the longwall system was 24.2 days lost per lost time accident.

Close inspection of the various functions to be accomplished in the borehole mining system reveals that a considerable amount of road building and maintenance is required to gain access to the coal field. This effort can then be compared to road construction as an analog, and the existing health and safety statistics of that industry used to project the statistics for this portion of the borehole mining system.

The remaining borehole mining system functions are: (1) drilling borehole, (2) setting casing, (3) installing and maintaining pipe lines, (4) maintaining equipment, and (5) moving drilling-type equipment. All of these functions are accomplished in the oil well drilling industry, and, again, the health and safety statistics for oil well drilling can be used to project the statistics for the borehole mining system.

To assist in formulating a health and safety statistic for the borehole mining system, the crew manning table was divided into road construction and oil drilling. Then the man-hours per year in each area were determined, and used to calculate the lost time days per lost time accident employing the methods explained in the California State Health and Safety Report.

To determine the same statistic for the borehole hydraulic system, the crew manning table was formulated as follows.

Crew Name	Number of Crew Man-hours	Number of Crews per Shift	Number of Shifts	Total Number of Men	Number of Man-hours Worked/yr
Road Construction Analogy					
1. Site Crew	2	5	2	20	35,200.
2. Survey Crew	4	2	1	8	14,080.
3. Road Maint. Crew	4	2	1	8	14,080.
4. Truck Drivers	11	1	3	33	58,080.
					121,440. Man-hours/yr
Oil Well Drilling Analog					
5. Mining Rig Crew	3	36	3	324	570,240.
6. Drill Crew	2	24	3	144	253,440.
7. Casing Crew	4	5	3	60	105,600.
8. Roving Crew	3	11	3	99	174,240.
9. Pipeline Crew	4	4	3	48	84,480.
10. Maint. Crew	5	4	3	60	105,600.
11. Fueling Crew	1	2	3	6	10,560.
					1,304,160. Man-hours/yr

Data taken from the Occupational Injuries and Illnesses Survey in California, 1974, indicates the following:

Incidence rate is calculated by the following equation:

$I = N/EH \times 200,000$

Where:

N = Number of injuries and/or illnesses, or lost workdays

E = Total hours worked by all employees during the year, and 200,000 = Base for 100 full-time equivalent workers (40 hr/wk, 50 wk/yr)

<u>For Highway and Street Construction Analogy</u>

Lost work day cases = 6.5

Lost work days = 103.1

$6.5 = N/121,440 \times 200,000$

$N = 6.5 \times 121,440/440/200,000 = 4$ lost day cases

and,

$N = 103.1 \times 121,440/200,000 = 62.6$ lost days

<u>For Oil Well Drilling Analogy</u>

Lost work day cases = 22.8

Lost work days = 469.0

$N = 22.8 \times 1,304,160/200,000 = 149$ lost work day cases

and

$N = 469.0 \times 1,304,160/200,000 = 3067$ lost days

$3067 + 62.6/4 + 149 = 3129.6/153$

$= 20.45$ lost days/lost time event

As can be seen, 153 lost time accidents could be expected for an average of 20 days lost per lost time accident. This compares to an average of 24 days lost per lost time accident for the longwall mining system.

The above analysis was made for the borehole mining system in a flat lying seam; however, no additional hazards can be seen if the system is used in a steeply pitched seam. Therefore, this analysis will be satisfactory for the preliminary pitched seam analysis. If additional work is undertaken of the pitched seam system, some differences may come to light in regards to the mobile equipment used in the pitched seam as opposed to the skid-mounted equipment used in the flat seam.

APPENDIX H

PRINTOUTS FROM COCOST COMPUTER PROGRAM

Discounted cash flow outputs form COCOST computer program for two cases of 2.64 mm-ton/gr hydraulic borehole mining system.

Outputs for the other fifteen cases are available from the author.

