WICONISCO CREEK WATERSHED ASSESSMENT AND PLAN

Publication No. 206

June 1999

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This report is prepared in cooperation with Pennsylvania Department of Environmental Protection, Bureau of Watershed Conservation, under Grant ME96353.

SUSQUEHANNA RIVER BASIN COMMISSION

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**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).*

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PREFACE

In 1996, the Pennsylvania Department of Environmental Protection, Bureau of Watershed Conservation contracted the Susquehanna River Basin Commission to conduct a comprehensive two-part study of the Wiconisco Creek Watershed. The first part, which was completed in 1998, assessed the water quality, physical habitat, and aquatic biological conditions of the Wiconisco Creek Watershed in Dauphin and Schuylkill Counties, Pennsylvania. The findings of that part of the study are available in the report, Water Quality and Biological Assessment of the Wiconisco Creek Watershed.

This report, Wiconisco Creek Watershed Assessment and Plan, provides the findings from the second part of the study. The primary objectives of this phase of the project were to prepare a comprehensive, integrated assessment of the water quality conditions of the Wiconisco Creek Watershed and to develop a strategy for water quality restoration and protection of the watershed.

The findings in this report will be valuable for developing a comprehensive watershed-scale database that can serve as a baseline for comparison in future water quality studies.

The author would like to acknowledge and give special thanks to several individuals for their support and interest in this project.

Dauphin County Conservation District

- Charles McGarrell
- John Orr

Eastern Pennsylvania Coalition for Abandoned Mine Reclamation

- Robert Hughes
- Ed Wytovich

Hedin Environmental

- Dr. Robert Hedin

Schuylkill County Conservation District

- Craig Morgan

Susquehanna River Basin Commission (current and former employees)

- Scott Bollinger
- Harry Campbell
- Robert Edwards
- Donna Fiscus
- David Heicher
- Charles McGarrell
- Susan Obleski
- JoAnn Painter
- Duane Peters
- Jennifer Rowles
- Darryl Sitlinger
- Charles Takita
- Carrie Traver

Wiconisco Creek Restoration Association

- Bill Nace
- Dale Schlylaske
- Doc Tallon
- George Whitcomb

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ABSTRACT

Problems defined in the Water Quality and Biological Assessment of the Wiconisco Creek Watershed (Stoe, 1998) were used as a basis for targeting areas of the Wiconisco Creek Watershed for remediation activities. Three sites (Porter Tunnel, Big Lick Tunnel, and the Lykens Tunnel discharges) were identified as having the highest priority for treatment in the area of the watershed affected by coal mining activities.

The Susquehanna River Basin Commission (SRBC) consulted with Dr. Robert Hedin, Hedin Environmental on treatment alternatives. Hedin Environmental (specialists in contaminated coal mine drainage cleanup) recommended practical solutions, including construction of wetlands for precipitation of metals from mine water in the watershed. Low pH in the Rattling Creek Watershed is a result of acid precipitation, and remediation plans in this watershed should include buffering the acidity of the stream with limestone ($CaCO_3$) sand. Agricultural impacts in the watershed were addressed based on the Best Management Practices (BMPs) defined in Pennsylvania's Chesapeake Bay Nutrient Reduction Strategy (1996).

INTRODUCTION

Wiconisco Creek has its headwaters in western Schuylkill County, Pa., and flows westward to its terminus, emptying into the Susquehanna River at Millersburg, in northern Dauphin County. Wiconisco Creek is a 42-mile stream located approximately 20 miles north of Harrisburg, Pa. The creek and its tributaries drain a 116-square-mile area (74,418 acres) that is the Wiconisco Creek Watershed. The watershed is in the Appalachian Mountain Section of the Valley and Ridge Physiographic Province in northern Dauphin and western Schuylkill Counties, Pa. Table 1 and Plate 1 show municipalities that are totally or partially in the Wiconisco Creek Watershed.

Table 1. Municipalities in the Wiconisco Creek Watershed

County	Township	Borough
Dauphin	Upper Paxton Jefferson Williams Rush Lykens Wiconisco Jackson Washington Mifflin	Millersburg Berrysburg Elizabethville Gratz Lykens Williamstown
Schuylkill	Porter Tremont	Tower City

The watershed is shown on the following U.S. Department of the Interior, Geologic Survey (USGS) 7.5 Minute Topographic Quadrangle Maps: Millersburg, Elizabethville, Lykens, Tower City, and Pine Grove. Major streams entering Wiconisco Creek include East Branch Rattling Creek, West Branch Rattling Creek, Bear Creek, and Little Wiconisco Creek (Plate 1).

PURPOSE

Wiconisco Creek is impacted by various nonpoint source pollutants (NPS) that range from acid and alkaline mine drainage, to coal fines, urban runoff, and nutrient and sediment loads from agricultural operations. The most comprehensive studies of the water quality and biological conditions of the Wiconisco Creek Watershed were those conducted by the Pa.

Department of Environmental Protection, (formerly Environmental Resources) in 1977 and 1983. Since these studies, a variety of NPS abatement and restoration projects have been completed, and others have been initiated within the watershed. However, no comprehensive study has been conducted to document the water quality, instream habitat, and biological conditions of the watershed since many of these projects were completed and/or initiated. Furthermore, anticipating the future developmental and recreational demands on the watershed due to greater access from major urban centers, NPS pollution problems need to be mitigated in the Wiconisco Creek Watershed. The primary objective of this project was to assess the existing environmental health of the watershed and develop a comprehensive watershed implementation plan for managing NPS pollution. This watershed assessment and implementation plan should be viewed as the first phase of a long-range commitment to improving the overall environmental health of this high priority watershed (for NPS pollution), located in the Susquehanna and Chesapeake Bay drainage basins.

PROJECT SETTING AND WATERSHED INFORMATION

Hydrologic Unit Code

The watershed is located in the U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS) and USGS Water Resources Council Hydrologic Unit 02050301-090.

Endangered Species

According to a report published by the Pennsylvania Department of Environmental Protection (Pa. DEP), northeastern bullrush (Scirpus ancistrochaelus), a species listed as endangered by both the Commonwealth of Pennsylvania and the U.S. Fish and Wildlife Service (USFWS), is found at the Bear Puddles, a series of wetland areas at the headwaters of Doc Smith Run. Doc Smith Run is a tributary to West Branch Rattling Creek (Plate 2). The current Special Protection Waters selection criteria characterize Rattling Creek and its tributaries as waters of substantial ecological significance (Pa. Department of Environmental Resources, 1994).

State and Federal Lands

State and federal lands within the Wiconisco Creek Watershed include the Wieser State Forest (9.67 square miles) and Pennsylvania State Game Land numbers 264, 210, and 211 (20.98 square miles). There is a total of 30.65 square miles (19,616 acres) of state land in the watershed. Plate 3 shows the distribution of state land in and around the Wiconisco Creek Watershed.

School Districts

Five school districts are located within the Wiconisco Creek Watershed: Pine Grove Area; Williams Valley; Upper Dauphin Area; Halifax Area; and Millersburg Area (Plate 1).

Physiography

The headwaters (Upper Basin) of Wiconisco Creek are located between Big Lick Mountain to the north and Broad Mountain to the south (Figures 1 and 2). The middle reach (Bear Creek Basin, Rattling Creek Basin, Middle Basin, and Gratz Creek Basin) of the creek is bounded on the north by both Bear and Short Mountains, while Berry, Broad, and Peters Mountains serve as the southern border. Berry Mountain continues as the southern boundary for the lower reach (Lower Basin and Little Wiconisco Creek Basin), and Mahantango Mountain borders the northwestern edge of the basin.

Elevation within the watershed ranges from 380 feet at the mouth of Wiconisco Creek to 1,785 feet at the top of Big Lick Mountain. The upper section of the main stem of Wiconisco Creek is generally straight and flat and is characterized by wetlands and slow pool/run habitats. Two significant tributaries (Bear Creek and Rattling Creek) enter Wiconisco Creek near the western end of the Upper Basin at Lykens Borough. Bear Creek drains southward through Bear Valley from its headwaters in Bear Swamp, and Rattling Creek enters Wiconisco Creek from

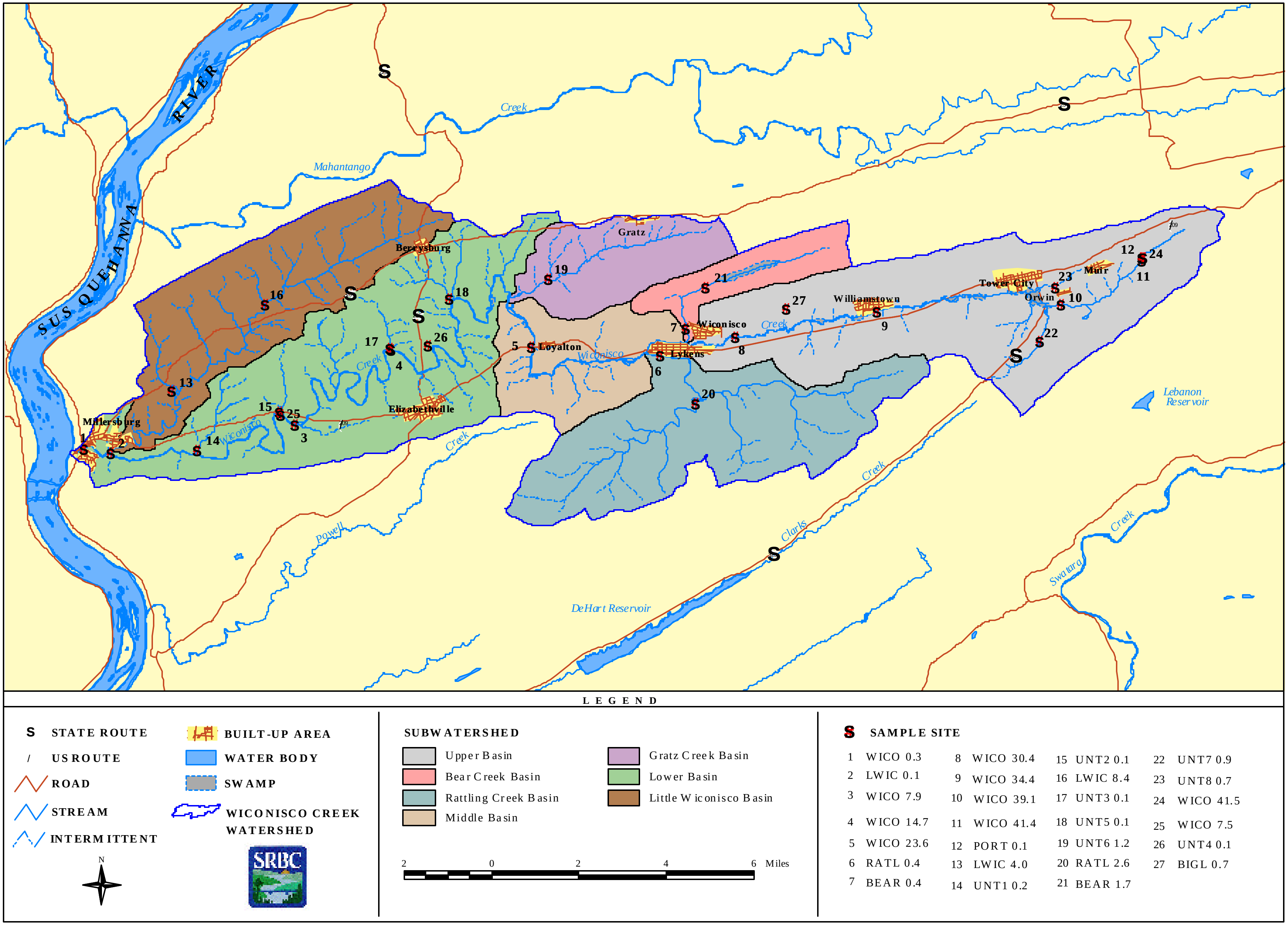

Figure 1. Susquehanna River Basin Commission Sample Sites and Subwatersheds in the Wiconisco Creek Watershed

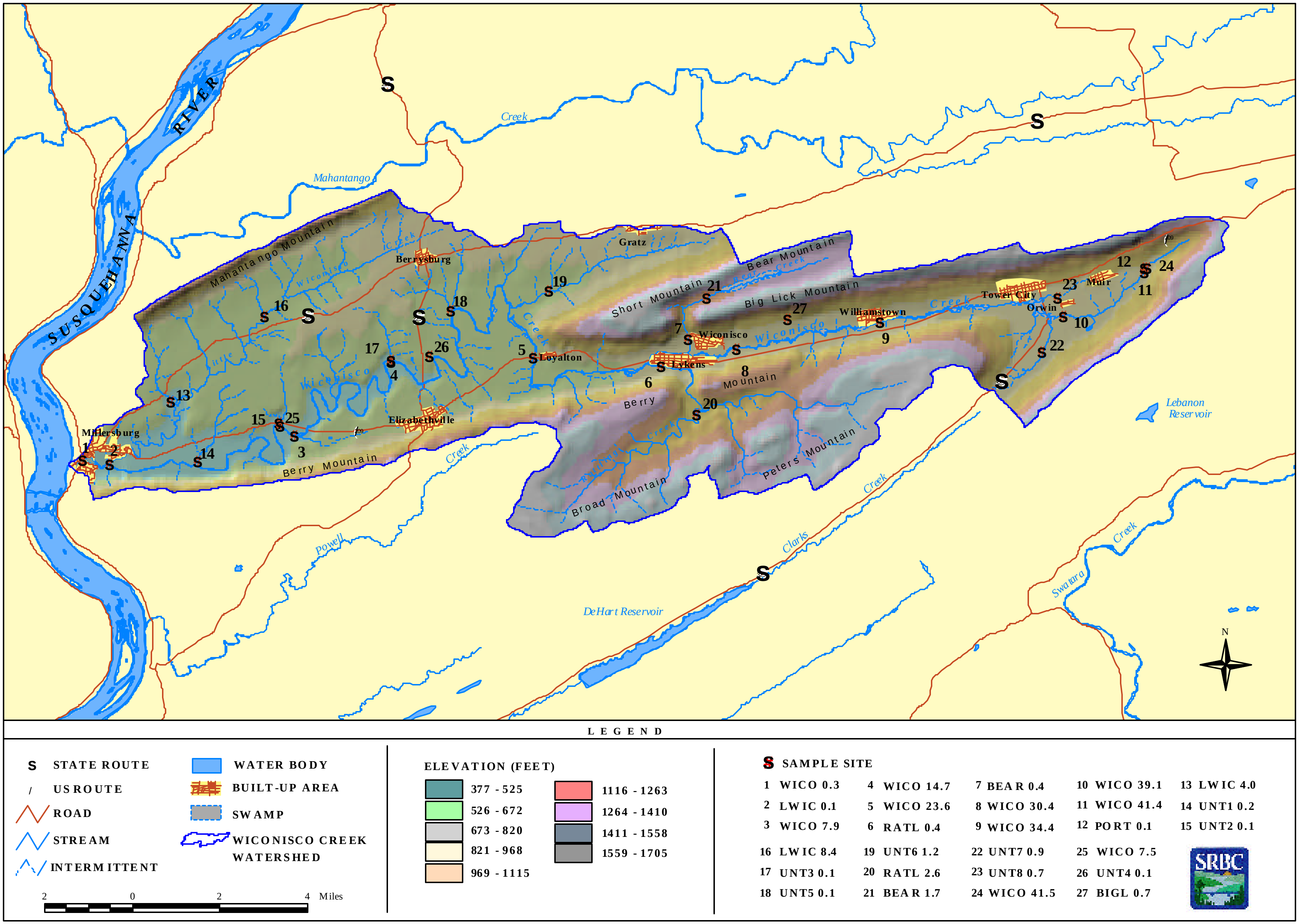

Figure 2. Susquehanna River Basin Commission Sample Sites and Topography in the Wiconisco Creek Watershed

its beginnings in Broad and Peters Mountains. Wiconisco Creek passes between Short Mountain and Berry Mountain, just east of the borough of Lykens. At this point, the characteristics of the stream change. The stream is still relatively flat, but without the confinements of the mountains, the stream becomes highly sinuous. There are many small, unnamed tributaries that add to the flow of Wiconisco Creek between Lykens and the mouth at Millersburg. The largest of these unnamed streams drains the area to the west of Short Mountain near the borough of Gratz. The last major tributary, Little Wiconisco Creek, drains a large area southeast of Mahantango Mountain, and enters Wiconisco Creek near Millersburg (Figure 2).

Flood Plains

The low-flat topography present in many parts of the Wiconisco Creek Watershed makes it an area prone to flooding. Population centers most likely to be affected by flood impacts appear to be Lykens and Millersburg. Figure 3 shows areas in the 100-year flood plain (Pa. Department of Environmental Protection, 1996).

Soils

Based on the U.S. Department of Agriculture, Soil Conservation Service (USDA SCS) 1:250,000 scale State Soil Geographic (also known as STATSGO) data, four soil associations are found in the Wiconisco Creek Watershed (U.S. Department of Agriculture, 1994) (Figure 3, Table 2).

***Table 2. Soil Associations and Acreage in the Wiconisco Creek Watershed** (USDA SCS)*

Soil Association	Acres in Watershed
Duncannon-Urban Land-Chavies	49
Hazleton-Dekalb-Buchannan	34,128
Leck-Kill-Meckesville-Calvin	35
Uderthents-Dekalb-Hazleton	40,205

The main stem of Wiconisco Creek, and most of the developed areas of the watershed, lie in the Uderthents-Dekalb-Hazleton Association. These soils are characterized as deep to shallow, predominantly well drained, gently sloping, and having a shaly, silt loam subsoil in upland areas between mountains. Mountainous areas on the outskirts of the basin are composed of the Hazleton-Dekalb-Buchannan Association. This association has moderately deep, gently sloping to very steep soils that have a channery sandy loam to channery loam subsoil on upper mountain slopes and ridges. The Duncannon-Urban Land-Chavies and Leck-Kill-Meckesville-Calvin Soil Associations are present in such insignificant proportions (less than 1 percent of the watershed per association) that the influence from these soils on water quality is negligible (U.S. Geological Survey, 1986).

Geology

The Wiconisco Creek Watershed is underlain with carboniferous rocks that originated between the Pennsylvanian and Lower Mississippian Periods, approximately 320 million years ago. These rocks consist of sandstones, shales, conglomerates, and anthracite coal, as explained below and located on Figure 4. Mining of coal and the disturbance of ferric-bearing shales has resulted in water quality degradation in the upper part of the watershed.

Llewellyn Formation

The Llewellyn Formation consists of gray, fine to course-grained sandstone, siltstone, shale, and conglomerate and anthracite coals. Coal seams are the most persistent units within the Llewellyn Formation. Large, lateral changes in thickness and lithology characterize the intervening strata and are estimated to be between 1,200 and 1,800 feet thick. This formation is the youngest in the watershed, originating in the Pennsylvanian Period (approximately 320 million years ago).

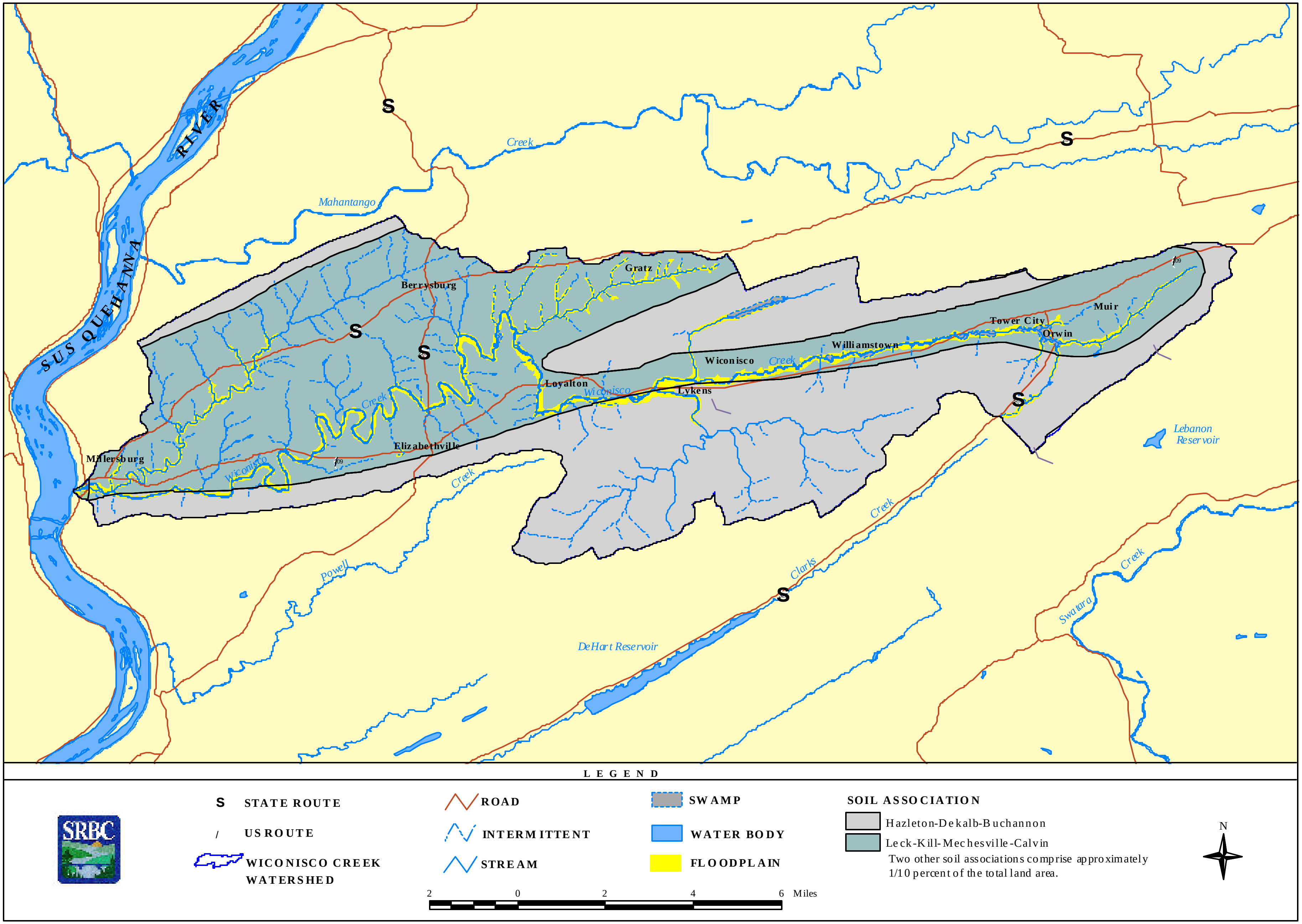

Figure 3. Soil Associations and 100-Year Flood Plains in the Wiconisco Creek Watershed

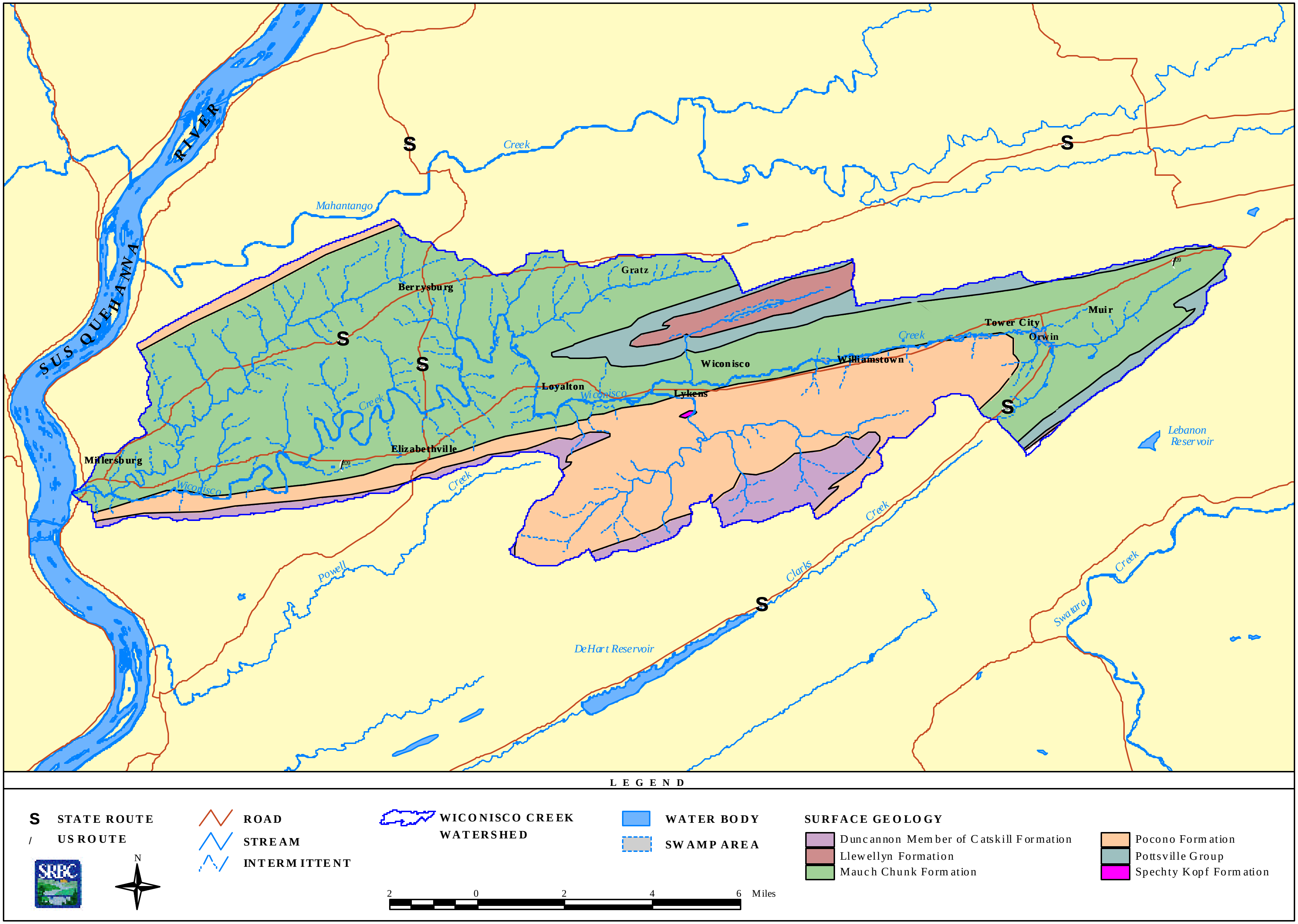

Figure 4. Surface Geology in the Wiconisco Creek Watershed

Pottsville Group (Tumbling Run, Schuylkill, and Sharp Mountain members)

The Pottsville Group consists of gray conglomerate, sandstone, sandstone, siltstone, and some anthracite coal. This formation is estimated to be 275 to 800 feet thick (Taylor and Werkheiser, 1984; Sanders and Thomas, 1973).

Mauch Chunk Formation

The Mauch Chunk Formation consists of interbedded brownish-gray to grayish-red siltstone, claystone, and brownish-gray to pale-red, poorly cemented sandstone. Beds of light-olive-gray mudstone and sandstone also are present in the lower part of the formation. This formation is estimated to be 3,700 to 4,500 feet thick (Taylor and Werkheiser, 1984; Sanders and Thomas, 1973).

Pocono Formation

The Pocono Formation consists of light gray to medium dark gray sandstone and minor siltstone. The Pocono Formation is generally found along the ridges of Berry Mountain. This formation is 1,100 to over 1,700 feet thick (Taylor and Werkheiser, 1984; Sanders and Thomas, 1973).

Spechty Kopf Formation

The Spechty Kopf Formation consists of light- to olive-gray, cross-bedded sandstone and siltstone formed during the Mississippian Age (approximately 350 million years ago) (Taylor and Werkheiser, 1984; Sanders and Thomas, 1973).

Duncannon Member of the Catskill Formation

The Duncannon Member of the Catskill Formation consists of a succession of grayish-red sandstone, siltstone, and shale, some sandstone and conglomerate, and was formed in the Devonian Age (approximately 400 million years ago) (Figure 4) (Taylor and Werkheiser, 1984; Sanders and Thomas, 1973).

Land Use

Agriculture and forest are the dominant land uses (96 percent) in the Wiconisco Creek Watershed. The predominant areas for agriculture are in the Lower Basin and the Little Wiconisco Creek Basin, although there is some agricultural land in the Upper Basin. Woodlands dominate mountainous areas on the edge of the drainage basin and coal mining is present in headwater areas. The majority of the urban or built-up land is concentrated in the upper half of the basin between the mountains. (See Plate 3 and Table 3.)

Ecoregion

Ecoregions and subecoregions are areas of relative homogeneity based on environmental

Table 3. Land Use Distribution in the Wiconisco Creek Watershed

Land Use	Square Miles	Acres	Percent of Watershed
Residential	2.86	1,830.4	2.46
Commercial and Services	0.50	316.8	0.43
Mixed Urban or Built-up Land	0.21	133.8	0.18
Other Urban or Built-up Land	0.02	11.5	0.02
Cropland and Pasture	45.93	29,395.8	39.48
Deciduous Forestland	66.11	42,307.8	56.82
Evergreen Forestland	0.19	122.2	0.16
Nonforested Wetland	0.08	49.3	0.07
Strip Mines, Quarries, and Gravel Pits	0.27	175.4	0.24
Transitional Areas	0.17	106.9	0.14
Total	**116.34**	**74,449.9**	**100.00**

factors such as soils, vegetative cover, climate, geology, physiography, land use, wildlife, and hydrology. Because these environmental factors contribute to the ambient water quality and biological conditions, subecoregions have been used as a tool for assessing the best attainable biological and water quality conditions on a regional basis (Wood and others, 1996). Subecoregions are a more finely defined unit within an ecoregion and are indicated by a letter following the ecoregion number.

There are three subecoregions in the Wiconisco Creek Watershed: 67b; 67c; and 67e (Figure 5). Subecoregion 67b (Northern Shale Valleys) covers the lowland areas, including the valley floor in the headwaters of the Upper Basin and most of the basin to the west of Loyalton. This subecoregion is characterized by rolling valleys and low hills that are underlain mostly by shale, siltstone, and fine-grained sandstone. The underlying bedrock is impermeable, and the resulting surface streams are large. Streams in this ecoregion commonly have high turbidity and degraded habitat because the soil is susceptible to erosion. Appalachian oak forests are the most common natural vegetation on steep sites. Farming is the dominant land use in most of this subecoregion.

Subecoregion 67c (Northern Sandstone Ridges) encompasses the mountain areas in the Wiconisco Creek drainage basin. This ecoregion is characterized by high, steep, forested ridges with narrow crests. The streams in these areas have high gradients and flow through narrow valleys. Mountain streams in this area have low buffering capacity and are subject to acidification. Appalachian oak forests dominate this subecoregion.

Subecoregion 67e (Anthracite) is an area that has been extensively disturbed by anthracite coal mining and urban-industrial development. Landforms, soils, and vegetation have all been impacted by mining operations and subsequent runoff. Streams tend to be very acidic and have high turbidity. The natural forests in this area were predominantly Appalachian oak and other hardwoods, but cherry and birch are recolonizing some of the mined areas.

Socioeconomics

The Wiconisco Creek Watershed is largely rural, with small boroughs and villages. The estimated population of the watershed in 1990 was 18,435. The population of this area is expected to increase by only 70 persons by the year 2000, according to estimates from the U.S. Bureau of Census (Table 4). With the completion of the Route 322 expansion project, greater growth is expected as local residents will have better access to the metropolitan Harrisburg area.

Farming, which has been present within the watershed for over 250 years, is one of the major economic bases within the Wiconisco Creek Watershed today. However, the scope of information is limited, since a county-level farming inventory has not been conducted in Dauphin County. Mennonite and Amish farms populate the western part of the watershed, although the actual numbers have not been documented.

The percentage of families below poverty level in the Wiconisco Creek Watershed is 5.6 percent, which is low compared to the national average of 13.3 percent. The minority population is very low, accounting for only 0.9 percent of the total watershed population.

Point Sources

The Wiconisco Creek Watershed has a number of point source discharges that could potentially influence water quality and aquatic life. Table 5 lists permitted point source discharges. Figure 6 identifies the location of point source discharges in the watershed and shows water and sewer service areas.

Fisheries

The Commonwealth of Pennsylvania classifies streams in Chapter 93 of the Pennsylvania Code. *(Text continued on page 18.)*

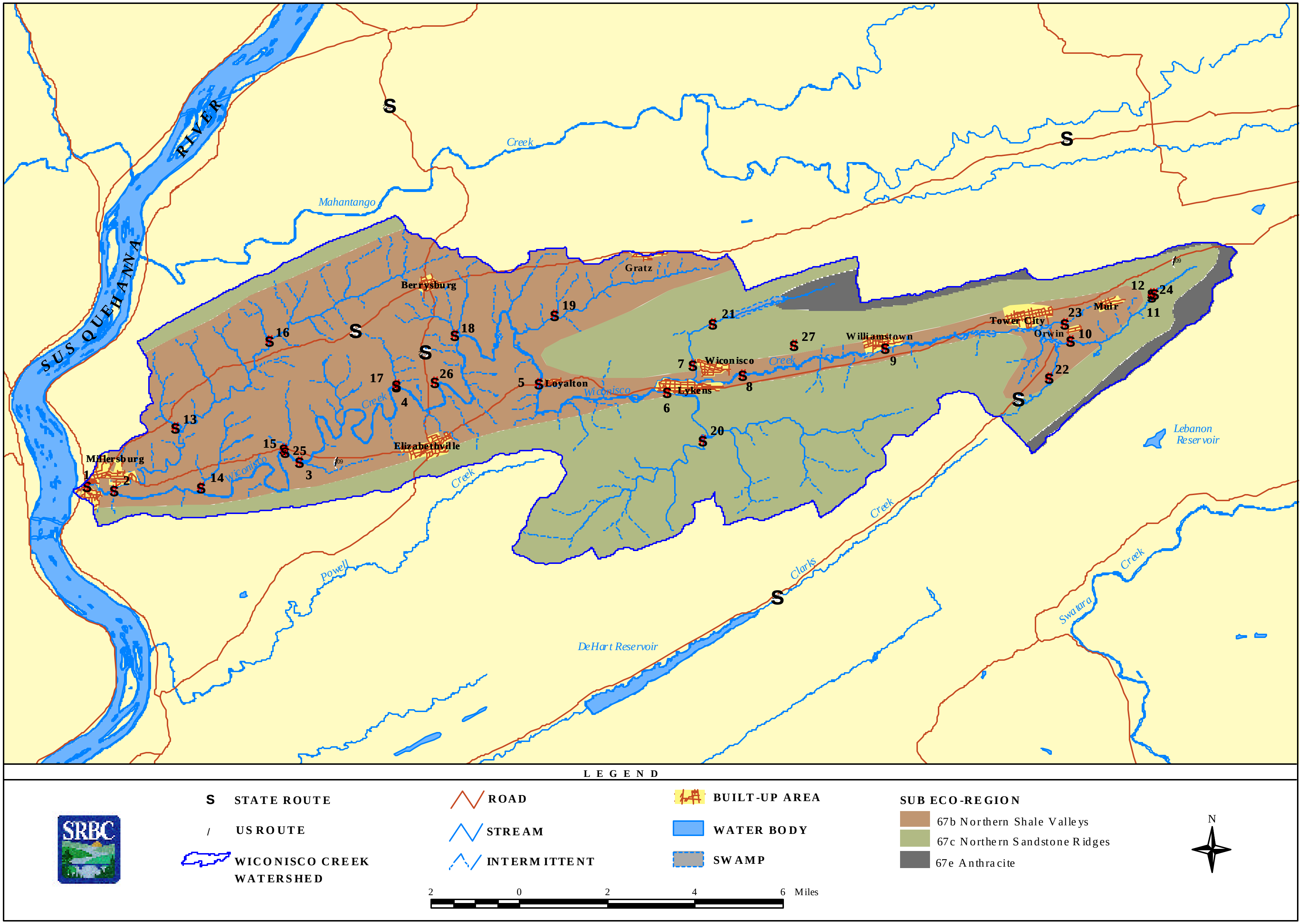

Figure 5. Subecoregions in the Wiconisco Creek Watershed

Table 4. Socioeconomics in the Wiconisco Creek Watershed

Municipality	Percent of Municipality in the Watershed	Wiconisco Creek Watershed Municipality Population				Family Household Characteristics					Non Family Households Total
		1970	1980	1990	2000	All Households	Total Family Households	Married Couple	Male Householder/ No Wife	Female Householder/ No Husband	
Berrysburg Borough	100.00	443.0	447.0	376.0	356.0	137.0	104.0	87.0	9.0	8.0	33.0
Elizabethville Borough	100.00	1,629.0	1,531.0	1,467.0	1,420.0	585.0	401.0	333.0	23.0	45.0	184.0
Gratz Borough	72.45	489.0	491.2	504.3	516.6	213.0	147.8	131.9	2.9	13.0	65.2
Jackson Township	41.89	484.2	656.8	752.8	853.7	257.6	211.5	186.0	9.2	16.3	46.1
Jefferson Township	32.87	53.9	111.8	126.6	142.0	46.0	35.5	31.9	3.0	0.7	10.5
Lykens Borough	100.00	2,506.0	2,181.0	1,986.0	1,822.0	852.0	557.0	450.0	30.0	77.0	295.0
Lykens Township	30.52	304.3	347.4	377.9	411.5	120.9	103.2	90.4	5.5	7.3	17.7
Mifflin Township	74.81	355.3	413.7	505.7	591.7	160.1	139.9	128.7	4.5	6.7	20.2
Millersburg	55.32	1,700.5	1,532.3	1,509.7	1,450.5	683.2	416.6	328.6	18.3	69.7	266.6
Porter Township	63.14	1,594.3	1,637.2	1,616.4	1,630.3	0.0	0.0	0.0	0.0	0.0	0.0
Rush Township	8.10	13.0	17.2	16.3	17.3	6.5	4.7	4.3	0.1	0.3	1.8
Tower City	100.00	1,774.0	1,667.0	1,518.0	1,425.0	0.0	0.0	0.0	0.0	0.0	0.0
Tremont Township	10.65	26.8	30.8	31.6	32.4	0.0	0.0	0.0	0.0	0.0	0.0
Upper Paxton Township	56.20	1,527.5	1,930.4	2,068.1	2,223.8	726.6	571.0	502.4	23.6	45.0	155.7
Washington Township	100.00	1,114.0	1,734.0	1,816.0	1,915.0	642.0	534.0	475.0	17.0	42.0	108.0
Wiconisco Township	97.81	1,438.7	1,531.7	1,341.9	1,321.4	503.7	398.1	326.7	19.6	51.8	105.6
Williams Township	79.60	752.2	822.3	912.2	999.0	353.4	265.1	215.7	17.5	31.8	88.4
Williamstown Township	100.00	1,919.0	1,664.0	1,509.0	1,379.0	645.0	426.0	337.0	22.0	67.0	219.0
TOTAL		18,124.7	18,746.8	18,435.5	18,507.2	5,932.0	4,315.4	3,628.6	205.2	481.6	1,616.8

Source: U.S. Bureau of Census (1990)

Table 4. Socioeconomics in the Wiconisco Creek Watershed —Continued

Municipality	Percent of Municipality in the Watershed	Summary of General Income Characteristics						
		Total Persons	Total Families	Per Capita Income	Median Family Income	Median Household Income	Persons Below Poverty Level	Families Below Poverty Level
Berrysburg Borough	100.00	382.0	103.0	11,237.0	29,750.0	24,464.0	42.0	7.0
Elizabethville Borough	100.00	1,467.0	399.0	12,014.0	30,809.0	24,200.0	115.0	17.0
Gratz Borough	72.45	512.9	144.9	11,744.2	22,292.2	15,999.2	36.2	5.8
Jackson Township	41.89	752.8	213.6	5,350.6	14,661.5	13,993.8	41.1	8.0
Jefferson Township	32.87	133.8	32.2	3,901.6	12,163.6	11,506.1	9.5	2.6
Lykens Borough	100.00	1,986.0	558.0	11,416.0	30,988.0	22,562.0	207.0	38.0
Lykens Township	30.52	375.8	102.3	3,032.6	8,726.7	8,127.2	34.2	6.7
Mifflin Township	74.81	510.9	138.4	7,976.5	23,036.4	22,375.2	47.9	6.7
Millersburg	55.32	1,509.7	416.6	7,184.3	17,122.9	12,558.6	152.7	31.0
Porter Township	63.14	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rush Township	8.10	16.3	4.2	957.2	2,227.6	1,721.3	1.0	0.2
Tower City	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tremont Township	10.65	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upper Paxton Township	56.20	2,068.1	575.5	6,656.2	18,056.1	16,663.5	128.7	20.2
Washington Township	100.00	1,816.0	521.0	12,684.0	34,620.0	31,250.0	124.0	26.0
Wiconisco Township	97.81	1,341.9	403.9	10,365.6	29,839.8	26,664.1	113.5	27.4
Williams Township	79.60	912.2	265.1	9,343.3	26,969.6	24,003.7	91.5	17.5
Williamstown Township	100.00	1,509.0	432.0	10,307.0	27,303.0	22,321.0	147.0	27.0
TOTAL		15,294.4	4,309.7	124,170.1	328,566.4	278,409.7	1,291.3	241.1

Source: U.S. Bureau of Census (1990)

Table 4. Socioeconomics in the Wiconisco Creek Watershed —Continued

Municipality	Percent of Municipality in the Watershed	Race and Hispanic Origin Dauphin County						
		All Persons	White	Black	American Indian, Eskimo, or Aleut	Asian or Pacific Islander	Other Race	Hispanic Origin (of any race)
Berrysburg Borough	100.00	376.0	374.0	1.0	1.0	0.0	0.0	0.0
Elizabethville Borough	100.00	1,467.0	1,455.0	3.0	4.0	4.0	1.0	2.0
Gratz Borough	72.45	504.3	504.3	0.0	0.0	0.0	0.0	0.7
Jackson Township	41.89	752.8	746.5	2.5	1.7	0.0	2.1	5.4
Jefferson Township	32.87	126.6	126.2	0.0	0.0	0.3	0.0	1.0
Lykens Borough	100.00	1,986.0	1,967.0	4.0	0.0	12.0	3.0	10.0
Lykens Township	30.52	377.9	376.1	0.3	0.6	0.9	0.0	1.5
Mifflin Township	74.81	505.7	505.7	0.0	0.0	0.0	0.0	3.0
Millersburg	55.32	1,509.7	1,506.3	1.7	0.6	1.1	0.0	5.5
Porter Township	63.14	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rush Township	8.10	16.3	16.2	0.0	0.1	0.0	0.0	0.0
Tower City	100.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tremont Township	10.65	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Upper Paxton Township	56.20	2,068.1	2,048.4	3.4	0.0	12.9	3.4	2.8
Washington Township	100.00	1,816.0	1,813.0	1.0	0.0	2.0	0.0	7.0
Wiconisco Township	97.81	1,341.9	1,339.0	0.0	2.0	1.0	0.0	8.8
Williams Township	79.60	912.2	901.9	2.4	1.6	0.8	5.6	5.6
Williamstown Township	100.00	1,509.0	1,505.0	0.0	0.0	4.0	0.0	5.0
TOTAL		15,269.5	15,184.6	19.3	11.6	39.0	15.1	58.3

