WATER BALANCE FOR THE JEDDO TUNNEL BASIN LUZERNE COUNTY, PENNSYLVANIA

Publication No. 208 *August 1999*

Paula B. Ballaron, P.G.
Hydrogeologist

Printed on recycled paper.

This report was prepared for Pennsylvania Department of Environmental Protection, Pottsville District Mining Office, under Grant ME97105.

SUSQUEHANNA RIVER BASIN COMMISSION

Paul O. Swartz, Executive Director

John T. Hicks, N.Y. Commissioner
Scott J. Foti., N.Y. Alternate

James M. Seif, Pa. Commissioner
Irene B. Brooks, Pa. Alternate

Jane T. Nishida, Md. Commissioner
J.L. Hearn, Md. Alternate

Brigadier General M. Stephens Rhoades, U.S. Commissioner
Colonel Bruce A. Berwick, U.S. Alternate

The Susquehanna River Basin Commission was created as an independent agency by a federal-interstate compact* among the states of Maryland, New York, Commonwealth of Pennsylvania, and the federal government. In creating the Commission, the Congress and state legislatures formally recognized the water resources of the Susquehanna River Basin as a regional asset vested with local, state, and national interests for which all the parties share responsibility. As the single federal-interstate water resources agency with basinwide authority, the Commission's goal is to coordinate the planning, conservation, management, utilization, development and control of basin water resources among the public and private sectors.

**Statutory Citations: Federal - Pub. L. 91-575, 84 Stat. 1509 (December 1970); Maryland - Natural Resources Sec. 8-301 (Michie 1974); New York - ECL Sec. 21-1301 (McKinney 1973); and Pennsylvania - 32 P.S. 820.1 (Supp. 1976).*

For additional copies of this publication, contact the Susquehanna River Basin Commission, 1721 N. Front Street, Harrisburg, Pa. 17102-2391, (717) 238-0423, FAX (717) 238-2436, E-mail srbc@srbc.net. For more information concerning the Commission, visit our web site: www.srbc.net.

CONTENTS

APPENDIX

FIGURES

PLATES

TABLES

WATER BALANCE FOR THE JEDDO TUNNEL BASIN, LUZERNE COUNTY, PENNSYLVANIA

Paula B. Ballaron, P.G.
Hydrogeologist

INTRODUCTION

The Jeddo Tunnel, a man-made water-level drainage tunnel, was constructed at the turn of the century to dewater deep mined coal measures in the Eastern Middle Anthracite Field (Ash and others, 1950; LaRegina, 1988). The Jeddo Tunnel drainage system involves four major coal basins: Big Black Creek, Little Black Creek, Cross Creek, and Hazleton.

Following the collapse of the deep mining industry in 1955, the tunnel has continued to drain the abandoned mine workings. Currently, the Jeddo Tunnel drains over 30 square miles and discharges an average of 80 cubic feet per second (cfs) into Little Nescopeck Creek, located outside of the coal measures.

The Little Nescopeck Creek, a tributary to Nescopeck Creek, receives all the flow from the tunnel and is severely impacted by the water-quality-impaired discharge from the adjacent mined watershed. The discharge from the tunnel is the primary source of pollution in the Little Nescopeck Creek Watershed. The quality-impaired Little Nescopeck Creek joins Nescopeck Creek, which eventually enters the Susquehanna River near Berwick, Pa.

A project focused on the assessment of acid mine drainage (AMD) and an abatement plan (Ballaron and others, 1999) addresses factors and conditions relevant to improving the quality of the Jeddo Tunnel discharge to the Little Nescopeck Creek. A reduction in AMD at the mouth of the Jeddo Tunnel will decrease the negative impact on the Nescopeck Creek, which is classified as a High Quality Cold Water Fishery (HQ-CWF) above the confluence with the Little Nescopeck Creek. This, in turn, will provide a significant benefit downstream to the Susquehanna River.

PURPOSE AND SCOPE

To complete the Little Nescopeck Creek Watershed Assessment and Abatement Plan, the Susquehanna River Basin Commission (SRBC) and its subcontractor, Wildlands Conservancy (the Conservancy), have partnered with Pa. Department of Environmental Protection, Bureau of Mining and Reclamation (Pa. DEP-BMR), Pa. DEP, Bureau of Abandoned Mine Reclamation (Pa. DEP-BAMR), Pa. DEP's Citizens Water Quality Monitoring Program, U.S. Geological Survey (USGS), Friends of the Nescopeck, Bloomsburg University, Wilkes University, Kings College, and Pennsylvania State University—Hazleton Campus.

However, during coordination and planning sessions for the Little Nescopeck Creek Watershed Assessment and Abatement Project, the project partners identified the need for additional work tasks. These tasks included additional data collection and analysis of the Jeddo Tunnel discharge, completed by the USGS under a separate funding arrangement; and additional data collection and analysis relating to enhancements of the hydrologic budget, completed by SRBC.

Consequently, this study will focus on the Jeddo Tunnel. Long-term records, as well as ongoing and recently-collected data, were used to further characterize the quality of the Jeddo Tunnel discharge, evaluate surface to tunnel water routing, and refine the hydrologic budget. The principal objective of this report is to present the hydrologic budget, as refined by this study, that was used to support a prioritization of abatement options in the Little Nescopeck Creek Watershed. The water budget also is described in the watershed assessment and abatement report (Ballaron and others, 1999).

STUDY PROCEDURES

The various team members were responsible for different aspects of data collection and analysis for the assessment and abatement plan. SRBC used USGS streamflow data, available local precipitation data, estimated areas draining to the tunnel, and flow measurements of larger surface flows to develop a rudimentary hydrologic budget. For this study, SRBC made additional stream flow measurements to improve the characterization of surface drainage to the mine complex, and to estimate sub-basin water budgets.

Additionally, SRBC evaluated water quality data collected by Pa. DEP and others to characterize overall water quality and loads from the tunnel discharge.

THE JEDDO TUNNEL SYSTEM

System Hydrology

Thirteen functional mine drainage tunnels in the Eastern Middle field were specifically driven to dewater the mine workings. Of the thirteen, the Jeddo Tunnel is the most extensive. These constructed gravity-drainage systems were most successful in the Eastern Middle Anthracite Field because of the comparable elevation of the drainage tunnel discharge to the receiving stream.

The Jeddo Tunnel, and its associated tunnel complex, was constructed to dewater underground mines of four major coal basins: the Hazleton Coal Basin, the Black Creek Coal Basin, the Little Black Creek Coal Basin, and the Cross Creek Coal Basin. The tunnel drains a total of 12.6 square miles of the coal basins, and has a total drainage area of 32.24 square miles. Plate 1 is a plan map showing the Jeddo Tunnel drainage system and general internal flow directions. A schematic cross section of the Jeddo drainage tunnel is shown in Figure 1.

To prevent flooding during operation, water that entered the mines drained by gravity to the tunnel system or, where coal was deep mined below the elevation of the gravity drain, infiltrated water was collected in a sump and pumped up to the gravity drain. In 1965, a major drought year, it was estimated that the tunnel discharged an average of 20 million gallons per day (31 cfs). On March 29, 1940, following well-above normal precipitation of 7.77 inches of rainfall for the month, a peak flow of 157,000 gallons per minute (gpm), or 350 cfs, was recorded (Ash and others, 1950).

Since the completion of the initial rock tunnels and subsequent connecting tunnels and slopes, and the subsequent loss of an effective perimeter drain system, the Jeddo Tunnel collects and discharges more than half of the precipitation received in the drainage area. During the current study, a peak flow of 195,200 gpm, or 435 cfs, was measured on November 9, 1996, following 3.89 inches of rain. Higher tunnel discharges after smaller amounts of precipitation, as in recent times, are not surprising due to the loss of the perimeter drain system.

Principal sources of water to the drainage tunnel include infiltration of precipitation, seepage from stream channels, and ground-water discharge. Both underground and surface mining, with associated subsidence, create surface catchment basins, fractured rock strata, and artificial ponding that increase the amount of water getting into the mines and being discharged by the tunnel. Field reconnaissance (Ballaron and others, 1999) identified 22 locations where surface water directly enters the mines through sinks.

Today, the deep mines are abandoned and pumping has been discontinued. Gangways, tunnels, and chambers that interconnected coal beds have collapsed in some areas. Any underground voids are filled with water to the elevation of the gravity drain (sometimes called

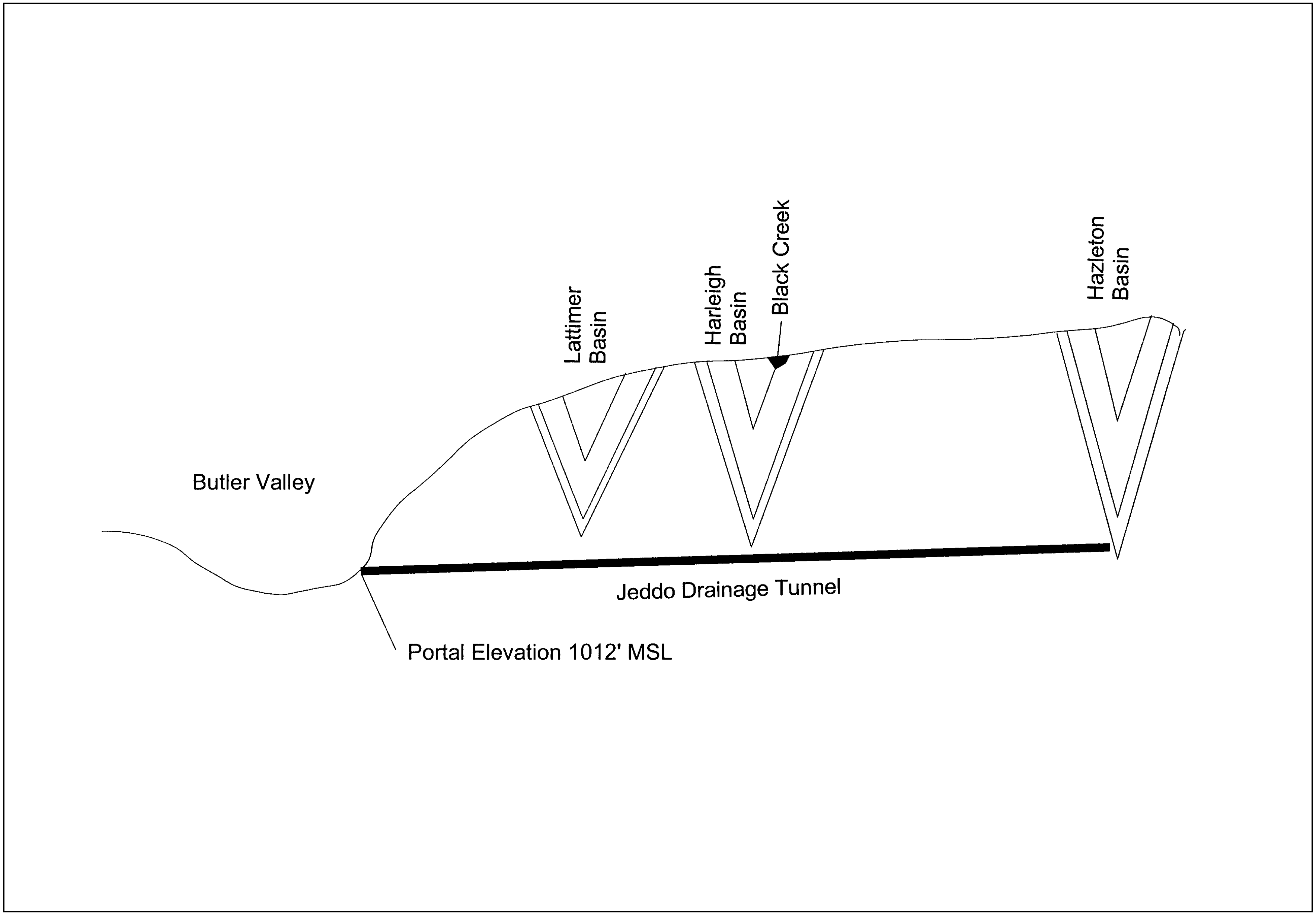

Figure 1. Schematic Cross Section of the Jeddo Tunnel *(Anonymous, circa 1960)*

mine pools). These flooded mine workings overflow and are collected, along with surface water that penetrates the scarred land surface and percolates into what remains of the extensive honeycomb of subsurface tunnels, into the single tunnel discharge. The abandoned mining operations have completely destroyed the natural surface-water and ground-water systems within the mining area. Thus, the Jeddo Tunnel discharge comes from a vast and predominantly man-made drainage system.

Nasilowski and Owens (1998) indicate that there are nine major mine pools in the Hazleton Coal Basin that contain great quantities of water and overflow to the Jeddo Tunnel. These are the West Woodside Basin, the East Woodside Basin, the Harley Colliery Pool, the Jeddo No. 7 Fishtail, the Jeddo No. 4 Slope B, the Cranberry No. 11 Plane Basin, the Hazleton Basin, the Diamond Basin, and the Stockton Basin. Some of the mine pools were contained to various levels by a system of barrier pillars that were left in place during mining to separate colliery workings and their water systems.

Analysis of existing mine maps found nearly complete mining of pillars, suggesting barrier pillar breaches were likely created by "bootleg" deep-mine operations, pillar squeeze, and/or local collapse. The basin delineation for this study assumes barrier pillars have been breached.

