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# **RESEARCH ON WATER PROPORTIONING FOR DUST CONTROL ON LONGWALLS**

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KETRON, Inc.**

**BUREAU OF MINES  
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## FOREWORD

This report was prepared by KETRON, Inc., Wayne, Pennsylvania, under USBM Contract number J0318096. The contract was initiated under the Respirable Dust Control Research Program. It was administered under the technical direction of the Dust Control and Ventilation Group with Mr. Robert A. Jankowski acting as Technical Project Officer. Mr. Michael L. Nowicki was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period July 31, 1981 to August 1, 1985. This report was submitted by the authors on February 20, 1986.

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## EXECUTIVE SUMMARY

The need existed for research on longwall faces which optimized the water usage on the shearer instead of maximizing the quantity of water delivered. Substantial improvement in the water application technique should be possible with a water distribution system which optimizes the quantity of water delivered to the drums of the shearer based on the respirable dust generated by each drum. It would increase the potential of operating in compliance with the dust standard, while giving operators a wider range of operating modes from which to select a face operating method, including unidirectional and bidirectional cutting, homotropical or antitropical ventilation.

The original research plan was to design a system which was totally automated and which proportioned the water dependent on the operation of the shearer. However, since the efficiency of water proportioning had not yet been determined and the development cost of an automated system was prohibitive, it was decided to initially explore the benefits of water proportioning through the use of a manual system.

A manually controlled valve system was fabricated and installed on a shearer. This type of proportioning system is inexpensive and easily installed. Such a valve system can be retrofit on all longwall shearers in operation today.

The research focused on the optimization of water usage through the use of the valve system. Further research into flow and pressure variations substantiated the results obtained from the manual valve proportioning system. These results can be applied to the shearer water distribution system to optimize the flows to the various circuits, particularly the drums, and to maintain compliance with respirable dust standards.

The findings on effects of varying pressure and flow show that increasing flow is beneficial only if pressure increase does not generate a boilover detrimental to the shearer operator exposure. In such a case the advantages of increasing the flow are hidden by the pressure increase. Therefore, changes in water distribution must be carefully monitored.

The shearer operator respirable dust exposure was affected by the changes in water distribution. Generally, when the water flow and pressure on the downwind drum increases so does the dust exposure of the operator. This is due to the increased boilover into the walkway from the downwind drum. Therefore, if the operator moves downwind from the shearer controls to examine the location and positioning of the drum, then it is beneficial to decrease the flow and pressure to limit the operator's exposure.

Based on the testing, increases in water flow at the upwind drum had little effect on the operator exposure in the head-to-tail direction. Increases in water flow on the upwind drum may decrease the dust level in the air stream over the shearer but this may be counteracted by an increase in

boilover from the drum into the walkway. Essentially, there is a tradeoff between the respirable dust production and the boilover from the drum.

In the tail-to-head cutting direction, there is more positive results for the operator exposure when increasing the flow to the upwind drum. Increases in water flow are helpful; however, associated pressure increases may increase boilover. Induced turbulences around the upwind drum tends to conflict with the airflow subsequently increasing boilover.

Increases in water flows at the shearer also had a positive effect on dust levels created by the stage loader and the transfer point. Therefore, to control dust from the transfer point at the shearer, it is best to increase the drum flows.

Increasing the shearer drum flows is beneficial in decreasing the total respirable dust produced by the shearer. The problem remains; which is more important to the mine operator, minimizing the respirable dust exposure of the operators or decreasing the total respirable dust produced by the shearer because of miners working downwind of the shearer. Flow increases to the drums can decrease total respirable dust produced but can have detrimental effects at the operator location particularly due to boilover.

A recommendation for future research is to develop an automatic variable delivery distribution system which could optimize water flows for particular face operations and conditions and should not require adjustment by shearer operators. It will permit to increase the water quantity without disturbing the operations.

water in accordance with the coal production it is necessary to have a regulator and a sensor to obtain an automatic variable delivery of water to the shearer. The first phase of the research showed it was feasible and relatively easy to install a valve on the shearer which can regulate the flow in accordance with an indicator of the coal production.

During the first phase of this research it appeared that not only the amount of water was important but also the way the water was distributed on the shearer, especially when the dust exposure of the shearer operator is given priority. It is not the drum which generates the most respirable dust, but the drum which creates the most exposure to respirable dust (upwind drum) which should be supplied with more water.

Consequently, it was decided to optimize the water distribution before automatically regulating the total flow and to design a valve system to change the distribution between drums. The valve system had to be tested and measurements made of the total respirable dust made, as well as the respirable dust exposure of the shearer operator. The use of different water distribution schemes confirmed that the upwind drum, even though it cuts less coal, is responsible for most of the respirable dust exposure and requires more water.

It also appears necessary that not only is the quantity of water important, but also the spray pressure and orientation should be studied because of the increased turbulence when the pressure increases and/or the sprays are not adequately oriented.

During this contract, two longwall faces were analyzed in different seams and seam heights while using different operating methods.

The report first explores the design of a longwall shearer water delivery system in Section 2.0. This effort included a literature review and a study of various water delivery concepts. Also, a detailed design and analysis was made for a specific water distribution system design.

In Section 3.0, the text describes the installation of a water delivery system on a shearer and the effects of varying the water flow with the proportioning system. The material describes the longwall face where the analysis was made and presents the results and conclusions based on the respirable dust measurements.

Additional testing on the effect of water flow and pressure variations on a shearer was carried out and described in Section 4.0. Finally, conclusions along with recommendations for future research are presented in Section 5.0.

## 2.0 DESIGN OF A WATER DELIVERY SYSTEM

The primary objective of the original contract as awarded by the Bureau of Mines was to design, fabricate and test an automatic variable delivery system for water application on longwall mining operations, and to evaluate its dust control effectiveness. A second objective of this contract was to evaluate adding calcium chloride to the water supply to determine if additional dust suppression could be obtained, or if equivalent suppression could be obtained with lower flow volumes.

The original scope of work was divided into four (4) distinct phases as follows:

- Phase I - Literature Review on Longwall Dust Control;
- Phase II - Procurement and Final Preparation of an Automatic Variable Delivery System (AVDS);
- Phase III - Underground Demonstration of the AVDS System and Evaluation of the Results; and
- Phase IV - Establishment of Specifications for a Marketable AVDS System.

### 2.1 Literature Review

A thorough domestic and foreign literature review was conducted on dust control research including the following subject areas:

- variable water supply delivery systems;
- relationship between shearer coal production and the concentration of respirable dust produced;
- use of and effectiveness of adding a surfactant or calcium chloride to the water supply system to reduce dust production during underground coal mining operations; and
- geophysical parameters, such as coal moisture, coal wetting index, etc., and their influence on dust concentration.

Over thirty-five publications on various methodologies for dust control were identified. Several of these publications reported research on the effectiveness of surfactants. Other publications included reports on on-going investigations concerning geophysical parameters, such as inherent coal moisture. No references were identified with respect to the other subject areas mentioned above except for some studies performed by the National Coal Board. This led us to the conclusion that very little research has been directed towards the design of an automatic variable water supply system. It appears that this development would have been a pioneering effort.

The literature review pointed out how various approaches in controlling dust in each country is dependent on mining conditions and mining regulations. In Great Britain, the coal is generally so hard that water infusion is difficult and coal seams are usually surrounded by soft strata which are sensitive to water. Therefore, research has been oriented towards

limiting dust production by decreasing the number of picks and reducing the drum rotational speed; thereby increasing the depth of cut and preventing the remaining dust from becoming airborne by spraying water close to each pick (pick face flushing). In Germany, as well as in France, coal is generally softer and the strata are harder and less sensitive to water than in British coal mines. Water infusion is considered the most efficient respirable dust control system for these particular conditions. In addition to infusion, respirable dust is suppressed by spraying water at the shearer drums. There is more concern about the quantity of water used for spraying in Great Britain than there is in France and Germany. In Europe, mandated dust measurements are made in the return air, yielding total dust production per shift, independent of the source of the dust. In the United States, measurement of total dust exposure per shift of the designated occupation is the law. This regulatory discrepancy alters dust control approaches in Europe versus the United States.

Spraying effectiveness depends on numerous variables, including the number, location and design of spray nozzles; the particle size of the spray; the water volume; and the pressure. The effects of these variables are of primary importance to this research program. The literature concerning these variables is discussed below. The numbers in brackets refer to the list of references at the end of this report.

At one operation, an increase of water flow from 18-21 gpm to 24-29 gpm reduced mean dust levels at the machine by about 20 percent (26). A change from external spraying to pick face flushing resulted in a 35-40 percent reduction in the dust levels at the machine, at water flows of 25 gpm. It was found that below 25 gpm, the difference was incidental, and it appeared that there was not enough water to ensure proper wetting of the dust. The change from external spraying to spraying from a pipe mounted behind the vane of the shearer's drum resulted in a decrease of 30-40 percent in dust levels at the machine, at water flows around 25 gpm (38).

It can be seen that the improvements achieved are of the same order of magnitude for both injection through the picks and injection through a piping arrangement behind the vane. However, it must be kept in mind that a standard drum can be fitted with external vane sprays and is less expensive than a pick face flushing drum which must be specially manufactured. The drum which supplies water through the pick costs more than twice that of a normal drum (26). In addition, this "wet pick" drum requires constant surveillance of the jets while the drum fitted with a pipe behind the vane needs no special attention. The wet pick drum may, however, reduce the risk of methane ignition.

The most significant factor in the application of water for reducing respirable dust is the volume used (22, 26, 38). Very often the problem at longwall faces is found to be insufficient water quantities and pressures (13). This problem can originate from several sources, such as:

- water supply to feed the longwall section's pump is limited by supply system design constraints;
- long distance from the pump to the face causes substantial pressure loss;
- particulate build-up in the pipe reduces the effective inside diameter and increases the pressure drop;
- use of PVC pipe limits the operating pressure;
- poor filtration systems fail to catch particulates, resulting in clogged sprays (4); and
- use of water hose of insufficient size results in substantial pressure losses.

These problems can readily be solved with little or moderate expense. For instance, if the water supply rate is limited, the installation of a reservoir is a relatively inexpensive and effective solution enabling the temporary supply of a large quantity of water. A clean mine car can be used as a reservoir. A twelve ton mine car has a capacity of 422 cubic feet, or 3,200 gallons of water, enough for one pass of the shearer, if the water flowrate is 150 gpm and the pass takes 20 minutes. A booster pump capable of delivering over 100 gallons per minute at pressures of 600 psi should be a prerequisite for each longwall section. Steel pipe of 3 to 4 inches in diameter should be used to carry the water from the pump to the face, and the water hose at the face should be at least 1-1/2 inches in diameter (13). A good filtration system should also be an integral part of the circuit.

Given the conclusion that the increased application of water reduces dust entrainment, many longwall operations in the United Kingdom have increased the amount of water sprayed at the face. This increase has caused problems in preparation plants at some collieries where the run-of-mine coal is dry-screened to remove fines prior to washing. In addition, other problems and costs can be associated with the use of larger quantities of water for dust suppression (see Section 2.4). Thus, the problem is one of optimization, rather than maximization.

## 2.2 Study of the Automatic Variable Water Delivery Concept

KETRON proposed to analyze the effect of water quantity and pressure by using an Automatic Variable Delivery System (AVDS) controlled by the power consumption of the shearer. Such a system can be divided into four main components:

- the water distribution system on the shearer,
- the water line along the face connecting the delivery system to the distribution system on the shearer,
- the variable water supply system, and
- the control system, including the shearer power measurement device.

The shearer water distribution system can be divided into two sub-systems. The main purpose of the first subsystem is to cool the motor and

gearbox, which require about 10 gallons per minute according to the manufacturer. This water is sprayed from sprays arranged on the machine body. The second subsystem is the water supply to the drums delivered through their shaft.

Spraying close to the picks before the dust becomes airborne is the most efficient approach to dust control. The main concern of this research, therefore, was an increase in the amount of water at this optimal location as required by an increase in the coal production rate. The water flows to the drum through a 25 millimeter (1 inch) conduit system. It should be possible to increase the internal diameter of the conduit system from 25 millimeters to 30 millimeters.

Another important fact is that, depending on the face organization, both drums may or may not alternate functions. When the shearer is used bidirectionally, the functions of the two drums alternate with the cutting direction. Thus, the nozzle arrangements on both drums must be the same and each must be capable of handling the maximum flow of water. Consequently, the minimum flow required to prevent clogging of the nozzles is quite high.

The widest discretionary range of flows on the cutting drum can be obtained with a unidirectional shearer. Here, the spray system on the trailing drum can be designed with smaller nozzles, and thus a lower minimum flow is required to prevent clogging, leaving more of the total available pressure range for experimentation.

For these reasons, it was decided to use a unidirectional cutting system for the tests to assess the effectiveness of a variable delivery system.

It was already projected that in the AVDS, the distribution on the shearer will include the possibility of splitting the flow inequally between both drums.

The approaches to achieve this project are varied. Possible AVD systems considered were:

- centrifugal pump, providing variable flow without speed variation;
- multi-pump system, providing variation of flow in discrete steps;
- variable stroke piston pump;
- valve system to bypass portions of the flow; and
- valve system to regulate the flow.

The selection of a control signal to automatically vary the flow of water was to be decided based on the following criteria:

- correlation with dust make
  - what is the best indicator of dust concentration?

- ° simplicity in design
  - cost effectiveness
  - least amount of interference with overall mining operation
  - system maintenance
- ° location
  - in headgate
  - on shearer
  - in tailgate

Initially, the total shearer power consumption seemed to be a convenient signal with a good correlation with dust make at the face. Delivering water in proportion to power indicates that the quantity of water deposited on the face would be proportional to the energy expended which should have some relation to dust production. The assumption was that while the shearer is using more energy to cut more coal, the dust concentration increases and visa versa.

The control signal can be derived from variations in the power delivered to the shearer, and be measured at the distribution box at the headgate. A simple circuit containing current transformers, potential transformers and a transducer would provide the required signal. The circuit will include limiters preventing the water flow from dropping below its minimum limit or exceeding its maximum.

Preliminary results of a study by the National Coal Board indicate that power may not be closely correlated with dust generation rate. However, some uncertainty exists with respect to the validity of the findings. Nevertheless, a number of alternatives are possible. These include shearer speed, shearer haulage force, and dust generation rate itself.

If the water flow rate is made proportional to the shearer speed, then a constant water quantity per unit of face length will be deposited. If the speed increases, more water would be delivered; however, the gallons per foot of face length would remain constant.

Monitoring dust generation is a method which does not utilize a correlation, but delivers water directly as it is needed, on the basis of actual dust generation. In fact, this should be the best approach since dust suppression is the ultimate goal. The main problem is the location of the dust measurement point because if the distance to the shearer is too great the system response comes too late.

It would seem that hands-on measurements of the effects of each of these approaches is warranted. The signals would not be used initially, but just measured and recorded to allow correlation with dust measurements.

An investigation of six longwall operations consistently in compliance with the Federal Dust Standard has shown that most of the mines which were studied employ atypically high water flowrates (85 to 100 gpm) and

direct a larger amount of the water to the drum responsible for most of the miners' exposure to dust.

Therefore, a water distribution system that optimizes the quantity of water delivered to each drum of a shearer by prorating to the dust exposure generated should substantially improve the water application technique. It would increase the potential of operating in compliance with the dust standard, while giving operators a wider range of operating modes from which to select a face operating method.

The original contract was modified to reflect this change in the research orientation.

The original design capacities for the water supply system, including the pump filtration system, face hose, etc., were not modified:

- hydrocyclone filtration system
- total flowrate of 150 gpm
- 30 gallons for cooling
- 120 gallons for the drums

The major change was the elimination of the study of surfactants and the design of a manual water distribution system instead of an automatic variable delivery system.

### 2.3 Water Distribution System Design

The new objective of the Phase I study was to design and evaluate the potential of a system on a double-drum shearer that would deliver water to each drum proportionately to the need, to effectively control dust. The quantity of water was to be proportioned according to its effect on the level of dust exposure. The maximum amount of water to be delivered to the shearer would be 150 gallons per minute. With this flowrate, three percent water can be added to a coal production of 1,000 tons/hour.

The valve system design consisted of two subsystems. The main purpose of the first subsystem was to cool the motor and gearbox, which required up to 30 gallons per minute. This water is ultimately released from sprays arranged on the machine body to confine the dust cloud to the face. The function of the second subsystem is to supply up to 120 gpm of water to the drums through their shafts. Spraying water close to the picks before the dust becomes airborne is the most efficient approach to dust control. Therefore, the 120 gpm flow would be delivered through spray nozzles on the drum mounted on the pipe welded to the drum vane, or mounted on the vane itself (pick face flushing). By simply turning one or two valves, the proposed system would provide the operator with the capability to increase or decrease the flow to each drum with a maximum of 80 gpm to one drum and a maximum of 40 gpm to the other. The primary objective of this research was to determine the optimum value of the total amount of water and its most effective distribution. This water distribution system is unique in both concepts of using

large quantities of water and prorating water delivery to each drum. It is also untested.

If it can be shown that increasing and prorating the water flow makes spraying more efficient, the development of an automatic variable delivery system that continuously regulates the flow of water as a function of actual dust generation should be considered because it is probably the only way to increase the total flow in an operating longwall face which will be acceptable to the operator.

Significant strides, through the efforts of the U. S. Bureau of Mines, have been made in dust reduction with water application. Prior to Bureau of Mines' involvement, very little research had been conducted to analyze the effectiveness of external spraying systems. The Bureau's research has shown that water sprays, aligned in the proper way, can confine the shearer's dust cloud to the face and improve the dust exposure of the operators. Improper orientation of sprays can have a negative impact on dust exposure, making it worse than without water spraying. The optimal external spraying system will be used in this research.

The objective of the proposed proportional valve system research was to provide a system that supplies more water and also proportions the flow to each drum, relative to its function, to improve the efficiency of water spraying. The proportion selected was specifically designed for the operation. Depending on the direction in which the air flow is traveling and whether or not there is more dust generated during the cutting or the cleaning cycle.

The initial design of the water distribution system supplied a maximum of 30 gpm of water to cool the motors, and proportioned 120 gpm of water in varying quantities for delivery to the drums. This system is unique, in that the 150 gpm of water flow provided is significantly greater than that supplied to existing longwall installations. This should allow a reduction in dust generation and possibly an increase in production. The system provides the operator the capability to vary the quantity of water sprayed from the nozzles on the drums, depending on the amount of dust generated.

Dust generation attributable to the operation of the shearer is dependent on several variables. Some of these factors include:

- machine design,
- mining conditions,
- ventilation, and
- method of operation.

The valve system design can be adjusted to the site specific conditions.

By simply turning one or two valves, the system provides the operator with the capability to increase or decrease the flow to each drum with a maximum of 80 gpm to one drum, leaving a maximum of 40 gpm to the other. These flowrates have been selected as a baseline for the research because:

1. the quantity of water currently pumped to shearers averages 50 gpm;
2. operators who have increased the flow of water to the shearer have experienced a decrease in dust levels; and
3. the total amount of 150 gpm corresponds to current shearer capabilities of 1,000 tons per hour and 3 percent added moisture.

The system has been designed so that the flow quantity for each drum can be adjusted to avoid using more water than necessary. For the same reason, limiter valves were specified to automatically turn off the flow of water to the drums when they are not cutting and to turn it on when cutting operation starts.

Consideration in design was given to differences in face organization. When a shearer loader is used in a bidirectional mining plan, the functions of the two drums alternate with the cutting direction. In a unidirectional mining system, they do not. To accommodate both systems, each drum will be equipped with the same nozzles and orientation, and will be capable of handling the maximum flow of water.

Figure 2-1 illustrates the major components of the water distribution system. Water is supplied to the system by a pump. Water leaving the pump passes through a filtration system and is delivered to a second filtration system at the face via four-inch standard pipe. Water is then discharged into a two-inch hose and delivered to the valve system on the shearer for distribution to the cooling system and drums.

Figure 2-2 presents a schematic diagram of the water pattern to the drums through the valve system mounted on the shearer.

The following two sections describe the water supply system and the valve system, respectively. Many of the components discussed in Section 2.3.1 are required to meet the objectives, but a mine may already have a comparable system. All of the items described in Section 2.3.2 (Water Distribution Valve System) will be new to the water system and may need to be purchased.

### 2.3.1 Water Supply System

It is necessary that an adequate water supply for the longwall section be maintained. In many mines, one source of water supplies several sections, which may cause water shortages. This would necessitate the use of an isolated source of water for the longwall section or the installation of a reservoir.

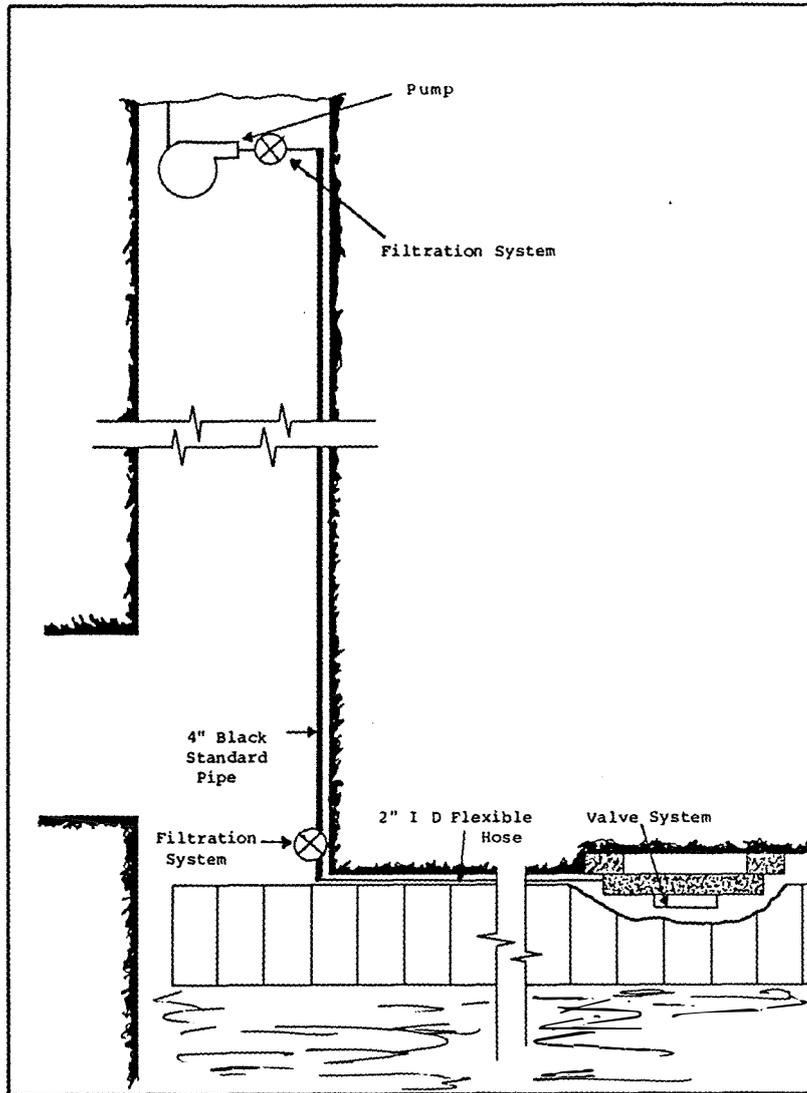


Figure 2-1  
Water Distribution System

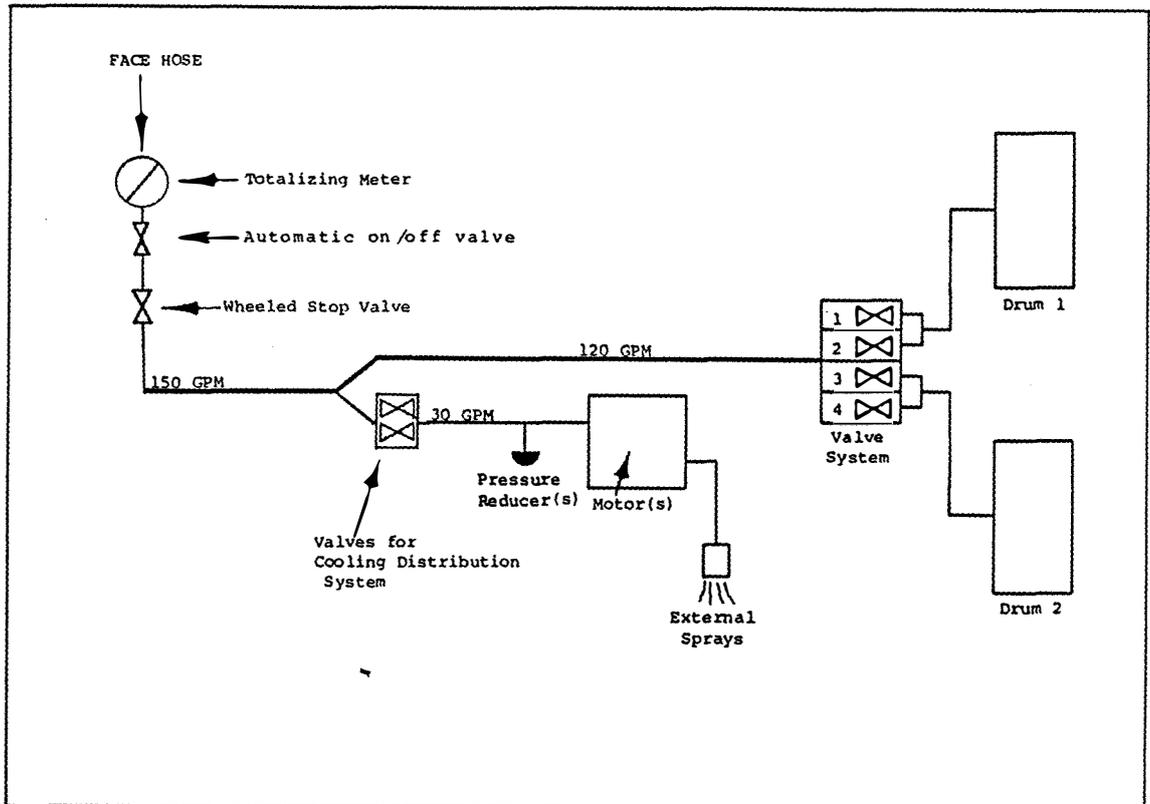


Figure 2-2  
Schematic Diagram of the Shearer's Water Distribution Valve System

The water is delivered to the shearer by a pump located at the mouth of the longwall section. Based on the requirements of 150 gpm and 200 psi spray discharge pressure, the following total head loss was calculated when using a 2 inch flexible hose and when using a 1-1/2 inch flexible hose for the section in the cable handler.

Water Circuit	Total Head Loss		
	1-1/2" hose	1-1/2" and 2" hose	2" hose
Five thousand feet of pipe (4 inch standard)	127'	127'	127'
Six hundred feet of 2 inch rubber hose			245'
Three hundred feet of 2 inch rubber hose		122'	
Three hundred feet of 1-1/2 inch rubber hose		350'	
Six hundred feet of 1-1/2 inch rubber hose	700'		
Valve system	27'	27'	27'
Required pressure 200 psi (exit from sprays)	462'	462'	462'
<b>Total</b>	<b>1,316'</b>	<b>1,188'</b>	<b>857'</b>

A KOBE Model RG-150 Roto-Jet pump, marketed by Barrett Haentjens Company of Pittsburgh, was selected. This pump is capable of providing 1,271 feet, 550 psi, of head.

The KOBE Roto-Jet pump provides the following advantages:

- ease of maintenance,
- performance flexibility,
- reliable operation, and
- economical installation.

This pump was also selected for its simplicity. It has two basic working parts, a rotating case and a stationary pick-up tube collector arm within the rotor. The design eliminates the need for packing glands, wear rings or throat and throttle bushings as used in conventional centrifugal pumps, and also eliminates the complex pistons, rods, valves and springs required in reciprocating pumps.

The Roto-Jet operates in the following manner. Liquid enters the intake manifold and passes into the patented rotating case where its velocity is increased. Centrifugal force causes the liquid to enter the rotor under pressure. The velocity energy of the liquid in the rotor is converted into additional pressure energy as it jets into the pick-up tube. The liquid flows through the collector arm and into the discharge manifold at pressures as high as 1,100 psi and capacities up to 400 gallons per minute.

The pump's specifications are:

Gallons per minute	150
Total dynamic head (550 psi)	1,271 feet
Revolutions per minute (V-belt drive)	3,550
Efficiency	60%
Brake horse power - clear water	84.3
Brake horse power less 5% belt loss	80.2
HP motor recommended	100
Suction	2" ID pipe
Discharge	2" ID pipe
Head required on inlet side	70'

Strainer and valve manifold systems have been developed to protect booster pumps, such as the KOBE pump, and also provide a valve manifold for auxiliary water requirements (see Figure 2-3).

A twin system has been designed so that down time is minimized. A strainer element or reducing valve on one branch can be replaced while still maintaining filtered flow through the other. When using the flow through both lines, pressure drop is kept to a minimum. The 1-1/4 inch twin system can therefore pass flows up to 180 gpm. Auxiliary inlet and outlet adaptors can be attached to the filtration system to provide a connection for various

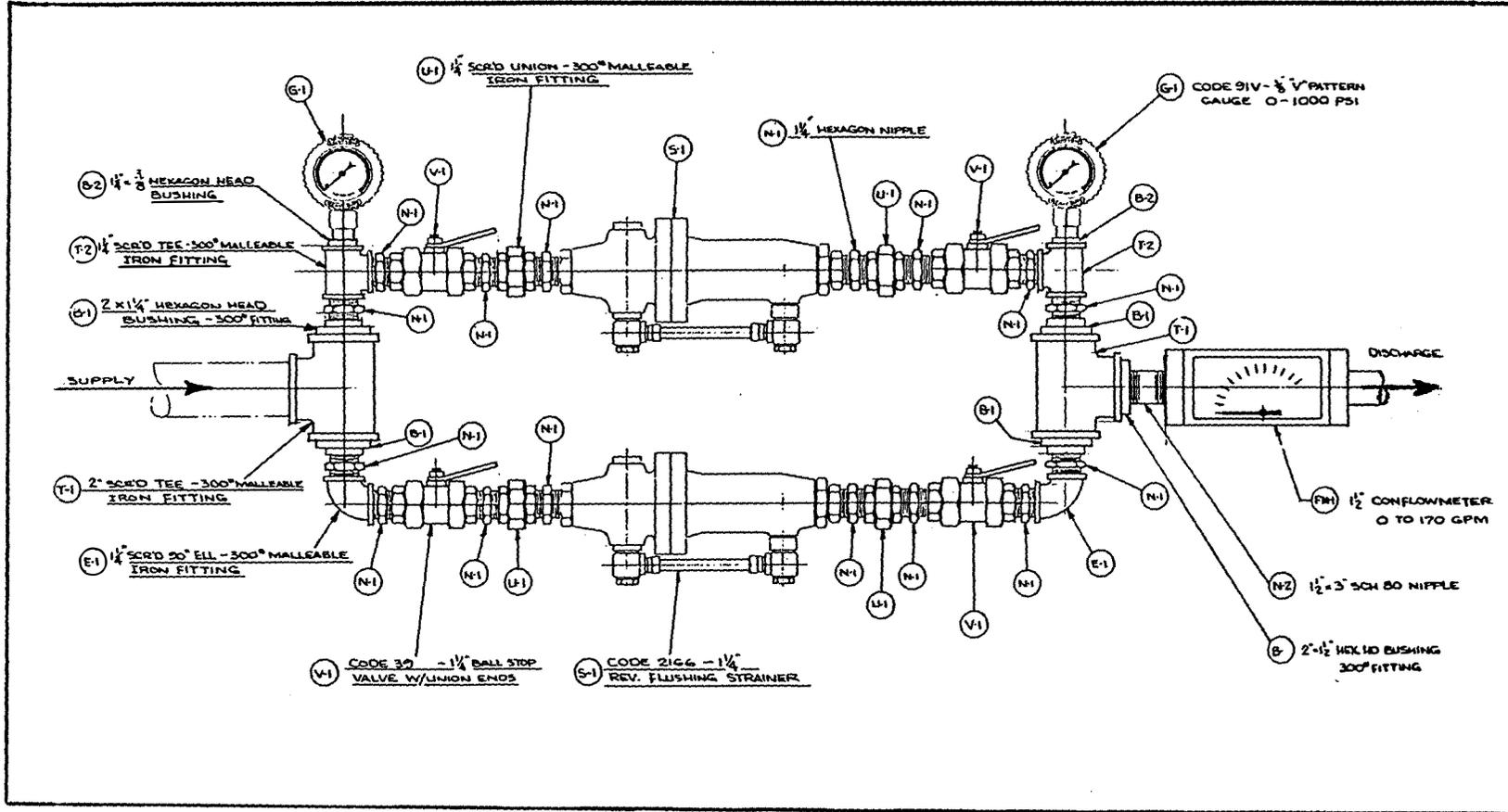


Figure 2-3  
Filtration System

safety devices such as fire hydrants. These additional components can be selected by the mine operator to suit his requirements.

A flow meter and a pressure recorder would be essential monitoring devices in the system.

The pipe to the section from the pump should be 4 inch steel and grooved for simple connection.

The face water hose can be 300 feet of 2 inch ID and 300 feet of 1-1/2 inch ID industrial rubber hose, available in 50 foot lengths. The 2 inch section of hose completes the water circuit between the 4 inch steel pipe in the headgate and the middle of the face. The 1-1/2 inch hose completes the circuit to the shearer's valve system. These hoses can handle approximately 500 psi working pressure. To facilitate water hose and power cable handling, it should be possible during the demonstrations to temporarily suppress the use of a cable handler and to use 600 feet of 2 inch ID industrial rubber hose. A 2 inch flexible hose is too large to fit inside a standard cable handler.

### 2.3.2 Water Distribution Valve System

The water distribution valve system diverts 150 gpm of water into two circuits at the shearer. The first is used for cooling the motor and gearbox and requires 10 to 30 gallons/minute, depending upon the specific machine. In the second circuit, approximately 120 gpm of water is directed through a series of valves that controls the flow to each drum.

The valve system is shown in Figure 2-4. The system is described from the point of entry at the 2 inch face hose to the point of discharge, i.e., the drums and external sprays. The exact location of the valve system on the shearer body and its configuration was determined by the characteristics of the shearer.

The water (150 gpm) arriving at the valve system will first pass through a totalizing meter, which must be able to withstand 1,000 psi pressure due to the potential exposure to "water hammer." From the meter, the water flows through a stainless steel and bronze wheeled stop valve (Figure 2-5). This valve is necessary when the flow to the shearer must be shut off. The gradual decrease in flow will prevent damage to the pump by "water hammer."

Valve F, a maxway stop valve (Figure 2-6 and valve F in Figure 2-4), will be set to limit the water flow at 30 gpm for cooling the shearer's motors. The valve is key operated to prevent tampering with the setting.