Source: U.S. Bureau of Census (1990)

Table 5. Permitted Point Source Discharges in the Wiconisco Creek Watershed

Facility	NPDES	Type	Latitude	Longitude
AMP Inc./Williamstown	PA0010294	IW	40°34’42”	76°37’16”
Bendar, Connie	PA0087203	SN	40°33’58”	76°48’53”
Berrysburg Municipal Authority	PA0080900	SP	40°36’15”	76°48’42”
Dauphin Meadows, Inc.	PA0080187	IW	40°32’52”	76°52’30”
Elizabethville Borough Authority	PA0037737	SP	40°33’38”	76°48’50”
Metal Industries Inc. of California	PA0086495	IW	40°36’27”	76°43’49”
Millersburg Area Authority	PA0085570	IW	40°32’10”	76°55’23”
Porter-Tower Joint Authority	PA0046272	SP	40°34’59”	76°34’46”
Thompson, Fred	NO PM REC*	IW	40°34’10”	76°41’04”
Upper Dauphin Area School Authority	PA0035301	SN	40°34’00”	76°45’50”
Washington Township Sewer Authority	PA0086185	SP	40°34’01”	76°05’57”
Wiconisco Township	PA0084697	SP	40°34’17”	76°41’59”
Williams Valley School Authority	PA0083062	SN	40°34’56”	76°35’03”
Williamstown Borough Sewer Authority	PA0021491	SP	40°34’40”	76°37’35”

*NO PM REC =No permit number recorded

Type: IW Industrial Waste
SN Sewage Nonmunicipal
SP Spray Field

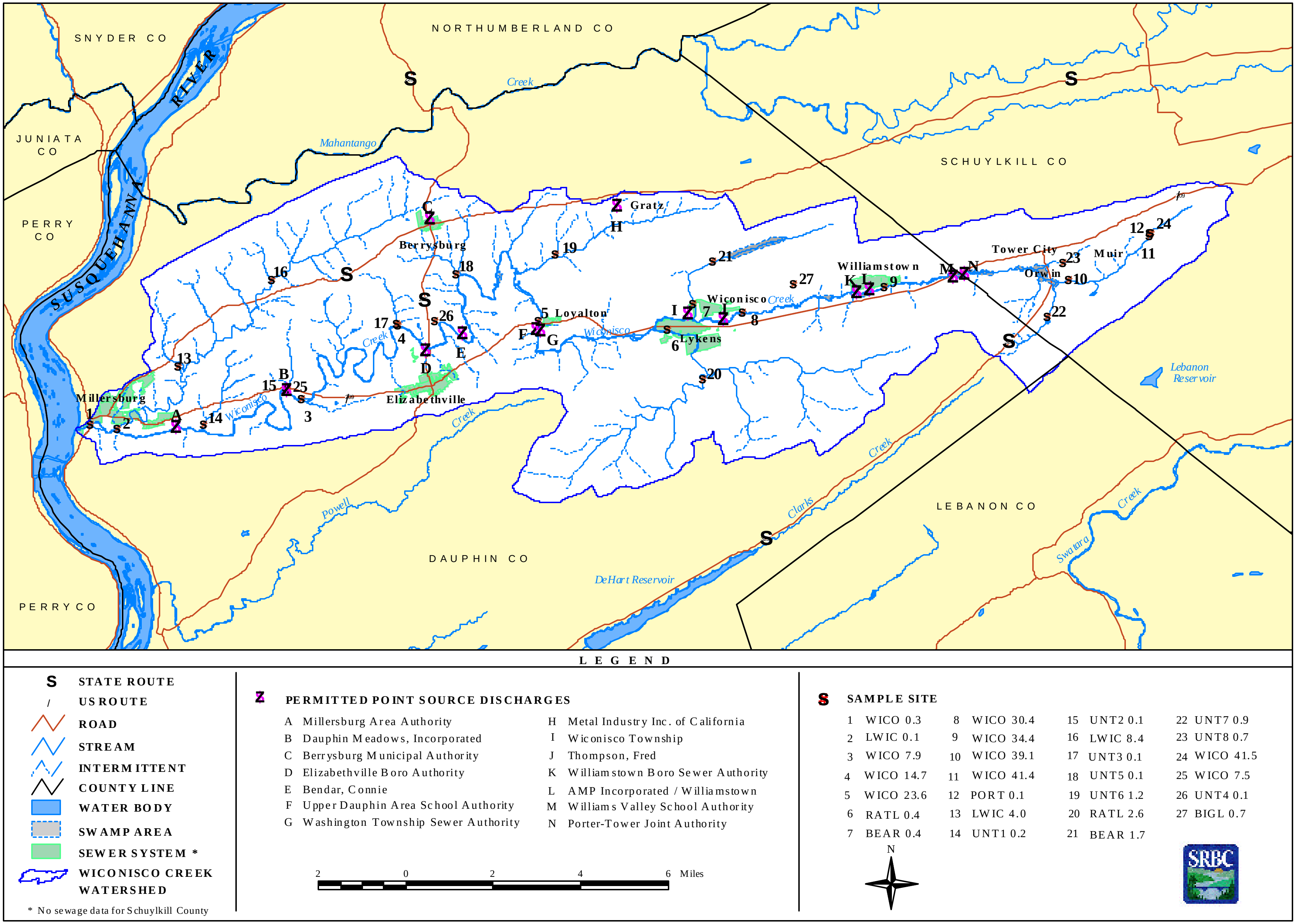

Figure 6. Susquehanna River Basin Commission Sample Sites and Permitted Point Source Discharges in the Wiconisco Creek Watershed

Designations for streams in the Wiconisco Creek Watershed are shown in Figure 7. The main stem of Wiconisco Creek, Little Wiconisco Creek, and all unnamed tributaries to Wiconisco Creek west of the Route 209 bridge at Loyalton, Pa., are classified as warm water fisheries (WWF). Cold water fisheries (CWF) within the Wiconisco Creek Watershed include all unnamed tributaries east of Loyalton and Bear Creek. Rattling Creek is included in the Commonwealth's Special Protection Program, and the stream from the confluence of the east and west branches to the mouth is designated as a high quality cold water fishery (HQ-CWF). The headwaters of Rattling Creek, from the source to the confluence of the east and west branches, are designated as an exceptional value (EV) watershed. An exceptional value stream or watershed is defined as "a stream or watershed which constitutes an outstanding national, state, regional, or local resource, such as waters of national, state or county parks or forests, or waters which are used as a source of unfiltered potable water supply, or waters of wildlife refuges or state game lands, or waters which have been characterized by the Pennsylvania Fish and Boat Commission (PFBC) as "wilderness trout streams," and other waters of substantial recreational or ecological significance" (Pa. Department of Environmental Protection, 1998). The PFBC stocks trout in the lower 16 miles of Wiconisco Creek.

Streams

The Wiconisco Creek Watershed has 15 named tributaries (Figure 7), and the main stem of Wiconisco Creek drains into the Susquehanna River at Millersburg, Pa. Table 6 describes the drainage areas of each of the streams and the percentage of the Wiconisco Creek Watershed that each tributary represents (Pa. Department of Environmental Resources, 1994).

Table 6. Wiconisco Creek Watershed Drainage Areas

Stream Name	Drainage Area (square miles)	Percent of Wiconisco Creek Watershed
Wiconisco Creek	116.0	100.0
Bear Creek	4.69	4.0
Rattling Creek	19.5	16.8
E. Branch Rattling Creek	9.31	8.0
Nine O'clock Run	2.31	2.0
Stone Cabin Run	2.06	1.8
W. Branch Rattling Creek	9.14	7.9
Wolf Run	0.73	0.6
Mud Run	1.1	0.9
Hawk's Nest Run	0.62	0.5
Shale Run	1.4	1.2
Dry Run	0.31	0.3
Doc Smith Run	0.82	0.7
Big Run	0.56	0.5
Canoe Gap Run	0.82	0.7
Little Wiconisco Creek	17.5	15.1

FIELD AND LABORATORY METHODS

Field Methods

Physical habitat and biological conditions

Physical habitat conditions at each sample site were assessed using a slightly modified version of the habitat assessment procedure outlined in the U.S. Environmental Protection Agency's Rapid Bioassessment Protocol for Use in Streams and Rivers (RBP III) by Plafkin and others (1989). Eleven habitat parameters were field-evaluated at each site and used to calculate a site-specific Habitat Assessment Score. Habitat parameters were identified as primary, secondary, or tertiary, based on their contribution to habitat quality.

Primary parameters, stream habitat features that have the greatest direct influence on the structure of aquatic communities, were evaluated on a scale of 0-20 and included characterization of the stream bottom substrate, instream cover, embeddedness, and velocity/depth diversity. Secondary parameters included stream channel morphology characteristics and were scored on a

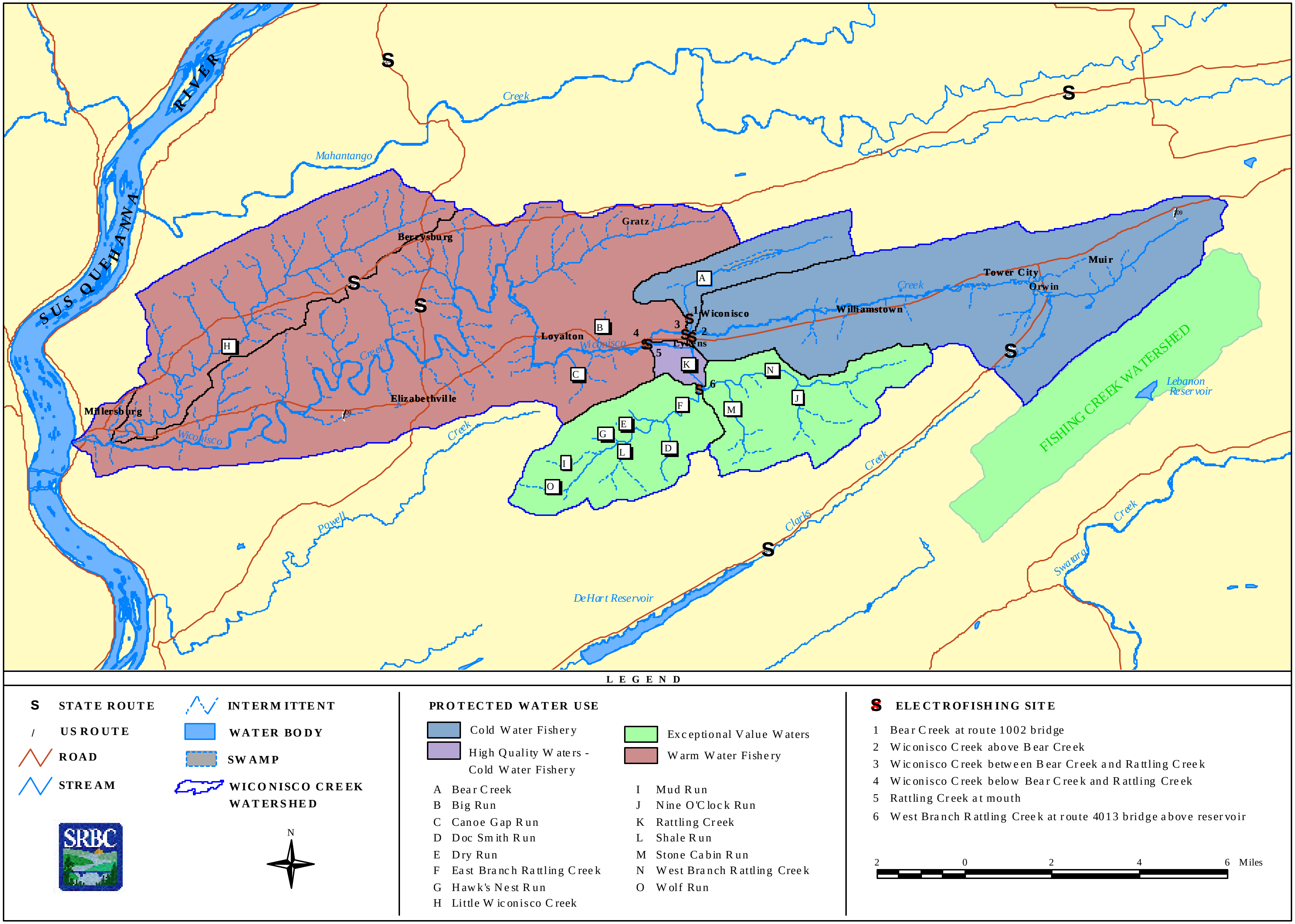

Figure 7. Susquehanna River Basin Commission Electrofishing Sites and Protected Water Use Designations in the Wiconisco Creek Watershed

scale of 0-15. Tertiary parameters characterized riparian and bank conditions and were scored on a scale of 0-10. The criteria used to evaluate habitat parameters are summarized in Table 7.

Benthic macroinvertebrate samples were analyzed using field and laboratory methods described by Plafkin and others (1989). Samples were collected using a 1-meter-square kick screen with size No. 30 mesh. The kick screen was stretched across the current to collect organisms dislodged from riffle/run areas by physical agitation of the stream substrate. Two kick screen samples were collected from a representative riffle/run at each station. The two samples were composited and preserved in isopropyl alcohol for later laboratory analysis.

In the laboratory, composite samples were sorted into 100-organism subsamples using a gridded pan and a random numbers table. The organisms contained in the subsamples were identified to genus (except Chironomidae) and enumerated. Each taxon was assigned an organic pollution tolerance value and a functional feeding category as outlined in Appendix A. A taxa list for each station can be found in Appendix B.

Chemical water quality

Field water quality measurements included water temperature, dissolved oxygen, conductivity, pH, alkalinity, and acidity. Dissolved oxygen was measured using a YSI dissolved oxygen meter. Conductivity was measured using a Cole Parmer meter. An Orion Model 399A meter was used to measure pH. Alkalinity was measured by titrating a known volume of sample water to pH 4.5 with 0.02 N H_2SO_4. Acidity was measured by titrating a known volume of sample water to pH 8.3 with 0.02 N NaOH. Approximately 2 liters of water from each site were collected for laboratory analysis.

Laboratory samples consisted of two 500-ml bottles of water for nutrient analysis (one filtered and one unfiltered) and two 500-ml bottles of water for metal analyses (also one filtered and one unfiltered). Sample water was filtered through a cellulose nitrate filter with a 0.45 um pore size before bottling. The samples for metal analyses were acidified to pH 2 or less with nitric acid. All samples were chilled on ice and shipped within 24 hours to the Pa. DEP, Bureau of Laboratories, in Harrisburg, Pa.

Base flow

Field data were collected during periods of little or no precipitation, when streamflows were maintained primarily by base flow. Twenty-four sites were sampled in the Wiconisco Creek Watershed in September 1996 and May 1997 (Plate 1)—nine sites on the main stem of Wiconisco Creek, and 15 sites distributed among Wiconisco Creek tributaries (Table 8). Physical habitat and chemical water quality conditions were documented at each sample site, and benthic macroinvertebrate and chemical water quality samples were collected for analysis in the laboratory.

Storm flow

Storm chemical water quality samples were collected during periods of high precipitation, when streamflow was supported mainly by surface-water runoff. Twelve sites were sampled in the Wiconisco Creek Watershed in June and July 1997—eight sites on the main stem of Wiconisco Creek, and four sites distributed among Wiconisco Creek tributaries (Table 8).

Flows were estimated by relating a measured water height to previously-developed rating curves. One sample per day was collected per site over several days to allow for the interpretation of runoff characteristics of the watershed during the rise, peak, and fall of the streams.

Laboratory Data Analyses

Physical habitat and biological conditions

Habitat assessment scores of sample sites were compared to those of reference sites to classify each sample site within a Habitat Condition Category (Table 9). The biological integrity of each sample site was assessed using a modified version of RBP III, as described by Plafkin and others (1989). This modification

Table 7. Criteria Used to Evaluate Physical Habitat Parameters

Habitat Parameter	Excellent	Good	Fair	Poor
1. Bottom Substrate	Greater than 50% cobble, gravel, submerged logs, undercut banks, or other stable habitat **(16-20)**	30-50% cobble, gravel, or other stable habitat. Adequate habitat. **(11-15)**	10-30% cobble, gravel, or other stable habitat. Habitat availability is less than desirable. **(6-10)**	Less than 10% cobble, gravel, or other stable habitat. Lack of habitat is obvious. **(0-5)**
2. Embeddedness (a)	Larger substrate particles (e.g., gravel, cobble, boulders) are between 0 and 25% surrounded by fine sediment. **(16-20)**	Larger substrate particles (e.g., gravel, cobble, boulders) are between 25 and 50% surrounded by fine sediment. **(11-15)**	Larger substrate particles (e.g., gravel, cobble, boulders) are between 50 and 75% surrounded by fine sediment. **(6-10)**	Larger substrate particles (e.g., gravel, cobble, boulders) are over 75% surrounded by fine sediment. **(0-5)**
3. Velocity/Depth Diversity	Four habitat categories consisting of slow (<1.0 ft/s), deep (>1.5 ft); slow, shallow (<1.5 ft); fast (> 1.0 ft/s), deep; fast, shallow habitats are all present. **(16-20)**	Only 3 of the 4 habitat categories are present. **(11-15)**	Only 2 of the 4 habitat categories are present. **(6-10)**	Dominated by 1 velocity/depth category (usually pools). **(0-5)**
4. Pool/Riffle Ratio (or Run/Bend)	Distance between riffles divided by mean wetted width equals 5-7. Stream contains a variety of habitats including deep riffles and pools. **(12-15)**	Distance between riffles divided by mean wetted width equals 7-15. Adequate depth in pools and riffles. **(8-11)**	Distance between riffles divided by mean wetted width equals 15-25. Stream contains occasional riffles. **(4-7)**	Distance between riffles divided by mean wetted width >25. Stream is essentially straight with all flat water or shallow riffle. Poor habitat. **(0-3)**
5. Pool Quality (b)	Pool habitat contains both deep (>1.5 ft) and shallow areas (<1.5 ft) with complex cover and/or depth greater than 5 ft. **(12-15)**	Pool habitat contains both deep (>1.5 ft) and shallow (<1.5 ft) areas with some cover present. **(8-11)**	Pool habitat consists primarily of shallow (<1.5 ft) areas with little cover. **(4-7)**	Pool habitat rare with maximum depth <0.5 ft, or pool habitat absent completely. **(0-3)**

Table 7. Criteria Used to Evaluate Physical Habitat Parameters—Continued

Habitat Parameter	Excellent	Good	Fair	Poor
6. Riffle/Run Quality (c)	Riffle/run depth generally >8 in. and consisting of stable substrate materials and a variety of current velocities. **(12-15)**	Riffle/run depth generally 4-8 in. and with a variety of current velocities. **(8-11)**	Riffle/run depth generally 1-4 in.; primarily a single current velocity. **(4-7)**	Riffle/run depth <1 in.; or riffle/run substrates concreted. **(0-3)**
7. Channel Alteration (d)	Little or no enlargement of islands or point bars, and/or no channelization. **(12-15)**	Some new increase in bar formation, mostly from coarse gravel; and/or some channelization present. **(8-11)**	Moderate deposition of new gravel, coarse sand on old and new bars; pools partially filled with silt; and/or embankments on both banks. **(4-7)**	Heavy deposits of fine material, increased bar development; most pools filled with silt; and/or extensive channelization. **(0-3)**
8. Upper and Lower Streambank Erosion (e)	Stable. No evidence of erosion or bank failure. Side slopes generally <30%. Little potential for future problems. **(9-10)**	Moderately stable. Infrequent, small areas of erosion mostly healed over. Side slopes up to 40% on one bank. Slight potential in extreme floods. **(6-8)**	Moderately unstable. Moderate frequency and size of erosional areas. Side slopes up to 60% in some areas. High erosion potential during extreme high flow. **(3-5)**	Unstable. Many eroded areas. Side slopes >60% common. "Raw" areas frequent along straight sections and bends. **(0-2)**
9 Upper and Lower Streambank Stability (e)	Over 80% of the streambank surface is covered by vegetation or boulders and cobble. **(9-10)**	50-79% of the streambank surface is covered by vegetation, gravel, or larger material. **(6-8)**	25-49% of the streambank surface is covered by vegetation, gravel, or larger material. **(3-5)**	Less than 25% of the streambank surface is covered by vegetation, gravel, or larger material. **(0-2)**
10. Streamside Vegetative Cover *(Both Banks)*	Dominant vegetation that provides stream-shading, escape cover, and/or refuge for fish within the bankfull stream channel is shrub. **(9-10)**	Dominant vegetation that provides stream-shading, escape cover, and/or refuge for fish within the bankfull stream channel is trees **(6-8)**	Dominant vegetation that provides stream-shading, escape cover, and/or refuge for fish within the bankfull stream channel is forbs and grasses. **(3-5)**	Over 50% of the streambank has no vegetation and dominant material is soil, rock, bridge materials, culverts, or mine tailings. **(0-2)**

Table 7. Criteria Used to Evaluate Physical Habitat Parameters—Continued

Habitat Parameter	Excellent	Good	Fair	Poor
11. Forested Riparian Buffer Zone Width (f) ***(Least Forested Bank)***	Riparian area consists of all three zones of vegetation, Zones 1-3. (see zone descriptions (e)) **(9-10)**	Riparian area consists of Zones1 and 2. **(6-8)**	Riparian area is limited primarily to Zone 1. Zone 2 may be forested but is subject to disturbance (e.g. grazing, intensive forestry practices, roads). **(3-5)**	Riparian area lacks Zone 1 with or without Zones 2 and/or 3. **(0-2)**

(a) Embeddedness — The degree to which the substrate materials that serve as habitat for benthic macroinvertebrates and for fish spawning and egg incubation (predominantly cobble and/or gravel) are surrounded by fine sediment. Embeddedness is evaluated with respect to the suitability of these substrate materials as habitat for macroinvertebrates and fish by providing shelter from the current and predators, and by providing egg deposition and incubation sites.

(b) Pool Quality — Rated based on the variety and spatial complexity of slow- or still-water habitat within the sample segment. It should be noted that even in high- gradient segments, functionally important slow-water habitat may exist in the form of plunge-pools and/or larger eddies. Within a category, higher scores are assigned to segments that have undercut banks, woody debris, or other types of cover for fish.

(c) Riffle/Run Quality — Rated based on the depth, complexity, and functional importance of riffle/run habitat in the segment, with highest scores assigned to segments dominated by deeper riffle/run areas, stable substrates, and a variety of current velocities.

(d) Channel Alteration — A measure of large-scale changes in the shape of the stream channel. Channel alteration includes: concrete channels, artificial embankments, obvious straightening of the natural channel, rip-rap, or other structures, as well as recent sediment bar development. Sediment bars typically form on the inside of bends, below channel constrictions, and where stream gradient decreases. Bars tend to increase in depth and length with continued watershed disturbance. Ratings for this metric are based on the presence of artificial structures as well as the existence, extent, and coarseness of sediment bars, which indicate the degree of flow fluctuations and substrate stability.

(e) Upper and Lower Streambank Erosion and Stability — These parameters include the concurrent assessment of both the upper and lower banks. The upper bank is the land area from the break in the general slope of the surrounding land to the top of the bankfull channel. The lower bank is the intermittently submerged portion of the stream cross section from the top of the bankfull channel to the existing water-line.

(f) Forested Riparian Buffer Zone Width —
Zone 1: a 15-ft-wide buffer of essentially undisturbed forest located immediately adjacent to the stream.
Zone 2: a 100-ft-wide buffer of forest, located adjacent to Zone 1, which may be subject to non-intensive forest management practices.
Zone 3: a 20-ft-wide buffer of vegetation, located adjacent to Zone 2, that provides sediment filtering and promotes the formation of sheet flow of runoff into Zone 2. Zone 3 may be composed of trees, shrubs, and/or dense grasses and forbs, which are subject to haying and grazing, as long as vegetation is maintained in vigorous condition.

Source: Modified from Plafkin and others, 1989.

Table 8. Description of Wiconisco Creek Watershed Sampling Sites

Collection ID	Sample Site	Description	Latitude	Longitude
Sample Sites				
*WICO 01	WICO 0.3	Wiconisco Creek at the mouth (Route 147 bridge)	40°32’14”	76°57’39”
*WICO 02	LWIC 0.1	Little Wiconisco Creek at the mouth	40°32’08”	76°56’57”
*WICO 03	WICO 7.9	Wiconisco Creek near Rife, Pa.	40°32’40”	76°52’08”
*WICO 04	WICO 14.7	Wiconisco Creek near Elizabethville, Pa.	40°34’07”	76°49’35”
*WICO 05	WICO 23.6	Wiconisco Creek at Loyalton (Route 209 bridge)	40°34’09”	76°45’54”
*WICO 06	RATL 0.4	Rattling Creek near the mouth in Lykens, Pa.	40°33’57”	76°42’33”
*WICO 07	BEAR 0.4	Bear Creek near the mouth (SR 1002 bridge)	40°34’28”	76°41’52”
*WICO 08	WICO 30.4	Wiconisco Creek near Wiconisco, Pa.	40°34’16”	76°40’36”
*WICO 09	WICO 34.4	Wiconisco Creek near Williamstown, Pa. (Railroad St.)	40°34’45”	76°36’52”
*WICO 10	WICO 39.1	Wiconisco Creek near Orwin, Pa.	40°34’49”	76°32’04”
*WICO 11	WICO 41.4	Wiconisco Creek below the Porter Tunnel discharge	40°35’40”	76°29’57”
*WICO 12	PORT 0.1	Porter Tunnel acid mine discharge	40°35’44”	76°29’57”
WICO 13	LWIC 4.0	Little Wiconisco Creek near Killinger	40°33’22”	76°55’19”
WICO 14	UNT1 0.2	Tributary to Wiconisco Creek near Reservoir Heights, Pa.	40°32’11”	76°54’40”
WICO 15	UNT2 0.1	Tributary to Wiconisco Creek near Rife, Pa.	40°32’55”	76°52’31”
WICO 16	LWIC 8.4	Little Wiconisco Creek in the headwaters	40°35’03”	76°52’51”
WICO 17	UNT3 0.1	Tributary to Wiconisco Creek near Reservoir Heights, Pa.	40°34’09”	76°49’36”
WICO 18	UNT5 0.1	Tributary to Wiconisco Creek near Berrysburg, Pa.	40°35’07”	76°48’02”
WICO 19	UNT6 1.2	Tributary to Wiconisco Creek near Gratz, Pa.	40°35’29”	76°45’27”
WICO 20	RATL 2.6	West Branch of Rattling Creek above the reservoir	40°32’58”	76°41’39”
WICO 21	BEAR 1.7	Bear Creek below Bear Swamp	40°35’17”	76°41’21”
WICO 22	UNT7 0.9	Tributary to Wiconisco Creek near Gold Mine Road	40°34’06”	76°32’38”
WICO 23	UNT8 0.7	Tributary to Wiconisco Creek near Muir, Pa.	40°35’10”	76°32’13”
WICO 24	WICO 41.5	Wiconisco Creek above the Porter Tunnel discharge	40°35’44”	76°29’53”

* Indicates a storm sample location

Table 9. Summary of Criteria Used to Classify the Habitat Conditions of Sample Sites

DETERMINATION OF HABITAT ASSESSMENT SCORES

Parameter	Habitat Parameter Scoring Criteria			
	Excellent	Good	Fair	Poor
Bottom Substrate	20-16	15-11	10-6	5-0
Embeddedness	20-16	15-11	10-6	5-0
Velocity/Depth Diversity	20-16	15-11	10-6	5-0
Pool-Riffle (Run-Bend) Ratio	15-12	11-8	7-4	3-0
Pool Quality	15-12	11-8	7-4	3-0
Riffle/Run Quality	15-12	11-8	7-4	3-0
Channel Alteration	15-12	11-8	7-4	3-0
Upper and Lower Streambank Erosion	10-9	8-6	5-3	2-0
Upper and Lower Streambank Stability	10-9	8-6	5-3	2-0
Streamside Vegetative Cover	10-9	8-6	5-3	2-0
Forested Riparian Buffer Zone Width	10-9	8-6	5-3	2-0
Habitat Assessment Score (a)				

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HABITAT ASSESSMENT

Percent Comparability of Study and Reference Site Habitat Assessment Scores	Habitat Condition Category
>90 %	Excellent (comparable to reference)
89-75 %	Supporting
74-60 %	Partially Supporting
<60 %	Nonsupporting

(a) Habitat Assessment Score = Sum of Habitat Parameter Scores included the substitution of several of the indexes ("metrics") used to evaluate the overall integrity of the site's benthic macroinvertebrate community. These substitutions included: (1) Shannon Diversity (log base 2) for the Percent Contribution of Dominant Taxa Metric; (2) Percent Taxonomic Similarity for the EPT/Chironomidae Abundances and Community Loss Metrics; and (3) Percent Trophic Similarity for the Scrapers/Filtering Collectors and Shredders/Total Metrics. The metrics used in this survey are summarized in Table 10.

The 100-organism subsample data were used to generate scores for each of the six metrics. Each metric score was then converted to a Biological Condition Score based on the percent similarity of the metric score, relative to the metric score of the appropriate reference site. The sum of the biological condition scores constituted the total biological score for the sample site, and total biological scores were used to assign each site to a Biological Condition Category (Table 11).

HIGHLIGHTS OF THE FIRST YEAR ENVIRONMENTAL ASSESSMENT ACTIVITIES

SRBC completed an assessment of the Wiconisco Creek Watershed and published the results in the Water Quality and Biological Assessment of the Wiconisco Creek Watershed (Stoe, 1998). Findings of this study are described below.

Raw macroinvertebrate and water quality data are shown in Appendixes A through D. Sampling in 1996 revealed that, according to RBP III methods (Plafkin and others, 1989), no sites on the main stem of Wiconisco Creek possessed nonimpaired biological communities. Approximately 44 percent of these sites possessed slightly impaired biological communities, while the remaining sites (56 percent) possessed moderately or severely impaired biological communities (Figure 8). There seemed to be a direct correlation between biological scores and habitat scores at main-stem sites, as shown in Figure 9.

In the Upper Basin, mine drainage was the major source of impacts to water quality. Increased metal loads and a low pH, as well as the associated precipitation of these metals, rendered parts of the headwaters of Wiconisco Creek devoid of life. Water quality improved with the addition of flow contributed by lesser-impacted tributaries in the area near Tower City. Also, a wetland near Tower City improved water quality by allowing precipitation of metals and uptake of nutrients by aquatic plants. The wetland acts as a retention and settling basin for much of the iron and sulfate present in water passing through the wetland.

Sedimentation was a problem throughout the Wiconisco Creek Watershed, but the impacts could be seen easily in the Upper Basin from the headwaters to the confluence of Bear and Rattling Creeks at Lykens. The impact of Big Lick Tunnel discharge was seen clearly in water quality data from May 1997. Higher flows at the time of sampling, due to seasonal variations in flow, resulted in greater influence from this discharge.

Bear Creek was a major contributor of metals to the middle part of Wiconisco Creek. Water in Bear Creek had high concentrations of metals and high alkalinity and pH. Metals from Bear Creek precipitated out of solution after mixing with water from Wiconisco Creek, resulting in precipitate-covered substrate immediately downstream of Bear Creek. Biological conditions directly downstream of the confluence of Bear Creek with Wiconisco Creek could be improved by removal of metals from Bear Creek.

The Rattling Creek Basin was one of the most pristine areas in the Wiconisco Creek Watershed. Diversity and taxanomic richness of the benthic macroinvertebrate community were hampered by the sterility of water. Also a lack of buffering capacity in the headwaters resulted in slightly acidic conditions. An abundance of filter-feeding macroinvertebrates downstream of the reservoirs near Lykens indicated an abundance of organic material in the water.

The Middle Basin of Wiconisco Creek near Loyalton was a transition zone between the

Table 10. Summary of Metrics Used to Evaluate the Overall Biological Integrity of Stream Benthic Macroinvertebrate Communities

Metric	Description
1. Taxonomic Richness (1)	The total number of taxa present in the 100 organism subsample
2. Shannon Diversity Index (2)	A measure of biological community complexity based on the number of equally or nearly equally abundant taxa in the community
3. Modified Hilsenhoff Biotic Index (1)	A measure of the overall pollution tolerance of a benthic macroinvertebrate community
4. EPT Index (1)	The total number of Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly) taxa present in the 100 organism subsample
5. Percent Taxonomic Similarity (2)	A measure of the similarity between the taxonomic composition of the sample site and its appropriate reference community
6. Percent Trophic Similarity (2)	A measure of the similarity between the functional feeding group composition of a sample site and its appropriate reference community

Sources: (1) Plafkin and others (1989); and
(2) calculated using software developed by Kovach (1993).

Table 11. Summary of Criteria Used to Classify the Biological Conditions of Sample Sites

SAMPLING AND ANALYSIS

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TOTAL BIOLOGICAL SCORE DETERMINATION

	Biological Condition Scoring Criteria			
Metric	**6**	**4**	**2**	**0**
1. Taxonomic Richness (a)	>80 %	79 – 60 %	59 – 40 %	<40 %
2. Shannon Diversity Index (a)	>75 %	74 – 50 %	49 – 25 %	<25 %
3. Modified Hilsenhoff Biotic Index (b)	>85 %	84 – 70 %	69 – 50 %	<50 %
4. EPT Index (a)	>90 %	89 – 80 %	79 – 70 %	<70 %
5. Percent Taxonomic Similarity (c)	>45 %	44 – 33 %	32 – 20 %	<20 %
6. Percent Trophic Similarity (c, d)	>75 %	74 – 50 %	49 – 25 %	<25 %
Total Biological Score (e)				

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BIOASSESSMENT

Percent Comparability of Study and Reference Site Total Biological Scores	Biological Condition Category
>81 %	Nonimpaired
81-53 %	Slightly Impaired
52-20 %	Moderately Impaired
<20 %	Severely Impaired

(a) Score is study site value/reference site value X 100.
(b) Score is reference site value/study site value X 100.
(c) Range of values obtained. A comparison to the reference site is incorporated in this index.
(d) Functional Feeding Group Designations are summarized in Appendix A.
(e) Total Biological Score = the sum of Biological Condition Scores assigned to each metric.

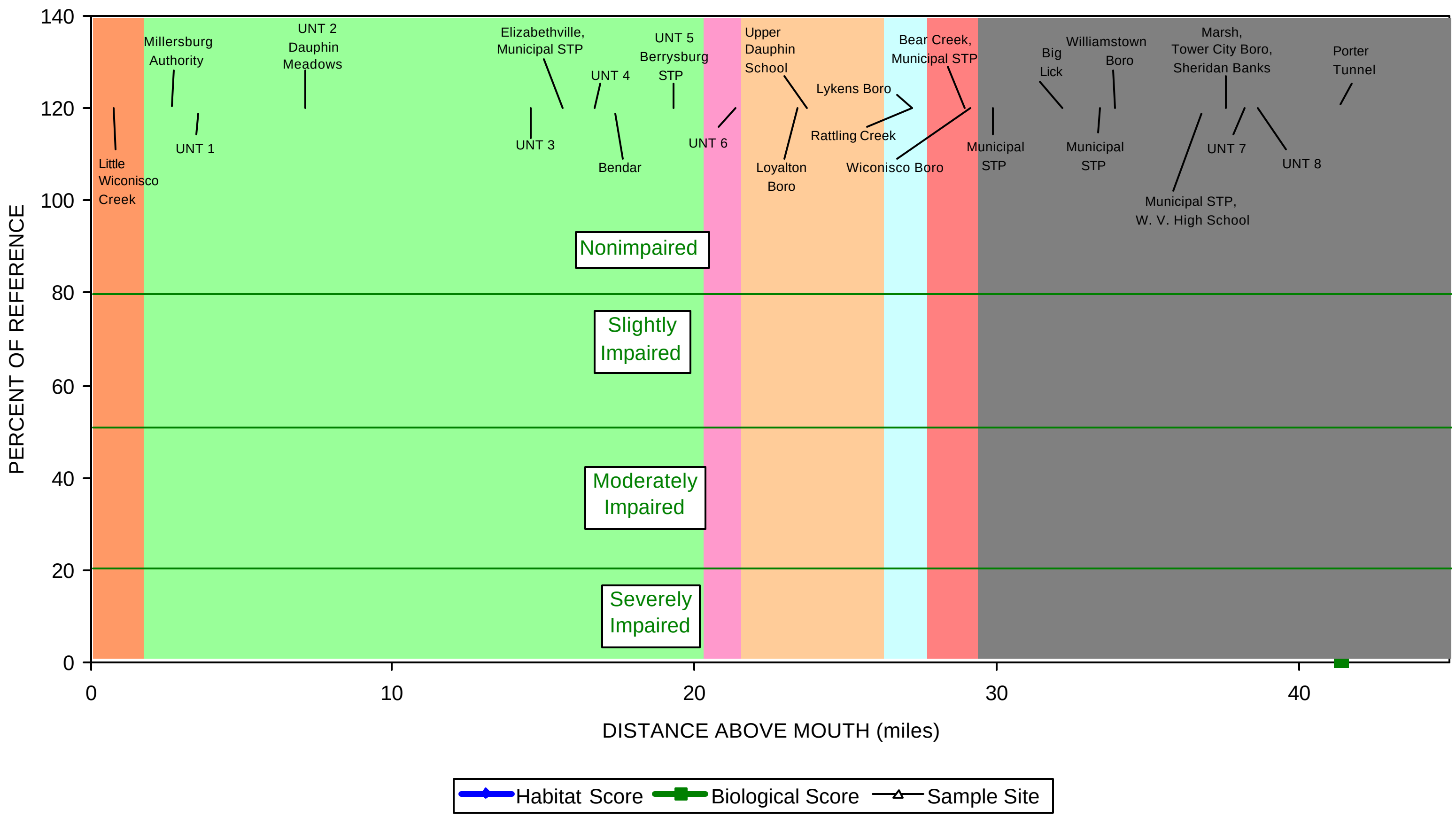

***Figure 8.* Habitat and Biological Condition Scores of Main Stem Wiconisco Creek Sample Sites, as Related to Potential Sources of Impacts, 1996 (**_color denotes subwatersheds)_

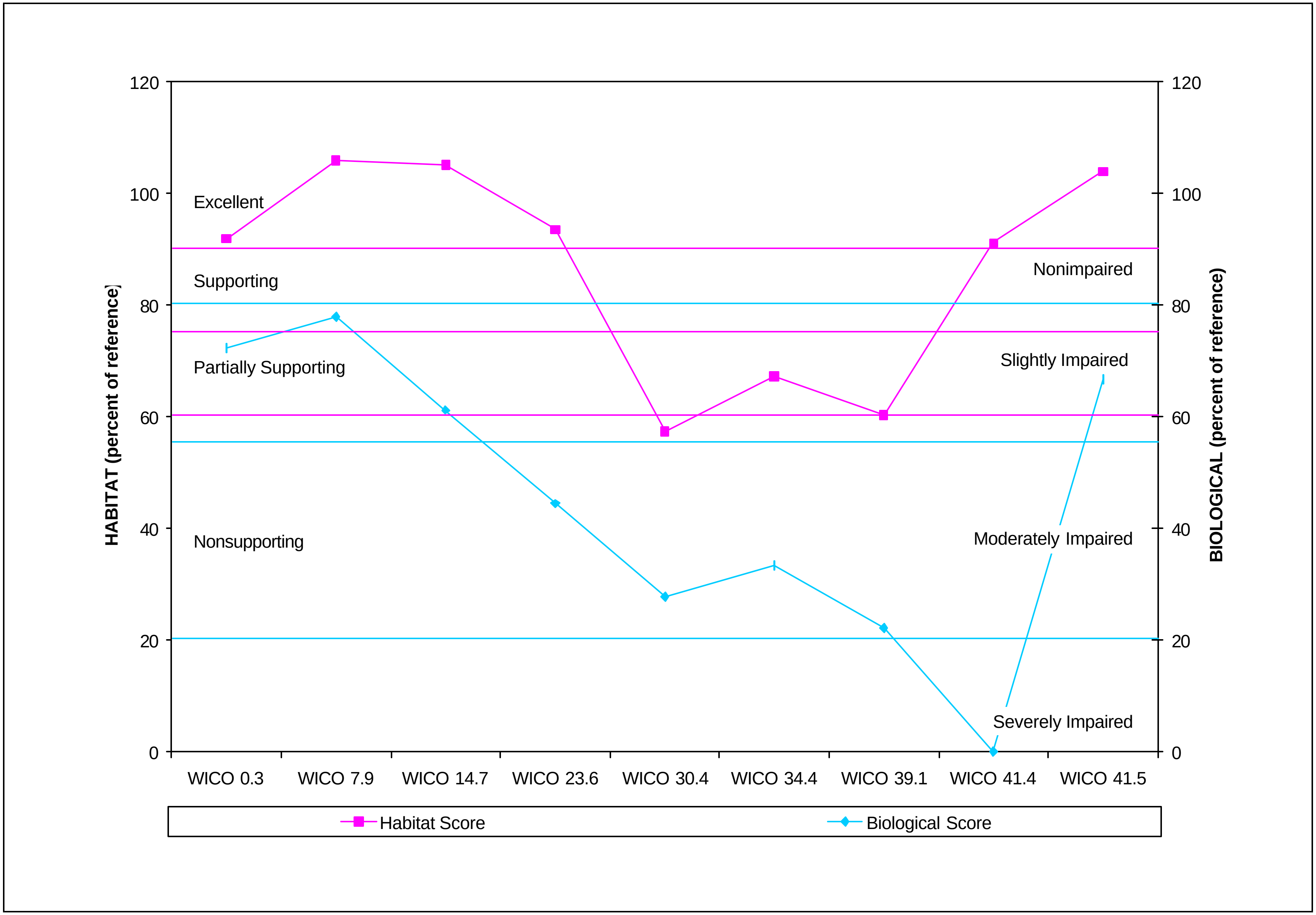

Figure 9. Habitat and Biological Condition Scores of Main Stem Wiconisco Creek Sample Sites, 1996

mining and agricultural influences in the Wiconisco Creek Watershed. The transition between mining/forest land and agricultural land was reflected in the biological conditions, physical habitat, and water quality of samples collected in this area during September 1996 and May 1997 (Figure 8). Water quality and biological conditions improve downstream of this site, as shown in Figure 9.

The Gratz Creek Basin was unimpaired and possessed high quality water, as well as a diverse biological community. The biological community at this site supported several pollution-intolerant genera. Water contributed to Wiconisco Creek by this tributary aided the biological recovery downstream (Figures 8 and 9).

The Lower Basin of Wiconisco Creek was an area of biological recovery. Tributaries buffered impacts from the headwaters, resulting in healthy biological communities at the majority of Lower Basin sites. Although biological quality improved, habitat values remained slightly reduced due to sedimentation from agricultural activities.

