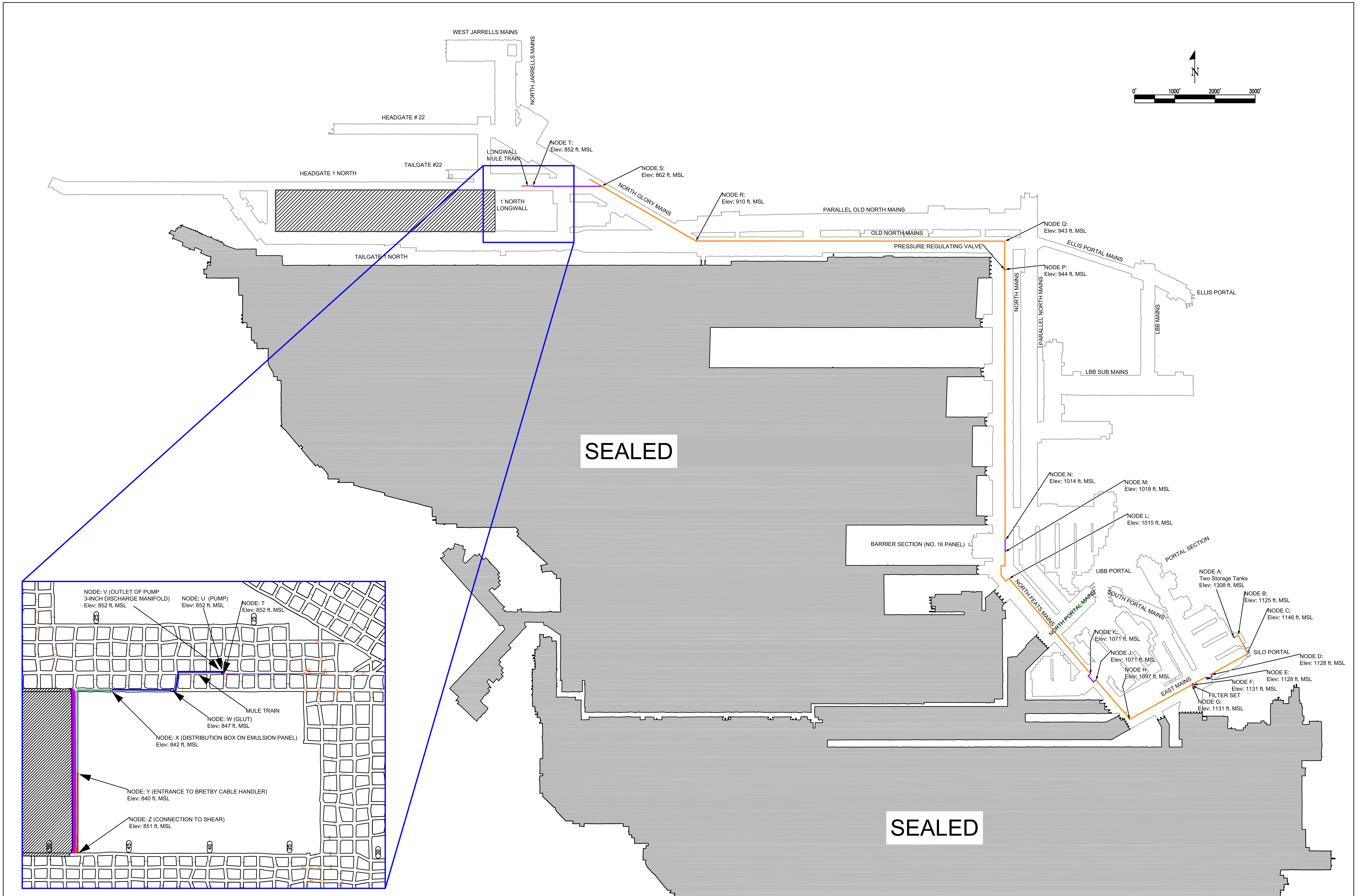

FIGURE R–1

Location of Waterline Supplying the Mule Train

Upper Big Branch Mine – South
Performance Coal Company
MSHA ID No. 46–08436

U.S. DEPARTMENT OF LABOR
MINE SAFETY AND HEALTH ADMINISTRATION
TECHNICAL SUPPORT

Appendix R: HYDRAULIC ANALYSIS REPORT

Water Supply System to the Longwall Shearer Dust Sprays

Upper Big Branch Mine-South (MSHA ID 46-08436)
Montcoal (Raleigh County), WV

April 5, 2010

PAR 98947

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Executive Summary

This report identifies the methods and conclusions of an analysis conducted to determine the capability of the mine water system to adequately supply water to the Shearer dust sprays on the Longwall mining machine at the No. 1 Longwall Panel. This analysis was requested by Upper Big Branch Mine Accident Investigation Team Leader, Norman Page. The analysis is based upon conditions believed to be existing just prior to the mine explosion of April 5, 2010.

The methodology herein was a four step process:

Step 1: Determine the rate of water flow needed for various equipment, along with the pressures at the equipment. In this case, the equipment in question was the dust control sprays on the longwall Shearer and related longwall equipment (longwall Shields and Stage Loader).

Step 2: Evaluate the water supply to determine the available pressure for the needed flow at a strategic location in the water distribution system. For this analysis, the strategic location chosen was the discharge side of the booster pump on the longwall mule train (Node U on the corresponding mine map, Appendix R, Figure R-1).

Step 3: Starting at the Shearer sprays and using the flows determined in Step 1, calculate hydraulic pressure losses traveling upstream to the same strategic location referenced in Step 2 (Node U). This provides the pressure required to maintain the needed flow determined in Step 1.

Step 4: Compare the pressure required in Step 3 to the available pressure determined in Step 2. If the required pressure exceeds the available pressure, the water system is deemed inadequate. For the analysis conducted herein, the required pressure exceeded the available pressure for all the flow scenarios that were considered.

The following assumptions and conditions apply to the analysis.

1. Because the fluid is water and all piping and hoses are assumed to have smooth internal linings, hydraulic pressure losses due to friction in the piping or hoses can be determined accurately using the Hazen-Williams formula. This accuracy is generally considered adequate for water up to velocities of approximately 25 feet per second. The Hazen-Williams formula is normally expressed as:

$$P_{loss} = \frac{4.52Q^{1.85}}{C^{1.85}D^{4.87}}L \qquad \text{(R-1)}$$

Where:

P_{loss} = pressure loss in pounds per square inch (psi) end to end in the pipe or hose
Q = flow through the pipe in gallons per minute (gpm)
D = internal diameter of the pipe or hose (inches)
L = length of the pipe or hose (feet)
C = Hazen-Williams factor representing the internal smoothness of the pipe

2. A Hazen-Williams C value (pipe smoothness factor) of 150 was used for all calculations. The lower the C value, the rougher the pipe or hose lining and the greater will be the pressure losses for a given flow. A C value of 150 represents very smooth pipe or hoses in a typically brand new condition. This value is being used since the actual internal conditions of the hoses and piping is unknown. One method of determining the actual C values for piping would be to conduct a detail hydraulic profile flow test of the system. However, the water system was damaged by the explosion and out of service, thus eliminating any opportunity to flow test it.

3. Velocity pressure differences between any reference point and related locations were not considered where such differences were less than 4 psi, which was the case in all analyzed situations. Furthermore, flow velocities were well below the upper limit of about 25 feet per second.

4. The flow characteristics of the Shearer are based upon both flow testing conducted underground on the Shearer on December 20, 2010, and upon flow estimates based upon nozzle data received from the MSHA UBB accident investigation team. Four scenarios for various combinations of flows were considered in the analysis.

5. For large diameter piping and hoses, and for long runs of smaller hoses, minor losses for fittings were considered negligible and have been excluded from the analysis. Where minor losses were deemed important, details were included in the Node by Node description of the water system. Additionally, the main water line contained a number of in-line control valves to isolate sections of the water line for the purpose of maintenance. It is assumed all of theses valves were in the fully open position and any losses across these valves are negligible.