Drainage Area

A map was prepared showing the approximate configuration of the land ultimately draining to the Jeddo Tunnel (Plate 1). Most of the data used to prepare the map were collected during 1996 by Bloomsburg University (Ballaron and others, 1999). However, some adjustments were made based on field investigations by SRBC in 1997-98 and review of maps of underground mining.

The basin divides developed for this study indicate the Jeddo Tunnel drains 32.24 square miles. The subbasins of Little Black Creek, Black Creek, Hazle Creek, and Cranberry Creek, delineated on Figure 2, drain areas of 4.64, 12.45, 6.62 and 8.53 square miles, respectively. Surface-water divides generally match ground-water divides. The eastern-most parts of the coal basins (Cross Creek, Big Black Creek, and Hazleton Basins) drain to the Lehigh River. The drainage divide is expressed on the surface by a broadening of the coal basins, and its location estimated from structural geology maps and field observations.

Streams in the basin have significant losses to the deep-mine complex and most water that leaves the basin flows out through the Jeddo Tunnel. However, at four locations, streams exit the Jeddo basin; these are Little Black Creek, Black Creek, Hazle Creek, and Cranberry Creek (Figure 2). The flows of Black Creek and Hazle Creek are perennial, except during exceptionally dry seasons. The other streams have intermittent to ephemeral flow with sharp, multiple crest hydrography and a mobile bed, as documented by Braun (Bloomsburg University, written communication, April 1997) and Witmer (1995). Current surface hydrology, by subbasin, is described in Ballaron and others, 1999.

Chemical Characteristics

A number of factors affect the quality of abandoned mine water discharges. The role of these factors (physical, chemical, and biological) vary with underground and surface mining conditions, spoil distribution, geology and mineralogy, and abundance of biological catalysts. These factors are discussed in detail in scientific literature on coal mine drainage (Hornberger and others, 1990; Carruccio and others, 1978).

The water discharges from the mine drainage tunnels in the Eastern Middle Anthracite Field are predominately acidic. Highest pH levels are 4.8, with 9 of the 16 discharges measuring less than 4.0 (Hollowell, 1999). The plots of loads in Hollowell (1999) show that alkalinity is minimal for discharges from the eastern-most basins. Although alkalinity is not high for the western and central basins, the plots suggest some buffering sources are present. This could include the presence of minor carbonate strata, or cementing, in the clastic rocks. Because of the complexity of sedimentation in the northern Appalachians, the

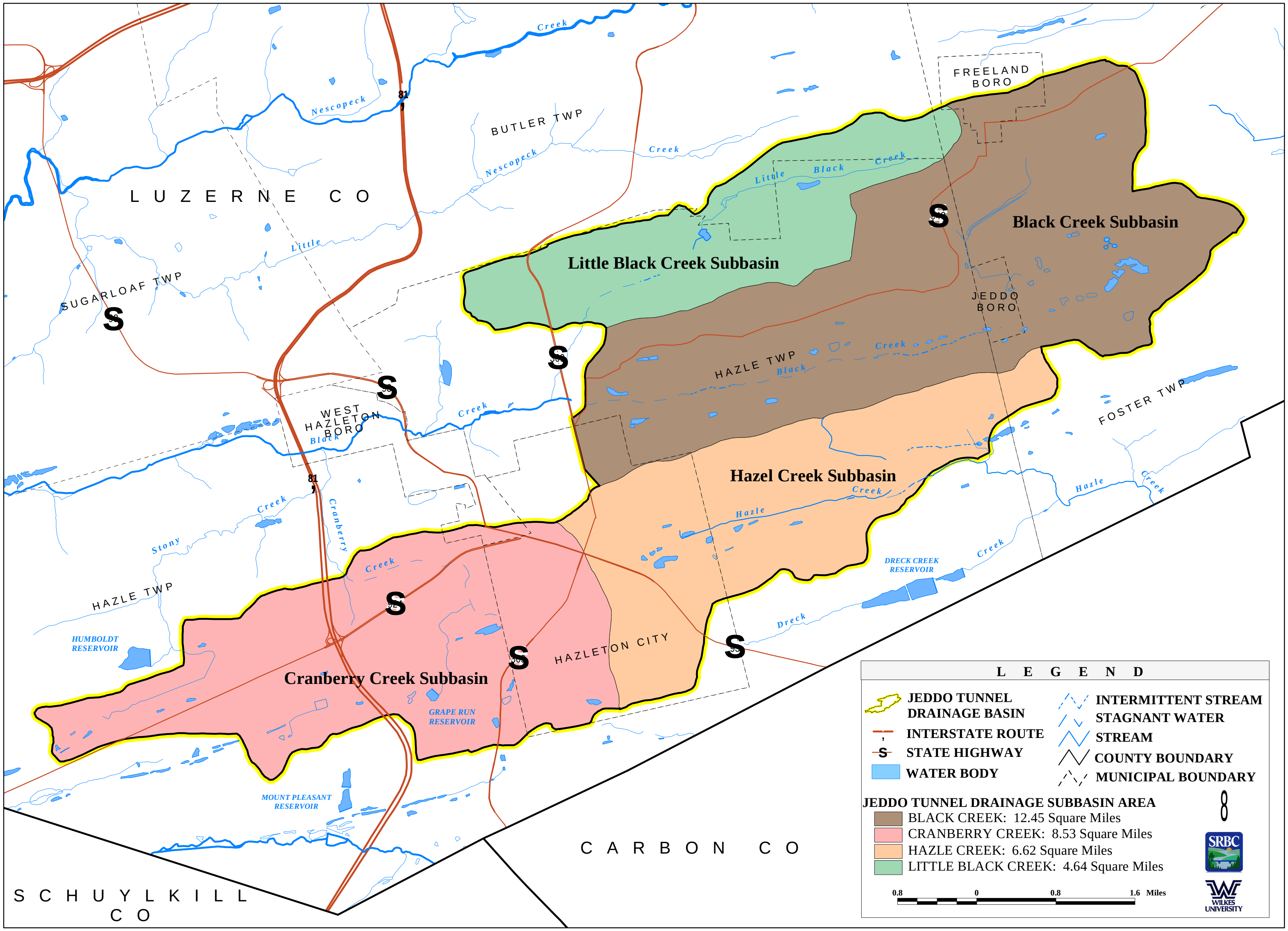

Figure 2. Little Black Creek, Black Creek, Hazle Creek, and Cranberry Creek Subbasins

distribution of coal and intervening sediments that influence mine water quality are poorly described in the literature.

The source strata associated with the alkalinity are below the Buck Vein (Hollowell, 1999). In addition, the source strata are common to those basins discharging water with some alkalinity and having a mine-to-surface drainage tunnel elevation below 1,290 feet. Even though some alkalinity is available to the Eastern Middle Anthracite Field, it is inadequate to neutralize the acidic discharges from the field. The loads are flow-related with the higher flows carrying the greater loads. The loads of metals are relatively low, with magnesium being the highest and iron the lowest (Hollowell, 1999).

The water quality of the Jeddo Tunnel discharge was monitored monthly by Pa. DEP from April 1995 through June 1998 and reported in detail in Ballaron and others (1999). Annual average concentrations of selected parameters are shown in Table 1. The analyses show values typical of surface waters impacted by acid mine drainage in eastern Pennsylvania. The tunnel outflow can be characterized as predominantly acidic, with elevated levels of dissolved metals such as iron, manganese, and aluminum. The magnesium concentration exceeds that of all other metals.

The pH of the discharge ranged from approximately 3.6 to 5. The average pH was approximately 4.3. Acidity levels from the Jeddo Tunnel were highest during late summer and early fall. Comparing water quality data to discharge rates has shown that, as flow rises, the pH increases, and as flow decreases, so does pH.

High concentrations of sulfide minerals and the lack of carbonate minerals in the bedrock result in high acidity and low alkalinity, respectively. Alkalinity refers to the amount of carbonate present that could neutralize acidity. Acidic pollution will reduce the pH of a system with low alkalinity (also referred to as buffering capacity) much more rapidly than it would a well-buffered system. In other words, the Jeddo discharge is relatively incapable of stabilizing its pH and is impacted by acidic contamination.

At pH levels this low, metals such as aluminum and lead are released in forms that are toxic to aquatic life. Mayflies and other insects are absent, and the stream is likely devoid of fish, salamanders and frogs. Furthermore, the majority of eggs lain, if any species are present to produce them, would be incapable of hatching.

The most dominant cation in solution is magnesium, having an average concentration of approximately 52 milligrams per liter (mg/l). This was closely followed by calcium, with an average concentration of approximately 35 mg/l, and to a lesser degree by sodium and potassium, with average concentrations of approximately 12 and 2.2 mg/l, respectively. The dominant anion found in solution was sulfate, which results from the oxidation of pyritic minerals. The average concentrations of sulfate and chloride were approximately 284 mg/l and 13.5 mg/l, respectively. These constituents all demonstrated an inverse relationship to flow rates, which points to a dilution and reduced exposure effect from increased discharges. Most peak concentrations of these parameters occurred between July and November, the time of the year with the lowest flows.

Excessively high concentrations of dissolved metals also were identified as a characteristic of the Jeddo discharge. Iron was present in concentrations ranging from 0 to 90 mg/l, with an average of approximately 9 mg/l. For comparison, the suggested maximum contaminant level (MCL) for municipal water systems is 0.3 mg/l. Similarly, manganese exceeded the suggested MCL of 0.05 mg/l, with an average concentration of approximately 4.2 mg/l. The range for manganese was from 1.4 to 6.8 mg/l. Aluminum concentrations ranged from 2.5 mg/l to 44 mg/l, exceeding the suggested MCL of 0.05 to 0.2 mg/l. Zinc concentrations averaged 0.7 mg/l, near maximum recommended levels.

High concentrations of metals are detrimental to fish and other aquatic life, as they tend to

Table 1. Jeddo Tunnel Water Quality, Annual Average Concentrations, 1978-98

Calender Year	Specific Conductance	pH	Alkalinity	Total Solids, as Residue	Dissolved Solids, as Residue	Suspended Solids, Nonfilterable, as Residue	Calcium	Magnesium	Sodium
	■mhos/cm		mg/l						
1978	--	3.52	--	--	--	--	--	--	--
1979	--	3.67	--	--	--	--	--	--	--
1980	--	3.78	--	--	--	--	--	--	--
1981	--	3.66	--	--	--	--	--	--	--
1982	--	3.64	--	--	--	--	--	--	--
1983	--	3.79	--	--	--	--	--	--	--
1984	--	3.82	--	--	--	--	--	--	--
1985	--	3.78	--	--	--	--	--	--	--
1986	--	3.55	--	--	--	--	--	--	--
1987	--	3.83	--	--	--	--	--	--	--
1988	--	3.99	--	--	--	--	--	--	--
1989	--	4.06	--	--	--	--	--	--	--
1990	--	4.18	--	--	--	--	--	--	--
1995	785.71	4.16	6.33	1,074.27	854.23	221.95	37.06	50.65	9.67
1996	699.63	4.37	7.95	951.07	764.61	185.26	35.98	54.84	10.20
1997	697.14	4.39	8.25	789.37	764.10	26.76	34.39	55.44	12.21
1998	721.90	4.04	7.54	658.23	628.77	11.74	33.20	53.52	12.40

Calender Year	Potassium	Chloride	Sulfate	Iron	Manganese	Zinc	Aluminum	Total Acidity, Hot
	mg/l							
1978	--	--	410.13	5.49	--	--	--	222.75
1979	--	--	376.64	5.37	--	--	--	179.92
1980	--	--	436.33	4.21	--	--	--	136
1981	--	--	439.1	4.88	--	--	--	192.5
1982	--	--	415.73	6.06	--	--	--	151.33
1983	--	--	414.43	3.79	--	--	--	115.14
1984	--	--	414.82	3.71	--	--	--	114.67
1985		--	371.5	4.12	--	--	--	112
1986	--	--	426.27	9.56	5.42	--	17.47	114.33
1987	--	--	429.82	7.24	6.06	--	17.95	117.67
1988	--	--	411.73	8.8	6	--	15.76	107.17
1989	--	--	400.82	5.51	5.72	--	15.15	102.33
1990	--	--	359.67	17.94	4.97	--	16.15	84.83
1995	2.81	11.68	324.31	13.94	4.98	0.77	15.98	82.89
1996	2.54	12.12	286.58	12.86	4.22	0.70	13.16	73.36
1997	1.80	15.79	248.02	3.56	4.33	0.66	9.74	71.86
1998	1.59	16.18	260.39	3.05	3.87	0.59	8.61	59.82

accumulate over time in the organism's biomass. Some concentrations also may be significant enough to cause acute toxicity in various species. Raising the pH of the system would reduce metal concentrations in the aqueous form, which is the most readily available to aquatic life.

Total solids in the Jeddo Tunnel outflow range from 0 to approximately 6,800 mg/l, with an average of 900 mg/l. Suspended solids contribute an average of approximately 125 mg/l to the total solids concentration; the remainder is comprised of dissolved solids. The average specific conductance of the Jeddo discharge is approximately 728 micromhos/cm. Specific conductance is a measure of the capacity of a water to conduct an electrical current and it varies with concentration and degree of ionization of the constituents. Specific conductance is commonly used in the field to obtain a rapid estimate of the approximate dissolved-solids content of water.

The annual loads of selected parameters were computed for 1996 and 1997, the only years where discharge data were available (Table 2). Vandalism at the gage created a significant data gap from the period November 24, 1997, through January 21, 1998, which prevented calculation of annual loads for 1998. In addition, loads were computed for comparable parameters from earlier samplings by USGS for one sample each in April 1975 and November 1991. Graphical representations of these loads are shown on Figure 3.