Little Wiconisco Creek was stressed by agricultural impacts such as streambank destruction in pastures and soil erosion in poorly managed crop land. The addition of streambank stabilization methods and channel restoration could vastly improve the overall physical habitat, biological conditions, and water quality of the Little Wiconisco Creek Watershed.

Figure 10 shows biological and habitat condition scores of all sites assessed in this survey in 1996 and 1997.

SECOND YEAR ASSESSMENT RESULTS

Figure 11 shows flow at each sample site in both June and July 1997. The June storm event produced higher flows.

Summaries of loads in pounds per day (lb/day) of each chemical parameter at the Wiconisco Creek sampling sites are presented in Figures 12 through 18. The graphs show loads from both June and July storm samples. Figures 12 through 18 show sulfate, manganese, iron, acid, alkalinity, suspended sediment, and residue loads, respectively.

Tables 12 and 13 show electrofishing results from the summer of 1998 in areas near Lykens. Trout were found in Rattling Creek, Bear Creek, and Wiconisco Creek below the confluence of Bear Creek with Rattling Creek. No trout were found in Wiconisco Creek directly above the confluence of Bear Creek.

DISCUSSION OF SECOND YEAR ASSESSMENT RESULTS

Storm Data

Storm samples were collected at 12 sites along Wiconisco Creek, Little Wiconisco Creek, Bear Creek, and Rattling Creek in early June and late July 1997 (Table 8). After calculating loads (lb/day) at each site, time series graphs were made for each parameter, and anomalies in the graphs were identified and analyzed. Loading patterns during storms were identified by a comparison of the June and July graphs and are shown in Figures 12 through 18.

Figure 11 shows that flow increases as drainage area increases, as expected, but there are a few peculiarities in the graphs in the lower 15 miles of Wiconisco Creek. Despite increased drainage area of almost 9.5 square miles between WICO 14.7 and WICO 7.9, flow remained similar or was lower at WICO 7.9, the downstream site. No point source or withdrawal permit facilities are listed in this reach.

Sulfate loads at WICO 7.9 on June 4, 1997, showed an unusual increase (Figure 12), but the cause of the increase is not evident. Sulfate loads were reduced between WICO 30.4 and WICO 23.6. This reduction in sulfate loads may have been the result of a chemical reaction of the sulfate ion due to a decrease in acidity.

(Text continues on page 41.)

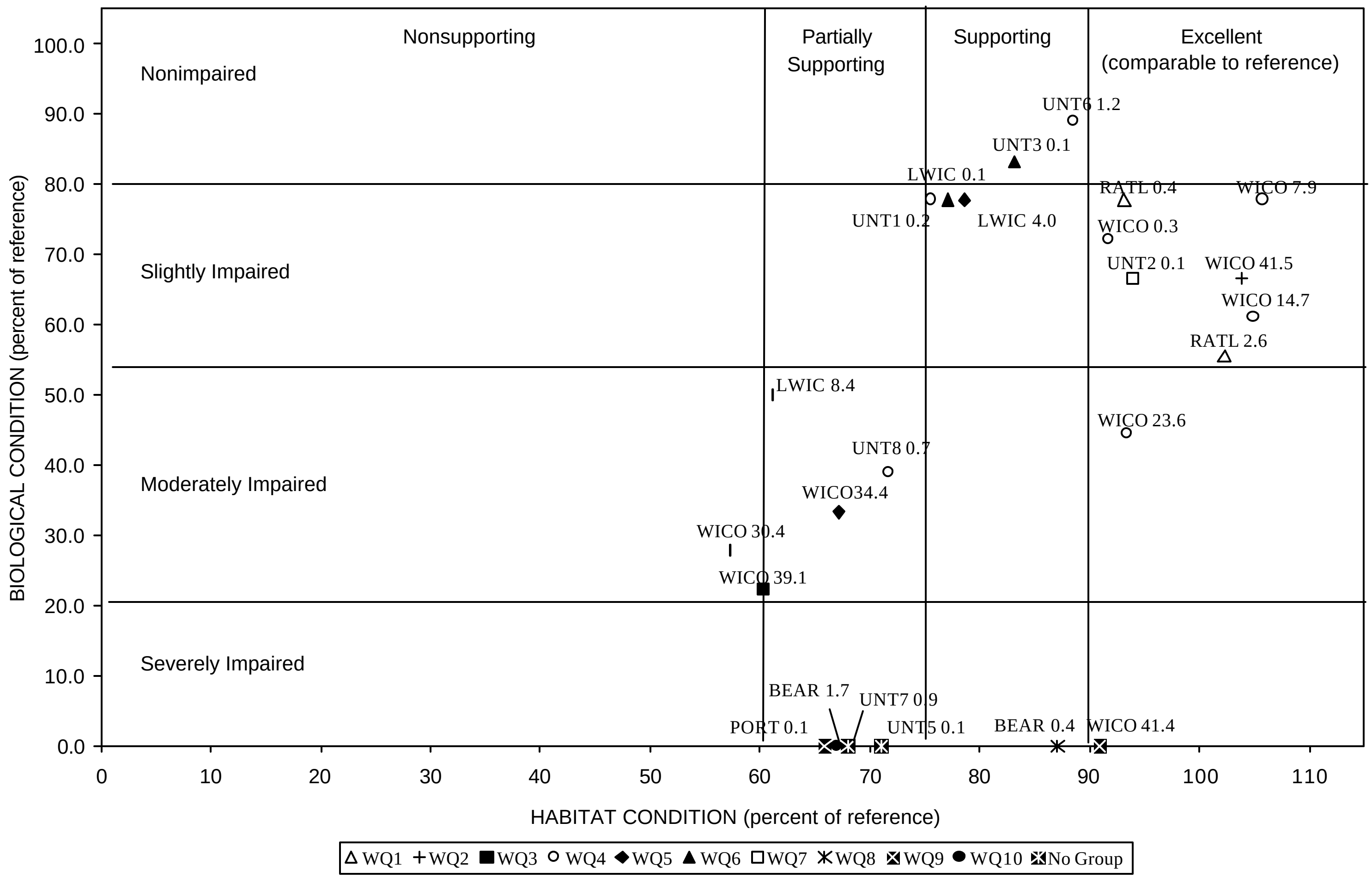

Figure 10. Habitat and Biological Condition Scores and Water Quality Groupings of Wiconisco Creek Watershed Sample Sites, 1996

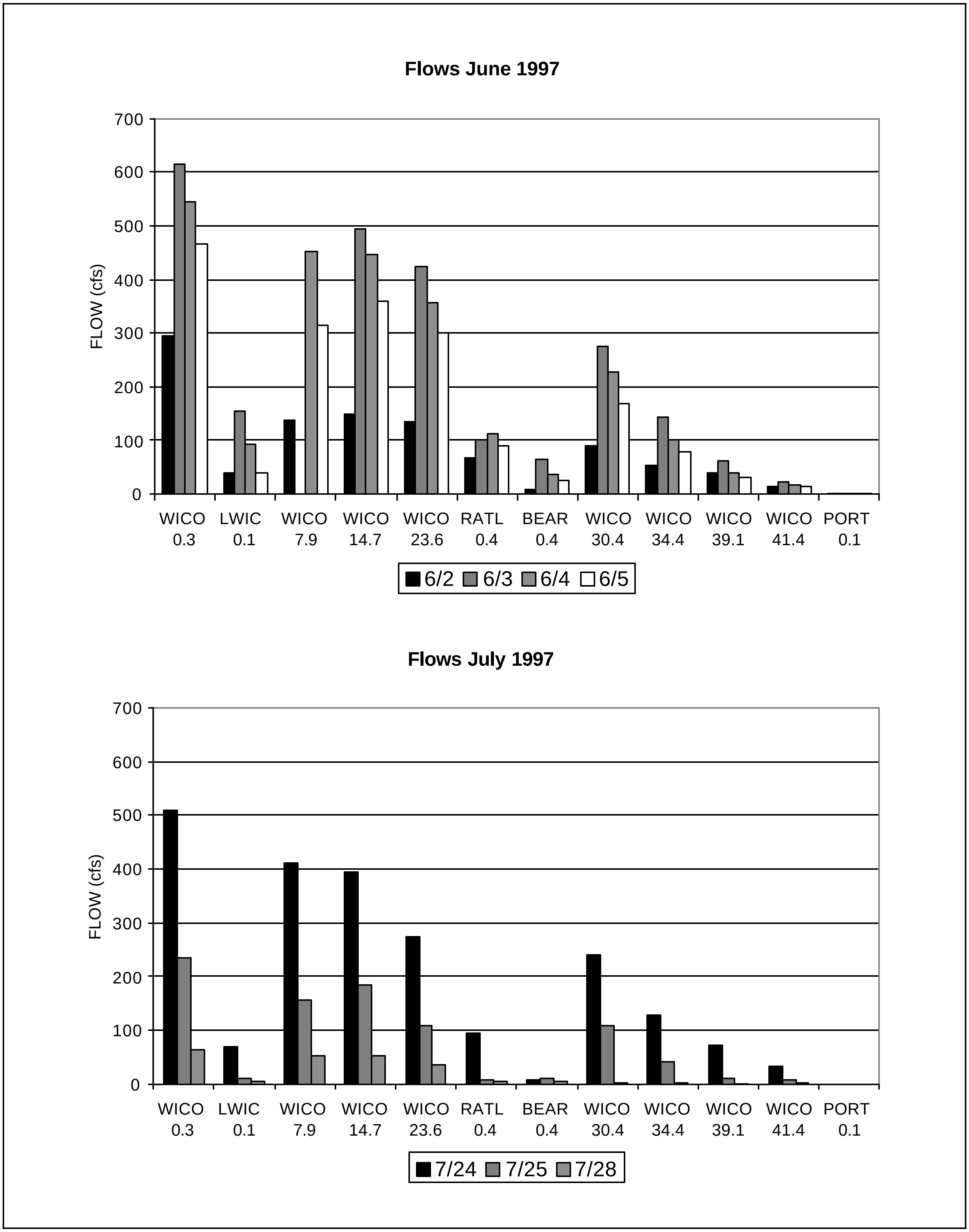

Figure 11. Wiconisco Creek Watershed Flows, June and July 1997

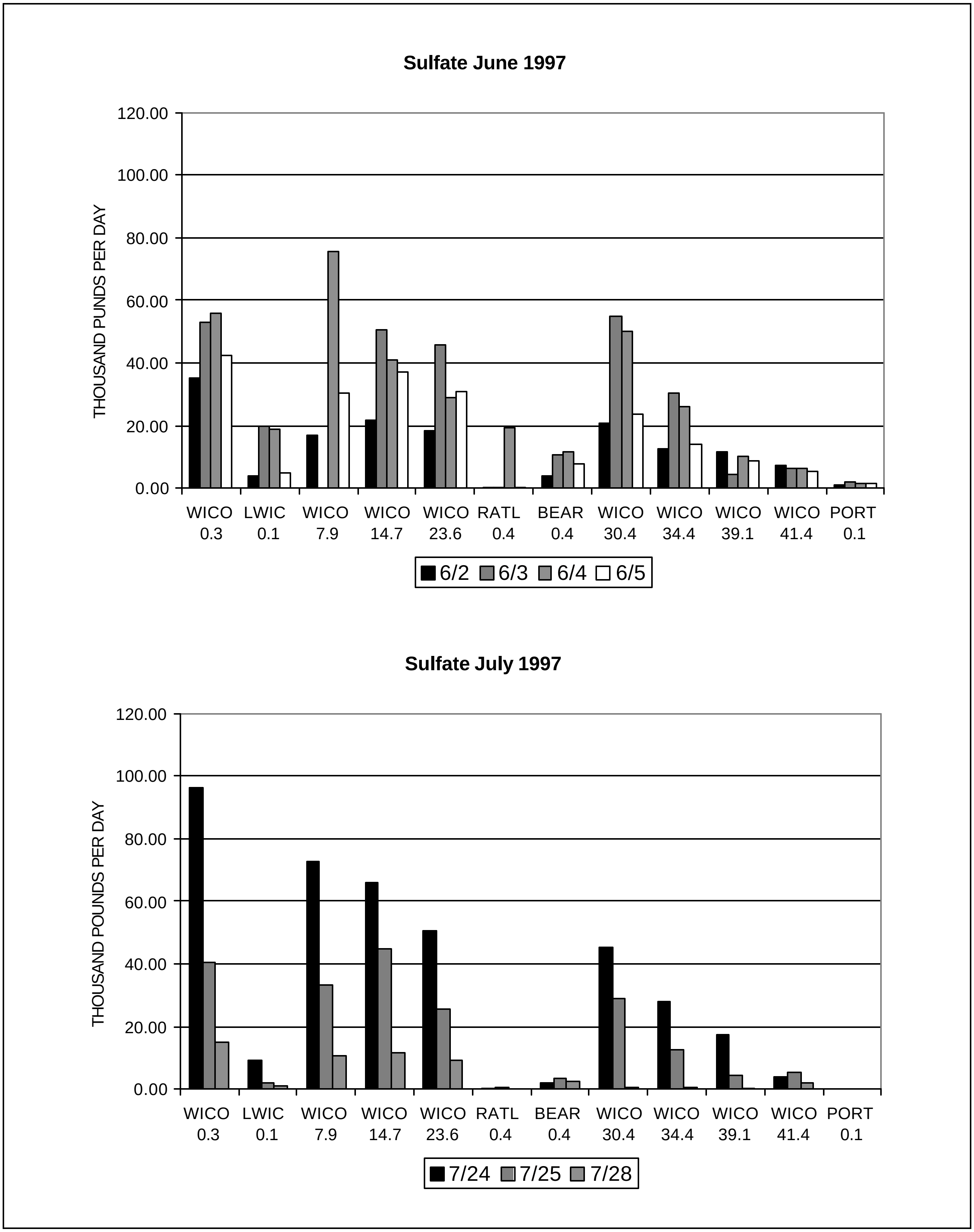

Figure 12. Wiconisco Creek Watershed Sulfate Loads, June and July 1997

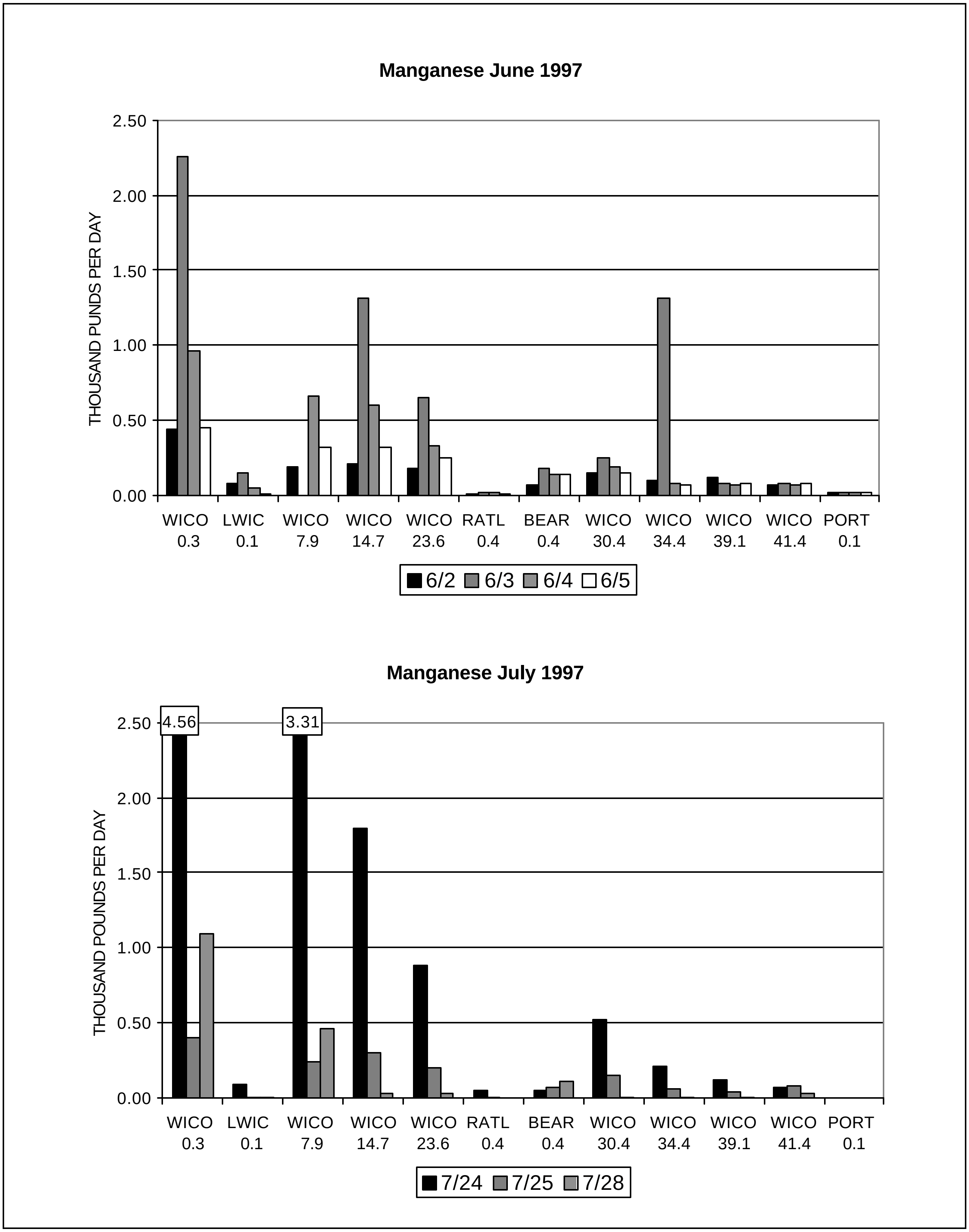

Figure 13. Wiconisco Creek Watershed Manganese Loads, June and July 1997

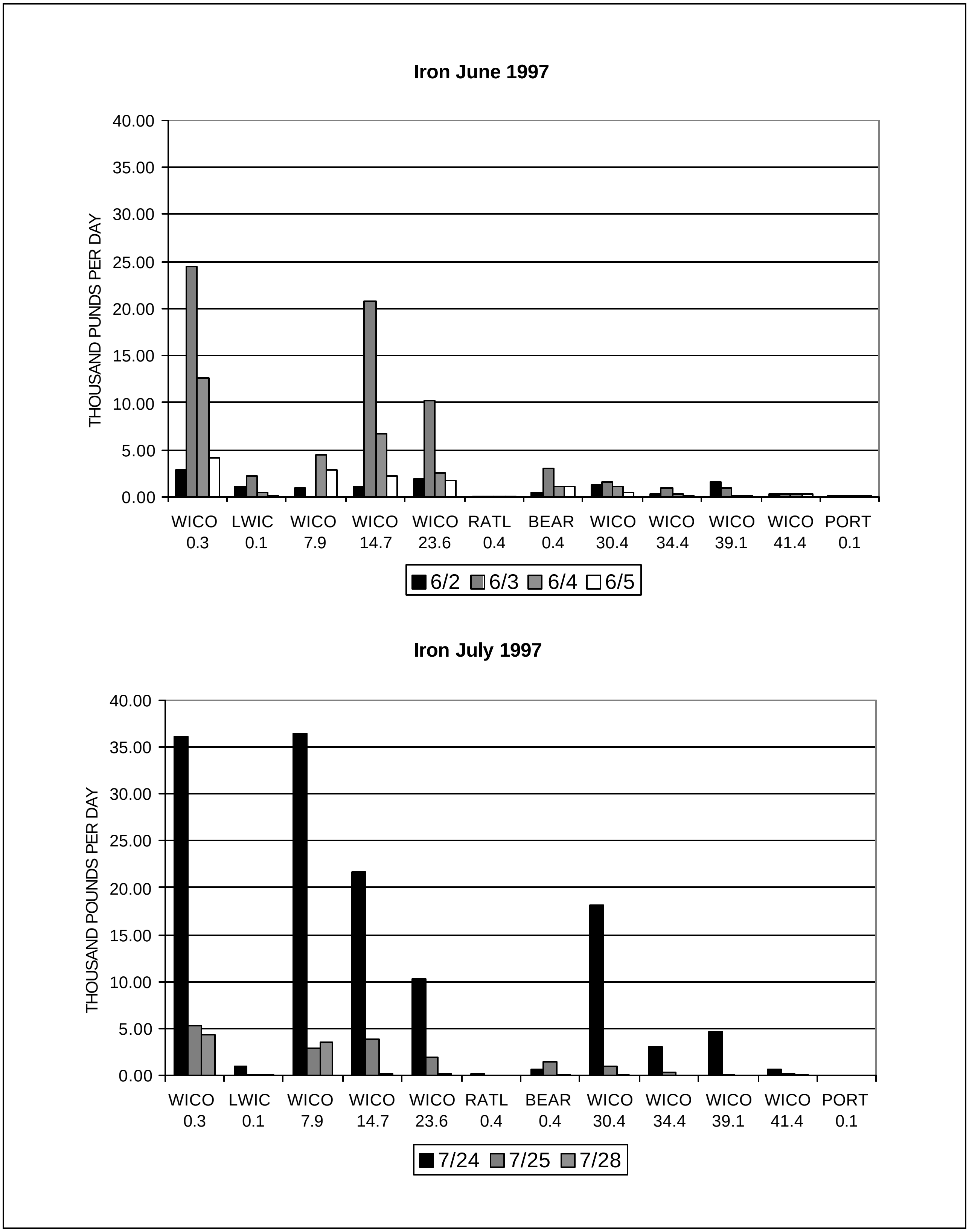

Figure 14. Wiconisco Creek Watershed Iron Loads, June and July 1997

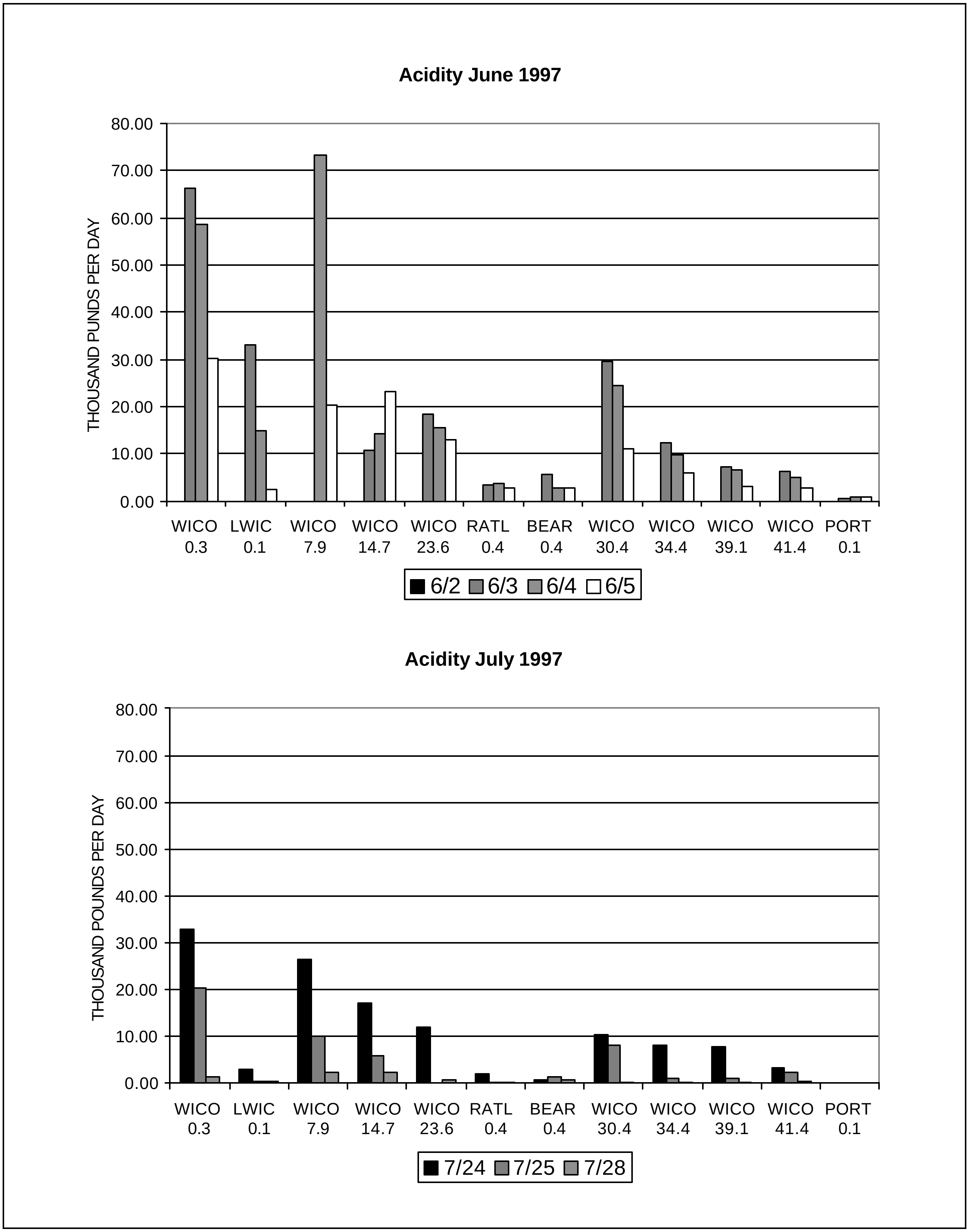

Figure 15. Wiconisco Creek Watershed Acid Loads, June and July 1997

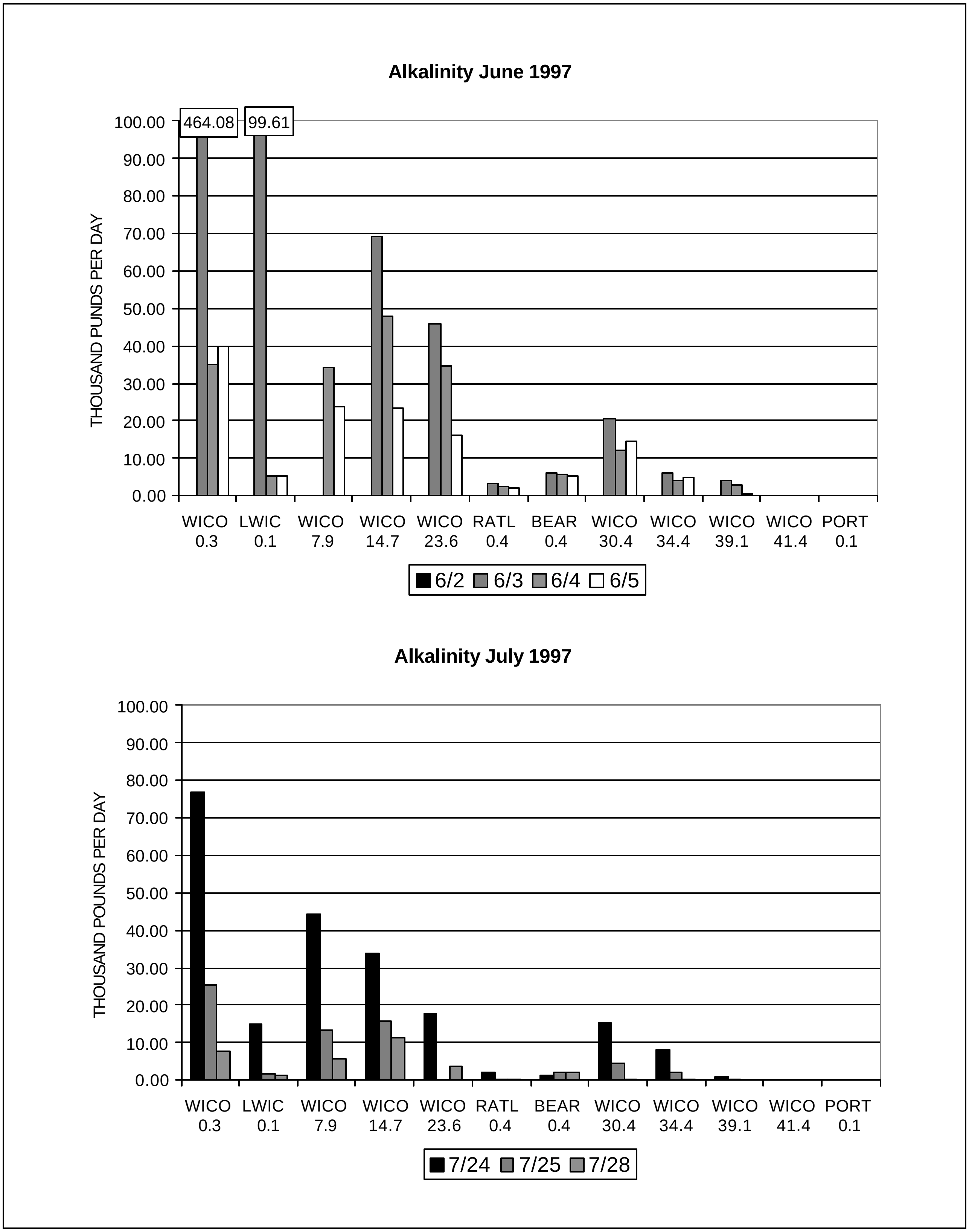

Figure 16. Wiconisco Creek Watershed Alkaline Loads (Alkalinity), June and July 1997

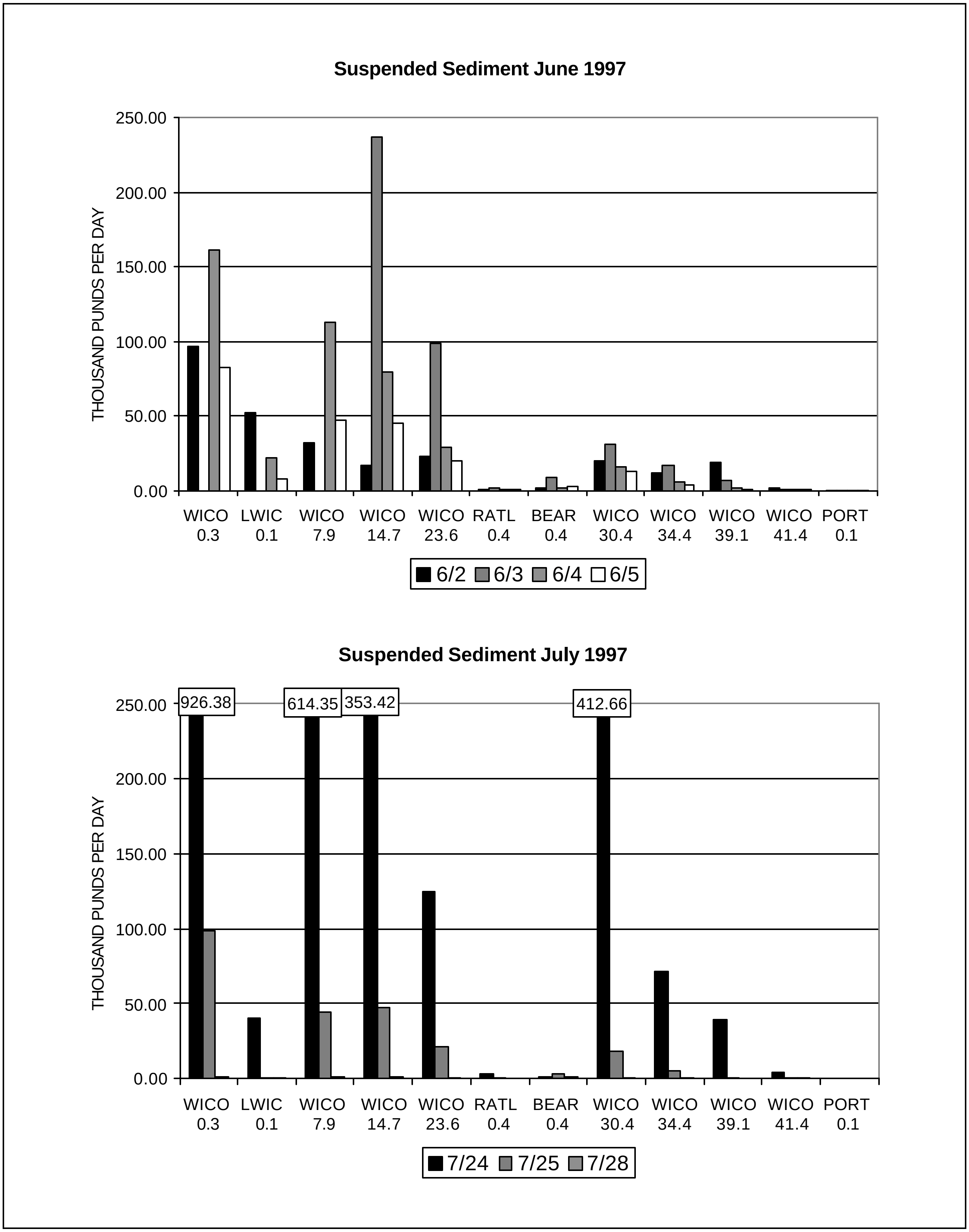

Figure 17. Wiconisco Creek Watershed Suspended-Sediment Loads, June and July 1997

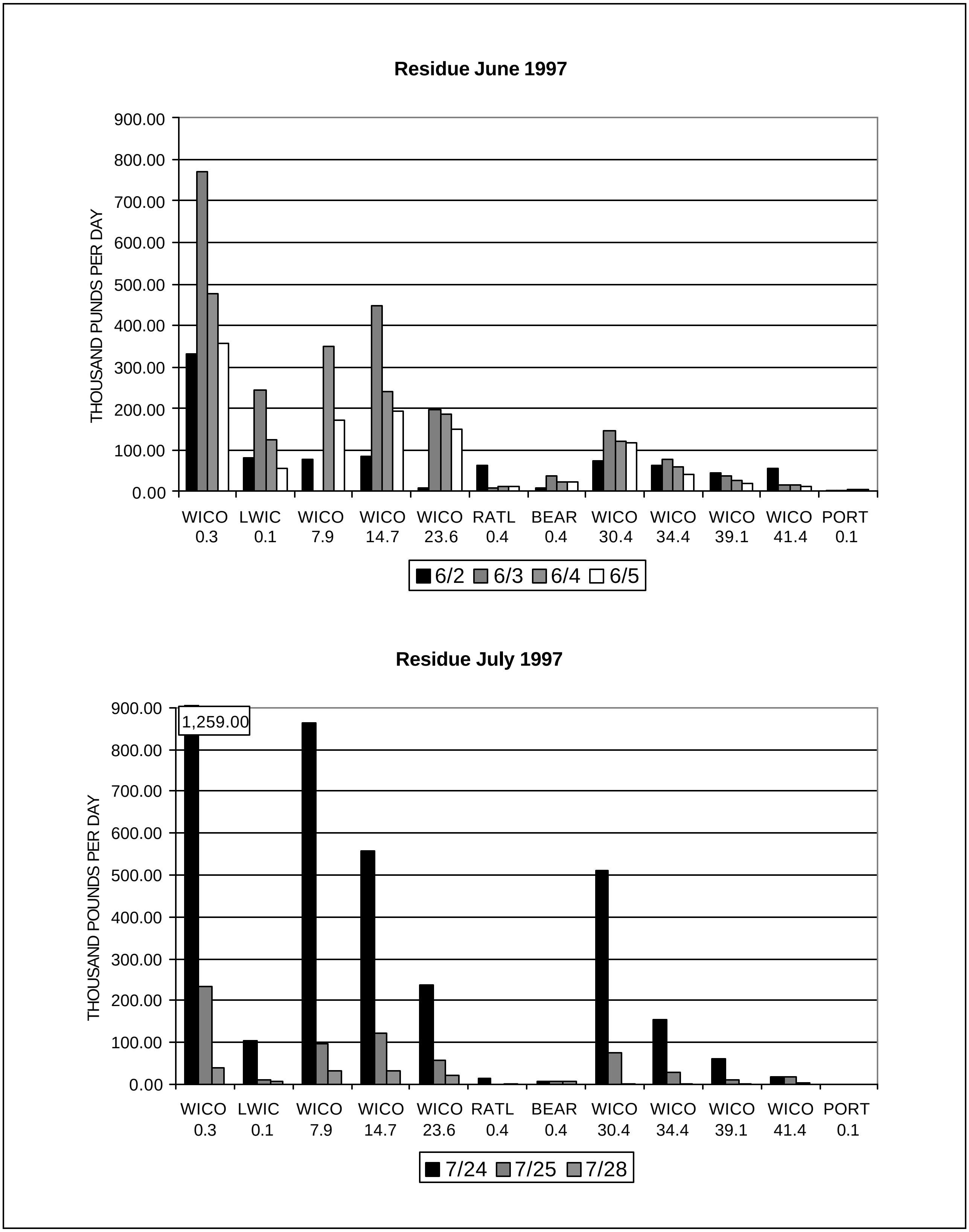

Figure 18. Wiconisco Creek Watershed Residue, June and July 1997

Table 12. Wiconisco Creek Electrofishing Results, September 11, 1998

Number of Individuals	Species	Common Name	Size (Inches)	Comments
Bear Creek at Bear 4.0				
3	*Salvelinus fontinalis*	Brook Trout	10.0, 10.5, 11.5	One fish appeared to be wild.
Wiconisco Above Bear Creek				
5	*Catastomus commersoni*	White Sucker	12.25, 10.5, 10.25, 8, 8	Not able to shock main channel because it was too deep. Shocking time ~ 10 minutes.
1	*Esox niger*	Chain Pickerel	8.5	
1	*Etheostoma blenoides*	Greenside Darter		
11	*Etheostoma olmstedi*	Tessellated Darter		
5	*Exoglossum maxillingua*	Cutlips Minnow		
1	*Hypertelium Nigricans*	Northern Hognose Sucker		
Wiconisco Below Bear Creek				
Abundant	*Catastomus commersoni*	White Sucker	All size classes	Missed numerous White Suckers and other small fish, including darters and minnows. Shocking time ~ 10 minutes.
4	*Esox niger*	Chain Pickerel	14.75, 11.5, 9, 4.75	
20	*Etheostoma olmstedi*	Tessellated Darter		
2	*Exoglossum maxillingua*	Cutlips Minnow		
1	*Rhynichthys atratulus*	Blacknose Dace		
1	*Rhynichthys cataractae*	Longnose Dace		
4	*Salmo trutta*	Brown Trout	15, 11.5, 11, 10.25	
2	*Salvelinus fontinalis*	Brook Trout	11.5, 9.75	
8	*Semotilus corporalis*	Fallfish	9.25, 7.75, 5, 4, 4	

Table 13. Wiconisco Creek Electrofishing Results, September 21, 1998

Number of Individuals	Species	Common Name	Size (Inches)	Comments
Wiconisco Above Bear Creek				
9	*Catastomus commersoni*	White Sucker	15, 14.5, 11, 10.5, 8.75, 4.5, 5.5, 3.75, 1.5	Not able to shock some of the main channel because it was too deep. Shocking time about 15 minutes.
4	*Esox niger*	Chain Pickerel	13, 13, 4.5, 6.5	
5	*Etheostoma blenoides*	Greenside Darter	4.5, 4	
28	*Etheostoma olmstedi*	Tessellated Darter		
1	*Lepomis macrochirus*	Bluegill	3.5	
1	*Percina peltata*	Shield Darter		
Wiconisco Below Bear and Rattling Creek				
3	*Campostoma anomalum*	Central Stoneroller		Missed numerous White Suckers and other small fish, including darters and minnows. Shocking time ~ 10 minutes.
Abundant	*Catastomus commersoni*	White Sucker	All size classes	
8	*Etheostoma blenoides*	Greenside Darter		
7	*Etheostoma olmstedi*	Tessellated Darter		
1	*Exoglossum maxillingua*	Cutlips Minnow	4.5	
1	*Hypertelium Nigricans*	Northern Hognose Sucker	5.75	
1	*Lepomis macrochirus*	Bluegill	3.5	
3	*Percina peltata*	Shield Darter		
62	*Rhynichthys atratulus*	Blacknose Dace		
26	*Rhynichthys cataractae*	Longnose Dace		
1	*Salvelinus fontinalis*	Brook Trout	11.5	
18	*Semotilus corporalis*	Fallfish	4.75, 4.5, 3.5, 3.5	
Rattling Creek at Mouth				
2	*Esox niger*	Chain Pickerel	6.5, 4.5	Water was clear, low, and shallow.
4	*Etheostoma blenoides*	Greenside Darter		
4	*Etheostoma nigrum*	Johnny Darter		
1	*Etheostoma olmstedi*	Tessellated Darter		
1	*Percina peltata*	Shield Darter		
Abundant	*Rhynichthys atratulus*	Blacknose Dace		
Abundant	*Rhynichthys cataractae*	Longnose Dace		
1	*Semotilus atromaculatus*	Creek Chub	5.5	
Present	*Semotilus corporalis*	Fallfish	4.75, 4.5, 3.5, 3.5	
Rattling Creek Above Reservoirs				
3	*Salmo trutta*	Brown Trout	10, 9.25, 9	Sedimentation in stream channel, and present in bars on streambank.
15	*Salvelinus fontinalis*	Brook Trout	7.75, 7.5, 6.5, 3-5.5, 4.75, 3.75, 3.5 3.25, 2-3.0, 2.75	

Manganese (Figure 13) and iron loads (Figure 14) responded similarly in both the June and July storms. Loads of these metals were elevated at both WICO 34.4 and WICO 30.4 and may be due to the flushing of metal precipitates stored in the stream channel and wetlands upstream. The Big Lick Tunnel discharge was believed to be the cause of increased metal loads between WICO 34.4 and WICO 30.4, which can be seen in the graphs showing metal loads (Figures 13 and 14).

Acidity (Figure 15) and alkalinity (Figure 16) graphs reveal some abnormalities between WICO 14.7 and WICO 7.9. A spike in the acidity graph in both June and July, despite decreasing flow, indicates an anomalous influx of acidic material. Alkaline substances such as limestone from fields or naturally occurring calcareous substances partially buffer the acidity of the stream, but Wiconisco Creek was net acidic at these sites.

Suspended sediments (Figure 17) and residue (Figure 18) graphs also show an increase near WICO 14.7. This increase is believed to be a result of agricultural runoff and the scouring of accumulated sediment by increased stream velocity. A spike in the graph at WICO 30.4 is probably due to the influence of solid metal precipitates entering the stream from the Big Lick Tunnel discharge. Sedimentation in Wiconisco Creek is one of the biggest problems in the lower portion of the watershed, as illustrated by the high loads shown in Figure 17.

Nutrient graphs displayed a relationship that appeared to mirror the flow graphs. Loads increased at sites nearer the mouth of Wiconisco Creek, but these increases were reflective of higher flows. There was greater loading of nutrients in the Lower and Little Wiconisco Basins, but this was expected due to the increased amount of agriculture in these basins.

Electrofishing

Electrofishing was conducted to document the usability of Wiconisco Creek and tributaries by fish, especially trout species. All fish were collected and identified, and trout species were measured. All fish also were examined for anomalies.

Bear Creek

Although turbidity of the water may have hindered shocking success, three brook trout (*Salvelinus fontinalis)* were recorded. Since trout are fish that move toward colder water, especially in the fall of the year when large creeks get warmer, it is believed that the trout found in Bear Creek moved into this area seeking cold water (Site 1, Figure 7). The temperature was 14° C at the time of sampling.

