HYDROLOGY

Hydrologic data were used to determine the amount of surface water entering the underground mine pools of the region, which are the sources of the thirty-one (31) discharges in the watershed. Application of this data included the calculation of the maximum reduction in flow for each mine discharge which could be expected from various abatement techniques as well as the total reduction in the pollution load of the watershed. In addition, abatement techniques for reducing the flow were evaluated to determine which techniques were the most cost effective. Some of the techniques included the reclamation of abandoned strip mines, diversion of surface runoff, relocation of permanent streams, and treatment systems.

Information published by the National Climatic Center provides precipitation values for the various regions of Pennsylvania. Since no rain gages are located within the Mahanoy Creek Watershed, values from nearby gaging stations were averaged so a single value for the Mahanoy Creek area could be determined. It was found that the average yearly amount of precipitation over the Mahanoy Creek Watershed is approximately 42.9 inches (see Figure 15, p. 56).

During the 12 month sampling period from November, 1973 to October, 1974 the total amount of precipitation over the watershed was 46.2 inches. The total is 7.7 percent above the yearly average, and all stream and discharge flow readings can be expected to be above their yearly normal averages by a similar amount. All engineering calculations utilitzing the flow measurements taken during the study period can be considered conservative because they used as average conditions, flows which were actually above normal.

The infiltration of water into most mine pools (ground water) occurs primarily through recharge due to rainfall. Additional amounts of water enter these mine pools from disruption of natural aquifers which at times may become the major source of water, rock fracture zones, and faults. Faults and fracture zones may often collect and transport large quantities of water. Abatement techniques evaluated in this report to reduce this water entering the mine pools included the techniques mentioned above as well as sealing bore holes and mine seals. Increasing runoff involves changing surface drainage and installation of flumes, stream lining and diversion ditches or channels.