6. Elevations of important or useful locations in the mine were estimated using a mine map showing "bottom" elevations. These elevations are listed in feet above mean sea level (MSL)[1]. All elevations, pressure sources, pressure losses, and net pump discharge pressure have been converted to equivalent feet of head for inclusion on the hydraulic profiles (Figures R-2 through R-5). Before plotting the data on a hydraulic profile, each pressure head value must be added to the elevation at the location in question. The equivalent feet of head for a pressure value can be determined by multiplying the pressure in psi by 2.31. The equivalent pressure value in psi for a given feet of head can be found by dividing the head by 2.31.

7. For the analysis, calculated pressures were rounded down to the nearest whole psi for required pressures, and rounded up to the nearest whole psi for available pressures, except where the decimal value was within about 0.2 psi of a whole psi. For those cases, the pressure was rounded to the nearest whole psi.

General Description of the Mine Water System

The Upper Big Branch mine water supply was a gravity fed system supplemented with underground booster pumps placed at strategic locations. For the long wall section at the 1 North Panel, two booster pumps, arranged in parallel, were located on the most outby car of the longwall mule train.

Water for the system was stored in two steel cone roof surface tanks located on the hilltop above the southeast corner of the mine near the Silo Portal where the No. 1 South Belt exits the mine. The bottom elevation of the tanks was reported to be 1308 feet above MSL.

The main water line between the tanks and the various parts of the mine consisted primarily of PVC plastic piping known as "Yelomine" pipe, a trademark of the Certainteed Corporation. The wall thicknesses and pressure ratings for this type of pipe are based upon SDR (standard dimensional ratio number) specifications. The main water line is primarily 8-inch piping but there were some sections consisting of 6-inch piping, including a long run in the No. 1 Headgate North Mains. Yelomine piping sections visually examined had an SDR number of 13.5, giving it a pressure rating of 315 psig.

The water system had two locations where filter canisters removed sediment or debris from the water. The first bank of filters consisted of ten filters in parallel located approximately midway in the East Mains. The second bank consisted of

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[1] "feet above mean sea level" is hereafter abbreviated "ft MSL".

four filters in parallel located on the longwall mule train booster pump car. The filter media were metal baskets consisting of No. 60 sieve material[2]. Several weeks before the explosion, the mine operator had stopped using cloth bags, commonly referred to as socks, typically sized to filter either at the 10 micron or 100 micron particle size.

The layout of the water system is shown on two mine views presented in Appendix R, Figure R-1. One view shows the overall water line routing from the tanks to the longwall mule train connection; the second view shows the routing from the mule train connection to the Shearer connection. In both views, important locations are identified with individually lettered node labels. Certain letters, specifically I and O, were not used to designate nodes to prevent possible confusion with the numbers one or zero. The nodes were established as part of this analysis for the convenience of specifying various strategic locations along the water system routing.

Node to Node Description of the Water System

Node information, along with estimated pipe lengths between nodes, is summarized in Table 9 and Table 10. Elevations and node descriptions are also shown in these two tables. As indicated above, node locations are shown on the Appendix R Mine Map, Figure R-1.

Node A

This node is at the discharge from the storage tanks. Its elevation was reported to be 1308 feet MSL. Assuming a tank height of 28 feet including cone roof, and a fill level of 25 feet within each tank, the elevation when the tank is full would be at approximately 1333 ft MSL.

Piping to next node

The exact route of piping was not determined, but was approximated based upon the location of most likely useful mine entries. It is assumed that all piping is 8-inch Yelomine with an SDR of 13.5.

Node B

The exact location of this node is assumed based upon the location of mine entries. The elevation is approximately 1125 ft MSL.

Piping to next node

As with the piping between Node A and B, the exact route of piping was not determined, but was approximated based upon the location of most likely

[2] A US 60 sieve will prevent passage of particles larger than 250 microns.

useful mine entries. It is assumed that all piping is 8-inch Yelomine with an SDR of 13.5.

Node C

The exact location of this node is assumed. The connection point to the East Mains water line in this area could not be found due to a large build up of rib sloughage and rock dust which buried this part of the water line. The elevation is approximately 1146 ft MSL.

Piping to next node

Except for the portion near the No 1 belt Silo Portal exit where the pipe was covered in sloughage, the piping was field verified as 8-inch Yelomine, SDR 13.5 piping. It ran on the mine floor alongside the belt conveyor in the East Mains.

Node D

This node is located at the No. 17 Break of the East Mains belt entry, at approximately 1128 ft MSL.

Piping to next node

This piping was field verified as 6-inch Yelomine, SDR 13.5 piping which moved over to an adjacent entry for two breaks, possibly to avoid the congestion created by a section-belt dumping point onto the main belt at Break 18.

Node E

This node is located at the No. 19 Break of the East Mains in the belt entry. It's elevation is approximately 1128 ft MSL.

Piping to next node

This piping was field verified as 8-inch Yelomine, SDR 13.5 piping. It ran on the mine floor alongside the No.1 Belt conveyor in the East Mains.

Nodes F and G

These two nodes are at an elevation of approximately 1131 ft MSL. They are located in the belt entry, between break Nos. 24 and 25, and represent the connections into and out of a filter set consisting of ten parallel metal basket filters contained within individual cylindrical stainless steel pressure enclosures. These filters are Rosedale model 8-30-2P-150-S-B-S-BM60 filters.

Even under the highest flow rate considered (344 gpm), the flow through this filter set would be split roughly equally between the ten filters, or about 35 gpm through each. Examination of performance curves in the Rosedale technical literature indicate that at a flow of approximately 35 gpm, the loss across the filter is about 0.1 psi. Even with the short lengths of intervening 2-inch piping and fittings, the loss across the entire filter set is considered negligible at less than 1 psi.

Piping to next node
This piping was field verified as 8-inch Yelomine, SDR 13.5 piping. As before, it ran on the mine floor alongside the No.1 Belt conveyor in the East Mains.

Node H
This node is located at the No. 49 Break of the East Mains in the belt entry. It's elevation is approximately 1097 ft MSL. At this point, the line makes a 90 degree turn into the Northeast Mains.

Piping to next node
This piping was field verified as 8-inch Yelomine, SDR 13.5 piping. It ran on the mine floor alongside the Northeast Mains belt conveyor line.

Node J
This node is located at the No. 15 Break of the Northeast Mains in the belt line entry. It's elevation is approximately 1071 ft MSL.

Piping to next node
At Node J, the 8 inch piping reduces to 6-inch Yelomine, SDR 13.5 piping and moved over to the adjoining parallel entry for two breaks.

Node K
This node is located at the No. 17 Break of the Northeast Mains in the belt conveyor entry. It's elevation was also approximately 1071 ft MSL.

Piping to next node
At Node K, the 6-inch piping transitions back to 8-inch Yelomine, SDR 13.5 piping and continued along the belt line. At about No. 31/32 Break, the water line was located near the roof, crossing over the track entering along the North Portal Mains.

Node L
This node is located at the No. 51 Break of the East Mains in the belt entry. It's elevation was approximately 1015 ft MSL.

Piping to next node
At Node L, the water line rerouted over to the adjacent track entry and continued along the track for approximately 4 breaks. It then returned to the

belt entry at No. 56 Break and continued inby. This piping was field verified as 8-inch Yelomine, SDR 13.5 piping. Starting at No. 56 Break, the Northeast Mains became the North Mains.

Node M

This node is located between the No. 59 and 60 Breaks of the North Mains in the belt entry. It's elevation is approximately 1018 ft MSL.

Piping to next node

At Node M, the piping reduced to 6-inch Yelomine, SDR 13.5 piping. It ran on the mine floor alongside the Belt conveyor. However, the belt conveyor ends at No. 61 Break.

Node N

This node is located between the No. 62 and 63 Breaks of the North Mains in the belt entry. It's elevation is approximately 1014 ft MSL.

Piping to next node

This piping was field verified as 8-inch Yelomine, SDR 13.5 piping. It ran on the mine floor in the former belt entry in the North Mains. This run of pipe is the second longest section of piping at just over 7000 feet in length.

Node P

This node is located at the No. 128 Break of the North Mains. It's elevation is approximately 944 ft MSL. At this location, an in-line pressure reducing valve (CLA-VAL model CLA 90-01/690, rated at 0 to 300 psi) was installed. Statements by mine personnel indicated the valve was set to maintain a maximum pressure of 150 psig to the inlet of the booster pump at the longwall mule train. Based upon the difference in elevation between the pump and this reducing valve, the valve would have been set to reduce pressure to approximately 115 psig at the reducing valve outlet. (The pump is located at Node U.)