Rattling Creek

A naturally reproducing brook trout fishery exists above the reservoir on the West Branch of Rattling Creek (Site 5, Figure 7). A healthy population of brook trout of all size classes was recorded, and brown trout (*Salmo trutta*) also were recorded in this area. Only adult brown trout were present, and they are believed to have moved up into the creek from the reservoir.

The population of fish changed dramatically in the area from the outflow of the reservoir downstream to the mouth of Rattling Creek (Site 5, Figure 7). The population shifted from trout species to a community consisting of dace (*Rhynichthys sp*.), darters (*Etheostoma and Percina sp*.), fallfish (*Semotilus corporalis*), and creek chubs (*Semotilus atromaculatus*). Temperatures at both sites exceeded of the standard of 60° F for HQ-CWF. Temperature was 5°C warmer at the mouth, compared to the site above the reservoir (21°C (69.8° F) and 16°C (60.8° F), respectively). The pH also increased from 5.6 to 6.8.

Wiconisco Creek

Wiconisco Creek above the confluence of Bear Creek (Site 2, Figure 7) possessed a fish population suggesting a stressed warm water fishery. There was an abundance of fish, but the diversity of species was low. Lack of trout in the sample was believed to be due to the warm temperature and high acidity of the water in

Wiconisco Creek. Fish present at this site were more tolerant of low pH than trout.

Fish in Wiconisco Creek were congregated near the mouth of Bear Creek (Site 3, Figure 7) in September, probably due to the input of cold, alkaline water from Bear Creek. Cold water fishes such as trout will seek and move into areas of colder water when the main creeks warm in late summer. Wiconisco Creek, just below the mouth of Bear Creek, possessed a diverse population of cold and warm water species, including brook and brown trout, darters, minnows, and suckers (Table 8).

Below Rattling Creek (Site 4, Figure 7), the temperature was 16°C (60.8° F), and the pH was 7.2. One adult brook trout was recorded at this site, and many other fish were missed due to poor shocking conditions, including high turbidity and deep pools. The other fish in this sample were species typically found in warm water streams. The abundance and diversity of fish sampled below both tributaries reflects the dilution and buffering effects of Bear and Rattling Creeks.

PROBLEMS, NEEDS, AND OPPORTUNITIES

Many natural resource problems contribute to degraded aquatic resources in the Wiconisco Creek Watershed. Degraded conditions result in the loss of many beneficial uses of surface water, and some factors have potential to impact ground water and drinking water supplies.

Problems identified in the Wiconisco Creek Watershed include:

- Degraded surface water quality;
- Impaired instream and riparian habitats;
- Reduced and impaired recreational fisheries and water contact opportunities;
- Impacted cold- and warm-water fishes and aquatic macroinvertebrates;
- Lost domestic, agricultural, and livestock water supplies;
- Affected water conveyance structures;
- Increased undesirable sights and offensive odors;
- Stormwater runoff; and
- Decreased property values.

Degraded surface water quality is a result of several factors, including point source discharges and nonpoint source runoff from agricultural and mining land. Mine tunnel discharges, runoff from unreclaimed strip mines, and spoil piles add sediment to the stream, especially during storm events, causing instream and riparian habitat to be degraded. Impaired water-based recreation, impacts to aquatic life, and loss of water supplies are primarily due to the degraded surface water quality. Decreased property values result from a loss of recreational activities and visual impacts of degraded surface water.

Solving these identified problems in the watershed provides the opportunity to enhance ecological, social, and economic values such as:

- Improved aesthetics
- Increased property values
- Improved fish and wildlife habitat
- Increased biodiversity
- Enhanced wetland habitat
- Improved livestock health
- Reduced risk to human health
- Enhanced agricultural production
- Improved status of agriculture in the community
- Enhanced environmental awareness in the watershed

Degraded Surface Water Quality

Surface water degradation is prevalent in many areas of the Wiconisco Creek Watershed, especially the headwaters area. Several deep mine drainage tunnels, as well as runoff from coal mine related refuse areas in the Upper Basin, contribute to the low pH, high metal concentrations, and high turbidity values in this area.

Water quality is degraded in the Bear Creek Basin due to low pH in the headwaters and high concentrations of suspended metals in the lower half of the stream. Mine discharges in the Bear

Creek Watershed cause it to be choked with metal oxides.

Rattling Creek is one of the most pristine watersheds in the Wiconisco Creek Watershed, but water quality in the watershed is affected by acid precipitation and the geology's lack of buffering capacity. The sandstone geology, combined with high gradients, also causes problems with sedimentation and turbidity.

Water quality in streams in the Wiconisco Creek Watershed west of Loyalton, Pa., is markedly improved in comparison to the Upper Basin, but there are impacts related to agricultural problems. Elevated nutrient concentrations and turbidity typical of agricultural runoff are evident in both baseflow and stormflow samples.

Impaired Instream and Riparian Habitats

Instream habitat is severely to moderately degraded throughout parts of the Wiconisco Creek Watershed. Sedimentation contributes to degradation of instream habitats by causing physical changes that change aquatic communities. Silty sediments prevent fish spawning and eliminate suitable macroinvertabrate attachment areas.

The sources of sediment are highly varied, and occur in a number of locations in the watershed. Sediment in the Upper Basin (main stem east of Loyalton) is mostly metal precipitates from mine drainage tunnels and coal fines from unreclaimed (unvegetated) spoil and culm (waste coal) banks. Embedded habitat in this area deters macroinvertebrate attachment, and high turbidity and suspended sediment prohibit filter feeders from colonizing the stream substance. Toxicity of sediments with metals has not been documented.

Sediments in Bear Creek are primarily from metal precipitates from mine discharges. Iron and aluminum precipitates coat rocks and cause the stream to be devoid of aquatic macroinvertebrates. The presence of brook trout, found by the SRBC and Dauphin County Conservation District (DCCD) in 1998, demonstrates that Bear Creek supports some fish. The reduction of sedimentation and establishment of a macroinvertebrate community need to take place before a healthy community of fish can inhabit this area.

Rattling Creek Basin also is plagued by sedimentation. Sedimentation in Rattling Creek is due to natural weathering and erosion of sandstone and runoff from secondary roads. Sedimentation is increased by logging operations and encroachment on stream buffer areas.

In the western part of the watershed, including the Little Wiconisco Creek Watershed, sedimentation is due to a loss of forested riparian buffer zones, erosion from crop and pasture lands, and trampling of stream banks by livestock.

Reduced and Impaired Recreational Fisheries and Water Contact Opportunities

Fishing

Stream water quality degradation, due to the influence of mine drainage discharges, high suspended-sediment loads, high sedimentation rates, and loss of stable streambanks, results in degradation of the recreational fisheries in the watershed. Temperatures in headwater streams, including the main stem of Wiconisco Creek, are suitable for trout, but degraded water quality prohibits the establishment of a sustainable population of trout. The presence of a breeding trout population in Rattling Creek suggests that Bear Creek and Wiconisco Creek above Lykens could support increased numbers of trout if water quality and habitat problems were remedied.

Undesirable aesthetic conditions may deter anglers from using some streams, despite the presence of fish. Anglers may avoid using stretches of creeks due to adverse odors, the presence of refuse in the flood plain, and high turbidity/suspended sediments in the water, which make angling unpleasant. Increased appreciation for renewed quality of streams associated with this restoration plan could lead to public support for riparian cleanup.

Water contact opportunities

Degraded water quality, sedimentation, and high turbidity negatively impact water contact activities such as wading, swimming, and water play. Water play, especially by children, is evident in Rattling Creek near parks in the Lykens area. In other parts of the Wiconisco Creek Watershed, water contact opportunities are impeded by the unpleasant condition of the waterway. Incidental use of surface waters for water contact activities is expected to increase with increased residential development of this area.

Adverse Impacts to Cold and Warm Water Fishes and Aquatic Macroinvertebrates

Degraded water quality (low pH, high metals, and nutrients), excess sedimentation, and high turbidity have degraded aquatic communities in the Wiconisco Creek Watershed. Degraded conditions in some portions of the watershed render it devoid of aquatic life. Decades of mining throughout the upper headwaters of the watershed have resulted in a stream that is incapable of supporting a naturally-balanced aquatic community. A lack of suitable substrate material and degraded water quality are believed to be the main causes of the deficient biological community. Without a macroinvertebrate community as a food base, the capacity of the stream to support a healthy fish population is severely reduced.

Affected Water Conveyance

Elevated sediment loads running off into storm drains and other water conveyance structures hinder water flow and effectiveness of these systems. Stabilizing barren areas, including spoil piles, culm banks, and abandoned strip mines, will reduce sediment runoff, thus increasing the effectiveness and life span of the water conveyance systems.

Degradation of support timbers in the Porter Tunnel poses a potential threat to the stability of Route 209 near Muir, Pa. Periodic inspection and maintenance of this passage is recommended to ensure the safety of Pa. Route 209.

Loss of Domestic, Agricultural, and Livestock Water Supplies

Due to degraded surface water quality, waters that could be used for livestock, irrigation, or domestic water supply are not available. Low pH, high turbidity, and suspended and dissolved metals make water unsafe for consumption.

Increased Undesirable Sights and Offensive Odors

Stream degradation due to mining, agriculture, and other human activities has left parts of the Wiconisco Creek Watershed with aesthetic problems. Land disturbed from past mining operations can still be seen throughout the watershed between Lykens and Tower City, and the presence of wastes within the stream corridor results in visual degradation of the watershed. Actual stream channel degradation ranges from orange/red metal precipitates in the Upper Basin and Bear Creek Watersheds, black/gray coal fines in the upper watershed, milky/brown agricultural runoff in the lower basin, to a mixture of these impairments (Plate 2). Offensive odors emitted from sulfur-rich mine discharges and agricultural waste disposal occur in the watershed. Continued growth and development within the watershed, especially in close proximity to these areas, may cause tension within the community.

Stormwater Runoff

Build-up of sediment in the stream channel, loss of holding capacity of wetlands, and an increase in impervious surfaces, as a result of development, lead to more extreme peaks in flow during storm events. Downstream areas in the Susquehanna River are affected by increased sediment, nutrients, and metal loading due to the scouring of the Wiconisco Creek stream channel during storms.

Decreased Property Values

Poor water quality, presence of spoil piles, and unreclaimed mine lands have reduced property values in the Wiconisco Creek Watershed.

REMEDIATION AND PROTECTION OPTIONS

Environmental Treatment Options Considered for Mining Remediation

Physical and chemical treatment of contaminated coal mine drainage

The installation of physical and chemical treatment mechanisms at each discharge site in Wiconisco Creek is impractical due to high installation, operation, and maintenance costs. In the past, such facilities were built to treat mine drainage. Now, more cost-effective, passive treatment systems are available.

Passive treatment of contaminated coal mine drainage

The passive treatment of coal mine drainage has advanced considerably in the last decade (Brodie,1990; Faulkner and Skousen, 1993; Hedin and others, 1994; Hellier and others, 1994; Hedin, 1996). Increased confidence in the effectiveness of passive treatment systems has resulted in new regulations that encourage passive treatment at permitted mine sites (Pennsylvania Code, Title 25, Chapter 87, Section 102.). Federal and state reclamation programs have substantially increased expenditures on passive systems at abandoned sites. Most stream restoration efforts in the Appalachian coal fields are economically justified with the use of passive treatment techniques.

An important advance in the evolution of passive technology was the recognition of the variability of mine water chemistry and its importance in designing efficient, effective treatment systems. While polluting discharges from coal mines are ubiquitously referred to as "acid" mine drainage, many are, in fact, alkaline. The alkaline discharges, particularly common from flooded underground coal mines, are primarily contaminated with ferrous iron and, secondarily, with manganese. Alkaline discharges are effectively treated with sedimentation ponds and constructed wetlands that provide the aeration and retention necessary to naturally precipitate the metal contaminants. No alkaline materials are necessary because the water is already neutralized by naturally-occurring bicarbonate ions.

When mine water is acidic, treatment requires the generation of alkalinity and the precipitation of metals. The most reliable technique for satisfying these requirements is pretreatment of the acidic water with an appropriate quantity of limestone (which generates alkalinity), followed by flow through ponds and wetlands (which precipitate the metals). Anoxic limestone drains (ALDs) are buried beds of limestone aggregate that generate alkalinity. ALDs are increasingly common components of passive systems in the bituminous coal fields. ALDs have proven capable of generating 150 to 300 milligrams per liter (mg/l) alkalinity for eight years (or more), with minimal operation and maintenance requirements (Turner and McCoy, 1990; Watzlaf and Hedin, 1993; Hedin and others, 1994; Hedin and Watzlaf, 1994). ALDs that contain enough limestone to theoretically last for decades are being constructed. The drawback of ALDs is that they are most appropriate for anoxic acidic water contaminated with dissolved ferrous iron and manganese. Waters containing ferric iron or aluminum (Al) are not appropriate because both ions precipitate within the ALD, potentially decreasing its permeability and reactivity. ALDs constructed to treat acidic water containing these ions in concentrations greater than 20 mg/l have failed within months of their construction.

Unfortunately, many acidic mine waters contain ferric iron (Fe) and aluminum (Al). Passive treatment of these waters is occurring with innovative systems having variable performance records and less certain long-term reliability than ALDs and constructed wetlands. The most common approach is the construction of *vertical flow ponds* (VFP) that contain limestone overlain by an organic substrate. Water flows down through the organic substrate, into the limestone aggregate, and into an underdrain system that discharges to a pond or constructed wetland. As water flows through the organic substrate, microbial activity reduces the ferric iron to ferrous iron and precipitates a portion of the iron. Aluminum precipitates within the organic substrate and the limestone aggregate. Alkalinity is generated by microbial processes in the organic substrate and limestone dissolution.

The performance of VFPs can be dramatic—complete removal of Al, substantial removal of Fe, and a discharge with neutral pH. However, the accumulation of metal solids within the organic substrate and limestone is problematic because it eventually armors or plugs the substrates. When this occurs, less water flows through the system, and the water is less effectively treated. Despite uncertainties, VFPs are being constructed by many private companies and public restoration groups throughout Appalachia.

Short descriptions of the primary units utilized in passive mine water treatment systems are presented below.

Passive treatment components

Sedimentation pond—A sedimentation pond is intended to collect iron solids. At the iron concentrations observed for Wiconisco Creek discharges (10-20 mg/l), iron solids would accumulate in the ponds at a rate of 0.5 to 1.0 inches per year. Sedimentation ponds generally are constructed with depths of 4 to 6 feet, so they have decades of iron oxide sludge storage capacity. Recently, the idea that iron oxides might be recovered from passive systems for sale has attracted attention (Hedin, 1998). If this option is pursued, the ponds could be designed in a manner to facilitate the periodic removal of the iron oxide solids.

***Constructed wetland*—**A wetland is intended to polish the discharge of a sedimentation pond or vertical flow pond. The wetland is constructed with a fertile soil substrate and planted with emergent wetland plant species (typically cattails and bulrushes). Water depths are 3 to 6 inches. The water level in the wetland is maintained by the overflow structure, which can be gradually raised if the accumulation of organic matter and sludge causes short-circuiting of flow paths. Iron solids accumulate in wetlands at a rate of approximately 0.2 to 0.5 inch per year. Berms are sized to allow the accumulation of organic matter and iron sludge over the lifetime of the system.

Anoxic limestone drain—An anoxic limestone drain (ALD) is a buried bed of limestone gravel that generates alkalinity through the dissolution of limestone. The quantity of limestone included in the ALD is calculated from 25 years of expected limestone dissolution plus the targeted performance under the design high flow conditions. Calcitic limestone with at least 85 percent $CaCO_3$ content is preferred. The limestone aggregate is placed in an excavated rectangular pit, covered with plastic, and buried with 2 to 3 feet of soil or spoil. Mine water enters one end of the limestone bed and is collected from the opposite end by a manifold system. The water level in the ALD is maintained at the top of the limestone through proper positioning the effluent pipe.

Vertical flow pond—A vertical flow pond (VFP) is a combination of limestone and organic substrate that retains metals, decreases acidity, and generates alkalinity. Water flows from the surface, downward through the substrate and limestone gravel, and into an underdrain system. The recommended VFP design contains 2 feet of surface water, overlying 1 foot of organic substrate, which overlies 2 feet of limestone aggregate. The organic substrate is sometimes amended with limestone aggregate (25 percent by volume) to increase its acid neutralization capability. An underdrain plumbing system, which is constructed with perforated drainage pipe that feeds into a solid manifold, is placed at the bottom of the limestone aggregate bed. The manifold connects to solid pipe that passes through the berm and rises to an elevation consistent with the designed water level. The emergency spillway is placed 2 to 3 feet above the design water level and provides the capacity for water storage during high flow events and allows the passive development of additional head (Figure 19).

Successive alkalinity producing system—The successive alkalinity producing system (SAPS) was proposed by Damariscotta, an environmental consulting firm in Clarion, Pa. (Kepler and McCleary, 1994). A SAPS consists of a VFP, followed by a sedimentation pond. The VFP generates alkalinity and removes Al, while the sedimentation pond precipitates Fe. If more alkalinity generation and Fe removal are required, a second VFP/pond combination is constructed downstream of the first VFP/pond. SAPS can be

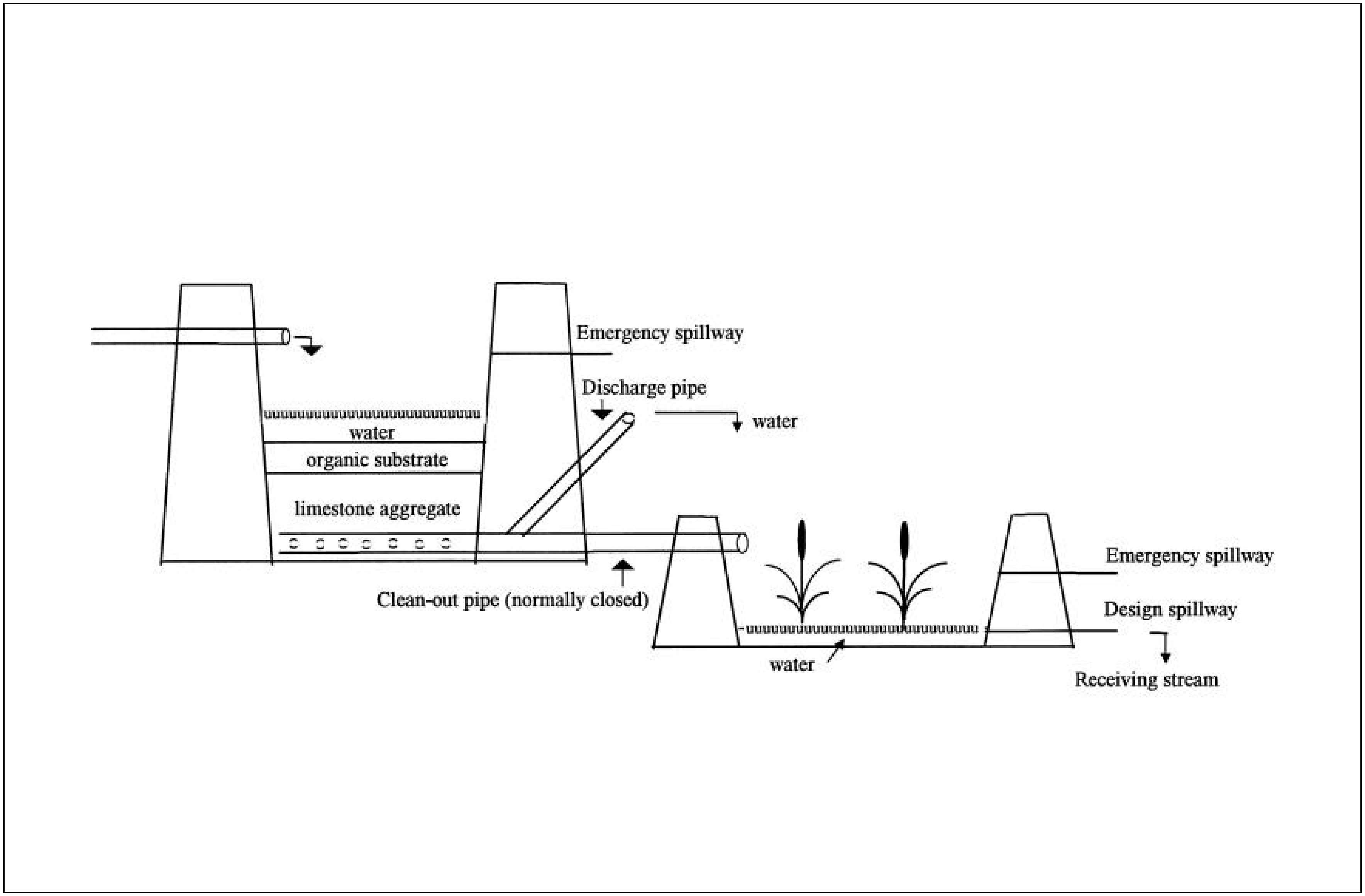

Figure 19. General Schematic of a Vertical Flow Pond Followed by a Constructed Wetland

constructed that, through successive treatment, neutralize many hundreds or thousands of mg/l of acidity. Kepler and McCleary (1994) have recently adapted the SAPS concept to facilitate the flushing and recovery of Al solids that may have marketable value.

Limestone sand dosing—Limestone sand dosing generates alkalinity, decreases acidity, and increases pH. Limestone sand is placed directly in the stream channel where the acidity of the water dissolves the limestone. Because the sand particles are small, the rate of dissolution is generally greater than the rate at which iron precipitate coats the stone. Hydraulic action agitates the sand particles, helping to keep them free of metal precipitates. The increase in alkalinity, decrease in acidity, and increase in pH result in precipitation of metals from the water. Metals settle out of the water and are deposited on the stream bottom. This treatment is effective for treating both acidic mine water and streams affected by acidic precipitation.

Limestone diversion well—A limestone diversion well generates alkalinity and decreases acidity by acidic water reacting with limestone. A limestone diversion well is a structure that is filled with limestone gravel. Water is piped into the diversion well and is released at the bottom of the limestone through a manifold. Hydraulic action churns and pulverizes the limestone gravel to increase the dissolution rate of the limestone. Diversion wells work best on streams with high gradient and flow that is sufficient to provide enough hydraulic head to agitate and pulverize the limestone gravel. This system requires extensive maintenance because it can use up to a ton of gravel per week.

Best Management Practices for Use on Agricultural and Urban Lands

Highlights on Best Management Practices
(Chesapeake Bay Program Homepage)

Nonpoint source runoff from agriculture and urban areas has been treated using a wide array of Best Management Practices (BMPs) designed to reduce or prevent runoff of nutrients and sediments. Several examples of the more widely applied practices are described below. Much of this information is described as it relates to the Chesapeake Bay Watershed Model (Chesapeake Bay Program, 1998).

Agricultural practices

Substantial progress is expected from farmers implementing BMPs contained in farm plans and nutrient management plans. These BMPs include a range of different practices that reduce or eliminate soil loss and provide for the proper application rates of nutrients to cropland. The types of agricultural/silvicultural BMPs included in the Chesapeake Bay Watershed Model simulations are: cropland nutrient management, soil conservation water quality plan implementation, animal waste BMPs, barnyard runoff control, rotational grazing, streambank protection, forest harvesting BMPs, nutrient management plans, forested and grass buffer strips, and cover crops.

Cropland nutrient management—Cropland nutrient management is the net pound reduction of fertilizers applied to conventional tillage, conservation tillage, and hayland acres. Fertilizer reductions are enacted as a part of cropland nutrient management in order to only apply nutrients at rates that ensure adequate soil fertility for crop production, thus reducing the availability of excess nutrients to runoff waters. The nutrient management application rates are according to the appropriate agronomic rate for each crop, with a minimum reduction of 10 percent. Maximum nutrient fertilizer reductions are determined from an analysis of available nutrients versus expected crop uptake. Nutrient reduction efficiencies range from 5 to 39 percent for nitrogen and

5 to 35 percent for phosphorous, when calculated from nutrient fertilizer pound reductions (Chesapeake Bay Program, 1998).

Soil conservation and water quality plan—Soil conservation and water quality plans are comprehensive plans that address natural resource management concerns on agricultural lands and utilize BMPs to control erosion and runoff. A USDA professional and/or a Soil Conservation District employee assists in developing these plans at the request of a landowner. They work with farmers to determine which BMPs and/or systems are needed to address specific erosion and/or runoff problems on farms. Together, these practices control erosion (within acceptable levels) in a manner compatible with the farm operation and cropping systems. Soil conservation and water quality plans are based on current farming objectives and should be reviewed and/or revised if changes occur. Nutrient reductions are only one of many benefits derived from soil conservation and water quality plans. Other benefits include, but are not limited to, better soil quality (therefore better crop yields), the establishment of constructed ponds, and the enhancement of wildlife and plant habitats (Chesapeake Bay Program, 1998).

Manure application to cropland—It is assumed that all manure voided in unconfined areas occurs in pasturelands. The application rate for each crop type is determined to allow for the comparison between the amount of manure produced in collectible/confined areas and that applied to agricultural lands. Using the total acreage for each crop type (conventional tillage, conservation tillage, and hayland) and the respective application rates, total nutrients applied for a given crop type are calculated. Adding the three crop types together yields the total nutrients from manure applied to cropland (Chesapeake Bay Program, 1998).

Grazing land rotation—The rotation of livestock on grazing land limits the manure load and other impacts of livestock to pasture. Benefits of this BMP include improved infiltration/runoff characteristics, healthier grass stands, reduced need for fertilizers, and reduced erosion. It is estimated that the nitrogen and phosphorous load is reduced by 50 percent, and suspended-sediment loads are reduced by 25 percent for pastures utilizing grazing rotation. See the description of stream protection practices (below) for an explanation of how this BMP is incorporated into pasture management (Chesapeake Bay Program, 1998).

Cover crops—This BMP refers to (non-harvested) cover crops planted for nutrient removal. This BMP is more prevalent in the lower Chesapeake basin, due to the longer growing season. Significant amounts of nitrogen may remain in the soil after harvest, regardless of yield, especially during drought years. Nitrate nitrogen is particularly subject to leaching to ground water over the winter if substantial amounts are in the soil in the fall. Small grains (i.e., rye, barley, wheat) planted without fertilizer in late summer or early fall will greatly reduce nitrate leaching losses. These small grains use the nitrogen as they grow, provided root growth is sufficient to reach the available nitrogen. (Proper timing of cover crop plow-down in spring releases "trapped" nitrogen for use by the following crop.) Cover crops also help reduce phosphorus losses through reduced soil erosion.

While nutrient reduction is the principal benefit of cover crops, the quality of the soil also may be improved in the long term. Cover crop acres are assumed to be in the conventional and conservation tillage land uses, and will receive average reductions of 43 percent for nitrogen and 15 percent for phosphorus and sediment (Chesapeake Bay Program, 1998).

Conservation tillage (conversion)—Conservation tillage involves planting and growing crops with minimal disturbance of the surface soil using a noninversion plowing technique, while maintaining a 30 percent minimum crop residue cover on the soil surface. No-till farming is a form of conservation tillage in which the crop is seeded directly into slits cut into the soil; therefore, no tillage of the soil surface is needed. Minimum tillage farming involves some disturbance of the soil surface, but maintains a minimum of 30 percent crop residue on the surface. Research has shown that, with at least 30 percent of the crop residue remaining at the time of planting, the amount of erosion and resultant nutrient loss are substantially reduced (Chesapeake Bay Program, 1998).

Animal waste management practices

Substantial benefits in reductions of nutrients and improved water quality, in both surface and ground water, can be achieved through the adoption of state-of-the-art animal waste management systems. These include manure storage structures, runoff controls for barnyards, guttering and nutrient management. These systems address the handling, storage, transport, and utilization of animal waste as fertilizer on cropland.

***Runoff control for animal confinement areas*—**A facility with an existing animal waste storage structure may not have runoff controls for animal confinement areas. As a result, runoff from up-slope areas and roof flows to feedlots can carry waste nutrients to surface water bodies. In some cases, excess runoff flows into waste lagoons to cause overflow problems. Animal confinement runoff control consists of practices such as up-slope diversions and directed downspouts to minimize off-site water entering the facility. In some cases, improved conditions at the confinement facility can improve animal health and production. Both supplemental and full runoff control systems can be installed. Supplemental systems are those installed in addition to a waste storage structure. Full systems are installed at a site without a preexisting storage structure. Implementation of a full system (without a waste storage system) reduces current nutrient loads by an estimated 75 percent for nitrogen, phosphorus, and sediment. A supplemental system (with a waste storage system) can reduce nutrient loads by an additional 10 percent for nitrogen, phosphorus, and suspended sediment beyond those reductions gained by the storage structure (Chesapeake Bay Program, 1998).

Animal waste management systems—Agricultural livestock produces manure, and consequentially, nutrient flow into water supplies, which can impact Chesapeake Bay water quality (Ritler and Scarbourgh, 1996; Evanylo, 1995). Understanding such an influence is important in modeling nutrient loads from land uses, both from surface and subsurface flow (Johnson and Parker, 1993). Nutrients in manure are a vital resource and can be collected for application to cropland (Krider, 1992; Graves 1986).

Manure from agricultural livestock may either be voided in confined areas or unconfined areas (Gilbertson, 1979). These manure-acres are areas of high concentrations of confined animals in which a large amount of nutrient load runoff occurs. Manure-acres are representative of all portions of manure management, including manure in feedlots, production houses, processing centers, collection practices, and leakage from holding facilities.

Manure produced in confined areas can be properly or improperly stored (Loser and Hogan 1989). Animal waste management systems are designed for the proper handling, storage, and utilization of wastes generated from animal confinement operations. These systems include a means of collecting wastes and wash water from confinement areas into appropriate waste storage structures. Waste management facilities take on many forms, based on the animal type and handling method (i.e., solid, slurry, and liquid). Lagoons, ponds, and concrete tanks are used for the treatment and/or storage of liquid wastes. Storage sheds or pits are commonly used to store solid wastes. Adequate storage allows operators to apply manure to their land when crops can utilize the nutrients, and when the soil and weather conditions are appropriate. Animal waste management systems not only provide major nutrient reduction benefits, but also greatly reduce a farmer's need for chemical fertilizers.

Animal waste management system nutrient reductions for dairy/beef/swine operations have been estimated by the Chesapeake Bay Program Nutrient Subcommittee's Tributary Strategy Workgroup to be 80 percent for nitrogen and phosphorus, assuming that an animal waste system treats 145 animal units (or 1 manure-acre). Using the same 145 animal unit assumption, nutrient reductions for poultry animal waste systems have been determined to be 14 percent for nitrogen and phosphorus (Chesapeake Bay Program, 1998).

Estimated BMP efficiencies were developed separately for livestock (primarily dairy and swine) and poultry waste systems. Livestock manure must be stockpiled or spread daily if no storage system is available, resulting in a high potential for nutrient pollution to ground and surface water sources. On the other hand, poultry manure remains in the production house for a majority of the time. Small amounts of manure are removed with each flock (approximately every 7 weeks for broilers), and the entire production house is cleaned approximately every 2 years. Poultry manure is relatively dry, so if it is properly stacked outside, the potential for nutrient loss is less than that of livestock waste (Chesapeake Bay Program, 1998).

Riparian forest buffers and other buffers

Forested and other vegetated buffers serve as traps for nutrients and sediment from upland sites. Many jurisdictions are actively involved in establishing riparian forest buffers in the Susquehanna River Basin.

Tree planting (conversion)—The tree planting BMP includes any tree plantings on any site, except those along rivers and streams. Plantings along rivers and streams are considered riparian buffers and are treated differently. The tree planting BMP does not include reforestation. Reforestation replaces trees removed during timber harvest and does not result in an additional nutrient reduction or an increase in forest acreage (Chesapeake Bay Program, 1998).

Forest and grass buffers (conversion)—Buffers, which are linear strips of vegetation along rivers and streams, help to filter nutrients, sediment, and other pollutants carried in runoff, as well as excess nutrients in ground water. Buffers are assumed to be 100 feet wide on a streamside. Based on this buffer width, nutrient reductions are assumed to be 2 acres of upgradient land treated for each buffer acre.

Forest/grass buffers include both a land use conversion on the riparian area and a land use load reduction from upgradient land. Forest buffer land use conversion is a change in land use from cropland to forest. Grass buffer land use conversion is a change from cropland to pastureland.

Buffers also reduce nutrient loads from land adjacent to, and upgradient of, the buffer. Although soil types, vegetative type, width of buffer, and other factors alter a buffer's effectiveness, it is assumed that an acre of forest or grass buffer reduces loads from 2 acres of land adjacent to, and upgradient of the buffer (Chesapeake Bay Program, 1998).

Forestry BMPs—Forestry BMPs focus on minimizing the environmental impacts from forest harvesting operations such as road building, and harvesting and thinning operations. These BMPs reduce soil erosion and the loss of nutrients that adhere to the eroding soil particles. Timber harvesting is a regulated activity. Additional controls are required when working in nontidal wetlands, and along stream buffers.

Forest BMPs reduce the nutrient and suspended-sediment flow from the forest. The Chesapeake Bay Program Nutrient Subcommittee's Tributary Strategy Workgroup determines that, when BMPs are used during forest harvesting operations, a reduction of 50 percent of total nitrogen, total phosphorus, and total suspended-sediment loading is achieved (Chesapeake Bay Program, 1998).

Forest and grass buffers—Forest and grass buffers also have estimated nutrient reduction efficiencies. For forested buffers, the average reduction for nitrogen is estimated to be 57 percent, with an estimated 70 percent reduction for phosphorous and suspended sediment. Grass buffers have an average nutrient reduction estimated at 43 percent for nitrogen and 53 percent for phosphorous and sediment (Chesapeake Bay Program, 1998).

Stream protection practices

Implementation of stream protection practices, including stream fencing and alternative watering sites, has the potential to provide substantial reductions of sediment loadings.

Stream protection (with and without fencing)—Direct animal contact with surface waters, and associated streambank erosion, are primary causes of nutrient loss from pastures. Stream protection with fencing excludes livestock from land along streams. The fenced areas may be planted with trees or grass, but are typically not wide enough to provide the benefits of buffers. Stream fencing limits the lengths of streambanks where animals can enter into a stream, but does not exclude animals from entering the stream within limited watering and stream crossing areas (Chesapeake Bay Program, 1998).

Streambank fencing greatly reduces the nutrient losses from pasture, in addition to improving streambank stability, reducing sedimentation, and creating wildlife habitat. The establishment of 208 feet of streambank fencing results in a nutrient reduction equal to 75 percent of the load from 3 acres of pasture (Chesapeake Bay Program, 1998).

Stream protection without fencing involves the use of troughs or "water holes" away from streams. In some instances, trees are planted away from the stream to provide shade for the livestock. Research has indicated that these measures greatly reduce the time livestock spend in streams, decreasing nutrient losses (Chesapeake Bay Program, 1998).

The Chesapeake Bay Program Nutrient Subcommittee's Tributary Strategy Workgroup determined that stream protection with fencing reduces nutrient and suspended-sediment loads to pasture by 75 percent for total nitrogen, total phosphorous, and total suspended sediment. For stream protection without fencing, the reduction is an estimated 40 percent for total nitrogen, phosphorous, and sediment (Chesapeake Bay Program, 1998).

Urban practices

Urban BMPs have the potential to reduce erosion and sediment losses, as well as nutrients that are applied in urban/suburban areas. Urban BMPs are erosion and sediment control, extended stormwater detention (dry), pond-wetland systems, stormwater wetlands, retention ponds, stormwater retention structure conversions (dry to wet), sand filters, septic systems (pumping, connections, and denitrification), and urban nutrient management. The following section describes each of these BMPs. These practices are applied across a broad spectrum of sites ranging from industrial, commercial, and residential facility construction sites to lawns and open spaces.

Erosion and sediment controls—Erosion and sediment controls, including construction of sediment ponds and silt fencing, are applied to construction sites. Erosion and sediment controls reduce high nutrient and suspended-sediment loads during project construction.

Erosion and sediment controls primarily protect off-site areas from sediment runoff and nutrient pollution. Numerous technologies allow for the reduction of sediment from erodible lands. By retaining the soil on-site, nutrients attached to the sediment are prevented from leaving the disturbed area, thus reducing off-site impacts.

Incorporation of erosion and sediment controls results in the reduction of suspended sediment and nutrient loads from pervious urban land. Erosion and sediment controls are estimated to reduce nutrient loads from urban acres by 33 percent for total nitrogen and 50 percent for both total phosphorus and sediment.

Stormwater management systems—Stormwater management systems include extended detention areas (dry basins or ponds), retention ponds (wet), stormwater wetlands (one step), pond-wetland systems (series), stormwater retrofits, stormwater conversions (conversion from dry to retention), and sand filters. Nutrient reduction is not the only benefit provided by stormwater management systems; they also reduce sediment transport, and control peak runoff flows. Stormwater management systems with adequate storage and extended detention (1-year, 24-hour design criteria), can provide significant pollutant removal (Chesapeake Bay Program, 1998).

Stormwater retrofits are extended detention retention ponds, stormwater wetlands, or other water bodies designed to detection peak flows and nonpoint source nutrient loads generated on existing urban land developed before stormwater management systems were required. Retrofits provide the same reductions as new stormwater management practices and may be designed to reduce stormwater flows and/or control nutrients and sediment (Chesapeake Bay Program, 1998).

Stormwater conversions reduce nonpoint source pollution reductions from areas served by dry basins. Dry basins, without extended detention, are designed to control peak flows and provide relatively few water quality benefits. A stormwater conversion changes a detention basin to a retention pond. For a stormwater conversion, the estimated nutrient and suspended-sediment load reductions are 32 percent for total nitrogen loading, and 46 percent for both total phosphorus and total suspended-sediment loading (Chesapeake Bay Program, 1998).

Sand filters also are used to reduce urban nutrient loads. It is estimated that sand filters reduce the total nitrogen load by 30 percent, the total phosphorus load by 45 percent, and the total suspended-sediment load by 80 percent (Chesapeake Bay Program, 1998).

On-site wastewater management systems—For on-site wastewater management systems (OSWMS), commonly called septic systems, nutrient reductions are achieved through three types of management practices. These practices are frequent maintenance and pumping, connection of OSWMS to sewage treatment systems, and OSWMS denitrification. For all of these septic system BMPs, the nutrient reduction efficiency is applied only to nitrogen, as it is assumed that phosphorus is entirely treated by OSWMS.

Public education can promote on-site wastewater management system maintenance and inform people how these systems impact receiving waterbodies. When septic tanks are pumped and septage is removed, the on-site wastewater management system has an increased capacity to remove settable and floatable solids from the wastewater (Robillard and Martin, 1990a). Septic tank pumping promotes biological digestion of a portion of the solids and allows for storage space for the remaining undigested solid portion of the wastewater. OSWMS effluent flows out of septic tanks and into an underground soil adsorption system (field).

The pumping of septic tanks is one of several measures that can be implemented to protect soil adsorption systems from clogging and failing (Robillard and Martin, 1990b). This measure reduces the nitrogen loads by an estimated 5 percent. The level of BMP implementation is the number of systems implemented. A ratio is formed of the number of pumpouts reported and the total number of septic systems. If a system fails, soil adsorption fields are often unable to adequately filter and treat wastewater; consequently nontreated septic system effluent can drain directly into ground and surface water. Septic connections reduce total nitrogen load by an estimated 55 percent (Chesapeake Bay Program, 1998).

Denitrification in OSWMS is accomplished through a sand mound system with effluent recirculation. The nitrogen load is reduced by 50 percent (Chesapeake Bay Program, 1998).

FORMULATION OF ALTERNATIVES

When formulating the proposed alternatives, many social, economic, and ecological concerns were considered. Table 14 lists the concerns and the significance to the decision making process. “Degree of concern” reflects the importance of the concern to local interests or local, state, or federal laws. “Degree of significance to decision making” reflects the weight with which the concern was considered during the formulation of alternatives.

In the Wiconisco Creek Watershed, concerns with a high degree of significance to decision making include water quality, sediment damage, water-based recreation, aquatic resources, threatened and endangered species, riparian

Table 14. Identified Concerns in the Wiconisco Creek Watershed

Economic, Social, Ecological, and Cultural Concerns	Degree of Concern	Degree of Significance to Decision Making[1]	Issues/Actions
Aquatic Resources	High	High	Improve fishery and biodiversity
Riparian Forests	High	High	Slow the loss
Sediment Damage	High	High	Cropland runoff and mining damage
Socioeconomic Resource Base	High	High	Protect
Surface Water	High	High	Sediments, nutrients, metals, and pH
Threatened/Endangered Species	High	High	Protect/enhance habitat—Northern Bullrush
Visual/Aesthetic Resources	High	High	Preserve/enhance
Water-Based Recreation	High	High	Degraded water quality
Water Quantity	High	High	Degradation stresses biological community
Wetlands	High	Medium	Protect/restore/enhance
Cultural Resources	High	Low	Protect/preserve
Public Health	High	Low	Minimal problems
Flood Plain Urbanization	Medium	Medium	Population growth due to Rte 322 project
Flood Water Damage	Medium	Medium	Location of wetlands to trap sediment
Ground Water	Medium	Medium	Need more data
Wildlife Resources	Medium	Medium	Slow habitat loss
Air Quality	Low	Low	Reduce odors

[1]High—must be considered in the analysis of alternatives.
Medium—may be affected by some alternative solutions.
Low—need not be considered in analysis.

forests, visual and aesthetic resources, socioeconomic resource base, and relative costs.

Formulation Process

The formulation of alternatives involved an evaluation of all practical and pertinent methods of remediation of impaired water quality. The formulation process also included consideration of social effects of each alternative to prevent social, political, religious, and ethnic impacts of proposed solutions from inadvertently favoring or adversely impacting any particular group.

In compliance with Presidential Executive Order 11988, Flood Plain Management (1977), alternatives were developed to avoid adverse effects and incompatible development in the flood plain. In compliance with Presidential Executive Order 11990, Protection of Wetlands (1977), alternatives were developed to avoid adverse effects to wetlands. The potential for developing wetlands suitable for educational, recreational, and scientific purposes was considered.

Formulation of alternatives for the clean up of mining-related impacts was conducted by Hedin Environmental. Dr. Robert Hedin is a well-respected and published professional in mining-related remediation techniques. The proposed plan is detailed in the Hedin report (Appendix E).

RECOMMENDATIONS FOR THE RESTORATION OF AGRICULTURAL POLLUTION IN THE WICONISCO CREEK WATERSHED

SRBC staff utilized the Chesapeake Bay Program's nutrient management strategy to evaluate remediation in areas of the watershed impacted by various agricultural and developmental practices. The Chesapeake Bay Program and its members have done extensive research in the documentation of the effectiveness of available BMPs, and this information has been used in the Chesapeake Bay Watershed Model. Agricultural problems described in the Water Quality and Biological Assessment of the Wiconisco Creek Watershed will be recommended for remediation on an acre-by-acre basis. Estimation of BMP allocation is based on results presented in Nutrient Reduction Cost Effectiveness Analysis, 1996 Update (Edwards and Stoe, 1998). Averages have been adjusted to accommodate only the Wiconisco Creek Watershed portion of he Chesapeake Bay Model Watershed Segment 80 (Table 15.)