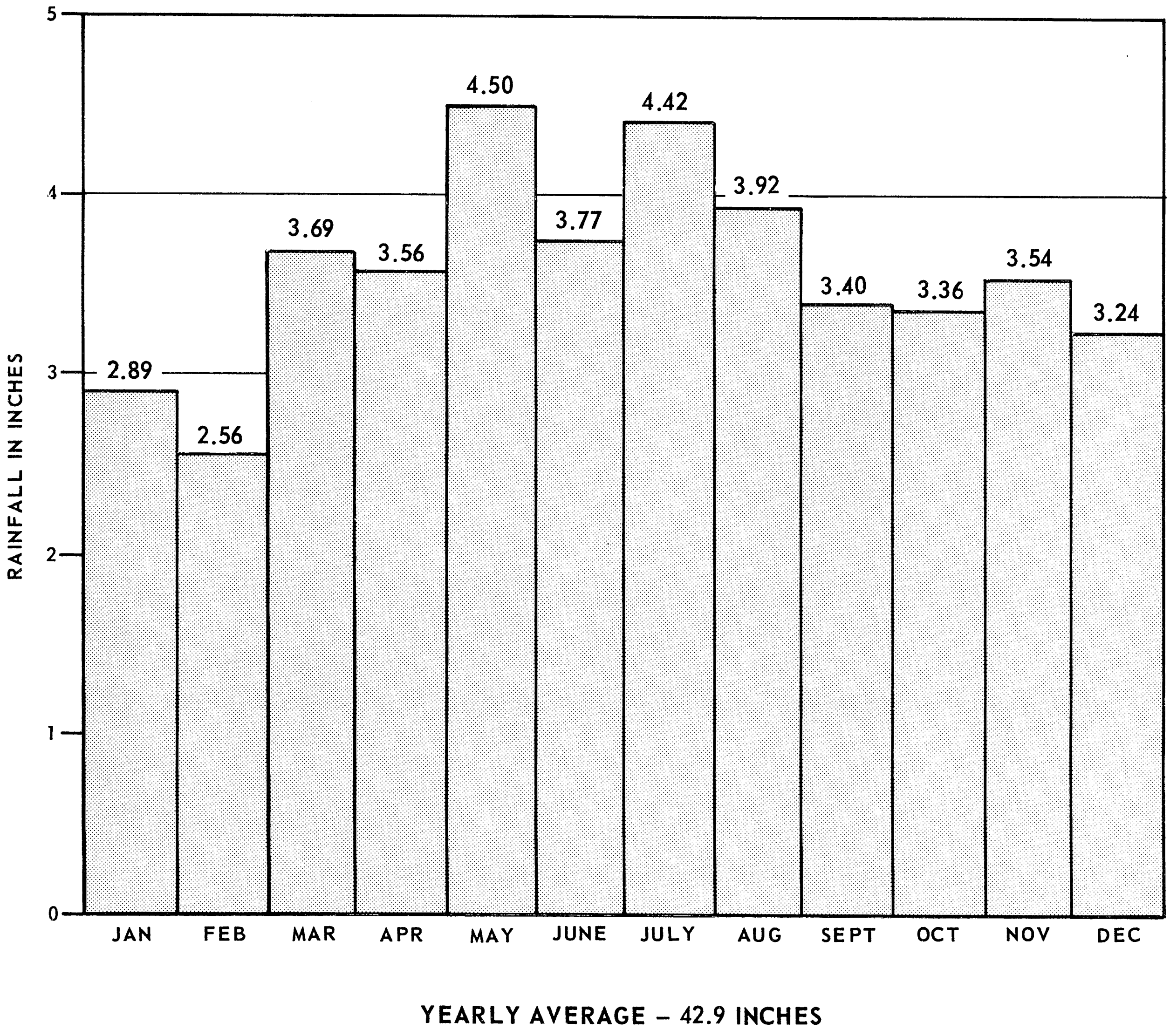

Figure 15. Average monthly precipitation for the Mahanoy Creek Watershed

In a hydrologic study of a watershed, the total amount of precipitation must be balanced with all forms of water consumption. The basic balance equation relating precipitation to total consumption is:

P = ET + R + S + I where:

P - is the total amount of precipitation.

ET - is the consumptive rate which is the amount of water consumed through evaporation and transpiration (evapotranspiration).

R - is the amount of direct surface runoff contributing to steam flow.

S - is the amount of water stored in lakes, stream channels, natural depressions, etc., the amount is very minor and may be considered zero.

I - is the amount of water that infiltrates into the ground water system. Although the elevation of the water table and mine pools may vary significantly during the year, the average elevation from year to year is relatively constant. Because of this, all water that infiltrates into the ground water system will be assumed to resurface as either intermittent and permanent springs or mine drainage discharges.

Factors which effect these values include:

ET - wind, temperature, humidity, sunlight, type and density of vegetation, type and amount of soil cover.

R and I - topography, soil type, ground cover (vegetation), rainfall intensity.

Before the quantities of mine drainage, generated by the disturbed portions of the watershed can be determined, the consumptive rate for these areas must be known. No direct method of determining this value could be found, but by determining all the remaining parameters of the watershed, the consumptive rate can be indirectly calculated.

By utilizing available information, the percentage of precipitation contributing to the flow of Mahanoy Creek can be directly determined. During the study period, the average flow of Mahanoy Creek at sample site No. 71 at Otto was 311.5 ft^3/sec. The flow includes the Doutyville and Helfenstein Tunnel Discharges, as well as an estimated 35 percent of the Centralia Tunnel Discharge which drains areas outside the study region. Summing these flows and deducting them from the total flow of Mahanoy Creek gives the following results:

Centralia Tunnel Disc.	5.32 ft^3/sec (35% of total flow)
Helfenstein Tunnel Disc.	2.78 ft^3/sec
Doutyville Tunnel Disc.	13.58 ft^3/sec
	21.68 ft^3/sec

Flow at sample site No. 71	311.5 ft^3/sec
Flow from other watersheds	-21.7 ft^3/sec
	289.8 ft^3/sec

The average amount of flow at sample site No. 71 that is contributed by the Mahanoy Creek Watershed is 289.8 ft^3/sec. The flow includes both direct surface runoff and infiltration that later resurfaces as springs and discharges.

The total area of the Mahanoy Creek Watershed is 157.1 square miles. However, sample site No. 71 is located upstream from the mouth of the creek and did not measure the flow contributed by the entire watershed. Approximately 3.5 square miles of land contribute water to Mahanoy Creek below the last sample site.