These data are insufficient for any type of quantitative analyses, however, some qualitative observations can be made from a comparison of loads between the synoptic values and the monitored values. In Figure 3, which relates loads with discharge, the 1975 and 1991 load values for sulfate and acidity are more than double the average annual values obtained since 1996. This disparity may be attributed to one or more of the following: (1) in 1991, a severe drought occurred that decreased recharge to the Jeddo Tunnel drainage system; (2) a decrease in leachable minerals available to circulating water in the Jeddo drainage system; and (3) a cessation in disposal of breaker waste water to the underground mines.

Table 2. Annual Jeddo Tunnel Water Quality and Discharge Data

Year	Flow	Acidity	Alkalinity	Iron	Sulfate
	cubic feet per second	pounds per day			
1975	65.08	58,858.80	--	2,102.10	150,650.60
1991	24.03	16,946.00	--	362.20	77,616.00
1996	102.45	36,460.94	4,992.62	6,088.40	150,842.80
1997	55.40	19,235.47	2,720.05	882.09	69,611.85

Year	Flow	Manganese	Aluminum	Magnesium	Zinc
	cubic feet per second	pounds per day			
1975	65.08	--	--	--	--
1991	24.03	1,086.60	--	--	--
1996	102.45	2,124.27	6,428.14	29,115.33	365.66
1997	55.40	1,159.96	2,606.04	15,010.41	186.41

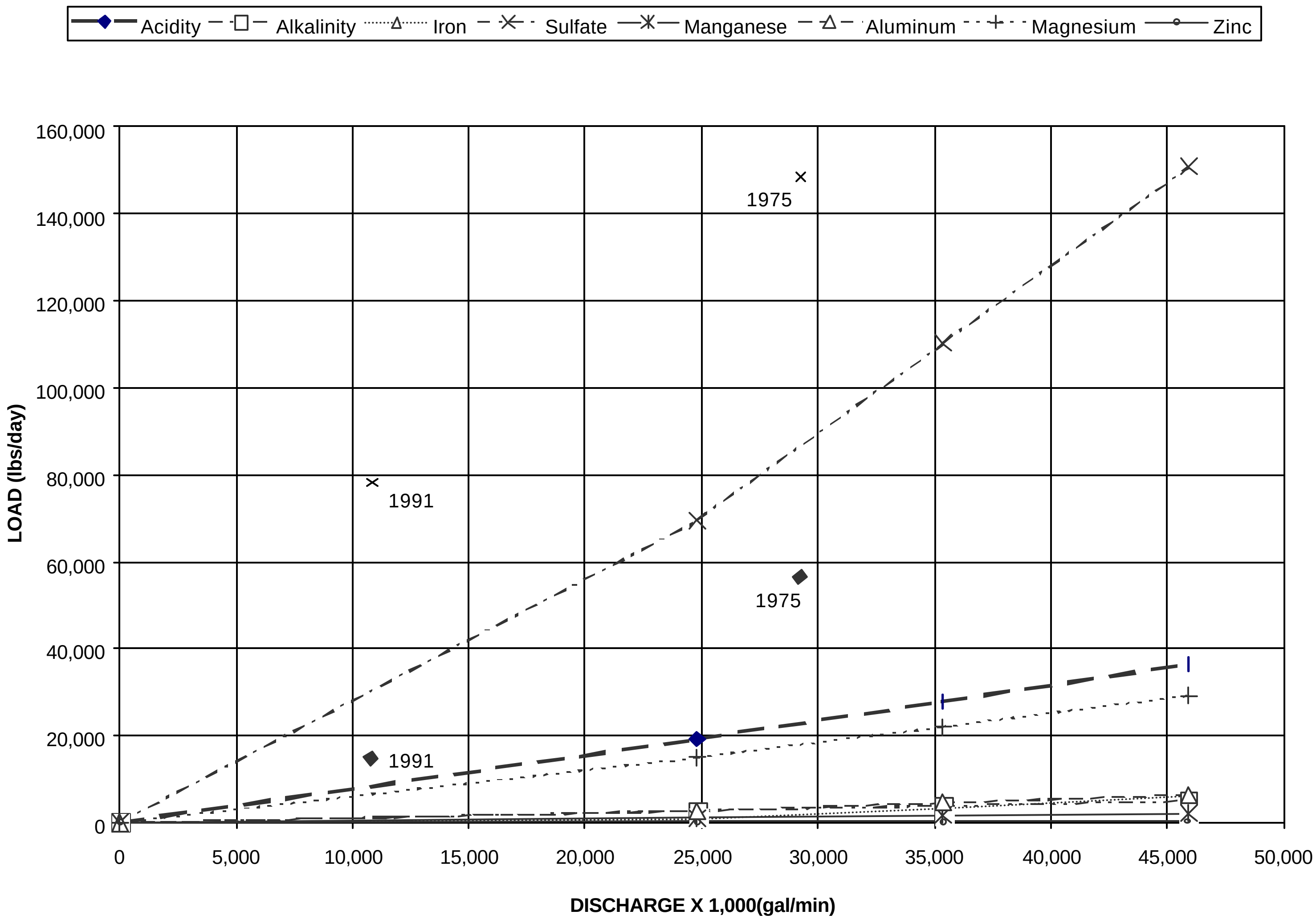

Figure 3. Jeddo Tunnel Water Quality Characteristics

WATER BUDGET

A water budget analysis for the years 1996 to 1998 was performed as a part of this study and the Little Nescopeck Creek assessment and abatement plan (Ballaron and others, 1999). A water budget is a quantitative expression of the major components of the hydrologic cycle. Water that enters a drainage basin as precipitation is balanced against the water that leaves a basin as evaporation and streamflow. This balance can be expressed in a simplified equation as follows:

$$P = R_s + R_g + ET + \Delta S \qquad (1)$$

Where:

- P = precipitation
- R_s = direct runoff
- R_g = ground-water runoff (tunnel discharge)
- ET = evapotranspiration
- ΔS = change in storage

Information is available on two of the items in the above equation; precipitation and runoff (streamflows and tunnel discharge). However, changes in the amount of water stored within a basin are only indirectly measured and are difficult to calculate. Normally, changes in storage are significant from season to season, but are negligible when averaged over a longer period. Therefore, the water budget equations are evaluated over a period of time in which the beginning and ending quantity of stored water is approximately equal, so the storage factor in the above equation can be ignored. In other words, recharge is assumed to equal discharge.

The time period used is the water year, which is the 12-month period from October 1 through September 30. September and October are generally the months in which the annual streamflows and ground-water levels are at their lowest values. The water year is designated by the calendar year in which it ends, and which includes 9 of the 12 months. Thus, the year ending September 30, 1998, is named the "1998 Water Year."

Being able to ignore the changes in storage allows the evapotranspiration to be calculated as a residual, as the other two items of the equation are known. Water budgets for the Jeddo Tunnel Basin are shown in Table 3.

Drainage Basin

The size of the drainage basin is an important factor in calculating the water budget for a particular stream. Commonly, the area of the basin above a stream gage is used in the calculation because the surface- and ground-water divides are generally coincident. In the case of the Jeddo Tunnel, the stream gage is located about 60 feet downstream of the outlet of the tunnel and 0.3 miles upstream from the confluence with the Little Nescopeck Creek. The gage measures the discharge diverted from adjacent watersheds that include the extensively-mined Eastern Middle Anthracite Field near Hazleton.

Table 3. Annual Water Budget for Jeddo Tunnel Basin *(based on a drainage area of 33.53 square miles)*

Water Year	Precipitation (inches)	Surface Runoff (inches)	Base Runoff --Jeddo T. (inches)	Evapotranspiration (inches)
1996	54.25	4.07	36.36	13.82
1997	48.54	3.42	31.89	13.23
1998	42.71	2.88	28.28	11.55
Average	48.50	3.46	32.18	12.87

The basin divides developed for this study indicated the Jeddo Tunnel drains approximately 32.24 square miles. For water budget calculations, an area of 1.29 square miles in the southeast that includes the Hazle Brook outfall and some land draining to Hazle Creek, near the former Ashmore Yards site, was added to the Jeddo Tunnel drainage area. This area was included because (1) information on the location of the barrier separating the mine workings that drain to the Lehigh was not available, and (2) surface flow leaving the basin in Hazle Creek was measured downstream of the overflow.

Precipitation

Precipitation records are available for two stations in the Jeddo Tunnel Basin. The USGS precipitation gage at the Hazleton Airport has a complete, provisional data set for the period of water budget analysis. Precipitation in the City of Hazleton also was measured and recorded daily by Pa. DEP staff during the period November 28, 1995, through November 9, 1997, and at the Penn State Hazleton campus during the period November 10, 1997, through September 30, 1998. Observer data were used to supplement the airport data.

Long-term records of the National Oceanic and Atmospheric Administration station at Tamaqua, covering the period October 1931 to September 1998, were used to determine average precipitation values (Appendix A). Data from the U.S. Weather Bureau station at Freeland, covering the period January 1931 to August 1989 (Appendix A), were used to supplement the long-term records, where possible.

Precipitation varies monthly, seasonally, and annually; Tables 4A through 4C illustrates the temporal variation in Hazleton.

Precipitation averaged about 49 inches in the area (based on data from Tamaqua reservoir) for the 66-year period from 1932 to 1998. A comparison of this average with precipitation in 1996, 1997, and 1998 indicates that, in 1996, precipitation in Hazleton exceeded the average by 11 percent. Precipitation was about average in 1997. For 1998, precipitation was 13 percent below average in the Jeddo Tunnel Basin.

Runoff

Surface runoff from Black Creek, Little Black Creek, Cranberry Creek, and Hazle Creek (R_s in equation 1) was estimated from discharge data for Jeddo Tunnel, based on measurements of flow exiting the basin. Flows were measured at the locations shown in Plate 2.

Ballaron and others (1999) intended to collect synchronous flow measurements of the four streams for precipitation events during several different times of the year (a summer thunderstorm event, an autumn low-intensity frontal passage, and a winter rain-snowmelt event) to understand the effect of storm intensity and seasonal effects on the water budget. However, drought conditions during much of the study period limited opportunities for data collection.

Runoff data for Black Creek, Little Black Creek, Cranberry Creek, and Hazle Creek and total surface runoff (R_s in equation 1) are shown in Table 5. Jeddo Tunnel discharge, R_g in equation 1, also is listed for the day the flow measurements were made. As an indication of storm intensity, total precipitation from the preceding 7 days also is noted in the table.

Immediately following rainfall events, surface runoff varies from about 5 percent of tunnel flow during drought periods to about 11 percent during spring 1998. The relationship between total surface runoff and tunnel discharge is plotted in Figure 4, which was used to estimate annual surface runoff for the water budget. Average annual surface runoff is estimated to be 9 cfs, equivalent to 3.46 inches spread across the drainage basin.

Table 4A. Precipitation Data From Hazleton, Pa., Water Year 1996 (in inches)

Day	October	November	December	January	February	March	April	May	June	July	August	September
1	0	0	0	0	0	0	0.35	0	0	0	0	0
2	0	0.3	0	0.4	0	0	0	0	0	0	0	0
3	0	0	0	0.4	0	0	0	0	0	0.1	0	0
4	0.68	0	0	0	0	0	0	0	0.32	0	0	0.02
5	1.41	0	0.2	0	0	0.25	0	0	0	0	0	0.05
6	0.2	0	0	0	0	0.25	0	0.18	0	0	0	0.2
7	0	0.2	0	0.55	0	0.65	0.55	0.02	0	0	0	0.86
8	0	0	0	0.18	0	0.12	0	0.07	0	0.53	0	0
9	0	0	0	0	0	0	0.12	0.1	0	0	0.07	0
10	0	0	0	0.25	0	0.11	0	0.1	1.18	0	0	0
11	0	2.32	0	0	0	0	0	1.93	0.05	0	0	0
12	0	0.37	0	0.15	0	0	0	0.03	0	0.01	0	0
13	0	0	0	0.65	0	0	0.37	0	0	2.71	0.38	0.41
14	1.85	1.8	0.25	0	0	0	0.07	0	0	0.03	0	0
15	0.05	0.42	0.13	0	0	0	0.71	0	0	0.17	0	0
16	0	0	0	0	0	0	0.87	0	0	0	0	0.18
17	0	0	0	0.38	0	0	0	0	0	0.41	0	1.32
18	0	0	0	0	0	0	0	0	0.03	0	0	0.06
19	0	0	0.75	2.56	0	1.09	0	0	0.15	0.23	0	0
20	0.6	0	0.21	0	0.55	0.21	0	0	0	0	0	0
21	3.05	0	0.1	0	0.48	0.05	0	0.1	0	0	0.22	0
22	0	0	0	0	0.1	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0.6	0	0	0	0	0
24	0	0	0	1.32	0.17	0	0	0	0.14	0	0.13	0
25	0	0	0	0	0	0.03	0	0	0	0	0	0
26	0	0	0	0.28	0	0.02	0.08	0	0	0.33	0	0
27	0.25	0	0	2.95	0	0	0	0.12	0	0	0	0
28	0.38	0	0	0.53	0.15	0.19	0	0	0	0	0	0.66
29	0.14	0.47	0	0.58	0	0.57	0.65	0	0.02	0.6	0	0.02
30	0.03	0	0	0	---	0	1.63	0	1.59	0.03	0	0
31	0.06	---	0	0	---	0	---	0	---	0	0	---
TOTAL	**8.7**	**5.88**	**1.64**	**11.18**	**1.45**	**3.54**	**6**	**2.65**	**3.48**	**5.15**	**0.8**	**3.78**
MAX	**3.05**	**2.32**	**0.75**	**2.95**	**0.55**	**1.09**	**1.63**	**1.93**	**1.59**	**2.71**	**0.38**	**1.32**