Results of the Cost-Effectiveness Evaluation of the Wiconisco Creek Watershed

Nonpoint source impacts within the Wiconisco Creek Watershed include impacts from agricultural activities, acid precipitation, and mine drainage. Because extensive farm inventories have not been conducted in Dauphin County, another method had to be used to evaluate agricultural remediation alternatives. SRBC developed remediation recommendations based on Pennsylvania's Chesapeake Bay Nutrient Reduction Strategy that outlines mandatory reduction goals, as defined by Chesapeake Bay Agreements (Pa. Department of Environmental Protection, 1994). "This agreement established the goal of reducing controllable nutrient loads measured during 1985 by 40 percent by the year 2000" (Pa. Department of Environmental Protection, 1994). To meet this goal, Pennsylvania must reduce nitrogen loads by 19.8 million pounds and phosphorous loads by 2.5 million pounds by the year 2000. To account for growth between 1985 and 2000, Pennsylvania agreed to maintain nutrient loads at a cap of 60 percent of the 1985 load. This loading cap translates to a maximum controllable load of 29.7 million pounds of nitrogen and 3.7 million pounds of phosphorous by the year 2000. This strategy involves both point and nonpoint source nutrient reduction. Nonpoint BMPs, point source retrofits, nutrient reduction rates, and available acreage for implementation are defined.

A copy of Pennsylvania's Chesapeake Bay Nutrient Reduction Strategy is available at http://www.dep.state.pa.us (subjects – watermgmt – Bur of Water Conserv – NPS mgmt.).

Table 15. Formulation of Acreages Used in the Analysis of Agricultural Land in the Wiconisco Creek Watershed (WCW)

1. Percent of WCW in Segment 80

   Acres WCW (74,449.92) / Total acres segment 80 (1,441,354) * 100 = Percent of Segment 80 in WCW (5.17%)

2. Acres per Land Use in WCW

   Acres per land use in segment 80 * percent in WCW = Acres per Land Use in WCW

3. Excess Urban Land

   Urban Acres in WCW from 2 (10,169.6) - Urban Acres in WCW (based on SRBC GIS) (2,574.7) = Excess Urban Acres (7,594.9)

4. <u>Total Agricultural Land in WCW</u>

   Conventional Tillage + Conservation Tillage + Hay Acres + Pasture Acres + Manure = Total Agriculture in WCW (23,720.1)

5. <u>Percent of Each Agricultural Land Use in WCW</u>

   Acres per Land Use in WCW / Total Agricultural Land in WCW (23,720.1) * 100 = Percent of Each Land Use in WCW

6. <u>Excess Urban Land Per Land Use</u>

   Excess Urban Acres * Percent of Each Land Use in WCW = Excess Urban Land Per Land Use

7. <u>Total Acres per Land Use in WCW</u>

   Excess Urban Land per Land Use + Acres per Land Use in WCW = Total Acres per Land Use in WCW

SRBC, along with the Pa. DEP, Bureau of Land and Water Conservation (now Bureau of Watershed Conservation), conducted a cost-effective analysis based on the Chesapeake Bay's Watershed Model segmentation and Pennsylvania's Chesapeake Bay Nutrient Reduction Strategy (Pa. Department of Environmental Protection, 1994). Using information generated by the SRBC model (minimized cost scenario), estimates of acreage, nitrogen load reduced, phosphorous load reduced, and costs have been derived for the Wiconisco Creek Watershed.

Estimates were made using percentages (percent composition of Chesapeake Bay Model segment (segment 80) related to acreage of Wiconisco Creek Watershed (Table 15)). Because of large urban centers in watershed model segment 80 (Harrisburg, Carlisle, Shippensburg, Mechanicsburg, Camp Hill, etc.), estimates of urban land in the Wiconisco Creek Watershed were elevated, as confirmed by calculation of acreage using SRBC's geographic information system (GIS) land use coverage. Acreages were then adjusted to account for reduced amount of urban land in the Wiconisco Creek Watershed. The steps used in the formulation are shown in Table 15. Results are shown in Tables 16 and 17.

Discussion of the Cost-Effectiveness Evaluation

The cost-effectiveness analysis of the Wiconisco Creek Watershed revealed that BMPs should be implemented on all available agricultural land currently in the Wiconisco Creek Watershed. BMPs were recommended on all conventional tillage, conservation tillage, hay, pasture, and manure lands. Implementation of BMPs on forest and urban lands was not the cost-effective alternative, according to this analysis.

Estimated benefits of BMP implementation are reductions in loads to the Chesapeake Bay of approximately 460 (613 with nutrient management legislation (NML)) thousand pounds per year of nitrogen and 13 (16.5 with NML) thousand pounds per year of phosphorous. Estimated cost for implementing these BMPs is 1.04 (303 with NML) million dollars. Costs are elevated when NML is applied, because it focuses on high cost practices associated with cleaning up concentrated animal wastes. The Nutrient Management Law is documented in Pennsylvania's Chesapeake Bay Nutrient Reduction Strategy (Pa. Department of Environmental Protection, 1994).

Two point source facilities in the Wiconisco Creek Watershed were evaluated using the SRBC model. The recommended retrofit on both facilities was the Phosphorous Only Retrofit #2. Phosphorous only retrofits involve removal of total phosphorous by retrofitting existing facilities with phosphorous control technologies. Retrofit costs are based on effluent limit concentrations and designed flows. This option is still under evaluation by Pa. DEP and the Chesapeake Bay Program (CBP). Predicted results of the retrofitting of the two facilities are listed in Table 17.

RECOMMENDATIONS FOR THE RESTORATION OF MINE DRAINAGE POLLUTION IN THE WICONISCO CREEK WATERSHED

Bear Creek Discharges

Discharge characteristics

Water is discharged from the Lykens Water Level Tunnel and from several abandoned adits (drift mine entrances). An Operation Scarlift report (Sanders and Thomas, 1973) and November 1998 observations[1] indicate that the majority of flow is from the northern-most adit (Point #3 in the Scarlift report). The entrance is still open, with water discharging a foot beneath the apparent floor of the adit.

The Scarlift Report provides 12 months of flow data for the Lykens Tunnel and five other discharges to Bear Creek. Summary flows are

[1] On November 19, 1995, the Bear Creek site and discharges were inspected and sampled by R. S. Hedin and SRBC personnel.

Table 16. Nonpoint Source Information for the Wiconisco Creek Watershed Generated From the Cost-Effectiveness Analysis *(Edwards and Stoe, 1998)*

Acres to be Treated			Nitrogen Load Reduced (pounds per year)		
Original Land Use	Treatment Type	Acres	Original Land Use	Treatment Type	Load (lb/yr)
Conventional Tillage	CVT.HEL	374.7	Conventional Tillage	CVT.HEL	3968.5
	CVT.CNF	4372.1		CVT.CNF	66546.2
	CVT.NML	3741.4		CVT.NML	7363.9
Conservation Tillage	CST.HEL	347.4	Conservation Tillage	CST.HEL	3677.7
	CST.NMF	4054.1		CST.NMF	62174.4
	CST.NML	3469.2		CST.NML	6828.1
Hay Acres	HAY.NUT	4926.0	Hay Acres	HAY.NUT	29432.8
	HAY.NML	3882.7		HAY.NML	7641.9
Pasture Acres	PAS.FPL	5867.3	Pasture Acres	PAS.FPL	49677.8
	PAS.SBF2	228.3		PAS.SBF2	604.1
Manure	AWA.AWT	46.3	Manure	AWA.AWT	12665.9
	AWA.NML	5.5		AWA.NML	131454.4
Urban	URP.URP	1570.6	Urban	URP.URP	12209.7
	URI.URI	1004.1		URI.URI	84044.6
Forest	FOR.FOR	40560.2	Forest	FOR.FOR	134822.2
Total		**74,449.9**	**Total**		**613,112.1**
Total Acres-NML		**63,351.1**	**Total Nitrogen Reduction-NML**		**459,823.8**

Phosphorous Reduced (pounds per year)			Cost of Implementation		
Original Land Use	Treatment Type	Load (lb/yr)	Original Land Use	Treatment Type	Dollars
Conventional Tillage	CVT.HEL	18.8	Conventional Tillage	CVT.HEL	30,411.60
	CVT.CNF	2,144.0		CVT.CNF	102,304.47
	CVT.NML	1,174.0		CVT.NML	101,924,761.38
Conservation Tillage	CST.HEL	17.5	Conservation Tillage	CST.HEL	28,195.70
	CST.NMF	2,034.3		CST.NMF	51,075.87
	CST.NML	1,088.6		CST.NML	94,509,362.56
Hay Acres	HAY.NUT	2,110.8	Hay Acres	HAY.NUT	7,380.91
	HAY.NML	1,218.3		HAY.NML	105,772,217.33
Pasture Acres	PAS.FPL	253.8	Pasture Acres	PAS.FPL	27,106.46
	PAS.SBF2	2.9		PAS.SBF2	13,446.71
Manure	AWA.AWT	1,444.6	Manure	AWA.AWT	786,412.96
	AWA.NML	1.7		AWA.NML	150,044.03
Urban	URP.URP	2,470.0	Urban	URP.URP	-
	URI.URI	1,579.2		URI.URI	-
Forest	FOR.FOR	961.3	Forest	FOR.FOR	-
Total		**16,519.9**	**Total**		**303,402,720.00**
Total Phosphorous Reduction-NML		**13,037.2**	**Total Costs-NML**		**1,046,335.00**

Definition of Best Management Practices (BMP) and Land Uses in the Chesapeake Bay Program Model

AWA: Animal waste acres Concentrated Barnyard Operations)
AWT: Animal waste treatment (Barnyard Runoff Program)
CST: Conservation tillage land use
CTF: Conservation tillage with farm plan
CTN: Conservation tillage with nutrient management
CVT: Conventional tillage land use
FPL: Farm plan
FOR: Forest land use
HAY: Hay land use
HEL: Highly erodible land
NMF: Nutrient management with farm plan
NML: Nutrient Management Legislation
NUT: Nutrient Management
PAS: Pasture land use
SBF: Stream Bank Fencing
URI: Impervious urban land use
URP: Previous urban land use

Table 17. Point Source Information for the Wiconisco Creek Watershed Generated From the Cost-Effectiveness Analysis *(Edwards and Stoe, 1998)*

Facility Name	NPDES	Retrofit	Base Load (Pre-Retrofit)		Future Load (No Action)	
			Nitrogen	Phosphorous	Nitrogen	Phosphorous
Lykens Borough	PA0043575	Phosphorous Only #2	4,537.2	1,055.5	8,401.0	567.1
Porter Tower Joint MA	PA0046272	Phosphorous Only #2	22,754.2	4,321.5	10,879.5	1,050.4

Facility Name	NPDES	Retrofit	Post-Retrofit Load		Retrofit Reduction	
			Nitrogen	Phosphorous	Nitrogen	Phosphorous
Lykens Borough	PA0043575	Phosphorous Only #2	8,401.0	394.5	-	480.5
Porter Tower Joint MA	PA0046272	Phosphorous Only #2	10,879.5	736.4	-	888.8

Facility Name	NPDES	Retrofit	Reduction Credit (1985-2000)		Total Reduction (Ret+Credit)	
			Nitrogen	Phosphorous	Nitrogen	Phosphorous
Lykens Borough	PA0043575	Phosphorous Only #2	-	488.4	-	968.9
Porter Tower Joint MA	PA0046272	Phosphorous Only #2	11,874.7	3,271.1	11,874.7	4,159.9

Facility Name	NPDES	Retrofit	Annual Cost ($ thousand)
Lykens Borough	PA0043575	Phosphorous Only #2	16,456
Porter Tower Joint MA	PA0046272	Phosphorous Only #2	16,456

shown below in Table 18. The Lykens Tunnel discharge averaged 760 gallons per minute (gpm), while the adit discharges averaged 3,079 gpm. The total flow averaged 3,839 gpm and was as high as 6,672 gpm. The highest flow occurred in March 1971.

In November 1998, the chemical conditions of the discharges were generally similar to the conditions documented by the Scarlift Report in 1971. The Lykens Tunnel was an acidic discharge (pH 3.4 in 1971, pH 4.6 in November 1998), while the adit discharges were alkaline. An analysis of the largest drift discharge is shown in Table 19. The flow of the discharge in November 1998 was estimated as 1,000 gpm.

Another sample, collected from a secondary discharge in the same area, had similar chemical constituents (results not shown). Scarlift data for the primary discharge (point #3) also are shown in Table 19. Five other sampling points in the vicinity of point #3 had similar chemistry (alkalinity > acidity, Fe 10 to 12 mg/l). Note that the November 1998 analysis indicates 20 mg/l Fe, while the average for point #3 in 1970-71 was 10 mg/l. Further monitoring of the primary adit discharge would determine whether the November 1998 sample is representative of current average conditions or whether the iron concentration was elevated because of the drought conditions at the time of sampling.

The alkalinity contained in the adit discharges is more than sufficient to neutralize the acidity present in the Lykens Tunnel discharge. The adits discharge approximately 1,850 kilograms per day (kg/day) of alkalinity (3,079 gpm at 110 mg/l alkalinity), while the Lykens Tunnel discharges approximately 195 kg/day of acidity (760 gpm at 47 mg/l acidity). This condition also was documented by SRBC sampling in 1996 and 1997 (Table 20). Bear Creek is an *alkaline* Fe-contaminated stream below the adits. Ten water samples collected between September 1996 and July 1997 had pH values > 5.8 and alkalinity concentrations greater than acidity concentrations. Fe concentrations at this point ranged between 2 and 24 mg/l and averaged 10 mg/l.

Treatment recommendations

The mixture of the Lykens Tunnel and adit discharges results in alkaline water that contains between 10 and 20 mg/l Fe. The water could be reliably treated with a properly sized constructed wetland. Many wetlands constructed to treat alkaline Fe-contaminated mine water in the bituminous coal fields are effectively decreasing iron concentrations to low levels (<2 mg/l) (Hellier and others, 1994; Hedin and others, 1994). These systems generally remove iron at rates of 5 to 30 grams of Fe per square meter of wetland surface area per day (g $m^{-2}d^{-1}$) (Hedin and others, 1994; Hellier and others, 1994). Rates of removal decrease with decreasing iron concentrations.

Because iron concentrations in the raw Bear Creek discharges are low relative to discharges in the bituminous fields (which are generally 50 to 100 mg/l Fe), it is recommended that the systems be sized assuming the lower range of observed removal rates. A rate of 6g $m^{-2}d^{-1}$ is currently recommended. Hedin Environmental bases this rate on empirical observations of iron removal in passive systems that receive water with less than 20 mg/l Fe and consistently discharge less than 1 mg/l Fe.

To estimate current iron loadings, the 1971 Scarlift flows were combined with the recent mine water analyses (20 mg/l). The use of the Scarlift flows is probably reasonable, because the upper Bear Creek Watershed has not been significantly disturbed since 1970 (personal communication, Ed Wytovich, Eastern Pennsylvania Coalition for Abandoned Mine Reclamation). The use of the recently measured Fe concentration might yield an erroneously large wetland size if the iron concentration measured in November 1998 was higher than average.

Comparisons of the estimated discharge loadings (Table 21) to the iron loadings measured by the SRBC in 1996/1997 at a downstream Bear Creek point (Table 20) suggest that the loading assumptions are reasonable. At the SRBC sampling point, flow in Bear Creek is primarily a

Table 18. Flow Rates (gpm) for the Bear Creek Mine Discharges Between December 1970 and November 1971 *(Sanders and Thomas, 1973)*

Flow Condition	Lykens	#3	#4	#5	#6	#7	Total
Average (gpm)	760	2,269	155	53	476	126	3,839
50th percentile*	634	2,092	154	50	476	116	3,622
75th percentile	920	2,356	171	58	506	158	4,014
90th percentile	1,006	2,978	203	67	546	171	4,809
Maximum	1,764	4,181	206	80	548	217	6,672

** 50% of the flows are expected to be less than this quantity*

Table 19. Chemical Composition of the Largest Bear Creek Adit Discharge *(Values for 1971 are the average of point #3 from the Scarlift report (Sanders and Thomas, 1973). Data for 1998 are from the analysis of one sample collected on November 19, 1998, by R. S. Hedin.)*

Year	pH	Alkalinity (mg/l)	Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Sulfate (mg/l)
1971	6.3	118	10	NA	NA	NA	NA	194
1998	6.2	110	20	2	<1	26	10	78

NA—not available

Table 20. Bear Creek Flow and Iron Loadings at State Route 1002 *(Stoe, 1998)*

Date	Flow Rate (gpm)	Iron (mg/l)	Iron (kg/day	pH	Alkalinity (mg/l)	Acidity (mg/l)
09/04/96	2,943	4	70	7.1	72	16
05/14/97	3,959	13	270	6.7	68	14
06/02/97	4,211	10	227	6.2	16	16
06/03/97	28,851	9	1,399	6.4	18	16
06/04/97	16,666	6	500	6.5	28	14
06/05/97	11,648	8	482	6.6	38	20
07/16/97	NA	15	NA	7.1	64	14
07/24/97	3,360	15	277	5.9	36	16
07/25/97	4,928	24	637	5.8	36	22
07/28/97	2,957	2	37	6.7	60	20
Average	8,836	10	433	6.5	44	17

NA—not available

combination of the Lykens Tunnel discharge, the adit discharges, and the Bear Creek Swamp discharge.

The SBRC data consist of nine measurements of streamflow and iron concentrations in September 1996, and May, June, and July 1997. The data are intentionally biased toward two storm events, during which iron oxide solids precipitated in the stream channel were, presumably, flushed from Bear Creek to Wiconisco Creek. The average iron loading measured on the nine sampling dates is 433 kg/day—a value close to the 418 kg/day average calculated from Scarlift flow record and the November 19, 1998, discharge samples.

Calculated wetland sizes are shown for a variety of flow and loading conditions in Table 21. Acreage recommendations range from 16 acres (median flow) to 30 acres (maximum flow). A reasonable goal would be to target the 75th – 90th percentile conditions, which results in a 20-acre treatment system. When the area for berms and roads is considered, the total acreage for the treatment complex would be likely to encompass 30 acres.

Twenty acres of constructed wetlands would be expected to discharge alkaline water with Fe concentrations <1 mg/l whenever the total mine drainage flow rate is less than 4,500 gpm. When flows are higher than 4,500 gpm, particulate iron would be discharged. At the maximum Scarlift flow rate, 6,672 gpm, the system effluent would likely contain 3 to 5 mg/l Fe. Water with this Fe content has a slight orange tint.

Figure 20 is a map showing the lower Bear Creek Watershed and the principal mine discharges. The highlighted area below the discharges is identified as potential treatment area. The area is designated as Tracts A, B, C, and D comprises approximately 143 acres. Portions of Tract A are unavailable because of a recent housing development. A waste water treatment plant has been constructed in a portion of Tract B. All of the tracts contain refuse that would need to be moved or removed. A detailed investigation of the current condition of these tracts is warranted. It appears likely that 30 acres of suitable land could be identified in this area.

It is recommended that the passive system be constructed to receive only contaminated mine water. The mine water should be separated from the flow of Bear Creek and directed to the passive treatment system. Mine discharges are commonly collected and gravity piped to treatment systems. Because of the close proximity of Tract A to the discharges, it would not be unduly expensive to separate the mine water and uncontaminated stream flow.

Estimated cost

Wetlands can be constructed in undisturbed ground for approximately $1 per square foot. This cost includes excavation, berm and road construction, wetland planting, and appropriate influent and effluent structures. This cost does

Table 21. Estimated Iron Loadings and Calculated Wetland Sizes for the Bear Creek Discharges

Flow Conditions	Flow Rate* (gpm)	*Iron*** (mg/l)	Iron Loading (kg/day	Wetland Acreage @ 6 g $m^{-2}d^{-1}$Removal
Average	3,839	20	418	17 acres
50th percentile	3,622	20	395	16
75th percentile	4,014	20	438	18
90th percentile	4,809	20	524	22
Maximum	6,672	20	727	30

** from the Operation Scarlift Report (1970-1971 data)*
*** from the recent analysis of adit discharge chemistry*

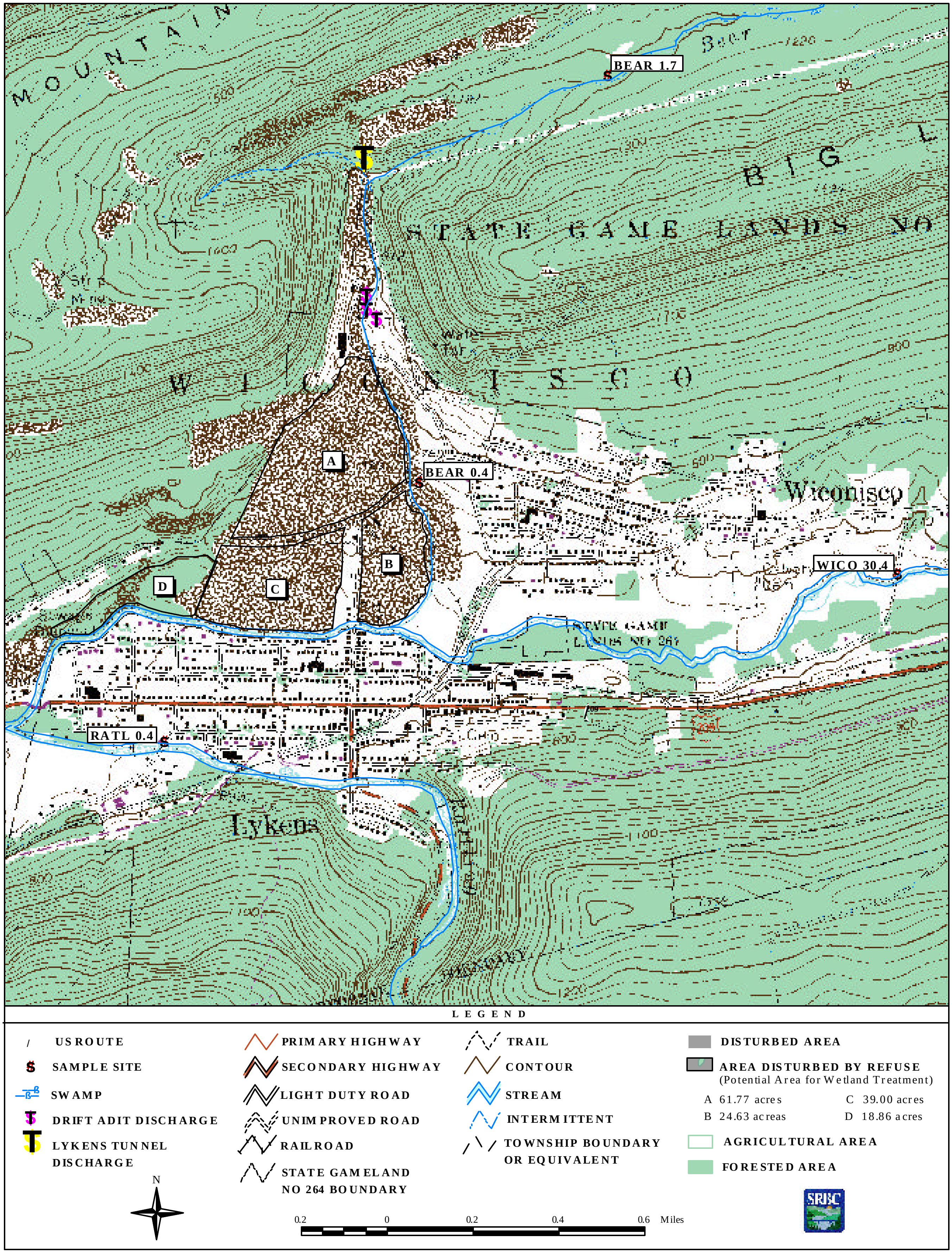

Figure 20. Mine Drainage Discharges and Potential Wetland Treatment Areas in the Bear Creek Watershed

not include the installation of an artificial liner, the removal of refuse, or the acquisition of land.

The installation of an artificial liner would cost $0.30 to $0.50 per square foot ($400,000 to $500,000). Because of the high cost of artificial liner material, Hedin Environmental suggests lining the wetland with impermeable soils. Materials from on-site or adjacent areas have been used in past projects at considerably less cost than an artificial liner. An estimated cost for the passive system, assuming it can be constructed in Tracts A, B, C, or D, is detailed in Table 22.

Comparison to existing passive systems

The size of the proposed system is large, but consistent with existing passive systems. A private mining company in Tennessee has treated a 700 to 1,200 gpm flow of alkaline water containing 40 mg/l Fe with 10 acres of ponds and wetlands for five years. The final discharge has always contained less than 1 mg/l Fe (Hedin, 1998).

In Latrobe, Pa., the Monastery Run Improvement Project has facilitated the construction of wetlands for the treatment of 1,000 gpm (average) of alkaline water contaminated with 90 mg/l Fe. A complex of three treatment systems, comprising a total of 19 acres, has been constructed by St. Vincent College (using USEPA 319 funds), the Natural Resource Conservation Service, and the Pa. DEP Bureau of Abandoned Mine Reclamation. The total cost of the Monastery Run Improvement Project was approximately $1 million. Fact sheets for the project are attached to this report.

Big Lick Tunnel

Discharge characteristics

On November 17, 1998, the discharge from the Big Lick Tunnel flowed less than 1 gpm. This low flow was unusual. SRBC personnel had never seen the flow this low over a 2-year observation period. The lowest flow reported in the Scarlift report (1970-1971) was 67 gpm (Table 23).

The Scarlift study reported an average flow of 664 gpm, with a range of 67 to 4,874 gpm. The discharge was chemically variable. Under lower flow conditions the discharge was marginally acidic with low concentrations of sulfate and metal. Under two higher flow conditions (1,600 gpm and 4,900 gpm), the flow was alkaline with concentrations of Fe 3 to 8 mg/l and sulfate 120 to 235 mg/l. A single sample collected by the SRBC in July 1997 was alkaline, with 9 mg/l Fe and low sulfate concentrations (41 mg/l).

Treatment recommendations and cost estimate

Treatment of the Big Lick Tunnel discharge is problematic because of the highly variable flow and chemistry. The primary recommendation is to implement a monitoring program that would determine whether the Scarlift results are still representative. These data, combined with SRBC *instream* monitoring data, should allow a determination of the conditions under which the Big Lick Tunnel discharge degrades Wiconisco Creek. Treatment options should be developed to target these conditions.

Table 22. Estimated Cost to Construct a Passive System for the Bear Creek Discharges

Mine discharge collection system (estimate)	$ 75,000
20 acres of constructed wetland at $\$1/ft^2$	900,000
Subtotal	**975,000**
Design, engineering, permitting, construction oversight (15% of subtotal)	146,250
Total	**$1,121,250**

Table 23. Big Lick Tunnel Discharge Flow and Chemical *Characteristics (Data for 1970-1971 are from the Operation Scarlift report (Sanders and Thomas, 1973). Data for July 1997 are from SRBC (Stoe, 1998).)*

Date	Flow Rate (gpm)	pH	Alkalinity (mg/l)	Acidity (mg/l)	Iron (mg/l)	Sulfate (mg/l)
12/17/70	110	5.2	0	6	<1	42
01/19/71	161	4.4	0	10	<1	70
02/17/71	217	5.2	0	8	<1	70
03/18/71	4,874	6.5	72	0	8	120
04/16/71	1,593	6.9	66	0	3	235
05/18/71	161	4.6	0	14	2	48
06/16/71	135	5.0	10	0	<1	90
07/21/71	67	6.8	12	0	<1	42
08/19/71	67	5.6	0	0	<1	60
09/21/71	188	4.2	0	14	3	70
10/21/71	217	5.4	0	0	<1	50
11/23/71	188	4.6	0	6	1	70
07/16/97		8.1	92	6	9	41

A review of the SRCB *instream* data for sampling station WICO 08 (revised WICO 30.4) suggests that the Big Lick discharge periodically has a detrimental effect on Wiconisco Creek (Table 24). Under base flow conditions, *instream* iron concentrations were <1 mg/l. However, concentrations appeared to increase substantially in conjunction with two rainstorm events.

If the cause of the degradation is storm-related flushing of the Big Lick Creek discharge channel, it would be useful to develop and implement a management plan that would prevent these flushing events. A system consisting of a sedimentation pond(s), in conjunction with constructed wetlands, would lessen the impact of these flushing events on Wiconisco Creek.

A passive system designed to treat high flows of alkaline, Fe-contaminated water would encompass 3 to 10 acres in the area shown in Figure 21. This range in size is based on an assumption that the system is sized to remove iron at a rate of 6 g $m^{-2}day^{-1}$ from a flow of 1,600 to 4,900 gpm containing 9 mg/l Fe (the most recent SRBC Fe analysis).

The cost of the system would likely be $150,000 to $500,000. Because the discharge flows through state gamelands, there may be no land acquisition costs (assuming the wetland could be benched into the hill below the discharge). The treatment system would be unnecessary during base and low flow periods when, according to the Scarlift Report, iron concentrations are <1 mg/l. Between December 1970 and November 1971, treatment was only needed during two months.

If a large treatment system was constructed, it would act as a retention basin and flow-dissipater during storm events, and would eliminate most of the *instream* problems associated with water chemistry shown on Table 24. During low and base flow conditions, when Fe contamination may be less significant, the system would discharge high quality water and would benefit fish and wildlife.

Porter Tunnel

Discharge characteristics

Acidic water flows from the Porter Tunnel near Muir. Samples collected in 1971 by the Scarlift effort (Sanders and Thomas, 1973) and in 1997 by SRBC (Stoe, 1998) revealed similar flow rates and chemical conditions (Table 25). The discharge averages ~540 gpm of flow, containing approximately 140 mg/l acidity, 20 mg/l Fe and 4 mg/l Al.

Table 24. Water Quality in Wiconisco Creek at WICO 08 *(new ID WICO 30.4) (from Stoe, 1998)*

Date	pH	Iron (mg/l)	Manganese (mg/l)	Sulfage (mg/l)
09/04/96	6.6	0.5	0.4	55
05/14/97	6.7	0.4	0.4	50
06/02/97	6.3	2.5	0.3	43
06/03/97	6.3	1.0	0.2	37
06/04/97	6.4	0.9	0.1	41
06/05/97	6.5	0.6	0.2	26
07/16/97	6.9	0.8	0.5	49
07/24/97	6.2	14.0	0.4	35
07/25/97	5.9	1.8	0.3	50
07/28/98	5.9	1.2	0.3	64

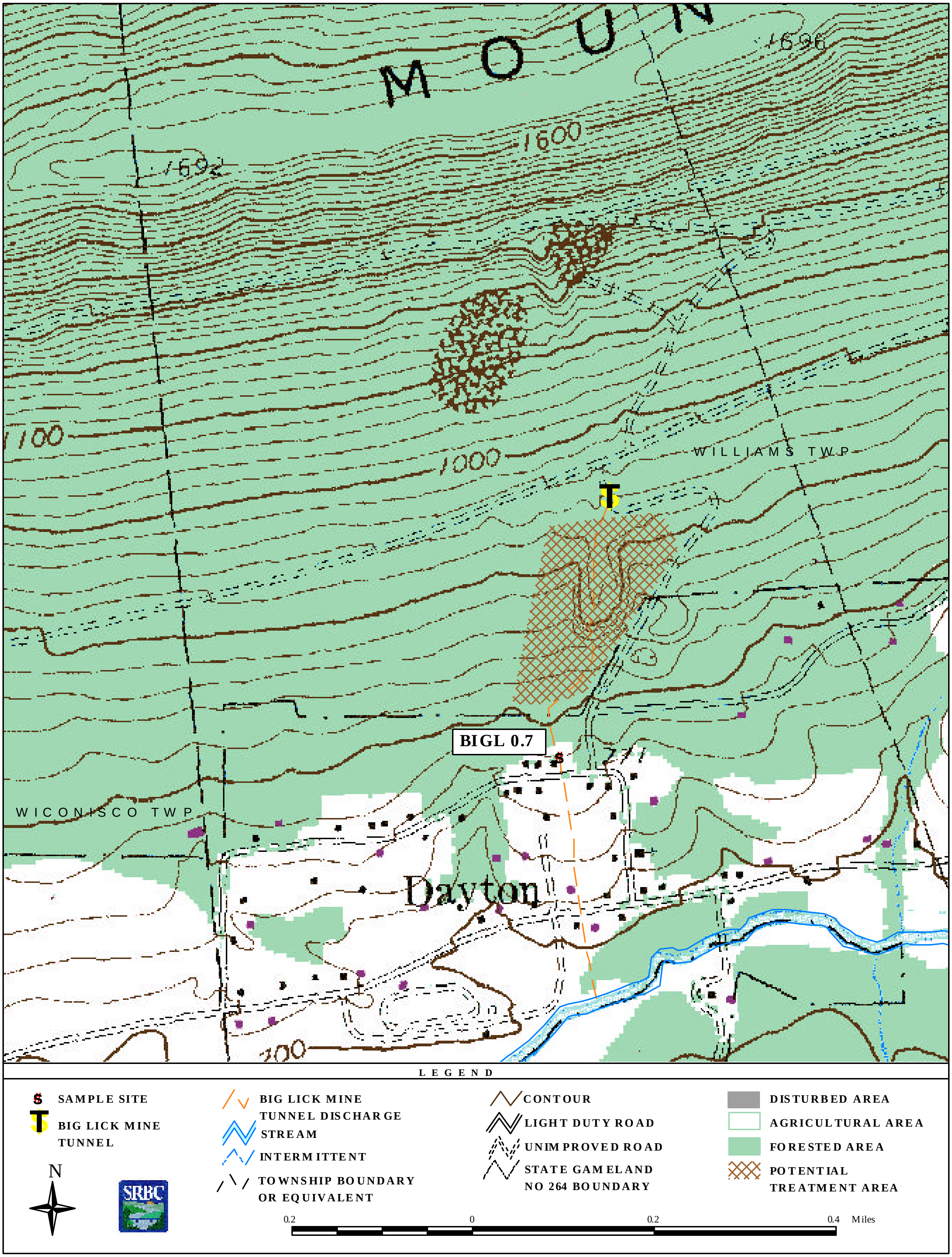

Figure 21. Big Lick Mine Tunnel Discharge and Potential Area for Settling Ponds and Wetland Treatment System

The discharge currently flows across an inactive mine yard to a limestone diversion well before discharging to the headwaters of Wiconisco Creek. On November 17, 1998, the diversion well was not functioning, because the intake was clogged with debris and the well was not full of limestone.

According to SRBC personnel, the owner of the tunnel and coal reserves, Reading Anthracite, is considering reopening the mine. Active mining may complicate treatment of the discharge using public funds, because, to our knowledge, Section 319, a 10 percent set-a-side program, and Abandoned Mine Land funds cannot be spent on sites where there is an active mining permit.

The federal Surface Mining Control and Reclamation Act (P.L. 95-87), of August 3, 1977, known as SMCRA, established a Title IV Grants Program providing monies to eligible states for abatement of abandoned mine problems. These problems were required to be addressed in a priority manner with varying degrees of health, safety, and general welfare hazards comprising the first two priorities. Acid mine drainage (AMD) abatement was defined as a Priority 3 problem and could not be addressed in Pennsylvania due to the enormous inventory of higher priority problems.

***Table 25. Porter Tunnel Discharge Flow and Chemical Characteristics** (Data for 1970-1971 are from the Operation Scarlift report (Sanders and Thomas, 1973). Data for 1996-1997 data from SRBC (Stoe, 1998).)*

Date	Flow Rate (gpm)	pH	Acidity (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Manganese (mg/l)	Sulfate (mg/l)	Acidity (g/day)
12/17/70	529	3.1	180	35	NA	NA	450	518,949
01/19/71	529	3.0	200	40	NA	NA	525	576,610
02/17/71	1,065	3.0	200	50	NA	NA	300	1,160,850
03/18/71	873	3.1	180	28	NA	NA	210	856,413
04/20/71	610	3.1	130	20	NA	NA	900	432,185
05/18/71					NA	NA		
06/18/71	345	3.3	140	6	NA	NA	100	263,235
07/21/71	278	3.0	130	6	NA	NA	525	196,963
08/19/71	490	3.0	240	6	NA	NA	475	640,920
09/21/71	380	2.9	100	12	NA	NA	350	207,100
10/21/71	345	3.0	110	9	NA	NA	475	206,828
11/23/71	490	2.8	100	26	NA	NA	500	267,050
09/05/96	744	2.5	140	17	4.4	4.5	324	567,672
05/15/97	450	2.3	120	16	3.8	3.9	161	294,300
06/02/97	426	2.2	122	17	3.7	3.7	213	283,247
06/03/97	450	2.4	126	16	3.6	3.6	345	309,015
06/04/97	469	2.5	140	15	3.9	3.9	247	357,847
06/05/97	473	3.0	124	16	3.9	3.8	232	319,653
07/16/97	NA	2.3	112	16	3.7	3.8	260	NA
07/24/97	NA	2.8	96	12	3.3	3.7	291	NA
07/25/97	NA	3.0	116	16	4.1	4.6	262	NA
07/28/97	NA	2.9	128	17	4.5	4.4	278	NA

NA—not available

In 1990, Congress amended SMCRA to include a provision allowing states to establish an AMD abatement and treatment program in an amount up to 10 percent of their annual abandoned mine reclamation (Title IV) grant. Pennsylvania amended its reclamation plan and received approval from the federal Office of Surface Mining (OSM) to establish a separate, interest-bearing AMD abatement and treatment fund. The fund and program are managed by the Bureau of Abandoned Mine Reclamation in the Pa. DEP (Pa. Department of Environmental Protection, 1990).

Monies from the Ten Percent Set-Aside Program may be used to abate and treat AMD in qualified hydrologic units affected by past-coal mining practices at eligible sites. Eligible sites are defined as those where mining ceased prior to August 3, 1977, and where no continuing reclamation responsibility can be determined. Those sites with Priority 1 or 2 hazards, where mining occurred between August 4, 1977, and July 30, 1982, also are eligible.

Treatment recommendations

Treatment of the discharge requires the generation of alkalinity and the precipitation of Fe and Al. An anoxic limestone drain is not recommended because the water is aerated, contains aluminum, and contains iron that is likely present in the ferric state. One passive treatment option currently used for low pH oxidized water is VFPs, in conjunction with constructed wetlands (see technology description). One pass through a VFP would result in the generation of alkaline water with low concentrations of metals (<1 mg/l Al and < 2 mg/l Fe). (Several VFPs could be built, but they should be arranged in a parallel manner in the area shown in Figure 22. There is no value to arranging VFPs in a "successive" manner.) Because the discharge of VFPs generally contains objectionable amounts of volatile organic compounds, hydrogen sulfide, and has biological oxygen demand (BOD), a wetland is recommended to polish the water before it discharges to Wiconisco Creek.

VFPs are generally sized based on the targeted flow and contaminant loadings and the measured acidity removal rates at existing VFPs. Experiences by Hedin Environmental suggest that VFP's generate an average of 40 grams of alkalinity per m^2 per day. This rate was used to size VFPs for the Porter Tunnel discharge. The wetlands are sized based on either retention time (12^+ hours) or iron loading (6 g $m^{-2}d^{-1}$ removal), whichever is larger. Several potential VFP and wetland configurations for the Porter Tunnel discharge are shown in Table 26.

Estimated cost

The cost of VFPs averages $5 per square foot (installed). Assuming that engineering costs are 15 percent, the costs of the systems in Table 25 range from $700,000 to $1,400,000. This cost assumes that sufficient flat land exists below the discharge and Wiconisco Creek, and does not include land acquisition costs.

The vertical flow pond technology is innovative and still under development. The long-term performance of VFP systems is uncertain. It is recommended that the passive treatment of the Porter Tunnel discharge be delayed until the discharge is better characterized (flow and chemistry), the status of renewed mining activity is resolved, and passive technologies for low pH acidity water are better developed.

Details of Hedin Environmental's findings are found in Appendix E.

Rattling Creek

Stream characteristics

The waters of Rattling Creek contribute to the recovery of Wiconisco Creek. However, substantial portions of both the East and West Branch Rattling Creek Watersheds are not attaining their designated use as Exceptional Value Waters. Nonattainment is due to low pH and alkalinity, which result from the combination of atmospheric deposition and the geologic composition of these watersheds.

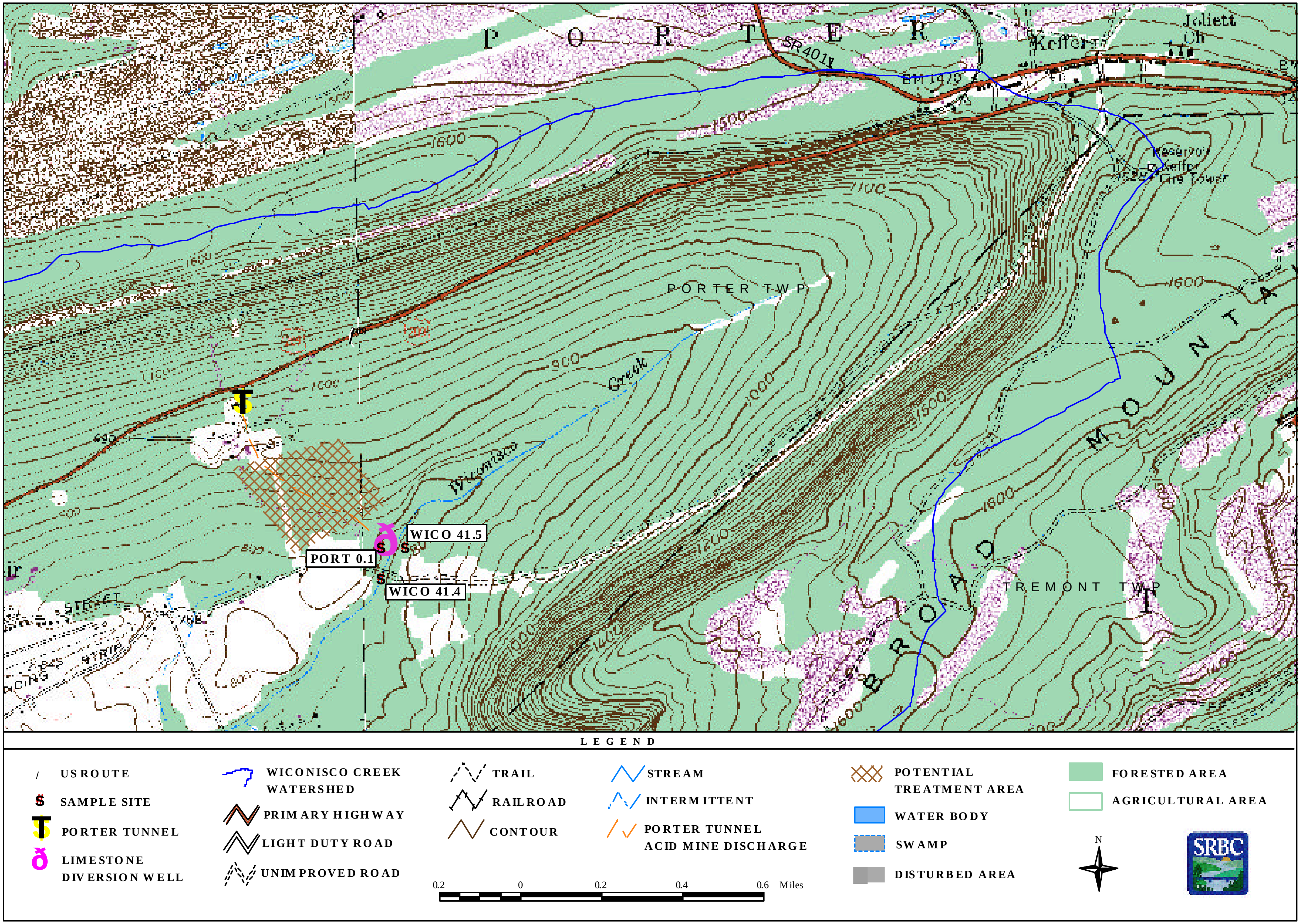

Figure 22. Porter Tunnel Acid Mine Discharge and Location of Land Suitable for a Treatment System

Table 26. Passive Treatment Scenarios for the Porter Tunnel Discharge

Flow Condition	Flow Rate (gpm)	Acidity (mg/l)	Acidity (kg/day)	VFP (acres)	Wetland (acres)
Average	539*	125**	411	2.3	2.4
75th percentile	570	125	435	2.4	2.5
90th percentile	873	125	666	3.7	3.8
Maximum*	1,065	125	813	4.5	4.7

** based on the Scarlift study (December 1970-November 1971)*
*** based on recently collected SRBC data*

Between September 1998 and March 1999, SRBC and DCCD staff collected stream discharge and chemical water quality data from various locations in the East and West Branch Rattling Creek Watersheds. Most of this work was conducted between November 1998 and March 1999 in the West Branch Rattling Creek Watershed in response to public inquiry related to a large timbering project in the watershed located on property owned by Lykens Borough.