From the maxway stop valve, the cooling water flows into the distribution manifold (Figure 2-7 and K in Figure 2-4). Attached to this manifold is a set of restrictor and relief valves (G and H) to protect the motors from adverse pressures (Figure 2-8). Pressure check monitoring valves can be

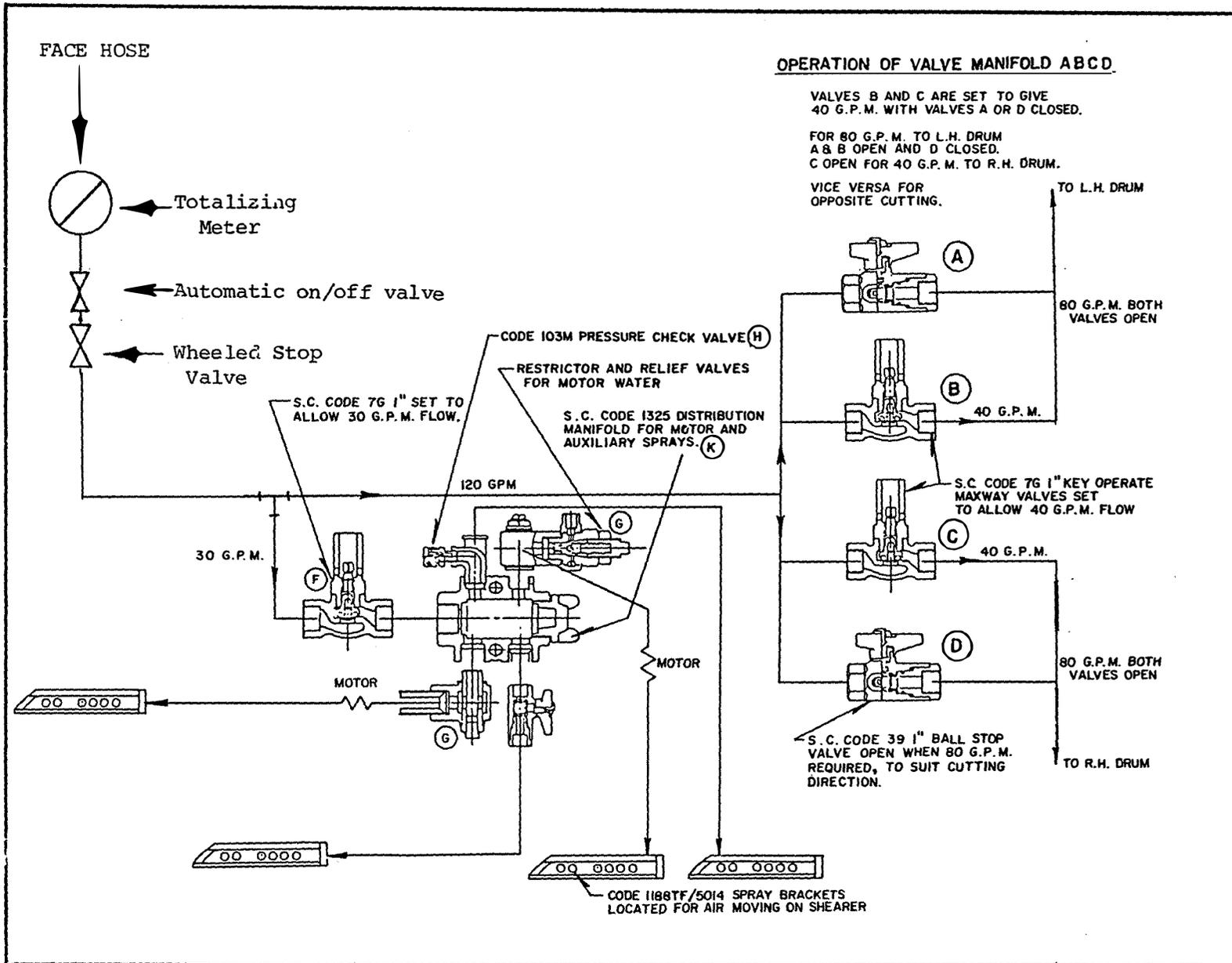


Figure 2-4  
Shearer's Water Distribution Valve System

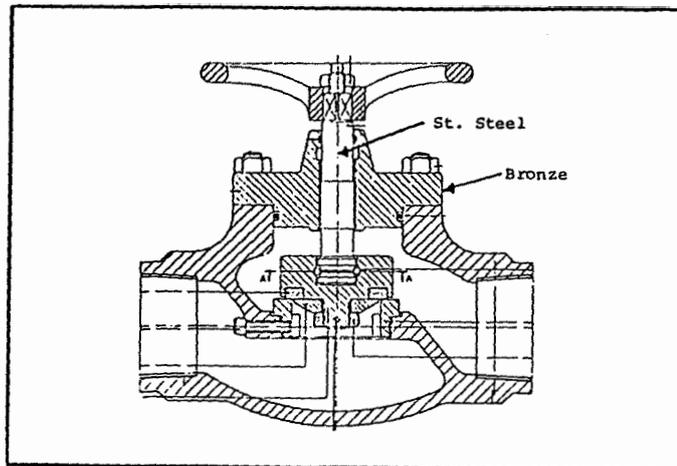


Figure 2-5  
Wheeled Stop Valve

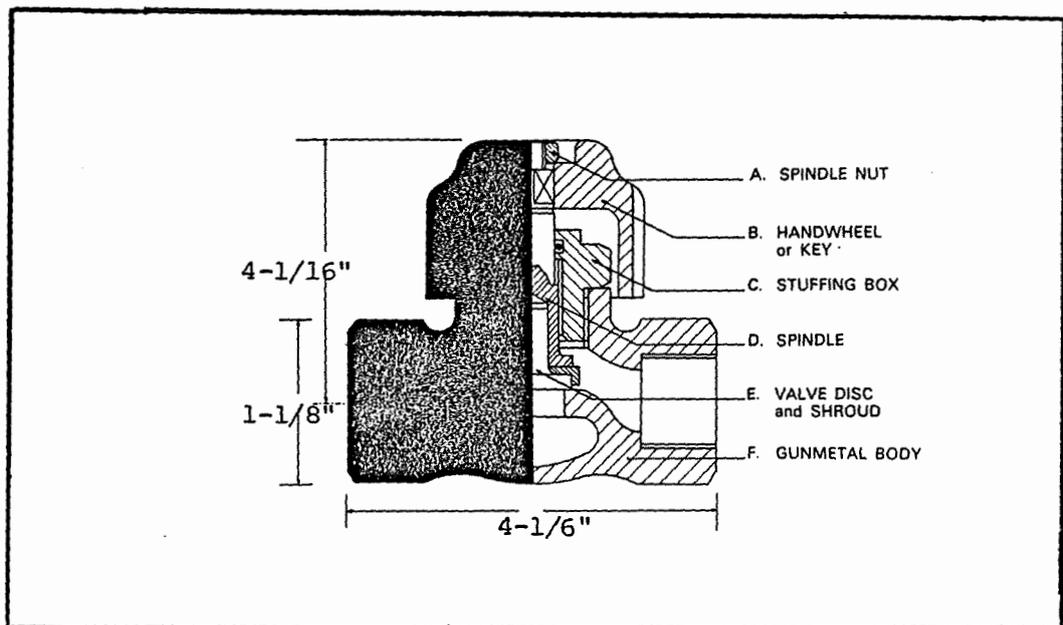


Figure 2-6  
Maxway Stop Valve

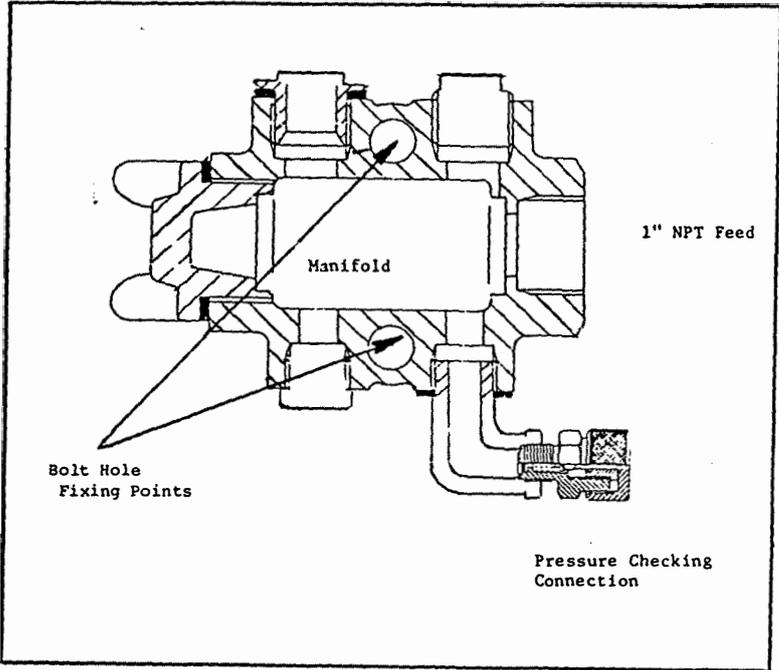


Figure 2-7  
Cooling Water Distribution Manifold

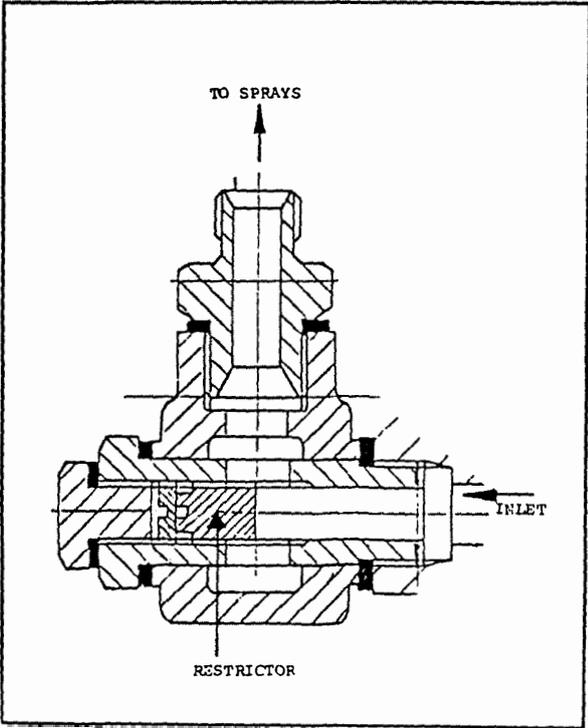


Figure 2-8  
Pressure Restrictor Valve

fitted into the circuit at any point where pressure measurements are to be made without interruption to the normal operation of the circuit. The cooling water will ultimately be discharged through externally mounted sprays or dumped onto the armored face conveyor.

The 120 gpm of water for the drums flows through an automatic on/off valve to a system of four valves (Manifold ABCD in Figure 2-4). The controls A and D of the manifold govern the main flow to the shearer's drums. They are of the rotating ball stop type, operated by a 90° turn of the handle (Figure 2-9). Valves B and C, the same as previously described maxway stop valve F, are set to give 40 gpm with valve A or D closed. To put 80 gpm to the left hand drum and 40 gpm to the right hand drum, both valves A and B would be open and valve D would be closed. To reverse the flow, simply open valve D and close valve A. The manifold ABCD can be easily constructed using union ties and fittings. The automatic on/off valve will stop and start water spraying whenever the drums are cutting (Figure 2-10). This shut off valve is essential where excess water is critical and only allows water to flow when cutting/loading conditions apply. The valve allows the dust reducing unit to operate only at the higher cutting pressure. The following advantages are obtained:

- minimum water usage with optimum dust control,
- reduced moisture in coal and improved proceeds,
- reduced degradation of seam floor, and
- improved working environment.

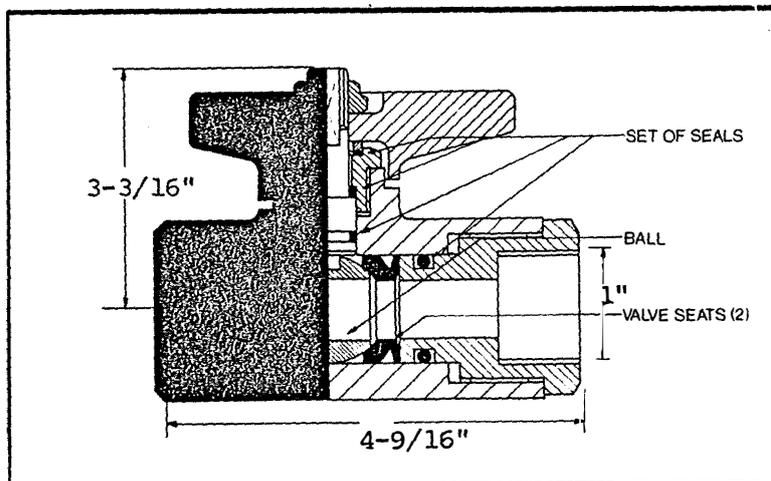


Figure 2-9  
Rotating Ball Stop Valve

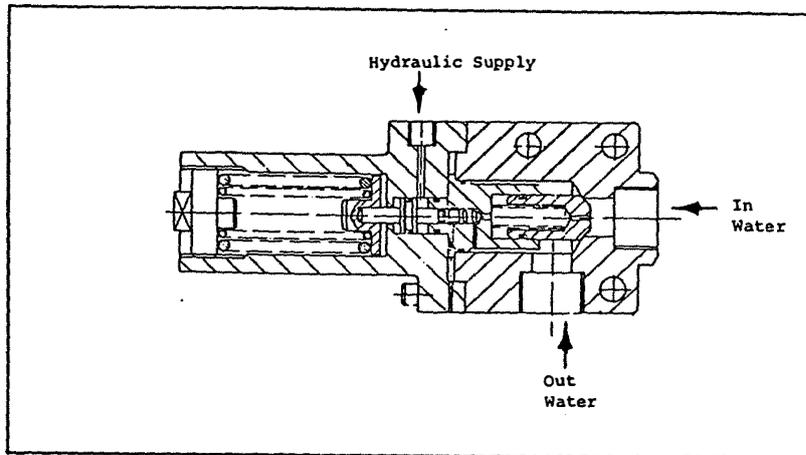


Figure 2-10  
Water Limiting Valve

When using a shearer with hydraulic haulage, the input signal is provided through a hydraulic connection to the shearer's haulage system. The hydraulically controlled valve can be fitted to all types of shearers where an external connection to the hydraulic haulage circuit is available. This type of hydraulic control is possible when the haulage force during cutting is significantly higher than the hydraulic force when tramping. For example, if the hydraulic pressure is 500 psi when tramping, 1,200 psi when loading loose coal, and 1,600 to 2,000 psi when cutting, the threshold that engages the hydraulic circuit can be set at 1,500 psi. When cutting hard coal, the electro-hydraulic control system may reduce the haulage force, thereby reducing the range between the two pressures. This hydraulic control may not be possible when cutting very hard coal. In this case, the on/off valve will be manual or electrically operated (Figure 2-11).

On a Joy shearer with electric haulage, the problem is technically easier to solve. A current transformer on the drum motor circuit will emit an electrical signal when the drum is cutting. The automatic on/off valve will be electrically operated from the electric control box of the shearer. The primary drawback to this system is that it will be contingent on MSHA approval. However, this approval will concern only the electrovalve. Electric outlets are available on a Joy shearer control box.

#### 2.4 Economic Impact Study

Excessive moisture in coal and in the mine workings is unwanted and is a cause of problems that may occur in all phases of the mining cycle, transportation, material handling, extraction, preparation and marketing. Final moisture content in coal is dependent on:

- inherent moisture,
- mining conditions,
- application of water at the face for dust suppression,

- use of water in the cleaning process,
- precipitation on open stockpiles, and
- addition of water during transportation to market.

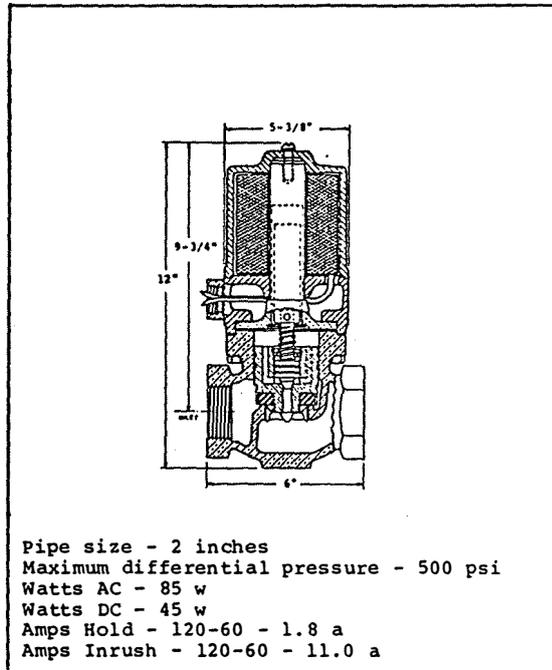


Figure 2-11  
Solenoid Valves - Normally Closed

To fully comprehend the negative effects of adding more water to a longwall face, water related problems in the mining environment must be addressed.

If water is allowed to accumulate, the mine will eventually fill up, or at the least, become "roofed" in low places, blocking ventilation and traffic. It must be controlled long before it reaches this stage. Water standing in the working face is unpleasant for the miners, and reduces their efficiency and productivity.

Machinery operating in water is subject to electrical and mechanical damage. Motors, contactors and cable splices may short out and a clay and water mixture from the bottom can "gum up" exposed bearings and sprocket chains. At a longwall face, excess water can cause problems in roof support and panline movement, especially with soft bottom conditions.

Back from the face, water may turn a soft bottom into a bog which becomes impassable to rubber-tired equipment. Standing water makes it impossible to keep the track in good condition. The area around belt transfer points becomes a quagmire, reducing accessibility to the transfer points.

Belts standing on the mine bottom pick up water accumulated in the entry and cause belt slippage.

Water can cause beneficiation problems where total wet cleaning is not utilized, particularly in crushing and dry screening operations. Most U. S. preparation plants today, however, use wet screening and in this case the moisture of the run of mine coal has no impact behind the cleaning plant feeding belt.

In the other case or if the coal is sold raw, the moisture content of coal is important to a successful coal sales contract. It influences the price, heating capability, weight and transportation of the coal. Domestic consumption of coal is primarily in two markets:

1. metallurgical, and
2. steam.

The metallurgical market utilizes a high grade coal which is processed through a plant equipped with wet screening. The addition of more water at the longwall face should not affect this market.

Steam coal is supplied to utility companies. This coal is usually a lower grade coal than that used in the metallurgical market and may be sold on a raw basis. Coal contracts are usually based on the heating value (Btu per pound) of the coal. Any increase in moisture will lower the value of the coal and thus its price per ton. This reduction is compensated by an increase in weight and the total price paid by the consumer is unchanged at the mine. Transportation costs, however, will be increased due to the added water. This cost is based on actual weight of material moved, regardless of Btu content.

A major concern to a company selling high moisture coal is rejection or penalties due to excessive water content and/or low Btu content. The addition of more water at a longwall face could alter the marketability of a coal sold raw by increasing the moisture to a point above the contractual limit. In addition, the excess water may correspondingly lower the Btu to an unacceptable value, thereby causing the coal to be rejected or sold at a lower price.

All of these problems can have a severe economic impact on the longwall and the mine in terms of an increased production cost if they occur. These costs have been accounted for in the sensitivity analysis (Section 2.4.4) and they must be weighed against the benefits of the water distribution system.

In the assumption that dust levels decrease proportionally with increases in the amount of water sprayed, the system should be capable of reducing dust levels by as much as an estimated 60 percent. The suppression of dust is beneficial to the miner and the operator in that there will be:

- a reduction of pneumoconiosis occurrence,
- a more agreeable working environment,
- a decrease in the possibility of coal dust explosion,
- compliance with mandated federal laws, and
- increased coal production.

The above benefits are difficult to quantify prior to implementation of the system but some gain should be realized in these areas.

The following economic analysis of increasing water quantity at a longwall face is based on the use of the proposed water distribution and valve system.

#### 2.4.1 Financial Analysis

Using the present value method, a financial analysis of the proposed water distribution system was performed for three cases. The following assumptions were made.

- The water distribution system will be incorporated in a longwall system that is already profitable. It will be assumed that the complete water distribution system will be retrofitted. This is the worst case scenario considering the mine would need to purchase and install the entire water distribution system.
- The longwall face is operated three shifts per day, 240 days per year, on a face averaging 960 tons per shift for a total yearly production of 640,800 tons.
- The selling price of coal is \$25 per ton.
- The system has a three-year useful life.
- The system has no salvage value.
- The straight-line depreciation method is used.
- Depletion allowance is 10% of gross revenue, dependent upon deduction limitation.
- Investment tax credit is ten percent of the original investment.
- Tax rate is 50 percent.
- To simplify the analysis, price escalation has not been taken into consideration.
- The discount rate was set at 20 percent.
- The monetary figures are based on 1982 (first quarter) dollars and can be tied to the Consumer Price Index to obtain updated figures.

In Sections 2.4.2 and 2.4.3, the capital costs and the operating costs are discussed, respectively.

#### 2.4.2 Capital Costs

The estimated costs for installing the proposed water distribution system are:

<u>Equipment</u>	<u>Cost</u>
Pump and filtration system	\$25,000
Pipe and hoses	42,980
Shearer water distribution system	6,498
Subtotal	<u>\$74,478</u>
Contingency (10%)	<u>7,448</u>
 Total	 \$81,926

In costing the equipment, all equipment is assumed to be purchased at the beginning of the project. Capital expenditures may be reduced by utilizing existing material (such as pipe, hose couplers, etc.) at the mine site.

#### 2.4.2.1 Pump and Filtration System

The primary function of the KOBE Model RG-150 Roto-Jet pump is to provide water to the headgate at a minimum pressure of 550 psi. The filtration system will be attached to the pump, filtering the water so that potential plugging of the sprays is minimal.

#### Estimated Capital Expenditure Schedule

<u>Number of Units</u>	<u>Unit</u>	<u>Unit Price</u>	<u>Total</u>
1	KOBE Model RG-150 Roto-Jet pump with 100 HP motor, No. 4 magnetic starter, mounted on base	\$19,249	\$19,249
1	Senior Conflow filtration system installed	4,751	<u>4,751</u>
	Total		\$25,000

#### 2.4.2.2 Pipes and Hoses

The piping and hose will transfer the water from the pumps to the face. It must be capable of handling at least 550 psi working pressure.

Estimated Capital Expenditure Schedule

<u>Number of Units</u>	<u>Unit</u>	<u>Unit Price</u>	<u>Total</u>
5,000 lineal feet	Victaulic 4 inch ID steel pipe	\$435/100 ft.	\$21,750
256 sets	Couplers	\$60/set	15,360
2	Fire suppression valves	\$1,000	2,000
600 lineal feet	Industrial rubber hose, 2 inch ID, 550 psi working pressure	\$5.40/lineal foot	3,240
18 sets	Couplers	\$35/set	<u>630</u>
	Total		\$42,980

2.4.2.3 Shearer Water Distribution System

This system will divert the 150 gpm supplied to the shearer into two circuits. The first will deliver approximately 10 to 30 gpm to the machine's cooling system. The second flow circuit will pass the water through a series of valves which will direct water flows to each drum according to a selectable ratio.

Estimated Capital Expenditure Schedule

<u>Number of Units</u>	<u>Unit</u>	<u>Unit Price</u>	<u>Total</u>
1	Main inlet on/off valve suitable for 800 psi, Code 18SW, 2 inches	\$ 420	\$ 420
1	Inlet, Code 7G (F) 1 inch NPT	65	65
4	Spray brackets, Code 1188/5014	181	742
1	Distribution manifold complete with relief valves and valves, Code 1325	416	416
1	Inlet rate of flowmeter complete with gauge, 170 gpm, 200 psi	575	575
2	Flowmeters complete with gauge, 70 gpm, 1,000 psi	330	660
1	Main control manifold ABCD	500	500
4	1/2 inch NPT pressure check valves for various points, Code 103M	11	44
1	0-2000 psi for pressure checking, Code 91V103NSA	190	190
1	Totalizing meter, 2 inches, 1,000 psi (estimated)	1,000	1,000
2	1-1/4 inch water limiting valve, Code 2577	702	1,404
	Estimate for hoses, etc., 1/2 inch and 1 inch on machine	500	<u>500</u>
	Total		\$6,498

2.4.3 Yearly Operating Costs

The estimated yearly operating costs of the water distribution system are:

Labor Associated Costs

Total UMWA labor at \$10.12 per man hour	\$4,858
Vacation and holiday pay at \$0.97 per man hour	466
Total UMWA labor	<u>\$5,324</u>
Taxes at 30%	1,597
Health and retirement fund at 20%	<u>1,065</u>
Yearly operating cost	\$7,986

2.4.3.2 Water Requirements

For a longwall installation with a shearer loading rate of 16 tons per minute and an average cutting time of 60 minutes per shift, the yearly water consumption of the water distribution system can be calculated as follows:

$$60 \text{ minutes/shift} \times 3 \text{ shifts/day} \times 240 \text{ days/year} \times 150 \text{ gallons/minute} = 6,480,000 \text{ gallons/year}$$

Estimated Water Cost

$$\$1.74/1,000 \text{ gallons} \times 6,480,000 \text{ gallons/year} = \$11,275/\text{year}$$

This cost is used in the present analysis. That overestimates the incremental cost since all longwall sections are currently using water.

2.4.3.3 Electrical Power Requirements

The pump is operating at 550 psi or 1,270 feet of head. The electrical power requirements per day are calculated as follows:

$$\text{Working Horsepower (WHP)} = \frac{Q \times H}{N \times C}$$

where:

C = 3960 (hp·min/ft·gal)

Q = flowrate gpm

H = head in feet

N = efficiency of pump percentage

$$\text{WHP} = \frac{150 \times 1,270}{0.8 \times 3,960} = 60 \text{ KW}$$

$$60 \text{ KW} \times 240 \text{ days/year} \times 100 \text{ operating minutes/day} \times 1 \text{ hour/60 minutes} = 24,000 \text{ KWH}$$

Estimated Electrical Costs

$$24,000 \text{ KWH} \times \$0.05/\text{KWH} = \$1,200$$

2.4.4 Net Present Value Analysis

Incremental increases in production (0.5%, 1% and 5%) were assumed for three net present value analyses. All costs were held constant for each case. Table 2-1 is a calculation of yearly cash flows for a 0.5 percent increase in production. Table 2-2 summarizes the net present value for each of the three incremental production increases. It can be seen that only 0.5% increase in production yields a net present value of \$38,409.

Table 2-1  
Yearly Cash Flow with 0.5 Percent Incremental Increase in Production

	<u>Year 1</u>	<u>Year 2</u>	<u>Year 3</u>
Gross Revenue	\$86,400	\$86,400	\$86,400
Less:			
Operating Cost	28,000	23,000	23,000
Depreciation	27,000	27,000	27,000
Depletion	<u>8,600</u>	<u>8,600</u>	<u>8,600</u>
Taxable Income	\$22,800	\$27,800	\$27,800
Tax	<u>11,400</u>	<u>13,900</u>	<u>13,900</u>
Income After Taxes	\$11,400	\$13,900	\$13,900
Plus:			
Depreciation	\$27,000	\$27,000	\$27,000
Depletion	<u>8,600</u>	<u>8,600</u>	<u>8,600</u>
Operating Cash Flow	\$47,000	\$49,500	\$49,500

Table 2-2  
Net Present Value Analysis

<u>0.5 Percent</u>			
<u>Year</u>	<u>Gross Cash Flow</u>	<u>Discount Factor</u>	<u>Net Present Value</u>
1	\$47,000	1	\$ 47,000
2	49,500	.833	41,234
3	49,500	.650	<u>32,175</u>
		Total	\$120,409

$$\text{NPV} = \text{Benefits} - \text{Costs} = \$120,409 - \$82,000 = \$38,409$$

<u>1.0 Percent</u>			
<u>Year</u>	<u>Gross Cash Flow</u>	<u>Discount Factor</u>	<u>Net Present Value</u>
1	\$94,500	1	\$ 94,500
2	97,000	.833	80,801
3	97,000	.650	<u>63,050</u>
		Total	\$238,351

$$\text{NPV} = \text{Benefits} - \text{Costs} = \$238,351 - \$82,000 = \$156,351$$

<u>5.0 Percent</u>			
<u>Year</u>	<u>Gross Cash Flow</u>	<u>Discount Factor</u>	<u>Net Present Value</u>
1	\$474,700	1	\$ 474,700
2	477,200	.833	397,508
3	477,200	.650	<u>310,180</u>
		Total	\$1,182,388

$$\text{NPV} = \text{Benefits} - \text{Costs} = \$1,182,388 - \$82,000 = \$1,100,388$$

## 2.5 Conclusions

The technical and economic feasibility of suppressing dust at a double-drum shearer longwall face using a proportioning water distribution system was assessed. This proposed system is advantageous to the operator in that the application of water will be optimized, and is potentially capable of reducing shearer dust generation by an estimated 60 percent. Based on a 0.5 percent increase in production, directly attributable to this dust reduction, the water distribution system was judged economically feasible. The production increase may be much greater than 0.5 percent.

A possible disadvantage of the system is the potential negative impact that the added water might have on the conveyor and/or rail haulage system. This effect, however, can be minimized if not eliminated by fully comprehending the capabilities of the existing coal transportation system. In some cases, redesign of the belt capacity or upgrading of mine drainage capabilities may be necessary.

The advantages should compensate for the disadvantages and if the water proportioning valve system can be economically developed in spite of these possible drawbacks, the technology will be widely applicable to the mining industry. The current system design is very flexible and adaptable to the majority of mines using double-drum shearers in longwall operations.

### 3.0 EVALUATION OF MANUAL WATER PROPORTIONING VALVE SYSTEM

#### 3.1 Introduction

After the Phase I effort, which included a literature study and a preliminary analysis of water delivery on shearers, the original contract was modified from the design, fabrication and testing of an automatic variable delivery system to the design and testing of a manual valve system with automatic on/off feature. The value of water proportioning would best be substantiated through the testing and evaluation of a manual valve system. Underground testing may show that by increasing and prorating the water flow to the drum sprays the dust control efficiency improves. Such results may lead to the development of an automatic variable delivery system that continuously regulates the flow of water as a function of actual dust generation with an optimum distribution.

The basic differences between the AVDS and the manual valve system are in their approaches toward the same objective. The valve system is simpler, manually operated and all components are currently manufactured. It will establish a basis for the AVDS which must be totally automated.

The valve system described in Section 2.0 was worked out in detail. A schematic drawing of the water distribution and spray system, including the experimental control and monitoring hardware, is shown in Figure 3-1. Calculations were made to estimate flows and pressures in the various branches of the system for a variety of valve settings to ascertain minimum flows to the cooling system and the effectiveness of the system in regulating the flows to the drums.

An assembly consisting of two valves, a pressure gauge and a flowmeter would be built into the water supply line to each of the drums. In addition, a flowmeter and pressure gauge would be installed directly after the face water hose connection on the shearer.

The automatic on/off feature was discussed with the major shearer manufacturers. For electrically driven shearers, a permissible solenoid valve manufactured by Magnatrol Valve Corporation was proposed. Application of this valve on the Joy 1LS2, 2LS1, 1LS4 and 1LS5 would require some modifications. The model 1LS6 may not require any modifications because it is designed to control valves and to monitor the current produced during cutting.

For hydraulically driven shearers, a hydraulically controlled on/off valve (see Figure 3-2) was proposed. On the Eickhoff 300 shearer, the control signal would come from the haulage system supply lines, as shown in Figure 3-3.