Table 4B. ***Precipitation Data From Hazleton, Pa., Water Year 1997*** *(in inches)*

Day	October	November	December	January	February	March	April	May	June	July	August	September
1	0	0	2.76	0	0.02	0	0.17	0	0.03	0	0	1.83
2	0	0	0.34	0.07	0	0.15	0	0	0.83	1.05	0	0
3	0	0	0	0.1	0.03	0.23	0	0.6	0.2	0	0.03	0
4	0	0	0	0	0.15	0	0	0	0.02	0	0.17	0
5	0	0	0	0.1	0.35	0.2	0	0	0	0	0.61	0
6	0	0	0.73	0	0	0.1	0	0.05	0	0	0	0
7	0	0	0.1	0	0	0	0	0	0	0	0.02	0
8	0.6	3.8	0.05	0	0	0	0	0.13	0	0	0	0
9	0.01	0.09	0.07	0.12	0	0	0	0.25	0	0.2	0	0
10	0.14	0.14	0	0.06	0	0	0	0	0	0	0	0.1
11	0	0	0.46	0	0	0	0	0	0	0	0	1.81
12	0	0	0.3	0	0.02	0	0.25	0	0	0	0	0
13	0	0	1.14	0	0	0	0	0.05	0.31	0	0.2	0
14	0	0	0.47	0	0.28	0.87	0	0	0	0	0	0
15	0	0	0	0	0.05	0	0	0.05	0	0	0.86	0
16	0	0	0	0.5	0.01	0	0	0	0	0	0.15	0
17	0	0	0	0	0.02	0	0.03	0	0	2.69	0.4	0
18	0.07	0.11	0	0	0	0	0.05	0.05	0.2	0.95	2.47	0.05
19	4.75	0.07	0.27	0	0.05	0	0	0.63	0	0	0	0
20	0.07	0	0	0	0	0	0	0.07	0	0	1.48	0.1
21	0.1	0	0	0	0.05	0	0	0	0	0.05	0	0
22	0.03	0.03	0	0.11	0	0.1	0	0	0.22	0.05	0	0
23	0.28	0	0	0	0	0	0	0	0	0.11	0	0
24	0	0	0.58	0.5	0	0	0	0	0	0.7	0	0
25	0	0	0	0.15	0	0.02	0	0.73	0	0	0	0
26	0	0.75	0	0	0.07	0.78	0	0	0	0	0	0
27	0	0	0	0.09	0	0	0.05	0.03	0	0	0	0
28	0	0	0	0.19	0	0	0.25	0	0	0	0.4	0.25
29	0	0	0.35	0	---	0	0	0	0	0	0.31	0.28
30	0	0.25	0	0	---	0.11	0	0.02	0	0	0	0.08
31	0	---	0	0	---	1.31	---	0	---	0	0	---
TOTAL	**6.05**	**5.24**	**7.62**	**1.99**	**1.1**	**3.87**	**0.8**	**2.66**	**1.81**	**5.8**	**7.1**	**4.5**
MAX	**4.75**	**3.8**	**2.76**	**0.5**	**0.35**	**1.31**	**0.25**	**0.73**	**0.83**	**2.69**	**2.47**	**1.83**

Table 4C. ***Precipitation Data From Hazleton, Pa., Water Year 1998*** *(in inches)*

Day	October	November	December	January	February	March	April	May	June	July	August	September
1	0.05	0.77	0	0	0	0	0.58	0.02	0.15	0	0	0
2	0	0.3	0	0	0	0	0.02	0.08	0	0	0	1.16
3	0	0.03	0	0	0	0.2	0	0.02	0	0	0	0
4	0	0	0.03	0	0.75	0.05	0.03	0.13	0	0.1	0	0
5	0	0	0.07	0	0.63	0	0	0.17	0	0.05	0	0
6	0	0	0	0.17	0	0	0	0.03	0	0	0	0
7	0	0.17	0.03	0.45	0	0	0	0.02	0.05	0	0	1.26
8	0	0.4	0	0.95	0	0.21	0.17	0.37	0	0.47	0	0.02
9	0	0.15	0	0.45	0	1.3	1.28	0.33	0	0	0	0
10	0.05	0	0.45	0	0	0.05	0.25	0.79	0.12	0	0.96	0
11	0	0	0.07	0	0.32	0	0	0.59	0.03	0	0	0
12	0	0	0.03	0.03	0.18	0	0	0.07	0.62	0	0	0
13	0	0	0	0.02	0	0	0	0	2.14	0	0	0
14	0.07	0.03	0.05	0	0.02	0.02	0.05	0	0.15	0	0	0
15	0.25	0	0	0.43	0	0	0.15	0	0.15	0	0.08	0
16	0.1	0	0	0.37	0	0	0.05	0	0.12	0.07	0	0
17	0	0	0	0	0.58	0	0.08	0	0.15	0.03	0.39	0.05
18	0	0.47	0	0.08	0.37	0.33	0	0	0	0	0.05	0.03
19	0	0.28	0	0.02	0.1	0.13	1.67	0	0	0	0	0
20	0	0	0	0.08	0	0.15	0.1	0	0	0.12	0	0
21	0	0.07	0.02	0	0	1	0	0	0	0.49	0	0
22	0	0.45	0.05	0.02	0	0.1	0	0	0	0	0.92	0.59
23	0	0	0.13	0.65	0.93	0.02	0	0	1.48	0	0	0
24	0.03	0.03	0.07	0.25	1.25	0	0	0	0	0.03	0	0
25	0.47	0	0.3	0.05	0	0	0	0.1	0	0	0.5	0.1
26	0.28	0.08	0	0	0	0	0.91	0	0.05	0	0.09	0
27	0.1	0	0.08	0	0	0	0.03	0	0	0	0	0.16
28	0	0.05	0.02	0	0.25	0	0	0	0	0	0	0.02
29	0	0.02	0.3	0	---	0	0	0.57	0.05	0.05	0	0
30	0	0.55	0.43	0	---	0	0	0.02	0.25	0.07	0	0
31	0	---	0	0	---	0	---	0.05	---	0.27	0	---
TOTAL	**1.4**	**3.85**	**2.13**	**4.02**	**5.38**	**3.56**	**5.37**	**3.36**	**5.51**	**1.75**	**2.99**	**3.39**
MAX	**0.47**	**0.77**	**0.45**	**0.95**	**1.25**	**1.3**	**1.67**	**0.79**	**2.14**	**0.49**	**0.96**	**1.26**

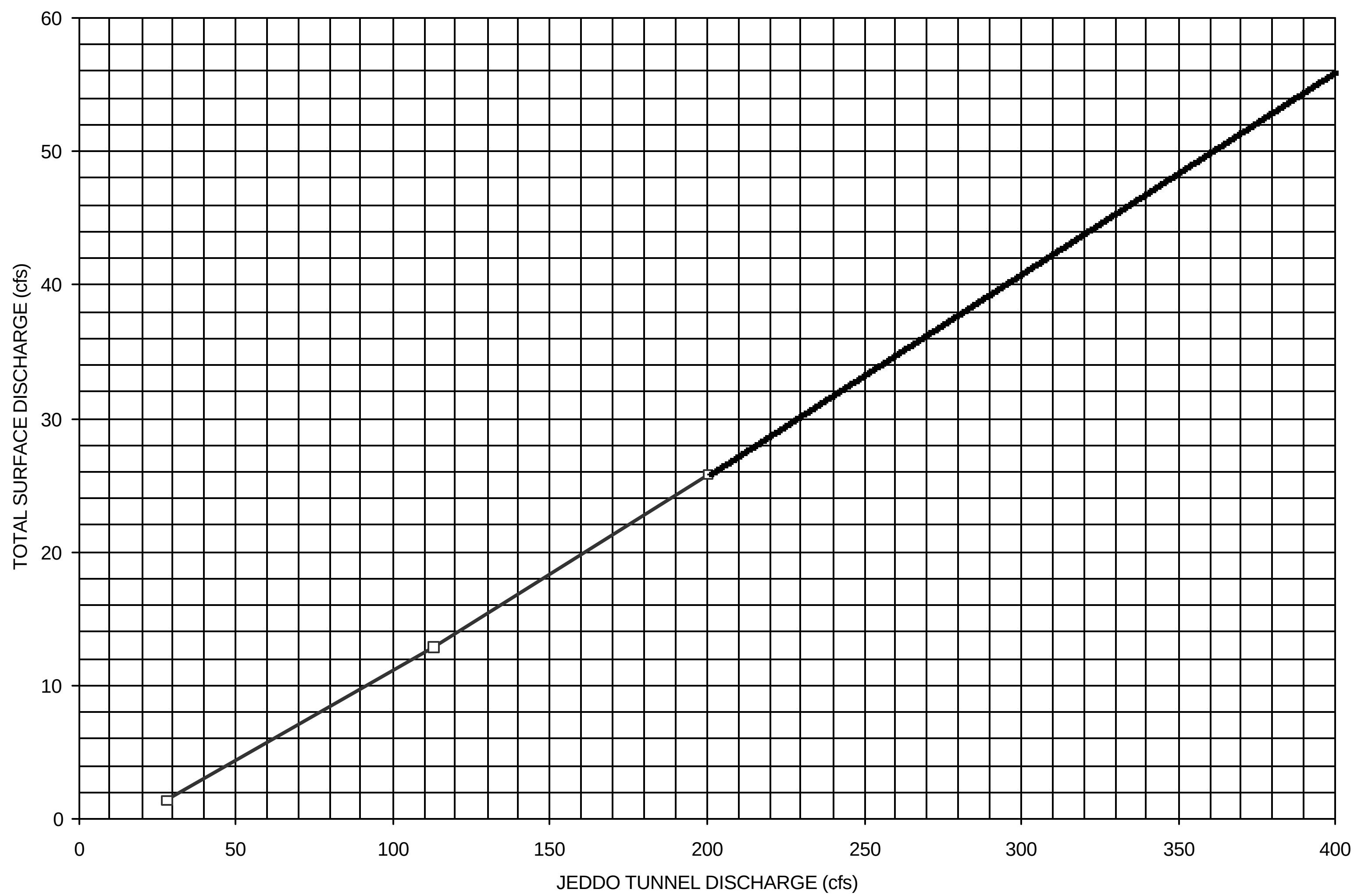

Figure 4. Relationship to Total Surface Flow Leaving the Basin and Jeddo Tunnel Discharge

***Table 5. Runoff Data for Streams Leaving the Jeddo Basin** (flow measurements in cubic feet per second) (Ballaron and others, 1999)*

	10/30/1997	11/03/1997	01/09/1998	01/21/1998	03/27/1998	10/09/1998
Black Creek	Dry channel	Dry channel	5.89	Minimal flow	1.80	No flow
Little Black Creek	No flow	No flow	2.04	No flow	1	No flow
Cranberry Creek	Dry channel	NA	0.51	--	0.15	0.07
Hazle Creek	1.35	NA	17.36	--	9.98	0.89
Total Surface Flow (R_s)	1.35		25.79		12.93	0.96
Jeddo Tunnel (R_g)	28	33	200	90	113	--
Precipitation (inches)	0.88	1.1	2.02	0.98	1.12	--

Of the surface flows leaving the Jeddo Basin, Hazle Creek is the largest, followed in decreasing order by Black Creek, Little Black Creek, and Cranberry Creek. Although Black Creek is usually perennial, the channel was dry or the stream had no measurable flow at the Pa. Route 940 bridge on several occasions during the study. Streamflows are not proportional to the drainage area of the subbasin due to direct and indirect losses to the mines.

Most water leaves the Jeddo basin through the Jeddo Tunnel (R_g in equation 1). Flow data from the Jeddo Tunnel (Figure 5) were obtained from records of the USGS gaging station 01538510 on a Little Nescopeck Creek tributary near Freeland (October 1995 through September 1998). The USGS also collected data at the station from December 1973 to October 1979; however, the gaging station was not active between 1979 and 1995.

There is one significant data gap in the recent record: data for the period November 24, 1997, through January 21, 1998, were lost due to vandalism. For days with missing flow data, the tunnel discharge was estimated based on the daily value hydrograph for Wapwallopen Creek near Wapwallopen, about 10 miles north of the Jeddo discharge (John Rote, USGS, written communication, February 24, 1999). Estimated flows account for general trends of recession and rise and are believed to be conservative (low).

The hydrograph shows the importance of winter-spring precipitation for recharging the ground-water and mine-water systems that sustain tunnel flow. Tunnel discharge is in many ways similar to typical stream flow systems; there is evidence of direct runoff due to precipitation as well as an apparent minimum sustained base flow. The maximum discharge during the study is 482 cfs, which occurred on November 9, 1996; this also is the maximum discharge for the period of record. The minimum discharge recorded during the study is 20 cfs on October 13, 1995. This minimum also occurred on August 15 and 16, 1977. The average annual discharge from the Jeddo Tunnel is 79.4 cfs. This discharge is equivalent to 32.18 inches spread across the drainage basin.

Total runoff, which includes flow through the Jeddo Tunnel and streams exiting the basin, during the 3-year study period, averages about 88 cfs, or about 2.6 cubic feet per second per square mile (cfsm). This is equivalent to 35.64 inches spread across the drainage basin. Precipitation for the same period averaged 48.50 inches. Total runoff (R_s + R_g in equation 1) is 74 percent of precipitation, on average.