During these surveys of chemical water quality conditions in the West Branch Rattling Creek, 30 pH values were recorded in the field, and 26 alkalinity and acidity values were determined in the laboratory. The pH values ranged from 3.60 to 5.60; acidity values ranged from 4 to 28 mg/l as $CaCO_3$, and alkalinity values ranged from 0 to 2 mg/l as $CaCO_3$. Every water quality sample had an acidity value that exceeded its alkalinity value (unpublished information from DCCD).

Based on macroinvertebrate community assessment data collected by the DCCD in the fall of 1998, the biological communities supported by the East and West Branches of Rattling Creek, immediately upstream of their confluence at the Lykens Borough Authority Reservoir, are in excellent condition. However, the biological condition scores of both streams scored substantially below their reference site, Pine Run, a HQ-CWF in Ecoregion 67c in northeastern Franklin County, Pa.

Although both Pine Run and the East Branch Rattling Creek supported at least remnant mayfly populations, no mayflies were included in macroinvertebrate samples collected in the West Branch Rattling Creek at (unpublished information from DCCD). Stoe (1998) indicated that macro-invertebrate diversity and taxonomic richness in the Rattling Creek Watershed are hampered by a lack of natural acid-buffering capacity and resulting acidic conditions.

Treatment recommendations

A variety of methods were considered as potential techniques to be used to raise stream pH and alkalinity. The direct application of limestone sand was selected, based on recommendation by Dave Spotts (PFBC, personal communication with DCCD) and published information from West Virginia (Clayton, and others, 1998). The specific objective of the limestone sand application project in the West Branch Rattling Creek Watershed is to raise and maintain pH and alkalinity values throughout the mainstem West Branch Rattling Creek to levels where heptageniid and/or ephemerellid mayfly populations are supported. The direct application of limestone sand in the headwaters of the West Branch Rattling Creek and several of its tributaries would accomplish this objective.

Potential sites to be used for the application of limestone sand are shown in Figure 23. These application sites are all on either state forest land or land owned by Lykens Borough. The Pennsylvania Bureau of Forestry, Lykens Borough, and the Lykens Borough Authority, which operates a municipal water treatment facility downstream of the project, all support the project.

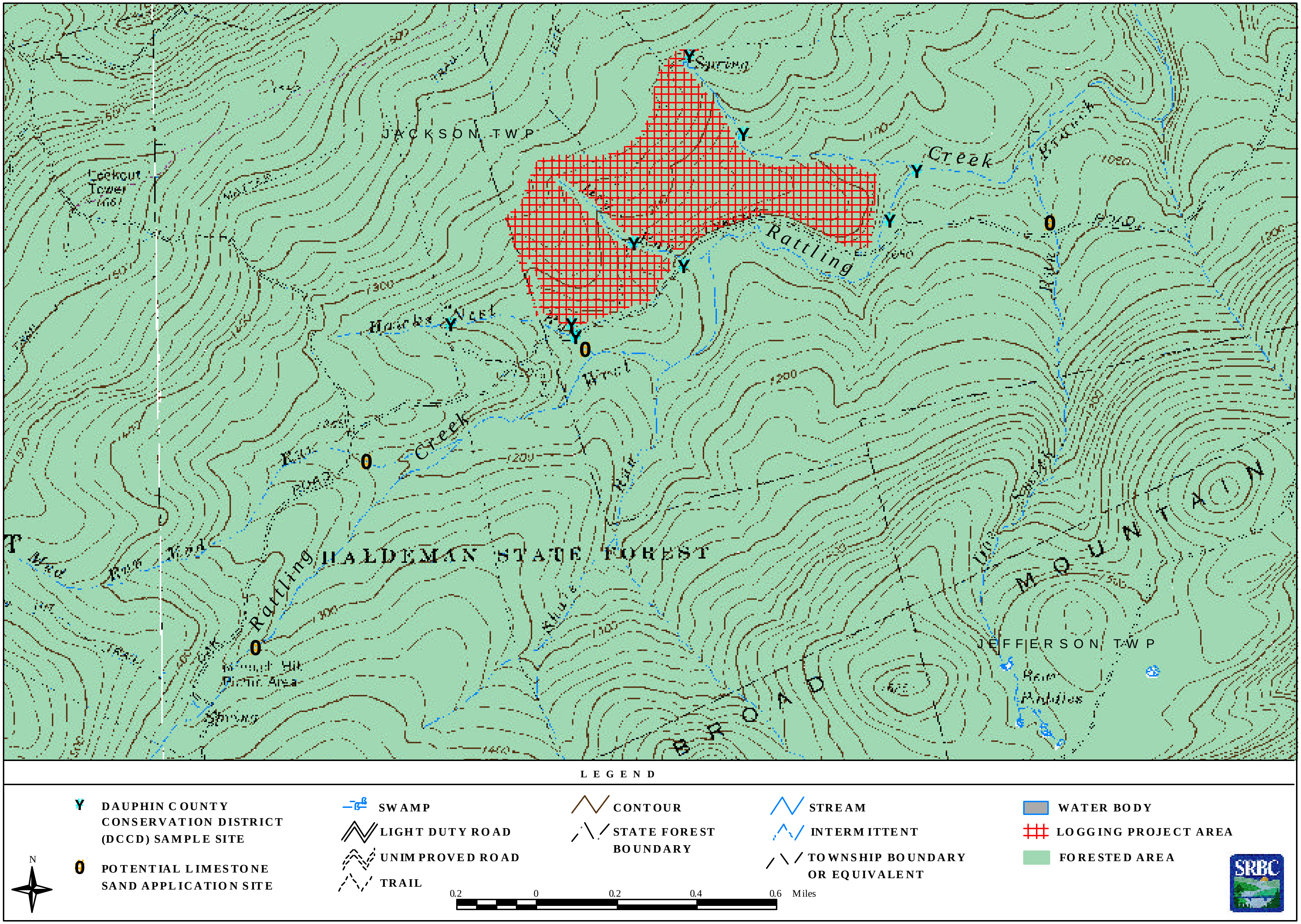

Figure 23. Location of Potential Limestone Application Sites, Dauphin County Conservation District Sample Sites, and Logging Project Area in the Rattling Creek Watershed

Estimated cost

- Limestone will be applied in four, 30-ton doses.
- Each 30-ton dose will be distributed among the four application sites identified on Figure 23.

  - West Branch Rattling Creek near Minnich Hit Picnic Area
  - Mud Run
  - Hawks Nest Run
  - Doc Smith Run

- Estimated total cost of the dosing project is $7,600.

Application Site Selection and Preparation	$4,100
Trucking (120 tones @ $25 per ton)	3,000
Limestone Sand (120 tons @ ~ $4 per ton)	500
TOTAL	$7,600

EFFECTS OF REMEDIATION AND PROTECTION PLANS

Bear Creek and Big Lick Tunnel Remediation

The plan recommended by Hedin Environmental and SRBC is to treat the Lykens Tunnel and adit discharges to Bear Creek by using properly-constructed and sized wetlands. About 20 acres of wetlands would be required to reduce metal concentrations to an acceptable level. The estimated cost of this remediation is $1,121,250. The following is a comparison between taking no action and implementing the plan recommended by Hedin Environmental and SRBC. Considerable community and environmental benefits are associated with the recommended plan.

Treatment of the Big Lick Tunnel discharge, with settling ponds and constructed wetlands, would reduce the effect that this discharge has during high flows. Proper sizing of treatment systems would ensure adequate retention time during flushing events. Three to ten acres of settling ponds and constructed wetlands, at a cost of $150,000 to $500,000, would eliminate iron contaminates during base flows, and would buffer loading during high flows.

Water quality

No action

Water quality in both Bear Creek and Big Lick Discharge and Wiconisco Creek would continue to be degraded by iron precipitation and would further prohibit biological colonization of streams in this area.

Recommended plan

Iron, aluminum, manganese, and sulfate levels would be reduced to comply with state standards in the Bear Creek, Big Lick discharge, and in Wiconisco Creek below the discharges. The proposed plan for the Big Lick Tunnel discharge also would reduce the effects of storm events on water quality by increasing the removal of metals before they could enter Wiconisco Creek.

Aquatic habitat

No action

Bear Creek, Big Lick discharge, and Wiconisco Creek below the discharges would continue to be plagued by sedimentation problems from iron precipitates. Habitat would continue to be reduced to the point where the streams are devoid of life. Diversity and abundance of aquatic organisms would continue to be reduced.

Recommended plan

Reduction of mine drainage precipitation and sedimentation would allow for recolonization of aquatic life in Bear Creek and Wiconisco Creek below Bear Creek. Reversal of habitat degradation, due to sedimentation, would provide suitable aquatic macroinvertebrate habitat. A sustainable fish population also should be established. The impact of remediation of the Big Lick discharge would be the reduction of sedimentation in Wiconisco Creek below the discharge.

Wildlife habitat

No action

There would be no change in the composition or the number of wildlife species that utilize habitat in the watershed.

Recommended plan

The project would create several acres of open-water/wetland habitat utilized by reptile, amphibian, waterfowl and mammal species. Installation of similar wetland projects has demonstrated use by several waterfowl species.

Wetlands

No action

Without this plan the few wetlands in this area would continue to be impacted by mining waste. Runoff from unreclaimed areas and sedimentation from currently unreclaimed discharges would add sediment to wetland areas.

Recommended plan

The recommended plan would create approximately 30 acres of constructed wetlands in the Bear Creek Watershed. Wetlands in the Big Lick Watershed would be limited to areas near the three to ten acres of ponded water. The recommended plan complies with Presidential Executive Order 11990, Protection of Wetlands (1977).

Flood plains

No action

Without the plan, the Wiconisco Creek Watershed flood plain would continue to have problesm associated with sedimentation in the stream channel. Flooding impacts would be increased because of increased flow and sediment from both Bear Creek and the Big Lick Tunnel discharge.

Recommended plan

The recommended plan does not include disturbance of areas in the flood plain. The recommended plan would help eliminate some sedimentation and flushing problems by acting as a retention area for mine water contaminated with metals. The plan complies with Presidential Executive Order 11988, Flood Plain Management (1977).

Visual resources

No action

Degraded visual aspects of the watershed would persist as iron and sediment continues to be deposited in stream channels.

Recommended plan

Because of the proposed plan, approximately two to four miles of previously iron-stained stream would be restored to nearly natural conditions.

Land use

No action

Without the project, only a slight change in woodlands is expected with the reforestation of previously disturbed mine lands.

Recommended plan

Thirty acres of disturbed land would be stabilized and converted to wetlands and open water.

Socioeconomics

No action

Without the project, Wiconisco Creek near Lykens and Bear Creek would remain contaminated by mine drainage, and there would be no recreational fishery in this area. There would be no economic gains associated with a trout fishery.

Recommended plan

Restoration of the fishery, as well as improvement to the aesthetics of the watershed, would translate into economic benefits realized by retailers in the watershed. Commercial services in the area would benefit from the increased use of the streams in the watershed.

Education

No action

There would be no improvement in availability of wetland educational sites. The area would be suitable for demonstration of impacts of mine drainage discharges, but the educational opportunity provided by the passive treatment systems would not exist.

Recommended plan

This project would create a passive treatment area that could be used for educational field studies. Effects before and after mining remediation could be demonstrated at this site and in other areas of the watershed.

Porter Tunnel Remediation

Treatment of the Porter Tunnel discharge with a series of vertical flow ponds, followed by constructed wetlands to polish off the treatment, would reduce acidity and metal concentrations. The total land area needed for treatment is less than 10 acres. The estimated cost of treating this discharge is $700,000 to $1,400,000.

Water quality

No action

Water quality in Wiconisco Creek would continue to be degraded by iron precipitate and acidic conditions, which would continue to prevent biological colonization of the stream.

Recommended plan

Iron, aluminum, manganese, and sulfate levels would be reduced in the headwaters area of Wiconisco Creek. Acidity also would be reduced, and the pH and alkalinity would be increased.

Aquatic habitat

No action

Wiconisco Creek below the discharge would continue to be plagued by sedimentation problems from iron precipitates. Habitat in this stream would continue to be degraded, and the stream would continue to be devoid of life. Diversity and abundance of aquatic organisms would continue to be reduced.

Recommended plan

Reduction of mine drainage precipitate and sedimentation should allow aquatic life to recolonize the stream. A sustainable macroinvertebrate community could result in the establishment of a naturally reproducing population of fish.

Wildlife habitat

No action

There would be no change in the composition or the number of wildlife species that utilize habitat in the watershed.

Recommended plan

The project would create several miles of stream that would enhance the quality of wetlands adjacent to Tower City, and would make several miles of stream suitable for use by wildlife.

Wetlands

No action

The quality and value of wetlands in the Upper Basin would continue to be reduced by the presence of metal precipitates. The wetlands would continue to accumulate mining-related sediments.

Recommended plan

The recommended plan would create between 2.5 and 5 acres of constructed wetlands. Wetlands adjacent to Tower City would be enhanced by the reduction in iron precipitate. The recommended plan complies with Presidential Executive Order 11990, Protection of Wetlands (1977).

Flood plains

No action

Without the plan, the Wiconisco Creek Watershed flood plain would continue to have problesm associated with sedimentation in the stream channel. Flooding impacts would be increased because of increased flow and sediment from both Bear Creek and the Big Lick Tunnel discharge.

Recommended plan

The recommended plan would not include disturbance of areas in the flood plain. The recommended plan would help eliminate some of the sedimentation and flushing problems by acting as a retention area for mine water contaminated with metals. The plan complies with Presidential Executive Order 11988, Flood Plain Management (1977).

Visual resources

No action

Visual features of the watershed would continue to be degraded as iron and sediment continue to be deposited in the stream channel.

Recommended plan

Because of the proposed plan, approximately 4 miles of previously iron-stained stream would be restored to near natural conditions.

Land use

No action

Land in the area would continue to be a mix of forest, agriculture, and disturbed land. The scars from past mining activities would be present in the barren/quarry area near Porter Tunnel.

Recommended plan

Approximately 10 acres of disturbed land would be stabilized and converted to grassland, open water, and wetlands.

Socioeconomics

No action

Without the project, Wiconisco Creek near Tower City would remain contaminated by mine drainage, and there would be no recreational fishery in this area. There would be no potential economic gain that would be associated with a trout fishery.

Recommended plan

Restoration of the fishery, as well as improvement to the aesthetics of the watershed, would provide for economic benefits realized by retailers in the watershed. Commercial services in the area would benefit from the increased use of Wiconisco Creek.

Education

No action

There would be no improvement in availability of wetland educational sites. The area, which would be suitable for demonstration of impacts associated with mine drainage discharges would not serve as an educational opportunity to demonstrate a passive treatment system.

Recommended plan

This project would create a passive treatment area that could be used for educational field studies. Effects before and after mining remediation could be demonstrated.

Installation of BMPs

Watershed restoration in the lower portion of the watershed should include the implementation of BMPs on 3,800 acres of farmland. The implementation of these BMPs would reduce nitrogen and phosphorous loads reaching Wiconisco Creek. Stream/riparian zone protection is a part of many of these BMPs.

Water quality

No action

Water quality in Wiconisco Creek would continue be degraded by sedimentation and nutrient loading.

Recommended plan

Implementation of this plan would significantly reduce nutrient and sediment loading to Wiconisco Creek.

Aquatic habitat

No action

Wiconisco Creek would continue to be plagued by sedimentation associated with agricultural runoff and streambank erosion. Habitat in this stream would continue to be degraded. Diversity and abundance of aquatic organisms would continue to be reduced.

Recommended plan

Reduced agricultural sedimentation would increase the diversity and abundance of macroinvertebrates and other aquatic life in the stream. A sustainable macroinvertebrate community could result in the establishment of a naturally reproducing population of fish.

Wildlife habitat

No action

There would be no change in the composition of the number of wildlife species that utilize habitat in the watershed.

Recommended plan

Streambank fencing and other BMPs would increase the diversity and abundance of riparian vegetation and wildlife habitat in the watershed. Significant benefits to birds and small mammals should result.

Wetlands

No action

Wetlands in this area would continue to suffer from sediment buildup from agricultural runoff.

Recommended plan

The reduction of sediment loads associated with the installation of BMPs would increase the quality and value of wetlands in this area. Reduction of sediment will allow for establishment of a more diverse plant base in the wetlands.

Flood plains

No action

Without the plan, the Wiconisco Creek Watershed flood plain would continue to have problesm associated with sedimentation in the stream channel. Flooding impacts would be increased because of increased flow and sediment from both Bear Creek and the Big Lick Tunnel discharge.

Recommended plan

The recommended plan would help eliminate some of the sedimentation and flushing problems by providing as a buffer area between croplands and the waterway. The plan complies with

Presidential Executive Order 11988, Flood Plain Management (1977).

Visual resources

No action

Visual features of the watershed would continue to be degraded as sediment continues to be deposited in the stream channel.

Recommended plan

The aesthetics of many areas would be significantly improved. Trampled streambanks and high livestock traffic areas would be restored to improve the appearance and herd health of farms in the watershed.

Land use

No action

Agricultural practices will continue with little change in land use in the area. Agricultural land will continue to add to environmental problems in the area, and land will continue to be degraded by livestock-, nutrient-, and sediment-related problems.

Recommended plan

While the project would not change land use classifications, better management of cropland and pastureland would occur.

Socioeconomics

No action

Without the project, Wiconisco Creek would remain impaired by agricultural runoff, and fertile farmland would continue to be lost to erosion each year.

Recommended plan

Implementation of this plan would increase the productivity of farmland in the Wiconisco Creek Watershed by decreasing erosion and cropland runoff. The use of farm plans and conservation tillage would increase the effectiveness of fertilizers applied to the land. Health of livestock also could be improved by the cleanup of concentrated barnyard areas, and removal of manure areas. More efficient use of manure also would reduce the need for costly fertilizers. Increased farming efficiency and improved animal health would strengthen the economy of the farming community within the watershed.

Education

No action

The area would be suitable for demonstrating impacts associated with agricultural runoff, but the educational opportunities that could be associated with remediation would be absent.

Recommended plan

This project would create agricultural BMPs that could be demonstrated in educational field studies. Effects before and after streambank stabilization and restoration can be demonstrated. Enhancement of ecological communities because of increased biodiversity would allow for enhanced educational opportunities in the watershed.

Rattling Creek Remediation

Treatment of water in Rattling Creek should be accomplished by placement of limestone sand in the creek to raise and maintain pH and alkalinity values throughout the mainstem West Branch Rattling Creek to levels where heptageniid and/or ephemerellid mayfly populations are supported. The comparison is made between no action and direct limestone application as recommended by PFBC, DCCD, and SRBC.

Water quality

No Action

Water quality in the West Branch Rattling Creek and Wiconisco Creek would continue be degraded by acid rain.

Recommended plan

The implementation of this plan would reduce the acidity and raise the alkalinity and pH levels in the West Branch Rattling Creek to comply with state standards.

Aquatic habitat

No action

Rattling Creek would continue to be plagued by sedimentation problems from sandstone erosion. Diversity and abundance of aquatic organisms would continue to be reduced.

Recommended plan

The addition of limestone sand to the West Branch of Rattling Creek will cause localized sedimentation problems. The problems associated with the direct application of limestone sand are limited because the limestone will be dissolved by the acidity of water in the creek.

Wildlife habitat

No action

There would be no change in the composition or number of wildlife species that utilize habitat in the watershed.

Recommended plan

There would be no change in the composition or of the number of wildlife species that utilize habitat in the watershed.

Wetlands

No action

Wetlands would continue to be an area of high biological diversity for this environment.

Recommended plan

There are no wetlands to be impacted in the proposed treatment areas. No wetlands would be created or destroyed. Wetlands would be enhanced by improved water quality.

Flood plains

No action

Without the plan, the West Branch Rattling Creek flood plain would not be changed.

Recommended plan

The small amounts of limestone placed in the stream would be dissolved and have no significant effect on the flood plain. The plan complies with Presidential Executive Order 11988, Flood Plain Management (1977).

Visual resources

No action

The watershed would continue to be a place of natural beauty. The stream channel would continue to be visually impaired by the presence of large amounts of sandstone sediments.

Recommended plan

Short segments of the stream would be visually impaired by the addition of limestone sand to the stream channel. The dissolution of limestone by acidic water makes this a short term impact.

Land use

No action

This area would continue to be largely a forest watershed.

Recommended plan

The forest could become healthier as the water that is available would be less acidic and of higher quality.

Socioeconomics

No action

Without the project, Rattling Creek Watershed would continue to be plagued by runoff from acid rain. The Lykens Borough Authority would need to continue treatment of water for high acidity and low pH.

Recommended plan

Cost of treatment of water by the Lykens Borough Authority would be reduced as water reaching the facility would have a higher pH and lower acidity.

Education

No action

There would be no change in educational opportunities in the watershed.

Recommended plan

This project would create a passive treatment area that could be used for educational field studies. Effects before and after remediation could be demonstrated.

CONCLUSIONS

The Wiconisco Creek Watershed is plagued with many nonpoint sources of pollution. Implementation of the remediation and protection plans suggested in this report could prevent further damage to areas of concern and protect unimpacted areas in the watershed.

As part of this project, SRBC staff attempted to use the U.S. Environmental Protection Agency's BASINS software application to model both point and nonpoint source influences in the Wiconisco Creek Watershed. This attempt to model this watershed, using the prepackaged data from the BASINS model, yielded unsatisfactory results. The prepackaged data represented this watershed as one stream segment, which was not detailed enough to allow for proper loading estimates.

With the BASINS application having been developed in the early stages of this project, SRBC had insufficient information necessary to determine field data requirements needed to fully utilize this model. Advanced watershed modeling using the BASINS software would require extensive data collection, including flow, water quality, and site specific cross-sectional information on all of the major tributaries in the watershed. SRBC data were not sufficient to fulfill all the needs, so advanced modeling was not performed by SRBC.

Additional sampling and documentation of site-specific discharge information also would aid in the development of more specific plans for properly sized treatment systems. Samples should be collected both bimonthly and during storms in all seasons. Documentation of flow, concentrations of parameters of concern (metals, acidity, alkalinity, and sulfate), and stream morphology information would be necessary to facilitate the modeling and proper development of treatment systems for each discharge.

This plan is intended to supplement efforts such as the Rivers Conservation Program and Section 319 Nonpoint Source Implementation Programs to address concerns in the watershed. The Wiconisco Creek Restoration Association, Dauphin and Schuylkill County Conservation Districts, and the Eastern Pennsylvania Coalition for Abandoned Mine Reclamation have aided in the development of this assessment and plan. Continued partnership activities are needed to implement the components of this remediation plan to improve aquatic habitat and the quality of life in the Wiconisco Creek Watershed.

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GLOSSARY OF ACRONYMS

CBP: Chesapeake Bay Program

DCCD: Dauphin County Conservation District

OSM: U.S. Office of Surface Mining

Pa. DEP: Pennsylvania Department of Environmental Protection
PFBC: Pennsylvania Fish and Boat Commission

SRBC: Susquehanna River Basin Commission

USDA NRCS: U.S. Department of Agriculture, Natural Resources Conservation Service
USDA SCS: U.S. Department of Agriculture, Soil Conservation Service
USEPA: U.S. Environmental Protection Agency
USFWS: U.S. Fish and Wildlife Service
USGS: U.S. Department of the Interior, Geologic Survey

APPENDIX A

ORGANIC POLLUTION TOLERANCE VALUES AND FUNCTIONAL FEEDING GROUP DESIGNATIONS OF BETHIC MACROINVERTEBRATE TAXA

Class: Order	Family	Family/*Genus*	*Tolera*	Trophic
Insecta: Coleoptera	**Dytiscidae**	*Agabus*	5	P
	Elmidae	*Ancyronyx variegata*	2	CG
		Dubiraphia	6	SC
		Optioservus	4	SC
		Ordobrevia	5	SC
		Stenelmis	5	SC
	Hydrophilidae	*Hydrobius*	5	P
		Laccobius	5	P
	Psephenidae	*Psephenus*	4	SC
Collembola	**Poduridae**	*Podura*	9	CG
Diptera	**Athericidae**	*Atherix*	2	P
	Ceratopogonidae	*Alluaudomyia*	6	P
	Chironomidae	**Chironomidae**	7	CG
	Empididae	*Hemerodromia*	6	P
	Simuliidae	**Simuliidae**	6	FC
	Tabanidae	*Tabanus*	5	P
	Tipulidae	*Antocha*	3	CG
		Dicranota	3	P
		Hexatoma	2	P
		Limonia	6	SH
		Limnophila	3	P
		Tipula	4	SH
Ephemeroptera	**Ameletidae**	*Ameletus*	0	CG
	Baetidae	*Acentrella*	4	CG
		Baetis	6	CG
		Centroptilum	2	CG
		Cloeon	4	CG
	Ephemerellidae	*Attenella*	2	CG
		Ephemerella	1	CG
		Serratella	2	CG
	Ephemeridae	*Ephemera*	2	CG
		Hexagenia	6	CG
	Heptageniidae	*Epeorus*	0	CG
		Leucrocuta	1	SC
		Macdunnoa	3	SC
		Nixe	2	SC
		Rhithrogena	0	CG
		Stenacron	4	CG
		Stenonema	3	SC
	Isonychiidae	*Isonychia*	2	FC
	Leptophlebiidae	*Leptophlebia*	4	CG
		Paraleptophlebia	1	CG
Hemiptera	**Veliidae**	*Microvelia*	8	P
		Rhagovelia	8	P
	Tricorythidae	*Leptohypes*	4	CG
Megaloptera	**Corydalidae**	*Corydalus*	4	P
		Nigronia	2	P
	Sialidae	*Sialis*	4	P
Odonata	**Aeshnidae**	*Boyeria*	2	P
	Calopterygidae	*Hataerina*	6	P
	Coenagrionidae	*Argia*	6	P
	Cordulegastridae	*Cordulegaster*	3	P
	Gomphidae	*Gomphus*	5	P

Class: Order	Family	Family/*Genus*	*Tolera*	Trophic
Plecoptera	**Capniidae**	*Capnia*	1	SH
		Paracapnia	1	SH
	Leuctridae	*Leuctra*	0	SH
	Nemouridae	*Amphinemura*	2	SH
	Peltoperlidae	*Peltoperla*	2	SH
	Perlidae	*Acroneuria*	0	P
		Agnetina	2	P
		Eccoptura	2	P
		Paragnetina	1	P
		Perlesta	4	P
	Perlodidae	*Isoperla*	2	P
Trichoptera	**Glossosomatidae**	*Glossosoma*	0	SC
	Hydropsychidae	*Ceratopsyche*	4	FC
		Cheumatopsyche	5	FC
		Diplectrona	0	FC
		Hydropsyche	4	FC
		Macrostemum	3	FC
		Potamyia flava	5	FC
	Philopotamidae	*Chimarra*	4	FC
		Dolophilodes	0	FC
	Phryganeidae	*Oligostomis*	2	P
	Polycentropodidae	*Neureclipsis*	7	FC
		Polycentropus	6	FC
	Psychomyiidae	*Lype diversa*	2	CG
	Rhyacophilidae	*Rhyacophila*	1	P
Oligochaeta: Haplotaxida	**Naididae**	**Naididae**	8	CG
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**	8	P
	Lymnaeidae	*Lymnaea stagnalis*	7	SC
Hirudinea: Gnathobdellida	**Hirudinidae**	**Hirudinidae**	8	P
Crustacea: Amphipoda	**Gammaridae**	*Gammarus*	6	SH
Decapoda	**Cambaridae**	*Cambarus*	6	CG
		Orconectes	6	SH
Gastropoda: Gastropoda	**Physidae**	*Physa*	8	SC
		Physella	8	SC
	Planorbidae	*Planorbella*	6	SC
Bivalvia: Pelecypoda	**Sphaeriidae**	*Pisidium*	8	FC

Appendix B

Raw Benthic Macroinvertebrate Data for 1996

Class: Order	Family	Family/*Genus*	Reference Category 67bl			
			WICO 0.3	WICO 7.9	WICO 14.7	WICO 23.6
Insecta: Coleoptera	**Elmidae**	*Optioservus*	1	2	3	
		Ordobrevia				
		Stenelmis	3	2		5
	Hydrophilidae	*Hydrobius*				
		Laccobius				
	Psephenidae	*Psephenus*	2	1	3	
Collembola	**Poduridae**	*Podura*				1
Diptera	**Athericidae**	*Atherix*			6	
	Ceratopogonidae	*Alluaudomyia*				
	Chironomidae	**Chironomidae**	13	4	18	13
	Empididae	*Hemerodromia*				2
	Simuliidae	**Simuliidae**	3	3		
	Tabanidae	*Tabanus*				
	Tipulidae	*Antocha*	1	1		
		Dicranota				
		Hexatoma				
		Limonia				
		Tipula				
Ephemeroptera	**Baetidae**	*Acentrella*	3	2		
		Baetis				
		Centroptilum	4	16		2
		Cloeon		11		
	Ephemerellidae	*Attenella*				
	Ephemeridae	*Ephemera*				
	Heptageniidae	*Epeorus*				
		Macdunnoa		2		
		Nixe				
		Rhithrogena	1			
		Stenacron				
		Stenonema	1	4	1	
	Isonychiidae	*Isonychia*	3	44	20	
	Leptophlebiidae	*Paraleptophlebia*			1	
Hemiptera	**Veliidae**	*Microvelia*				
		Rhagovelia				1
Megaloptera	**Corydalidae**	*Corydalus*	1	6	7	
		Nigronia		1	19	1
	Sialidae	*Sialis*				
Odonata	**Aeshnidae**	*Boyeria*				
	Coenagrionidae	*Argia*				
	Cordulegastridae	*Cordulegaster*				
	Gomphidae	*Gomphus*				
Plecoptera	**Capniidae**	*Capnia*				
		Paracapnia				
	Perlidae	*Acroneuria*	3	3		
		Agnetina				
		Eccoptura				
		Paragnetina	8			
	Perlodidae	*Isoperla*			1	
Trichoptera	**Glossosomatidae**	*Glossosoma*				

Class: Order	Family	Family/*Genus*	Reference Category 67bl			
			WICO 0.3	WICO 7.9	WICO 14.7	WICO 23.6
Trichoptera	**Hydropsychidae**	*Ceratopsyche*				
		Cheumatopsyche	6	13	23	17
		Diplectrona				
		Hydropsyche	46	44	49	41
		Macrostemum	2	2		
		Potamyia flava				
	Philopotamidae	*Chimarra*	20		1	4
		Dolophilodes				
	Phryganeidae	*Oligostomis*				
	Polycentropodidae	*Polycentropus*				
	Rhyacophilidae	*Rhyacophila*				
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**				
Hirudinea: Gnathobdellida	**Hirudinidae**	**Hirudinidae**				
Crustacea: Amphipoda	**Gammaridae**	*Gammarus*				
Decapoda	**Cambaridae**	*Cambarus*				
		Orconectes				
Gastropoda: Gastropoda	**Physidae**	*Physa*				
		Physella				
	Planorbidae	*Planorbella*				
Bivalvia: Pelecypoda	**Sphaeriidae**	*Pisidium*				

Class: Order	Family	Family/*Genus*	Reference Category 67bs		
			LWIC 0.1	LWIC 4.0	LWIC 8.4
Insecta: Coleoptera	**Elmidae**	*Optioservus*			
		Ordobrevia			
		Stenelmis	6	16	44
	Hydrophilidae	*Hydrobius*			3
		Laccobius			
	Psephenidae	*Psephenus*	2	11	4
Collembola	**Poduridae**	*Podura*			
Diptera	**Athericidae**	*Atherix*	2		
	Ceratopogonidae	*Alluaudomyia*			
	Chironomidae	**Chironomidae**	15	19	58
	Empididae	*Hemerodromia*			2
	Simuliidae	**Simuliidae**	2	4	1
	Tabanidae	*Tabanus*			
	Tipulidae	*Antocha*			
		Dicranota			
		Hexatoma			
		Limonia			
		Tipula			
Ephemeroptera	**Baetidae**	*Acentrella*	1		
		Baetis			29
		Centroptilum	1	6	
		Cloeon		2	
	Ephemerellidae	*Attenella*			
	Ephemeridae	*Ephemera*			
	Heptageniidae	*Epeorus*			
		Macdunnoa			
		Nixe			
		Rhithrogena			
		Stenacron			
		Stenonema		1	
	Isonychiidae	*Isonychia*	6	4	1
	Leptophlebiidae	*Paraleptophlebia*			
Hemiptera	**Veliidae**	*Microvelia*			
		Rhagovelia		1	2
Megaloptera	**Corydalidae**	*Corydalus*	2		
		Nigronia		1	1
	Sialidae	*Sialis*	2	1	
Odonata	**Aeshnidae**	*Boyeria*			
	Coenagrionidae	*Argia*		1	2
	Cordulegastridae	*Cordulegaster*			
	Gomphidae	*Gomphus*			
Plecoptera	**Capniidae**	*Capnia*			
		Paracapnia			
	Perlidae	*Acroneuria*	1		
		Agnetina			
		Eccoptura			
		Paragnetina	6		
	Perlodidae	*Isoperla*			
Trichoptera	**Glossosomatidae**	*Glossosoma*			

Class: Order	Family	Family/*Genus*	Reference Category 67bs		
			LWIC 0.1	LWIC 4.0	LWIC 8.4
Trichoptera	**Hydropsychidae**	*Ceratopsyche*			
		Cheumatopsyche	29	40	7
		Diplectrona			
		Hydropsyche	45	23	7
		Macrostemum		1	
		Potamyia flava			
	Philopotamidae	*Chimarra*	5	4	1
		Dolophilodes			
	Phryganeidae	*Oligostomis*			
	Polycentropodidae	*Polycentropus*			
	Rhyacophilidae	*Rhyacophila*			
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**			
Hirudinea: Gnathobdellida	**Hirudinidae**	**Hirudinidae**			
Crustacea: Amphipoda	**Gammaridae**	*Gammarus*			
Decapoda	**Cambaridae**	*Cambarus*			
		Orconectes			1
Gastropoda: Gastropoda	**Physidae**	*Physa*			
		Physella			
	Planorbidae	*Planorbella*			
Bivalvia: Pelecypoda	**Sphaeriidae**	*Pisidium*			

Class: Order	Family	Family/*Genus*	Reference Category 67bs			
			UNT1 0.2	UNT2 0.1	UNT3 0.1	UNT6 1.2
Insecta: Coleoptera	**Elmidae**	*Optioservus*				
		Ordobrevia				
		Stenelmis	17	3	6	47
	Hydrophilidae	*Hydrobius*				
		Laccobius				
	Psephenidae	*Psephenus*	9	15	9	20
Collembola	**Poduridae**	*Podura*				
Diptera	**Athericidae**	*Atherix*				25
	Ceratopogonidae	*Alluaudomyia*				
	Chironomidae	**Chironomidae**	23	24	25	27
	Empididae	*Hemerodromia*				
	Simuliidae	**Simuliidae**			3	3
	Tabanidae	*Tabanus*				
	Tipulidae	*Antocha*		1		
		Dicranota	2	4	1	10
		Hexatoma	1			
		Limonia				
		Tipula			1	
Ephemeroptera	**Baetidae**	*Acentrella*				
		Baetis	4	6	3	3
		Centroptilum				
		Cloeon				
	Ephemerellidae	*Attenella*				6
	Ephemeridae	*Ephemera*				2
	Heptageniidae	*Epeorus*				
		Macdunnoa				
		Nixe	1		1	
		Rhithrogena				
		Stenacron				
		Stenonema			1	19
	Isonychiidae	*Isonychia*	3		1	8
	Leptophlebiidae	*Paraleptophlebia*				1
Hemiptera	**Veliidae**	*Microvelia*	4	1		
		Rhagovelia	1	2		
Megaloptera	**Corydalidae**	*Corydalus*				1
		Nigronia	5	2	6	8
	Sialidae	*Sialis*			2	
Odonata	**Aeshnidae**	*Boyeria*				
	Coenagrionidae	*Argia*				
	Cordulegastridae	*Cordulegaster*	1			
	Gomphidae	*Gomphus*				
Plecoptera	**Capniidae**	*Capnia*			1	
		Paracapnia				
	Perlidae	*Acroneuria*	1			
		Agnetina				
		Eccoptura				
		Paragnetina				
	Perlodidae	*Isoperla*				
Trichoptera	**Glossosomatidae**	*Glossosoma*	1			

Class: Order	Family	Family/*Genus*	Reference Category 67bs			
			UNT1 0.2	UNT2 0.1	UNT3 0.1	UNT6 1.2
Trichoptera	**Hydropsychidae**	*Ceratopsyche*				
		Cheumatopsyche	38	21	25	20
		Diplectrona				
		Hydropsyche	17	25	33	25
		Macrostemum				
		Potamyia flava		2		
	Philopotamidae	*Chimarra*	4	34	1	16
		Dolophilodes				
	Phryganeidae	*Oligostomis*				
	Polycentropodidae	*Polycentropus*		2	1	
	Rhyacophilidae	*Rhyacophila*				
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**				
Hirudinea: Gnathobdellida	**Hirudinidae**	**Hirudinidae**				
Crustacea: Amphipoda	**Gammaridae**	*Gammarus*				
Decapoda	**Cambaridae**	*Cambarus*		1		
		Orconectes				
Gastropoda: Gastropoda	**Physidae**	*Physa*				
		Physella				
	Planorbidae	*Planorbella*				
Bivalvia: Pelecypoda	**Sphaeriidae**	*Pisidium*				

NOTE: Reference site is LSHM 0.8

Class: Order	Family	Family/*Genus*	Reference Category 67bs			
			UNT8 0.7	WICO 30.4	WICO 34.4	WICO 39.1
Insecta: Coleoptera	**Elmidae**	*Optioservus*				1
		Ordobrevia				
		Stenelmis				
	Hydrophilidae	*Hydrobius*				
		Laccobius				
	Psephenidae	*Psephenus*				
Collembola	**Poduridae**	*Podura*				
Diptera	**Athericidae**	*Atherix*				
	Ceratopogonidae	*Alluaudomyia*			1	6
	Chironomidae	**Chironomidae**	81	88	26	65
	Empididae	*Hemerodromia*				
	Simuliidae	**Simuliidae**	4	7	7	1
	Tabanidae	*Tabanus*				
	Tipulidae	*Antocha*	1			
		Dicranota		1	1	
		Hexatoma		1		
		Limonia				
		Tipula		1	1	
Ephemeroptera	**Baetidae**	*Acentrella*				
		Baetis				
		Centroptilum				
		Cloeon				
	Ephemerellidae	*Attenella*				
	Ephemeridae	*Ephemera*				
	Heptageniidae	*Epeorus*				
		Macdunnoa				
		Nixe				
		Rhithrogena				
		Stenacron				
		Stenonema				
	Isonychiidae	*Isonychia*				
	Leptophlebiidae	*Paraleptophlebia*	1			
Hemiptera	**Veliidae**	*Microvelia*	2			
		Rhagovelia				
Megaloptera	**Corydalidae**	*Corydalus*				
		Nigronia	3	2	2	1
	Sialidae	*Sialis*				37
Odonata	**Aeshnidae**	*Boyeria*				
	Coenagrionidae	*Argia*				
	Cordulegastridae	*Cordulegaster*				
	Gomphidae	*Gomphus*				
Plecoptera	**Capniidae**	*Capnia*				
		Paracapnia				
	Perlidae	*Acroneuria*				
		Agnetina				
		Eccoptura				
		Paragnetina				
	Perlodidae	*Isoperla*				
Trichoptera	**Glossosomatidae**	*Glossosoma*				

NOTE: Reference site is LSHM 0.8

Class: Order	Family	Family/*Genus*	Reference Category 67bs			
			UNT8 0.7	WICO 30.4	WICO 34.4	WICO 39.1
Trichoptera	**Hydropsychidae**	*Ceratopsyche*				
		Cheumatopsyche	9	13		
		Diplectrona	8			
		Hydropsyche	28	17	73	
		Macrostemum			3	
		Potamyia flava				
	Philopotamidae	*Chimarra*				
		Dolophilodes				
	Phryganeidae	*Oligostomis*				3
	Polycentropodidae	*Polycentropus*				
	Rhyacophilidae	*Rhyacophila*				
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**				
Hirudinea: Gnathobdellida	**Hirudinidae**	**Hirudinidae**				
Crustacea: Amphipoda	**Gammaridae**	*Gammarus*				
Decapoda	**Cambaridae**	*Cambarus*		1		
		Orconectes				
Gastropoda: Gastropoda	**Physidae**	*Physa*				
		Physella	1			
	Planorbidae	*Planorbella*	1			
Bivalvia: Pelecypoda	**Sphaeriidae**	*Pisidium*				