Total area of Mahanoy Creek Watershed	157.1 mi^2
Area below sample site No. 71	-3.5 mi^2
	153.6 mi^2

The effective area contributing to the flow of Mahanoy Creek at sample site No. 71 is 153.6 square miles.

As previously mentioned, during the study period of one year when flow measurements were taken, the amount of precipitation falling on the watershed was 46.2 inches. Utilizing the information just presented the runoff coefficient in the Rational Equation can be solved for.

The Rational Equation is:

Q = CIA where

Q - is the average flow rate draining a specific watershed (289.8 ft^3/sec or 25,040,000 ft^3/day).

C - is the coefficient dependent on the physical characteristics of the watershed, which expresses that portion of the precipitation which contributes to stream flow.

I - is the amount of precipitation over the watershed during the period when flow readings were recorded, (46.2 in./yr or 0.01055 ft/day).

A - is the area of the watershed, (153.6 mi^2 or 4,282,000,000 ft^2).

Solving for "C".

$$C = \frac{Q}{IA} = \frac{25{,}040{,}000 \text{ ft}^3/\text{day}}{(0.01055 \text{ ft/day})\ (4{,}282{,}000{,}000 \text{ ft}^2)} = 0.55$$

For the Mahanoy Creek Watershed the average "C" value is 0.55. Therefore, 55 percent of all precipitation that falls on the watershed contributes to the stream flow of Mahanoy Creek. It should be noted that this is a special adaptation of the Rational Equation.

The "C" factor is a combination of both the direct surface runoff R, and the infiltration I, that enters the streams as intermittent and permanent springs and discharges. Relating this to the hydrologic balance equation, all terms except the consumptive rate are known.

P = 100%

I + R = 55%

S = 0%

Solving for ET.

ET = P –I –R –S = 100 -55 -0 = 45%

Therefore, the average consumptive rate for the Mahanoy Creek Watershed is 45 percent. Within the watershed the consumptive rate will vary significantly from the average value because of factors previously mentioned. For the purposes of this study, only two specific consumptive rates will be determined. The first consumptive rate will be for natural areas undisturbed by mining and the second for portions of the watershed disrupted by strip mining.

There are numerous methods for determining the consumptive rate of natural areas, one such method involves utilizing the Lowry-Johnson equation. The equation is:

$$U = 0.00156\ H + 0.8$$

where U - is the amount of water lost through evaporation and transpiration each year in feet.

H = is the number of degree days above 32° for the growing season.

MONTH	AVERAGE MONTHLY TEMP. OF MAHANOY CREEK WATERSHED IN °F	DEGREES ABOVE 32° F	DAYS	DEGREE DAYS
April	48.9	16.9	30	507
May	58.6	26.6	31	825
June	67.7	35.7	30	1071
July	72.0	40.0	31	1240
August	70.0	38.0	31	1178
Sept.	63.0	31.0	30	930
Oct.	52.2	20.2	31	626
				6377

$$U = 0.000156\ (6377) + 0.8 = 0.995 + 0.8 = 1.795 \text{ ft/yr}$$

$$\text{Consumptive rate} = \frac{\text{rainfall lost through evapotranspiration}}{\text{total amount of rainfall}} \times 100$$

Average rainfall = 42.9 inches/yr = 3.575 ft/yr

$$\text{Consumptive rate} = \frac{1.795 \text{ ft/yr}}{3.575 \text{ ft/yr}} (100) = 50.2\%$$

Other methods were also used to determine the consumptive rate for undisturbed areas, and in each case the results were similar. The consumptive rate for the undisturbed portions of the Mahanoy Creek Watershed is therefore 50 percent. Of the remaining 50% of the precipitation not consumed through evapotranspiration it is estimated that one-half will become infiltration and the other half surface runoff.