Two mines were willing to cooperate in the testing of the water proportioning system. Underground tests were carried out at the two longwall faces, herein referred to as Site A and Site B. Excellent data was obtained during the testing at Site A and the remainder of Section 3.0 details the

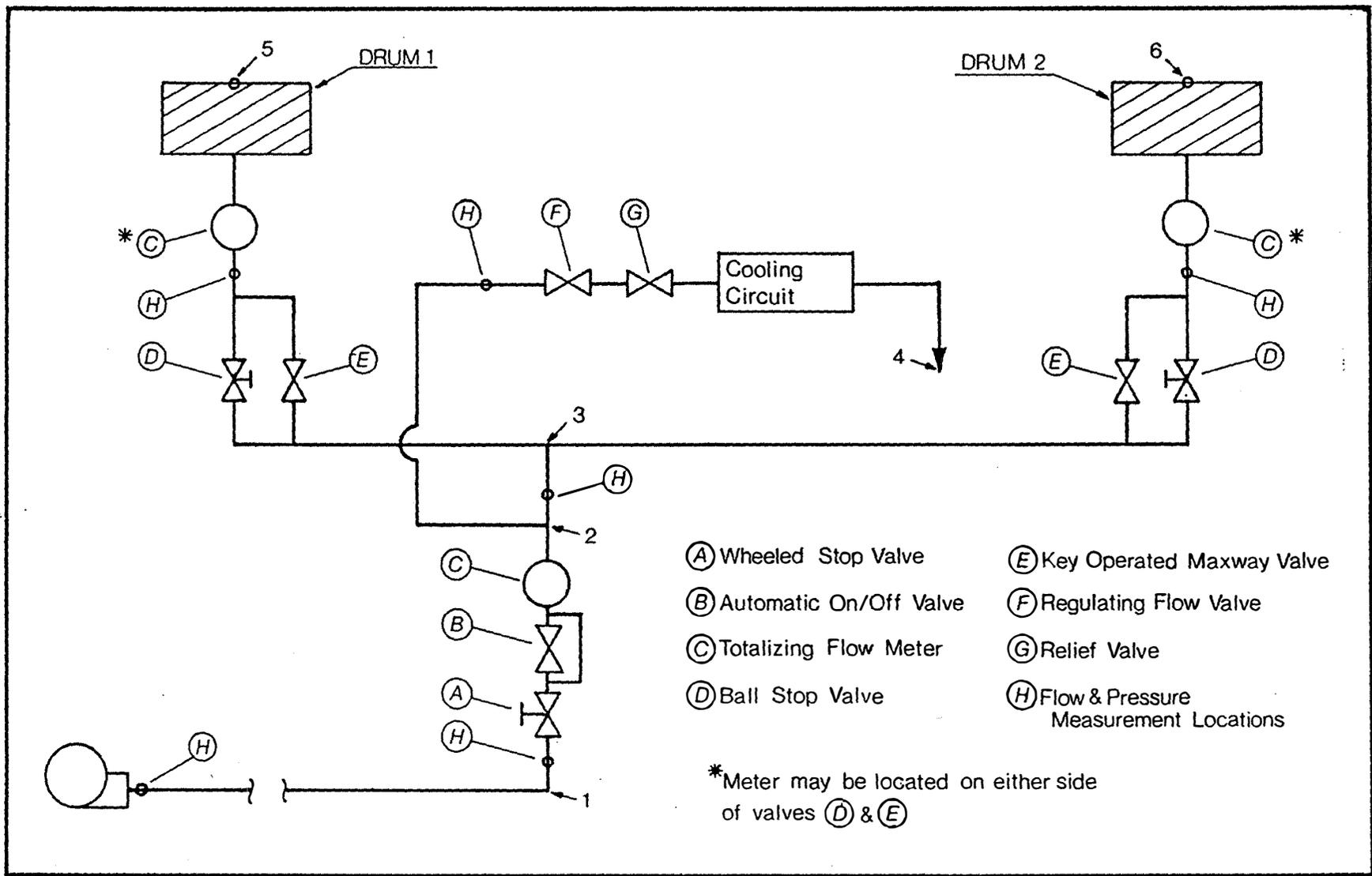


Figure 3-1  
Schematic Drawing of Water Distribution System

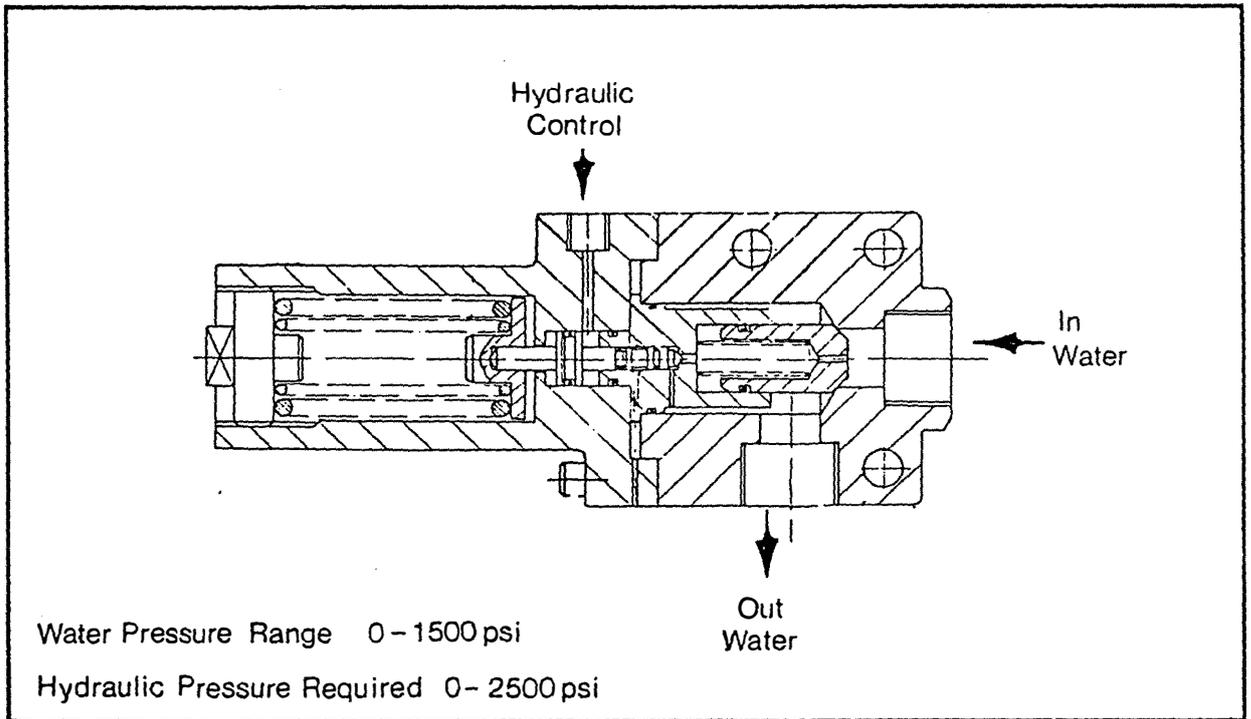


Figure 3-2  
Automatic On/Off Valve with Hydraulic Control

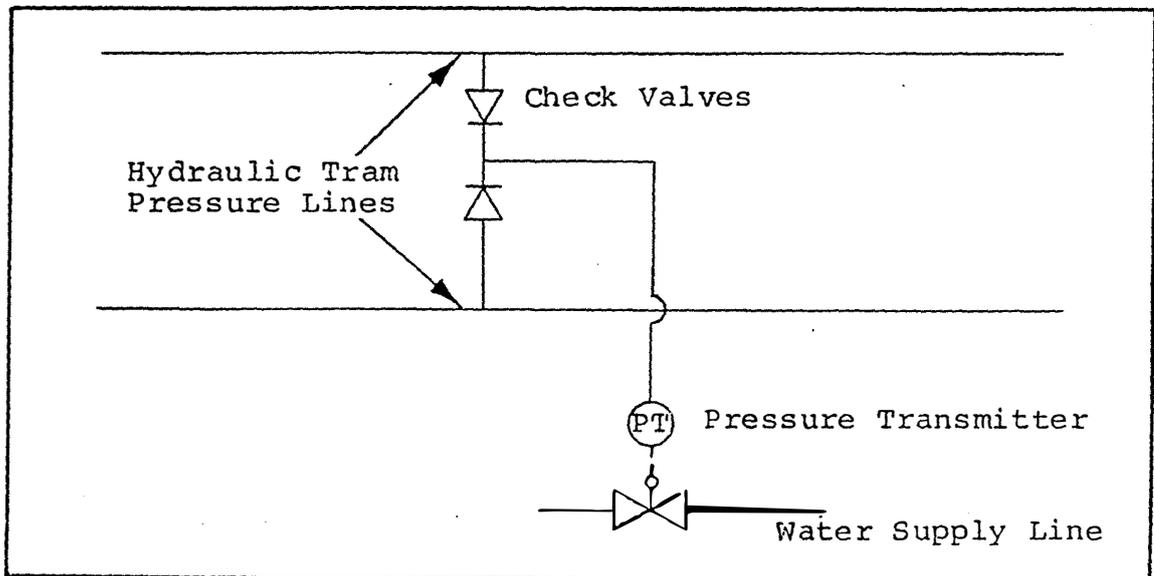


Figure 3-3  
Control Signal for the Hydraulically Controlled  
On/Off Valve on the Eickhoff 300

data collection and subsequent analyses. At Site B, very little information was obtained with regard to the water proportioning because of maintenance, system installation and other problems. The data from Site B does have some interesting information regarding dust control on longwalls and is important in that respect. The Site B dust analysis is detailed in Appendix C.

### 3.2 Site A Information

#### 3.2.1 Valve System Installation

After the management at Site A had offered its cooperation, the face equipment in the section was studied in detail to identify the adaptations required for the application of the valve system. It was decided to initially focus on proportioning tests and to test increased water flows only within the limited range of the available pump in the section and not increase the water system's capacity. More elaborate tests of increased water flows are only meaningful if the total water usage could be measured. However, totalizing meters had been ordered but were not delivered until after the testing period. Thus, only modifications to the Eickhoff 300 shearer had to be made. Some modifications had been made to the water distribution system on this machine by the mine.

The water distribution, cooling and spray system prior to the installation of the valve system is shown in Figure 3-4. To enable the water proportioning tests, modifications were designed as shown in Figure 3-5. Valve and gauge assemblies were to be installed in each of the water supply lines to the drums. In addition, gauges were to be installed to measure the flow and pressure of the water supplied to the shearer. It was decided to incorporate the existing distribution block in the design and not to change the water supply system to the motor. This could safely be done, because the modifications would not decrease the flow to the motor. Consequently, the modifications could be kept simple.

All hardware necessary for the tests at Site A was procured and the valve systems pre-assembled. The valve system was installed and the following tests were conducted: tests of the water distribution system using the complete shearer assembly, including the drums; measurements of the water pressure and flow at the pump outlet, the shearer inlet and the nozzles. All MSHA approvals necessary for the underground demonstration and evaluation of the valve system were obtained.

Measurements were made to determine pressures in the spray water system at various flow distributions used in the study. For each flow distribution, the pressures were recorded as registered by the three pressure gauges mounted in the valve system. In addition, the pressure was determined at the drum sprays. Two sets of measurements were made, one set including measurements of the spray pressure at the upwind drum (Table 3-1), and another set including measurements of the spray pressure at the downwind drum (Table 3-2).

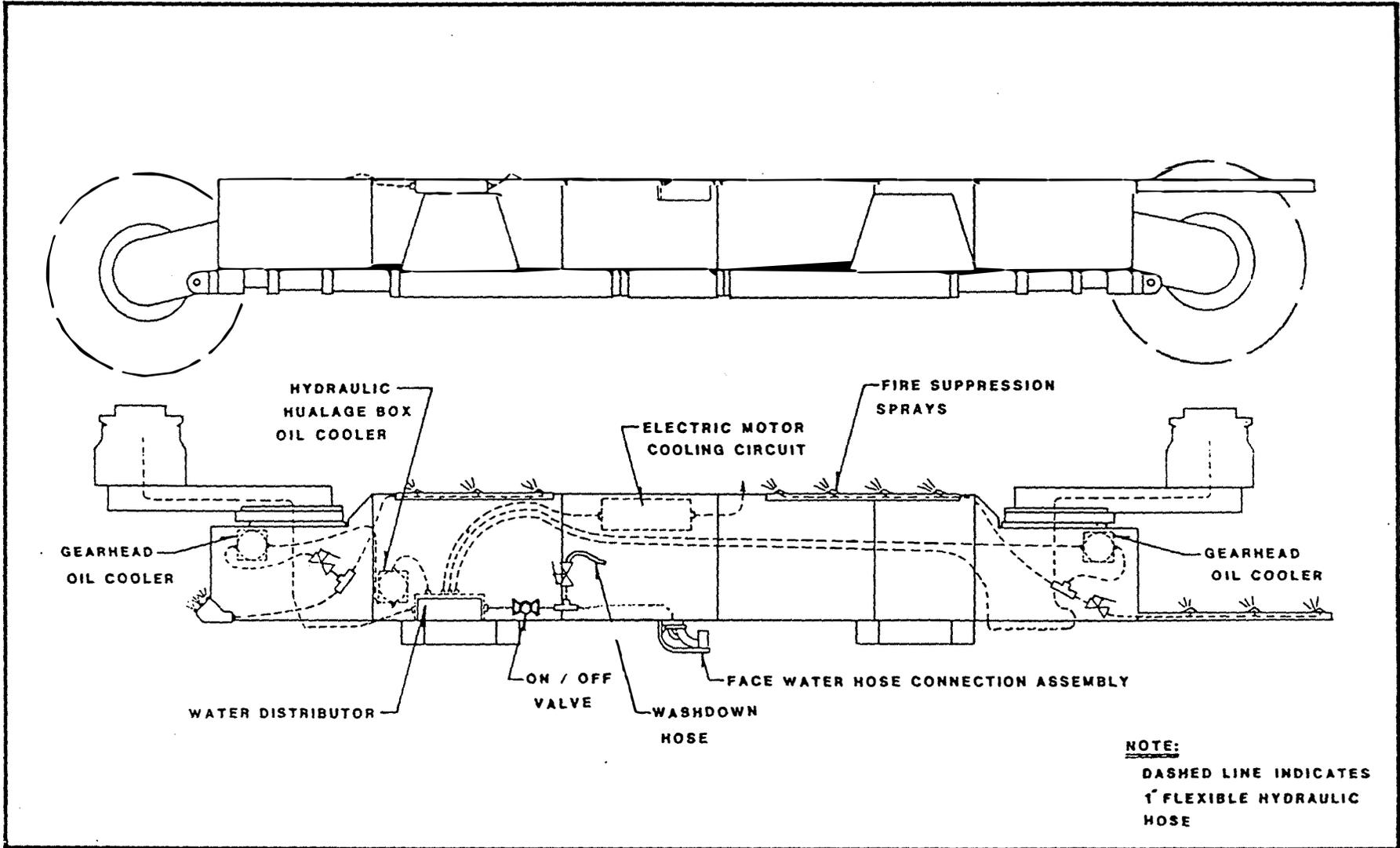


Figure 3-4  
Original Water Supply System

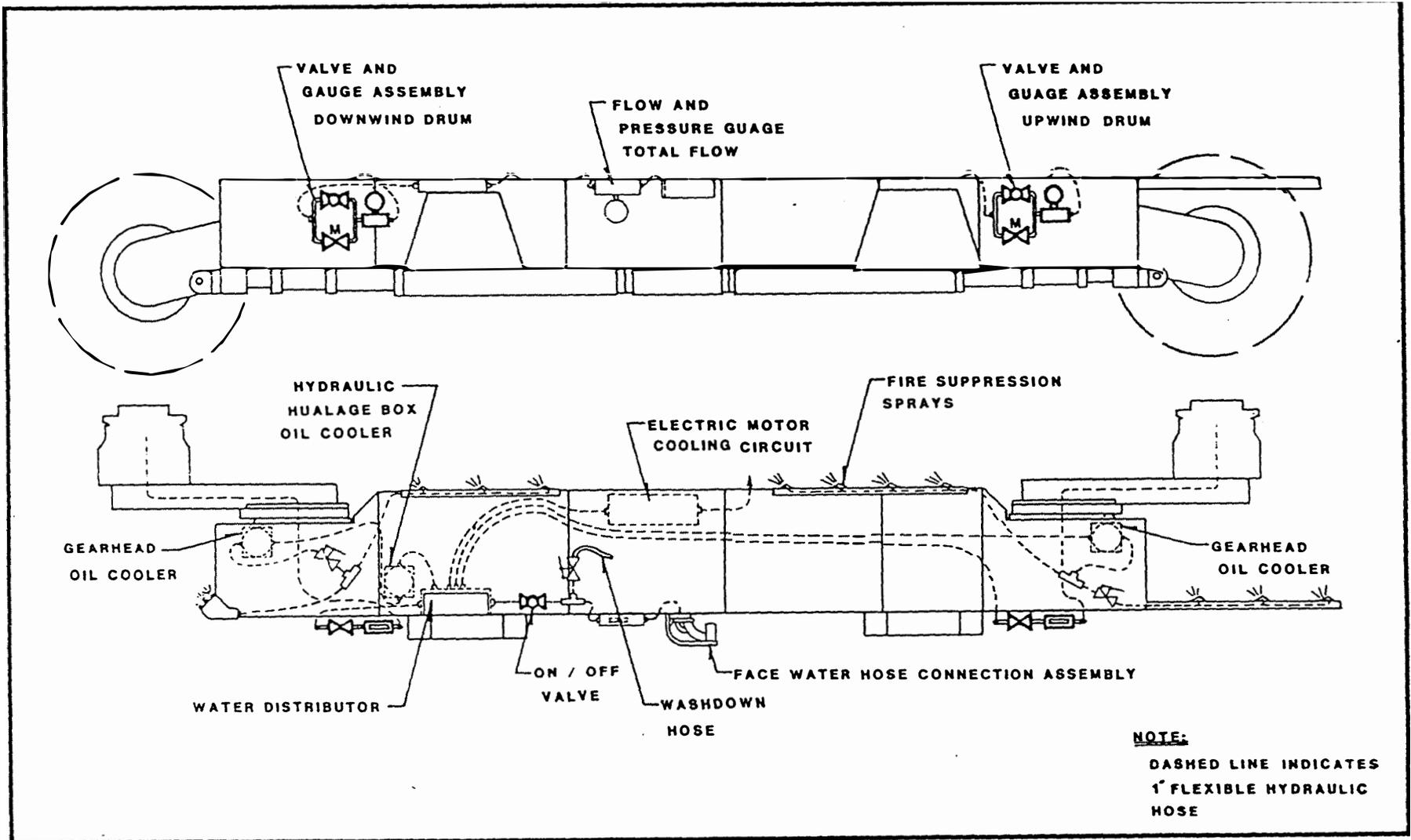


Figure 3-5  
Modified Water Supply System

Table 3-1  
Calibration Measurements of the Upwind Drum Spray Water System

	Flow Distribution (gpm through upwind drum: gpm through downwind drum)			
	24:24	29:28	36:12	12:36
Total flow (gpm)	70	75	65	60
Pressures (psi) at:				
Total flow meter	320	275	350	400
Upwind drum valve assembly	90	100	120	30
Upwind drum sprays	60	80	100	5
Downwind drum valve assembly	100	175	20	300

Table 3-2  
Calibration Measurements of the Downwind Drum Spray Water System

	Flow Distribution (gpm through upwind drum: gpm through downwind drum)			
	24:24	29:28	36:12	12:36
Total flow (gpm)	68	70	70	65
Pressures (psi) at:				
Total flow meter	300	250	320	320
Downwind drum valve assembly	140	180	20	280
Downwind drum sprays	80	100	5	150
Upwind drum valve assembly	105	110	180	90

The results appear to be not entirely consistent with the basic formula for the flow of incompressible liquids that states that pressure loss in a pipe or hose is proportional to the square of the flow. This may be the result of:

- inaccuracy in the measurement instruments,
- inaccurate gauge readings, or
- changes in the pressure drop over the sprays between flow settings due to clogging/unclogging of some sprays.

### 3.2.2 Mine Characteristics

The mine selected for the Site A testing worked in the Pittsburgh No. 8 coal seam and was located in Eastern Ohio. The survey was performed from November 16 through December 16, 1982, during the day shifts.

The 5 Left longwall section was located at a depth of approximately 500 to 600 feet. The coal in the section ranged from 48 to 52 inches. The shearer normally cut both roof and bottom rock. The roof was generally poor and fragmented and sometimes caused lengthy production delays.

The shearer was an Eickhoff 300 DL which was put into service in 1978. The drums were 58 inches in diameter bit-to-bit, 30 inches wide, and a rotational speed of 45 rpm. Each drum utilized 56 three-inch positive rake bits. The drums were equipped with water sprays in a pick face flushing arrangement with an orifice of 3/32 of an inch. The water supply system delivered approximately 70 gpm to the shearer at 300 psi resulting in a drum spray pressure of 80 psi.

The longwall face was approximately 500 feet long and cut unidirectionally, with approximately four-fifths of the face cut from head-to-tail with the airflow. The shields were advanced immediately behind the shearer on its head-to-tail pass.

The ventilation on the face was antitropical with an average of 186 fpm, representing an air quantity of approximately 10,000 cfm. Subsequently, due to a ventilation change, the air velocity steadily increased over a period of two weeks to 325 fpm, representing an air quantity of approximately 19,000 cfm. More detailed ventilation information is provided in Section 3.5.1.

### 3.2.3 Data Collection and Analysis

The purpose of the study was to assess the effect of proportioning the water flow to the shearer drums on the respirable dust. A second objective was to determine the effect of increasing the water flowrate. Without proportioning, a considerable amount of the incremental flow is ineffective and may cause more problems than it solves. With controlled proportioning, the benefits of increasing the water flow are maximized.

The majority of the data presented in this section resulted from respirable dust samples taken only while the shearer was cutting. These samples are not eight hour compliance test samples and the dust concentrations presented in this report cannot be directly related to the compliance limit of 2 mg/m<sup>3</sup>. In Section 3.6, the available data has been used to make an estimate of the section's production capacity as limited by the 2 mg/m<sup>3</sup> compliance regulation. Note that all dust information in the analysis refers to respirable dust concentrations.

The general sampling plan for the testing can be found in Appendix A. The following text expands on the plan in more detail.

All samples were taken with the shearer cutting from the headgate to the tailgate. Ventilation was antitropical (directed from headgate to tailgate). The shields were moved upwind of the shearer during the cutting pass.

The sampling procedure used is based on the fact that the respirable dust concentration measured at any location along the face is a composite of all dust sources upstream of that location. Four dust sampling stations were used. Figure 3-6 shows the location of dust sample stations. Stations A and D were stationary, Stations B and C moved with the shearer. Station A was located at shield No. 8 to measure the intake air dust and the dust generated by the crusher and the transfer point. On several occasions, the intake air dust was measured separately. Station B was located between the shearer and the shield movement, to obtain a measurement of the dust resulting from the movement of the shields (B minus A). Due to the bad roof condition in the section, the shields were typically moved directly behind the shearer. Station B was usually located approximately in line with the cowl of the upwind drum. It is therefore possible that the samples taken at Station B did contain some shearer created dust and that the dust concentrations resulting from the movement of the shields as measured at this station were not the fully diffused dust concentrations. Whenever shield movement lagged behind, Station B was moved further away from the shearer.

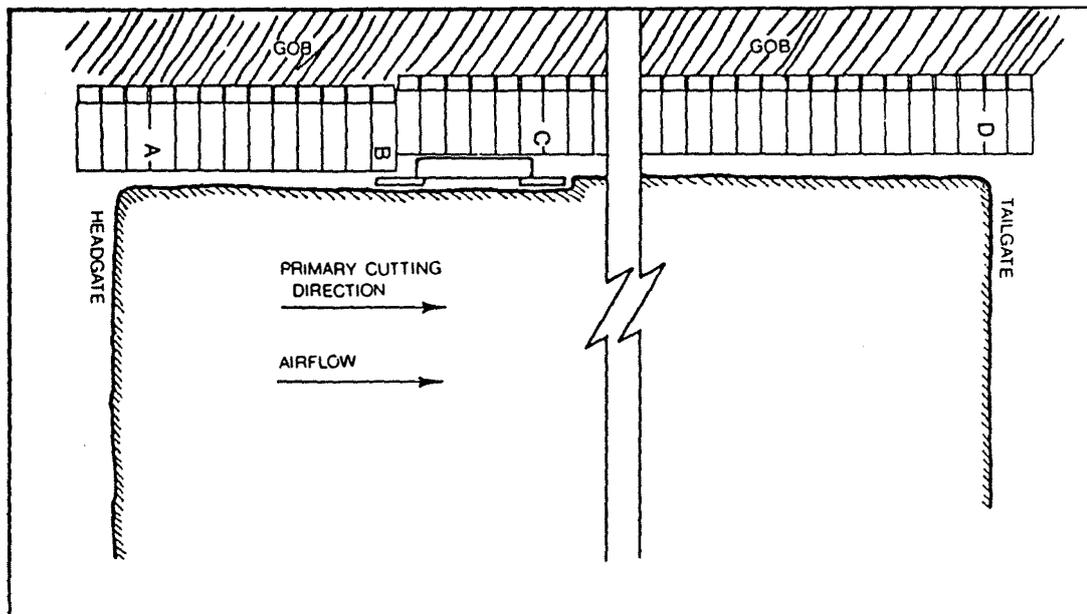


Figure 3-6  
Location of Dust Sample Stations

Station C was located in line with the downwind drum operator's work area. The measurements at Station C thus represent the upper limit of the operator's exposure hazard, and the difference between measurements at Stations B and C, the shearer's contribution to this hazard. Station D was located at shield No. 98, and D minus B was interpreted as the dust concentration resulting from the total dust make of the shearer cutting action. C minus B is interpreted as that part of the

total dust make of the shearer to which the downwind shearer operator may be exposed.

Except for the personal samplers at Station A, which operated throughout the shift, the samplers at all other stations were only turned on while the shearer was cutting toward the tailgate. During long delays, these samplers were turned off. Fresh filters were used for each new cutting pass.

Each station consisted of three simultaneously operating personal samplers. This was necessary to insure accuracy and to obtain a reliable average measurement of the respirable dust concentration despite the short sampling times. For the same reason, the filters were weighed before and after use to the nearest one thousandth of a milligram.

Air speed measurements were made at Station B, approximately every 20 feet of shearer advance. The measurements were made approximately one foot above the spillplates. Instantaneous dust measurement readings were made at Stations B and C every 10 feet of shearer advance. The clock time was recorded at Station C every 10 feet of shearer advance, to provide data for the calculation of the shearer speed.

Water flows and pressures were recorded at the start and the end of a pass and usually several times in between.

All data was recorded on voice-grade magnetic tape using MSHA approved cassette tape recorders.

A confidence interval of 90 percent (a 0.1 level of significance) was used to determine statistical significance. This means that only a 10 percent chance of a mistake was allowed in concluding that different water distributions resulted in different dust levels. A more detailed discussion of the statistical methods used is contained in Appendix B.

### 3.3 Investigation of Total Respirable Shearer Dust Make

In this section, the effect of increasing and proportioning the water flow to the drums is examined with respect to the total dust make.

#### 3.3.1 Total Respirable Shearer Dust Make as a Function of the Flowrate

Three flow levels to the drum circuit were investigated: 34, 48 and 56 gpm, each flow distributed equally over the two drums. The mean dust concentrations of the samples taken at each flow level are shown in Figure 3-7.

The data seem to indicate that total respirable dust make decreases with increasing water flows. The data were statistically analyzed with the following findings:

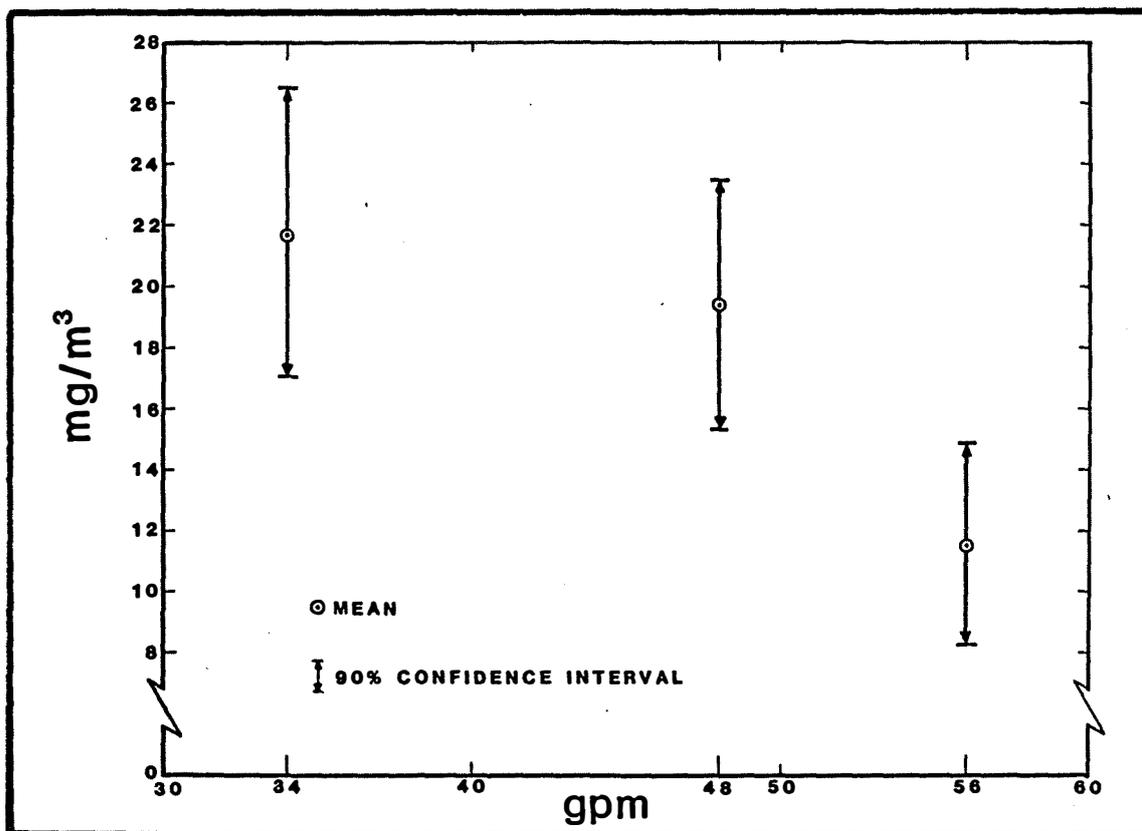


Figure 3-7  
Total Shearer Dust Make as a Function of Total Flow

- An increase in the water flow through the drums from 34 gpm to 56 gpm will result in a decrease in total respirable shearer dust make of approximately 47 percent. This was significant to a 95 percent confidence level.
- The data does not indicate a significant difference between flows of 34 gpm and 46 gpm with respect to their effect on total shearer dust make. The effect of an increase in flow from 34 gpm to 46 gpm will be small decrease in concentration from 21.8 to 19.4 mg/m<sup>3</sup> or 11 percent. An additional 10 gpm increase in the flow from 46 to 56 gpm resulted in a more significant reduction in the total dust make from 19.4 to 11.6 mg/m<sup>3</sup> or 40 percent.

For the flows of 34 and 48 gpm, samples were also taken at other than equal distributions over the drums. If these distributions are included in the data base, the mean concentrations shown in Figure 3-8 result. Overall, it can be concluded that an increase in the flowrate through the drum sprays had a tendency to decrease the shearer total dust make. More detailed information on water proportioning tests is presented in the following section.

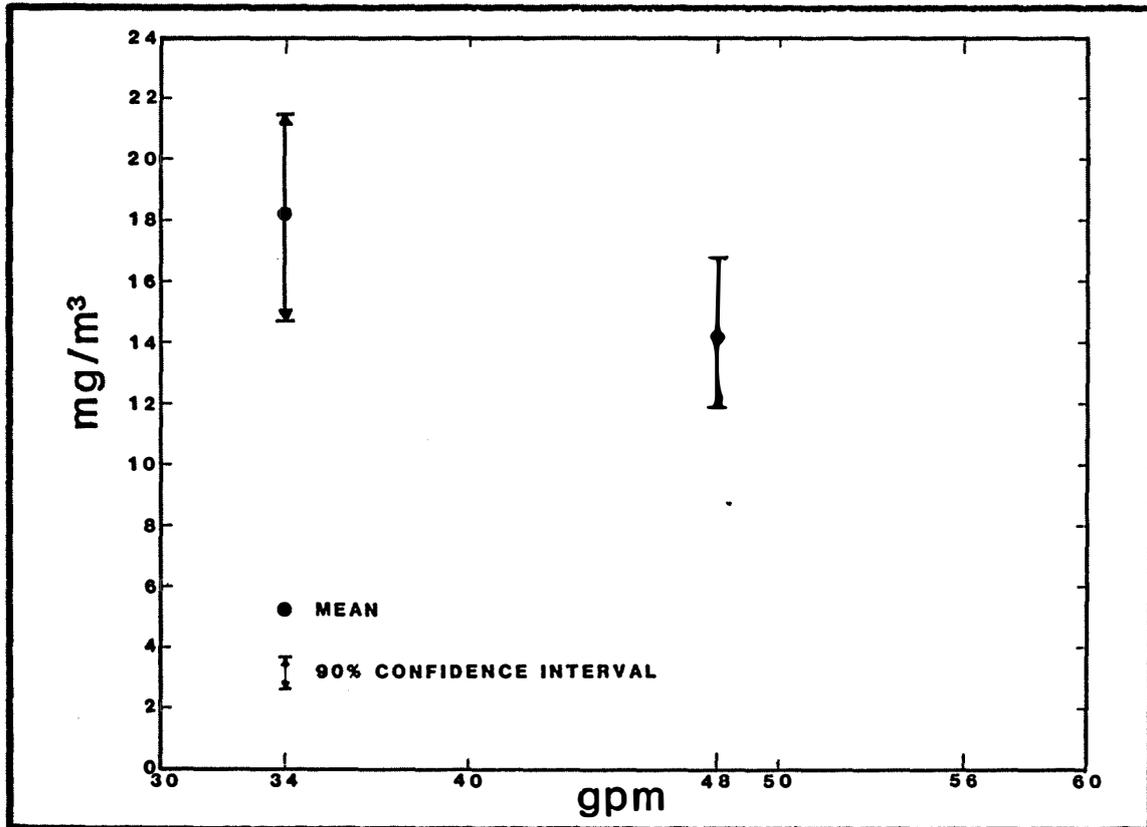


Figure 3-8  
Total Shearer Dust Make as a Function of Total Flow  
Expanded Data Base

### 3.3.2 Total Respirable Shearer Dust Make as a Function of Water Distribution

The flows of 34 and 48 gpm were distributed over the two drums in three different ratios as shown in Table 3-3.

In the remainder of Section 3.0, the distributions will be indicated by two flowrates separated by a colon. The first flowrate represents the upwind (headgate side) drum and the second flowrate represents the downwind (tailgate side) drum.

The mean dust concentrations measured for each of the six distributions listed in Table 3-3 are tabulated in Table 3-4 and graphically depicted in Figure 3-9.

Table 3-3  
Distributions for 34 and 48 GPM Total Flow

Total Flow (gpm)	Flow to Upwind Drum (gpm)	Flow to Downwind Drum (gpm)	Number of Passes Sampled
34	17	17	3
34	24	10	2
34	10	24	3
48	24	24	4
48	36	12	7
48	12	36	4
56	28	28	6

Table 3-4  
Total Shearer Dust Make Based on Water Distribution

Water Distribution Upwind Drum Flow:Downwind Drum Flow (gpm)	Total Shearer Dust Make (mg/m <sup>3</sup> )
17:17	21.76
24:10	11.20
10:24	19.06
23:23	19.44
36:12	11.19
12:36	14.75
28:28	11.61

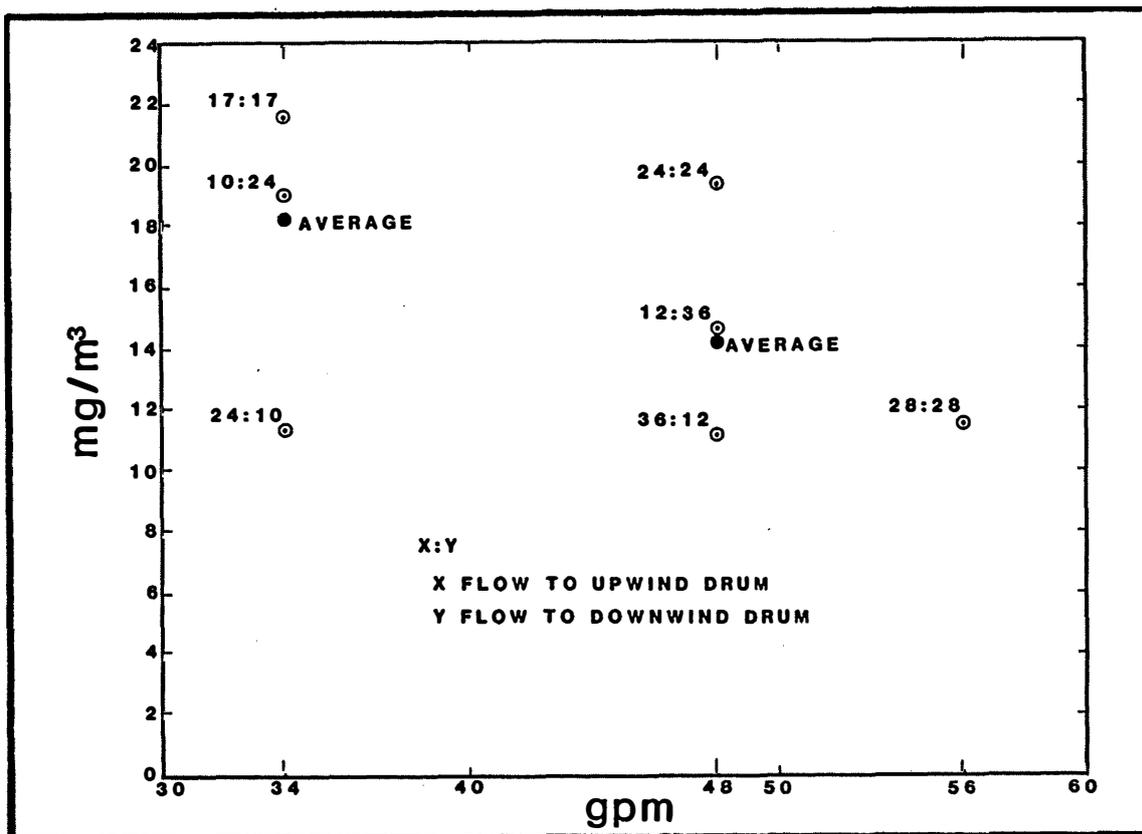


Figure 3-9  
Total Shearer Dust Make as a Function of Water Distribution  
(cutting with the air)

The distribution of water appeared to have inconsistent effects on the total dust make.