Tunnel Discharge

The discharge from the Jeddo Tunnel is comprised of: (1) direct infiltration of precipitation through the mined land; (2) seepage from streams, especially where they cross mined land; (3) stream flow directly entering the mines through cave-ins or other sinks; (4) unchanneled overland runoff and interflow from upland areas; and (5) natural ground-water discharge from bedrock aquifers. The small spikes in the record (Figure 5), following precipitation events, indicate the significance of the "direct" runoff that enters

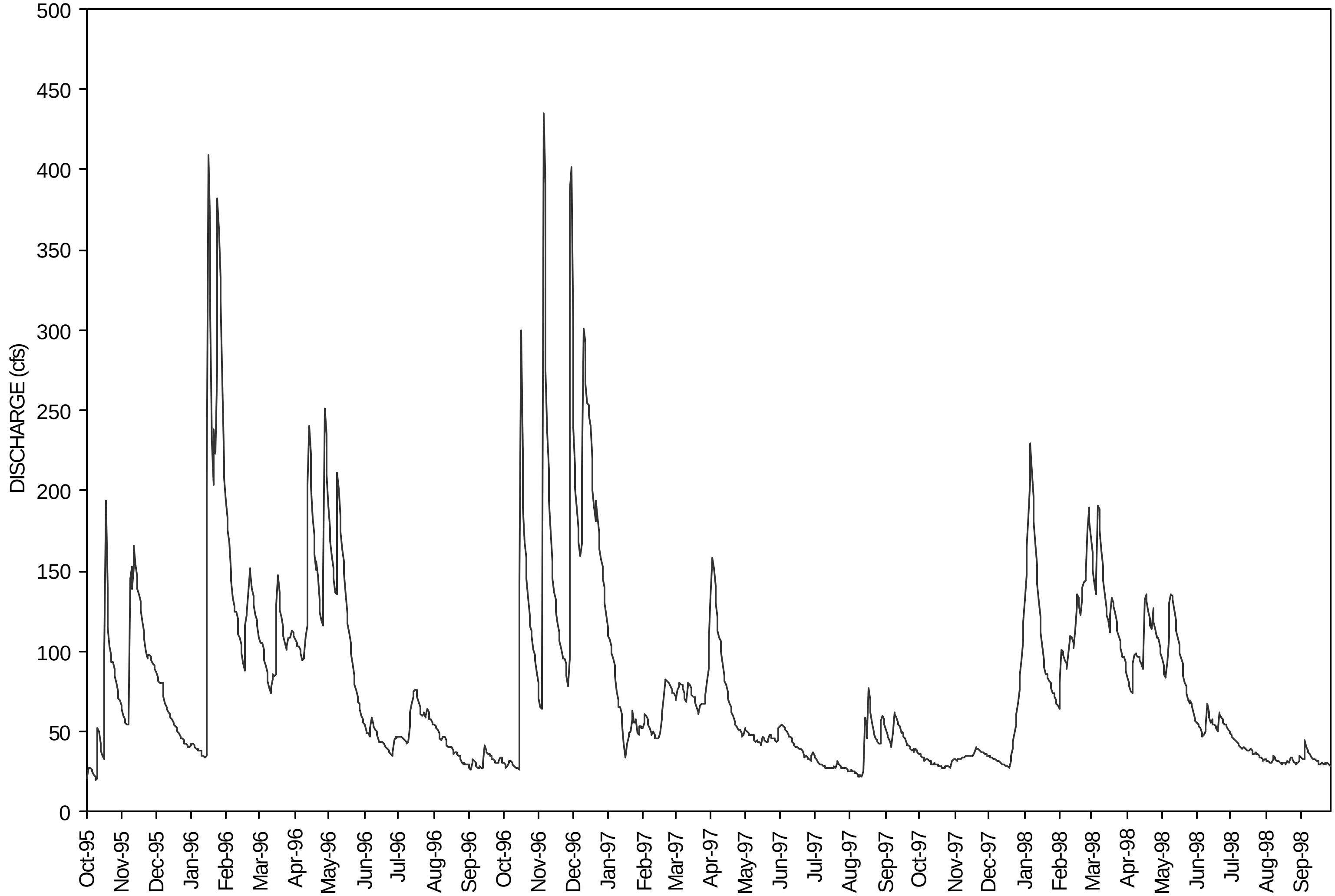

Figure 5. Discharge From Jeddo Tunnel, Water Years 1996-98

the mine complex. These pulses of surface water are most pronounced in the spring.

The hydrograph of tunnel discharge was analyzed with a technique commonly used for streamflow to separate ground-water discharge from total runoff. Base flow was separated from total flow using a modification (Taylor, 1997) of the local minimum technique developed by Pettyjohn and Henning (1979). The technique uses computer analysis of daily flow and allows the operator to select the time period after the peak flow, when essentially all of the flow is base flow.

Base flow averaged 72.3 cfs annually from the Jeddo Tunnel Basin (Table 6). This discharge is equivalent to about 29 inches spread over the entire basin. The direct or surface runoff component of tunnel discharge was computed as the difference between total flow and base flow. Surface runoff through the tunnel averaged 7.2 cfs, or an equivalent 3 inches spread over the basin. During 1998, a drier-than-average year, surface runoff decreased 55 percent compared to 1997, to an average discharge of 4.7 cfs.

Base flow discharged through the tunnel accounts for about 81 percent of total runoff in the basin. This percentage is high. Natural basins in the Susquehanna River Basin range from a high of 86 percent for the primarily carbonate rocks in Spring Creek Basin to between 60 and 65 percent for basins underlain by sandstone and shale of the Valley and Ridge physiographic province.

A large proportion of precipitation infiltrates to the mine workings and to the natural ground-water system through the disturbed land in mined areas (Ash and Link, 1953), reducing the amount of surface runoff and, conversely, increasing the ground-water discharge. In a mined basin above the gage on Shamokin Creek, Becher (1991) found ground water accounted for 41 percent of precipitation, or about 85 percent of total streamflow.

Currently, in the Jeddo Tunnel drainage area, there is easy ingress to precipitation through rock fissures, cave-ins, fissures in outcrops and strippings, and numerous sinks identified in Ballaron and others (1999). Remedial measures can eliminate many of the direct pathways for precipitation entering the mines and channel this flow to streams outside the Jeddo basin, which should significantly reduce the direct runoff component of tunnel discharge. These measures could reduce total tunnel discharge by about 11 percent, under average conditions.

Reestablishing perimeter drains that would intercept overland runoff from adjacent ridges would likely further reduce the discharge from the Jeddo Tunnel. The unchanneled overland runoff currently flows to the mined lands and percolates through the overburden to the flooded mine workings. As such, much of the existing overland runoff may not have been accounted for in the surface runoff component of tunnel discharge.

Uplands surrounding the coal basins comprise about 55 percent of the Jeddo basin. Diverting the runoff contributed by these areas away from the mined lands could potentially reduce tunnel flow another 10 percent, providing the channels are lined to minimize any seepage to the mine-water system from reestablished streams and perimeter drains.

Table 6. Base Flow Separation of Tunnel Discharge *(flow values in cubic feet per second)*

Water Year	Total Tunnel Discharge	"Direct Runoff"	Mean Base flow	Maximum Value (base flow)	Minimum Value (base flow)
1996	89.6	8.2	81.4	318	19
1997	78.8	8.6	70.2	253	22
1998	69.9	4.7	65.2	180	26
Average	79.4	7.2	72.3	--	--

Even after the surface drainage network is restored, infiltration of precipitation on mined lands, the natural ground-water discharge from the bedrock aquifers, and underflow from uplands adjacent to the coal basins will continue to support tunnel flow. The significance of natural ground-water discharge is described during tunnel construction (McNair, 1951):

> "The workers were troubled considerably by meeting a great many streams of underground water. These streams were of the purest spring water; on several occasions a blast would cut them in two like a hose pipe; so powerful was the force, some of them gushed two or three feet from the rock after being thus cut. As the tunnel was worked in sections having no communication with each other, except the boom-boom-boom of the dynamite blasts, it was necessary to clear out this water with pumps; 7 of these aggregating 799 HP were in constant use operated by special pump runners and attendants; 4 pumps were located in the Lattimer slope and 3 in the Ebervale-Jeddo slope."

During the moderate drought in 1998, when infiltration through the mined lands was minimal, flows declined and stabilized at 30 to 33 cfs. Flows of this magnitude also are typical during late summer and early fall in years with average levels of precipitation. This likely represents natural ground-water discharge, amounting to about 0.9 cubic feet per second per square mile (cfsm), and cannot be reduced by remedial measures.

Evapotranspiration

Water lost to the atmosphere by evaporation from surface bodies of water, wetted surfaces, moist soil, and by transpiration of plants constitutes the largest component in the water budget. Evapotranspiration (ET in equation 1) losses decline rapidly in early fall as plant growth stops and temperatures decrease. Through late fall and winter, ET is negligible, but in early spring it increases rapidly and reaches a maximum in summer. Commonly, recharge to the ground-water system and streamflow are greatest when ET is least, and least when ET is greatest.

ET was calculated in the budget as the difference between precipitation and total runoff. The average annual loss to ET is about 13 inches from the basin. This loss constitutes 26 percent of average annual precipitation in the basin. The low rate of ET is probably related to the lack of vegetation in the mined areas and the character of the "soils." Soils and other overburden in the mined areas allow for rapid infiltration of precipitation. Any water that enters the soils passes quickly below the root zone.

Subbasin Contributions

Average discharge from the Jeddo Tunnel amounts to 2.463 cfsm, or 1.591 mgd/mi^2. Using drainage areas and an unitized approach, the subbasins of Black Creek, Little Black Creek, Cranberry Creek, and Hazle Creek contribute an annual average 30.66 cfs (39 percent), 11.43 cfs (14 percent), 16.31 cfs (26 percent), and 21.01 cfs (21 percent), respectively.

Flow entering the mines and that could be diverted also was measured directly at several locations. Six potential sites for flow measurements were identified (Dr. Duane Braun, Bloomsburg University, written communication, April 1997):

- Little Black Creek, in the headwaters east of Pardeesville, an example of surface flows from a near natural subbasin (the reclaimed Woodside Coal Basin);
- Black Creek headwaters, at a road culvert near Eckley, an example of a near-natural wooded area;
- Black Creek at Stockton Road, an example of the amount of surface flow coming off a section of the Pottsville conglomerate dipslope;
- Hazle Creek at Stockton Road, an example of the largest of the flows going to the mines;
- Black Creek headwaters at railroad culvert; and
- Cranberry Creek headwaters.

The last two sites listed were eliminated when field checked because of indeterminate flow direction and dry and/or discontinuous channel, respectively. Table 7 shows the results, which were disappointing due to the dry conditions. Additionally, Jeddo Tunnel discharge is listed for the day the flow measurements were made. As an indication of storm intensity, total precipitation from the preceding seven days also is noted in the table.

The relationship between surface runoff at each site and Jeddo Tunnel discharge is plotted in Figure 6. The reestablished extension of Little Black Creek in the Woodside basin shows that flows in the stream increase as tunnel discharge increases; the linear relationship is plotted in the figure. This stream is perennial and continued to flow even during the moderate drought.

Conversely, Hazle Creek data demonstrate no predictable relationship between measured surface flow and Jeddo Tunnel flow. This may be due to the intermittent flow during the study, including instances of very low flows and dry channel, and/or a failure of investigators to consistently measure peak flows, or near peak flows. Hazle Creek is the largest and "flashiest" of the flows entering the mines, and has sharp, multi-crest hydrography that made it difficult for investigators to catch the crest or crests. Measured flows of the other streams were too low and the number of measurements was insufficient to establish a relationship with the tunnel discharge data.