Piping to next node

This piping was field verified as 8-inch Yelomine, SDR 13.5 piping. It continued north, and at the No. 134 Break of the North Mains, crossed the east/west track serving the Ellis Portal. It continued one more break north to the No. 4 belt entry in the Old North Mains.

Node Q

This node is located at Survey Station # 18655 in the Old North Mains. It has an elevation of approximately 943 ft MSL.

Piping to next node

This piping was field verified as 8-inch Yelomine, SDR 13.5 piping. It ran on the mine floor alongside the belt conveyor in the Old North Mains. This is the longest run of water line at just under 7700 feet in length.

Node R

This node is located at the No. 76 Break of the Old North Mains belt entry. It's elevation is approximately 910 ft MSL.

Piping to next node

From this node, the water line turns into the belt entry in the North Glory Mains. The piping was field verified as 8-inch Yelomine, SDR 13.5 piping.

Node S

This node is located between the No. 103 and 104 Break of the North Glory Mains. It's elevation is approximately 862 ft MSL. At this location, the water line flow path splits into two directions. The first direction is the existing the 8-inch line continuing inby along the belt conveyor toward for the No. 22 Longwall panel development section. The other flow path, the 6-inch pipe discussed next, is routed in the adjacent parallel entry to the belt entry for the No. 1 Headgate North Mains.

Piping to next node

This piping was field verified as 6-inch Yelomine, SDR 13.5 piping. It ran on the mine floor alongside the No. 1 Longwall Panel belt conveyor toward the mule train. At the No. 8 Break of the No. 1 Headgate North Mains, the track enters this entry and continues inby alongside the water line.

Node T

This node is located just inby No. 17 Break of the No. 1 Headgate North Mains. It's elevation is approximately 852 ft MSL.

Piping to next node

At this node, the 6-inch pipe changes to 4-inch hydraulic hose. This arrangement consisted of approximately 26 feet of 4-inch hydraulic hose connected to a 5 foot length of 4-inch schedule 40 steel pipe. Four 2-inch schedule 40 steel pipes tap off of the 4-inch pipe to feed four individual metal basket filters, each in a stainless steel filter housing. On the discharge side of the filters, 2-inch piping then connected the flow to a second 4-inch schedule 40 steel pipe approximately 7 feet long which fed the suction sides of the two parallel booster pumps.

The four filters were similar to the ten filters at the filter set located between Nodes F and G. The valving to one of the four filters was found shut, thus splitting the maximum considered flow of 344 gpm pump flow approximately evenly between the other three filters, or approximately 115 gpm through each. Even at this higher flow, the pressure loss across the filters was less than 1 psi and thus considered negligible. However, the 115 gpm flow through the 2inch piping was not considered negligible.

The 2-inch piping consisted of approximately 4 feet of actual pipe and 51 feet of equivalent pipe for the fittings consisting of four elbows, two gate valves, and one tee (total of 55 feet of equivalent 2 inch pipe). The equivalent pipe length for the fittings is based upon a Hazen-Williams C value of 150. To simplify the analysis, the Hazen-Williams equation was used to determine an equivalent length of 4 inch hose for the three parallel paths of 55 feet of 2-inch hose. This can be expressed as:

$$\frac{4.52Q_4^{1.85}}{C_4^{1.85}D_4^{4.87}}L_4 = \frac{4.52\left(\frac{Q_4}{3}\right)^{1.85}}{C_2^{1.85}D_2^{4.87}}L_2 \qquad \text{(R-2)}$$

Here the subscripts refer to the 2-inch and 4-inch pipe respectively. Assuming the C values for both pipes are the same (150) and using nominal diameter for the four inch hose (4.00 inches) and the schedule 40 steel pipe diameter (2.067 inches) for the 2-inch pipe, solving equation R-2 for L_4 yields an equivalent length of 180 feet for a single four inch hose carrying 344 gpm versus three parallel paths of 55 feet of 2-inch steel pipe, each carrying 115 gpm.

In addition to the 26 feet of 4-inch hydraulic hose, the total 4 inch steel pipe was approximately 11 feet in length. This brings the total length of equivalent four inch hose to 217 feet (26+180+11).

Node U

This node is located at the longwall mule train No. 1 booster pump. The pump is on the first car of the mule train just inby No. 17 Break of Headgate No. 1 North Mains. The elevation of this node is approximately 852 ft MSL.

There are actually two booster pumps plumbed in parallel. They were normally operated one at a time. After the accident, the pump located on the pump car toward the belt side of the entry (referred to as pump No. 1) was found with its valves open, indicating it was in use. The inlet and discharge valves for the other pump (referred to as pump No. 2) were found closed.

The nameplate data for the No. 1 booster pump is:

Mfgr: Sunflo
Model: P3-BVK
s/n B1020796-01
Rating: 350 gpm at 1470 feet discharge head

The No. 1 pump is powered by a three-phase AC induction motor with the following nameplate data.

Mfgr: Reliance Electric
Horsepower: 300
Volts: 460
Amps: 326
Service factor: 1.15
Model: P44G5183B
Frame: 449TS
Design: B
Speed: 3570 RPM

For reference, the No. 2 booster pump had a rating of 350 gpm at 1480 feet of head, and was thus nearly identical to the No. 1 pump.

Piping to next node
This piping is the discharge manifold off the pump and consists of 3-inch schedule 40 steel pipe. Together with the fittings, the equivalent length of 3-inch piping was 68 feet.

Node V

This node is at the inby end of the pump discharge manifold piping where the discharge flows into two parallel 2-inch hydraulic hoses. The elevation is also 852 ft MSL.

Piping to next node
This piping consists of two 2-inch hydraulic hoses running in parallel on the mine floor to No. 20 Break, where it turns and travels over to the longwall belt entry.

Node W

This node is located at a water distribution box referred to as the “glut.” At the glut, the flow connects to the hoses running in the longwall monorail system. The elevation of the glut is approximately 847 ft MSL.

Piping to next node

This piping is two 2-ich hydraulic hoses running in parallel on the monorail system.

Node X

At this node, located approximately one break outby the location of the longwall face, the two monorail 2-inch hoses connect into a distribution box that splits the incoming flow into three out going flows: water to the Shear, water to the shield dust sprays, and water to the Stage Loader sprays and cooling for the crusher motor.

It is assumed for the analysis that all three flows normally add to the flow rating of the booster pumps of 350 gpm, which would be the basis for the rating of the pumps used.

The elevation of this node is approximately 842 ft MSL.

Piping to next node

For the supply to the Shearer, the water traveled in a single 2-inch hydraulic hose that ran in a hose/wire bundle suspended beneath the chain conveyor framing.

The elevation of this node is approximately 840 ft MSL.

Node Y

This node is located where the 2-inch hydraulic hose connects to the hose in the Bretby cable handler. This is a traveling cable tray that runs between the center of the longwall and the Shearer. It allows cables and the water supply needed by the Shearer to travel back and forth with the Shearer as it traverses the length of the longwall from headgate to tailgate.

Piping to next node

This piping is single 2-inch hydraulic hose that is enclosed in the Bretby cable handler.

Node Z

This node is located at the Shearer water inlet connection on the Shearer body. At the location where the Shearer was found after the accident, the elevation was approximately 851 ft MSL.

STEP 1, Longwall Shearer Water Requirements

There are two aspects to developing the flow characteristics of the longwall Shearer. The first is to develop an estimate for minimum acceptable needed flow to the sprays on the Shearer to meet the requirements of the approved dust control plan. The second is to develop an estimate of the actual hydraulic characteristics of the Shearer water spray distribution system.

Required minimum Shearer flow per the dust control plan
The shearer dust sprays included a mixture of nozzles of various types different from those listed in the approved dust control plan. The approved dust control plan listed Conflow Code 2801CC full-cone staplelock nozzles having a 1/16-inch orifice. However, documentation from the mine operator indicated use of 116 nozzles identified as Flow Technologies model 791C full cone staplelock sprays having 3/32-inch orifices (0.094 inches). There were also 41 sprays listed as made by the Spraying Systems Company. Field examination of the nozzles confirmed them to be those made by Flow Technologies. Flow Technologies maintains that at the same pressure, their nozzles produce equivalent flow and patterns to Conflow nozzles having 3/32 inch orifice. The field examination found that approximately 1/3 of the installed staplelock sprays were jet sprays, with the remainder being cone sprays. Each pattern type produces a different flow rate at any given pressure.