- Increasing the flow to the downwind drum appears to have no linear correlation with the average total dust concentrations. When comparing the dust concentration at the 24:10 and the 24:24 distributions from Figure 3-9, a positive correlation appears to exist. However, a comparison of the 10:24 and the 12:36 distributions indicates a negative correlation. Apparently, an increase in the flow through the downwind drum from 10 to 24 gpm resulted in an increase in the total dust make. An additional increase in the flow from 24 to 36 gpm resulted in a reduction in the total dust make.
- Increasing the flow to the upwind drum seems to generally reduce the total dust make. The improvement for an increase of flow from 10 gpm to 36 gpm is from 19.06 mg/m<sup>3</sup> to 11.19 mg/m<sup>3</sup> or 41.3 percent. The other data is depicted in Figure 3-9. This conclusion was verified through single and multiple regression analyses.

Generally, it seems that an increase in the flow through the leading downwind drum (which cuts most of the coal) should reduce the total respirable dust make more than an increase in the flow through the trailing upwind drum. However, the data does not entirely support this assumption. The initial increase in flow resulted in an increase in the total dust make at relatively low flows (<24 gpm) and subsequently reduced the total dust make at higher flows (>24 gpm). The correlation obtained at the low flows seems to reduce the validity of the assumption that higher flows/pressures tend to be more effective in controlling respirable dust.

When water was shifted from the downwind drum to the upwind drum, the total respirable dust make was reduced. The switch from a low flow on the upwind drum and a high flow on the downwind drum to the reverse situation resulted in an average 32 percent reduction in the total dust make (the difference was significant at a 97.5 percent confidence level). To further investigate the significance of the difference between favoring the leading drum or the trailing drum, the samples obtained with the 10:24 and 12:36 distributions taken together were compared with the samples obtained with the 24:10 and 36:12 distributions. Thus, the evidence is strong that shifting the water flow to the trailing upwind drum reduces total dust make.

The question now arises if this finding resulted from an increase of flow at the upwind drum or from a decrease in flow at the downwind drum or from both. This issue was addressed above and is now further investigated by plotting the total dust make as a function of the flow through one drum without consideration of the flow through the other drum. Total dust make as a function of the flow through the upwind drum is shown in Figure 3-10. Figure 3-11 shows total dust make as a function of the flow through the downwind drum. The following observations are made:

- ° No significant relationship can be proven to exist between the flow at the upwind drum and the total dust make; however, the data does seem to indicate a negative correlation.
- ° No linear relationship can be proven to exist between the flow at the downwind drum and the total dust make but a non-linear correlation may exist (as described above).

These same analyses were performed for a dust value (D minus A) obtained by subtracting the intake air dust (measured at Station A) from the dust measured at the tailgate (Station D). This dust measure is the dust concentration resulting from all dust sources between Stations D and A, mainly the shearer and the shield movement. These analyses are justified because of some uncertainty about the measurements at Station B (see Section 3.1). The relationship between D minus A and the flow through the downwind drum is not much different from the relationship between D minus B and this flow. However, at a significance level of 0.1, the relationship between D minus A and the flow through the upwind drum shows a statistically significant linear correlation (see Figure 3-12). The dust concentration decreases as the water flow through the upwind drum increases.

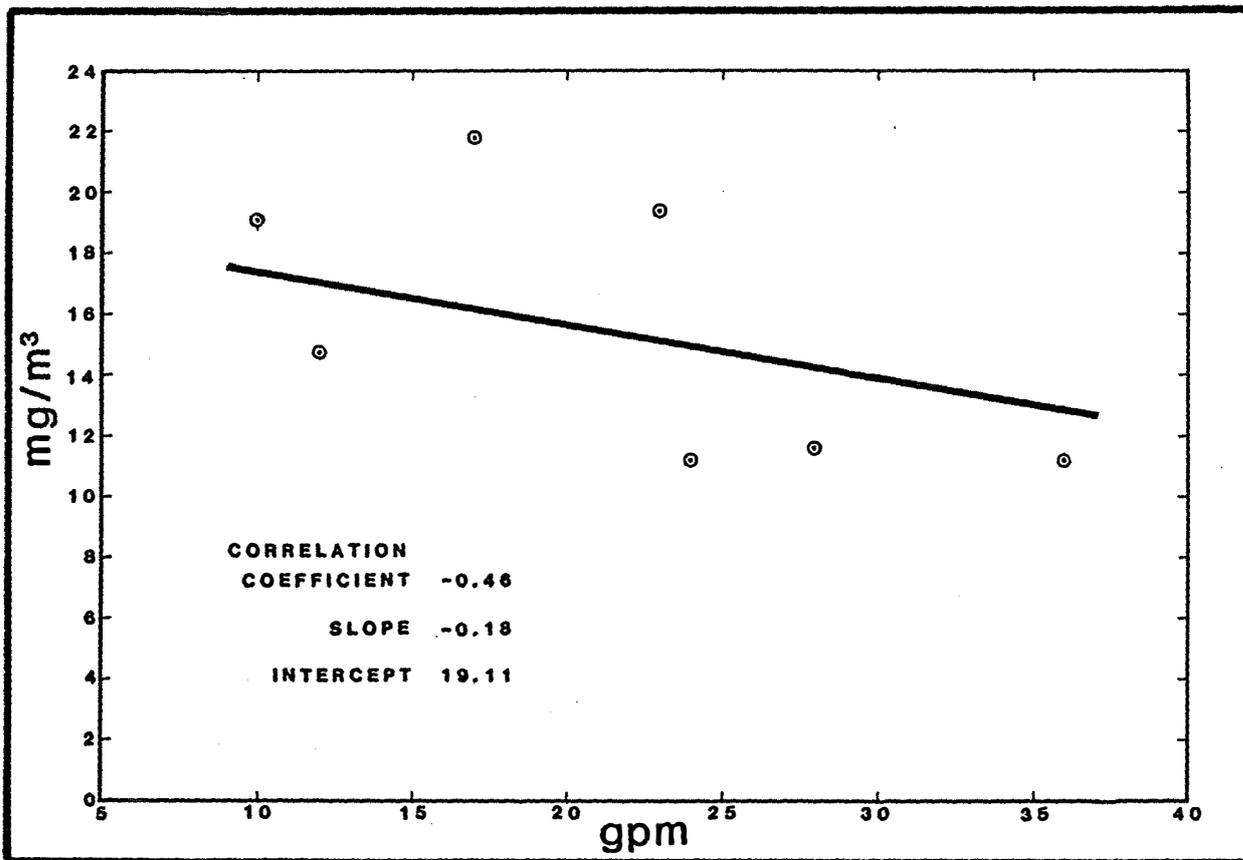


Figure 3-10  
 Total Shearer Dust Make as a Function  
 of the Flow Through the Upwind Drum

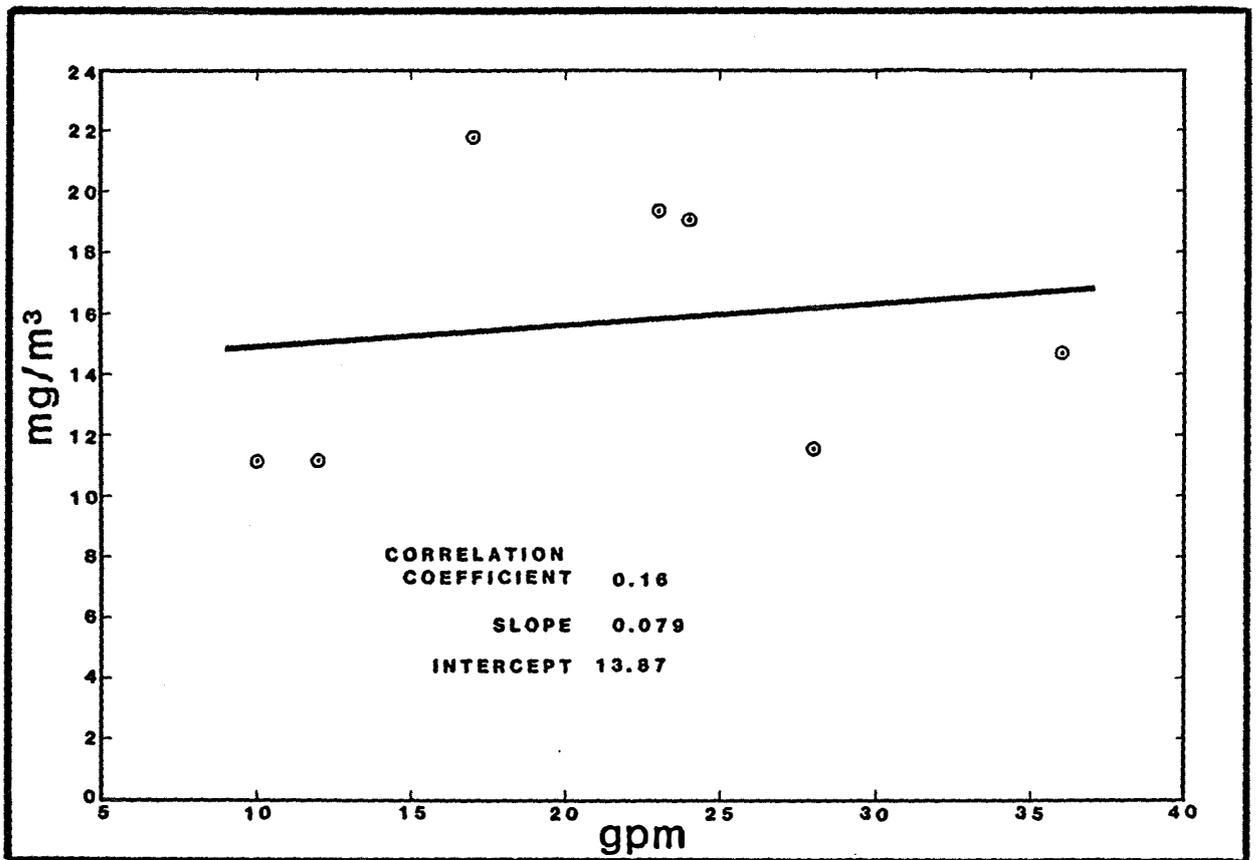


Figure 3-11  
 Total Shearer Dust Make as a Function  
 of the Flow Through the Downwind Drum

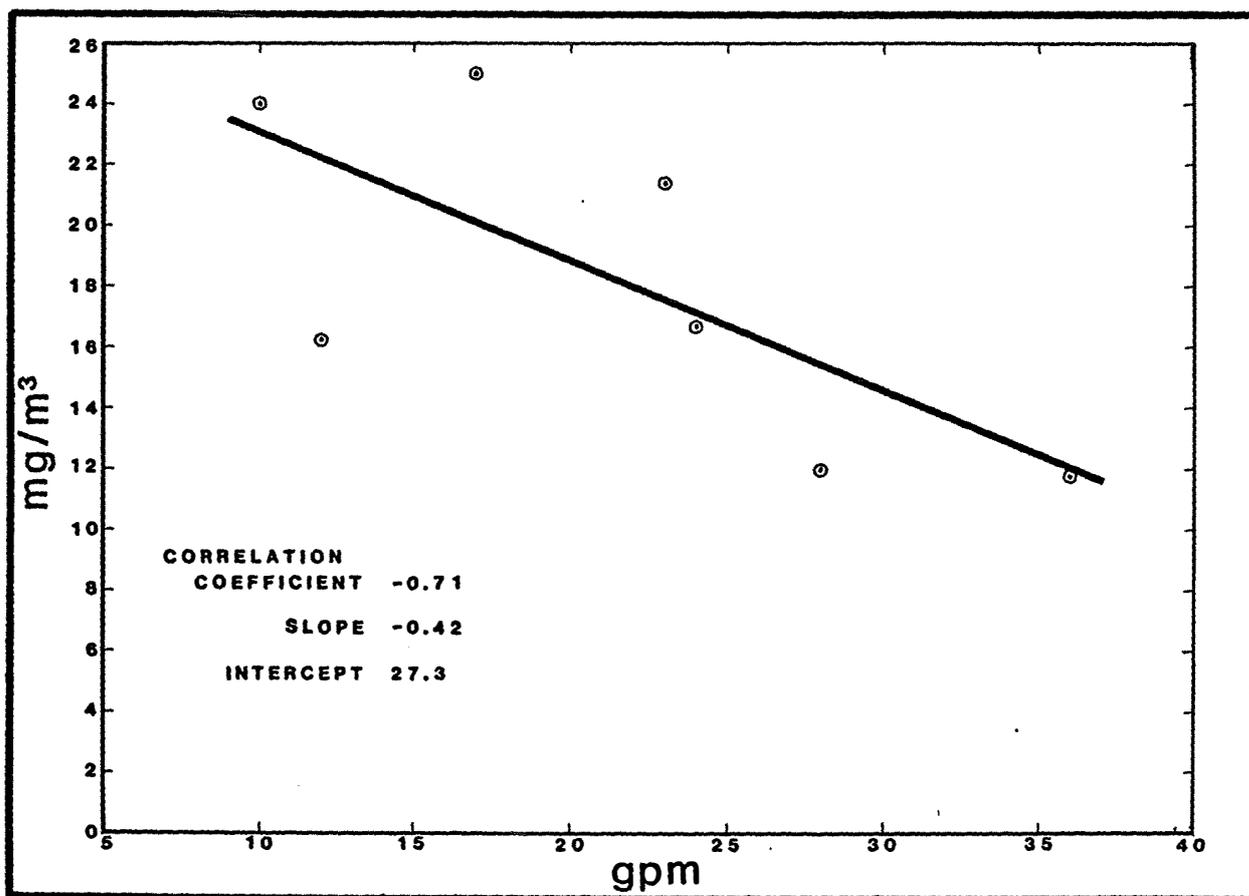


Figure 3-12  
 Total Dust Make Along the Face as a Function  
 of the Flow Through the Upwind Drum

Overall, it can be concluded that the observation that the total dust make is reduced when water is shifted from the downwind drum to the upwind drum results primarily from an increase in the flow through the upwind drum. The simultaneous reduction of the flow through the downwind drum contributes in an uncertain way to this result if there is a contribution at all.

### 3.4 Investigation of Downwind Operator Exposure to Shearer Dust

In this section, the effect of increasing and proportioning the water flow to the drums is examined with respect to the downwind drum operator dust exposure.

#### 3.4.1 Downwind Operator Exposure as a Function of the Flowrate

The mean dust concentrations of the gravimetric samples taken at each of the three drum flow levels (34, 48 and 56 gpm) with each flow distributed equally over the drums are shown in Figure 3-13. The data seem to

It is remarkable that at 34 gpm total flow, both the distribution favoring the downwind drum and the distribution favoring the upwind drum resulted in higher average dust concentrations than a distribution in equal flows.

Shifting the flow to the downwind drum appeared to increase the dust exposure, whereas a shift in flow to the upwind drum had little effect on the downwind operator dust exposure.

- ° A distribution favoring the downwind drum (12:36) will result in an increase in dust exposure of 50 percent when compared to a distribution in equal flows (24:24).
- ° Compared to a distribution favoring the upwind drum (36:12), the 12:36 distribution will result in an increase in dust exposure of 70 percent from 2.26 mg/m<sup>3</sup> to 7.49 mg/m<sup>3</sup>.

To further investigate the significance of the difference between favoring the leading drum and favoring the trailing drum, the samples obtained with the 10:24 and 12:36 distributions taken together were compared with the samples obtained with the 24:10 and 36:12 distributions. The difference between the two sets of samples was found to be statistically significant. Thus, there is rather strong evidence that shifting water from the leading (downwind) drum to the trailing (upwind) drum reduces dust exposure.

The question now arises if this finding resulted from an increase in the flowrate through the upwind drum or a decrease in the flowrate through the downwind drum. Figure 3-15 shows the dust exposure as a function of the flow through the upwind drum. Figure 3-16 shows the dust exposure as a function of the flow through the downwind drum. The following observations are made:

- ° No linear relationship can be proven to exist between the flow at the upwind drum and the dust exposure.
- ° A statistically significant linear relationship is present between the flow at the downwind drum and the dust exposure. The exposure increases as the flow through the downwind drum increases.

These same analyses were performed for a dust measure (C minus A) obtained by subtracting the intake air dust (measured at Station A) from the dust concentration measured in the walkway at the downwind drum (Station C). This dust measure can be interpreted as the downwind drum operator's exposure to both the shearer generated dust and the dust from moving the shields. These analyses are justified because of some uncertainty about the measurements at Station B (see Section 3.2).

The relationship between C minus A and the flow through the downwind drum is not much different from the relationship between C minus B and the flow. However, the relationship between C minus A and the flow through the upwind drum shows a statistically significant linear correlation (see

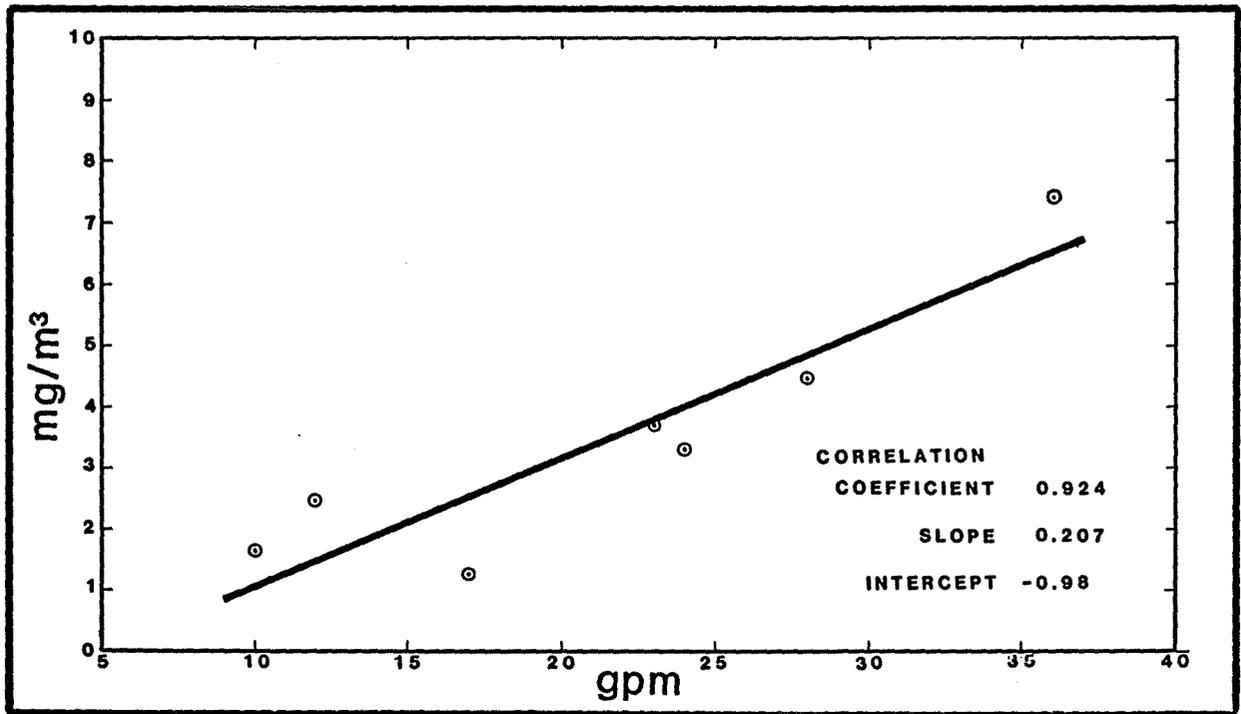


Figure 3-16  
Exposure to Shearer Dust as a Function  
of the Flow Through the Downwind Drum

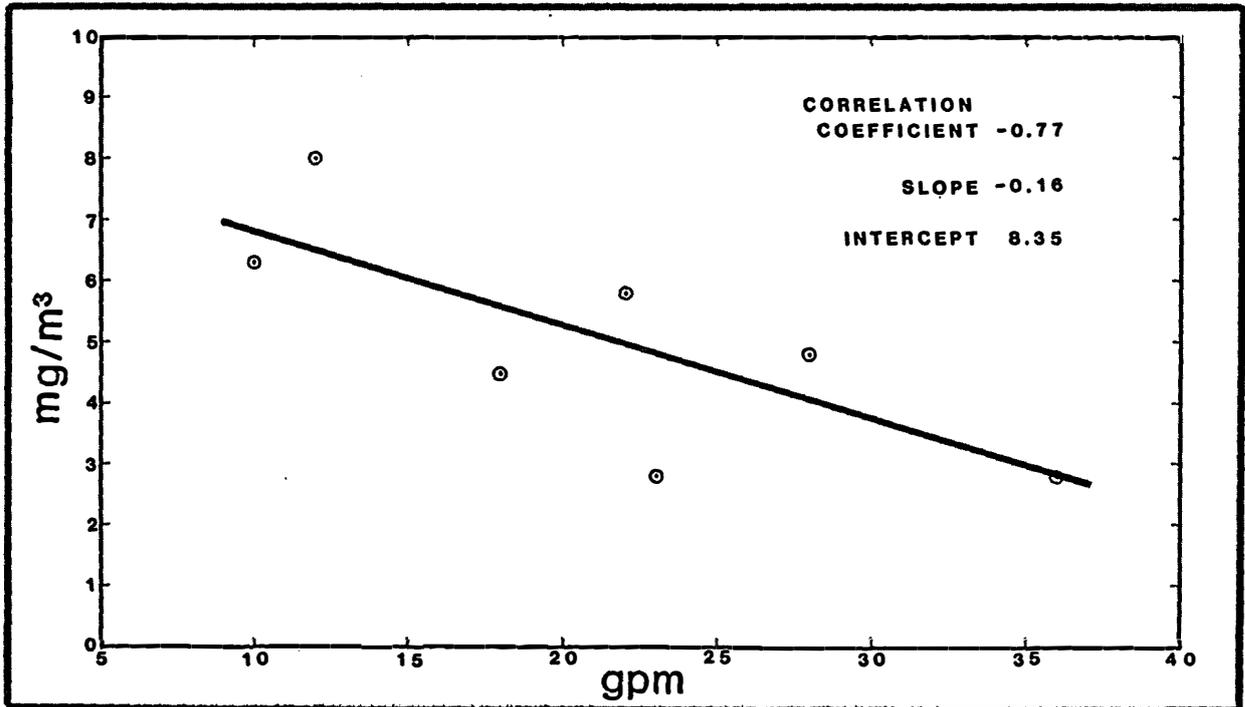


Figure 3-17  
Exposure to Dust Make Along the Face as a Function  
of the Flow Through the Upwind Drum

The multiple regression analysis described in Section 3.5.4, however, indicates a weak but positive correlation between the flow through the upwind drum and the dust exposure. This could indicate that the negative correlation shown in Figure 3-17 is the result of the correlation between the two drum flows and actually reflects the strongly positive correlation between the flow through the downwind drum and the dust exposure.

The data indicate that the flow through the downwind drum had a significant effect on the dust exposure. The fact that dust exposure was reduced when the flow at the (leading) downwind drum was reduced suggests that at this drum high flow rates (and spray pressures) push dust into the walkway. This drum is usually completely in the coal and one could expect that the water sprayed through this drum is immediately absorbed by the coal or at least that the operator is shielded from this water by the broken coal, the coal face and the cowl. It is possible that the webs taken were smaller than the width of the drums, leaving the gobside sprays on the drum unshielded. The same effect could have resulted from the face spalling ahead of the drum. If the gobside sprays were indeed unshielded, this went unnoticed by the observers. Moreover, the effect of unshielded sprays would more likely be exposure to spray mist than exposure to coal dust. Thus, it must be concluded that at the leading downwind drum, the broken coal is not a sufficient barrier in preventing coal dust from being pushed into the walkway by a spray water induced air movement. A possible reason for this is that not

much broken coal may be present at the top of the drum (assuming the drum cuts down). At the top of the drum (and at the bottom) the cut is most shallow and thus most of the dust will be generated there. Also, dust resulting from cutting top rock will be generated at the top of the drum.

### 3.5 Uncontrollable Variables

During the tests, three uncontrollable variables were measured:

- the air velocity,
- the shearer speed, and
- the quantity of water sprayed through "secondary sprays" (sprays not installed on the drums).

#### 3.5.1 Air Velocity

Air velocities were measured during the cutting passes normally above the spill plates. Figure 3-18 shows three typical velocity profiles along the face. No consistent features could be identified in these profiles.

During the first part of the test period, air velocities averaged 186 fpm, representing an air quantity of approximately 10,000 cfm.

Approximately halfway through the test period, a ventilation change occurred which increased the average air velocity to 256 fpm, representing a quantity of approximately 15,000 cfm. Actually, after the ventilation change was made, the air velocity steadily increased over a period of two weeks from 200 fpm to 325 fpm (19,000 cfm).

The improvement of the ventilation had a considerable effect in reducing the dust concentrations measured, as shown in Tables 3-6 and 3-7. In addition, the higher airflow reduced the boilover of spray water from the upwind drum. The sprays at the top of the drum rotation point upwind and are not completely shielded by the cut coal. Thus, at low air velocities, the water was sprayed a considerable distance upwind before the air current reversed the direction of the mist. As the mist was carried back over the shearer, the operators were exposed to a significant portion, which was clearly visible during the observations. It was feared that this mist was carrying so much dust that an increase of the water flow through the upwind drum would increase the dust exposure of the operators. The results of the analyses, however, are ambiguous on this point. Nevertheless, the mist presented an inconvenience to the operators, and this inconvenience was reduced when the ventilation was improved.

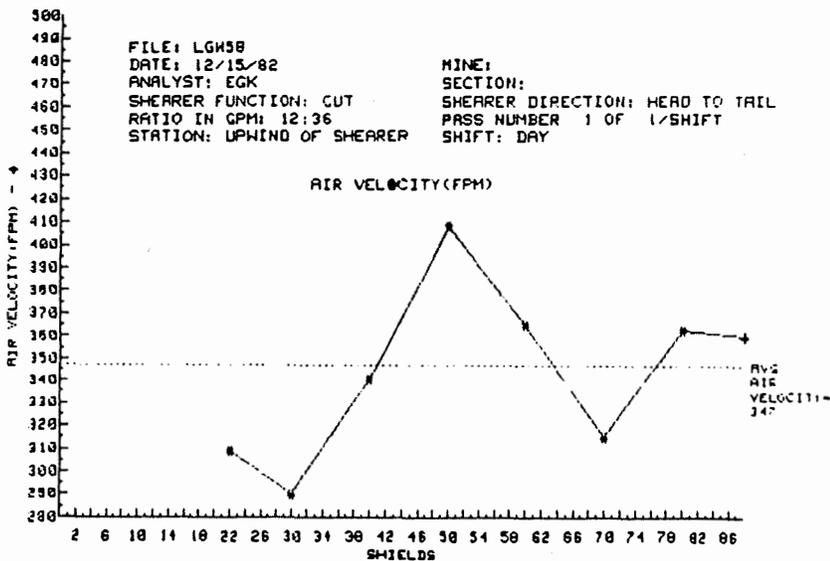
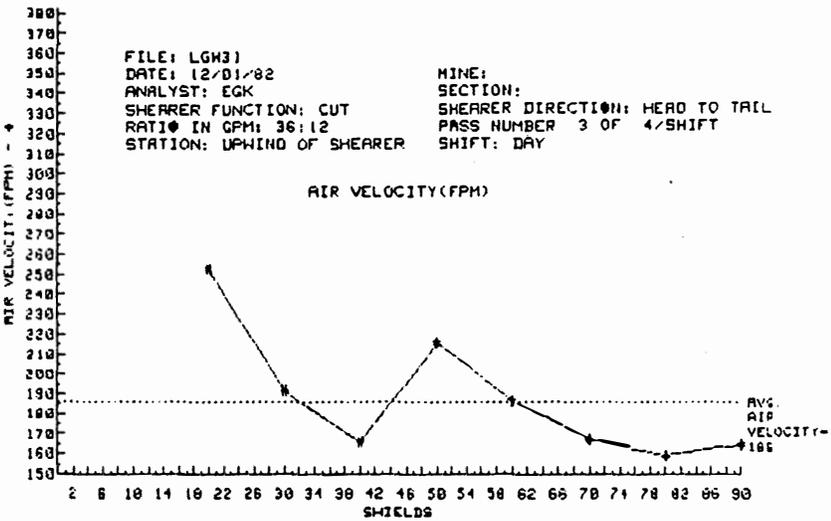
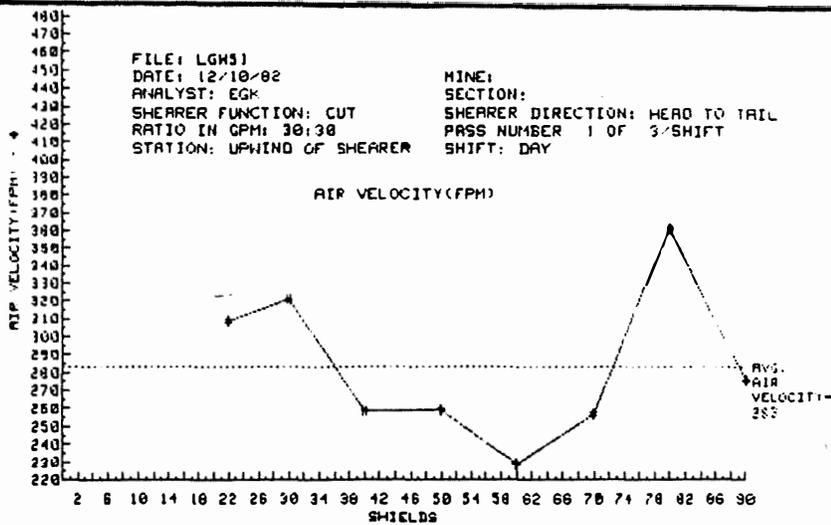


Figure 3-18  
 Examples of Air Velocity Profiles Along the Face

Table 3-6  
Examples of Total Shearer Dust Make Samples  
Before and After Ventilation Change

Water Flow Distribution (Head:Tail) in gpm	Low Velocity	High Velocity
12:36	20.00	11.11
12:36	21.32	6.58
28:28	14.39	10.71
28:28	15.29	8.18

Table 3-7  
Examples of Exposure to Shearer Dust Samples  
Before and After Ventilation Change

Water Flow Distribution (Head:Tail) in gpm	Low Velocity	High Velocity
12:36	8.16	5.28
12:36	10.26	5.93
28:28	6.40	2.30
28:28	7.28	3.45

Both before and after the ventilation change, a survey was made to determine the air velocity profile in the cross-sectional area perpendicular to the airflow. During both surveys, the shearer was at the headgate, the face was straight and the panline was pushed against the face. Measurements were made every tenth shield, starting at Shield No. 40, at five positions within each cross-sectional area. The average air velocities for each position are shown in Table 3-8.

The measurements indicate flowrates of 8,000 and 15,000 cfm before and after the ventilation change, respectively. In both cases, the resistance seemed lowest between the spillplates and the coal face. A considerable increase in friction was indicated in the shield area. At head level in the walkway, the air velocity was 16 percent lower than the average velocity above the panline. Although the air flow was turbulent, the dust generated by the shield movement may not have been fully dispersed throughout the cross-sectional area of the face before it reached the shearer and the operators, particularly if the shields were moved close behind the shearer. Therefore, adequate air velocities must be maintained in the walkway.

Table 3-8  
Average Air Velocities in Cross-Sectional Area

Before Ventilation Change			After Ventilation Change				
Vertical Location	Horizontal Location*			Vertical Location	Horizontal Location*		
	WW	SP	PL		WW	SP	PL
Top	147		176	Top	221		271
Middle		182		Middle		262	
Bottom	120		170	Bottom	207		274

\* Location: WW = Walkway; SP = Spillplate; PL = Panline

Because it appears that the shields did not contribute much to the operator dust exposure (Section 3.6), the measured cross-sectional variations in air velocity are not a major concern. The average air volume and velocity, however, need attention. They were relatively low during the study and only started to reach adequate levels at the end of the observation period. Volume, of course, is needed to dilute the airborne dust. Velocity is needed to better control the flow of contaminated air and to keep it away from the operators. The dispersion of dust from the downwind drum to the walkway at higher water flows would probably be reduced at higher air velocities.

### 3.5.2 Shearer Speed

The shearer speed was measured during the cutting passes by recording the incremental times for each 10 feet of shearer advance along the face. Figure 3-19 shows three typical shearer speed profiles along the face. No consistent features could be identified in these profiles. The average cutting speed during the study was 12 fpm with a standard deviation of 2.2 fpm. The average shearer speed during clean-up was 27 fpm.

The cutting speed of the shearer was variable due to a number of factors including:

- panline or outby haulage downtime
- clogging of panline
- cutting conditions (height, hardness, rock, etc.)