Table 7. Runoff Data for Streams That Directly Enter the Mines *(flow in cubic feet per second)*

Location	Drainage Area (mi^2)	05/20/97	09/11/97	10/27/97	10/30/97
Hazle Creek at Stockton Road	4.19	--	47.81	<0.1e[1]	dry
Black Creek at Stockton Road	8.65	--	dry	<0.1e[1]	dry
Woodside Basin	1.54	3.48	--	--	1.32
Culvert near Eckley	0.10	--	--	--	0.85
Culvert under RR near Eckley	eliminated due to undetermined flow directions				
Cranberry Creek south of Pa. Route 924	eliminated due to lack of channel and water				
Jeddo Tunnel	32.64	47	49	29	28
Precipitation (inches)		0.80	1.91	0.88	0.88

Location	01/9/98	01/21/98	02/5/98	03/27/98	05/11/98	10/9/98
Hazle Creek at Stockton Road	--	ice	12.6	0.15	19.5	1.39
Black Creek at Stockton Road	--	ice	0.4e[1]	0.10	<0.30e[1]	dry
Woodside Basin	2.12	--	--	4.71	<0.30e[1]	1.25
Culvert near Eckley	0.93	--	--	1.02	--	--
Culvert under RR near Eckley	eliminated due to undetermined flow directions					
Cranberry Creek south of Pa. Route 924	eliminated due to lack of channel and water					
Jeddo Tunnel	200	90	80	113	109	--
Precipitation (inches)	2.02	0.98	1.38	1.12	2.30	--

[1] estimated

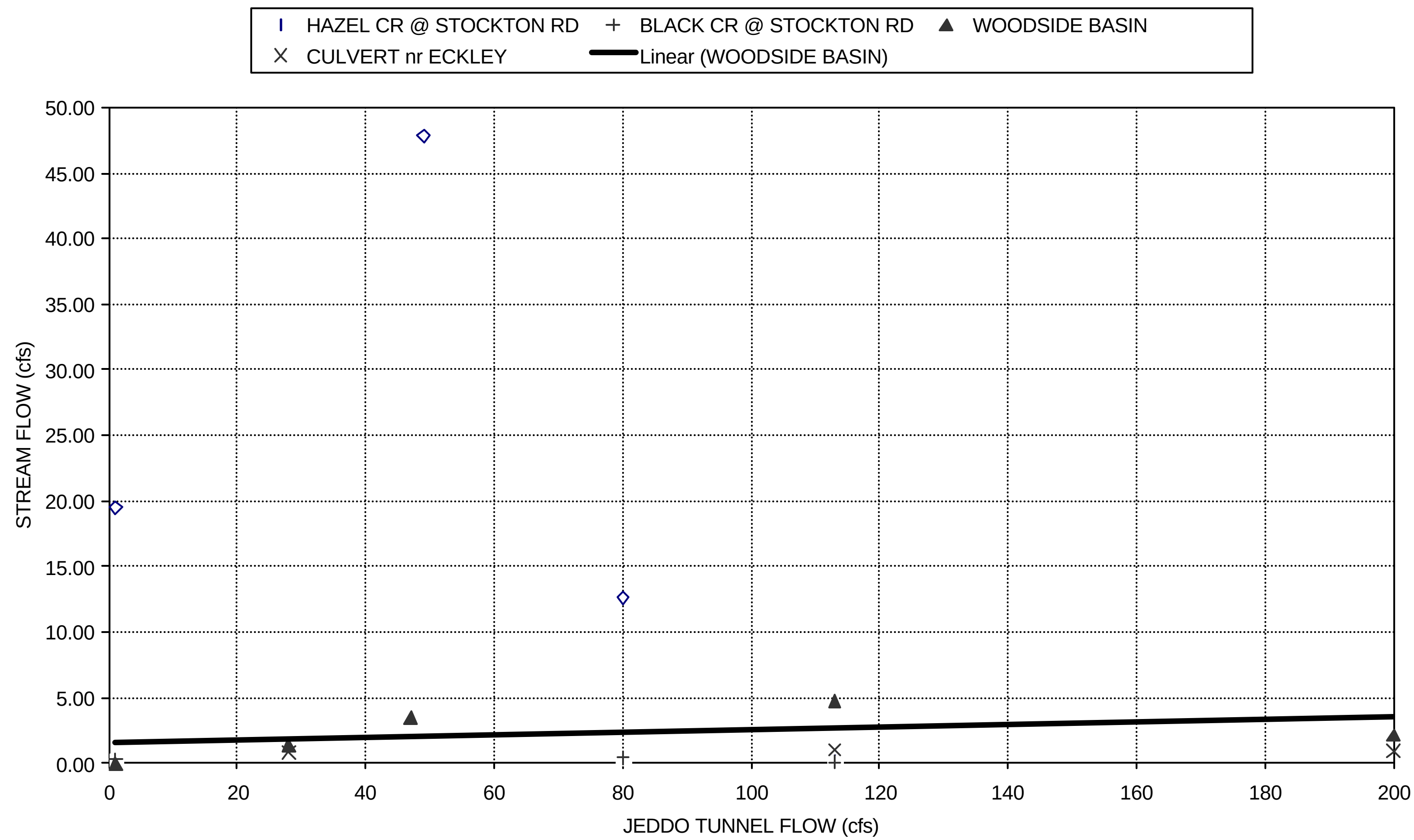

Figure 6. Relationship of Streamflow Entering the Mines and Jeddo Tunnel Discharge *(Ballaron, 1999)*

Using the limited data available, average annual runoff from the Woodside basin is estimated to be 2.34 cfs, or 1.51 cfsm. The Woodside basin would be expected to produce, using drainage areas and the average discharges from the Jeddo Tunnel Watershed, a proportional average annual flow (total runoff) of 4.004 cfs, of which 3.793 cfs would be contributed to the tunnel discharge. Predicted flow values are substantially higher than measured values (extrapolated to an average annual flow), probably illustrating the benefits of the remediation. Runoff from the remediated Woodside basin is similar to that expected for a natural basin. As a general rule, natural freestone basins in the Valley and Ridge physiographic province in Pennsylvania produce flows of about 1 mgd/mi^2 or 1.547 csfm.

Annual runoff of 2.34 cfs is equivalent to 20.3 inches spread across the subbasin, or 42 percent of precipitation on the subbasin. The quantity of ground-water discharge from the Woodside basin could not be determined directly, but can be calculated as a residual, assuming an ET for the wooded basin approaches the state average of 20 inches. Ground-water discharge amounts to about 8.2 inches, or only 17 percent of average annual precipitation.

Using the Woodside basin as a surrogate for the other coal basins would predict a substantial potential reduction of infiltration, assuming similar reclamation of coal basins in each hydrologic subbasin. This assumes the mine areas would be completely regraded and that surface water is directed to the reestablished surface water network and perimeter drains.

The only way to further reduce direct infiltration to the mine drainage system would be to bury a layer of low permeability material such as fly ash at a shallow depth under the regraded surface. That should reduce infiltration (and Jeddo Tunnel discharge) 10 to 25 percent (Dr. Duane Braun, Bloomsburg University, written communication, April 1997). Urbanization of the mine sites and the surrounding ridges might further reduce infiltration to the mine-water system, providing storm water is adequately controlled and the surface drainage network prevents water from entering the mines.

SUMMARY AND CONCLUSIONS

The Little Nescopeck Creek, a tributary to the Nescopeck Creek, is severely impacted by a water-quality impaired discharge from the adjacent mined watershed. The natural watersheds were interconnected by construction of a water level drainage tunnel. This tunnel, the Jeddo Tunnel, was constructed to dewater deep mined coal measures in the Eastern Middle Anthracite Field near Hazleton, Pennsylvania. The Jeddo Tunnel drainage system involves four major coal basins: Big Black Creek; Little Black Creek; Cross Creek; and Hazleton.

The Jeddo Tunnel is one of the largest mine water discharges in the anthracite region and the Little Nescopeck receives all its flow. This tunnel drains 32.24 square miles. Surface-water divides generally match ground-water divides. Most of this part of the Eastern Middle Anthracite Field drains to the Susquehanna River. The eastern-most parts of the coal basins (Cross Creek Basin, Big Black Creek Basin, and Hazleton Basin) drain to the Lehigh River. The drainage divide is expressed on the surface by a broadening of the coal basins and its location was estimated from structural geology maps and field observations.

More than a century of subsurface and surface mining activities has left a legacy of physical and chemical contamination of mine water draining the coal field through the water-level tunnel. The subsurface is a maze of collapsed gangways, tunnels, and chambers that interconnect the Buck Mountain, Gamma, Wharton, three splits of the Mammoth Vein, and numerous other beds of lesser thickness and poorer quality coal.

The surface also has been extensively disturbed by previously unregulated surface mining operations and is presently scarred with open abandoned pits, spoil piles, and refuse banks. These abandoned deep and surface mining operations have completely destroyed the natural surface and ground-water systems within the mining area. The open pits and fractured strata allow all surface water, not controlled at the surface, to infiltrate into the deep mine workings.

The quality of this water has been greatly affected through contact with acid-producing minerals present in the coal and associated rock exposed to infiltrating water. The water from the Jeddo Tunnel is predominantly acidic. Metal concentrations commonly exceed MCLs, and magnesium concentration exceeds that of all other metals.

The 1975 and 1991 load values for sulfate and acidity are more than double the average annual values obtained since 1996. This disparity may be attributed to one or more of the following reasons: (1) the 1991 drought; (2) a decrease in leachable minerals available to circulating water in the Jeddo Tunnel drainage system; and (3) a cessation in disposal of breaker waste water to the underground mines.

When underground mines were operating, surface water was captured in, or diverted to, channels outside the coal measures. Many of the channels are abandoned and no longer function as perimeter drains. Today, streams in the basin experience significant flow losses to the deep mine complex and most water that leaves the basin flows out through the Jeddo Tunnel. However, at four locations, streams exit the Jeddo basin; these are Black Creek, Little Black Creek, Cranberry Creek, and Hazle Creek.

Water budget analysis indicated that total runoff during the 3-year period of record is approximately 74 percent of precipitation. Tunnel discharge, on average, amounts to 66 percent of precipitation.

Base flow averaged 72.3 cfs annually from the Jeddo Tunnel Basin, and the direct or surface runoff component of tunnel discharge was computed to be 7.2 cfs (annual average). Base flow discharged through the tunnel accounts for about 81 percent of total runoff in the basin. This percentage is comparable to base flow from natural basins in the Susquehanna River Basin underlain by predominantly carbonate rocks.

The discharge from the Jeddo Tunnel is comprised of: (1) direct infiltration of precipitation through the mined land; (2) seepage from streams, especially where they cross mined land; (3) stream flow directly entering the mines through cave-ins or other sinks; (4) unchanneled overland runoff and interflow from upland areas; and (5) natural ground-water discharge from bedrock aquifers. Both underground and surface mining, with associated subsidence, create surface catchment basins, fractured rock strata, and artificial ponding that increases the amount of water discharged by the tunnel. To reduce mine water drainage from the Jeddo basin, measures will have to be taken to control water from entering at the surface.

Remedial measures can eliminate many of the direct pathways for precipitation entering the mines and channel this flow to streams outside the Jeddo basin, which should significantly reduce the direct runoff component of tunnel discharge. Water budget analyses indicate that these measures could reduce total tunnel discharge by about 11 percent, under average conditions. Reestablishing perimeter drains that would intercept overland runoff from adjacent ridges would likely further reduce the discharge from the Jeddo Tunnel, potentially another 10 percent, providing the channels are lined to minimize any seepage to the mine-water system.

Future reclamation, assuming similar measures to those used in the Woodside basin, should reduce infiltration to the mine-water system. To further reduce direct infiltration 10 to 25 percent, a layer of low permeability material such as fly ash might be buried at a shallow depth under the regraded surface. Urbanization of the mine sites and the surrounding ridges might further reduce infiltration to the mine-water system, providing storm water is adequately controlled and the surface drainage network prevents water from entering the mines.

Even after the surface drainage network is restored and mined lands are reclaimed, infiltration of precipitation on mined lands, the natural ground-water discharge from the bedrock aquifers, and underflow from uplands adjacent to the coal basins will continue to support tunnel flow. Natural ground-water discharge is estimated to be 30 to 33 cfs, and cannot be reduced by remedial measures.

The Nescopeck Creek Watershed assessment report and abatement plan (Ballaron and others, 1999) focuses on factors and conditions relevant to the quality of the Jeddo Tunnel discharge to the Little Nescopeck Creek, and the potential for reducing AMD entering the Little Nescopeck Creek. The abatement plan identifies 29 areas where surface water is directly entering the mine drainage system, and proposes a number of remediation options. In addition to the restoration of particular sites, the plan recommends that the following activities should be completed:

- Remining and reclamation of abandoned mine lands causing AMD;
- Use of Title IV and other SMCRA funding to reclaim priority sites that are causing AMD;
- Use of forfeited reclamation bonds to reclaim those sites, and Reclamation In-Lieu of Penalty funding from active industry;
- Increase public awareness through local environmental organizations;
- Use of partnerships to facilitate and monitor restoration activities;
- Selection of proven and innovative technologies to reduce the pollutant loads of the Jeddo Tunnel discharge; and
- Prevention of the sewage inflow into the Jeddo drainage system.

The completion of these recommended activities should dramatically reduce the impact of the Jeddo Tunnel discharge on its receiving stream. Monitoring of the quality and quantity of the Jeddo Tunnel discharge should be continued to document improvements.

REFERENCES

Anonymous. Circa 1960. History of Jeddo Tunnel. Unpublished report.

Ash, S.H., W.E. Cassap, W.L. Eaton, K.L. Hughes, W.M. Romischer, and J. Westfield. 1947. Flood-Prevention Projects at Pennsylvania Anthracite Mines. U.S. Bureau of Mines, Report of Investigations 4288, 51 pp.

Ash, S.H., H.D. Kynor, R.W. Fatzinger, B.S. Davies, and J.C. Gilbert. 1950. Inundated Anthracite Reserves: Eastern Middle Field of Pennsylvania. U.S. Bureau of Mines, Bulletin 491, 28 pp.

Ash, S.H. and H.B. Link. 1953. Surface-water Seepage Into Anthracite Mines in the Western Middle Field—Anthracite Region of Pennsylvania. U.S. Bureau of Mines, Bulletin 532, 26pp.

Ballaron, P.B., C.M. Kocher, and J.R. Hollowell. 1999. Assessment of Conditions Contributing Acid Mine Drainage to the Little Nescopeck Creek Watershed, Luzerne County, Pennsylvania, and an Abatement Plan to Mitigate Impaired Water Quality in the Watershed. Susquehanna River Basin Commission, Publication 204, 188 pp.

Becher, A.E. 1991. Groundwater Resources in and Near the Anthracite Basins of Schuylkill and Adjacent Counties, Pennsylvania. Pennsylvania Geological Survey, Water Resource Report 64, 60 pp.

Carruccio, F.T. and G. Geidel. 1978. Geochemical Factors Affecting Coal Mine Drainage Quality, *in* Reclamation of Drastically Disturbed Lands, Proceedings. Madison, Wisconsin, ASA-CSSA-SSA, pp. 129-147.