Of the total 153.6 square miles of the watershed contributing to sample point No. 71, 39.4 square miles, have been strip mined or otherwise disrupted by mining. The remaining 114.2 square miles are undisturbed. Since, the average consumptive rate for the entire Mahanoy Creek Watershed is known, along with that for the undisturbed areas, the consumptive rate for the disturbed areas can be easily found.

$$\frac{114.2\ mi^2\ (0.50) + 39.4\ mi^2\ (ET)}{153.6\ mi^2} = 0.45$$

$$ET = \frac{12.02\ mi^2}{39.4\ mi^2} = 0.305$$

The consumptive rate for the disturbed portions of the watershed is therefore 30 percent, leaving the remaining 70 percent to be either surface runoff or infiltration. For the disturbed portions of the watershed an estimated 85 percent of the precipitation not consumed through evapotranspiration will become infiltration and contribute to the mine pool system, while only 15 percent is surface runoff. These are quite realistic values considering the terrain. In the Mahanoy Creek Watershed, the stripped areas are characterized by rocky barren "soil" where the water infiltrates easily and enters the ground water system and mine pools through numerous mine openings and rock fractures. In addition, longitudinal stripping pits and low points, created by disrupting the natural drainage pattern, trap much surface water and direct it to the abandoned mine workings. A summary of the results are given below.

For areas disturbed by mining the precipitation distribution is as follows:

30 percent of all precipitation is consumed by evapotranspiration.

70 percent of all precipitation becomes runoff and infiltration, of this

85 percent becomes infiltration (59.7 percent of total precipitation)

15 percent becomes runoff (10.5 percent of total precipitation)

For natural areas undisturbed by mining the precipitation distribution is as follows:

50 percent of all precipitation is consumed by evapotranspiration.

50 percent of all precipitation becomes runoff and infiltration, of this

50 percent becomes infiltration (25 percent of total precipitation)

50 percent becomes runoff (25 percent of total precipitation)

The consumptive rate for natural areas is significantly higher than for the areas disturbed by mining. This is quite understandable. In natural areas the existing soil horizons retain a large percentage of the precipitation, which is partially absorbed by the vegetation where much of it is then lost to the atmosphere through transpiration. Also, a significant portion of the water retained in the soil is lost directly through evaporation.

In disturbed areas, the soil horizons have been destroyed and little if any top soil exists. The surface does not retain much moisture, nor are the soil characteristics favorable to plant growth. As a result, the consumptive rate for the disturbed areas will be much less than for the undisturbed regions of the watershed.

It should be noted that the numbers chosen for the coefficients are only average values. Within the watershed are different types of stripped as well as undisturbed areas, but it would be unrealistic to assign a separate set of coefficients for each specific area. Where required, a correction factor was applied to hydrologic calculations to bring the coefficients in line with actual field conditions.

To insure that the figures just presented are a reasonable representation of the actual physical characteristics of the Mahanoy Creek Watershed, a flow balance of the acid mine discharges is presented. The total flow from all the discharges draining the watershed during the study period was 25,500 million gallons per year. Excluded from this total are the flows from the Doutyville and Helfenstein Tunnel Discharges and a portion of the Centralia Tunnel Discharge which are all fed by areas outside the watershed.

Water from three distinct sources gains entry into the mine pools which feed the discharges, with the major source being the 39.4 square miles of disturbed regions. The disturbed areas have a consumptive rate of 30 percent, with 85 percent of the remaining precipitation not lost through evapotranspiration infiltrating into the mine pool system.

$$(46.2 \text{ in./yr}) (0.70) (0.85) = 27.5 \text{ in./yr}$$

$$(27.5 \text{ in./yr}) (39.4 \text{ mi}^2) (17.4 \text{ MG/in.-mi}^2) = 18{,}900 \text{ MG/yr}$$

During the study period the disturbed areas of the watershed contributed approximately 18,900 million gallons of acid mine drainage to Mahanoy Creek.

Another source of water to the mine pools are undisturbed regions which lie above areas that have been strip mined. Here, the 50 percent of the precipitation that is not consumed by evapotranspiration, contributes directly to acid mine drainage. In this type of situation, surface water which accumulates in undisturbed areas begins flowing overland until it reaches a stripped area. Here the water is intercepted by strip pits where it can easily infiltrate into the mine pools below. Also, the precipitation which infiltrates the soil in these regions either resurfaces as springs only to be later intercepted by strip pits, or becomes polluted when the flow in the natural aquifers is discharged in the abandoned mine workings. There are an estimated 13 square miles of area in this category.

$$(46.2 \text{ in./yr})\ (0.50) = 23.1 \text{ in./yr}$$

$$(23.1 \text{ in./yr})\ (13.0 \text{ mi}^2)\ (17.4 \text{ MG/in.-mi}^2) = 5200 \text{ MG/yr}$$

During the study period, the undisturbed areas draining into strip mined areas, were responsible for contributing 5200 million gallons of acid mine drainage into Mahanoy Creek.