### 3.5.3 Water Sprayed Through the Secondary Sprays

The total water flowrate through the secondary sprays was not only a function of the total water flowrate through the drums and its distribution, but also of fluctuations in the performance of the water supply system. Because the total flowrate to the shearer was measured in addition to the flowrates through the drums, the flowrate through the secondary sprays could be calculated. The average flowrate through the secondary sprays during the study was 28 gpm with a standard deviation of 5.9 gpm. As will be

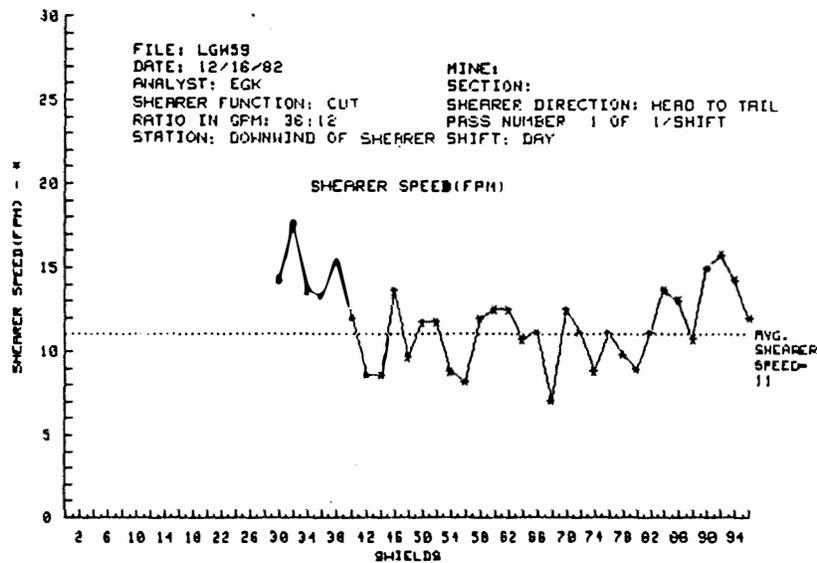
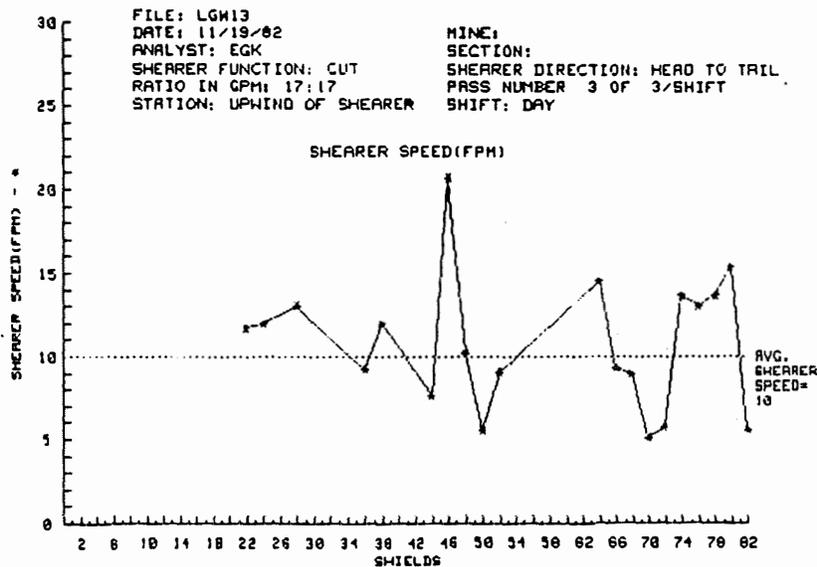
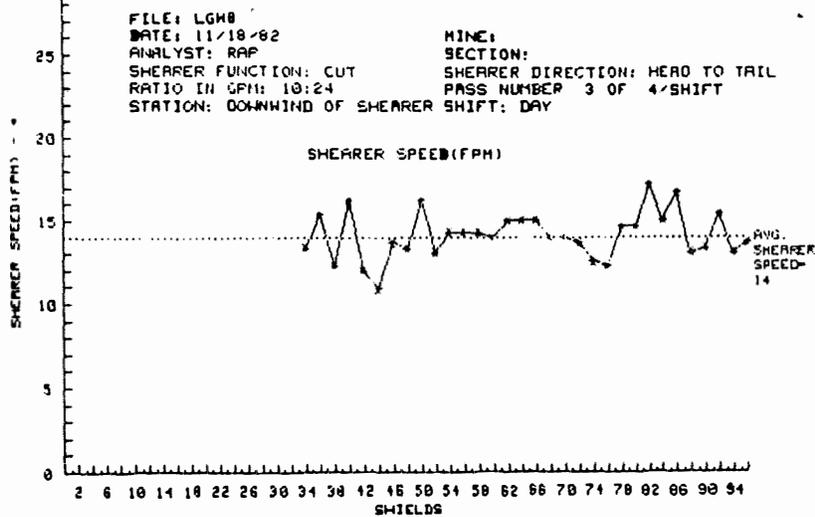


Figure 3-19  
 Examples of Shearer Speed Profiles Along the Face

shown in the following analysis, variations in this flowrate did not have much influence on the results of the study.

### 3.5.4 Multiple Regression Analyses

Multiple regression analysis of all available data was performed with the total shearer dust and the dust exposure as dependent variables and the following independent variables to assess the effect of each of these variables:

- air velocity,
- shearer speed,
- flowrate through the secondary sprays,
- flowrate through the downwind drum, and
- flowrate through the upwind drum.

In the regression analysis of the respirable dust exposure which included these five variables, only the estimated regression coefficients for the two drum flows and the shearer speed differed significantly from zero as shown in Table 3-9.

Table 3-9  
Regression Analysis Results for Respirable Dust Exposure

Independent Variable	Estimate of Coefficient	Probability that Coefficient is Zero	Standard Error of Estimate
Upwind drum flow	0.084	<0.1	0.048
Downwind drum flow	0.241	0.0001	0.048
Shearer speed	-0.343	<0.05	0.149

For proper interpretation of the regression results, it must be mentioned that the independent variables above were somewhat correlated among themselves. It was pointed out previously that the two drum flows were related ( $r = -0.53$ ). Also, the secondary spray flow was related to the flow through the upwind drum ( $r = -0.38$ ) and to the air velocity ( $r = -0.33$ ). These correlation coefficients differed from zero at the 0.1 level of significance. When independent variables are highly correlated, the estimated regression coefficients tend to vary widely from one sample to the next. Because the interdependence here is not very strong, it can be concluded with some reservation that:

- The dust exposure is weakly and positively correlated with the flow through the upwind drum. This is an interesting finding when compared to the single regression analysis (Figure 3-15) which showed an equally weak but negative correlation. This provides a possible indication that the negative correlation

found in the single regression analysis is actually the result of the correlation between the two drum flows as described in Section 3.4.2.

- The dust exposure is more sensitive to changes in the flow through the downwind drum than to changes in the flow through the upwind drum. This is also indicated by the single regression analyses in Section 3.4.2.

The variability in the dust exposure was 64 percent accounted for by the five variables. The downwind drum flow accounted for 48 percent of this variability. Stepwise regression with a 0.15 significance level for entry resulted in the model shown in Table 3-10 which accounts for 55 percent of the variability in the dust exposure.

Table 3-10  
Stepwise Regression Model for Respirable Dust Exposure

	Estimate of Coefficient	Probability that Coefficient is Zero	Standard Error of Estimate
Intercept	3.214		
Downwind drum flow	0.180	0.0001	0.035
Shearer speed	-0.295	<0.1	0.153

It can be concluded that:

- A one gallon per minute reduction in the flow through the downwind drum is expected to reduce the dust exposure an average 0.18 mg/m<sup>3</sup>.
- A one foot per minute increase in the shearer speed is expected to reduce the dust exposure an average 0.30 mg/m<sup>3</sup>.

In the regression analysis of the total respirable dust make which included the five independent variables listed above, only the estimated regression coefficient for the air velocity differed significantly from zero as indicated in Table 3-11.

Table 3-11  
Regression Analysis Results for Total Respirable Dust Make

Independent Variable	Estimate of Coefficient	Probability that Coefficient is Zero	Standard Error of Estimate
Air Velocity	-0.063	<0.005	0.018

The variability in the total shearer dust make was 52 percent accounted for by the five independent variables. The air velocity accounted for 44 percent of this variability. Stepwise regression with a 0.15 significance level for entry resulted in the model shown in Table 3-12 which accounts for 51 percent of the variability in the total shearer dust make.

Table 3-12  
Stepwise Regression Model for Total Respirable Dust Make

	Estimate of Coefficient	Probability that Coefficient is Zero	Standard Error of Estimate
Intercept	32.722		
Upwind drum flow	-0.162	<0.1	0.085
Air velocity	-0.064	<0.001	0.017

This indicates that:

- The flow through the downwind drum had a negligible effect on the total dust make.
- A one gallon per minute increase in the flow through the upwind drum is expected to reduce the dust concentration resulting from the total shearer dust make an average 0.16 mg/m<sup>3</sup>.
- A 10 fpm increase in the air velocity is expected to reduce this dust concentration an average 0.64 mg/m<sup>3</sup>.

### 3.6 Estimate of Production Capacity

Most of the gravimetric dust samples on which the analyses in the previous sections are based were taken only while the shearer was cutting and are not eight hour compliance test samples. Based on a water distribution of 28 gpm to both drums (the normal distribution in this section), Table 3-13 shows the average dust concentrations, per dust source, to which the downwind operator was exposed. This table also shows an estimate of the average exposure of the operator during a mining cycle of 72 minutes (42 minutes cutting, 18 minutes clean-up and 6 minutes turnaround time at each of the face ends).

The data show that most of the dust is generated by the shearer during the cutting pass. The second largest contributor to the dust exposure is the stage loader/transfer point.

The average exposure of the downwind operator during a 72 minute mining cycle is calculated to be 4.4 mg/m<sup>3</sup> (see Table 3-13). Based on this calculation, it can be shown that the section can average a maximum of 2.9 cutting cycles of 72 minutes per shift to stay in compliance.

Table 3-13  
 Estimate of Operator Exposure During  
 72 Minute Cycle and 28 GPM to Both Drums

Source	Amount (mg/m <sup>3</sup> )	x	Time Fraction of Mining Cycle	=	Contribution (mg/m <sup>3</sup> )	% of Total
Section Intake	<0.1	x	1.00	=	<0.1	<2
Stage Loader and Transfer Point	1.0	x	1.00	=	1.0	23
Shield Movement and Conveyor (cutting pass)	0.5	x	0.58	=	0.3	7
Shearer (cutting pass)	4.3	x	0.58	=	2.5	57
Shearer and Conveyor (clean-up pass)	1.9	x	0.25	=	<u>0.5</u>	11
Exposure of the downwind operator during a 72 minute cycle					4.4	

If water was redistributed so that 24 gpm would be sprayed through the upwind drum and 10 gpm through the downwind drum, the dust exposure caused by the shearer would expect to drop from 4.3 mg/m<sup>3</sup> to approximately 2.0 mg/m<sup>3</sup> during the cutting pass. The dust generated by the conveyor should also increase. Table 3-14 shows that the average exposure of the operator during a 72 minute cycle would be 3.3 mg/m<sup>3</sup> instead of 4.4 mg/m<sup>3</sup>. The section could now average a maximum of 3.9 cutting cycles (72 minutes) per shift to stay in compliance. This represents a production improvement of 34 percent.

If, in addition, the contribution of the stage loader/transfer point was reduced 50 percent, the operator exposure during the cycle would be 2.7 mg/m<sup>3</sup> and 4.8 cutting cycles could be completed per shift while remaining in compliance.

Table 3-14  
 Estimate of Operator Exposure During 72 Minute Cycle;  
 24 GPM to the Upwind Drum; 10 GPM to the Downwind Drum

Source	Amount (mg/m <sup>3</sup> )	x	Time Fraction of Mining Cycle	=	Contribution (mg/m <sup>3</sup> )	% of Total
Section Intake	<0.1	x	1.00	=	<0.1	3
Stage Loader and Transfer Point	1.0	x	1.00	=	1.0	30
Shield Movement and Conveyor (cutting pass)	0.8	x	0.58	=	0.5	15
Shearer (cutting pass)	2.0	x	0.58	=	1.2	36
Shearer and Conveyor (clean-up pass)	1.9	x	0.25	=	<u>0.5</u>	16
Exposure of the downwind operator during a 72 minute cycle					3.3	

### 3.7 Conclusions and Discussion

This study has provided statistical evidence of some important features of the dust suppression system of the observed longwall mining section. The major observations were:

#### Total Shearer Dust Make

- ° Total shearer dust make was reduced when the flow through the upwind drum was increased.
- ° The flow through the downwind drum had a positive correlation at relatively low flows and a negative correlation at higher flows.
- ° Consequently, the total shearer dust make was reduced when water was shifted from the downwind drum to the upwind drum.
- ° Because the total dust make was more sensitive to changes in the flow through the upwind drum than to changes in the flow through the downwind drum, the net effect of an increase of the total flow, with the total flow distributed equally between the drums, was a decrease in total dust make.

Operator Exposure to Shearer Dust

- Dust exposure was reduced when the flow through the downwind drum was reduced.
- The effect of changes in the flow through the upwind drum on the dust exposure was minimal.
- Consequently, the exposure was reduced when water was shifted from the downwind to the upwind drum.
- Because the dust exposure was more sensitive to changes in the flow through the downwind drum than to changes in the flow through the upwind drum, the net effect of an increase of the total flow, with the total flow equally distributed between the drums, was an increase of the dust exposure.

The above conclusions suggest that at high flowrates (and pressures) through the downwind drum, coal dust was actually pushed into the walkway as described in Section 3.4.2.

All of the conclusions presented so far can be illustrated in the form of a figure. Figure 3-20 is a combination of four graphs each representing the flow through either the upwind or downwind drum versus the downwind drum operator exposure or the total shearer dust make.

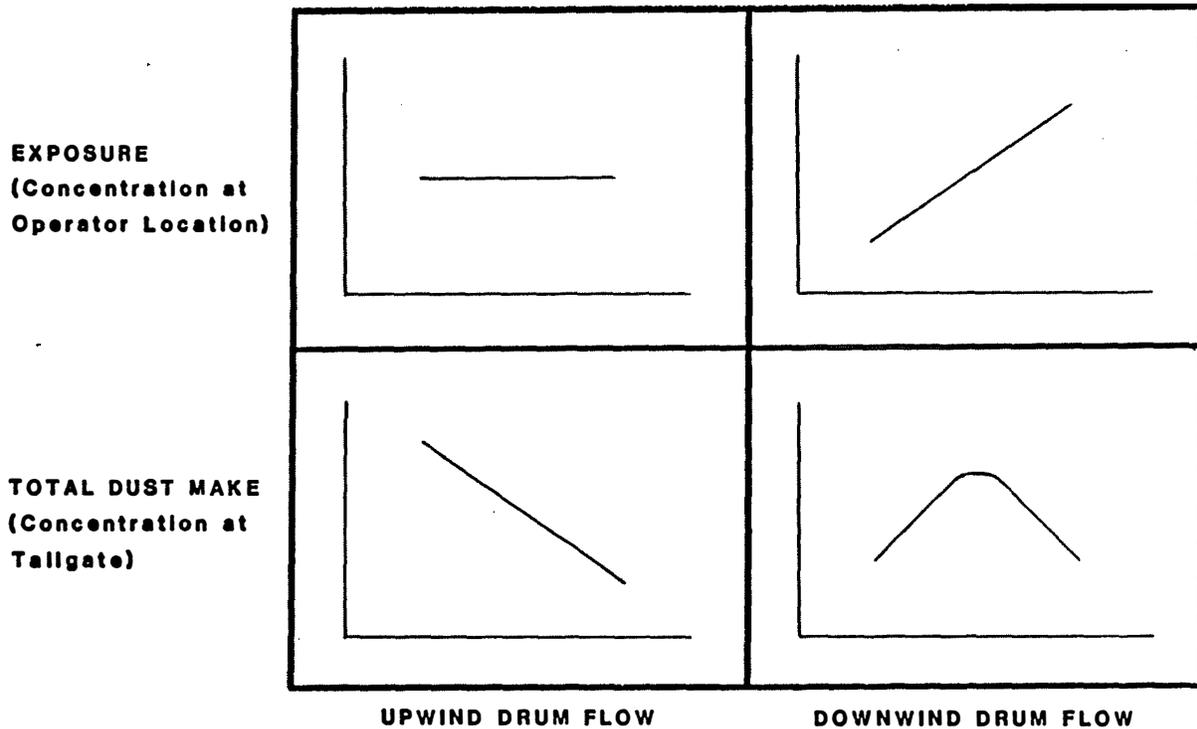


Figure 3-20

Exposure and Total Dust Make as Functions of the Flows at Each Drum;  
Cutting with the Air (Downwind Drum is Leading)

The data indicate that the flow through the downwind drum had a significant effect on the dust exposure. With respect to this finding, it must be remembered that the dust exposure was measured at a location near the downwind drum. In this particular section, the operator frequently moved downwind from the controls to be able to better observe the cutting action of the drums. Although this is also practiced in some other sections, in many sections the downwind operator remains at the controls and exposure to dust from the downwind drum is unlikely, provided there is sufficient ventilation and the external spray system is operating properly.

The fact that dust exposure was reduced when the flow at the (leading) downwind drum was reduced suggests that at this drum high flow rates (and spray pressures) push dust into the walkway. This explains why the dust exposure increased when the flow through the downwind drum was increased. But this increase in flow resulted in an increase in the total dust make at relatively low flows and reduced the total dust make at higher flows. The observation at relatively low flows runs counter to the research findings that higher flows/pressures are more effective. The observations and the research findings suggest the presence of two counteracting variables: (1) the potential effectiveness of the sprays and (2) the exposure time of the airborne dust to the spray water. It can be hypothesized that at relatively low flows, an increase in flow on the downwind drum may increase the effectiveness of the sprays, but not sufficiently to counteract the effect of a reduced exposure time of the dust to the spray water (due to an increase in the velocity of the axial air flow around the drum). Thus, more dust becomes airborne and more dust is pushed into the walkway. As the flow through the downwind drum is increased, the effect of the higher effectiveness of the sprays overtakes the effect of the increased axial airflow velocity. Thus, less dust enters the atmosphere, although increasingly more dust is pushed into the walkway. This hypothesis suggests that the dust exposure will also reach a maximum (and subsequently decline) as the flow through the downwind drum is increased. This maximum, if it exists, was apparently not reached within the range of water flows used during this study.

The non-linear relationship between the total respirable dust make and the flow through the downwind drum also helps explain another non-linear relationship, namely between the total dust make and the total flow (with the flow equally distributed between the drums). Apparently, an increase in total flow at a low flow level resulted in a decrease in total dust make due to the flow increase at the upwind drum outweighing the increase in total dust make due to the flow increase at the downwind drum. At higher flow levels, an increase in flow on either drum resulted in a decrease in total dust make.

At the upwind drum an increase in flow and pressure tended to reduce the total dust make and resulted in ambiguous findings with respect to the dust exposure. The theory outlined above can also explain these results. The difference in the findings for the two drums could be the result of a quantitative difference in the two previously described counteracting effects. Because the upwind (trailing) drum was not completely

enclosed, the axial air movement was not as significant. The effect from the exposure time reduction did not balance the improved dust suppression at higher flows, resulting in a lower dust level at the tailgate.

The downwind operator is exposed to two different dust flows from the upwind drum: (1) a flow crossing over the shearer (this flow decreased as the spray flow increased because the overall dust level decreased) and (2) a flow due to the spray induced axial air movement (this flow increased as the spray flow increased). During our observations, the changes in these flows were apparently in balance resulting in a zero net change at the operator's location.

The airflow causing boilover of dust into the walkway is a serious problem for more than one reasons. It not only carries dust directly from the drums into the walkway, but also disturbs the major airflow along the face and thus reduces the effectiveness of any attempt to provide a clean split of air for the operators.

At this time, the causes of the boilover can only be hypothesized. Possibly, the effect must be contributed to the fanning action of the drums. In addition, drum spray induced airflows apparently contribute, possibly because drum sprays are mounted under an angle toward the gob on many drum designs. It should also be noted that the boilover problem can be reduced by increasing the air velocity along the face and by a purposeful design of the external spray system.

On the basis of the evidence available so far, the following conclusions were presented. Because only data was analyzed for the shearer cutting in the direction of the airflow, the conclusions only apply to that situation.

#### When shearer operator is the designated occupation

- ° The flow and/or pressure at the downwind drum should be reduced. If the downwind operator frequently is near the drum to observe the cutting operation, boilover from the downwind drum may directly or indirectly (through deflection of the airflow over the shearer) be a significant contributor to the dust exposure. If the operator remains at the controls, the contribution of the downwind drum to the dust exposure is negligible and water sprayed at this drum is not very effective.
- ° At this time, no firm recommendations can be made with respect to the optimum flows and pressures at the upwind drum. The effect of increasing the flow and pressure at this drum depends on the extent of the boilover problem and thus is a function of the height of coal being mined by this drum relative to the drum diameter, the design of the drums and the internal and external spray systems and the ventilation. The flow should be increased if boilover is not a problem or if the problem can be eliminated, for instance by changing the spray orientation or

by reducing the spray pressure. In the absence of boilover in the section studied, for instance, a 40 percent increase in flow at the upwind drum is expected to result in a 40 percent reduction in the operator exposure to the dust produced by this drum. This expectation is based on the fact that total dust make was reduced by this percentage.

When the designated occupation is downwind of the shearer

- ° Flow and pressure at the upwind drum should be increased. Boilover, however, may reduce the incremental effect and counteractive measures may be necessary.
- ° The flow at the downwind drum should be kept low, unless a sufficient amount of water can be sprayed to overcome the initial negative effect on total dust make when the flow is increased. A high flow could have the advantage of reducing the dust make at the stage loader and the transfer point.

## 4.0 EVALUATION OF SHEARER WATER DISTRIBUTION VARIATIONS

### 4.1 Introduction

The second part of the Phase III effort focused on testing the effect of increasing the flow rate to the shearer drums while maintaining a constant pressure at the drums. In previous tests, an increase in flow was accompanied by an increase in the pressure measured at the sprays. Although it has been established that an increase in pressure alone improves the effectiveness of the sprays, the increased boilover provides a negative effect on the operator exposure which can completely eliminate the advantage. The tests were made to establish the effectiveness of increasing the flow without increasing the pressure at the sprays.

The testing amounted to an A-B comparison between the existing conditions on the shearer and the conditions present after some modifications. The modifications to the shearer were specifically done on the drum water distribution lines to decrease the pressure drop and increase the flow. The external sprays on the shearer clearer spray bar were also decreased to limit the observed turbulence between the drum sprays and the external sprays. These changes provided an incremental increase in flow and also a decrease in pressure at the drums. The decrease in pressure at the drums was due to the larger increase in pressure drop across the remainder of the water distribution system. The changes also redistributed the total quantities of water to each subsystem of the shearer which will be described in Section 4.2.2.

One week of testing was carried out under the existing conditions on the longwall face. The test of the existing conditions will be referred to as Test A. The modifications were made to the shearer following Test A and a second week of testing was completed. This test will be referred to as Test B.

One longwall section was selected for the evaluation, herein referred to as Site C. The following material describes the site in detail and presents the results of the testing and subsequent analysis.

### 4.2 Site C Information

#### 4.2.1 Mine Characteristics

The mine selected for the Site C testing mined coal in the Powellton coal seam and was located in southern West Virginia. The survey was performed from April 15 through April 26, 1985, during the day shifts.

The 13 Right longwall section was located at a depth of approximately 1,000 feet. The coal was approximately six feet thick which included three relatively soft binders which were one to three inches thick. The shearer typically cut the six foot seam with little or no top or bottom rock at a web depth of 24 to 30 inches. The roof rock was a variable layer of

shale ranging from one inch to one foot overlain by massive sandstone. The bottom rock was a shale.

The shearer was a Joy Manufacturing LLS-5 double drum shearer. The drums were 54 inches in diameter, 30 inches wide with a rotational speed of 57 rpm. Each drum utilized 38 picks along with 36 sprays arranged on two vanes with pick face flushing. The sprays were a full-cone type with an orifice of 1/16 of an inch.

The water supply system in the section used a Sunflow centrifugal pump rated for 120 gpm at 450 psi. The water line from the pump comprised 700 feet of 2 inch hose with an additional 300 feet of 1-1/2 inch hose which was encased in the cable handler. The system provided a pressure of 200-250 psi at the shearer and a flow of 60-68 gpm.

In addition to the drum sprays, the shearer was equipped with a spray bar and venturi cooling sprays arranged on the top of the machine. The spray bar was located on the upwind drum and consisted of eight full-cone sprays pointed downwind. Four venturi blocks sprayed cooling water from atop the shearer. One block was not used and two out of the remaining three only had one spray operational. Cooling water flow to the venturis was in the range of 12 to 14 gpm.

The longwall face was approximately 520 feet long. Shearing was done bidirectionally, full-face with no clean-up pass. The sumps were completed near the headgate and tailgate at approximately shields 20 and 90, respectively. The shields were moved approximately 40 feet behind the shearer on the head-to-tail passes and adjacent to the downwind drum on a tail-to-head pass.

The shearer averaged 7 to 8 cutting passes per shift which represented approximately 2300 raw tons per shift. The total cutting time from sump to cut out was determined to be 34 minutes. Each pass usually included approximately 4 minutes of delay time including panline and outby haulage problems. The average total cycle time for one cutting pass, including delays, was 38 minutes.

The shearer advance speed was monitored by recording the clock time every ten feet of shearer advance. The speed averaged 20 feet per minute during the testing and remained fairly stable.

The face ventilation was antitropical with an average of 154 fpm in the head-to-tail direction and 173 fpm in the tail-to-head direction. The air quantity averaged 8300 cfm. The ventilation remained stable during both tests (A and B) and showed only minor variations.

#### 4.2.2 Shearer Water Distribution

For Test A, the existing water distribution was used. Flow and pressure meters were installed on the shearer to monitor the changes during

the testing. The meters were installed on the main water inlet to the shearer and on each individual cutting drum circuit.

The water distribution on the shearer for Test A is illustrated in Figure 4-1. After the modifications discussed previously, the water distribution changed. The resulting changes are depicted in Figure 4-2. The major change was the substantial increase to the drum circuits. A large increase was made on the downwind drum and a small increase was made to the upwind drum. The changes were not planned with this in mind but were done to increase the total quantity of water to the drums. The characteristics of the individual drum circuits caused the increase to be more substantial on the downwind drum. Both the spray bar and the cooling flow decreased accordingly following the modifications.

Table 4-1 summarizes all the flows and pressures for each day of testing. They are also listed under the appropriate test, A or B. Looking closely at the data, there are some abnormal variations in the flows and pressures. For instance, on April 15, the downwind drum only had a flow of 12 gpm. This was due to the clogging of the sprays on the drums. Only about 10 to 20 percent of the sprays were operational. On the remaining sampling dates for Test A, only small variation occurred in the flows on the shearer. The pressures remained fairly stable except for the anomaly on April 19. The reason for this pressure increase was not evident to the observers.

The data for Test B is compiled in the second column of Table 4-1. Again, there was a problem on the first day of sampling (4/22/85). The downwind drum flow was extremely low due to the presence of a broken venturi spray in the cooling circuit near the drum. The flow could not be shut off because of the necessity of the cooling water. The spray was not repaired until the following shift. The remaining data for Test B remained fairly constant.

Because of the low flows on the downwind drum on 4/15 and 4/22, only the data for the remaining four days was used. The average flows and pressures on the shearer for the remaining days are compiled in Table 4-2.

From the data, a 6 percent increase in the total water flow to the shearer was obtained. The upwind drum flow increased 8 percent and the downwind drum increased 55 percent. The increases were not only due to the increase in flow to the shearer but mainly because of the redistribution of water from the spray bar and the cooling circuit to the drums as was illustrated in Figures 4-1 and 4-2.

The delivery pressure dropped considerably on the drum circuits. The pressure at the upwind drum decreased 35 percent while the pressure at the downwind drum decreased 51 percent. The overall pressure on the shearer inlet only dropped 9 percent. This decrease in pressure was due to the increase in pressure drop across the entire water distribution for the long-wall section.

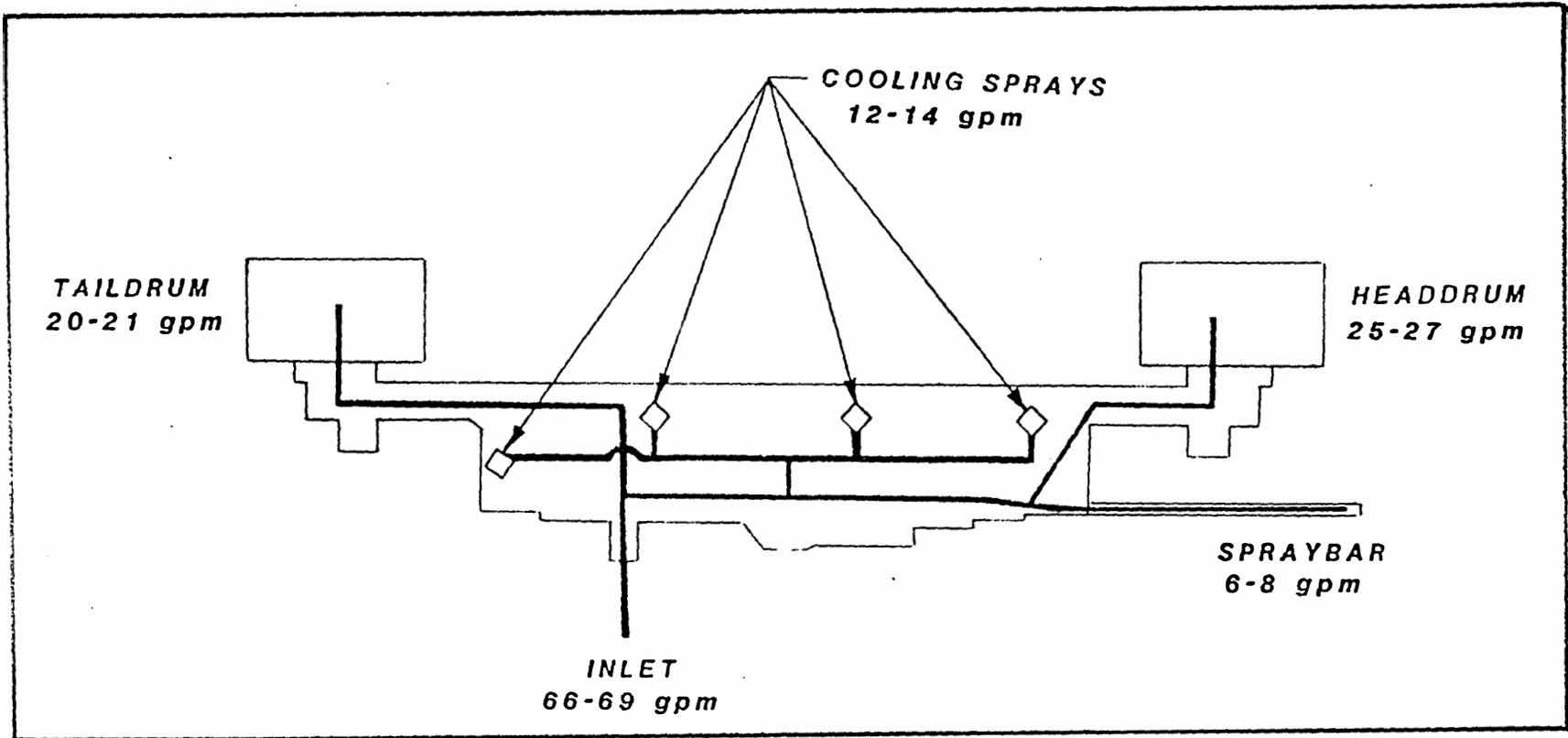


Figure 4-1  
Original Shearer Water Distribution (Test A)

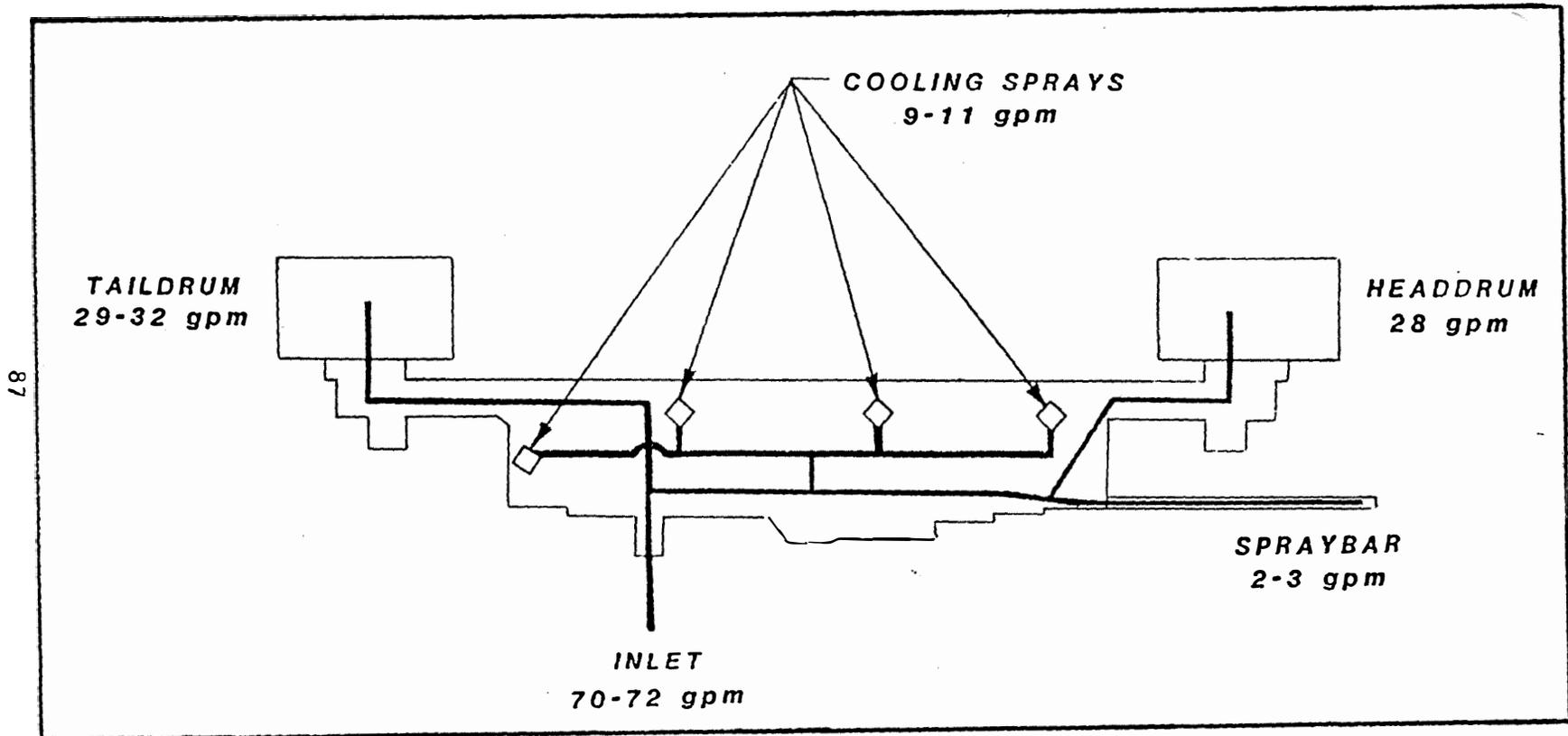


Figure 4-2  
Shearer Water Distribution After Modifications (Test B)

Table 4-1  
Water Flow and Pressure Summary

Test A		Test B	
Date:	4/15/85	Date:	4/22/85
Total:	59 gpm at 250 psi	Total:	65 gpm at 240 psi
Upwind Drum:	24 gpm at 150 psi	Upwind Drum:	28 gpm at 110 psi
Downwind Drum:	12 gpm at 170 psi	Downwind Drum:	10 gpm at 140 psi
Date:	4/16/85	Date:	4/23/85
Total:	69 gpm at 205 psi	Total:	70 gpm at 200 psi
Upwind Drum:	25 gpm at 100 psi	Upwind Drum:	28 gpm at 70 psi
Downwind Drum:	20 gpm at 125 psi	Downwind Drum:	29 gpm at 70 psi
Date:	4/17/85	Date:	4/24/85
Total:	66 gpm at 200 psi	Total:	71 gpm at 200 psi
Upwind Drum:	26 gpm at 100 psi	Upwind Drum:	28 gpm at 70 psi
Downwind Drum:	20 gpm at 125 psi	Downwind Drum:	30 gpm at 65 psi
Date:	4/18/85	Date:	4/25/85
Total:	66 gpm at 220 psi	Total:	70 gpm at 200 psi
Upwind Drum:	27 gpm at 110 psi	Upwind Drum:	28 gpm at 75 psi
Downwind Drum:	21 gpm at 150 psi	Downwind Drum:	32 gpm at 70 psi
Date:	4/19/85	Date:	4/26/85
Total:	67 gpm at 255 psi	Total:	72 gpm at 200 psi
Upwind Drum:	25 gpm at 150 psi	Upwind Drum:	28 gpm at 85 psi
Downwind Drum:	20 gpm at 180 psi	Downwind Drum:	32 gpm at 80 psi

Table 4-2  
Average Water Flow and Pressure for Tests A and B

Measurement Location	Test A		Test B	
	Flow (gpm)	Pressure (psi)	Flow (gpm)	Pressure (psi)
Shearer Inlet	67	220	71	200
Upwind Drum	26	115	28	75
Downwind Drum	20	145	31	71

#### 4.2.3 Data Collection and Analysis

The purpose of the study was to assess the effect of increasing the water flows to both drums on the shearer on the respirable dust concentrations. To do this, the overall water distribution was adjusted through a

shearer modification. The original intent was to maintain constant pressure while increasing the flows. However, due to conditions and constraints in the operating section, this was not possible. Subsequently, the pressure also changed.