Hollowell, J.R. 1999. Surface Overflows of Abandoned Mines in the Eastern Middle Field Unpublished report for the Susquehanna River Basin Commission (in preparation), 42 pp.

Hornberger, R.J., M.S. Smith, A.E. Friedrich, and H.L. Lovell. 1990. Acid Mine Drainage From Active and Abandoned Coal Mines in Pennsylvania: Water Resources in Pennsylvania. Chapter 32, Pennsylvania Academy of Science, Philadelphia, Pa.

LaRegina, J.A. 1988. The Mine Drainage Tunnels of the Eastern Middle Anthracite Field, *in* Bedrock and Glacial Geology of the North Branch Susquehanna Lowland and the Eastern Middle Anthracite Field of Northeastern Pennsylvania. Guidebook for the 53rd Annual Field Conference of Pennsylvania Geologists, pp. 63-74.

McNair, J.B. 1951. With Rod and Transit—The Engineering Career of Thomas S. McNair (1824-1901). Published by James B. McNair, Los Angeles, California.

Nasilowski, I.F. and T.D. Owen. 1998. Little Nescopeck Creek Watershed Rehabilitation Plan. Pa. Department of Environmental Protection, District Mining Operations, Pottsville District Office.

Pettyjohn, W.S. and R.J, Henning. 1979. Preliminary Estimate of Regional Effective Ground-Water Recharge Rates in Ohio. Ohio State University, Columbus, Ohio, Department of Geology and Mineralogy, Project Completion Report No. 552, 323 pp.

Taylor, L.E. 1997. Water Budget for the Spring Creek Basin. Susquehanna River Basin Commission Publication No. 184, 19 pp., 1 plate.

U.S. Army Corps of Engineers. 1998. Tranguch Gasoline Site Hazleton, Pa., Groundwater Model Report. Prepared for the U.S. Environmental Protection Agency Region III. 18 p., 43 figures.

Witmer, D.S. 1995. Portion of Jeddo Tunnel Acid Mine Drainage that is Surface Runoff Entering the Mines. Bloomsburg University senior research.

Wood, C.R. 1996. Water Quality of Large Discharges From Mines in the Anthracite Region of Eastern Pennsylvania. U.S. Geological Survey, Water Resources Investigations Report 95-4243, p 68.

APPENDIX

PRECIPITATION DATA FOR LONG-TERM STATIONS

Table A1. ***Tamaqua Precipitation for Period of Record, 1932-98*** *(in inches)*

Water Year	October	November	December	January	February	March	April	May	June	July	August	September	Total
1932	1.53	0.90	2.33	4.78	2.25	6.23	0.97	3.46	5.35	1.88	3.21	1.17	34.06
1933	8.33	6.67	1.83	2.00	2.79	6.18	6.52	5.75	3.65	5.96	14.93	10.46	75.07
1934	3.58	1.07	1.89	3.18	1.04	2.79	4.96	3.54	4.90	2.46	4.02	8.21	41.64
1935	1.81	6.09	3.52	2.35	1.99	2.58	3.77	1.36	7.53	10.55	2.77	3.16	47.48
1936	2.60	5.63	1.94	4.92	2.62	8.27	3.90	1.81	5.32	1.85	6.31	1.78	46.95
1937	3.17	2.53	5.63	6.00	3.50	1.96	6.32	2.09	3.47	4.51	7.70	1.45	48.33
1938	8.77	3.26	2.07	5.08	3.51	2.48	3.30	5.86	6.61	6.15	3.02	6.75	56.86
1939	2.49	4.26	5.36	4.03	4.73	3.98	4.53	1.20	3.60	1.83	4.24	3.79	44.04
1940	5.27	0.77	3.07	1.66	2.36	7.60	4.84	3.65	3.95	2.23	7.80	3.64	46.84
1941	2.79	4.74	2.63	2.97	1.57	1.94	2.04	1.37	3.54	4.03	5.05	0.99	33.66
1942	2.53	3.27	4.35	2.94	2.75	4.19	1.41	11.73	4.70	6.66	5.05	7.79	57.37
1943	4.89	3.24	6.03	2.04	2.17	2.60	2.82	7.47	4.57	3.32	3.75	0.39	43.29
1944	9.78	5.60	0.98	2.13	1.94	4.55	3.76	2.88	5.39	1.73	1.62	6.57	46.93
1945	1.87	3.52	3.51	3.33	1.95	2.53	4.76	5.75	4.13	10.64	3.90	6.53	52.42
1946	2.76	6.72	3.47	2.05	2.66	3.95	1.00	10.96	4.22	5.66	3.44	4.88	51.77
1947	3.94	1.00	2.32	3.62	1.48	3.74	4.31	8.98	4.73	14.82	3.58	3.34	55.86
1948	3.25	6.15	1.45	2.85	2.03	3.75	6.38	7.29	3.74	4.27	2.84	0.93	44.93
1949	2.79	6.95	6.12	3.47	3.02	1.66	5.46	4.40	2.11	4.01	5.07	4.47	49.53
1950	2.21	2.09	4.06	4.13	3.98	6.37	2.38	4.06	3.06	5.20	2.79	3.48	43.81
1951	3.99	7.10	7.00	5.70	5.75	5.91	3.53	2.18	3.83	8.35	4.30	4.74	62.38
1952	4.14	7.81	7.69	3.95	2.24	5.86	10.15	7.11	1.47	9.61	6.91	5.39	72.33
1953	1.03	9.23	5.55	5.88	3.24	5.42	5.99	7.87	2.57	2.95	1.12	4.22	55.07
1954	2.95	3.04	4.79	1.67	3.36	5.28	4.39	4.22	1.46	1.53	6.38	2.97	42.04
1955	3.74	4.15	3.55	0.79	3.20	4.40	2.70	3.02	2.99	0.62	18.22		47.38
1956	4.42		6.07	3.49		2.69		4.09	3.21	7.88	3.83	5.50	41.18
1957	3.10	2.18	4.52		2.65	1.70	6.87	2.24	5.89	1.24	2.14	2.46	34.99
1958	3.56	3.25		4.05	4.16	4.04	4.79	3.72	4.47	4.09	3.38	4.19	43.70
1959	3.74	3.58	0.90	3.00				1.59	5.29	4.18	3.16	3.15	28.59
1960	6.14	5.69	4.06	3.24	5.35	4.75	3.46	7.60	5.58	7.90	4.26	8.12	66.15
1961	1.90	2.09	1.50	2.87	3.62		3.31	3.86	7.61	5.46	5.36	1.46	39.04
1962	0.85	6.10	2.41	1.27		2.24	3.60	2.31	3.39	2.59	5.00	4.30	34.06
1963	4.36	3.40	3.95	2.40	2.38	3.20	1.10	3.63	1.88	3.00	1.83	2.58	33.71
1964	0.19	5.92	2.15	6.08	2.89	3.69	5.73	1.38	4.71	2.23	1.13	3.36	39.46
1965	1.17	2.98	4.14	2.08	4.00	2.61	2.72	1.57	0.60	2.66	5.77	3.49	33.79

Table A1. Tamaqua Precipitation for Period of Record, 1932-98** (in inches)**—Continued

Water Year	October	November	December	January	February	March	April	May	June	July	August	September	Total
1966	4.31	2.37	1.75	3.50	3.07	2.79	3.41	2.83	1.09	2.64	2.33	4.84	34.93
1967	2.93	4.27	3.03	1.98	1.48	5.58	3.36	5.67	2.96	5.28	4.07	2.89	43.50
1968	3.34	3.78	3.98	3.02	0.29	3.15	2.63	6.56	5.38	1.51	2.25	7.65	43.54
1969	2.62	3.48	3.05	1.72	1.39	2.55	4.20	3.39	2.98	8.77	4.78	2.32	41.25
1970	2.24	5.02	4.75	0.45	3.85	3.18	4.56	3.49	3.39	8.57	2.08	2.73	44.31
1971	5.59	7.14	1.24	2.05	6.08	3.20	0.94	4.47	2.71	7.12	6.73	5.05	52.32
1972	2.69	5.65	2.69	3.14	3.45	3.94	3.35	6.83	14.15	2.19	3.78	1.29	53.15
1973	2.57	9.63	6.59	4.41	3.07	4.25	5.53	5.22	6.88	2.32	6.56	7.34	64.37
1974	4.30	2.13	8.77	4.06	2.99	5.68	3.19	4.45	4.70	4.76	5.28	6.44	56.75
1975	1.14	2.94	5.69	5.51	3.81	4.89	2.86	4.32	7.13	9.24	3.89	8.14	59.56
1976	4.88	4.60	3.31	5.91	2.96	2.67	3.27	4.59	5.81	5.48	4.55	6.74	54.77
1977	9.41		1.75	1.16	2.58	8.45	4.91	2.79	3.83	3.15	3.39	6.65	48.07
1978	6.59	6.15	6.05	9.22	1.08	5.07	2.17	8.36	4.02	2.98	5.74	2.58	60.01
1979	4.50	2.84	4.03	11.42	3.87	3.48	4.93	6.51	2.64	3.92	4.71	8.79	61.64
1980	6.29	4.90	3.25	1.54	1.22	7.07	5.99	3.48	3.16	3.27	2.11	2.08	44.36
1981	2.89	3.15	1.40	1.21	10.59	1.41	4.06	5.90	7.53	4.72	2.33	4.35	49.54
1982	4.29	2.40	3.37	4.11	3.57	3.36	5.44	4.64	8.68	3.85	6.52	3.01	53.24
1983	2.18	3.29	3.30	2.69	4.28	4.80	13.33	5.70	8.33	2.67	1.69	2.25	54.51
1984	4.47	7.57	9.04	1.87	5.03	4.48	5.76	8.58	7.04	7.20	2.40	0.82	64.26
1985	2.65	4.32	3.25	1.13	2.40	2.31	1.75	4.28	4.39	4.15	4.86	4.96	40.45
1986	2.80	6.61	2.27	4.53	3.81	3.88	4.53	2.37	4.62	4.34	3.23	3.12	46.11
1987	2.69	5.73	4.61	3.52	0.79	2.58	5.95	2.04	5.12	5.71	4.99	11.55	55.28
1988	3.25	3.95	1.79	2.43	3.85	2.98	2.90	6.96	1.73	13.32	4.25	3.58	50.99
1989	2.77	4.27	1.17	2.44	2.39	3.00	1.38	11.80	7.11	4.65	1.91	4.26	47.15
1990	5.47	5.00	1.11	5.79	3.00	2.34	3.62	9.28	2.52	3.00	8.00	4.58	53.71
1991	7.64	3.66	9.29	2.64	1.48	5.36	3.34	3.38	2.00	3.60	4.78	2.54	49.71
1992	3.22	4.14	3.45	2.42	2.56	5.30	3.66	6.70	3.66	6.58		6.08	47.77
1993	3.86	7.04	3.24		2.12	6.08	10.71	1.96	4.02	3.82	5.72	6.50	55.07
1994	3.83	6.65	5.22	6.26	2.76	5.66	5.12	4.46	8.48	4.25	7.64	4.16	64.49
1995	0.84	6.72	2.48	4.30	1.79	1.82	2.36	3.55	6.18	5.18	1.50	2.61	39.33
1996	8.76	5.54	2.62	8.56	2.86		5.96	4.88	9.48	7.63	1.84	5.14	63.27
1997	7.34	4.54	8.58	3.72	1.99	4.20	2.30	3.70	3.16	4.64	6.22	4.76	55.15
1998	2.18	3.92	3.22	4.50	5.06	4.00	5.50	4.08	5.80	2.16	3.50	3.39	47.31
LTM Average	**3.79**	**4.53**	**3.79**	**3.56**	**3.01**	**4.04**	**4.23**	**4.73**	**4.63**	**4.85**	**4.51**	**4.38**	**49.17**

Table A2. ***Freeland Precipitation for Period of Record, 1931-89*** *(in inches)*