MINING RATE = 40TPH SEAM THICKNESS = 30FT OVERBURDEN THICKNESS = 200FT

TABLE I SUMMARY OF DISCOUNTED CASH FLOW

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 20.0 PERCENT

YEAR	CAPITAL INVESTMENT $	CASH FLOW $	PRESENT VALUE FACTOR	PRESENT VALUE CAPITAL INVESTMENT $	PRESENT VALUE CASH FLOW $
0	110598000.	-110598000.	1.0000	110598000.	-110598000.
1	447300.	23164925.	.8333	372750.	19304104.
2	447300.	23164925.	.6944	310625.	16086754.
3	447300.	23164925.	.5787	258854.	13405628.
4	447300.	23164925.	.4823	215712.	11171357.
5	618100.	22994125.	.4019	248401.	9240823.
6	447300.	23164925.	.3349	149800.	7757887.
7	447300.	23164925.	.2791	124833.	6464906.
8	447300.	23164925.	.2326	104028.	5387422.
9	447300.	23164925.	.1938	86690.	4489518.
10	15853100.	7759125.	.1615	2560364.	1253142.
11	447300.	23164925.	.1346	60201.	3117721.
12	447300.	23164925.	.1122	50168.	2598101.
13	447300.	23154925.	.0935	41806.	2165084.
14	447300.	23164925.	.0779	34839.	1804237.
15	618100.	22994125.	.0649	40118.	1492445.
16	447300.	23164925.	.0541	24194.	1252942.
17	447300.	23164925.	.0451	20161.	1044118.
18	447300.	23164925.	.0376	16801.	870099.
19	447300.	23164925.	.0313	14001.	725082.
20	-13446200.	37058425.	.0261	-350731.	966634.
				114981613.	2.

ESTIMATED INITIAL CAPITAL INVESTMENT = $ 110598000.

ESTIMATED DEFERRED CAPITAL INVESTMENT = $ 24693400.

ESTIMATED INITIAL AND DEFERRED CAPITAL INVESTMENT = $ 135291400.

TABLE 2 SUMMARY OF OUTPUTS OF COST ANALYSIS

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 20.0 PERCENT

DEPLETION ALLOWANCE = 10.0 PERCENT OF SALES

FEDERAL INCOME TAX = 50.0 PERCENT OF TAXABLE INCOME

SELLING PRICE = $	30.56 PER TON
ANNUAL SALES = $	80685136.
ANNUALIZED CASH FLOW = $	23612225.
ANNUAL OPERATING COST = $	53483000.
DEPLETION ALLOWANCE = $	8068514.
GROSS PROFIT = $	27202136.
TAXABLE INCOME = $	19133622.
FEDERAL INCOME TAX = $	9566811.
ANNUAL NET PROFIT = $	9566811.
DEPRECIATION CHARGE = $	5976900.

MINING RATE = 40TPH SEAM THICKNESS = 30FT OVERBURDEN THICKNESS = 200FT

TABLE 1 SUMMARY OF DISCOUNTED CASH FLOW

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 15.0 PERCENT

YEAR	CAPITAL INVESTMENT $	CASH FLOW $	PRESENT VALUE FACTOR	PRESENT VALUE CAPITAL INVESTMENT $	PRESENT VALUE CASH FLOW $
0	110598000.	-110598000.	1.0000	110598000.	-110598000.
1	447300.	18158982.	.8696	388957.	15790419.
2	447300.	18158982.	.7561	338223.	13730799.
3	447300.	18158982.	.6575	294107.	11939826.
4	447300.	18158982.	.5718	255745.	10382457.
5	618100.	17988182.	.4972	307305.	8943306.
6	447300.	18158982.	.4323	193380.	7850629.
7	447300.	18158982.	.3759	168157.	6826634.
8	447300.	18158982.	.3269	146223.	5936209.
9	447300.	18158982.	.2843	127151.	5161916.
10	15853100.	2753182.	.2472	3918644.	680545.
11	447300.	18158982.	.2149	96144.	3903150.
12	447300.	18158982.	.1869	83604.	3394044.
13	447300.	18158982.	.1625	72699.	2951343.
14	447300.	18158982.	.1413	63216.	2566385.
15	618100.	17988182.	.1229	75961.	2210649.
16	447300.	18158982.	.1069	47801.	1940556.
17	447300.	18158982.	.0929	41566.	1687440.
18	447300.	18158982.	.0808	36144.	1467339.
19	447300.	18158982.	.0703	31430.	1275947.
20	-13446200.	32052482.	.0611	-821567.	1958416.
				116462888.	0.