A two week test was carried out. The first week of testing (Test A) was based on original water flows and pressures on the shearer. The conditions for the second week (Test B) were changed by modifying the plumbing on the shearer and changing the resulting water distribution. By doing this, increases in water flows to the drums were realized. Pressures available to the drums also dropped proportionally. Details of the existing water flows and the modifications were explained in Section 4.2.2.

The majority of data presented in this section resulted from respirable dust samples taken only while the shearer was cutting. These samples are not eight hour compliance test samples and the respirable dust concentrations presented in this report cannot be directly related to the compliance limit of  $2 \text{ mg/m}^3$ . However, in Section 4.4.2 an estimate of the exposure at the shearer midpoint is calculated. All the data in the analyses refer to respirable dust concentrations.

The general sampling plan for the testing can be found in Appendix A. The following text expands on the general plan in more detail.

Respirable dust samples were taken with the shearer cutting in both directions. Ventilation was antitropal (directed from headgate to tailgate). The shields were moved upwind of the shearer during the head-to-tail pass and over the tailgate side drum during the tail-to-head pass.

The sampling procedure used is based on the fact that the dust concentration measured at any location along the face is a composite of all dust sources upstream of that location. Five dust sampling stations were used. Figure 4-3 shows the location of dust sample stations. Stations A, B and E were stationary, Stations C and D moved with the shearer. Station A measured the dust level in the intake air of the section. Station B was at Shield No. 10 and measured the dust level in the intake air to the face which included dust from the stage loader and the transfer point. Station C was intended to be sufficiently upwind of the shearer in order not to contaminate the sample with dust from the shearer, and sufficiently downwind of the shield movement to obtain a measurement of the dust resulting from the shield advancement (C minus B). Station D was located at the midpoint of the shearer. The samples taken here provided an approximation of the dust exposure of the shearer operators. Station E was located at Shield No. 102 and measured the total dust produced along the face.

In this section, E minus C is interpreted as the dust concentration resulting from the total dust make of the shearer cutting action. D minus C is interpreted as that part of the total dust make of the shearer to which the shearer operators may be exposed.

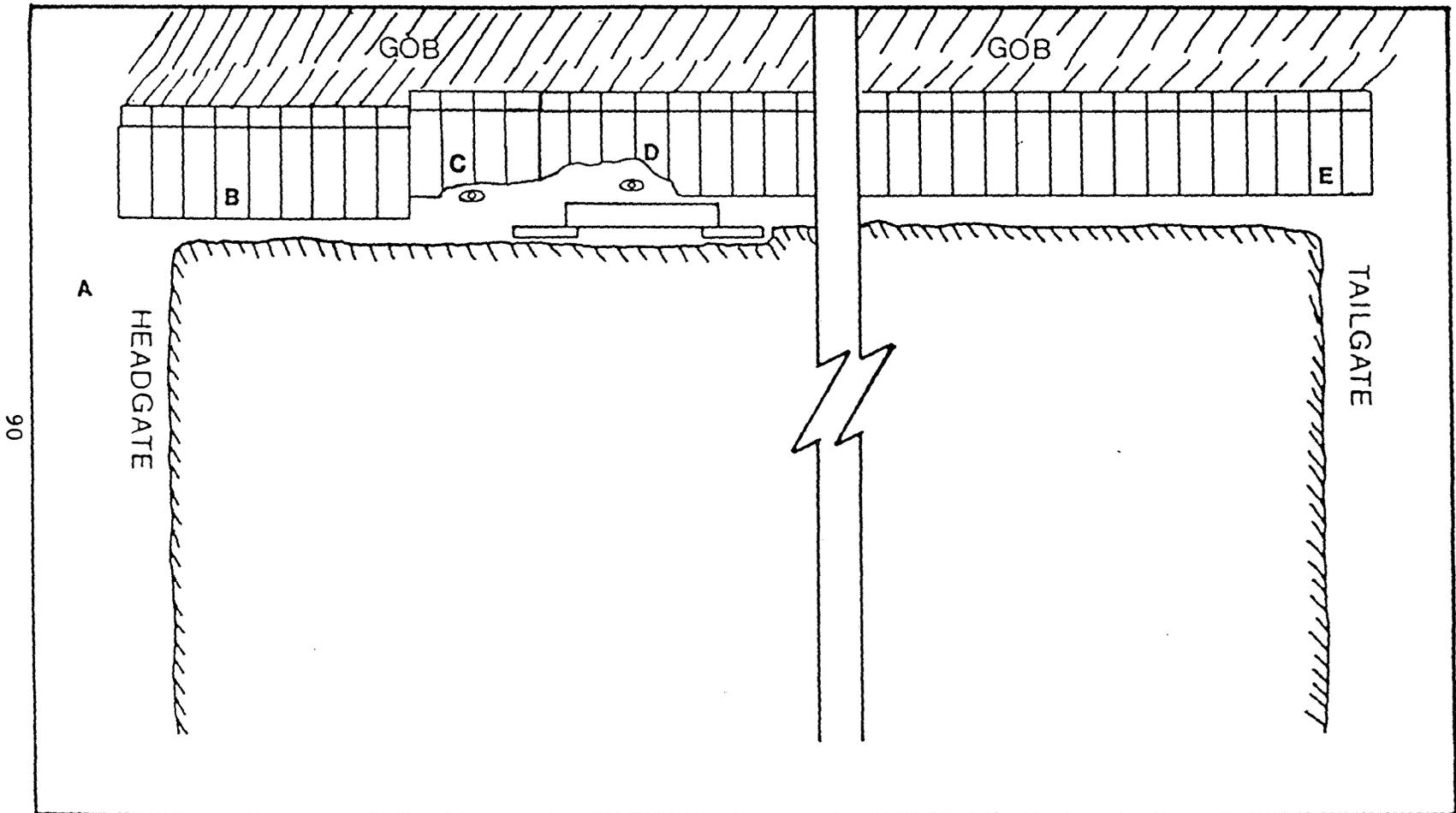


Figure 4-3  
Dust Sampling Locations

Except for the samplers at Station A, which operated throughout the shift, the samplers at all other stations were only turned on while the shearer was cutting. During long delays, these samplers were turned off. Filters were used for all cutting passes in one particular direction on each day. The following day, the sampling direction was reversed.

Each station consisted of three simultaneously operating personal samplers. This was necessary to insure accuracy and to obtain a reliable average measurement of the respirable dust concentrations. For the same reason, the filters were weighed before and after use to the nearest one thousandth of a milligram.

Air speed measurements were made at Station C, approximately every 20 feet of shearer advance. The measurements were made approximately one foot above the spillplates. Instantaneous dust measurement readings were made at Stations C and D every 10 feet of shearer advance. The clock time was recorded at Station D every 10 feet of shearer advance, to provide data for the calculation of the shearer speed.

Water flows and pressures on the various circuits were recorded at the start and the end of a pass and usually several times in between.

All data was recorded on voice-grade magnetic tape using MSHA approved cassette tape recorders.

#### 4.3 Investigation of Total Shearer Dust Make

In this section, the total respirable dust make is quantified for both weeks of testing and the effects of increasing the water flow to the drums are investigated.

##### 4.3.1 Dust Source Contribution

To avoid confusion, the first week of tests will be collectively called Test A, while the second week will be called Test B. For each test, the gravimetric dust data was reduced to quantify each specific dust source on the longwall face. This was carried out separately for both cutting pass directions. The results of Test A are tabulated first.

The respirable dust concentration and percentage contribution of the various dust sources to the total dust make in the head-to-tail direction are shown in Table 4-3.

The data was similarly calculated for the tail-to-head cutting passes. A measuring station was not possible between the shearer and the shield movement because the supports were typically moved over the downwind drum during the cutting pass. Subsequently, no separate quantification of dust between the shearer and the shields was possible in this direction. The data for the tail-to-head pass is shown in Table 4-4.

Table 4-3  
Dust Source Contribution to Total Dust Make  
for Head-to-Tail Passes for Test A

Respirable Dust Source	Concentration (mg/m <sup>3</sup> )	Percent Contribution
Intake Air	0.28	6
Stage Loader and Transfer Point	1.39	31
Shields	1.10	25
Shearer	1.66	38
Total Dust at Tailgate	4.43	100

Table 4-4  
Dust Source Contribution to Total Dust Make  
for Tail-to-Head Passes for Test A

Respirable Dust Source	Concentration (mg/m <sup>3</sup> )	Percent Contribution
Intake Air	0.28	8
Stage Loader, Transfer Point and Panline	0.79	24
Shearer and Shields	2.30	68
Total Dust at Tailgate	3.37	100

This data is illustrated for the head-to-tail case in Figure 4-4 and for the tail-to-head situation in Figure 4-5. These figures provide a visual comparison of the two cutting pass directions and show the amount of respirable dust present at any location along the face.

This data provides some interesting information. In the head-to-tail direction, 62 percent of the total respirable dust make is available in the air when it reaches the shearer. Even upwind of the shield movement, 37 percent of the total dust is present. Quite a large portion of the dust is produced independent of the shearer.

In the opposite direction, the distinction is not quite as clear because of the combined contribution of the shearer and the shields. However, the air present at the shearer contains 31 percent of the total dust. This figure is very similar to the dust levels for the intake air and transfer point in the head-to-tail passes.

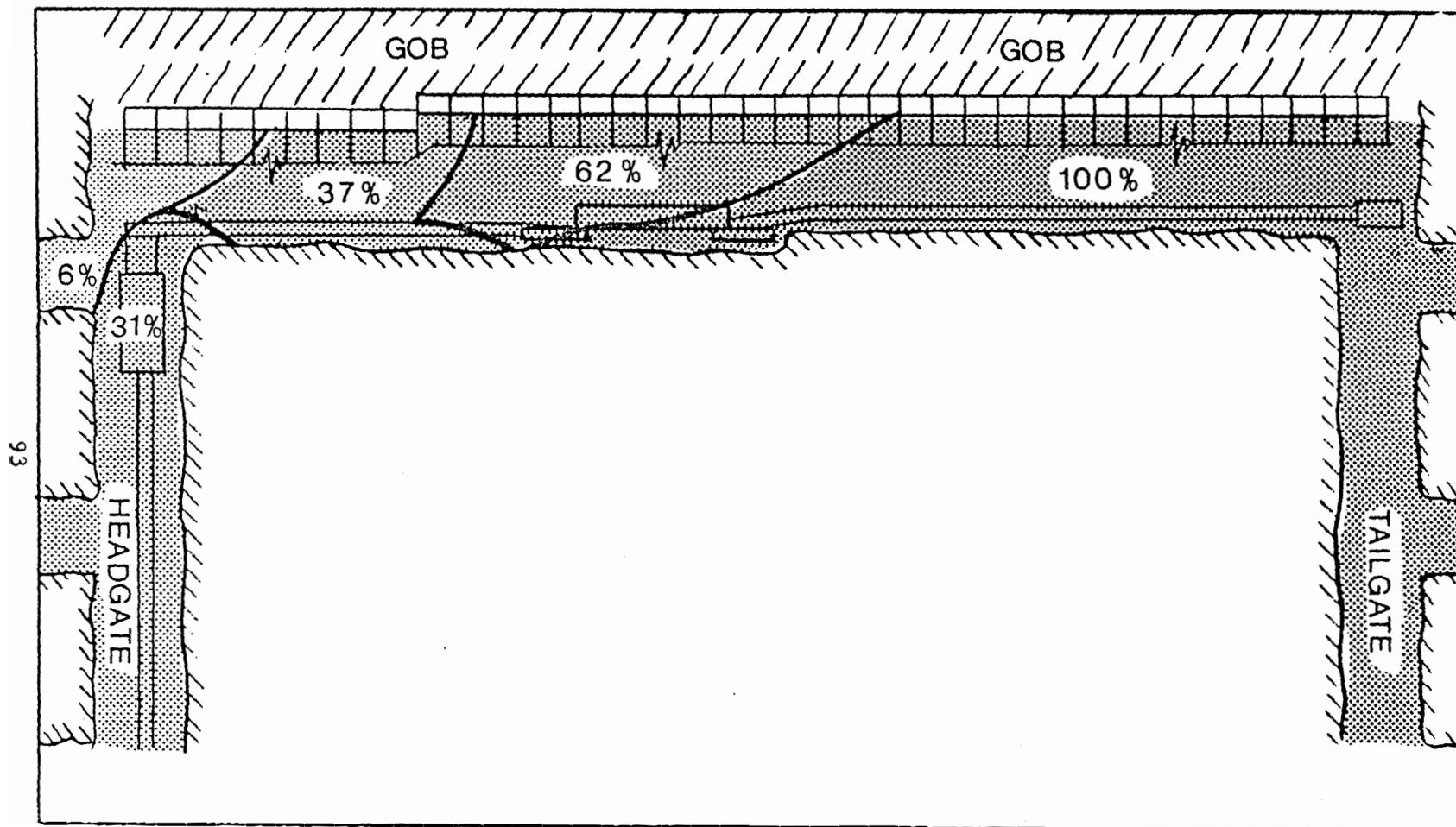


Figure 4-4  
 Head-to-Tail Pass  
 Illustration of Dust Source Contribution (Test A)

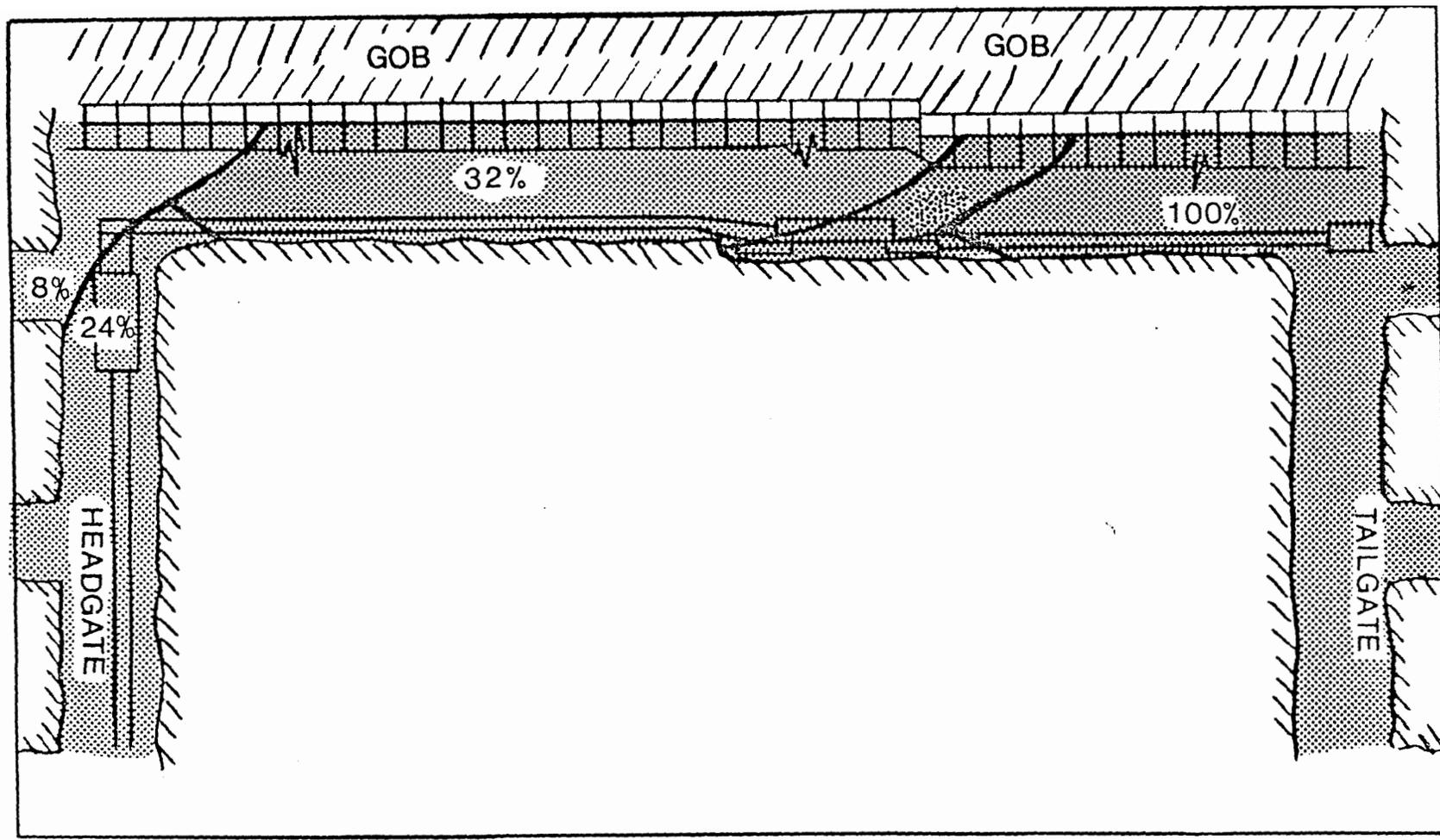


Figure 4-5  
Tail-to-Head Pass  
Illustration of Dust Source Contribution (Test A)

Generally, if you assume that the shield concentration in the tail-to-head direction is equal to the concentration in the head-to-tail direction (1.10 mg/m<sup>3</sup>), then approximately one-third of the dust is obtained from intake and stage loader, one-third from the shields, and one-third from the shearer.

The same types of analyses were carried out for the second week of testing (Test B) to determine if the changes in flows and pressures had any effect on the contribution of each dust source to the total dust make.

The respirable dust concentrations and percentage contribution of the various dust sources in the head-to-tail direction for Test B is shown in Table 4-5.

Table 4-5  
Dust Source Contribution to Total Dust Make  
for Head-to-Tail Passes for Test B

Respirable Dust Source	Concentration (mg/m <sup>3</sup> )	Percent Contribution
Intake Air	0.11	3
Stage Loader and Transfer Point	1.16	32
Shields	1.21	34
Shearer	1.10	31
Total Dust at Tailgate	3.58	100

4-6. The data collected for the tail-to-head passes is compiled in Table

Table 4-6  
Dust Source Contribution to Total Dust Make  
for Tail-to-Head Passes for Test B

Respirable Dust Source	Concentration (mg/m <sup>3</sup> )	Percent Contribution
Intake Air	0.11	3
Stage Loader, Transfer Point and Panline	0.71	18
Shearer and Shields	3.06	79
Total Dust at Tailgate	3.88	100

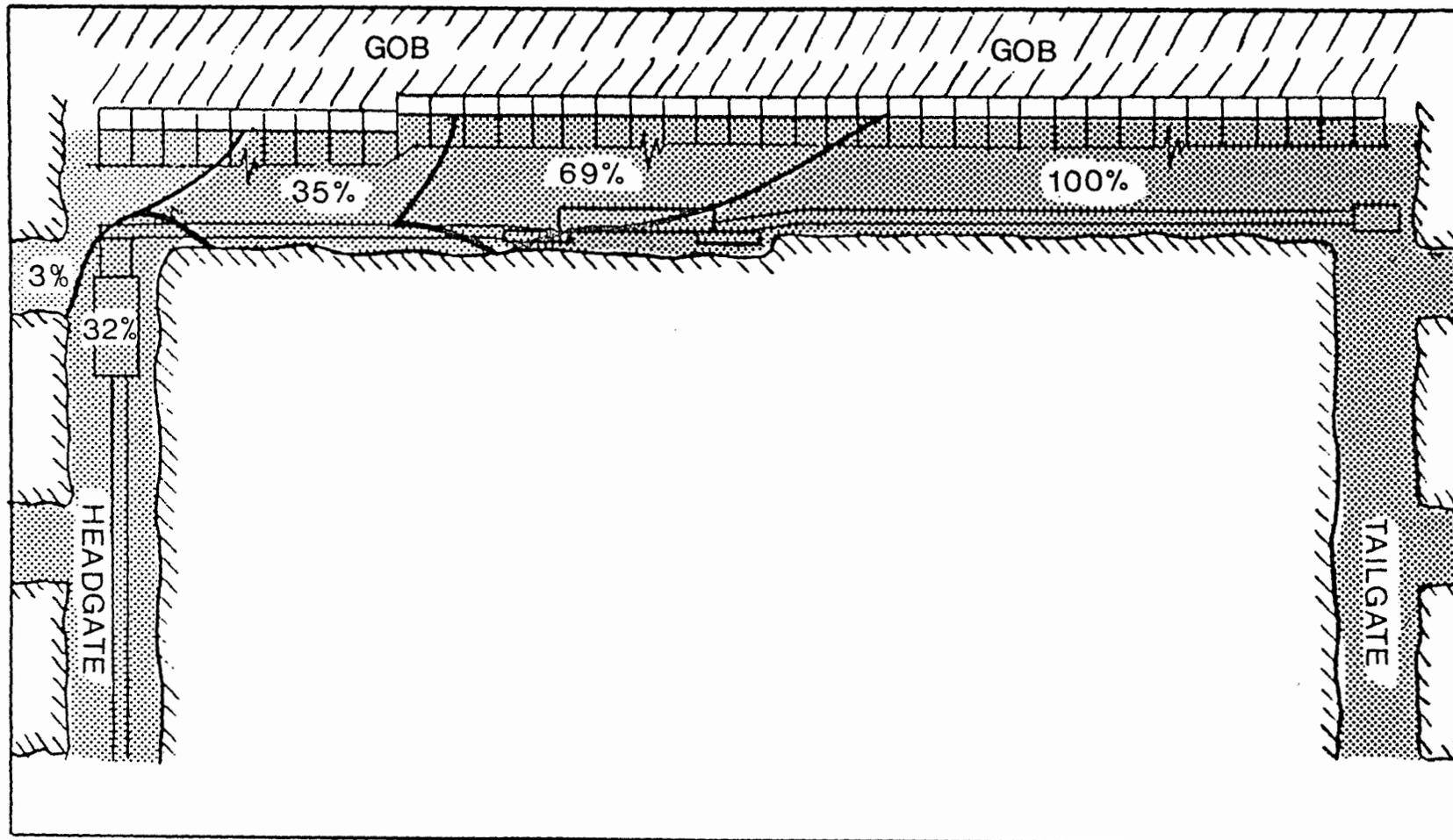


Figure 4-6  
Head-to-Tail Pass  
Illustration of Dust Source Contribution (Test B)

For the head-to-tail direction, the data for Test B showed nearly the same trends as Test A. The air arriving at the shearer had a total of 69 percent of the total dust make with 35 percent of the total present upwind of the shield movement. This is illustrated in Figure 4-6. The percentages were approximately the same as those obtained during Test A. Closer inspection shows some differences in the concentrations. These will be discussed in detail in the next section.

The tail-to-head passes (see Figure 4-7) also showed the same general trends for Test B as they did for Test A. There, however, was a decrease in the contribution from the intake and stage loader during the increased flow tests. The concentration data will provide some insight into the changes and will be discussed next.

#### 4.3.2 Comparison of Dust Source Concentrations Obtained From Test A and Test B

The data for the head-to-tail passes showed some improvement in the dust source contributions when comparing Tests A and B.

The intake air dust concentration was lower for Test B than Test A. This decrease was independent of the water flow to the drums. From discussions with the section foreman during Test B, it became apparent that the headgate area was watered down frequently during the testing. This accounted for the decreased intake air concentration.

The contribution of the stage loader and transfer point showed a statistically significant decrease in Test B. The concentration measured during Test A was  $1.39 \text{ mg/m}^3$  and was  $1.16 \text{ mg/m}^3$  for Test B. This represented a reduction of 17 percent in the dust contribution of this source. This decrease was due either to the incremental water flow increase on the shearer or because of the redistribution of the water to the cutting drums. The coal became wetter which helped decrease the liberation of respirable dust during transfer.

The figures for the tail-to-head passes exhibited similar results. The value decreased from  $0.79 \text{ mg/m}^3$  to  $0.71 \text{ mg/m}^3$  for the increased flow test which represented a 10 percent decrease in respirable dust concentration from the stage loader and transfer point. This decrease was statistically significant.

This was borne out by the results of a moisture analysis. Two coal samples were collected off the panline and analyzed for moisture content and size consist. The results are compiled in Table 4-7.

The samples were very similar in terms of size but the moisture was different. Apparently, the redistribution of water to the drums caused an increase in moisture from 3.78 percent to 4.41 percent representing a 17 percent increase in moisture content.

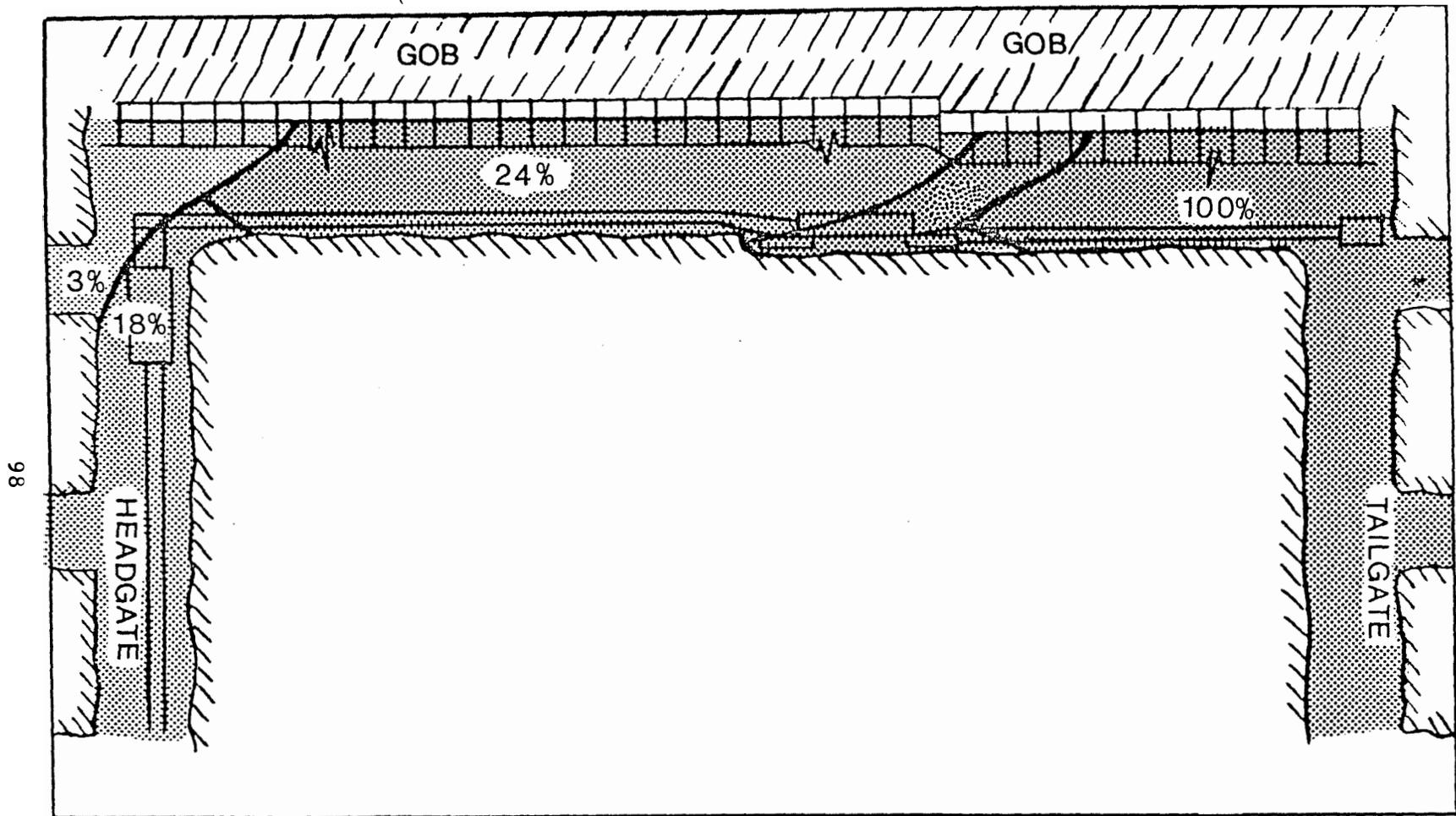


Figure 4-7  
Tail-to-Head Pass  
Illustration of Dust Source Contribution (Test B)

Table 4-7  
Moisture and Size Consist Sample

Test	Moisture (%)	Size Consist	
		-28 Mesh (%)	+28 Mesh (%)
A	3.78	8.28	91.72
B	4.41	7.99	92.01

The dust produced from the movement of the shields should be independent of the water flows on the shearer. Nevertheless, the shields contributed 1.10 mg/m<sup>3</sup> during Test A and 1.21 mg/m<sup>3</sup> during Test B for the head-to-tail direction. The reason for this increase may be due to local geological parameters such as roof pressure and rock hardness or maybe because of accumulation of material on the top of the shields which became pulverized and constituted a dust source.

The dust contribution values obtained for the shearer were quite interesting. The values for the tail-to-head direction could not be evaluated because of the combined concentration of the shields and shearer. However, they are quantified in the head-to-tail direction. The contribution of the shearer during Test A was 1.66 mg/m<sup>3</sup>. The results from Test B produced a figure of 1.10 mg/m<sup>3</sup>. This represents an overall decrease of 34 percent of the dust produced by the shearer.

The total concentration from both the shearer and shields in the tail-to-head direction actually showed an increase for the increased flows test (2.30 mg/m<sup>3</sup> to 3.06 mg/m<sup>3</sup>). The exact reason for this is not clear because the shearer and shield movement were not quantified separately in this direction, however, the shields produced more dust in the head-to-tail direction during Test B.

The overall concentration arriving at the tailgate for the head-to-tail passes showed substantial improvement for Test B versus Test A. The total dust produced during Test A was 4.43 mg/m<sup>3</sup> while 3.58 mg/m<sup>3</sup> was produced during Test B. This represents an overall improvement of total dust make of 19 percent even though the shield movement created more dust during Test B.

The dust values measured at the tailgate for the tail-to-head passes were not nearly as positive. The comparison of Test A and Test B resulted in an increase of dust from 3.37 mg/m<sup>3</sup> to 3.88 mg/m<sup>3</sup> or an increase of 15 percent. The specific reason for this is not quite clear because the shield movement contribution was not quantified in this direction and may have probably caused the increase in dust as was the case in the head-to-tail passes.

#### 4.4 Investigation of Exposure of Shearer Operators

This section details analyses carried out to quantify the various respirable dust sources which contribute to the exposure of the shearer operators. Since measurements were not available specifically at each operator's location the computed values may not be exactly indicative of the operator's actual exposure. The concentrations measured were taken at the midpoint of the shearer approximately eight to ten feet from both operators. The values however should be fairly representative of dust levels present in the walkway.

##### 4.4.1 Quantification of Sources Available to Operator Exposure

A total of four dust sources were quantified which contribute to the respirable dust exposure of the shearer operators. These include:

- intake air dust,
- stage loader, transfer point and panline dust,
- shield movement dust, and
- shearer produced dust.

Each of these sources can be quantified given the dust measurements taken in the survey. The dust from each source can be computed by subtracting the appropriate concentration upwind of the source in question. Figure 4-8 illustrates the actual measured data at each sampling point and shows the computed concentration per source for Test A. For instance, the dust contribution from the shearer cutting to the midpoint location in the head-to-tail direction is obtained by subtracting the concentration upwind of the shearer from the midpoint concentration (column reference E minus D).

The same procedure was completed for the data obtained in the second week of testing (Test B). The sources were quantified using the exact same procedure and are presented in Figure 4-9.

Note that some of the dust concentrations shown in Figures 4-8 and 4-9 were presented in Section 4.3.1 during the discussion of the total shearer dust make and need not be repeated in this material. These analyses will focus on the dust levels responsible for the exposure at the shearer midpoint.

For these analyses, all of the respirable dust measured in the intake air, from the stage loader and transfer point, and from the shields in the head-to-tail direction is assumed to contribute to the operators exposure. Only a portion of the dust produced by the shearer actually contributes to the operator exposure. This concentration is important because analyses can determine the efficiency of increasing the water flows with respect to the operators exposure. This shearer contribution will be examined for both directions.

Table 4-8 presents the dust contribution of the shearer to the shearer midpoint for all cases.