The remaining source of recharge to the acid mine discharges, are undisturbed areas which overlie areas that have been deep mined. Here, only that portion of precipitation which infiltrates the soil, contributes to the mine pools. There are approximately 4.0 square miles of land which satisfy this category.

$$(46.2 \text{ in./yr})\ (0.50)\ (0.50) = 11.6 \text{ in./yr}$$

$$(11.6 \text{ in./yr})\ (4.0 \text{ mi}^2)\ (17.4 \text{ MG/in.-mi}^2) = 800 \text{ MG/yr}$$

During the study period, undisturbed areas overlying deep mined regions, were responsible for contributing 800 million gallons of acid mine drainage to Mahanoy Creek. The total flow from all sources is:

18,900 MG/yr (areas affected by strip mining)

5,200 MG/yr (undisturbed areas)

800 MG/yr (areas overlying deep mines)

24,900 MG/yr

Utilizing the hydrologic coefficients previously determined, the total amount of acid mine drainage that should be generated by the Mahanoy Creek Watershed was calculated to be 24,900 million gallons per year. The calculated value is only 600 million gallons less than the actual measured value of 25,500 million gallons per year. This is a difference of 2.4 percent, which is well within measurement error.

AMOUNTS OF ACID MINE DRAINAGE GENERATED

The average rainfall for the Mahanoy Creek Watershed is 42.9 inches per year. Utilizing the consumptive rate of 30 percent, the amount of water available for runoff and infiltration for an average hydrologic year in disturbed areas can be determined.

(42.9 in./yr) (0.30) = 12.87 in./yr lost through evapotranspiration

42.9 in./yr -12.87 in./yr = 30.03 in./yr total infiltration and runoff

As previously stated 85 percent of the remaining precipitation not consumed by evapotranspiration will become infiltration.

(30.03 in./yr) (0.85) = 25.53 in./yr infiltrating into the groundwater system

In the Mahanoy Creek Watershed, during an average precipitation year, 25.53 inches of the total precipitation falling on areas disturbed by mining contribute directly to acid mine drainage.

In natural undisturbed areas located near regions that have been mined, both the portion of precipitation that contributes to runoff, and the portion that is infiltration may be entering the mine pools. The consumptive rate for undisturbed areas was found to be 50 percent, and of the remaining 50 percent half will be infiltration and half surface runoff.

(42.9 in./yr) (0.50) = 21.45 in./yr

In undisturbed areas, where both infiltration and runoff are entering mine pools, 21.45 inches of the total precipitation that falls will contribute to acid mine drainage.

In undisturbed areas, where only infiltration is entering mine pools, one half of the precipitation not consumed by evapotranspiration contributes to mine drainage.

(42.9 in./yr) (0.50) (0.50) = 10.73 in./yr

In these areas 10.73 in./yr of the total precipitation will contribute to mine drainage.

REDUCTION IN ACID MINE DRAINAGE (AVERAGE YEAR)

Disturbed Areas

By backfilling, regrading and planting the disturbed areas, the amount of water entering the deep mines and contributing to acid mine drainage can be significantly reduced. In theory, the reclamation measures should restore the land to its original state. If so, the disturbed areas would take on the same hydrological coefficients as the undisturbed areas presently have. Therefore, the only precipitation that would contribute to acid mine drainage would be that which infiltrated directly into the ground water system. That value for an undisturbed area is 10.73 inches/year.

The reduction in the amount of precipitation contributing to acid mine drainage in disturbed areas is equal to the amount of precipitation entering the deep mines before reclamation measures, minus the amount of precipitation entering the deep mines after reclamation measures are completed.

25.53 in./yr -10.73 in./yr = 14.80 in./yr

By backfilling and reclaiming stripped areas, the amount of water infiltrating into the soil and contributing to acid mine drainage can be reduced by 14.80 inches per year.