ESTIMATED INITIAL CAPITAL INVESTMENT = $ 110598000.

ESTIMATED DEFERRED CAPITAL INVESTMENT = $ 24693400.

ESTIMATED INITIAL AND DEFERRED CAPITAL INVESTMENT = $ 135291400.

TABLE 2   SUMMARY OF OUTPUTS OF COST ANALYSIS

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 15.0 PERCENT

DEPLETION ALLOWANCE = 10.0 PERCENT OF SALES

FEDERAL INCOME TAX = 50.0 PERCENT OF TAXABLE INCOME

SELLING PRICE = $	27.11 PER TON
ANNUAL SALES = $	71533422.
ANNUALIZED CASH FLOW = $	18606282.
ANNUAL OPERATING COST = $	53493000.
DEPLETION ALLOWANCE = $	7158342.
GROSS PROFIT = $	18100422.
TAXABLE INCOME = $	10942080.
FEDERAL INCOME TAX = $	5471040.
ANNUAL NET PROFIT = $	5471040.
DEPRECIATION CHARGE = $	5976900.

MINING RATE = 40TPH SEAM THICKNESS = 30FT OVERBURDEN THICKNESS = 200FT

TABLE 1 SUMMARY OF DISCOUNTED CASH FLOW

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 10.0 PERCENT

YEAR	CAPITAL INVESTMENT $	CASH FLOW $	PRESENT VALUE FACTOR	PRESENT VALUE CAPITAL INVESTMENT $	PRESENT VALUE CASH FLOW $
0	110598000.	10598000.	1.0000	110598000.	-110598000.
1	447300.	13463148.	.9091	406636.	12239225.
2	447300.	13463148.	.8264	369669.	11126568.
3	447300.	13463148.	.7513	336063.	10115062.
4	447300.	13463148.	.6830	305512.	9195511.
5	618100.	13292348.	.6209	383791.	8253502.
6	447300.	13463148.	.5645	252489.	7599596.
7	447300.	13463148.	.5132	229536.	6908729.
8	447300.	13463148.	.4665	208669.	6280658.
9	447300.	13463148.	.4241	189699.	5709689.
10	15853100.	-1942652.	.3855	6112057.	-748977.
11	447300.	13463148.	.3505	156776.	4718751.
12	447300.	13463148.	.3186	142524.	4289779.
13	447300.	13463148.	.2897	129567.	3899795.
14	447300.	13463148.	.2633	117788.	3545268.
15	618100.	13292348.	.2394	147968.	3182083.
16	447300.	13463148.	.2176	97346.	2929973.
17	447300.	13463148.	.1978	88496.	2663612.
18	447300.	13463148.	.1799	80451.	2421966.
19	447300.	13463148.	.1635	73137.	2201332.
20	-13446200.	27356647.	.1486	-1998692.	4066392.
				118427480	2.

ESTIMATED INITIAL CAPITAL INVESTMENT = $ 110598000.

ESTIMATED DEFERRED CAPITAL INVESTMENT = $ 24693400.

ESTIMATED INITIAL AND DEFERRED CAPITAL INVESTMENT = $ 135291400.

TABLE 2 SUMMARY OF OUTPUTS OF COST ANALYSIS

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 10.0 PERCENT

DEPLETION ALLOWANCE = 10.0 PERCENT OF SALES

FEDERAL INCOME TAX = 50.0 PERCENT OF TAXABLE INCOME

SELLING PRICE = $	23.88	PER TON
ANNUAL SALES = $	63045541.	
ANNUALIZED CASH FLOW = $	13910448.	
ANNUAL OPERATING COST = $	53483000.	
DEPLETION ALLOWANCE = $	6304554.	
GROSS PROFIT = $	9562541.	
TAXABLE INCOME = $	3257987.	
FEDERAL INCOME TAX = $	1628993.	
ANNUAL NET PROFIT = $	1628993.	
DEPRECIATION CHARGE = $	5976900.	