DUST PER LOCATION									
LOCATION	INTAKE	H-T SHIELD 10	T-H SHIELD 10	<-----CUT TO TAILGATE----->			<-----CUT TO HEADGATE----->		
COLUMN REFERENCE	A	B	C	UPWIND D	MIDPOINT E	TAILGATE F	UPWIND G	MIDPOINT H	TAILGATE I
DUST (MG/M <sup>3</sup> )	.28	1.67	.92	2.77	3.67	4.43	1.07	1.62	3.37
CONCENTRATIONS PER SOURCE									
	PER REFERENCE	DUST (MG/M <sup>3</sup> )							
INTAKE AIR CONCENTRATION	A	.28							
STAGE LOAD. AND TRANS.PT. (H-T)	B-A	1.39							
STAGE LOAD. AND TRANS.PT. (T-H)	C-A	.64							
SHIELDS (CUTTING TO TAILGATE)	D-B	1.1							
SHEARER TO MIDPOINT (CUT TO TAIL)	E-D	.9							
SHEARER TOTAL (CUTTING TO TAIL)	F-D	1.66							
SHEARER TO MIDPOINT (CUT TO HEAD)	H-G	.55							
SHR. AND SHLDS. TOTAL (CUT TO HEAD)	I-G	2.3							
PANLINE CONTRIBUTION (CUT TO HEAD)	G-C	.15							

Figure 4-8  
Dust Source Analysis (Test A)

DUST PER LOCATION										
LOCATION	INTAKE	H-T SHIELD 10	T-H SHIELD 10	<-----CUT TO TAILGATE----->			<-----CUT TO HEADGATE----->			
COLUMN REFERENCE	A	B	C	UPWIND D	MIDPOINT E	TAILGATE F	UPWIND G	MIDPOINT H	TAILGATE I	
DUST (MG/M <sup>3</sup> )	.11	1.27	.63	2.48	3.52	3.58	.82	1.26	3.88	
CONCENTRATIONS PER SOURCE										
	PER REFERENCE	DUST (MG/M <sup>3</sup> )								
INTAKE AIR CONCENTRATION	A	.11								
STAGE LOAD. AND TRANS.PT. (H-T)	B-A	1.16								
STAGE LOAD. AND TRANS.PT. (T-H)	C-A	.52								
SHIELDS (CUTTING TO TAILGATE)	D-B	1.21								
SHEARER TO MIDPOINT (CUT TO TAIL)	E-D	1.04								
SHEARER TOTAL (CUTTING TO TAIL)	F-D	1.1								
SHEARER TO MIDPOINT (CUT TO HEAD)	H-G	.44								
SHR. AND SHLDS. TOTAL (CUT TO HEAD)	I-G	3.06								
PANLINE CONTRIBUTION (CUT TO HEAD)	G-C	.19								

Figure 4-9  
Dust Source Analysis (Test B)

Table 4-8  
Respirable Dust Contribution from Shearer  
Present at the Midpoint of the Shearer

Cutting Direction	Dust Concentration (mg/m <sup>3</sup> )	
	Test A	Test B
Head-to-Tail	0.90	1.04
Tail-to-Head	0.55	0.44

This data provides some interesting results. The contribution actually increased between the two tests for the head-to-tail direction. This is remarkable since the total dust produced by the shearer actually decreased 34 percent (see Section 4.3.2). Although the 16 percent increase was statistically significant, the reason is not very clear. The water flows to the drums increased, however, the pressure actually decreased 25 to 30 percent. If this increase in flow had a corresponding increase in pressure then the increase in dust may be caused by increased pressure creating more boilover into the walkway. This, however, was not the case.

A better reason for this increase may stem from the specific cutting and shield movement sequence. Figure 4-10 illustrates the section layout around the shearer for a head-to-tail cut. Note the constraints of the solid block of coal and the leading drum of the shearer. The air and dust naturally tend to flow toward the walkway in this direction. Dust from the upwind drum will contaminate the walkway and increases in flow with a drop in pressure at the drums may have little effect in decreasing the dust concentration.

The values for the tail-to-head direction provide more positive results. A comparison of the results between Test A and Test B show a decrease from 0.55 mg/m<sup>3</sup> to 0.44 mg/m<sup>3</sup> or 20 percent. The decrease in dust level may be due to both the increase in flows or the drop in pressure. The decreased flow from the spray bar may also have had an effect in that less turbulence was created around the upwind drum.

#### 4.4.2 Estimate of Operator Exposure

Based on the dust measurements per source presented in Figures 4-8 and 4-9, an estimate can be made of the shearer operator's exposure to dust. Again, because the sampling location at the shearer midpoint was used in the estimations of the operator exposure, the values should be representative of actual values for each operator.

The "Shearer Midpoint Exposure" for the entire shift can be calculated based on the absolute contributions of the various dust sources. By

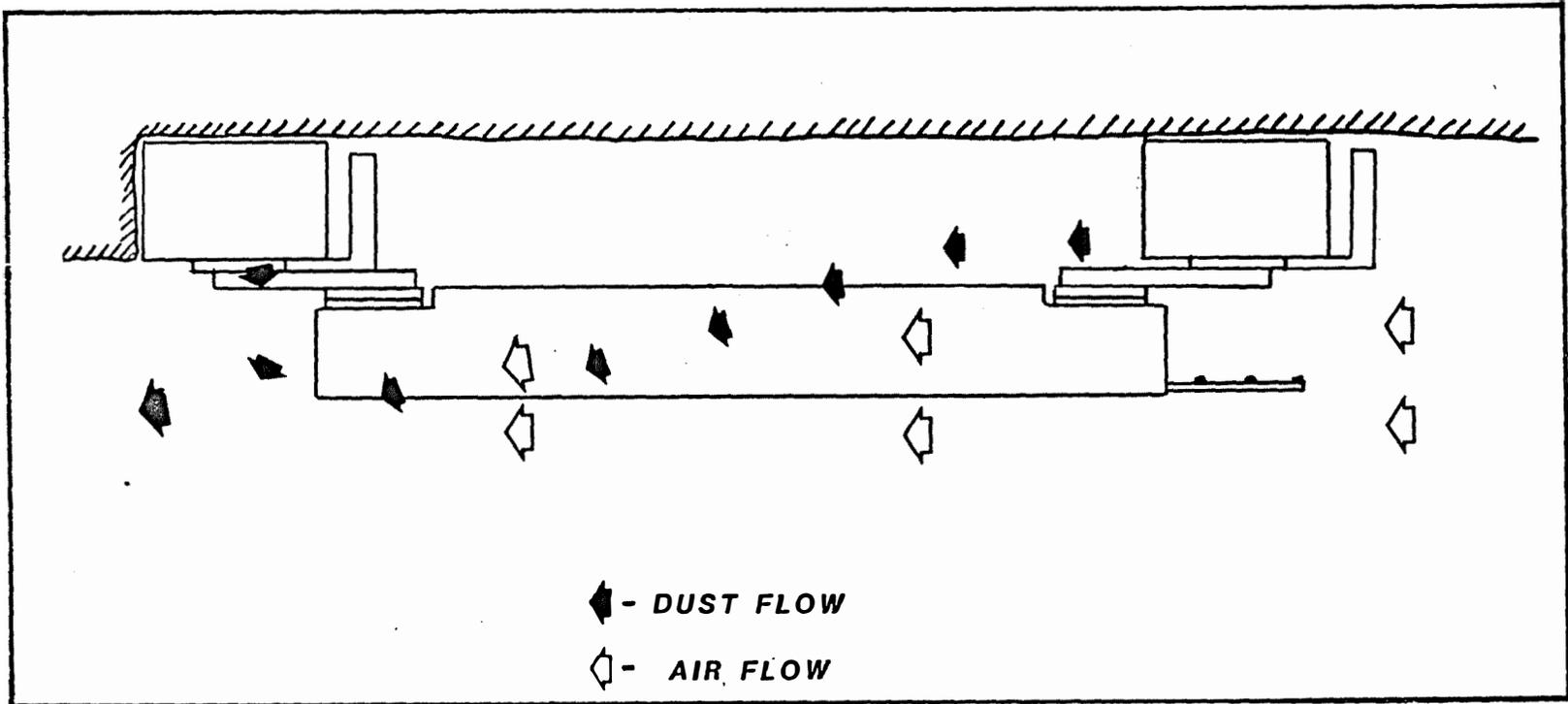


Figure 4-10  
Dust and Air Flow Around the Shearer

applying data obtained from time study, including number of cutting passes per shift, time per cutting pass and dust source contribution the average shift dust exposure can be obtained.

The cycle time and the cycle per shift were obtained from the time study data. The average values used in the analyses were 38 minutes for the cycle time and 8 cuts per shift (4 head-to-tail and 4 tail-to-head).

The dust levels present during the sump and cut out operations at the gates were assumed to be equal to the levels during the cutting passes. These may not be representative; however, no quantification of the levels during the gate operations was made.

The total shift time available for mining was determined to be 390 minutes. Travel time into the section and to the surface was estimated to be 45 minutes for each direction. Therefore, the dust exposure estimates only represent a 6-1/2 hour exposure since dust levels were not quantified for the mantrip ride.

The intake air dust level is present the entire time in the section while the other sources are only present for a portion of the available shift time depending on the operation of the longwall.

Based on the dust per source concentrations and the time a particular source is present, then a contribution per source can be computed for the total shift. Each of these contributions are then added together to provide an estimate of the operator exposure for the shift.

The exposure analysis of the shearer midpoint location for Test A and Test B is shown in Figures 4-11 and 4-12, respectively. The data under "Midpoint Location Exposure" not only shows the dust contribution of each source to the theoretical shearer operator exposure but also shows the percentage that each source contributes to the exposure level.

From the data for Test A (Figure 4-11), the midpoint exposure is quantified at 2.12 mg/m<sup>3</sup>. Of this total, 24 percent is due to the operation of the shearer. The movement of the shields, which only contributes in the head-to-tail direction, is responsible for 20 percent of the operator exposure. The largest source contribution seems to be the dust produced by the stage loader and transfer point. This source contributes 40 percent of the dust exposure present at the midpoint of the shearer. The dust present in the intake air represents 13 percent of the exposure measured at the shearer midpoint.

The same procedure was done for Test B in order that a direct comparison could be made between the two tests. These results are illustrated in Figure 4-12. The overall dust exposure decreased approximately 11 percent from 2.12 mg/m<sup>3</sup> to 1.89 mg/m<sup>3</sup>. The contributions per source to the exposure at the shearer midpoint also changed. The dust produced by the stage loader and the transfer point remains the largest contributor, comprising 39

DUST PER LOCATION											
LOCATION COLUMN REFERENCE DUST (MG/M <sup>3</sup> )	INTAKE A	H-T		T-H		<-----CUT TO TAILGATE----->			<-----CUT TO HEADGATE----->		
		SHIELD 10 B	SHIELD 10 C	UPWIND D	MIDPOINT E	TAILGATE F	UPWIND G	MIDPOINT H	TAILGATE I		
	.28	1.67	.92	2.77	3.67	4.43	1.07	1.62	3.37		
CONCENTRATIONS PER SOURCE											
	PER REFERENCE	DUST (MG/M <sup>3</sup> )									
INTAKE AIR CONCENTRATION	A	.28									
STAGE LOAD. AND TRANS.PT. (H-T)	B-A	1.39									
STAGE LOAD. AND TRANS.PT. (T-H)	C-A	.64									
SHIELDS (CUTTING TO TAILGATE)	D-B	1.1									
SHEARER TO MIDPOINT (CUT TO TAIL)	E-D	.9									
SHEARER TOTAL (CUTTING TO TAIL)	F-D	1.66									
SHEARER TO MIDPOINT (CUT TO HEAD)	H-G	.55									
SHR. AND SHLDS. TOTAL (CUT TO HEAD)	I-G	2.3									
PANLINE CONTRIBUTION (CUT TO HEAD)	G-C	.15									
MIDPOINT LOCATION EXPOSURE											
	CYCLS/SHIFT	TIME/CYCL (MIN)	TIME/SHIFT (MIN)	SHIFT TIME	<-----DUST----->						
					% OF CNCENTRATN (MG/M <sup>3</sup> )	CNTRIBUTN (MG/M <sup>3</sup> )	% OF TOTAL				
INTAKE CONTRIBUTION			390	100	.28	0.28	13				
LDR+TRSF.R.PT. (H-T)	4	38	152	39	1.39	0.54	26				
SHIELDS (CUT TO TAIL)	4	38	152	39	1.1	0.43	20				
SHEARER (CUT TO TAIL)	4	38	152	39	.9	0.35	17				
LDR+TRSF.R.PT. (T-H)	4	38	152	39	.79	0.31	14				
SHEARER (CUT TO HEAD)	4	38	152	39	.55	0.21	10				
DUST EXPOSURE						2.12					

Figure 4-11  
Operator Dust Exposure Analysis (Test A)

DUST PER LOCATION										
LOCATION	INTAKE	H-T SHIELD 10	T-H SHIELD 10	<-----CUT TO TAILGATE----->			<-----CUT TO HEADGATE----->			
COLUMN REFERENCE	A	B	C	UPWIND D	MIDPOINT E	TAILGATE F	UPWIND G	MIDPOINT H	TAILGATE I	
DUST (MG/M <sup>3</sup> )	.11	1.27	.63	2.48	3.52	3.58	.82	1.26	3.88	
CONCENTRATIONS PER SOURCE										
	PER REFERENCE	DUST (MG/M <sup>3</sup> )								
INTAKE AIR CONCENTRATION	A	.11								
STAGE LOAD. AND TRANS.PT. (H-T)	B-A	1.16								
STAGE LOAD. AND TRANS.PT. (T-H)	C-A	.52								
SHIELDS (CUTTING TO TAILGATE)	D-B	1.21								
SHEARER TO MIDPOINT (CUT TO TAIL)	E-D	1.04								
SHEARER TOTAL (CUTTING TO TAIL)	F-D	1.1								
SHEARER TO MIDPOINT (CUT TO HEAD)	H-G	.44								
SHR. AND SHLDS. TOTAL (CUT TO HEAD)	I-G	3.06								
PANLINE CONTRIBUTION (CUT TO HEAD)	G-C	.19								
MIDPOINT LOCATION EXPOSURE										
	CYCLS/SHIFT	TIME/CYCL (MIN)	TIME/SHIFT (MIN)	SHIFT TIME	% OF CNCENTRATN (MG/M <sup>3</sup> )	<-----DUST----->		% OF TOTAL		
INTAKE CONTRIBUTION			390	100	.11	0.11		6		
LDR+TRSFR.PT. (H-T)	4	38	152	39	1.16	0.45		24		
SHIELDS (CUT TO TAIL)	4	38	152	39	1.21	0.47		25		
SHEARER (CUT TO TAIL)	4	38	152	39	1.04	0.41		21		
LDR+TRSFR.PT. (T-H)	4	38	152	39	.71	0.28		15		
SHEARER (CUT TO HEAD)	4	38	152	39	.44	0.17		9		
						-----DUST-----				
DUST EXPOSURE						1.89				

Figure 4-12  
Operator Dust Exposure Analysis (Test B)

percent of the exposure. The shearer contributed 30 percent and the shields 25 percent. Finally, the dust present in the intake air contributed 6 percent to the exposure at the shearer midpoint.

A comparison of the percent contribution of each source is not entirely conclusive. A closer examination of the contributions of each dust source which make up the exposure is more meaningful. The data for both Test A and Test B is summarized in Table 4-9.

Table 4-9  
Dust Exposure Summary

Dust Source	Dust Concentration (mg/m <sup>3</sup> )	
	Test A	Test B
Intake Air	0.28	0.11
Loader and Transfer Point	0.85	0.73
Shields	0.43	0.47
Shearer	<u>0.56</u>	<u>0.58</u>
Total Exposure at Shearer Midpoint	2.12	1.89

The largest decrease in concentration was for the intake air dust source. The contribution from this source decreased 61 percent. This decrease was entirely independent of the water usage on the shearer and is the result of decreased vehicle movement (scoops) in the headgate area coupled with the wetting of roadways in the headgate area.

The largest decrease from Test A to Test B which can be directly attributable to the water usage on the shearer is the dust produced by the stage loader and the transfer point. The incremental increase in total shearer flow and the increased water delivery to the drums proportionally increased the moisture content (as described in Section 4.3.2) and led to a 14 percent decrease in dust produced by this source.

The dust produced by the shearer and the shields changed very little and actually increased slightly during Test B. The shield dust was not directly related to the water flow but may have occurred because of geologic conditions. The dust produced by the shearer may have increased in Test B for the reasons discussed previously. The tail-to-head cutting direction showed positive results for Test B because of the decrease in pressure and the creation of less turbulence from the spraybar. These decreases were offset by a corresponding increase in shearer produced dust at the midpoint in the head-to-tail direction. This was because of the dust and air flow characteristics due to the shield movement location and the physical barrier provided by the solid block of coal as was described in Section 4.4.

Without taking into account the decrease in dust in the intake air, the shearer modifications in Test B still resulted in an improvement of 3 percent over the exposure at the shearer midpoint calculated for Test A. The increase mainly resulted due to the reduction of stage loader and transfer point dust.

## 5.0 CONCLUSIONS

The results of this research, limited to two longwall faces with different geological and mining conditions, have to be studied in the frame of the overall dust program directed by the U. S. Bureau of Mines. Conclusions derived from the research cannot be applied to all longwall faces without further investigation.

The manual water proportioning system was designed to research the optimization of water usage on shearers and to formulate conclusions based on underground testing of the system. It was fabricated and installed on a longwall shearer. This type of proportioning system can be developed inexpensively and easily installed. The valve system can be retrofit on many of the longwall shearers in operation today.

The findings on effects of varying pressure and flow show that if increasing flow is beneficial, a pressure increase can generate more boilover and be detrimental to the shearer operator exposure. In such a case the advantages of increasing the flow are hidden by the pressure increase. Therefore, changes in water distribution must be carefully monitored.

More specific conclusions were reached with regard to the proportioning of water to the shearer drums and on the effect of pressure variations on the total dust make and the shearer operator's exposure.

The shearer operator exposure was affected by the changes in water distribution. The value of the changes have to be examined in conjunction with the location of the downwind shearer operator. Generally, when the water flow and pressure on the downwind drum increases so does the dust exposure of the operator. This is due to the increased boilover into the walkway from the downwind drum. Therefore, if the operator moves downwind from the shearer controls to examine the location and positioning of the drum, then it is beneficial to decrease the flow and pressure to limit the operator's exposure. On the other hand, if the operator remains at the controls, water flow on the downwind drum could be increased as much as possible just as long as boilover from the drum is minimized. Increases in this flow should have a positive effect on the total dust make also.

One possible solution for the situation where the operators move downwind to examine the drum would be to decrease the drum flow and establish a bank of sprays pointing downwind to act as shield to the boilover. One mine visited used this idea but the sprays were aimed toward the drums to operate as dust knockdown sprays. Efficiency of the sprays with respect to the operator exposure would be increased if the sprays were used as a barrier.

Based on the testing at both Sites A and C, increases in flow at the upwind drum had little effect on the operator exposure in the head-to-tail direction. At Site C, the increase in flow also had a corresponding decrease in pressure without positive effects.

This phenomena may be explained by the layout of the face in the head-to-tail direction. Because of geometric constraints of the solid coal block, the airflow and the dust cloud from the upwind drum naturally cross over the shearer and can increase the exposure of the operator.

Increases in flow on the upwind drum may decrease the dust level in the flow over the shearer but this may be counteracted by an increase in boilover from the drum into the walkway. Essentially, there is a tradeoff between the dust flow over the shearer and the boilover from the drum.

In the tail-to-head cutting direction, there is more positive results for the operator exposure when increasing the flow to the upwind drum. The layout of the face is just the opposite in the tail-to-head direction as was described above. Therefore, the airflow and the associated dust produced by the upwind drum tend to flow toward the solid coal. Increases in flow are helpful; however, associated pressure increases may increase boilover. Induced airflow around the upwind drum tends to conflict with the airflow subsequently increasing boilover.

At Site C, the small increase of flow (Test B) on the upwind drum had a corresponding decrease in pressure which led to a reduction of 20 percent in the exposure measured at the shearer midpoint. The decrease in pressure decreased the boilover of dust providing the reduction. The reduction of spray bar flow also contributed in that there was less turbulence created by the conflict of drum sprays and the sprays on the spray bar.

Increases in water flows also had a positive effect on dust levels created by the stage loader and the transfer point. At Site C, the changes made to the shearer for Test B resulted in a decrease of 14 percent for this dust source. The total water flow on the shearer increased only incrementally but the effect may have been a combination of this and the substantial increase of 28 percent of the water going to the shearer drums. This data shows that the cooling sprays and outside sprays contribute very little moisture to the coal. Therefore, to control dust from the transfer point at the shearer, it is best to increase the drum flows.

Increasing the shearer drum flows is beneficial in decreasing the total dust produced by the shearer. The problem remains; which is more important to the mine operator, minimizing the dust exposure of the operators or decreasing the total shearer dust make because of miners working downwind of the shearer. Flow increases to the drums can decrease total dust produced but can have detrimental effects at the operator location particularly due to boilover.

Results from testing show that by substantially increasing the water flow to the downwind drum that total dust produced by the shearer will decrease. However, at Site A, relatively low flows resulted in an increase in total dust make. This suggests that the increase in flow may increase the effectiveness of the sprays but not sufficiently to counteract the effect of a reduced exposure time of the dust to the spray water (due to an increase in

the velocity of the axial air flow around the drum). More dust becomes airborne and is pushed into the walkway. As the flow through the downwind drum is increased, the effect of the higher effectiveness of the sprays overtakes the effect of the increased axial airflow velocity. Thus, less dust enters the atmosphere, although increasingly more dust is pushed into the walkway. This hypothesis suggests that the dust exposure will also reach a maximum (and subsequently decline) as the flow through the downwind drum is increased.

The results at Site B offer no support to this hypothesis unless the tests were done beyond the maximum. These results might be contributable to the increase in water flow to the drum circuits in addition to the slight increase in flow at the upwind drum. The flow on the upwind drum seems to be much more important to the total dust produced by the shearer. This will be discussed next.

At Site A, an increase in flow through the upwind drum clearly reduced the total dust produced by the shearer. The same type of test was attempted at Site C but only an incremental increase in flow on the upwind drum was realized. These tests showed a decrease in total dust made but the increased upwind drum flow may have not been entirely responsible.

As was described earlier, increases in flow to the upwind drum are beneficial if boilover into the walkway can be controlled. A tradeoff exists between the amount of total dust reduction and the amount of boilover produced.

From observations at both sites, the spray bar flow should be adjusted in both cutting directions to limit the effect of turbulence created by conflict with the drum sprays. This turbulence occurred in both directions but was more pronounced in the head-to-tail passes because the drum spray water was not confined by the coal. In addition, the spray bar should be positioned so that spray water acts as a shield from the drum dust rather than a dust knockdown mechanism aimed directly at the drums.

Based on the results of the research, particularly in regard to how the water flow and pressure should be delivered to the drums in a specific cutting direction, it would be advisable to develop an automatic variable delivery distribution system. Such a system could be established to optimize flows for particular face operations and conditions and should not require adjustment by shearer operators. It will permit an increase in the water quantity without disturbing the operations.

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APPENDIX A  
GENERAL SAMPLING PLAN

## 1.0 INTRODUCTION

The following text describes the sampling strategy used in the underground testing on the longwall faces. The tests were conducted to assess the primary and secondary sources of dust generation and entrainment at various locations along the longwall face. Underground measurements include the following data: ventilation, dust levels, shearer speed, water pressure, water quantity, production, shearer water spray system, cutting sequence, operator location and mine water supply system.

There were several considerations which made the analyses far from simple. Some of the important issues involved are discussed below:

- ° Assessing the effectiveness of dust control techniques was complicated by the fact that dust was generated and entrained at various sources within the longwall mining system. These locations included:
  - shearer/plow,
  - contaminated intake air,
  - belt and stage loader transfer points,
  - advancement of roof supports, and
  - caving of the gob.

In analyzing dust control techniques, the dust flow from each of these sources was controlled or measured.

- ° Further complications arose because of the numerous factors (independent variables) that affect dust generation and entrainment. Some of these factors are:
  - cutting sequence,
  - web depth,
  - face sloughing,
  - seam partings, floor and roof rock,
  - ventilation,
  - speed of the shearer,
  - production rate,
  - drum speed, number of picks and lacing,
  - pick design and wear, and
  - water distribution system, quantity, pressure and delivery.

## 2.0 GENERAL INFORMATION

General information about each specific mine was collected utilizing the General Data Collection Form attached. The reasons for gathering this information should be self-explanatory. This general information was obtained during the testing period. Some of the more important general information is discussed below.

### Face Operation

A systematic and detailed description of the longwall face operation was obtained by discussions with the mine operator and by actual observation. The information included:

- method of shearing (half-face, full-face, etc.),
- location of the sumps,
- direction of shearing,
- chock/shield movement, and
- location of miners during the various phases of the cutting cycle.

This information was necessary to assess whether or not the cutting sequence contributes to the miners' exposure to respirable dust. Actual observations enabled the determination of the location of the miners during the cutting sequence and aided the comparison of this information to the dust level mapping.

### Longwall Ventilation

A mine map detailing all relevant ventilation devices, such as shafts, intake and return airways, fans, regulators, stopping lines, overcasts, etc., was obtained from the mine operator. This enabled the engineers to pinpoint some problem areas that may be contributing to the mine operator's dust problem, such as contamination of intake air as a result of high air velocity.

### Shearer Design and Shearer Water Distribution System

The importance of the shearer design and its water spray distribution system has been discussed previously. A detailed sketch of the shearer was drawn indicating the water distribution system, spray locations and spray configurations (see the General Data Collection Form).

### Mine Water Supply System

A detailed schematic diagram was drawn by the observers that included the following information:

- type and location of water source (city system, treatment ponds, surface dams, underground dams, etc.),
- pressure head from surface to mine level,
- quality of water (concentration of impurities),
- all water line pipe diameters,
- type, number and location of pumps, and
- network junctions of all pipelines.

This information was necessary to account for changes in the amount of water and pressure delivered to the longwall face when other sections are using water from the same source.

### 3.0 SPECIFIC FACE MEASUREMENT AND OBSERVATIONS

The methods for obtaining dust samples of the underground mine environment had a significant impact on the results and subsequent conclusions drawn from these results. Strategies for evaluating dust sources and dust control technologies followed the methods developed by personnel of the Dust Control and Ventilation Group, Pittsburgh Research Center of the Bureau of Mines.

The basic sampling method, called the moving method, was used. In the moving sampling method, gravimetric and instantaneous dust samplers were carried by a survey engineer, walking at the midpoint of the shearer. The other individual remained approximately 15 to 20 feet on the intake air side of the machine. Dust levels and face position (support number) were taken while the shearer is cutting, during all phases of the mining cycle. These measurements provided information relating changes in airflow along the face to changes in the dust levels, and also showed how face specific (rock partings) and face method of coal getting, etc. (cutting the wedge), variables affected dust levels. In addition, this method provided information from which shearer speed could be determined as a function of time, and allowed for an assessment of the dust level as a function of shearer speed.

For example, given an operation employing a unidirectional tail-to-head cutting pass with support movement on the intake side of the shearer during the head-to-tail cleanup pass, the sampling proceeded as follows. With the survey team in the positions previously described, the dust samplers were turned on after the shearer was sumped in and began the cut from the tail to head, and the start time was recorded. Both individuals maintained their positions, traveling with the shearer as it cut toward the headgate. As the shearer approached the headgate entry, the samplers were turned off and the stop time recorded. The samplers were turned on (start time recorded) as the shearer started the cleanup pass toward the tail, and both individuals maintained their positions, following the shearer as it traveled toward the tailgate. As the shearer approached the tailgate entry, the samplers were turned off and the stop time recorded. In addition, three gravimetric sampling units were positioned in the primary intake airway and operated during both phases of the mining cycle. (These gravimetric samplers were operated for each pass without changing the sample cassettes.) This procedure was repeated for subsequent passes. Additionally, three gravimetric samplers were placed near the return to obtain an average shift concentration. The survey team also wore vests with a package of three gravimetric samplers, changing the individual cassettes after each pass.

The intake air samples provided a measurement of the dust levels in the intake air approaching the section. The samples collected 20 feet on the intake air side of the shearer during the tail-to-head pass yielded a

measurement of the dust levels associated with coal transport on the face conveyor and stage loader. The samples collected 20 feet on the intake air side of the shearer (between the shearer and support movement) during the head-to-tail pass were used to determine the dust levels associated with support movement. The samples collected at the mid-point of the shearer indicated the severity of dust levels produced by the shearer, and the effectiveness of the cutting sequence for minimizing the shearer operator's dust exposure. The results can be used to evaluate the effectiveness of the control procedure by sampling successive mining cycles.

Other measurements were taken simultaneously by each individual. One recorded dust levels and air velocities using a J-Tec anemometer. The air speed measurements were normally made with the anemometer positioned above the panline. The other engineer recorded observations and the shield location.

Water quantity and pressure were recorded at various intervals during the pass. The water meters were positioned in at least two places prior to entry into the shearer and at one point of the discharge supply onto the face. The direction and condition of the outside sprays were monitored closely.

A permissible tape recorder was used to aid data recording. All relevant information (face location, dust level, shearer location, etc.) was recorded and transcribed onto hard copy on the surface at the end of the survey.

GENERAL DATA COLLECTION FORM

I. GENERAL MINE INFORMATION

Company Name \_\_\_\_\_ Mine Name \_\_\_\_\_  
Company Address \_\_\_\_\_  
Mine Location \_\_\_\_\_  
Company Contacts \_\_\_\_\_ Phone Number \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
Age of Mine \_\_\_\_\_ Date of Study \_\_\_\_\_

II. GEOPHYSICAL CONDITIONS

Name of Seam \_\_\_\_\_ Thickness \_\_\_\_\_ Range of Depth \_\_\_\_\_  
USGS Map Names \_\_\_\_\_  
Roof Quality \_\_\_\_\_ Abnormalities \_\_\_\_\_  
Bottom Quality \_\_\_\_\_ Abnormalities \_\_\_\_\_  
Water \_\_\_\_\_ % Grade \_\_\_\_\_  
Describe any other conditions present that warrant consideration:  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

III. COAL CHARACTERISTICS

Moisture (%).....	_____	Fusion Temperature (°F).....	_____
Volatile Matter (%)	_____	FSI.....	_____
Fixed Carbon (%)...	_____	Compressive Strength (psi)..	_____
Ash (%).....	_____	Hardgrove Grindability Index	_____
Sulfur (%).....	_____	Permeability.....	_____
BTU (%).....	_____		

IV. PRODUCTION/PRODUCTIVITY INFORMATION

Total Mine Yearly Production \_\_\_\_\_ (tons)  
Clean or Raw, % Reject \_\_\_\_\_

- Source of water and location (city system, treatment ponds, dams, etc.)
- Head from surface to mine level
- Quality of water (concentration of impurities)
- Source to machine breakdown of all pipes, sizes, etc.
- Type and number of pumps used
- Network junctions of all pipelines

IX. SHEARER DESIGN

Manufacturer \_\_\_\_\_

Model No. \_\_\_\_\_ In Service Date \_\_\_\_\_

Power:

AC \_\_\_\_\_ DC \_\_\_\_\_ hp \_\_\_\_\_

Volts \_\_\_\_\_ Kw \_\_\_\_\_

Dimensions:

Length \_\_\_\_\_ (arms fully extended)

Width \_\_\_\_\_ (widest point)

Height \_\_\_\_\_ Weight \_\_\_\_\_

Drum:

Diameter \_\_\_\_\_ Depth of Web \_\_\_\_\_

Rotational Speed \_\_\_\_\_ Vane Angle \_\_\_\_\_

Vane Configuration \_\_\_\_\_ (sketch)

Number of Picks \_\_\_\_\_

Pick Type \_\_\_\_\_

Pick Length \_\_\_\_\_

Pick Width \_\_\_\_\_

Pick Angle(s) \_\_\_\_\_

Pick Spacing \_\_\_\_\_

Pick Lacing Including Pertinent Dimensions \_\_\_\_\_ (sketch)

Haulage System:

Type \_\_\_\_\_  
(roll rack, rack-a-track, chain)

Rate of Travel \_\_\_\_\_

Water Spray System:

Type \_\_\_\_\_

Spray Angle \_\_\_\_\_

Exit Bore \_\_\_\_\_

Connecting Thread \_\_\_\_\_

Spray Location - A detailed sketch of the shearer will be drawn indicating the water distribution system, spray locations, and spray configurations. This same sketch will be used for the Daily/Shift Data Collection Forms to indicate which sprays were clogged during our evaluation test.

**APPENDIX B**  
**STATISTICAL ANALYSIS PROCEDURE**

This appendix describes the statistical analysis procedure used to evaluate the respirable dust measurements taken during the testing of the manual water proportioning at Site A.

To analyze the effect of spray water distribution on the dust exposure of the downwind drum operator a data file ("Dust 1") was used, which was obtained by subtracting the dust concentration measured between the shield movement and the upwind drum (Station B) from the dust concentration measured at the downwind drum (Station C). This difference (C-B) can be interpreted as that part of the total dust make of the shearer to which the downwind drum operator may be exposed. These equalities assume that the ventilation is antitropical as was the case at Site A.

Due to the bad roof conditions, the shields were moved directly behind the shearer, causing Station B to be located approximately in line with the cowl of the upwind drum. It is therefore possible that the samples taken at Station B contained some shearer created dust and that the dust concentrations resulting from the movement of the shields as measured at this station were not the fully diffused dust concentrations.

For this reason, operator exposure was also analyzed using another data file ("Dust 2"). This file resulted from subtracting the intake air dust concentration (measured at Station A) from the dust concentration measured at the downwind drum (Station C). The difference (C-A) is the operator exposure to the combined dust sources between Stations C and A, mainly the shearer and the shield movement.

To analyze the effect of spray water distribution on total shearer dust make, a third data file ("Dust 3") was used, which was obtained by subtracting the dust concentration measured at Station B from the total dust concentration measured at the tailgate (Station D). In addition, a fourth data file ("Dust 4") was analyzed, which was obtained by subtracting the intake air dust concentration (measured at Station A) from the concentration measured at Station D.

The analyses based on files 2 and 4 are appropriate if the amount of dust generated by the movement of the shields was fairly constant across the samples taken. Unfortunately, no data is available to support such an assumption.

The analyses proceeded in several steps. First an F test was performed at a significance level of 0.1 to determine whether the mean dust concentrations for the various spray water distributions differed. Since this was true for all four data files, confidence intervals (at a significance level of 0.1) were determined for the mean dust concentrations associated with the various water distributions. Also, the mean dust concentrations were pair wise compared and confidence intervals determined for the differences.

For these pair wise comparisons, the confidence level of 0.1 is only valid for each pair wise comparison separately. Conclusions based on two or more pair wise comparisons are not at a 0.1 confidence level.

Where several pair wise comparisons had to be reviewed as a set and statements made at a 0.1 confidence level, the Bonferroni and Scheffe methods of multiple comparisons were used. Both methods are appropriate and the method which resulted in narrower confidence intervals was selected.

When zero is included in a confidence interval (whether in pair wise or multiple comparisons), one cannot conclude at a stated level of significance that the two mean dust concentrations being compared are different.

APPENDIX C  
SITE B DUST ANALYSIS

## 1.0 INTRODUCTION

This appendix describes the data and information obtained at Site B on the Second Left longwall section. Initially, this study aimed to assess the effectiveness of proportioning the water flows to the drums with regard to dust suppression. However, because of maintenance difficulties and other circumstances, insufficient data was collected to accurately do this. Also described is data collected while observations were made at the 1 West longwall section at an adjacent mine.

## 2.0 SITE B

### 2.1 Shearer Water Distribution System

The water distribution system on the Eickhoff 300 DL in the Second Left longwall was a standard construction and design of the manufacturer. The shearer itself has been modified by the replacement of the standard 300 hp motor with a 350 hp motor. Mine management had previously upgraded the water supply to the machine. During the testing, about 85 gpm at 300 psi was delivered to the shearer. Data collected on six U. S. longwalls that utilize high water flows and pressures show that a substantial reduction in dust exposure is possible. Higher pressures provide more dust allaying ability to drum sprays and secondary sprays. In contrast, higher pressures to the cooling system can have detrimental effects. The set screws of the existing manifold must be adjusted so that the proper flows are achieved. If no water reaches any of these systems, serious problems may occur. The machine is therefore protected by circuits that monitor the temperature and disrupt operation of the machine when the temperature increases to a certain level. The manufacturer's recommended water quantities and pressures for the cooling circuit of the Eickhoff 300 DL are as follows:

	<u>Flow (gpm)</u>	<u>Admissible Operating Pressure (psi)</u>
Oil coolers - gearhead	2x8	560
Oil cooler - haulage box	8	560
Electric cutter motor	4	280

The cooling system supply lines were not altered after the machine was put into service. Cooling water was discharged by two spray manifolds on each end of the shearer body on the face side of the machine. Each manifold has four sprays oriented as shown in Figure C-1A. When all sprays were mounted in these manifolds, they tended to clog and obstruct the cooling water flow. Therefore, one spray from each manifold was removed by the shearer operators, which also enabled them to more easily visually check the cooling water flow. When a spray is removed, the danger of complete flow obstruction is eliminated, but excessive quantities of water discharges from the remaining hole.