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
1931	1.79	2.28	4.10	3.92	6.31	2.64	5.92	2.20	3.39	1.76	1.16	2.66	38.13
1932	4.55	2.25	4.84	2.20	3.74	5.29	2.41	2.47	1.80	8.99	6.56	1.88	46.98
1933	2.00	3.30	4.87	5.00	4.06	2.89	6.31	11.30	6.51	3.80	1.69	2.60	54.33
1934	3.41	1.80	2.96	5.38	4.38	3.73	7.24	2.96	7.43	1.69	5.25	4.34	50.57
1935	2.92	2.73	2.97	3.77	2.15	5.52	8.32	3.53	3.29	1.19	6.35	2.24	44.98
1936	4.25	2.09	7.78	2.74	3.14	3.62	2.04	3.10	1.48	3.19	3.10	4.75	41.28
1937	5.52	3.52	2.31	4.81	3.77	3.58	3.68	6.60	1.70	9.50	3.74	1.80	50.53
1938	3.68	2.40	2.58	4.76	4.78	5.91	6.28	3.29	6.79	2.93	5.62	5.49	54.51
1939	3.51	4.31	4.12	4.45	1.79	2.74	1.42	4.14	1.94	3.72	1.39	2.98	36.51
1940	1.68	3.44	8.46	5.46	3.83	4.64	3.60	3.84	5.83	2.57	4.91	2.29	50.55
1941	2.19	0.91	2.55	2.02	1.69	5.47	6.26	4.48	1.15	2.19	3.76	4.46	37.13
1942	1.59	2.60	3.06	1.69	9.44	4.68	6.53	2.61	5.58	4.49	2.86	6.43	51.56
1943	2.70	2.55	3.14	2.27	5.84	3.41	3.14	2.74	0.36	9.84	5.41	0.87	42.27
1944	1.67	1.72	4.61	4.29	3.28	8.20	1.48	3.27	4.57	2.72	2.92	3.21	41.94
1945	3.36	2.29	2.37	4.09	4.48	3.82	10.14	3.50	5.62	2.46	5.94	4.26	52.33
1946	1.71	1.73	4.91	0.88	10.19	5.71	5.27	4.18	3.59	4.12	1.11	1.98	45.38
1947	3.74	1.64	3.12	4.67	11.84	3.91	15.32	2.77	2.14	1.23	3.13	2.53	56.04
1948	3.45	1.54	3.40	5.27	6.90	3.70	7.72	2.14	0.74	3.04	7.09	5.33	50.32
1949	3.47		1.59	4.76	5.66	1.85	4.01	4.38	3.93	1.41	1.43	4.69	37.18
1950	4.26	4.08	5.97	4.49		4.04			3.76	3.23	7.10	6.29	43.22
1951	4.58	3.76	4.15	1.61	3.31	2.61		1.71	2.22		8.34	6.25	38.54
1952	3.85	2.20	4.07	9.39	6.36	3.54	12.83		5.68	1.25	7.01	6.98	63.16
1953	6.87	2.88	5.35	4.92	6.49	2.23		1.40	5.81	3.50	3.45	4.66	47.56
1954	1.40	2.85	3.11	6.09	4.88	3.20	1.81	5.93	3.84	3.53	4.71	2.45	43.80
1955	1.25	3.25	3.13	2.27	2.29	5.47	0.86						18.52
1955								17.91	3.43		3.36	0.90	25.60
1956			2.90	2.73	4.02	3.91	5.61	3.79	6.59	4.42		6.07	40.04
1957	1.98				3.32	8.17	1.17	2.48	4.64	3.05	3.35	7.90	36.06
1958			3.68	4.30	3.24	3.33		2.70		3.54			20.79
1959				4.40	2.30	3.56			3.60	7.25		4.06	25.17
1960	2.40				7.78	4.68		7.77	7.53			1.84	32.00
1961		2.09		3.31		4.91		5.36	1.03				16.70
1962	1.27					1.86	3.30	7.84	4.09	5.88	1.58	1.26	27.08
1963			2.34							0.13			2.47
1964		3.67	1.39					2.88		1.81		3.62	13.37

Table A2. Freeland Precipitation for Period of Record, 1931-89 *(in inches)—Continued*

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
1965	3.37	1.83	2.42	1.79	2.40	2.51	1.29	6.40	4.47	4.32	2.51	1.22	34.53
1966	2.94	2.66	1.58	3.17		0.52	2.02	3.48	3.91		5.39	2.79	28.46
1967	1.61				6.24	1.84	4.44	6.04	3.33	3.83		2.62	29.95
1968		0.23		2.72	5.64	4.87	1.75	2.78	6.29	1.84	4.06	3.00	33.18
1969	1.31	0.99	2.27	4.71	2.75	6.25	9.02	3.92	2.12	1.60	3.90	7.96	46.80
1970	0.40	3.30	3.46	4.77	2.81	3.82	4.87	3.69	2.71	5.72	7.62	2.48	45.65
1971	2.02	6.17	2.63	0.98	4.29	1.58	4.66	5.49	5.10	3.56	5.82	2.23	44.53
1972	2.58	4.18	3.60	3.30	7.52	9.37	2.43	2.26	1.21	3.15	9.31	4.31	53.22
1973	3.97	1.77	3.67	6.47	6.80	8.74	2.57	8.04	5.68	4.13	2.32	7.90	62.06
1974	2.73	3.04	3.89	1.89	3.02	5.98	4.77	5.29	8.19	1.18	2.59	3.80	46.37
1975	2.70	3.41	4.07	2.63	3.71	9.56	8.49	4.05	6.36	3.79	3.66	1.89	54.32
1976	4.34	2.79	3.16	2.78	4.69		5.40	5.63	5.35	9.67		2.38	46.19
1977	1.89		5.95	4.55		2.48	4.15	2.76	7.49	6.54	3.51		39.32
1978		1.33											1.33
1979							2.20	5.09	8.06	4.81	4.08		24.24
1980	0.64	1.07		4.50	3.42	3.47	2.91	2.54	1.69	2.51	3.15	0.71	26.61
1981	1.15	7.28	1.24	3.85	4.42	6.86	3.62	2.12	3.62	3.98	2.32	2.58	43.04
1982	2.40	2.66	1.19	6.78	3.12	6.08	3.50	5.12	3.01	2.46	3.27	2.36	41.95
1983	1.96	3.88	4.12	12.35	6.09	7.24	1.37	3.57	2.60	4.33	6.85	8.02	62.38
1984	1.56	4.35		6.94	8.22	5.38	5.15	3.51	0.77	2.83	3.97	2.56	45.24
1985		2.28	1.72	1.59	4.90	6.11	4.50	5.77	6.82	2.48	7.18	2.51	45.86
1986	4.38	3.62	3.57	5.12	2.95	5.85	4.35	5.66	2.63	2.74	4.79	3.67	49.33
1987	3.94	0.70	1.68	6.00	1.47	2.06	5.99	7.75	10.43	3.02	5.29	2.11	50.44
1988	2.97		2.52		6.83	1.74	13.32	3.76	3.21	3.01	4.27		41.63
1989	0.31				7.96	7.85	2.75	2.68					21.55
LTM AVERAGE	**2.74**	**2.73**	**3.46**	**4.14**	**4.81**	**4.50**	**4.86**	**4.46**	**4.17**	**3.65**	**4.34**	**3.61**	**39.91**

Blank cells are insufficient or no data.

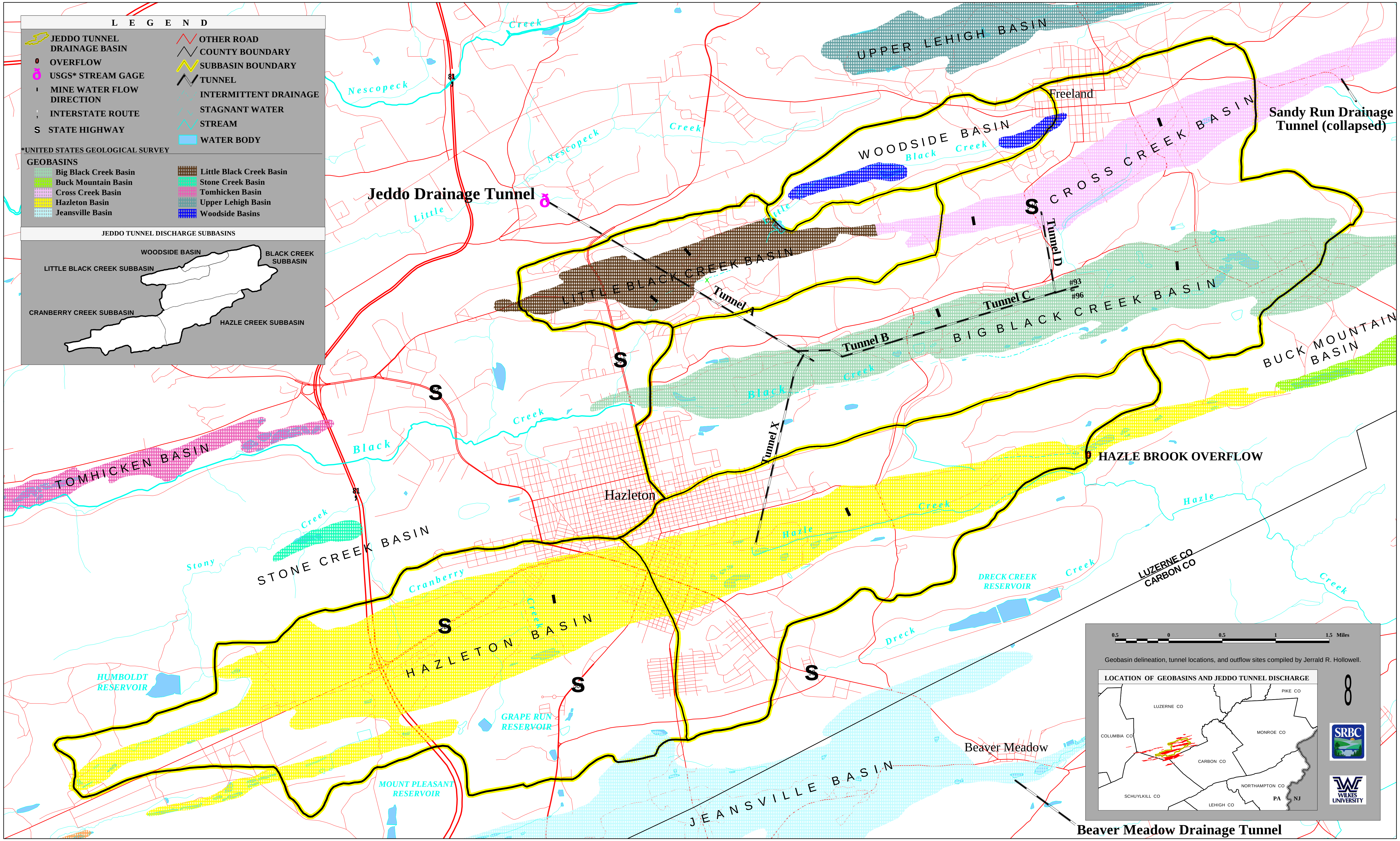

Plate 1. Jeddo Tunnel Drainage System

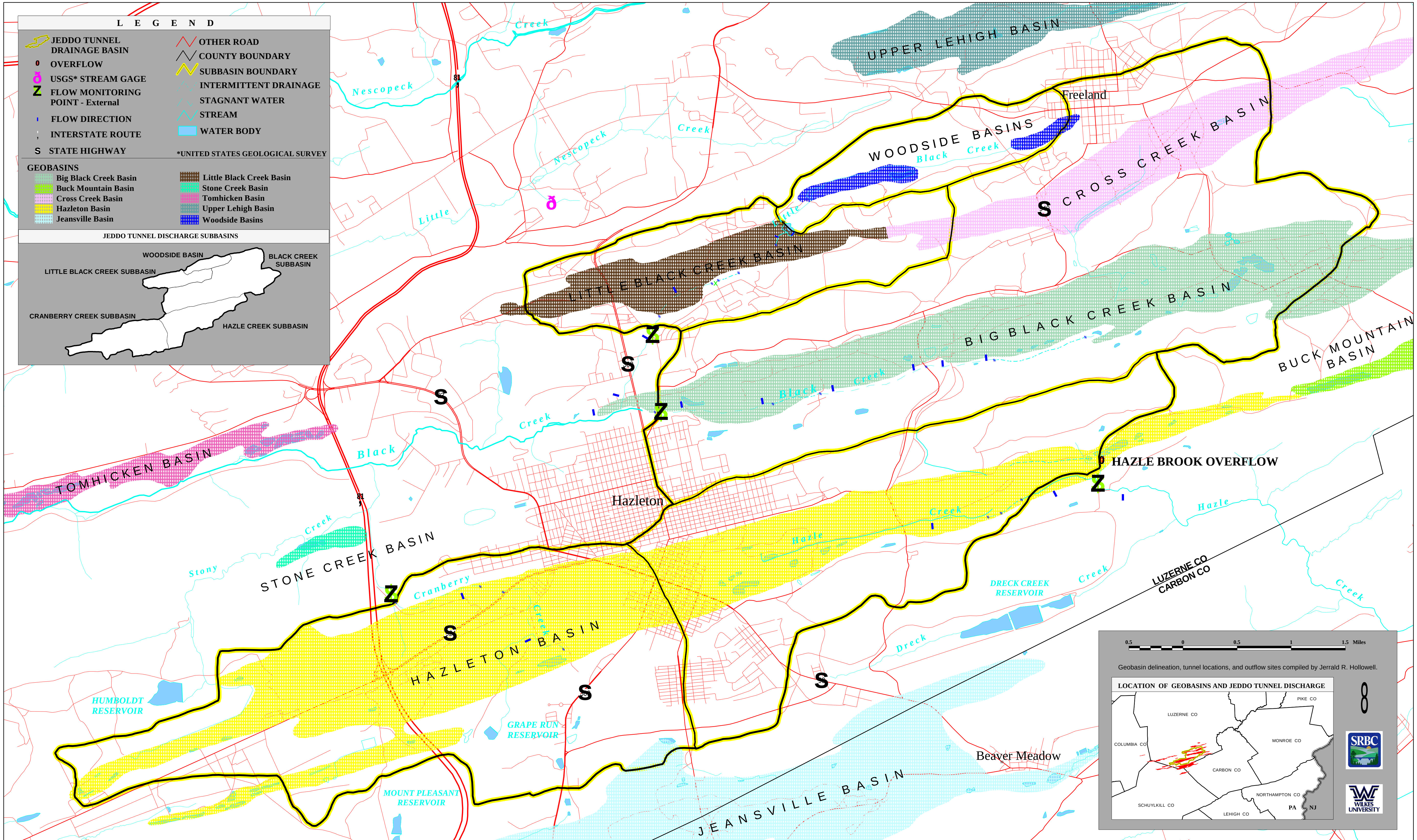

Plate 2. Locations of Flow Measurements for Streams Leaving the Jeddo Basin