MINING RATE = 100TPH SEAM THICKNESS = 60FT OVERBURDEN THICKNESS = 200FT

TABLE 1   SUMMARY OF DISCOUNTED CASH FLOW

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 20.0 PERCENT

YEAR	CAPITAL INVESTMENT $	CASH FLOW $	PRESENT VALUE FACTOR	PRESENT VALUE CAPITAL INVESTMENT $	PRESENT VALUE CASH FLOW $
0	81832200.	-81832200.	1.0000	81832200.	-81832200.
1	278700.	16790766.	.8333	232250.	13992305.
2	278700.	16790766.	.6944	193542.	11660254.
3	278700.	16790766.	.5787	161285.	9716879.
4	278700.	16790766.	.4823	134404.	8097399.
5	368600.	16700866.	.4019	148132.	6711704.
6	278700.	16790766.	.3349	93336.	5623194.
7	278700.	16790766.	.2791	77780.	4685995.
8	278700.	16790766.	.2326	64817.	3904996.
9	278700.	16790766.	.1938	54014.	3254163.
10	919600.	16149866.	.1615	148521.	2608294.
11	278700.	16790766.	.1346	37510.	2259836.
12	278700.	16790766.	.1122	31258.	1883196.
13	278700.	16790766.	.0935	26048.	1569330.
14	278700.	16790766.	.0779	21707.	1307775.
15	368600.	16700866.	.0649	23924.	1083978.
16	278700.	16790766.	.0541	15074.	908177.
17	270700.	16790766.	.0451	12562.	756814.
18	278700.	16790766.	.0376	10468.	630679.
19	278700.	16790766.	.0313	8724.	525566.
20	-7913900.	24983366.	.0261	-206427.	651668.
				83121128.	0.

ESTIMATED INITIAL CAPITAL INVESTMENT = $ 81832200.

ESTIMATED DEFERRED CAPITAL INVESTMENT = $ 6394700.

ESTIMATED INITIAL AND DEFERRED CAPITAL INVESTMENT = $ 88226900.

TABLE 2 SUMMARY OF OUTPUTS OF COST ANALYSIS

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 20.0 PERCENT

DEPLETION ALLOWANCE = 10.0 PERCENT OF SALES

FEDERAL INCOME TAX = 50.0 PERCENT OF TAXABLE INCOME

SELLING PRICE = $	20.63 PER TON
ANNUAL SALES = $	54466483.
ANNUALIZED CASH FLOW = $	17069466.
ANNUAL OPERATING COST = $	34434400.
DEPLETION ALLOWANCE = $	5446648.
GROSS PROFIT = $	20032083.
TAXABLE INCOME = $	14585435.
FEDERAL INCOME TAX = $	7292718.
ANNUAL NET PROFIT = $	7292718.
DEPRECIATION CHARGE = $	4330100.

MINING RATE = 100TPH SEAM THICKNESS = 60FT OVERBURDEN THICKNESS = 200FT

TABLE 1 SUMMARY OF DISCOUNTED CASH FLOW

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 15.0 PERCENT

YEAR	CAPITAL INVESTMENT $	CASH FLOW $	PRESENT VALUE FACTOR	PRESENT VALUE CAPITAL INVESTMENT $	PRESENT VALUE CASH FLOW $
0	81832200.	-31832200.	1.0000	81832200.	-81832200.
1	278700.	13027876.	.8696	242348.	11328588.
2	278700.	13027876.	.7561	210737.	9850946.
3	278700.	13027876.	.6575	183250.	8566040.
4	278700.	13027876.	.5718	159348.	7448731.
5	368600.	12937976.	.4972	183259.	6432461.
6	278700.	13027876.	.4323	120490.	5632311.
7	278700.	13027876.	.3759	104774.	4897661.
8	278700.	13027876.	.3269	91108.	4258836.
9	278700.	13027876.	.2843	79224.	3703336.
10	919600.	12386976.	.2472	227311.	3061871.
11	278700.	13027876.	.2149	59905.	2800259.
12	278700.	13027876.	.1869	52091.	2435003.
13	278700.	13027876.	.1625	45297.	2117394.
14	278700.	13027876.	.1413	39388.	1841212.
15	368600.	12937976.	.1229	45299.	1590006.
16	278700.	13027876.	.1069	29783.	1392221.
17	278700.	13027876.	.0929	25898.	1210627.
18	278700.	13027876.	.0808	22520.	1052719.
19	278700.	13027876.	.0703	19583.	915408.
20	-7913900.	21220476.	.0611	-483542.	1296577.
				83290270.	1.