The Spraying Systems nozzles were reported as model BD-5, based upon field examination of the nozzles installed on the Shearer and Stage Loader. Some spare nozzles found in the longwall supply area were BD-3 or Steinin 5-5 nozzles. Steinin indicated their 5-5 nozzles had the same flow characteristics as the Spraying Systems BD-5 nozzles. There were no BD-3 nozzles observed as installed on the Shearer or Stage Loader.

The dust control plan required all nozzles at the shearer to have at least 90 psi when flowing. At this pressure, the staplelock full cone spray nozzles would flow approximately 1.32 gpm each, while the staplelock jet spray nozzles would flow approximately 1.75 gpm each. The BD-5 nozzles had a flow of 1.5 gpm each.

Based upon nozzle counts and field observations, two possible flow conditions were estimated. These were based upon summing the minimum flow from each nozzle on the Shearer when each nozzle is at a pressure of 90 psi. A third flow condition was developed based upon data from the mine operator for nozzles at 125 psi (refer to Step 1 in the analysis for more detail).

Shearer Flow Condition 1
116 staplelock cone sprays

41 Systems Spraying BD-5 nozzles.
Total flow 214 gpm.

Flow condition 1 at the Shearer has been included in the analysis, but is not representative of nozzles observed as installed on the Shearer.

Shearer Flow Condition 2
116 staplelock nozzles,
  78 cone sprays,
  38 jet spray
41 Systems Spraying BD-5 nozzles.
Total flow 231 gpm.

This second flow condition is based upon the field observation that approximately one third of the Shearer staplelock nozzles were jet sprays, while the remainder were cone sprays.

Note that the total flows provided in the flow conditions are the minimum flows into the Shearer needed to conceptually meet the 90 psi criteria. Since it is not likely that all nozzles will have the same pressure at any given total flow condition, total flows higher than the minimum would probably be needed under realistic conditions to ensure each nozzle having the minimum pressure of 90 psi. However, only the minimum flow is considered here since determining or predicting the pressure at all nozzles simultaneously is not practicable.

Equivalent flow characteristics of the Shearer as found
To establish an estimated equivalent flow characteristic for the Shearer, it was necessary to flow test the Shearer spray system. Since the normal mine water system was damaged by the explosion and out of service, it was necessary to provide a temporary water supply. During the flow test, gravity fed water from the surface above the mine was delivered through a bore hole near the longwall section and then through temporary piping over to the Shearer. At the Shearer, a test manifold was assembled consisting of filters, an adjustable pressure reducing valve, two in-line flow meters (one belonging to MSHA and the other to the mine operator), and appropriate pressure gages. The pressure reducing valve was used to regulate and adjust the pressure into the Shearer. The flow was then measured at various inlet pressures.

Four tests were conducted on the Shearer on December 20, 2010. However, one of the tests was actually conducted twice after problems were identified when the filters on the test manifold had plugged up.

Because of the location of the Shearer, most nozzles on the headgate drum could not be reached and examined up close as this drum was mostly beneath unsupported roof and was not safely accessible. Additionally, fallen coal and rock around both Shearer drums created a situation making it impossible to view the condition of all nozzles, especially those at the bottom of the drums. Visible nozzles were identified as open, plugged, or missing.

The Shearer flow tests are summarized as follows:

<u>Field Test No. 1</u>
This was the Shearer tested in the post accident (as-found) condition including both plugged and missing nozzles.

<u>Field Test Nos. 2 and 2A</u>
Test 2 was also with the Shearer in the "as-found" condition including plugged and missing nozzles, but with one plugged nozzle on each drum replaced with a pressure gage. The second test (2A) was run after the filters that plugged during test 2 were replaced with clean filters.

<u>Field Test No. 3</u>
In this test, those accessible nozzle openings with missing nozzles had open nozzles installed in those openings. This test represents the Shearer in an arrangement under conditions closer to what it should have been during operating in a properly maintained condition.

<u>Field Test No. 4</u>
In this test, the nozzles that had been installed in openings with missing nozzles for Test No. 3 were again removed. However, nozzles found to be plugged were replaced with un-plugged nozzles. Again, this was done only for nozzle locations that were safely accessible and visible. This test also represents the Shearer in a semi-repaired condition.

For each of the above flow tests, the flow and pressure data were used to estimate an equivalent single orifice nozzle having the same flow characteristics as the entire Shearer with its individual nozzles.

A single orifice nozzle, or an equivalent single orifice nozzle representing multiple nozzles, will have flow characteristics that can be modeled as:

$$Q = kP^n \qquad \text{(R-3)}$$

Where Q is the flow in gpm, P is the nozzle pressure in psi, n is an exponent (equal to 0.5 for an ideal smooth circular orifice), and k is a factor associated with the characteristics of a particular nozzle and takes into account the size, shape, and smoothness of the orifice.

Using appropriate logarithmic identities, equation R-3 can be recast as:

$$\ln Q = n \ln P + \ln k \qquad \text{(R-4)}$$

Equation R-4 has the form of a straight line given as:

$$y = mx + b \qquad \text{(R-5)}$$

Where *x* and *y* are the independent and dependent variable respectively, *m* is the slope of the line, and *b* is the y-axis intercept. The association between equations R-5 and R-4 is as follows:

$$y \to \ln Q, \quad m \to n, \quad x \to \ln P, \quad b \to \ln k$$

For reasonably well behave nozzles, the plot of ln[3](*Q*) versus ln(*P*) will result in a straight line, or nearly straight line, having slope *n* and intercept ln(*k*). Using linear regression analysis, such as provided in the linear trend line feature of Microsoft Excel, the equation for the line can be determined. This linear equation then establishes the values for *n* and *k*. With these values determined, the pressure needed at the Shearer to maintain any specified flow can be estimated from the following:

$$P = \left(\frac{Q}{k}\right)^{1/n} \qquad \text{(R-6)}$$

Test No. 1 is the initial test and most closely represents the Shearer in its as-found condition. Test No. 3 and No. 4 each represent the Shearer in a partially repaired condition, more closely representing how it should have been arranged during normal mining conditions. Using the methodology described above, the equations for the "equivalent nozzle" represented by the Shearer in the various conditions can be expressed in the form of equation R-3. The results were the following:

Test No. 1 Configuration: $Q = 12.44P^{0.469}$

Test No. 3 Configuration: $Q = 7.61P^{0.539}$

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[3] The symbol 'ln' represents the natural log function.

Test No. 4 Configuration: $Q = 12.99P^{0.468}$

Note that the collective effects of various nozzle orifices are reflected in the equivalent *k* factor in equation R-3. The difference between the *k* factors for Test No. 1 and No. 3 should reflect the effect of installing unplugged nozzles where nozzles were missing. This should reduce the total effective discharge opening of the Shearer sprays. The result should be a reduced *k* factor from Test No. 1 to Test No. 3, which as the data reflects, is observed.

The difference between the *k* factors for Test No. 1 and No. 4 should reflect the effect of installing unplugged nozzles where plugged nozzles originally existed. This should increase the effective Shearer discharge opening and result in an increased *k* factor between Test No. 1 and Test No. 4, which as the data reflects, is also observed.

To estimate the overall effect of installing open nozzles where they were found missing (Test No. 3) and replacing plugged nozzles with unplugged nozzles (Test No. 4), the change in *k* factor between Test No. 1 and Test No. 4 is added to the *k* factor of Test No. 3. Inserting the appropriate values into equation R-6 results in an effective Shearer equivalent nozzle of:

Pre-accident Expected Configuration: $Q = 8.16P^{0.539}$

This would approximately be the hydraulic characteristics of the Shearer in the pre-accident condition when properly maintained (no missing nozzles and no plugged nozzles).