NOTE: Reference site is LSHM 0.8

Class: Order	Family	Family/*Genus*	Reference Category 67c		
			RATL 0.4	RATL 2.6	WICO 41.5
Insecta: Coleoptera	**Elmidae**	*Optioservus*			
		Ordobrevia			
		Stenelmis		3	
	Hydrophilidae	*Hydrobius*			
		Laccobius			
	Psephenidae	*Psephenus*	4		
Collembola	**Poduridae**	*Podura*			1
Diptera	**Athericidae**	*Atherix*			
	Ceratopogonidae	*Alluaudomyia*			8
	Chironomidae	**Chironomidae**	16	2	41
	Empididae	*Hemerodromia*			
	Simuliidae	**Simuliidae**	1	1	11
	Tabanidae	*Tabanus*			
	Tipulidae	*Antocha*			1
		Dicranota		6	1
		Hexatoma	3	1	
		Limonia			
		Tipula			
Ephemeroptera	**Baetidae**	*Acentrella*	3		
		Baetis			
		Centroptilum			
		Cloeon			
	Ephemerellidae	*Attenella*			
	Ephemeridae	*Ephemera*			
	Heptageniidae	*Epeorus*			
		Macdunnoa			
		Nixe			
		Rhithrogena	5		
		Stenacron			
		Stenonema	1		
	Isonychiidae	*Isonychia*			
	Leptophlebiidae	*Paraleptophlebia*			
Hemiptera	**Veliidae**	*Microvelia*			
		Rhagovelia			
Megaloptera	**Corydalidae**	*Corydalus*			
		Nigronia		5	4
	Sialidae	*Sialis*			1
Odonata	**Aeshnidae**	*Boyeria*		5	
	Coenagrionidae	*Argia*			
	Cordulegastridae	*Cordulegaster*			
	Gomphidae	*Gomphus*			
Plecoptera	**Capniidae**	*Capnia*	1	12	4
		Paracapnia			
	Perlidae	*Acroneuria*	6		
		Agnetina			
		Eccoptura		10	
		Paragnetina			
	Perlodidae	*Isoperla*			
Trichoptera	**Glossosomatidae**	*Glossosoma*			

*Reference Site

Class: Order	Family	Family/*Genus*	Reference Category 67c		
			RATL 0.4	RATL 2.6	WICO 41.5
Trichoptera	**Hydropsychidae**	*Ceratopsyche*			
		Cheumatopsyche	3	43	6
		Diplectrona			54
		Hydropsyche	27	19	
		Macrostemum			
		Potamyia flava			
	Philopotamidae	*Chimarra*		5	
		Dolophilodes	72		1
	Phryganeidae	*Oligostomis*			
	Polycentropodidae	*Polycentropus*		1	
	Rhyacophilidae	*Rhyacophila*	2	7	
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**		1	
Hirudinea: Gnathobdellida	**Hirudinidae**	**Hirudinidae**			
Crustacea: Amphipoda	**Gammaridae**	*Gammarus*			
Decapoda	**Cambaridae**	*Cambarus*			
		Orconectes			
Gastropoda: Gastropoda	**Physidae**	*Physa*			
		Physella			
	Planorbidae	*Planorbella*			
Bivalvia: Pelecypoda	**Sphaeriidae**	*Pisidium*			

*Reference Site

APPENDIX C

RAW BENTHIC MACROINVERTEBRATE DATA FOR 1997

Class: Order	Family	Family/*Genus*	Reference Category 67bl			
			WICO 0.3	WICO 7.9	WICO 14.7	WICO 23.6
Insecta: Coleoptera	**Dytiscidae**	*Agabus*				
	Elmidae	*Ancyronyx variegata*	1			
		Dubiraphia				
		Optioservus	2	3	21	1
		Stenelmis	3	4	2	1
	Psephenidae	*Psephenus*	2	3		
Diptera	**Athericidae**	*Atherix*		1		
	Ceratopogonidae	*Alluaudomyia*		6		
	Chironomidae	**Chironomidae**	51	51	24	61
	Empididae	*Hemerodromia*	2	4		9
	Simuliidae	**Simuliidae**	1	9		1
	Tipulidae	*Antocha*	2			
		Hexatoma				
		Limnophila				
		Tipula	2			
Ephemeroptera	**Ameletidae**	*Ameletus*				
	Baetidae	*Acentrella*				
		Baetis	3		2	
	Ephemerellidae	*Attenella*			3	
		Ephemerella	2	9		2
		Serratella				
	Ephemeridae	*Ephemera*	7			
		Hexagenia			1	
	Heptageniidae	*Epeorus*			3	1
		Leucrocuta				
		Stenacron	1			
		Stenonema	9	6	14	
	Isonychiidae	*Isonychia*	8	1		
	Leptophlebiidae	*Leptophlebia*				
		Paraleptophlebia				
	Tricorythidae	*Leptohypes*		1		
Megaloptera	**Corydalidae**	*Corydalus*		1		
		Nigronia			1	
	Sialidae	*Sialis*				
Odonata	**Calopterygidae**	*Hataerina*				
	Coenagrionidae	*Argia*				
Plecoptera	**Capniidae**	*Paracapnia*				
	Leuctridae	*Leuctra*				
	Nemouridae	*Amphinemura*	8			1
	Peltoperlidae	*Peltoperla*				
	Perlidae	*Acroneuria*	9			
		Agnetina				
		Perlesta				
	Perlodidae	*Isoperla*			1	
Trichoptera	**Hydropsychidae**	*Ceratopsyche*	2	7	6	
		Cheumatopsyche	9	1	7	18
		Hydropsyche	1		34	3
	Philopotamidae	*Chimarra*	2			
		Dolophilodes				
	Polycentropodidae	*Neureclipsis*				
		Polycentropus				
	Psychomyiidae	*Lype diversa*				
	Rhyacophilidae	*Rhyacophila*				
Oligochaeta: Haplotaxida	**Naididae**	**Naididae**				4
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**				
	Lymnaeidae	*Lymnaea stagnalis*				

Class: Order	Family	Family/*Genus*	Reference Category 67bs			
			LWIC 0.1	LWIC 4.0	LWIC 8.4	UNT1 0.2
Insecta: Coleoptera	**Dytiscidae**	*Agabus*				
	Elmidae	*Ancyronyx variegata*				
		Dubiraphia			1	
		Optioservus	4			1
		Stenelmis	20	2	18	3
	Psephenidae	*Psephenus*	2	8		4
Diptera	**Athericidae**	*Atherix*				
	Ceratopogonidae	*Alluaudomyia*			1	
	Chironomidae	**Chironomidae**	45	60	55	38
	Empididae	*Hemerodromia*	4		5	1
	Simuliidae	**Simuliidae**		4	9	1
	Tipulidae	*Antocha*				1
		Hexatoma				
		Limnophila				
		Tipula	1			
Ephemeroptera	**Ameletidae**	*Ameletus*				1
	Baetidae	*Acentrella*	1			
		Baetis	4	9	8	12
	Ephemerellidae	*Attenella*				
		Ephemerella			10	34
		Serratella		2		
	Ephemeridae	*Ephemera*	1			
		Hexagenia				1
	Heptageniidae	*Epeorus*				
		Leucrocuta		1		1
		Stenacron				
		Stenonema		1		
	Isonychiidae	*Isonychia*	10	1		
	Leptophlebiidae	*Leptophlebia*				
		Paraleptophlebia				
	Tricorythidae	*Leptohypes*				
Megaloptera	**Corydalidae**	*Corydalus*				
		Nigronia	1			
	Sialidae	*Sialis*	1			
Odonata	**Calopterygidae**	*Hataerina*				1
	Coenagrionidae	*Argia*		1		
Plecoptera	**Capniidae**	*Paracapnia*				
	Leuctridae	*Leuctra*				
	Nemouridae	*Amphinemura*	1	1	7	1
	Peltoperlidae	*Peltoperla*				
	Perlidae	*Acroneuria*				1
		Agnetina	4	10		
		Perlesta				
	Perlodidae	*Isoperla*		1	1	1
Trichoptera	**Hydropsychidae**	*Ceratopsyche*	2		2	1
		Cheumatopsyche	14	5	10	3
		Hydropsyche	1	3	1	3
	Philopotamidae	*Chimarra*	3	2		
		Dolophilodes			1	
	Polycentropodidae	*Neureclipsis*				
		Polycentropus				
	Psychomyiidae	*Lype diversa*				
	Rhyacophilidae	*Rhyacophila*				
Oligochaeta: Haplotaxida	**Naididae**	**Naididae**				
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**				
	Lymnaeidae	*Lymnaea stagnalis*				

Class: Order	Family	Family/*Genus*	Reference Category 67bs			
			UNT2 0.1	UNT3 0.1	UNT6 1.2	UNT8 0.7
Insecta: Coleoptera	**Dytiscidae**	*Agabus*		1		
	Elmidae	*Ancyronyx variegata*				
		Dubiraphia				
		Optioservus				5
		Stenelmis	1		22	
	Psephenidae	*Psephenus*	2		3	
Diptera	**Athericidae**	*Atherix*			2	
	Ceratopogonidae	*Alluaudomyia*	1	1		
	Chironomidae	**Chironomidae**	63	52	49	69
	Empididae	*Hemerodromia*			4	4
	Simuliidae	**Simuliidae**		3	1	2
	Tipulidae	*Antocha*				
		Hexatoma				
		Limnophila				1
		Tipula				4
Ephemeroptera	**Ameletidae**	*Ameletus*				
	Baetidae	*Acentrella*	1			
		Baetis	36	7		
	Ephemerellidae	*Attenella*				
		Ephemerella	1		23	
		Serratella				
	Ephemeridae	*Ephemera*				
		Hexagenia				
	Heptageniidae	*Epeorus*				
		Leucrocuta				
		Stenacron				
		Stenonema			3	
	Isonychiidae	*Isonychia*			1	
	Leptophlebiidae	*Leptophlebia*			1	
		Paraleptophlebia		2		
	Tricorythidae	*Leptohypes*				
Megaloptera	**Corydalidae**	*Corydalus*				
		Nigronia				1
	Sialidae	*Sialis*				
Odonata	**Calopterygidae**	*Hataerina*				
	Coenagrionidae	*Argia*				
Plecoptera	**Capniidae**	*Paracapnia*				1
	Leuctridae	*Leuctra*			1	
	Nemouridae	*Amphinemura*	4	12		1
	Peltoperlidae	*Peltoperla*				
	Perlidae	*Acroneuria*				
		Agnetina				
		Perlesta		2		
	Perlodidae	*Isoperla*				2
Trichoptera	**Hydropsychidae**	*Ceratopsyche*			1	13
		Cheumatopsyche	1		2	
		Hydropsyche	1		2	
	Philopotamidae	*Chimarra*	2			
		Dolophilodes	6	41	6	
	Polycentropodidae	*Neureclipsis*				
		Polycentropus				
	Psychomyiidae	*Lype diversa*				
	Rhyacophilidae	*Rhyacophila*		1		
Oligochaeta: Haplotaxida	**Naididae**	**Naididae**				
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**				
	Lymnaeidae	*Lymnaea stagnalis*				

Class: Order	Family	Family/*Genus*	Reference Category 67bs		
			WICO 30.4	WICO 34.4	WICO 39.1
Insecta: Coleoptera	**Dytiscidae**	*Agabus*			
	Elmidae	*Ancyronyx variegata*			
		Dubiraphia			
		Optioservus	1		
		Stenelmis			
	Psephenidae	*Psephenus*			
Diptera	**Athericidae**	*Atherix*			
	Ceratopogonidae	*Alluaudomyia*			
	Chironomidae	**Chironomidae**	120	15	15
	Empididae	*Hemerodromia*			1
	Simuliidae	**Simuliidae**		65	
	Tipulidae	*Antocha*			
		Hexatoma			
		Limnophila		1	
		Tipula		1	
Ephemeroptera	**Ameletidae**	*Ameletus*			
	Baetidae	*Acentrella*			
		Baetis			
	Ephemerellidae	*Attenella*			
		Ephemerella			
		Serratella			
	Ephemeridae	*Ephemera*			
		Hexagenia			
	Heptageniidae	*Epeorus*			
		Leucrocuta			
		Stenacron			
		Stenonema			
	Isonychiidae	*Isonychia*			
	Leptophlebiidae	*Leptophlebia*			
		Paraleptophlebia			
	Tricorythidae	*Leptohypes*			
Megaloptera	**Corydalidae**	*Corydalus*			
		Nigronia			
	Sialidae	*Sialis*			1
Odonata	**Calopterygidae**	*Hataerina*			
	Coenagrionidae	*Argia*			
Plecoptera	**Capniidae**	*Paracapnia*			
	Leuctridae	*Leuctra*			
	Nemouridae	*Amphinemura*			
	Peltoperlidae	*Peltoperla*			
	Perlidae	*Acroneuria*			
		Agnetina			
		Perlesta			
	Perlodidae	*Isoperla*			
Trichoptera	**Hydropsychidae**	*Ceratopsyche*			
		Cheumatopsyche			
		Hydropsyche		14	1
	Philopotamidae	*Chimarra*			
		Dolophilodes			
	Polycentropodidae	*Neureclipsis*			
		Polycentropus			1
	Psychomyiidae	*Lype diversa*			
	Rhyacophilidae	*Rhyacophila*			
Oligochaeta: Haplotaxida	**Naididae**	**Naididae**		3	
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**			
	Lymnaeidae	*Lymnaea stagnalis*			

Class: Order	Family	Family/*Genus*	Reference Category 67c		
			RATL 0.4	RATL 2.6	WICO 41.5
Insecta: Coleoptera	**Dytiscidae**	*Agabus*			
	Elmidae	*Ancyronyx variegata*			
		Dubiraphia			
		Optioservus		13	
		Stenelmis			
	Psephenidae	*Psephenus*	1		
Diptera	**Athericidae**	*Atherix*			
	Ceratopogonidae	*Alluaudomyia*			
	Chironomidae	**Chironomidae**	44	8	7
	Empididae	*Hemerodromia*	1	1	1
	Simuliidae	**Simuliidae**	1	9	22
	Tipulidae	*Antocha*		1	
		Hexatoma	1		
		Limnophila			
		Tipula			
Ephemeroptera	**Ameletidae**	*Ameletus*			
	Baetidae	*Acentrella*			
		Baetis	1		
	Ephemerellidae	*Attenella*			
		Ephemerella	1		
		Serratella			
	Ephemeridae	*Ephemera*			
		Hexagenia			
	Heptageniidae	*Epeorus*	3	1	
		Leucrocuta			
		Stenacron			
		Stenonema			
	Isonychiidae	*Isonychia*			
	Leptophlebiidae	*Leptophlebia*			
		Paraleptophlebia			
	Tricorythidae	*Leptohypes*			
Megaloptera	**Corydalidae**	*Corydalus*			
		Nigronia			2
	Sialidae	*Sialis*			
Odonata	**Calopterygidae**	*Hataerina*			
	Coenagrionidae	*Argia*			
Plecoptera	**Capniidae**	*Paracapnia*			
	Leuctridae	*Leuctra*		11	
	Nemouridae	*Amphinemura*	10	44	35
	Peltoperlidae	*Peltoperla*		2	
	Perlidae	*Acroneuria*	2	2	
		Agnetina	3		
		Perlesta			
	Perlodidae	*Isoperla*			19
Trichoptera	**Hydropsychidae**	*Ceratopsyche*	1	9	
		Cheumatopsyche			
		Hydropsyche	1		6
	Philopotamidae	*Chimarra*		1	
		Dolophilodes	35		2
	Polycentropodidae	*Neureclipsis*		1	
		Polycentropus			
	Psychomyiidae	*Lype diversa*	7	3	
	Rhyacophilidae	*Rhyacophila*		2	
Oligochaeta: Haplotaxida	**Naididae**	**Naididae**			
Hirudinea: Rhynchobdellida	**Glossiphoniidae**	**Glossiphoniidae**		1	
	Lymnaeidae	*Lymnaea stagnalis*			

Appendix D

Raw Water Quality Data From Sample Sites in the Wiconisco Creek Watershed

Sample Site	WICO 01	WICO 02	WICO 03	WICO 04	WICO 13	WICO 14	WICO 15	WICO 16
New ID	WICO 0.3	LWIC 0.1	WICO 7.9	WICO 14.7	LWIC 4.0	UNT1 0.2	UNT2 0.1	LWIC 8.4
Date	960903	960903	960903	960903	960903	960903	960903	960903
Flow (cfs)	43.94	1.84	33.647	32.97	1.668	0.149	0.375	0.558
Sediment (mg/l)	1	9	2	6				
Temperature (C)	19.3	18.3	19.6	20.6	20	17.9	18.8	21.4
pH (SU)	7.3	7.65	7.35	7.1	7.5	7.65	7.8	7.55
DO (umhos/cm)	7.69	7.47	8.49	7.55	7.47	8.29	8.2	7.67
Cond (mg/l)	184	229	196	175	210	209	982	211
Alk (mg/l)	28	68	24	24	56	58	110	64
Acid (mg/l)	4	4	4	4	6	6	4	4
Residue, Total (mg/l)	158	176	136	164	184	182	718	198
Residue, Diss. (mg/l)	134	166	133	150	166	174	718	194
Nitrogen, Total (mg/l)	1.066	3.228	1.074	0.994	4.190	2.226	15.428	4.198
Nitrogen, Diss. (mg/l)	0.826	3.206	1.024	0.844	3.532	2.186	14.138	3.972
NH_3N, Diss. (mg/l)	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
NH_3N, Total (mg/l)	0.05	0.06	< 0.02	0.05	0.10	0.04	0.02	0.10
NO_2N, Diss. (mg/l)	0.016	0.006	0.004	0.004	0.032	0.006	0.008	0.032
NO_2N, Total (mg/l)	0.016	0.008	0.004	0.004	0.04	0.006	0.008	0.038
NO_3N, Diss. (mg/l)	0.71	2.63	0.75	0.62	3.40	2.08	14.03	3.40
NO_3N, Total (mg/l)	0.78	2.63	0.75	0.64	3.39	2.120	14.27	3.40
P, Total (mg/l)	0.03	0.06	0.03	0.04	0.12	0.04	0.98	0.08
P, Diss. (mg/l)	0.032	0.03	0.011	0.02	0.052	0.023	0.94	0.025
DOP (mg/l)	0.043	0.032	0.012	0.016	0.056	0.025	0.900	0.022
TOC (mg/l)	1.8	3.5	1.6	1.6	3.8	2.7	5.6	3.7
Ca (mg/l)	12.7	24.0	12.3	12.2	20.3	22.1	26.6	21.9
Mg (mg/l)	6.46	6.11	6.53	6.73	5.68	5.54	11.20	5.89
Chl (mg/l)	8	16	7	6	14	14	69	12
SO_4 (mg/l)	50	19	38	47	16	18	234	16
Fe, Total (µg/l)	162	175	185	277	373	110	107	378
Fe, Diss. (µg/l)	16	38	18	28	55	14	19	50
Mn, Total (µg/l)	54	40	44	52	108	16	28	104
Mn, Diss. (µg/l)	41	32	39	46	81	13	28	94
Al, Total (µg/l)	< 135	17,400	< 135	< 135	275	< 135	< 135	144
Al, Diss. (µg/l)	< 135	< 135	< 135	< 135	< 135	< 135	< 135	< 135
TOP (mg/l)	0.043	0.055	0.025	0.029	0.107	0.039	0.97	0.056
Turb (NTU)	1.6	1.9	1.8	1.3	5.9	1.3	1.2	5.2

Sample Site	WICO 17	WICO 05	WICO 06	WICO 07	WICO 18	WICO 19	WICO 20
New ID	UNT3 0.1	WICO 23.6	RATL 0.4	BEAR 0.4	UNT5 0.1	UNT6 1.2	RATL 2.6
Date	960903	960904	960904	960904	960904	960904	960904
Flow (cfs)	0.107	25.498	7.212	6.57		0.357	3.574
Sediment (mg/l)		1	1	27			
Temperature (C)	20.6	18.5	19.3	15.1	19.7	20.4	17.0
pH (SU)	7.40	7.12	6.30	7.05	7.55	7.40	5.75
DO (umhos/cm)	7.24	8.11	7.91	8.72	7.00	6.93	8.22
Cond (mg/l)	225	175	18	298	358	103	17
Alk (mg/l)	52	22	6	72	72	38	4
Acid (mg/l)	6	6	6	16	6	4	6
Residue, Total (mg/l)	250	166	24	240	272	104	34
Residue, Diss. (mg/l)	172	166	20	230	256	96	30
Nitrogen, Total (mg/l)	5.646	1.204	0.212	0.326	5.256	0.956	0.122
Nitrogen, Diss. (mg/l)	5.346	0.734	0.212	0.126	4.316	0.906	0.122
NH_3N, Diss. (mg/l)	0.03	< 0.02	0.04	0.18	<0.02	< 0.02	0.06
NH_3N, Total (mg/l)	0.03	< 0.02	0.04	0.28	< 0.02	0.04	0.06
NO_2N, Diss. (mg/l)	0.006	0.004	< 0.004	0.006	0.016	0.006	< 0.004
NO_2N, Total (mg/l)	0.006	0.004	< 0.004	0.006	0.016	0.006	< 0.004
NO_3N, Diss. (mg/l)	4.88	0.63	0.11	<0.04	4.20	0.70	< 0.04
NO_3N, Total (mg/l)	4.88	1.10	0.11	< 0.04	5.14	0.72	< 0.04
P, Total (mg/l)	0.10	0.03	< 0.02	< 0.02	0.15	0.07	< 0.02
P, Diss. (mg/l)	0.037	0.009	0.006	0.004	0.111	0.040	0.006
DOP (mg/l)	0.035	0.009	0.006	0.020	0.094	0.038	0.007
TOC (mg/l)	2.4	1.4	< 1.0	< 1.0	2.8	2.9	1.1
Ca (mg/l)	23.200	15.500	0.878	24.500	33.800	11.200	0.420
Mg (mg/l)	6.03	7.62	0.60	20.20	6.99	2.26	0.53
Chl (mg/l)	14	5	2	1	39	4	2
SO_4 (mg/l)	< 10	50	< 10	88	26	< 10	< 10
Fe, Total (µg/l)	1,000	575	24	4,360	52	260	23
Fe, Diss. (µg/l)	16	44	< 50	4,360	30	99	21
Mn, Total (µg/l)	53	192	< 10	1,870	31	38	23
Mn, Diss. (µg/l)	24	144	< 10	1,870	29	30	22
Al, Total (µg/l)	1,230	< 135	< 135	< 135	< 135	< 135	< 135
Al, Diss (µg/l)	< 135	< 135	< 135	< 135	< 135	< 135	< 135
TOP (mg/l)	0.066	0.016	0.008	0.028	0.155	0.065	0.007
Turb (NTU)	4.5	3.2	< 1.0	110	< 1.0	3.7	< 1.0

Sample Site	WICO 21	WICO 08	WICO 09	WICO 10	WICO 11	WICO 12	WICO 22
New ID	BEAR 1.7	WICO 30.4	WICO 34.4	WICO 39.1	WICO 41.4	PORT 0.1	UNT7 0.9
Date	960904	960905	960905	960905	960905	960905	960905
Flow (cfs)		20.716	17.417	4.881	3.189	1.661	
Sediment (mg/l)		7	14	10	36	31	
Temperature (C)	19.1	18.5	19.3	16.9	16.2	14.4	17.2
pH (SU)	4.35	6.55	6.45	3.90	2.70	2.50	6.05
DO (umhos/cm)	4.59	6.84	6.34	7.74	8.63	9.12	7.88
Cond (mg/l)	26	185	214	264	564	975	53
Alk (mg/l)	0	14	12	0	0	0	10
Acid (mg/l)	34	10	10	28	70	140	8
Residue, Total (mg/l)	238	166	204	130	484	918	56
Residue, Diss. (mg/l)	226	150	188	226	490	828	36
Nitrogen, Total (mg/l)	1.900	0.800	0.536	0.452	0.172	0.122	0.742
Nitrogen, Diss. (mg/l)	1.506	0.794	0.516	0.452	0.172	0.122	0.742
NH_3N, Diss. (mg/l)	0.2	0.11	0.10	0.08	0.10	0.31	< 0.02
NH_3N, Total (mg/l)	0.2	0.11	0.12	0.08	0.10	0.31	< 0.02
NO_2N, Diss. (mg/l)	0.006	0.014	0.026	< 0.004	< 0.004	< 0.004	< 0.004
NO_2N, Total (mg/l)	0.010	0.020	0.026	< 0.004	< 0.004	< 0.004	< 0.004
NO_3N, Diss. (mg/l)	<0.040	0.680	0.390	0.350	0.070	< 0.04	0.640
NO_3N, Total (mg/l)	< 0.04	0.68	0.41	0.35	0.07	< 0.04	0.64
P, Total (mg/l)	0.07	0.04	0.06	< 0.02	0.02	< 0.02	0.02
P, Diss. (mg/l)	0.010	0.020	0.012	0.007	0.006	0.009	0.020
DOP (mg/l)	0.013	0.022	< 0.002	0.007	0.003	0.005	0.011
TOC (mg/l)	67.3	2.9	2.1	1.9	< 1.0	< 1.0	2.6
Ca (mg/l)	1.85	14.80	16.80	14.50	22.10	41.60	4.20
Mg (mg/l)	0.87	7.31	10.10	12.70	28.40	53.70	1.36
Chl (mg/l)	5	7	6	4	3	2	6
SO_4 (mg/l)	20	55	69	81	162	324	< 10.0
Fe, Total (µg/l)	19,100	481	596	1,370	9,780	16,500	377
Fe, Diss. (µg/l)	5,980	208	50	782	6,540	13,400	150
Mn, Total (µg/l)	174	410	626	1,080	2,370	4,450	34
Mn, Diss. (µg/l)	174	410	606	1,080	2,370	4,150	44
Al, Total (µg/l)	1,230	177	241	915	2,400	4,430	190
Al, Diss. (µg/l)	583	< 135	< 135	762	2,220	4,040	< 135
TOP (mg/l)	0.056	0.041	0.023	0.012	0.020	0.012	0.019
Turb (NTU)	31	3.9	2.7	2.8	32	57	4.6

Sample Site	WICO 23	WICO 24	WICO 01	WICO 02	WICO 03	WICO 13	WICO 14
New ID	UNT8 0.7	WICO 41.5	WICO 0.3	LWIC 0.1	WICO 7.9	LWIC 4.0	UNT1 0.2
Date	960905	960905	970512	970512	970512	970512	970512
Flow (cfs)	0.272		136.85	7.62	111.28	3.96	0.25
Sediment (mg/l)			3	7	3		
Temperature (C)	19.3	16.7	13.2	13.1	13.1	16.5	14.9
pH (SU)	6.85	5.20	7.15	7.40	7.25	7.30	7.55
DO (umhos/cm)	7.51	8.26	9.05	9.27	9.83	9.62	9.27
Cond (mg/l)	186	84	135	161	132	147	208
Alk (mg/l)	30	4	22	42	22	30	52
Acid (mg/l)	10	14	4	4	4	8	8
Residue, Total (mg/l)	154	84	130	116	132	114	154
Residue, Diss. (mg/l)	162	98	124	112	120	94	136
Nitrogen, Total (mg/l)	1.38	0.192	1.04	3.28	0.71	3.60	2.99
Nitrogen, Diss. (mg/l)	1.376	0.172	0.890	3.120	0.570	3.410	2.930
NH_3N, Diss. (mg/l)	< 0.02	< 0.02	<0.02	<0.02	<0.02	<0.02	<0.02
NH_3N, Total (mg/l)	< 0.02	< 0.02	0.02	<0.02	<0.02	0.04	0.03
NO_2N, Diss. (mg/l)	0.006	< 0.004	0.020	0.040	0.020	0.050	0.030
NO_2N, Total (mg/l)	0.010	< 0.004	0.020	0.040	0.020	0.050	0.030
NO_3N, Diss. (mg/l)	1.27	0.07	0.58	2.80	0.38	3.15	2.67
NO_3N, Total (mg/l)	1.27	0.09	0.59	2.97	0.38	3.28	2.67
P, Total (mg/l)	0.03	< 0.02	<0.02	0.02	<0.02	0.02	0.02
P, Diss. (mg/l)	0.019	0.01	0.012	0.014	0.008	0.016	0.014
DOP (mg/l)	0.01	< 0.002	0.011	0.013	0.006	0.013	0.011
TOC (mg/l)	3.2	1.3	1.6	3	1.3	2.7	2.6
Ca (mg/l)	18.30	4.91	12.8	18.80	11.60	16.60	25.10
Mg (mg/l)	4.73	3.70	5.46	4.76	5.51	4.45	5.51
Chl (mg/l)	13	3	6	10	5	9	16
SO_4 (mg/l)	36	15	33	20	35	14	23
Fe, Total (µg/l)	319	465	254	231	306	194	187
Fe, Diss. (µg/l)	94	921	54	75	113	54	39
Mn, Total (µg/l)	64	426	117	45	162	49	46
Mn, Diss (µg/l)	64	779	91	37	162	38	34
Al, Total (µg/l)	240	180	<135	<135	<135	<135	203
Al, Diss. (µg/l)	< 135	499	<135	<135	<135	<135	<135
TOP (mg/l)	0.01	< 0.002	0.006	0.012	0.01	0.014	0.017
Turb (NTU)	6.4	1.8	1.6	3.8	1.8	4.5	38

Sample Site	WICO 16	WICO 04	WICO 15	WICO 17	WICO 18	WICO 19	WICO 05
New ID	LWIC 8.4	WICO 14.7	UNT2 0.1	UNT3 0.1	UNT5 0.1	UNT6 1.2	WICO 23.6
Date	970512	970513	970513	970513	970513	970513	970514
Flow (cfs)	1.65	112.5	0.49		0.326	1.63	113.83
Sediment (mg/l)		3					4
Temperature (C)	18.6	13.0	12.3	12.1	12.6	12.5	10.3
pH (SU)	7.40	6.90	7.35	7.30	7.15	7.10	6.97
DO (umhos/cm)	9.24	8.13	8.01	9.02	7.68	9.27	9.03
Cond (mg/l)	143	135	223	212	344	80	130
Alk (mg/l)	26	22	68	44	56	24	24
Acid (mg/l)	4	6	8	6	4	6	6
Residue, Total (mg/l)	118	88	158	156	262	90	116
Residue, Diss. (mg/l)	94	86	158	152	260	86	106
Nitrogen ,Total (mg/l)	4.45	0.75	4.59	5.93	8.64	1.23	0.71
Nitrogen, Diss. (mg/l)	4.21	0.67	4.52	5.93	8.08	1.19	0.63
NH_3N, Diss. (mg/l)	<0.02	0.03	0.05	<0.02	0.06	<0.02	0.04
NH_3N, Total (mg/l)	0.07	0.03	0.05	<0.02	0.06	<0.02	0.04
NO_2N, Diss. (mg/l)	0.06	0.02	0.05	0.03	0.1	0.02	0.01
NO_2N, Total (mg/l)	0.06	0.02	0.05	0.03	0.1	0.02	0.01
NO_3N, Diss. (mg/l)	3.82	0.42	3.9	5.19	7.72	0.89	0.43
NO_3N, Total (mg/l)	3.83	0.42	4.05	5.24	7.73	0.9	0.44
P, Total (mg/l)	0.03	0.02	0.04	0.03	0.14	0.03	0.02
P, Diss. (mg/l)	0.019	0.014	0.041	0.025	0.129	0.022	0.010
DOP (mg/l)	0.013	0.012	0.039	0.025	0.143	0.017	0.008
TOC (mg/l)	3.1	1.3	2.4	2.4	3.4	2.0	1.3
Ca (mg/l)	16.70	12.00	24.50	25.90	36.60	8.69	9.77
Mg (mg/l)	4.47	5.59	6.25	6.20	7.51	2.18	5.78
Chl (mg/l)	8	5	11	14	40	4	4
SO_4 (mg/l)	13	34	24	21	22	<10	38
Fe, Total (µg/l)	499	410	101	94	102	199	529
Fe, Diss. (µg/l)	67	50	27	25	24	65	28
Mn, Total (µg/l)	87	264	30	18	19	32	282
Mn, Diss. (µg/l)	71	221	18	18	17	24	247
Al, Total (µg/l)	425	<135	<135	<135	<135	150	<135
Al, Diss. (µg/l)	<135	<135	<135	<135	<135	<135	9,770
TOP (mg/l)	0.021	0.008	0.061	0.033	0.158	0.022	0.014
Turb (NTU)	9.8	2.9	2.1	2.1	1.7	4	3.7

Sample Site	WICO 06	WICO 07	WICO 08	WICO 20	WICO 21	WICO 09	WICO 10
New ID	RATL 0.4	BEAR 0.4	WICO 30.4	RATL 2.6	BEAR 1.7	WICO 34.4	WICO 39.1
Date	970514	970514	970514	970514	970514	970515	970515
Flow (cfs)	43.96	8.837	45.79	10.26		35.18	12.83
Sediment (mg/l)	1	25	4			4	1
Temperature (C)	9.7	12.3	11.4	9.1	10.5	11.9	10.4
pH (SU)	6.50	6.65	6.65	6.00	4.50	6.35	3.00
DO (umhos/cm)	9.28	8.75	9.07	9.98	7.73	8.36	9.28
Cond (mg/l)	17	271	160	18	27	152	269
Alk (mg/l)	6	68	14	6	0	8	0
Acid (mg/l)	4	14	14	6	14	12	22
Residue, Total (mg/l)	62	204	120	56	72	176	216
Residue, Diss. (mg/l)	60	172	130	54	60	174	214
Nitrogen, Total (mg/l)	0.16	0.41	0.89	0.12	0.52	0.88	0.33
Nitrogen, Diss. (mg/l)	0.13	0.36	0.89	0.12	0.49	0.85	0.29
NH_3N, Diss. (mg/l)	<0.02	0.26	0.29	<0.02	<0.02	0.27	<0.02
NH_3N, Total (mg/l)	<0.02	0.27	0.29	<0.02	0.02	0.29	0.02
NO_2N, Diss. (mg/l)	<0.01	0.03	0.01	<0.01	<0.01	<0.01	<0.01
NO_2N, Total (mg/l)	<0.01	0.04	0.01	<0.01	<0.01	<0.01	<0.01
NO_3N, Diss. (mg/l)	0.04	<0.04	0.43	<0.04	<0.04	0.33	0.17
NO_3N, Total (mg/l)	0.04	<0.04	0.43	<0.04	<0.04	0.34	0.17
P, Total (mg/l)	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02
P, Diss. (mg/l)	0.006	0.005	0.006	0.007	0.011	0.006	0.006
DOP (mg/l)	0.006	0.003	0.004	0.004	0.004	0.002	0.002
TOC (mg/l)	<1	<1	1.3	<1	10.6	1.2	<1
Ca (mg/l)	1.150	23.900	12.700	0.671	2.260	10.700	14.200
Mg (mg/l)	0.832	20.400	6.940	0.624	1.360	6.290	14.500
Chl (mg/l)	2	1	6	2	<1	5	4
SO_4 (mg/l)	<10	91	50	<10	38	44	67
Fe, Total (µg/l)	38	12,500	384	40	1,300	165	820
Fe, Diss. (µg/l)	15	4,300	85	40	593	109	653
Mn, Total (µg/l)	20	2,310	384	40	176	418	936
Mn, Diss. (µg/l)	20	1,700	375	40	176	418	884
Al, Total (µg/l)	<135	<135	<135	<135	310	171	844
Al, Diss. (µg/l)	1,150	<135	<135	<135	210	<135	780
TOP (mg/l)	0.011	0.006	0.013	0.005	0.009	0.008	0.007
Turb (NTU)	<1	121.8	2	<1	1	1.5	<1

Sample Site	WICO 11	WICO 12	WICO 22	WICO 23	WICO 24	WICO 01	WICO 02
New ID	WICO 41.4	PORT 0.1	UNT7 0.9	UNT8 0.7	WICO 41.5	WICO 0.3	LWIC 0.1
Date	970515	970515	970515	970515	970515	970602	970602
Flow (cfs)	12.25	2.2		0.341	3.02	295	40
Sediment (mg/l)	8	15				61	240
Temperature (C)	11.1	12.3	10.5	11.0	11.6	13.1	13.0
pH (SU)	2.60	2.25	6.25	6.80	6.15	6.20	6.97
DO (umhos/cm)	9.11	8.71	9.26	9.08	9.63	7.67	7.96
Cond (mg/l)	415	836	44	199	85	171	253
Alk (mg/l)	0	0	10	14	4	12	10
Acid (mg/l)	48	120	6	8	12	18	42
Residue, Total (mg/l)	348	752	78	192	152	208	378
Residue, Diss. (mg/l)	336	752	78	192	152	144	144
Nitrogen ,Total (mg/l)	0.24	0.27	0.63	1.56	0.19	1.89	4.48
Nitrogen, Diss. (mg/l)	0.17	0.24	0.59	1.56	0.16	1.60	3.87
NH_3N, Diss. (mg/l)	0.06	0.13	<0.02	<0.02	<0.02	0.04	0.06
NH_3N, Total (mg/l)	0.06	0.14	0.02	<0.02	<0.02	0.04	0.06
NO_2N, Diss. (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.04
NO_2N, Total (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.05
NO_3N, Diss. (mg/l)	<0.04	<0.04	0.41	1.30	<0.04	1.11	3.12
NO_3N, Total (mg/l)	<0.04	<0.04	0.42	1.30	<0.04	1.12	3.66
P, Total (mg/l)	0.02	<0.02	<0.02	<0.02	<0.02	0.07	0.17
P, Diss. (mg/l)	0.006	0.006	0.016	0.009	0.005	0.014	0.024
DOP (mg/l)	0.004	0.002	0.010	0.009	0.002	0.010	0.028
TOC (mg/l)	<1	<1	1.2	1.1	<1	3.1	4.2
Ca (mg/l)	16.60	37.20	3.460	17.50	4.95	9.86	16.30
Mg (mg/l)	21.00	54.1	1.19	6.47	3.65	4.00	5.24
Chl (mg/l)	5	4	5	15	5	6	10
SO_4 (mg/l)	105	161	<10	44	19	22	19
Fe, Total (µg/l)	5,520	15,700	140	82	406	1,760	4,930
Fe, Diss. (µg/l)	4,610	16,000	71	37	175	129	100
Mn, Total (µg/l)	1,710	3,910	48	204	328	280	392
Mn, Diss. (µg/l)	1,680	3,900	48	204	328	110	57
Al, Total (µg/l)	1,550	3,790	<135	<135	250	1,600	5,570
Al, Diss. (µg/l)	1,490	3,790	<135	<135	148	<135	<135
TOP (mg/l)	0.005	0.006	0.01	0.008	0.007	0.032	0.064
Turb (NTU)	6.2	4.2	3.8	1	2.1	16.7	81.9

Sample Site	WICO 03	WICO 04	WICO 05	WICO 06	WICO 07	WICO 08	WICO 09
New ID	WICO 7.9	WICO 14.7	WICO 23.6	RATL 0.4	BEAR 0.4	WICO 30.4	WICO 34.4
Date	970602	970602	970602	970602	970602	970602	970602
Flow (cfs)	137.5	150	135	66.5	9.4	89.5	55
Sediment (mg/l)	43	21	31	2	24	41	40
Temperature (C)	13.0	12.2	11.8	10.6	12.1	12.5	12.0
pH (SU)	6.85	6.28	6.41	6.25	6.20	6.25	6.20
DO (umhos/cm)	7.67	8.01	8.63	9.17	8.85	7.47	7.62
Cond (mg/l)	147	117	78	15	85	100	100
Alk (mg/l)	16	28	22	6	16	12	8
Acid (mg/l)	40	4	8	6	16	20	12
Residue, Total (mg/l)	106	104	14	176	146	156	210
Residue, Diss. (mg/l)	70	94		166	116	110	160
Nitrogen, Total (mg/l)	1.19	1.2	0.75	0.16	0.37	1.2	1.27
Nitrogen, Diss. (mg/l)	0.88	0.05	0.65	0.15	0.36	1.01	0.87
NH_3N, Diss. (mg/l)	0.03	0.07	0.06	<0.02	0.21	0.23	0.27
NH_3N, Total (mg/l)	0.03	0.05	0.04	<0.02	0.21	0.21	0.28
NO_2N, Diss. (mg/l)	<0.01	0.02	0.01	<0.01	0.02	0.02	<0.01
NO_2N, Total (mg/l)	0.01	0.03	0.01	<0.01	0.02	0.02	0.01
NO_3N, Diss. (mg/l)	0.71	0.69	0.37	<0.04	<0.04	0.47	0.34
NO_3N, Total (mg/l)	0.71	0.7	0.37	<0.04	<0.04	0.48	0.34
P, Total (mg/l)	0.05	0.05	0.04	<0.02	<0.02	0.11	0.12
P, Diss. (mg/l)	0.011	0.014	0.009	0.008	0.004	0.012	0.008
DOP (mg/l)	0.013	0.012	0.007	0.007	<0.002	0.004	0.004
TOC (mg/l)	2.2	1.7	1.9	1.2	1.3	2.3	2.3
Ca (mg/l)	8.43	9.18	7.28	0.75	18.10	10.24	10.90
Mg (mg/l)	4.07	4.47	3.56	0.588	15.90	4.78	5.30
Chl (mg/l)	5	6	4	2	1	5	6
SO_4 (mg/l)	23	27	25	<10	74	43	42
Fe, Total (µg/l)	1,240	1,290	2,580	64	9,890	2,460	1,140
Fe, Diss. (µg/l)	78	64	101	31	4,070	93	102
Mn, Total (µg/l)	251	256	252	27	1,400	316	342
Mn, Diss. (µg/l)	157	186	170	27	1,400	279	311
Al, Total (µg/l)	608	477	561	<135	<135	1,480	782
Al, Diss. (µg/l)	<135	<135	<135	<135	<135	<135	<135
TOP (mg/l)	0.02	0.022	0.024	0.011	0.022	0.036	0.035
Turb (NTU)	7.6	6.1	9.6	1.3	66	11.4	12.8