ESTIMATED INITIAL CAPITAL INVESTMENT = $ 81832200.

ESTIMATED DEFERRED CAPITAL INVESTMENT = $ 6394700.

ESTIMATED INITIAL AND DEFERRED CAPITAL INVESTMENT = $ 88226900.

TABLE 2 SUMMARY OF OUTPUTS OF COST ANALYSIS

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 15.0 PERCENT

DEPLETION ALLOWANCE = 10.0 PERCENT OF SALES

FEDERAL INCOME TAX = 50.0 PERCENT OF TAXABLE INCOME

SELLING PRICE = $	18.04 PER TON
ANNUAL SALES = $	47624865.
ANNUALIZED CASH FLOW = $	13306576.
ANNUAL OPERATING COST = $	34434400.
DEPLETION ALLOWANCE = $	4762486.
GROSS PROFIT = $	13190465.
TAXABLE INCOME = $	8427979.
FEDERAL INCOME TAX = $	4213989.
ANNUAL NET PROFIT = $	4213989.
DEPRECIATION CHARGE = $	4330100.

MINING RATE = 100TPH SEAM THICKNESS = 60FT OVERBURDEN THICKNESS = 200FT

TABLE 1 SUMMARY OF DISCOUNTED CASH FLOW

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 10.0 PERCENT

YEAR	CAPITAL INVESTMENT $	CASH FLOW $	PRESENT VALUE FACTOR	PRESENT VALUE CAPITAL INVESTMENT $	PRESENT VALUE CASH FLOW $
0	81832200.	-81832200.	1.0000	81832200.	-81832200.
1	278700.	9507048.	.9091	253364.	8642771.
2	278700.	9507048.	.8264	230331.	7857064.
3	278700.	9507048.	.7513	209391.	7142786.
4	278700.	9507048.	.6830	190356.	6493442.
5	368600.	9417148.	.6209	228872.	5847308.
6	278700.	9507048.	.5645	157319.	5366481.
7	278700.	9507048.	.5132	143017.	4878619.
8	278700.	9507048.	.4665	130016.	4435108.
9	278700.	9507048.	.4241	118196.	4031917.
10	919600.	8866148.	.3855	354546.	3418284.
11	278700.	9507048.	.3505	97683.	3332163.
12	278700.	9507048.	.3186	88802.	3029239.
13	278700.	9507048.	.2897	80729.	2753853.
14	278700.	9507048.	.2633	73390.	2503503.
15	368600.	9417148.	.2394	88240.	2254391.
16	278700.	9507048.	.2176	60653.	2069011.
17	278700.	9507048.	.1978	55139.	1880919.
18	278700.	9507048.	.1799	50127.	1709926.
19	278700.	9507048.	.1635	45570.	1554478.
20	-7913900.	17699648.	.1486	-1176351.	2630940.
				83311589.	1.

ESTIMATED INITIAL CAPITAL INVESTMENT = $ 81832200.

ESTIMATED DEFERRED CAPITAL INVESTMENT = $ 6394700.

ESTIMATED INITIAL AND DEFERRED CAPITAL INVESTMENT = $ 88226900.

TABLE 2 SUMMARY OF OUTPUTS OF COST ANALYSIS

ANNUAL TONNAGE = 2.64 MILLION TONS

DISCOUNTED CASH FLOW RATE OF RETURN = 10.0 PERCENT

DEPLETION ALLOWANCE = 10.0 PERCENT OF SALES

FEDERAL INCOME TAX = 50.0 PERCENT OF TAXABLE INCOME

SELLING PRICE = $	15.61 PER TON
ANNUAL SALES = $	41223360.
ANNUALIZED CASH FLOW = $	9785743.
ANNUAL OPERATING COST = $	34439400.
DEPLETION ALLOWANCE = $	4122336.
GROSS PROFIT = $	6788960.
TAXABLE INCOMF = $	2666624.
FEDERAL INCOME TAX = $	1333312.
ANNUAL NET PROFIT = $	1333312.
DEPRECIATION CHARGE = $	4330100.

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