Using equation R-6, the appropriate values for *n* and *k* above, and the two flow conditions identified previously, the resulting needed Shearer inlet pressure was:

<u>Flow condition 1</u>: $P = \left(\frac{214}{8.16}\right)^{1/0.539}$ = 428 psi (990 feet of head)

<u>Flow condition 2</u>: $P = \left(\frac{231}{8.16}\right)^{1/0.539}$ = 494 psi (1141 feet of head)

A third flow condition was identified by the mine operator based upon documentation submitted as part of the plan to conduct the underground flow tests on the Shearer. That documentation identified a flow through the Shearer at 224 gpm with all nozzles at a minimum pressure of 125 psi. Additionally, Joy, the longwall mining machine manufacturer, quoted a pressure loss across the

Shearer of 250 psi, although the flow at which this loss occurs was not specified. Hence, a third flow condition was included in the analysis as follows.

Flow Condition 3: 224 gpm at a Shearer inlet pressure of 375 psi (125 + 250).

These flow conditions establish the minimum pressures needed at the Shearer water inlet to conceptually provide either the minimum 214 gpm or 231 gpm spray flows, based upon the flow test results. These pressures become the starting points for Step 3 in the analysis process.

Estimated flow for the Longwall Stage Loader

There were a number of spray nozzles in the Stage Loader and crusher area, including three banks of 5 nozzles and 3 banks of 6 nozzles. The nozzles were identified as a variety of staplelock nozzles and BD-5 nozzles.. The dust control plan referenced a minimum pressure of 60 psi for these sprays. Assuming six full cone staple lock sprays and twelve BD-5 nozzles, all flowing at the minimum 60 psi, a minimum flow of 21 gpm was estimated for the Stage Loader dust sprays. Because the Stage Loader is hydraulically upstream of the Shearer, the pressure in the supply to these Stage Loader nozzles, in reality, could be substantially higher than the minimum 60 psi indicated in the plan. Hence, the actual flow at the Stage Loader could very well have been measurably higher than the minimum estimated 21 gpm.

In addition to the sprays, the water system also supplied cooling water for the Stage Loader and Crusher motors. Four permanent flow meters were mounted on the Stage Loader. The readings of these flow meters were periodically documented in maintenance records. The last records for these flows were 10, 8, 9, and 10 gpm to each cooling circuit. This represents an additional possible flow demand of 37 gpm.

Estimated flow for the Longwall Shields

The survey of the Shields indicated that approximately every fourth or fifth shield was equipped with a pair of BD-5 spray nozzles. Most of these nozzles were operated manually by the longwall operator as the Shearer traveled the face. Most nozzles had control valves, although a limited number did not and were thus always on. Some were identified as having the control valves partially open. A few were disconnected. The Accident Investigation Team estimated the shield spray flow would have likely been about 55 gpm.

The flows for the Stage Loader and Shield sprays are added to the Shearer flow at Node X (emulsion panel distribution box) when these flows are considered in any given scenario.

Four flow scenarios were considered.

Scenario 1: This scenario only included the flow of 214 gpm from the Shearer (Flow Condition 1) in the calculations.

Scenario 2: This Scenario considered the more likely 231 gpm Shearer flow (Flow Condition 2) plus the addition of the minimum Stage Loader flow of 21 gpm, for a total flow upstream beyond Node X of 252 gpm. The Stage Loader motor cooling flow and the Shield spray flow were not considered.

Scenario 3: This Scenario considered Shearer Flow Condition 2 plus all other flows at the Stage Loader and Shield sprays for a total flow of 344 gpm. This is the most realistic flow required. Note that this flow lends credence to the chosen rated capacity of the mule train booster pumps of 350 gpm for each.

Scenario 4: This Scenario considers only the Shearer flow condition 3. No flow demands for the Stage Loader or shield sprays are included.

STEP 2, Determine the Available Pressure at the Mule Train Booster Pump Discharge.

The pressure from the tank to the pump is supplied by gravity. Hence, the pressure available at the pump inlet is the static pressure at the pump inlet minus the friction losses in the piping from Node A to Node U. However, a pressure reducing value is located in this run of pipe (at Node P) and affects the maximum pressure available to the pump inlet. It was reported that this pressure reducing valve was normally set to ensure the pressure at the pump inlet did not exceed 150 psi (347 feet of head).

If the losses in the upstream main piping reduce the pump inlet pressure below the regulated pressure of 150 psi, then the lower pressure is used in the analysis. If the losses do not reduce the pressure at the pump inlet below the regulated value, then the regulated pressure value of 150 psi is used for the pump inlet. To determine which condition exists, the losses in the water line from the tank to the pump inlet must be determined.

Pressure losses in the water supply from the storage tanks to the pump under flowing conditions
The run of pipe from Node A to Node U consists approximately of:

27,525 feet of 8-inch, SDR=13.5 piping (actual ID of 7.347 inches)
2635 feet of 6-inch, SDR=13.5 piping (actual ID of 5.644 inches)
217 equivalent feet of 4-inch hydraulic hose (actual diameter of 4.00 inches)

It is a common practice in water supply analysis to use the Hazen-Williams formula to convert pipes of different sizes to an equivalent length of pipe of one referenced size. In this case, the 6-inch pipe and 4-inch hydraulic hose are converted to equivalent lengths of 8-inch SDR 13.5 piping.

For the 6-inch SDR piping, the equivalent length is:

$$\textbf{Equiv. Length of 8 inch} = (2635) \times \left(\frac{7.347}{5.644} \right)^{4.87} = 9515 \text{ feet}$$

For the 4-inch hose, the equivalent is:

$$\textbf{Equiv. Length of 8 inch} = (217) \times \left(\frac{7.347}{4.0} \right)^{4.87} = 4190 \text{ feet}$$

The total equivalent length of 8-inch pipe from Node A to Node U is thus:

27,525 + 9515 + 4190 = 41,230 feet

Hence, 41,230 feet of 8-inch SDR 13.5 piping will create the same losses at any given flow as the sum of the losses in the actual 8-inch, 6-inch, and 4-inch piping and hoses.

The maximum static pressure occurs with the tank full. This would be at an elevation of 1333 ft MSL. The elevation of Node U is 852 ft MSL, resulting in a difference in elevation of 481 feet of head, or 209 psi of static pressure at the pump inlet.

The four flows were previously identified as: 214 gpm, 252, gpm, 344 gpm, and 224 gpm. Using the Hazen-Williams formula, the losses in the equivalent length of 8-inch piping (41,230 ft) can be calculated for each flow and then subtracted from the available static pressure of 209 psi to get the resulting residual flow at the inlet of the pump. The results are summarized in Table 1. Since all of the resulting net residual pressures are above the regulated pressure of 150 psi, the 150 psi regulated value will be used as the pump input pressure for all four scenarios.

Table 1 – Residual Pressure Available at Pump Inlet for Each Flow Scenario

Flow Scenario	Flow Amount (gpm)	Pressure loss per foot of 8-inch (psi/foot)	Total pressure loss from Node A to Node U (psi)	Net Residual pressure at pump inlet Node U (psi)
1	214	0.0005	21	188
2	252	0.0007	29	180
3	344	0.0013	52	157
4	224	0.0006	23	186

Pressure added by the booster pump.

For each flow Scenario, the inlet pressure to the pump must be added to the net pump discharge pressure. This net pump pressure is the pressure added by the pump to the incoming pressure at the pump inlet. The net discharge pressure varies with flow and is usually provided by the pump manufacturer in the form of a curve plotting pressure against flow, tabulated test data of pressure and flow, or both. In general, as the flow increases through the pump, the discharge pressure decreases.

Although the pump nameplate data indicated a discharge head of 1470 feet (637 psi) at the rated flow of 350 gpm, additional information was obtained from the manufacturer's pump test data for this particular pump. The as-new shop test data indicated a pump curve slightly higher than that identified for this general model of pumps. The information is summarized below.

Table 2 – Booster Pump Net Discharge Characteristics

Pump Flow (gpm) (7.760 inch impeller)	Sunflo Model Discharge Head (feet)	Sunflo Shop Test Discharge Head (feet)
0	1548	n/a
70	n/a	1598
140	1545	1617
210	1532	1621
280	1506	1585
350	1470	1543
385	n/a	1492
420	1351	1428

For the analysis, the higher tested pump data was used. Additionally, where the scenario flow values do not match a test flow, it is a common practice to interpolate the discharge pressure from the curve or tabulated data. However, in this case for any flow scenario, in order to give the water system the benefit of the doubt, the discharge pressure at the next lower flow (higher pressure) is used rather than interpolating the data. This is justified at least in part because the interpolation is a linear process while the curve is non-linear. Linear interpolation will slightly under predict the discharge pressure.