Undisturbed Areas

Reclaiming stripped areas downslope from undisturbed regions, makes it possible for the surface runoff from these regions to flow over the reclaimed strip mines, and enter the various streams. The reduction in the amount of precipitation contributing to acid mine drainage from the undisturbed area, would be equal to the surface runoff from the area, which is 10.73 inches/year.

SAMPLE CALCULATIONS

A number of sample calculations are presented as examples of how the reductions in the flows of the discharges were determined. To simplify the calculations, a conversion factor of 0.0737 was used. A flow of one inch of precipitation a year over an area of one square mile is equal to a flow of 0.0737 cubic feet per second.

Mahanoy City Group

An area of 180 acres should be backfilled, regraded and seeded. This would reduce the amount of precipitation entering the deep mines by 14.80 inches/year.

$$\frac{180 \text{ acres}}{640 \text{ acres/mile}^2} (14.80 \text{ inches/year}) (0.0737) (0.9) = 0.28 \text{ ft}^3\text{/sec}$$

An area of approximately 400 acres of undisturbed land is presently draining into the 180 acres of land to be reclaimed, the surface water from the undisturbed areas could drain directly into a stream, reducing the amount of precipitation entering the deep mines by 10.73 inches/year.

$$\frac{180 \text{ acres}}{640 \text{ acres/mile}^2} (10.73 \text{ in./year}) (0.0737) (0.8) = 0.40 \text{ ft}^3\text{/sec}$$

A 0.9 correction factor was applied to the first calculation and a 0.8 factor to the second to take into account the differences between theoretical and actual field conditions. Backfilling, regrading and replanting does not insure that reforestation will be complete nor does it insure that all surface water will be effectively drained.

Construction of a drainage pipe beneath the railroad tracks 2 miles east of Mahanoy City will allow water to drain under the tracks into Mahanoy Creek. Presently water from a rather large area northeast of Buck Mountain collects there and then infiltrates into the deep mines. Installing the drainage pipe will reduce the flow at the discharges by approximately 0.35 ft^3/sec.

The total reduction in flow is:

0.28 ft^3/sec

0.40 ft^3/sec

<u>0.35 ft^3/sec</u>

1.03 ft^3/sec or 0.66 MGD

The percentage decrease of flow is equal to the amount that will be eliminated, divided by the sum of the flows of the discharges affected.

Mahanoy Creek Headwaters Discharge 0.37 ft^3/sec

Mahanoy City Bore Hole Discharge 11.31 ft3/sec

The percentage reduction is:

$$\frac{1.03 \text{ ft}^3\text{/sec}}{0.37 \text{ ft}^3\text{/sec} + 11.31 \text{ ft}^3\text{/sec}} (100) = 8.8\%$$

Packer Group Discharges

An area of 961 acres should be backfilled, regraded, and planted.

$$\frac{961 \text{ ac}}{640 \text{ ac/mi}^2} \text{ (14.80 inches/year) (0.0737) (0.8)} = 1.31 \text{ ft}^3\text{/sec}$$

An area of approximately 450 acres of undisturbed land would be affected by the backfilling.

$$\frac{450 \text{ ac}}{640 \text{ ac/mi}^2} \text{ (10.73 in./yr) (0.0737) (0.8)} = 0.44 \text{ ft}^3\text{/sec}$$

The construction of flumes and/or drainage ditches to direct clean streams across the stripped areas would reduce the flow at the discharges by the following:

Waste House Run	4.55 ft^3/sec
Lost Creek	0.66 ft^3/sec
N. Mahanoy Creek Trib.	0.25 ft^3/sec (estimate)
	5.46 ft^3/sec

The total reduction in flow is:

1.31 ft^3/sec

0.44 ft^3/sec

5.46 ft^3/sec

7.21 ft^3/sec or 4.65 MGD

The discharges affected by the abatement measures include:

Packer No. 5A Discharge	18.96 ft^3/sec
Packer No. 5B Discharge	22.49 ft^3/sec
Lost Creek Discharge	0.32 ft^3/sec

Lost Creek Ball Field Discharge	0.95 ft^3/sec
Connerton No. 1 Discharge	1.70 ft^3/sec
Connerton No. 2 Discharge	0.19 ft^3/sec
	44.61 ft^3/sec

The percentage reduction is:

$$\frac{7.21\ ft^3/sec}{44.61\ ft^3/sec}(100) = 16\%$$