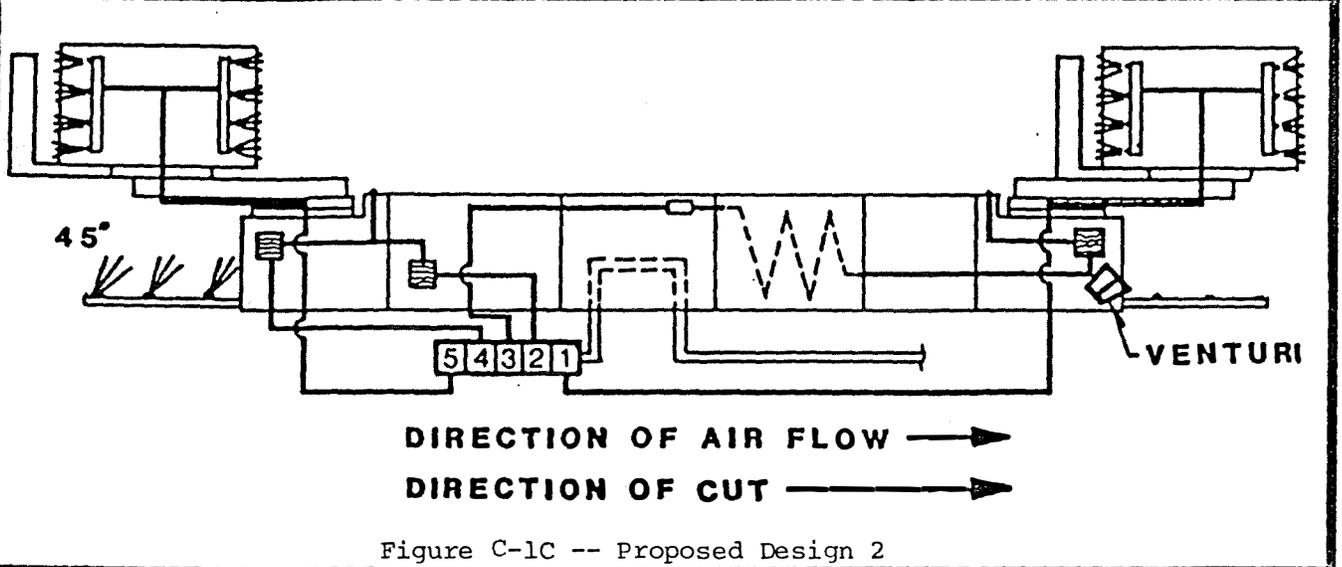
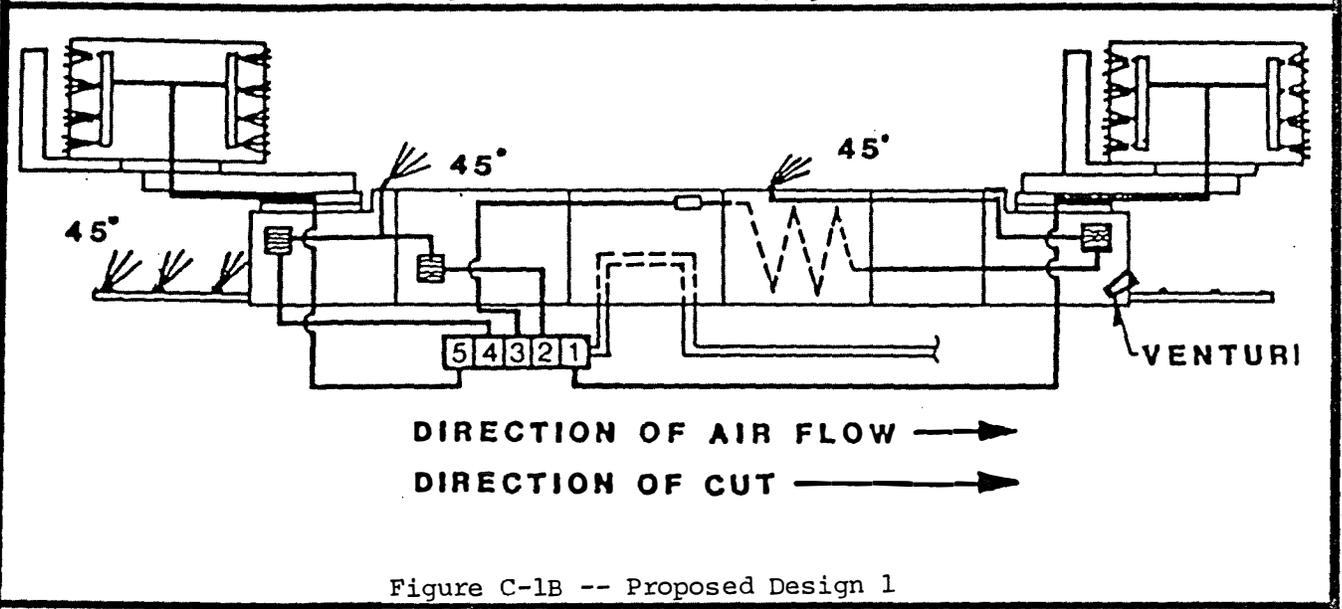
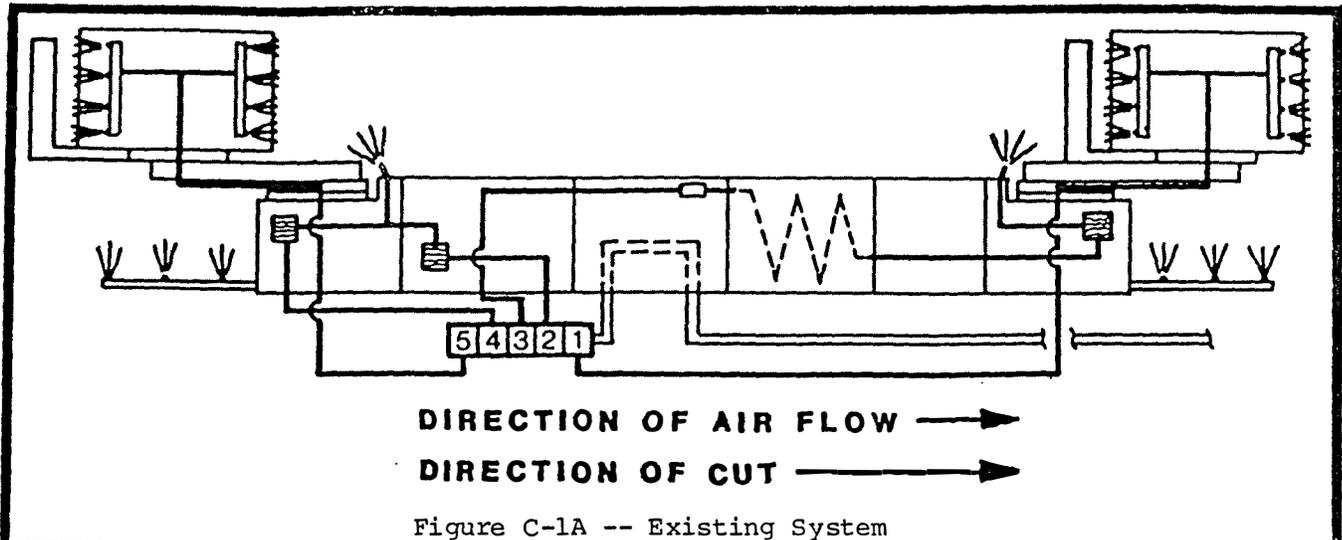


Figure C-1  
Water Distribution and Spray System

Initially, the drum sprays were inoperable due to clogging and a rotary seal problem. It is not clear whether clogging of the drum sprays was caused primarily by inlet water contamination or by fines entering the spray orifice. Some of the plastic caps inside the sprays had been pushed off, possibly indicating that fines had entered through the orifice. However, the sprays had not been in operation for a while. Fines are likely to enter the orifice when no water pressure is present. Therefore, it cannot be concluded that fines entering the orifice would have been the primary cause of clogging if the sprays had been normally used. The fact that the cooling water sprays reportedly clogged when all sprays were installed indicates contamination of the cooling water. The location of the cooling sprays makes entry of fines through the orifice unlikely, particularly because the sprays were being used. The sprays were cleaned a number of times during the testing.

With both the drum sprays and cooling sprays operating (no flow to the outriggers), flows of 40 gallons per minute to the drums (at approximately 50 psi) and 60 gallons per minute to the coolers, were measured. Even with all sprays operating, including the secondary sprays, flow to the coolers remained at high levels, >40 gpm.

The secondary sprays (outriggers) are located on an arm at each end of the machine (see Figure C-1A). While sufficient flow and pressure was measured, improper orientation of these sprays often led to dust boil-over into the walkway.

## 2.2 Ventilation

A survey was made to determine the air velocity profile in the cross-sectional area perpendicular to the airflow. During the survey, the shearer was at shield No. 100, the face was straight and the panline was pushed against the face. Measurements were made every tenth shield, starting with shield No. 20, in six positions within each cross-sectional area. The average air velocity for each position is shown in Figure C-2.

The average flow over the length of the face from shield No. 20 to shield No. 110 decreased from 19,400 cfm to 13,800 cfm. This is naturally due to bleeding through the gob. There was a gradual decrease from shield No. 20 to shield No. 60 but then a substantial increase at shield No. 70, due to a reduction of the cross-sectional area. Then the velocity decreased as the air continued down to the tailgate.

The highest air velocities occurred over the panline. The lowest velocities were measured at points near the perimeter of the cross-sectional area where increased friction is encountered.

## 2.3 Respirable Dust Analysis

Data was collected on March 3, 24 and 25, 1983, at the Second Left longwall. All observations were made during the headgate to tailgate cutting pass.

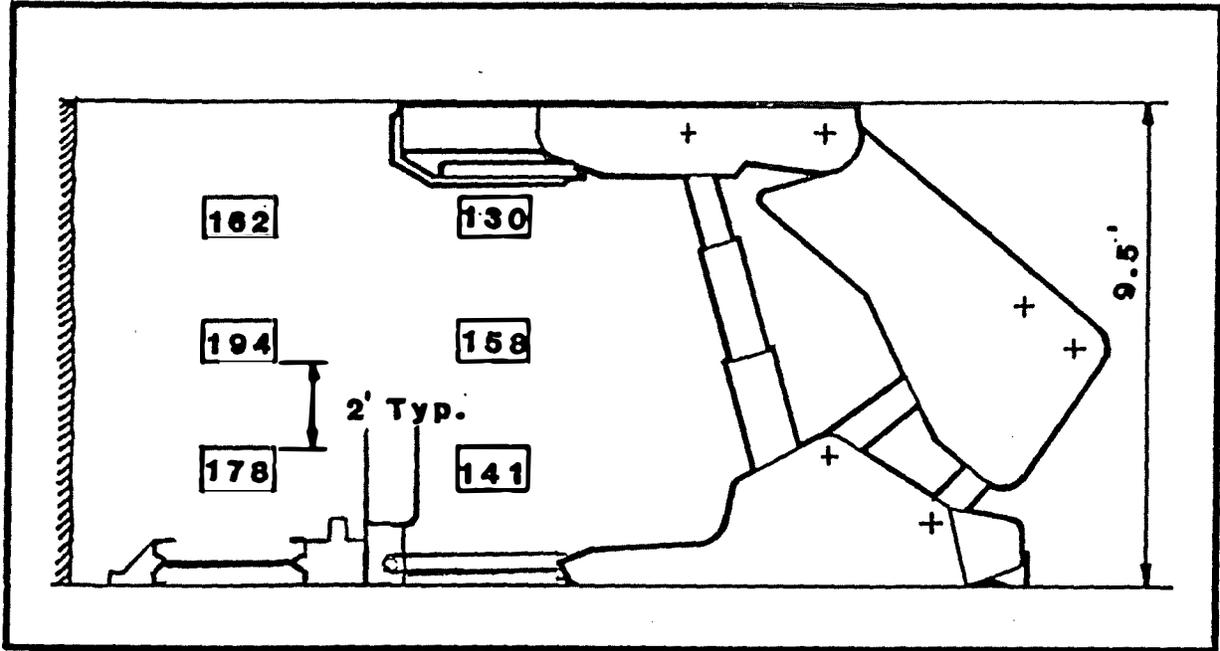


Figure C-2  
Cross-Sectional Air Velocity

Information collected on March 3 was made prior to the installation of flow and pressure meters; therefore, the exact quantities and pressures of water delivered to the machine's various circuits could not be determined. Measurements were made by two observers, each carrying three gravimetric samplers as they walked with the machine. One observer was positioned 30 feet upwind of the shearer and the other was located at the downwind drum operator's position. Measurements showed approximately  $4.3 \text{ mg/m}^3$  at the upwind position and  $6.7 \text{ mg/m}^3$  located at the downwind position. These samples and all instantaneous samples obtained during data collection were not 8 hour compliance test samples. Therefore, dust concentrations presented in this report cannot be directly related to the compliance limit of  $2 \text{ mg/m}^3$ . Average shearer speed was 16 feet per minute with an average air velocity of 162 feet per minute. The data indicated that a dust exposure problem does exist.

On March 24 and 25, measurements were taken by two engineers carrying GCA RAM-1 instantaneous dust monitors at the same positions mentioned previously. This data was collected after the flowmeters and pressure gauges were installed. The following table shows the water flows to the shearer and the cutting drums during the measurements.

	<u>Total Flow/Pressure</u>	<u>Headgate Drum</u>	<u>Tailgate Drum</u>
3/24	70 gpm at 300 psi	30 gpm at 120 psi	12 gpm at <10 psi
3/25			
pass 1	80 gpm at 280 psi	30 gpm at 100 psi	30 gpm at 140 psi
pass 2	85 gpm at 280 psi	10 gpm at <10 psi	34 gpm at 160 psi

The results of the instantaneous dust measurements are shown in Figures C-3 through C-5. Only the measurement taken at the upwind position on March 24 is shown because there were mechanical difficulties with the data recorder at the tailgate operator's position. On this day, values ranged from 0 to 7 RAM units with an average of 3.4. Instantaneous samples measured on RAMs have  $\text{mg}/\text{m}^3$  as units but are referred to in the text as RAM units to avoid comparison with compliance standards. When this pass is compared with the two passes measured on March 25, there is a large discrepancy between dust measurements. Average RAM units of 8.2 and 12.1 were measured at the upwind position on March 25. The downwind position averages were 25.9 and 21.8 RAM units. This discrepancy can be attributed to the substantial difference in air velocity for the two days, illustrated in Figure C-6. The values obtained on March 25 are exceedingly high due to the limited air velocity. The problem was corrected before we left the site and we concluded that this condition was an anomaly. Shearer speed averaged 19.5 feet per minute for the two passes on March 25.

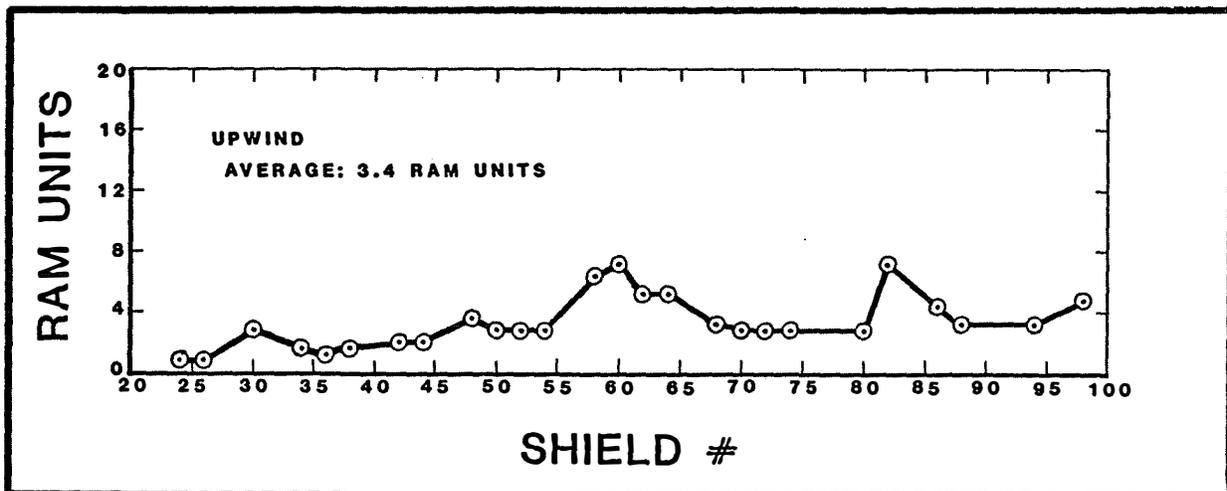


Figure C-3  
Dust Levels Approximately 30 Feet Upwind of the  
Shearer During a Cutting Pass on 3/24/83

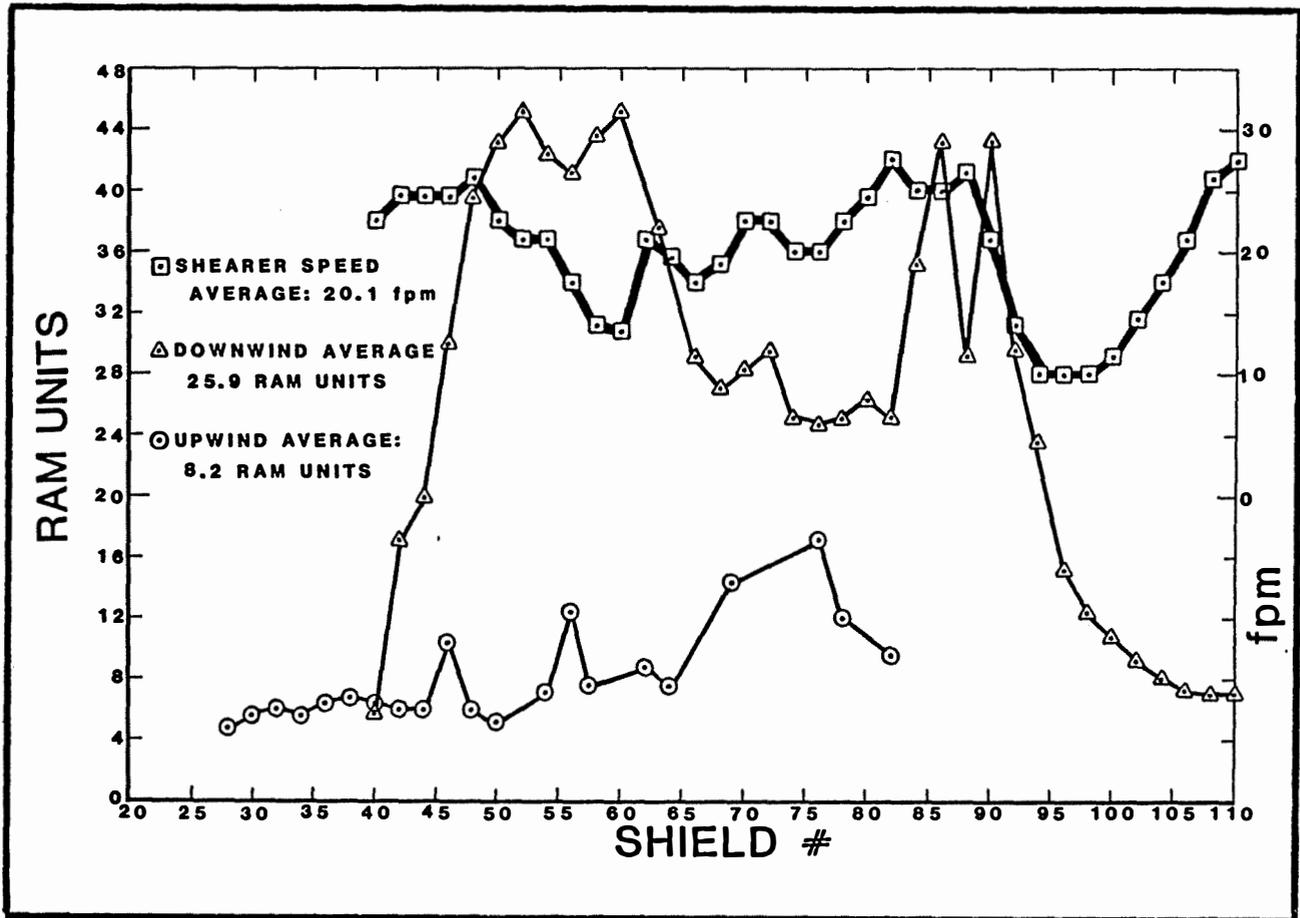


Figure C-4  
 Dust Levels and Shearer Speed During Cutting Pass 1 on 3/25/83

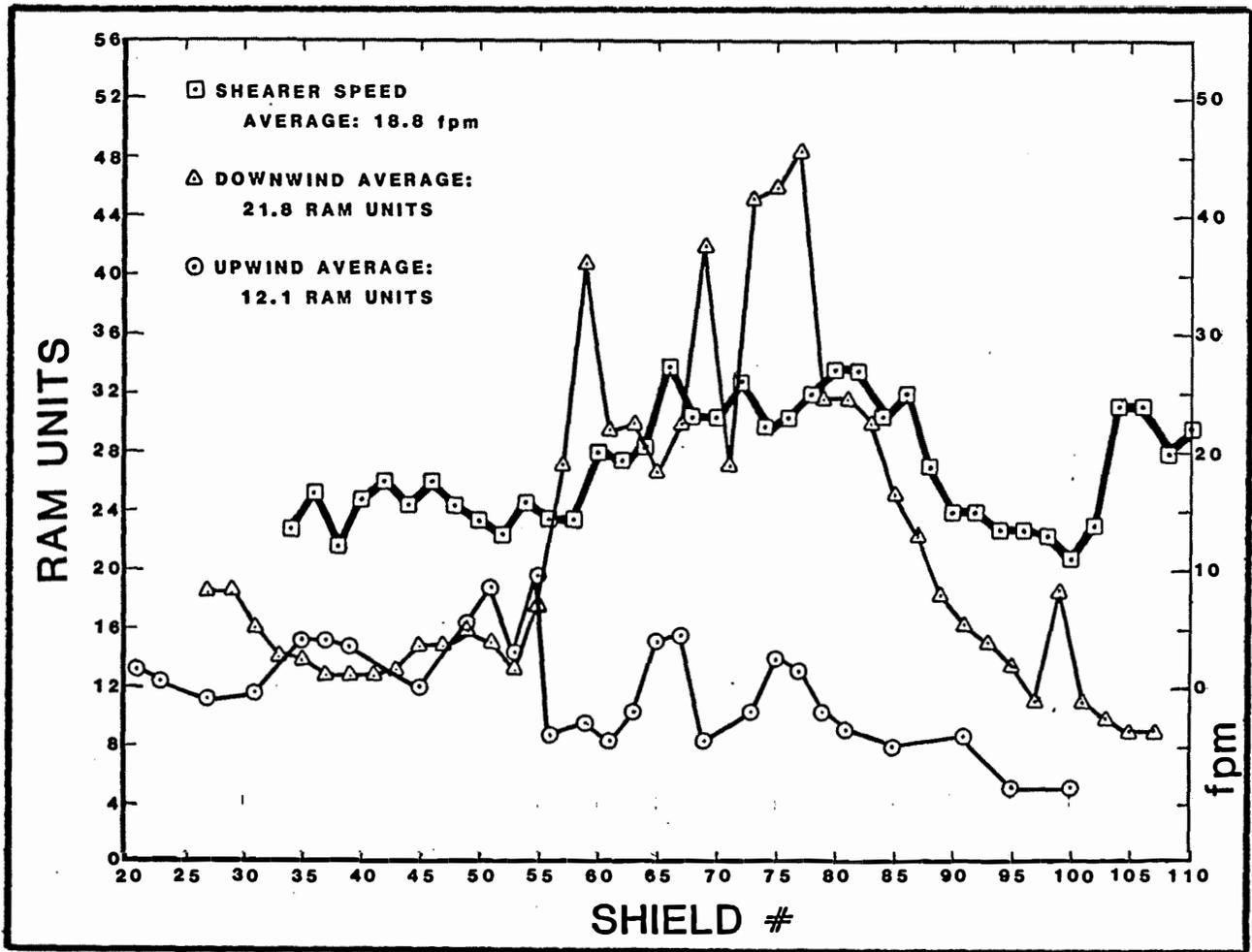


Figure C-5  
Dust Levels and Shearer Speed During Cutting Pass 2 on 3/25/83

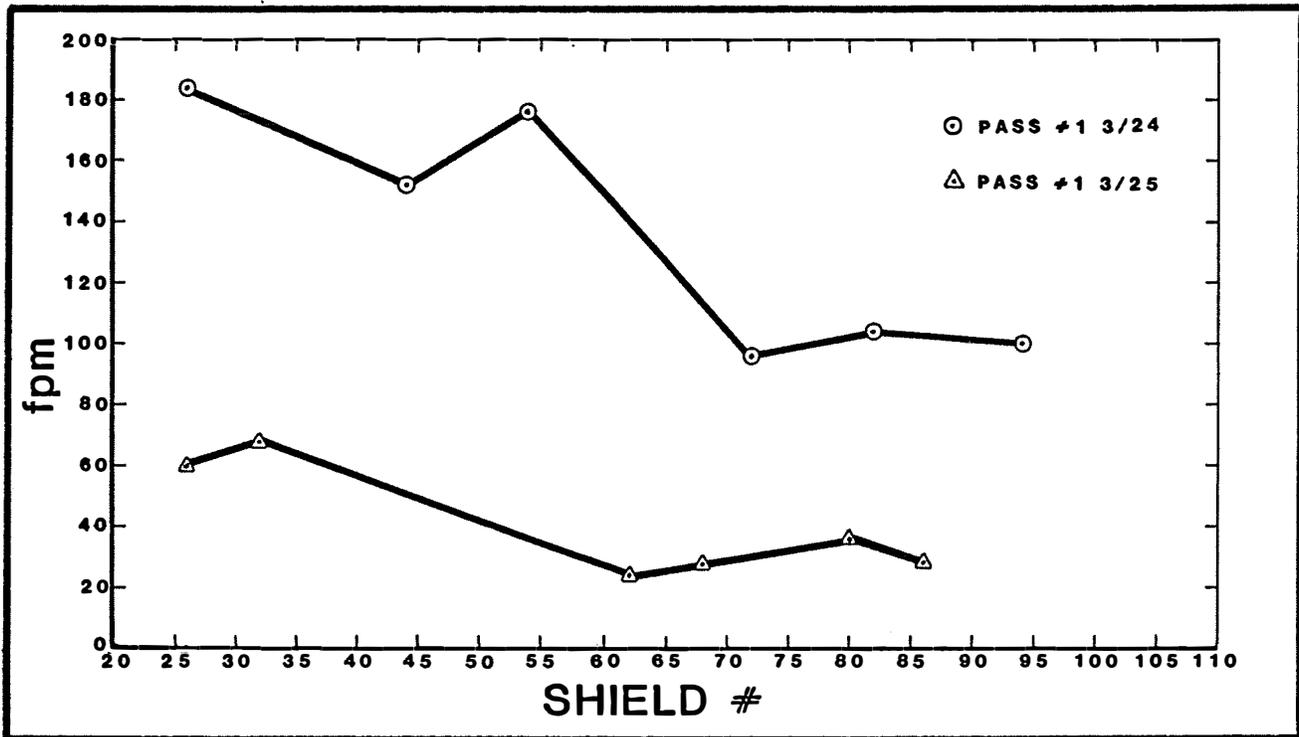


Figure C-6  
Air Velocities

#### 2.4 Conclusions and Recommendations

Despite the fact that little information was gained concerning the proportioning of water on longwall drums, some beneficial results were obtained during the sampling. The results showed that there was definitely a dust problem on the face and procedures could be implemented on the shearer to reduce the dust exposure of the operators.

Optimize the water distribution system on the shearer to efficiently utilize the large flow being provided to the machine. With a total flow of 100 gallons, the breakdown would be as follows:

	<u>Quantity (gpm)</u>	<u>Number of Sprays</u>	<u>Spray Type</u>
Cooling circuit	28	0	Open discharge
Headgate drum	30	27	3/32" cone
Tailgate drum	30	27	3/32" cone
Outrigger/HG	15	12	1/16" cone
Outrigger/TG <sup>1</sup>	5	2	Flat Venturi, in vertical position

<sup>1</sup> Replaces three existing spray manifolds on the existing tailgate outrigger.

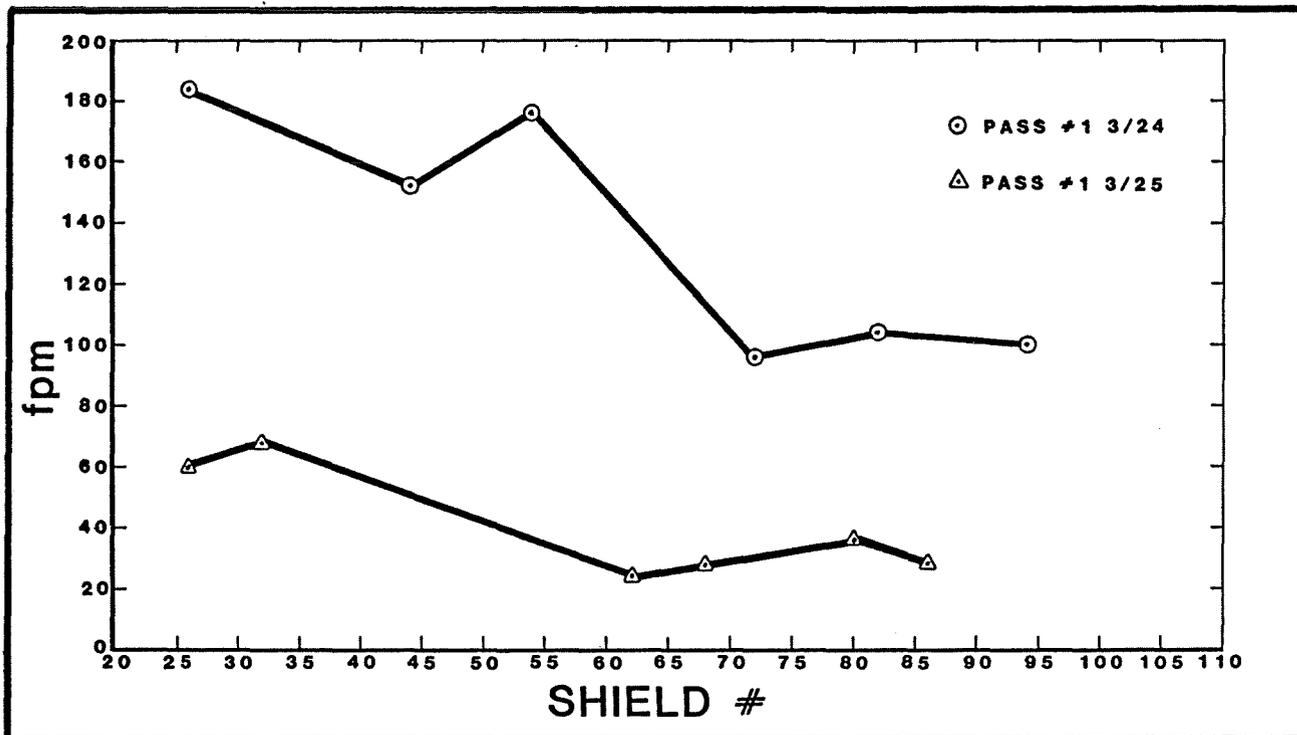


Figure C-6  
Air Velocities

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These flows should provide adequate cooling and a sufficient quantity of water for dust control.

The current orientation of the cooling sprays, particularly those at the headgate side, may have a deleterious effect on dust exposure (6). An open discharge, instead of sprays (see Figure C-1C), is preferable to eliminate the danger of flow interruption by clogging of the sprays. To obtain the desired flow, an orifice on the inlet side of each cooling circuit should be provided. This eliminates any unnecessary outside tampering with the cooling water flows. This orifice will be much larger than the orifices in the sprays now being used and clogging of this orifice will not occur.

If clogging of cooling water sprays is considered an acceptable risk, a second possibility is to discharge the cooling water through the sprays as shown in Figure C-1B. The sprays are directed with the airflow and the downwind spray system is located approximately in the middle of the shearer to prevent dust from passing over the shearer into the walkway. All sprays should be mounted so they point from headgate to the tailgate at a 45° angle with the face. If fan sprays would be used, the sprays should be installed so that the spray water forms a vertical shield.

Figures C-1B and C-1C also illustrate recommended changes for the outriggers. Both are similar to the shearer clearer system designed under a Bureau of Mines contract (10). One or two Venturi sprays on the tailgate side of the machine body will prevent boil-over of dust into the walkway and maintain a separation between the dirty air split over the machine and the clean air split in the walkway. These Venturi sprays can replace all sprays of the tailgate side outriggers. The headgate side outrigger sprays should be rigidly mounted at a 45° angle on a spring loaded steel bar as shown. They should have a constant fixed flow of 20 gallons per minute. Therefore, we recommend replacing the three on/off valves that these sprays now have with one on/off valve and the operators will not be able to reduce this quantity.

It may be considered to bypass the water distribution manifold on the shearer. According to observations, this manifold causes a considerable pressure drop (no formal measurements, however, have been made). The manifold can be replaced with a system of valves and orifices for proper distribution and control of the water. This system would cause a considerable decrease in pressure drop. The disadvantage is that the system which would replace the manifold would be less compact.

Belting should be maintained from both outrigger arms to the top of the conveyor. Conveyor belt screens should be installed at various locations on the body of the shearer to contain and hold the dust cloud toward the face side of the machine. This approach provides a cleaner air split in the walkway, over the shearer operators (12).

Air velocity in the intake side should be at least 300 fpm if possible. Higher air velocity will keep more of the dust generated by the

upwind drum closer to the face and away from the walkway and the downwind operator. The utility of drum and secondary water sprays decreases as air velocity decreases. Adequate air velocity also improves the dispersion and dilution of dust generated by secondary sources upwind of the machine.

Daily preventative maintenance should include the cleaning of drum sprays. This can be labor intensive, but improved non-clogging sprays or quick connect/disconnect sprays can reduce problems of spray blockage and cleaning. Clogging can be reduced by a good filtration system and by maintaining a constant flow to the sprays.