The net pump discharge pressures used in the analysis are summarized in Table 3. In Table 4, the regulated pump inlet pressure of 150 psi has been added to the net pump discharge pressure to arrive at the total pump discharge pressure available for each flow scenario.

Table 3 – Net Pump Discharge Pressure Used for Each Flow Scenario

Flow Scenario	Flow Amount in analysis (gpm)	Pump flow test datum used (gpm)	Net discharge head at flow datum (ft)	Equivalent discharge pressure (psi)
1	214	210	1621	702
2	252	210	1621	702
3	344	280	1585	686
4	224	210	1621	702

Table 4– Total Pressure at Pump Discharge Used for Each Flow Scenario

Flow Scenario	Total Available Pump Discharge pressure (psi)	Equivalent available discharge head (ft)	Elevation plot point on hydraulic profile (ft MSL)
1	852	1968	2820
2	852	1968	2820
3	836	1931	2783
4	852	1968	2820

STEP 3, Determine the Required Pressure needed at the Mule Train Booster Pump Discharge to maintain required flow at the Shearer.

This process requires taking the pressure needed at the Shearer connection (Node Z) and then working backward upstream to Node U. The total required pressure is the sum of the pressure needed at the Shearer plus the losses in the piping or hoses from Node Z back to Node U.

From Node Z back to Node X represents a single run of 1210 feet of 2-inch hydraulic hose. The pressure losses are as follows for the four scenarios, assuming the actual hose diameter is the nominal diameter, which is usually the case for hydraulic hoses.

At node X, additional flow is added for Scenarios 2 and 3, resulting in the total flows of 252 and 344 gpm respectively. Scenarios 1 and 4 do not include any additional flows to the Shearer flow. Table 5 summarized the pressure needed at the Shearer inlet, the line loss back to Node X, and the sum of these pressures resulting in the total required pressure at this node.

Table 5 Resulting Pressure Required at Node X for Each Flow Scenario

Flow Scenario	Flow Amount (gpm)	Required pressure at Node Z	Pressure loss per foot of 2-inch hose (psi/ft)	Total pressure loss from Node Z to Node X	Total pressure required
1	214	428	0.298	360	788
2	231	494	0.344	415	909
3	231	494	0.344	415	909
4	224	375	0.325	392	767

From Node X back to Node V, the total flow is through 1400 feet of dual 2-inch hydraulic hoses in parallel. Because the lines are in parallel, it is only necessary to calculate the loss for one line, with the flow assumed to split evenly between the two hoses. For a 1400 foot length of 2-inch hydraulic hose, the pressure losses are as follows.

Table 6 Resulting Pressure Required at Node V for Each Flow Scenario

Flow Scenario	Total flow Amount (gpm)	Split flow amount	Pressure loss per foot of 2-inch hose (psi/ft)	Total pressure loss from Node X to Node V	Total pressure required
1	214	107	0.083	115	903
2	252	126	0.112	156	1065
3	344	172	0.199	278	1187
4	224	112	0.090	126	893

Finally, from Node V to Node U, we have a single run of 3-inch piping consisting of 68 equivalent feet of schedule 40 pipe. The pressure losses and the final total pressures required are summarized in Table 7.

Table 7 Resulting Pressure Required at Node U – Pump Discharge

Flow Scenario	Total flow Amount (gpm)	Pressure loss per foot of 3-inch Sch 40 pipe (psi/ft)	Total pressure loss from Node V to Node U	Total pressure required at pump discharge (psi)	Elevation plot point on Hydraulic profile (ft MSL)
1	214	0.037	2	905	2942
2	252	0.050	3	1068	3319
3	344	0.089	6	1193	3607
4	224	0.040	2	895	2919

STEP 4, Compare the required pressure to the available pressure.

Table 8 summarizes the results of this comparison.

Table 8 Summary of System Pressure Shortages at Pump Discharge

Flow Scenario	Total flow Amount (gpm)	Total pressure available at pump discharge (psi)	Total pressure required at pump discharge (psi)	Pressure difference (psi) (negative number indicates a deficit)
1	214	852	905	–53
2	252	852	1068	–216
3	344	836	1193	–357
4	224	852	895	–43

Conclusion

For all of the scenarios, the required pump pressures exceed the available pump discharge pressures. Note that Scenario 4 is the closest to being adequate but does not include any flows for the Stage Loader or the shield sprays. Additionally, the pressure required for this scenario, 375 psi, is based upon data from the manufacturer of the longwall but does not indicate for what flow the pressure loss of 250 psi occurs. Note that using the pressure versus flow characteristics of the Shearer as tested, coupled with the associated methods utilized within this report, the required pressure at a flow of 224 gpm would be 466 psi, not 375. Hence, a more realistic pressure deficit for scenario 4 would be closer to a value of –134 psi rather than to –43 psi.

It must be emphasized that Scenario 3 represents the most realistic flow requirement for the dust control effort on the No. 1 Longwall Panel mining machine because it includes flows for the Shield sprays and the Stage Loader sprays and motor cooling. As the analysis indicates, there is a significant water pressure deficit between what is required to maintain this identified flow and what is available from the water system. The other three scenarios, included for reference, are also inadequate but represent less realistic water flows since they do not include complete water flows for the dust control sprays and motor cooling needs on all parts of the mining machine.

TABLE 9 – NODE DATA FROM TANK TO LONGWALL MULE TRAIN

Node	Elevation	Delt Elev	8" length to next node	6" length to next node	size of pipe to next node	SS	Break No.	Mains Reference	Comments
A	1308		280	0	8		n/a		Water Tanks
B	1125	-183	520	0	8		2	EAST	#1 East Mains South Belt-pipe routing assumed
C	1146	21	1045	0	8		2	EAST	Location of connection assumed
D	1128	-18	0	270	6		17	EAST	
E	1128	0	365	0	8		19	EAST	
F	1131	3	0	0	8		btwn 24 & 25	EAST	Filter set Between F and G
G	1131	0	1785	0	8			EAST	
H	1097	-34	1310	0	8		49	EAST	
J	1071	-26	0	356	6		15	NORTHEAST	
K	1071	0	3120	0	8		17	NORTHEAST	
L	1015	-56	975	0	8		51	NORTHEAST	
M	1018	3	0	300	6		btwn 59 & 60	NORTH	
N	1014	-4	7015	0	8		btwn 62 & 63	NORTH	
P	944	-70	715	0	8		128	NORTH	Pressure regulating valve at Node P.
Q	943	-1	7680	0	8		135 /0	NORTH /OLD NORTH	
R	910	-33	2715	0	8		76	OLD NORTH	
S	862	-48	0	1710	6		btwn 103 & 104	NORTH GLORY	
T	852	-10	0	0			17	HG 1 NORTH	Mule train

TABLE 10 — NODE DATA FROM LONGWALL MULE TRAIN TO SHEARER CONNECTION

Node	Elevation	Length	Node description	Pipe description	Notes
T	852	217	6" SDR Connection to 4 inch pump feed hydraulic hose and piping and filters	26 ft 4" HH, 55 ft equiv 2" pipe, 4 ft 4" after filter to pump	total Equvalent feet of 4 inch
U	852	68	Pump	3 inch Sch 40	total equivalent feet of 3 inch
V	852	400	End of 3" pump discahrge manifold	Parallel 2 inch HH to glut	111 equiv feet for parallel split flow
W	847	1000	Glut	Parallel 2 inch on monorail system	280 equiv feet for parallel split flow
X	842	710	Distribution box on emulsion panel	single 2 inch for shear water demand	
Y	840	500	connection into Bretby cable handler	single 2 inch for shear water demand	
Z	851		SHEARER connection		

HH = hydraulic hose

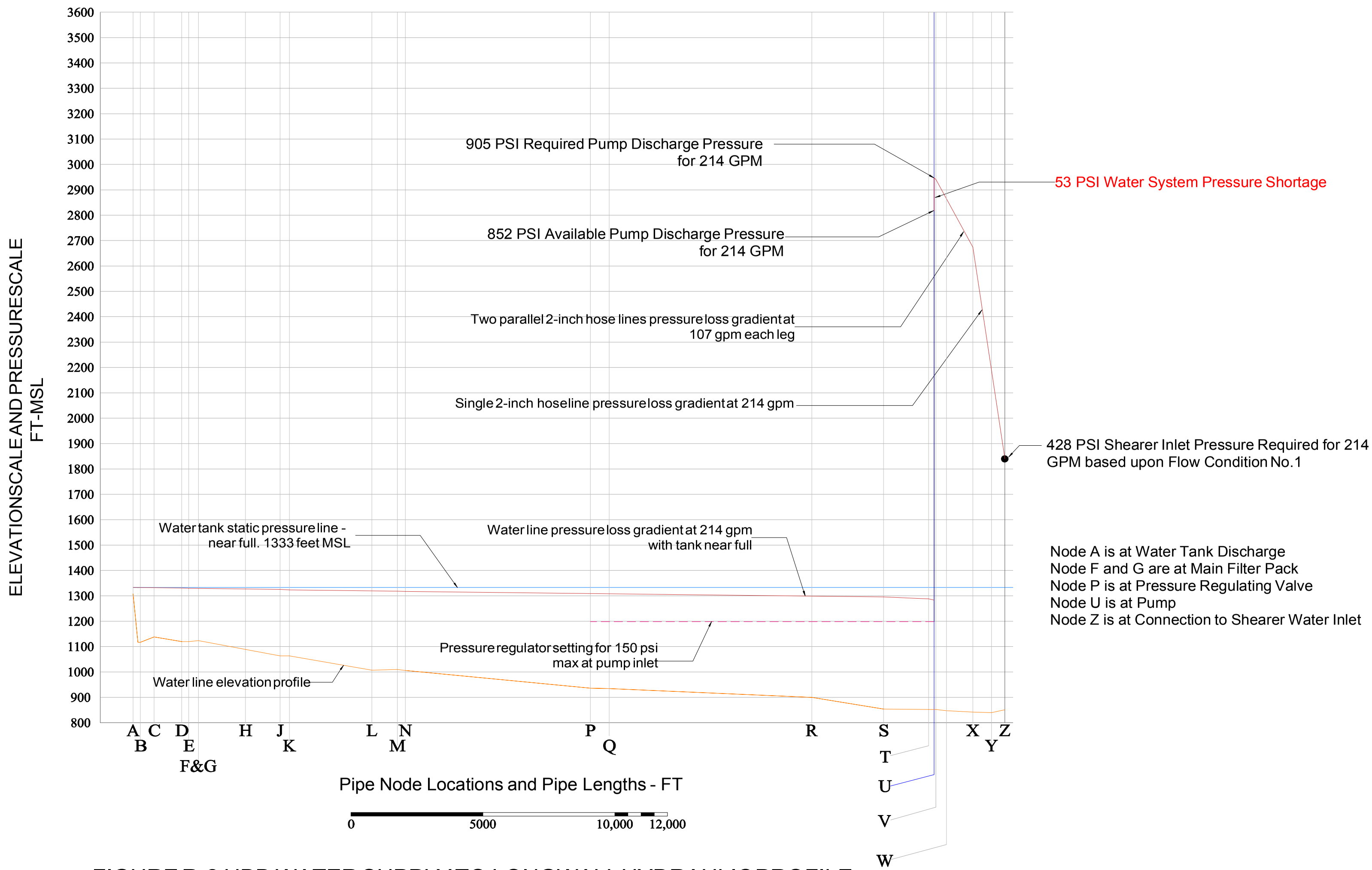
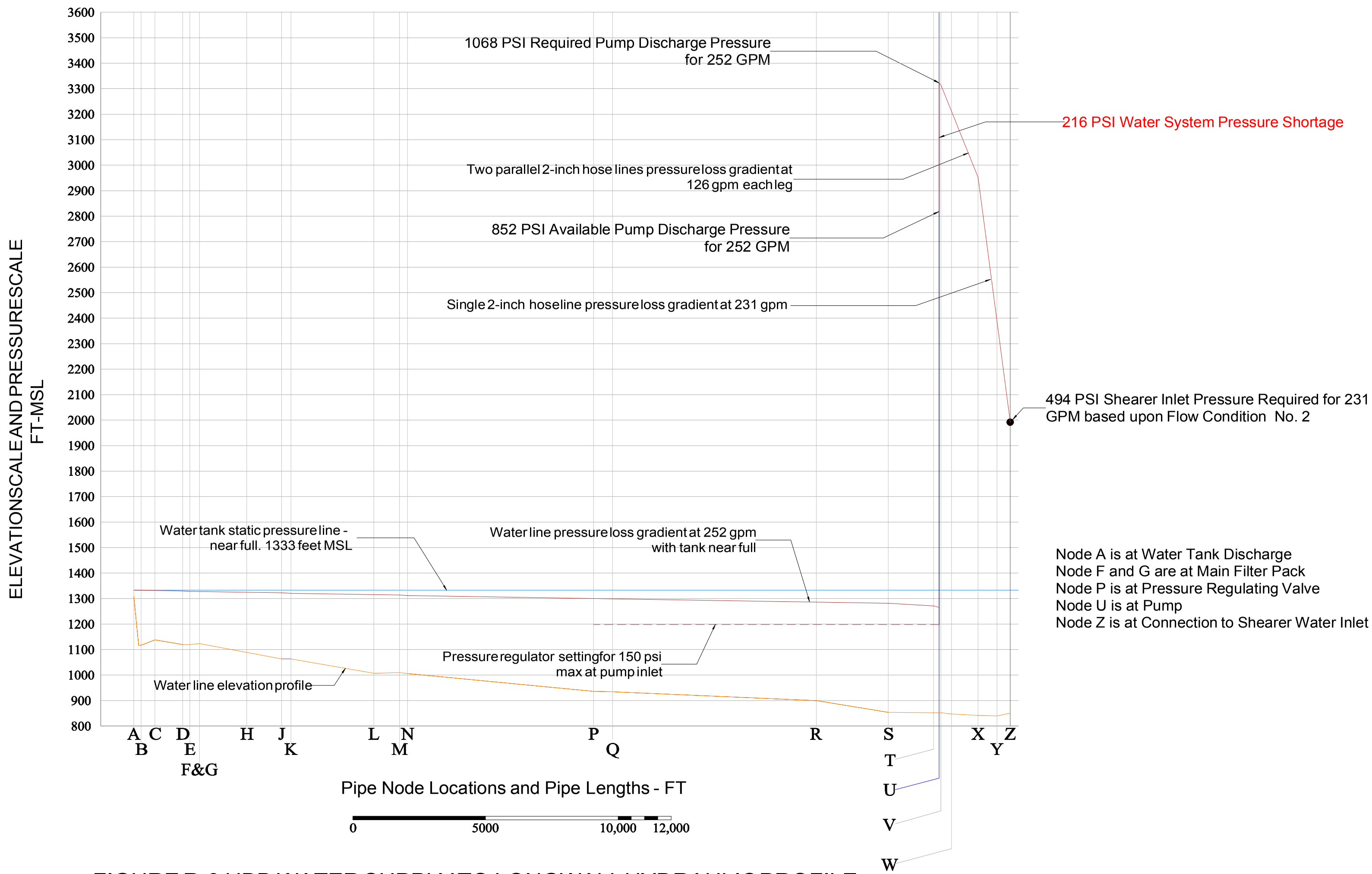


FIGURE R-2 UBB WATER SUPPLY TO LONGWALL HYDRAULIC PROFILE
Flow Scenario 1
Shearer Flow 214 GPM
Total Flow 214 GPM



Node A is at Water Tank Discharge
Node F and G are at Main Filter Pack
Node P is at Pressure Regulating Valve
Node U is at Pump
Node Z is at Connection to Shearer Water Inlet

FIGURE R-3 UBB WATER SUPPLY TO LONGWALL HYDRAULIC PROFILE
Flow Scenario 2
Shearer Flow 231 GPM
Total Flow 252 GPM

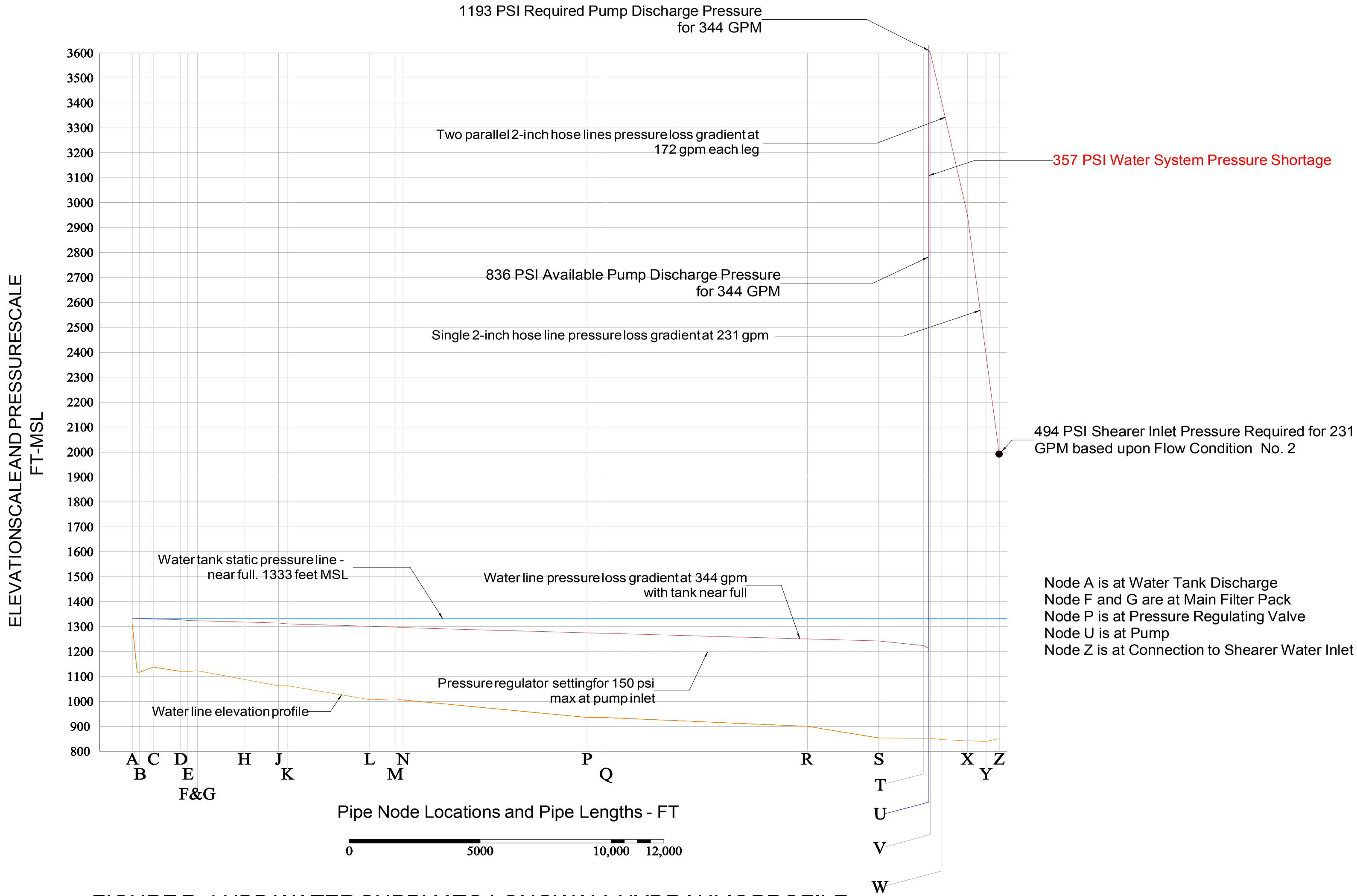


FIGURE R-4 UBB WATER SUPPLY TO LONGWALL HYDRAULIC PROFILE
Flow Scenario 3
Shearer Flow 231 GPM
Total Flow 344 GPM

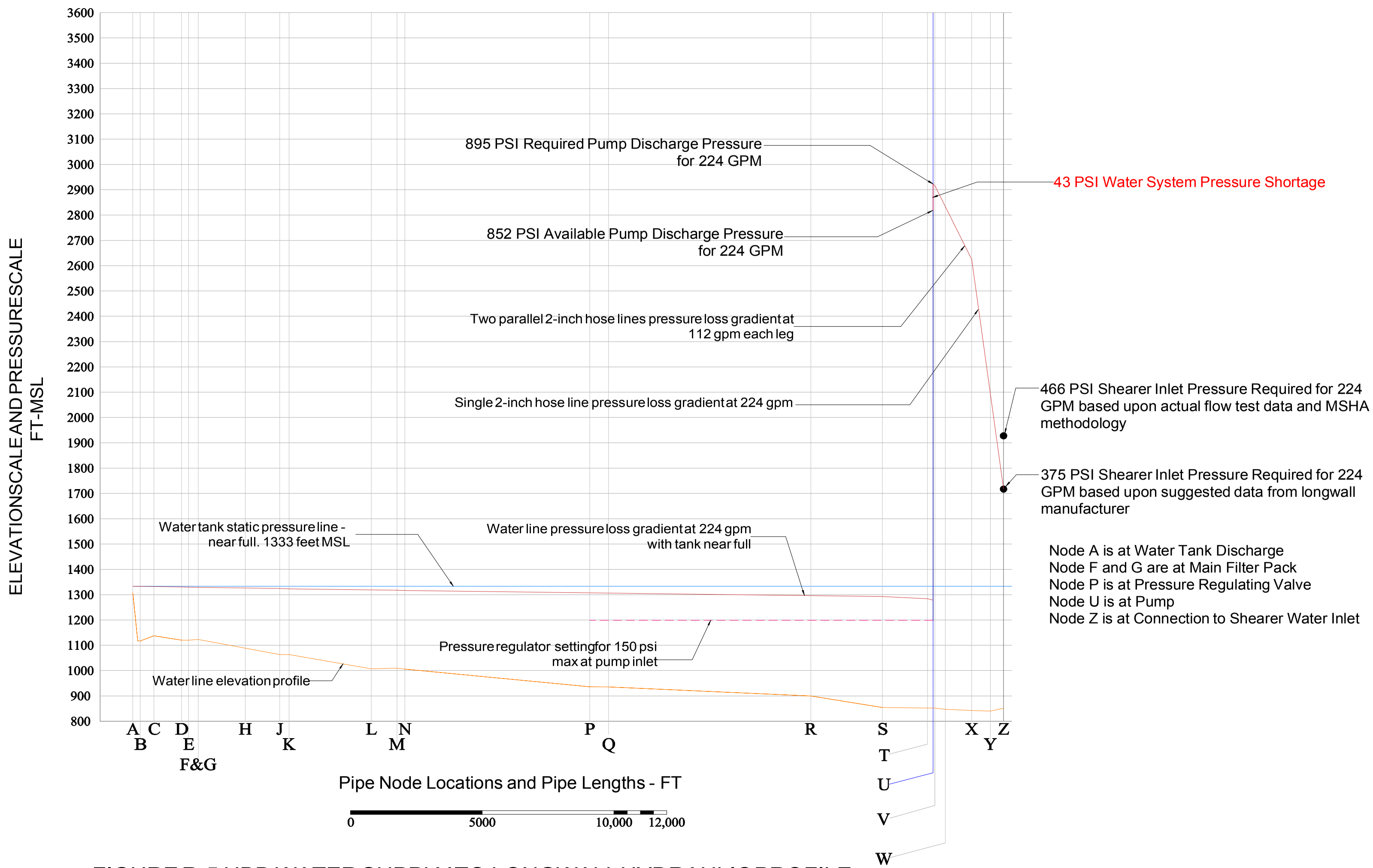


FIGURE R-5 UBB WATER SUPPLY TO LONGWALL HYDRAULIC PROFILE
Flow Scenario 4
Shearer Flow 224 GPM
Total Flow 224 GPM

APPENDIX S

SEDIMENT ANALYSIS FROM WATER BASKETS AND SPRAY NOZZLES