Sample Site	WICO 10	WICO 11	WICO 12	WICO 01	WICO 02	WICO 03	WICO 04
New ID	WICO 39.1	WICO 41.4	PORT 0.1	WICO 0.3	LWIC 0.1	WICO 7.9	WICO 14.7
Date	970602	970602	970602	970603	970603	970603	970603
Flow (cfs)	41.5	14.5		615	154		495
Sediment (mg/l)	85	19	15				89
Temperature (C)	10.9	10.7	10.8	13.5	13.2	13.2	12.5
pH (SU)	6.05	3.20	2.20	6.40	7.00	7.10	6.50
DO (umhos/cm)	8.02	8.71	9.12	7.99	8.02	7.70	8.18
Cond (mg/l)	90	147	780	154	238	136	100
Alk (mg/l)	8	0	0	140	120	160	26
Acid (mg/l)	18	40	122	20	40	40	4
Residue, Total (mg/l)	212	734	64	232	296	242	168
Residue, Diss. (mg/l)	118	716	42	78	194	108	84
Nitrogen, Total (mg/l)	1.05	0.24	0.17	5.24	10.90	3.71	2.69
Nitrogen, Diss. (mg/l)	0.87	0.20	0.16	4.33	10.70	3.09	2.27
NH_3N, Diss. (mg/l)	0.09	0.04	0.14	0.10	0.17	0.07	0.06
NH_3N, Total (mg/l)	0.09	0.04	0.14	0.08	0.18	0.07	0.04
NO_2N, Diss. (mg/l)	<0.01	<0.01	<0.01	0.02	0.03	0.02	0.02
NO_2N, Total (mg/l)	0.01	<0.01	<0.01	0.03	0.05	0.02	0.03
NO_3N, Diss. (mg/l)	0.29	0.06	<0.04	3.72	9.45	2.69	1.85
NO_3N, Total (mg/l)	0.29	0.08	<0.04	3.72	9.49	2.72	1.85
P, Total (mg/l)	0.07	0.02	0.02	0.22	0.20	0.18	0.11
P, Diss. (mg/l)	0.007	0.011	0.012	0.023	0.080	0.013	0.012
DOP (mg/l)	0.004	<0.002	0.014	0.023	0.089	0.018	0.010
TOC (mg/l)	3.3	1.4	1.0	4.6	6.9	4.5	4.4
Ca (mg/l)	8.90	14.80	37.60	12.00	19.70	9.79	8.94
Mg (mg/l)	6.05	10.30	50.40	4.38	6.31	3.59	3.43
Chl (mg/l)	4	4	4	8	10	7	5
SO_4 (mg/l)	53	94	213	16	24	20	19
Fe, Total (µg/l)	7,120	3,230	16,700	7,390	2,660	6,560	7,770
Fe, Diss. (µg/l)	152	1,950	14,300	173	125	188	227
Mn, Total (µg/l)	561	944	3,730	681	183	592	492
Mn, Diss. (µg/l)	504	944	3,610	192	80	234	232
Al, Total (µg/l)	1,840	954	3,700	3,770	3,270	2,320	2,070
Al, Diss. (µg/l)	163	815	3,550	<135	<135	<135	<135
TOP (mg/l)	0.059	0.012	0.022	0.054	0.14	0.05	0.036
Turb (NTU)	525	6.7	12.2	54.6	29	48	60.9

Sample Site	WICO 05	WICO 06	WICO 07	WICO 08	WICO 09	WICO 10	WICO 11
New ID	WICO 23.6	RATL 0.4	BEAR 0.4	WICO 30.4	WICO 34.4	WICO 39.1	WICO 41.4
Date	970603	970603	970603	970603	970603	970603	970603
Flow (cfs)	425	102.5	64.4	275	144.5	61	22.7
Sediment (mg/l)	43	3	24	21	22	19	9
Temperature (C)	12.3	10.9	12.3	12.6	12.3	11.2	11
pH (SU)	6.45		6.35	6.3	6.25	6.15	3.40
DO (umhos/cm)	8.58	9.12	8.79	7.54	7.71	8.23	8.82
Cond (mg/l)	75	17	89	104	102	98	158
Alk (mg/l)	20	6	18	14	8	12	0
Acid (mg/l)	8	6	16	20	16	22	52
Residue, Total (mg/l)	86	18	110	100	98	110	126
Residue, Diss. (mg/l)	52	18	90	78	84	108	116
Nitrogen, Total (mg/l)	0.81	0.17	0.51	0.97	1.03	1.28	0.4
Nitrogen, Diss. (mg/l)	0.61	0.15	0.4	0.92	0.96	1.11	0.29
NH_3N, Diss. (mg/l)	0.04	<0.02	0.07	0.08	0.09	0.04	0.03
NH_3N, Total (mg/l)	0.04	<0.02	0.07	0.08	0.1	0.07	0.03
NO_2N, Diss. (mg/l)	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NO_2N, Total (mg/l)	0.01	<0.01	0.01	0.01	0.01	<0.01	<0.01
NO_3N, Diss. (mg/l)	0.32	<0.04	<0.04	0.40	0.56	0.81	0.10
NO_3N, Total (mg/l)	0.35	<0.04	0.15	0.40	0.60	0.82	0.14
P, Total (mg/l)	0.04	<0.02	0.02	0.04	0.04	0.02	0.02
P, Diss. (mg/l)	0.011	0.005	0.007	0.01	0.009	0.006	0.005
DOP (mg/l)	0.08	0.007	0.005	0.011	0.008	0.003	0.003
TOC (mg/l)	3.6	2.0	6.8	3.8	4.5	3.6	2.6
Ca (mg/l)	5.680	0.768	6.000	8.170	7.740	6.640	7.290
Mg (mg/l)	2.470	0.609	4.250	3.120	3.030	3.400	5.980
Chl (mg/l)	4	2	1	5	6	4	5
SO_4 (mg/l)	20	<10	30	37	39	14	50
Fe, Total (µg/l))	4,450	112	8,910	1,040	1,120	2,890	1,950
Fe, Diss. (µg/l)	281	72	2,580	188	230	329	1,340
Mn, Total (µg/l)	286	35	518	168	1,690	258	621
Mn, Diss. (µg/l)	161	33	447	163	159	247	621
Al, Total (µg/l)	866	182	430	443	573	546	633
Al, Diss. (µg/l)	<135	<135	173	<135	<135	177	613
TOP (mg/l)	0.03	0.015	0.013	0.037	0.029	0.024	0.016
Turb (NTU)	33	1.6	39	9.2	8.9	8.1	5.4

Sample Site	WICO 12	WICO 01	WICO 02	WICO 03	WICO 04	WICO 05	WICO 06
New ID	PORT 0.1	WICO 0.3	LWIC 0.1	WICO 7.9	WICO 14.7	WICO 23.6	RATL 0.4
Date	970603	970604	970604	970604	970604	970604	970604
Flow (cfs)			92.5	453	445	358	111.5
Sediment (mg/l)	15	55	43	46	33	15	1
Temperature (C)	11.2	14.2	14.3	13.5	12.8	12.5	11.5
pH (SU)	2.35	6.65	7.05	7.00	6.70	6.55	6.20
DO (umhos/cm)	9.30	8.24	8.39	8.37	8.29	8.51	8.88
Cond (mg/l)	786	114	206	101	91	71	17
Alk (mg/l)	0	12	11	14	20	18	4
Acid (mg/l)	126	20	30	30	6	8	6
Residue, Total (mg/l)	638	162	254	144	100	96	22
Residue, Diss. (mg/l)	616	102	220	124	84	78	12
Nitrogen ,Total (mg/l)	0.26	3.85	11.8	2.95	2.19	0.73	0.15
Nitrogen, Diss. (mg/l)	0.32	3.41	11.4	2.89	1.99	0.59	0.13
NH_3N, Diss. (mg/l)	0.14	0.03	0.03	0.03	0.03	0.02	<0.02
NH_3N, Total (mg/l)	0.14	0.03	0.03	0.03	0.03	0.02	<0.02
NO_2N, Diss. (mg/l)	<0.01	0.01	0.03	0.01	0.01	<0.01	<0.01
NO_2N, Total (mg/l)	<0.01	0.02	0.04	0.01	0.01	<0.01	<0.01
NO_3N, Diss. (mg/l)	<0.04	3	10.1	2.21	1.65	0.39	<0.04
NO_3N, Total (mg/l)	<0.04	3.04	10.1	2.22	1.65	0.39	<0.04
P, Total (mg/l)	0.02	0.06	0.06	0.05	0.03	0.02	<0.02
P, Diss. (mg/l)	0.008	0.013	0.025	0.007	0.009	0.007	0.006
DOP (mg/l)	0.004	0.013	0.022	0.004	0.007	0.002	0.003
TOC (mg/l)	<1.0	3.2	4.1	2.9	2.6	2.2	1.4
Ca (mg/l)	36.40	11.40	20.90	8.22	7.43	5.24	0.695
Mg (mg/l)	48.100	3.7000	6.230	3.210	3.010	2.560	0.649
Chl (mg/l)	4	6	11	6	5	4	2
SO_4 (mg/l)	345	19	38	31	17	15	32
Fe, Total (µg/l)	15,700	4,290	817	1,840	2,770	1,280	75
Fe, Diss. (µg/l)	14,200	191	61	148	178	232	68
Mn, Total (µg/l)	3,570	328	96	271	249	172	31
Mn, Diss. (µg/l)	3,580	128	53	143	139	132	31
Al, Total (µg/l)	3,560	1,840	760	500	764	277	<135
Al, Diss. (µg/l)	3,560	<135	<135	<135	<135	<135	<135
TOP (mg/l)	0.016	0.014	0.032	0.012	0.01	0.012	0.003
Turb (NTU)	11.2	9.7	10.3	18.2	22	6.2	<1

Sample Site	WICO 07	WICO 08	WICO 09	WICO 10	WICO 11	WICO 12	WICO 01
New ID	BEAR 0.4	WICO 30.4	WICO 34.4	WICO 39.1	WICO 41.4	PORT 0.1	WICO 0.3
Date	970604	970604	970604	970604	970604	970604	970605
Flow (cfs)	37.2	227.5	100	40	17		465
Sediment (mg/l)	9	13	11	7	8	20	33
Temperature (C)	12.7	12.3	12.1	11	11.2	12	15.5
pH (SU)	6.50	6.35	6.30	5.80	3.20	2.50	6.75
DO (umhos/cm)	8.45	7.7	7.72	8.38	8.71	8.39	8.27
Cond (mg/l)	128	101	104	125	219	800	107
Alk (mg/l)	28	10	8	14	0	0	16
Acid (mg/l)	14	20	18	30	56	140	12
Residue, Total (mg/l)	112	98	112	128	194	742	142
Residue, Diss .(mg/l)	110	78	110	128	190	702	124
Nitrogen, Total (mg/l)	0.36	1.12	1.27	1.41	0.25	0.24	3.29
Nitrogen, Diss. (mg/l)	0.31	1.03	1.08	1.23	0.21	0.24	3.16
NH_3N, Diss. (mg/l)	0.09	0.07	0.07	0.03	0.03	0.13	<0.02
NH_3N, Total (mg/l)	0.10	0.07	0.07	0.04	0.03	0.13	<0.02
NO_2N, Diss. (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NO_2N, Total (mg/l)	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.01
NO_3N, Diss. (mg/l)	<0.04	0.69	0.87	1.04	0.10	<0.04	2.69
NO_3N, Total (mg/l)	<0.04	0.69	0.88	1.05	0.11	<0.04	2.69
P, Total (mg/l)	<0.02	0.03	0.02	<0.02	<0.02	<0.02	0.04
P, Diss. (mg/l)	0.007	0.008	0.008	0.010	0.007	0.006	0.013
DOP (mg/l)	0.002	0.003	0.020	0.002	<0.002	0.004	0.012
TOC (mg/l)	4.7	2.6	2.6	1.7	1.1	<1	2.3
Ca (mg/l)	8.39	8.26	8.03	7.70	9.50	33.60	8.23
Mg (mg/l)	6.73	3.56	3.31	4.69	9.13	44.6	3.16
Chl (mg/l)	1	5	6	5	6	3	6
SO_4 (mg/l)	59	41	48	48	70	247	17
Fe, Total (µg/l)	5,540	911	684	878	2,590	14,600	1,680
Fe, Diss. (µg/l)	3,620	136	129	244	1,820	12,900	163
Mn, Total (µg/l)	705	157	152	340	823	3,850	180
Mn, Dis.s (µg/l)	650	139	150	340	773	3,850	87
Al, Total (µg/l)	259	334	342	360	813	3,920	741
Al, Diss. (µg/l)	152	<135	<135	234	747	3,920	<135
TOP (mg/l)	0.002	0.008	0.011	0.005	0.005	0.01	0.006
Turb (NTU)	8.3	5.3	4.1	3.2	4.8	12.5	8.3

Sample Site	WICO 02	WICO 03	WICO 04	WICO 05	WICO 06	WICO 07	WICO 08
New ID	LWIC 0.1	WICO 7.9	WICO 14.7	WICO 23.6	RATL 0.4	BEAR 0.4	WICO 30.4
Date	970605	970605	970605	970605	970605	970605	970605
Flow (cfs)	40	315	360	300	90.5	26	16
Sediment (mg/l)	34	28	23	12	2	17	14
Temperature (C)	15.9	14.4	13.6	13.4	11.9	13.5	13.1
pH (SU)	6.80	6.65		6.50	6.30	6.60	6.50
DO (umhos/cm)	8.00	8.27	8.22	8.37	8.67	8.28	7.65
Cond (mg/l)	197	97	90	75	18	165	107
Alk (mg/l)	24	14	12	10	4	38	16
Acid (mg/l)	12	12	12	8	6	20	12
Residue, Total (mg/l)	254	102	100	92	28	170	128
Residue, Diss. (mg/l)	244	90	92	90	26	170	112
Nitrogen, Total (mg/l)	10.40	2.44	1.88	0.69	0.19	0.41	1.13
Nitrogen, Diss. (mg/l)	9.94	2.32	1.75	0.63	0.15	0.37	1.01
NH_3N, Diss. (mg/l)	0.03	0.02	0.02	0.03	<0.02	0.13	0.07
NH_3N, Total (mg/l)	0.03	0.02	0.02	0.03	<0.02	0.13	0.07
NO_2N, Diss. (mg/l)	0.02	<0.01	0.01	<0.01	<0.01	<0.01	<0.01
NO_2N, Total (mg/l)	0.03	0.01	0.01	<0.01	<0.01	<0.01	<0.01
NO_3N, Diss. (mg/l)	9.38	1.89	1.42	0.39	<0.04	<0.04	0.65
NO_3N, Total (mg/l)	9.52	1.90	1.44	0.39	<0.04	<0.04	0.67
P, Total (mg/l)	0.04	0.04	0.03	0.02	<0.02	<0.02	0.03
P, Diss. (mg/l)	0.016	0.011	0.009	0.009	0.008	0.007	0.008
DOP (mg/l)	0.015	0.010	0.009	0.009	0.006	0.004	0.010
TOC (mg/l)	3.1	2.1	1.9	1.8	1.3	2.7	2
Ca (mg/l)	19.500	7.660	6.780	5.290	0.739	13.400	8.860
Mg (mg/l)	5.880	3.270	3.000	2.720	0.674	9.300	3.770
Chl (mg/l)	11	6	5	4	2	<1	5
SO_4 (mg/l)	22	18	19	19	<10	56	26
Fe, Total (µg/l)	699	1,680	1,130	1,040	67	7,590	582
Fe, Diss. (µg/l)	40	169	106	2,720	54	3,240	133
Mn, Total (µg/l)	60	189	168	153	28	984	167
Mn, Diss. (µg/l)	35	106	131	134	43	950	157
Al, Total (µg/l)	789	569	285	207	<135	195	232
Al, Diss. (µg/l)	<135	<135	<135	<135	<135	<135	<135
TOP (mg/l)	0.019	0.011	0.011	0.01	0.004	0.006	0.006
Turb (NTU)	9.2	5.6	4.9	3.8	<1	13.5	4.8

Sample Site	WICO 09	WICO 10	WICO 11	WICO 12	WICO 01	WICO 02	WICO 03
New ID	WICO 34.4	WICO 39.1	WICO 41.4	PORT 0.1	WICO 0.3	LWIC 0.1	WICO 7.9
Date	970605	970605	970605	970605	970715	970715	970715
Flow (cfs)	77.5	30	14				
Sediment (mg/l))	9	4	5	14			
Temperature (C)	12.9	10.9	11.4	12.4	23.3	21.6	22.6
pH (SU)	6.25	5.95	3.60	3.00	7.65	7.60	7.50
DO (umhos/cm)	7.59	8.56	8.81	8.6	7.12	7.30	7.87
Cond (mg/l)	107	141	255	790	193	193	193
Alk (mg/l)	12	4	0	0	36	56	26
Acid (mg/l)	14	20	36	124	2	4	2
Residue, Total (mg/l))	96	128	184	692	156	152	148
Residue, Diss. (mg/l)	82	128	182	690	156	136	142
Nitrogen, Total (mg/l)	1.28	1.16	0.24	0.27	1.07	2.07	0.85
Nitrogen, Diss. (mg/l)	1.16	1.12	0.20	0.27	0.92	1.95	0.79
NH_3N, Diss. (mg/l)	0.09	0.03	0.04	0.13	0.03	0.02	<0.02
NH_3N, Total (mg/l)	0.09	0.04	0.04	0.13	0.03	0.02	<0.02
NO_2N, Diss. (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NO_2N, Total (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
NO_3N, Diss. (mg/l)	0.73	0.88	0.07	<0.04	0.55	1.33	0.52
NO_3N, Total (mg/l)	0.74	0.88	0.07	<0.04	0.56	1.34	0.52
P, Total (mg/l)	0.02	<0.02	<0.02	<0.02	0.03	0.06	0.03
P, Diss. (mg/l)	0.007	0.006	0.008	0.009	0.012	0.035	0.009
DOP (mg/l)	0.003	0.002	0.007	0.006	0.010	0.027	0.006
TOC (mg/l)	2.3	1.3	1	<1	2.1	3.9	1.8
Ca (mg/l)	9.17	9.84	12.60	39.20	18.20	23.10	15.90
Mg (mg/l)	3.93	6.50	13.60	52.90	10.40	5.75	8.45
Chl (mg/l)	6	5	6	3	7	12	6
SO_4 (mg/l)	33	53	73	232	36	14	33
Fe, Total (µg/l)	446	954	3,150	15,700	329	364	337
Fe, Diss. (µg/l)	144	362	2,640	14,600	32	48	26
Mn, Total (µg/l)	165	473	1,010	3,810	76	55	66
Mn, Diss. (µg/l)	165	455	1,010	3,670	49	32	40
Al, Total (µg/l)	196	439	949	3,940	<200	256	<200
Al, Diss. (µg/l)	<135	334	949	3,950	<200	<200	<200
TOP (mg/l)	0.009	0.004	0.005	0.006	0.013	0.061	0.008
Turb (NTU)	3.2	1.8	12.1	10.1	<1	9.5	2.8

Sample Site	WICO 04	WICO 05	WICO 25	WICO 06	WICO 07	WICO 08	WICO 09
New ID	WICO 14.7	WICO 23.6	WICO 7.5	RATL 0.4	BEAR 0.4	WICO 30.4	WICO 34.4
Date	970715	970715	970715	970716	970716	970716	970716
Flow (cfs)							
Sediment (mg/l)							
Temperature (C)	22.3	21.3	22.3	22.6	15.3	19.9	23
PH (SU)	6.80	7.55	7.35	6.05	7.05	6.90	6.10
DO (umhos/cm)	7.59	8.64	7.24	7.22	8.74	6.46	5.54
Cond (mg/l)	196	198	194	21	281	223	221
Alk (mg/l)	24	26	28	2	64	20	6
Acid (mg/l)	4	2	2	2	14	6	6
Residue, Total (mg/l)	156	140	166	16	246	152	238
Residue, Diss. (mg/l)	148	4	156	14	220	152	214
Nitrogen ,Total (mg/l)	0.85	0.83	0.95	0.17	0.43	1.28	1.09
Nitrogen, Diss. (mg/l)	0.75	0.83	0.81	0.27	0.43	1.24	1.05
NH_3N, Diss. (mg/l)	0.02	<0.02	<0.02	<0.02	0.27	0.12	0.17
NH_3N, Total (mg/l)	0.02	<0.02	<0.02	<0.02	0.27	0.12	0.17
NO_2N, Diss. (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.02
NO_2N, Total (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.02
NO_3N, Diss. (mg/l)	0.51	0.48	0.53	0.11	<0.04	0.76	0.51
NO_3N, Total (mg/l)	0.52	0.49	0.55	0.12	<0.04	0.76	0.51
P, Total (mg/l)	0.04	0.03	0.03	0.02	0.02	0.04	0.04
P, Diss. (mg/l)	0.013	0.006	0.011	0.005	0.008	0.010	0.009
DOP (mg/l)	0.012	0.005	0.006	0.004	0.013	0.005	0.005
TOC (mg/l)	1.6	1.4	2	<1	<1	1.6	1.8
Ca (mg/l)	16.0	80.5	17.4	1.21	24.2	19.5	19.1
Mg (mg/l)	8.69	36.50	9.23	0.748	20.80	12.10	12.80
Chl (mg/l)	6	5	7	2	1	8	7
SO_4 (mg/l)	41	74	42	<10	68	49	56
Fe, Total (µg/l)	556	16,200	411	63	14,700	768	682
Fe, Diss. (µg/l)	19	15	27	53	4,710	105	62
Mn, Total (µg/l)	90	6,180	84	14	2,000	528	779
Mn, Diss. (µg/l)	69	136	59	<10	1,990	528	779
Al, Total (µg/l)	<200	13,100	<200	<200	<200	<200	281
Al, Diss. (µg/l)	<200	200	<200	<200	<200	<200	<200
TOP (mg/l)	0.014	0.011	0.009	0.005	0.007	0.009	0.016
Turb (NTU)	4.6	4.9	3.9	<1	122.5	5.4	3.4

Sample Site	WICO 10	WICO 11	WICO 12	WICO 26	WICO 27	WICO 01	WICO 02
New ID	**WICO 39.1**	**WICO 41.4**	**PORT 0.1**	**UNT4 0.1**	**BIGL 0.7**	**WICO 0.3**	**LWIC 0.1**
Date	**970716**	**970716**	**970716**	**970716**	**970716**	**970724**	**970724**
Flow (cfs)						510	70
Sediment (mg/l)						337	107
Temperature (C)	17.6	16.5	14.3	21.7	15.6	19.1	19.4
pH (SU)	3.50	3.50	2.25	7.15	8.05	5.90	6.00
DO (umhos/cm)	7.64	8.56	8.9	6.89	8.81	7.21	7.73
Cond (mg/l)	325	445	858	199	296	185	225
Alk (mg/l)	0	0	0	28	92	28	40
Acid (mg/l)		36	112	4	6	12	8
Residue, Total (mg/l)	326	492	864	188	270	458	272
Residue, Diss. (mg/l)	324	476	844	182	248	134	170
Nitrogen, Total (mg/l)	0.40	0.12	0.27	0.92	0.57	3.53	4.08
Nitrogen, Diss. (mg/l)	0.39	0.23	0.29	0.87	0.63	2.16	3.45
NH_3N, Diss. (mg/l)	0.07	0.08	0.16	<0.02	0.32	0.10	0.23
NH_3N, Total (mg/l)	0.07	0.09	0.16	<0.02	0.32	0.10	0.29
NO_2N, Diss. (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	0.05
NO_2N, Total (mg/l)	<0.01	<0.01	<0.01	<0.01	0.01	0.03	0.05
NO_3N, Diss. (mg/l)	0.18	<0.04	<0.04	0.55	0.08	1.43	2.42
NO_3N, Total (mg/l)	0.18	<0.04	<0.04	0.55	0.08	1.51	2.43
P, Total (mg/l)	<0.02	<0.02	<0.02	0.02	0.02	0.54	0.40
P, Diss. (mg/l)	0.004	0.004	0.003	0.006	0.006	0.052	0.200
DOP (mg/l)	0.002	0.002	0.002	0.004	0.002	0.04	0.201
TOC (mg/l)	<1	<1	<1	1.6	<1	5.7	14.7
Ca (mg/l)	26.5	34.1	35	18.5	30.6	14.7	18.4
Mg (mg/l)	21.70	29.60	49.40	11.90	20.40	6.46	5.26
Chl (mg/l)	4	4	3	5	1	9	14
SO_4 (mg/l)	99	142	260	48	41	35	24
Fe, Total (µg/l)	352	7,820	15,500	547	9,050	13,100	2,680
Fe, Diss. (µg/l)	263	1,320	13,600	28	24	93	217
Mn, Total (µg/l)	1,650	2,130	3,830	98	1,430	1,660	235
Mn, Diss. (µg/l)	1,650	2,120	3,740	75	949	68	90
A,l Total (µg/l)	1,170	2,050	3,730	<200	353	5,690	2,200
Al, Diss. (µg/l)	1,030	1,720	3,590	<200	<200	<200	<200
TOP (mg/l)	0.003	0.011	0.009	0.008	0.012	0.065	0.233
Turb (NTU)	<1	35	20	3.8	40	174.3	48.3

Sample Site	WICO 03	WICO 04	WICO 05	WICO 06	WICO 07	WICO 08	WICO 09
New ID	WICO 7.9	WICO 14.7	WICO 23.6	RATL 0.4	BEAR 0.4	WICO 30.4	WICO 34.4
Date	970724	970724	970724	970724	970724	970724	970724
Flow (cfs)	410	395	275	95	7.5	240	127.5
Sediment (mg/l)	278	166	84	6	35	319	104
Temperature (C)	18.5	17.8	17.4	16	16.1	17.7	17.6
pH (SU)	5.4	7.0	6.0	6.8	5.9	6.2	6.0
DO (umhos/cm)	7.40	7.83	7.54	7.78	8.47	6.63	5.87
Cond (mg/l)	166	133	119	28	206	143	150
Alk (mg/l)	20	16	12	4	36	12	12
Acid (mg/l)	12	8	8	4	16	8	12
Residue, Total (mg/l)	390	262	160	28	150	394	224
Residue, Diss. (mg/l)	116	228	80	22	118	62	102
Nitrogen, Total (mg/l)	3.18	2.53	1.16	0.37	0.67	1.29	1.09
Nitrogen, Diss. (mg/l)	2.12	1.88	0.76	0.32	0.61	0.8	0.83
NH_3N, Diss. (mg/l)	0.09	0.07	0.03	<0.02	0.14	0.04	0.04
NH_3N, Total (mg/l)	0.09	0.08	0.03	<0.02	0.14	0.05	0.04
NO_2N, Diss. (mg/l)	0.02	0.01	<0.01	<0.01	<0.01	0.01	0.01
NO_2N, Total (mg/l)	0.02	0.02	<0.01	<0.01	<0.01	0.02	0.01
NO_3N, Diss. (mg/l)	1.49	1.35	0.46	0.1	0.29	0.46	0.47
NO_3N, Total (mg/l)	1.5	1.55	0.47	0.1	0.3	0.49	0.52
P, Total (mg/l)	0.41	0.25	0.14	<0.02	<0.02	0.19	0.25
P, Diss. (mg/l)	0.022	0.019	0.009	0.008	0.002	0.013	0.012
DOP (mg/l)	0.016	0.016	0.008	0.005	0.005	0.007	0.008
TOC (mg/l)	5	5.2	4	5.2	2	4.1	3.9
Ca (mg/l)	13.20	10.90	9.16	1.23	13.50	11.20	11.50
Mg (mg/l)	5.980	4.040	3.800	0.827	10.100	4.340	4.460
Chl (mg/l)	7	7	4	2	<1	6	5
SO_4 (mg/l)	33	31	34	<10	54	35	41
Fe, Total (µg/l)	16,500	10,200	6,950	253	15,100	14,000	4,550
Fe, Diss. (µg/l)	98	113	100	89	2,150	114	157
Mn, Total (µg/l)	1,500	844	598	100	1,230	401	314
Mn, Diss. (µg/l)	96	148	226	83	1,180	215	255
Al, Total (µg/l)	4,240	3310	1,420	359	252	5,610	1,810
Al, Diss. (µg/l)	<200	<200	<200	<200	<200	<200	<200
TOP (mg/l)	0.021	0.021	0.018	0.011	0.007	0.039	0.02
Turb (NTU)	152.5	<1	<1	6.9	52.5	270	<1

Sample Site	WICO 10	WICO 11	WICO 12	WICO 01	WICO 02	WICO 03	WICO 04
New ID	WICO 39.1	WICO 41.4	PORT 0.1	WICO 0.3	LWIC 0.1	WICO 7.9	WICO 14.7
Date	970724	970724	970724	970725	970725	970725	970725
Flow (cfs)	72.5	33.3		235	10.5	157	185
Sediment (mg/l)	101	25		78	14	53	48
Temperature (C)	16.4	15.8	13.7	20.5	21.4	19.9	19.4
pH (SU)	5.0	4.7	2.8	5.7	6.2	5.9	5.9
DO (umhos/cm)	5.85	7.63		7.59	7.89	7.83	8.00
Cond (mg/l)	113	121	901	173	24.9	174	170
Alk (mg/l)	2	0	0	20	32	16	16
Acid (mg/l)	20	18	96	16	8	12	6
Residue, Total (mg/l)	160	98	640	184	188	116	124
Residue, Diss. (mg/l)	60	64	626	118	175	72	80
Nitrogen, Total (mg/l)	1.57	0.68	0.29	3.28	8.82	3.00	2.61
Nitrogen, Diss. (mg/l)	1.77	0.59	0.25	2.96	7.40	2.85	2.07
NH_3N, Diss. (mg/l)	0.04	<0.02	0.13	0.04	0.05	0.04	0.03
NH_3N, Total (mg/l)	0.05	<0.02	0.13	0.06	0.05	0.04	0.04
NO_2N, Diss. (mg/l)	<0.01	<0.01	<0.01	0.02	0.03	0.01	0.02
NO_2N, Total (mg/l)	<0.01	<0.01	<0.01	0.03	0.04	0.02	0.02
NO_3N, Diss. (mg/l)	0.71	0.33	0.05	2.36	5.07	2.21	1.83
NO_3N, Total (mg/l)	0.72	0.34	0.05	2.36	5.23	2.23	1.84
P, Total (mg/l)	0.07	0.03	0.02	0.12	0.15	0.08	0.08
P, Diss. (mg/l)	0.010	0.010	0.011	0.022	0.090	0.016	0.014
DOP (mg/l)	0.010	0.010	0.002	0.020	0.042	0.012	0.012
TOC (mg/l)	4.7	5.2	1.2	4.2	7.6	3.7	3.6
Ca (mg/l)	7.91	71.40	32.00	13.50	22.20	14.10	13.30
Mg (mg/l)	3.32	3.99	40.50	4.88	5.91	5.24	4.75
Chl (mg/l)	4	4	3	8	14	7	7
SO_4 (mg/l)	45	23	291	32	35	39	45
Fe, Total (µg/l)	11,800	3,810	12,200	4,210	608	3,470	3,920
Fe, Diss. (µg/l)	477	714	10,700	120	110	110	188
Mn, Total (µg/l)	304	386	3,670	316	48	291	306
Mn, Diss. (µg/l)	282	386	3,640	45	23	102	151
Al, Total (µg/l)	1,810	868	3,270	2,190	356	867	1,100
Al, Diss. (µg/l)	<200	370	3,180	<200	<200	<200	<200
TOP (mg/l)	0.014	0.011	0.013	0.013	0.114	0.011	0.012
Turb (NTU)	87.5	15.6	35	95	12.5	61.5	29

Sample Site	WICO 05	WICO 06	WICO 07	WICO 08	WICO 09	WICO 10	WICO 11
New ID	WICO 23.6	RATL 0.4	BEAR 0.4	WICO 30.4	WICO 34.4	WICO 39.1	WICO 41.4
Date	970725	970725	970725	970725	970725	970725	970725
Flow (cfs)	108	8	11	107.5	42.5	14	9
Sediment (mg/l)	37	3	60	32	22	7	8
Temperature (C)	19.5	17.8	18.6	18.8	18.8	17.2	17.5
pH (SU)	5.8	5.8	5.8	5.9	5.9	5.5	3.5
DO (umhos/cm)	8.56	8.20	8.80	7.42	7.05	8.50	7.48
Cond (mg/l)	153	33	196	167	165	215	416
Alk (mg/l)		4	36	8	10	4	
Acid (mg/l)		4	22	14	4	14	46
Residue, Total (mg/l)	96	4	142	130	122	134	336
Residue, Diss. (mg/l)	70	4	96	228	106	130	330
Nitrogen, Total (mg/l)	1.19	0.31	0.40	1.47	1.61	2.64	0.32
Nitrogen, Diss. (mg/l)	1.00	0.29	0.37	1.39	1.52	2.57	0.29
NH_3N, Diss. (mg/l))	0.02	<0.02	0.13	0.04	0.05	0.05	0.05
NH_3N, Total (mg/l)	0.03	<0.02	0.13	0.04	0.05	0.05	0.05
NO_2N, Diss. (mg/l)	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
NO_2N, Total (mg/l)	0.01	<0.01	<0.01	0.01	0.01	<0.01	<0.01
NO_3N, Diss. (mg/l)	0.72	0.11	0.08	0.87	1.10	2.19	0.15
NO_3N, Total (mg/l)	0.73	0.12	0.09	0.85	1.10	2.19	0.15
P ,Total (mg/l)	0.06	<0.02	<0.02	0.06	0.04	<0.02	<0.02
P, Diss. (mg/l)	0.010	0.004	0.01	0.012	0.012	0.003	0.006
DOP (mg/l)	0.007	0.004	0.008	0.012	0.013	<0.002	0.004
TOC (mg/l)	3.4	2.6	2.4	3.6	3.4	2.0	1.3
Ca (mg/l)	11.1	1.61	13.3	11.7	12.3	15.0	18.2
Mg (mg/l)	4.600	0.932	9.460	4.380	4.730	8.810	20.300
Chl (mg/l)	6	3	<1	6	7	6	4
SO_4 (mg/l)	44	16	57	50	54	71	108
Fe, Total (µg/l)	3,200	158	23,700	1,760	1,260	835	4,800
Fe, Diss. (µg/l)	140	32	1,160	147	122	327	3,260
Mn, Total (µg/l)	338	38	1,200	263	267	633	1,680
Mn, Diss. (µg/l)	188	26	1,070	220	243	579	1,630
Al, Total (µg/l)	678	<200	231	843	538	330	1,390
Al, Diss. (µg/l)	<200	<200	<200	<200	<200	<200	1,290
TOP (mg/l)	0.008	0.004	0.009	0.014	0.014	0.006	0.009
Turb (NTU)	20	4.3	122.5	17.8	13.5	3	17.3

Sample Site	WICO 12	WICO 01	WICO 02	WICO 03	WICO 04	WICO 05	WICO 06
New ID	PORT 0.1	WICO 0.3	LWIC 0.1	WICO 7.9	WICO 14.7	WICO 23.6	RATL 0.4
Date	970725	970728	970728	970728	970728	970728	970728
Flow (cfs)		64	6.5	53	53	35	4.5
Sediment (mg/l)	21	5	8	4	6	4	0
Temperature (C)	14.1	25.5	25.9	24.4	23.3	22.8	23
pH (SU)	3.0	5.8	6.1	6.1	6.1	7.1	5.9
DO (umhos/cm)	7.86	9.17	8.83	8.52	8.61	10.03	9.25
Cond (mg/l)	1,031	213	266	200	221	216	29
Alk (mg/l)		22	40	20	40	20	4
Acid (mg/l)	116	4	10	8	8	4	4
Residue, Total (mg/l)	768	110	154	114	114	104	20
Residue, Diss. (mg/l)	754	106	150	110	106	94	20
Nitrogen, Total (mg/l)	0.31	4.45	8.52	3.05	2.43	1.19	0.24
Nitrogen, Diss. (mg/l)	0.27	4.45	7.22	2.97	2.37	1.19	0.23
NH_3N, Diss. (mg/l)	0.15	<0.02	<0.02	0.02	<0.02	<0.02	<0.02
NH_3N, Total (mg/l)	0.15	<0.02	<0.02	0.02	<0.02	<0.02	<0.02
NO_2N, Diss. (mg/l)	<0.01	<0.01	0.02	0.01	<0.01	<0.01	<0.01
NO_2N, Total (mg/l)	<0.01	<0.01	0.02	0.01	<0.01	<0.01	<0.01
NO_3N, Diss. (mg/l)	0.04	2.77	6.01	2.48	1.96	0.88	0.07
NO_3N, Total (mg/l)	0.05	2.98	6.04	2.48	1.96	0.88	0.07
P, Total (mg/l)	<0.02	0.03	0.06	0.03	0.04	0.02	<0.02
P, Diss. (mg/l)	0.011	0.016	0.04	0.013	0.015	0.006	0.008
DOP (mg/l)	0.012	0.013	0.04	0.012	0.014	0.010	0.009
TOC (mg/l)	<1	2.8	4.1	2.5	2.2	1.8	1.4
Ca (mg/l)	38.50	18.40	24.20	18.30	17.60	16.00	1.19
Mg (mg/l)	60.000	5.990	5.820	6.400	6.760	6.750	0.675
Chl (mg/l)	4	11	15	11	10	7	2
SO_4 (mg/l)	262	43	23	37	41	48	<10
Fe, Total (µg/l)	15,700	12,800	239	12,500	660	751	50
Fe, Diss. (µg/l)	13,500	41	32	20	42	33	22
Mn, Total (µg/l)	4,600	3,170	26	1,630	115	189	12
Mn, Diss. (µg/l)	4,380	29	14	42	99	166	12
Al, Total (µg/l)	4,070	1,050	<200	415	<200	<200	<200
Al, Diss. (µg/l)	3,870	<200	<200	<200	<200	<200	<200
TOP (mg/l)	0.015	0.009	0.05	0.008	0.01	0.01	0.011
Turb (NTU)	38	2.6	8.4	5.7	6.2	5.8	<1

Sample Site	WICO 07	WICO 08	WICO 09	WICO 10	WICO 11	WICO 12
New ID	BEAR 0.4	WICO 30.4	WICO 34.4	WICO 39.1	WICO 41.4	PORT 0.1
Date	970728	970728	970728	970728	970728	970728
Flow (cfs)	6.6	1.5	1.5	0.5	2.3	
Sediment (mg/l)	29	8	8	3	13	19
Temperature (C)	18.9	21.9	22.3	19.2	18.5	18.5
pH (SU)	6.7	5.9	5.9	4.1	3.4	2.9
DO (umhos/cm)	10.18	7.54	7.79	9.43	9.81	10.78
Cond (mg/l)	310	233	232	320	576	1,032
Alk (mg/l)	60	16	12		0	0
Acid (mg/l)	20	10	8	22	28	128
Residue, Total (mg/l)	202	148	162	224	352	790
Residue, Diss. (mg/l)	176	138	156	224	344	788
Nitrogen, Total (mg/l)	0.41	1.6	1.57	1.70	0.31	0.33
Nitrogen, Diss. (mg/l)	0.40	1.55	1.52	1.68	0.21	0.25
NH_3N, Diss. (mg/l)	0.24	0.08	0.14	0.07	0.08	0.16
NH_3N, Total (mg/l)	0.24	0.08	0.14	0.07	0.08	0.16
NO_2N, Diss. (mg/l)	<0.01	0.02	0.01	<0.01	<0.01	<0.01
NO_2N. Total (mg/l)	<0.01	0.02	0.02	<0.01	<0.01	<0.01
NO_3N, Diss. (mg/l)	0.04	1.15	1.09	1.35	0.05	<0.04
NO_3N, Total (mg/l)	0.04	1.16	1.09	1.35	0.05	<0.04
P, Total (mg/l)	<0.02	0.04	0.04	<0.02	<0.02	<0.02
P, Diss. (mg/l)	0.006	0.012	0.012	0.011	0.008	0.008
DOP (mg/l)	0.010	0.011	0.013	0.004	0.004	0.003
TOC (mg/l)	1.0	2.2	2.3	1.5	1.0	<1.0
Ca (mg/l)	24.1	18.9	15.0	19.6	24.4	39.7
Mg (mg/l)	19.3	7.66	7.7	15.8	27.9	60.3
Chl (mg/l)	<1	9	9	6	4	4
SO_4 (mg/l)	70	64	55	94	150	278
Fe, Total (µg/l)	2,300	1,150	542	524	7,140	16,900
Fe, Diss. (µg/l)	3,520	94	53	436	5,940	15,300
Mn, Total (µg/l)	3,180	269	320	1,110	2,220	4,390
Mn, Diss. (µg/l)	1,720	276	313	1,070	2,210	4,250
Al, Total (µg/l)	1,180	225	<200	1,050	2,090	4,460
Al, Diss. (µg/l)	<200	200	<135	946	2,060	4,280
TOP (mg/l)	0.008	0.016	0.011	0.004	0.005	0.007
Turb (NTU)	109.2	6.9	9.5	1.4	26	8.9

Appendix E

Remediation of Contaminated Coal Mine DIscharges in the Wiconisco Creek Watershed

Remediation of Contaminated Coal Mine Discharges in the Wiconisco Creek Watershed

An assessment prepared for the Susquehanna River Basin Commission by Hedin Environmental

December 23, 1998

Final Report

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BACKGROUND

Hedin Environmental is a small consulting firm that specializes in the passive treatment of contaminated coal mine drainage. The firm, which is located in western Pennsylvania, was founded in 1994 by Dr. Robert Hedin. Before 1994, Dr. Hedin was a research biologist with the U.S. Department of the Interior Bureau of Mines, where his principle research topic was the treatment of coal mine drainage with innovative biological and chemical techniques. Dr. Hedin's research on the passive treatment of coal mine drainage resulted in the publication of several technical papers that are widely used and referenced by the mine drainage treatment and stream restoration communities (Hedin et al., 1994; Hedin and Watzlaf, 1994).

Hedin Environmental's recent projects range from the oral presentation of conceptual treatment and restoration schemes to the design and construction of turnkey passive treatment systems. We have had substantial involvement in the construction of 16 passive treatment systems. Designs of several more systems are in review. Our clients include the Pa. Department of Watershed Conservation, private mining companies in Pa., N.Y., W.V. and Tenn., surety companies (who hold bonds for bankrupt companies), and engineering firms. We have designed and constructed anoxic limestone drains, vertical flow ponds (SAPS), sedimentation ponds and wetlands. We have worked on projects funded by the US EPA, Pa. DEP, U.S. Army Corps of Engineers, and Office of Surface Mining. Hedin Environmental also conducts research for private and public clients. We recently completed a study of remining practices for West Virginia University. The U.S. Department of Agriculture is currently funding an evaluation of the feasibility of producing a marketable iron product from mine drainage.

In October 1998, Mr. Travis Stoe of the Susquehanna River Basin Commission (SRBC) contacted Dr. Hedin about providing the SRBC with an evaluation of mine drainage passive treatment options for the Wiconisco Creek Watershed. The SRBC had already completed an assessment of water quality and biological features of the stream. The SRBC assessment revealed the pollutional significance of untreated discharges from abandoned anthracite coal mines in the watershed. On November 19, 1998, Dr. Hedin met with SRBC personnel and inspected mine drainage discharges in the Wiconisco Creek Watershed. Several water samples were collected by Dr. Hedin and analyzed by colleagues in the University of Pittsburgh Geology Program. Reports by SRBC (Stoe, 1998) and the Commonwealth's Operation Scarlift Program (Sanders and Thomas, 1973) were provided to Hedin Environmental by SRBC.

This report provides an assessment of mine drainage problems and potential solutions for the Wiconisco Creek Watershed. The assessment focuses on characterization of the discharges and their treatment using passive treatment techniques. The recommendations include state-of-the-art passive treatment techniques that are currently in use at public and private sites in Pennsylvania.

PASSIVE TREATMENT OF CONTAMINATED COAL MINE DRAINAGE

The passive treatment of coal mine drainage has advanced considerably in the last decade (Brodie,1990; Faulkner and Skousen, 1993; Hedin et al., 1994; Hellier et al., 1994; Hedin, 1996). Increased confidence in the effectiveness of passive treatment systems has resulted in new regulations that encourage passive treatment on permitted mine sites (Pennsylvania Code, Title 25, Chapter 87, Section 102.). Federal and state reclamation programs have substantially increased their expenditures on passive systems at abandoned sites. Most stream restoration efforts in the Appalachia coal fields are economically justified by plans to utilize passive treatment techniques.

An important advance in the evolution of passive technology was the recognition of the variability of mine water chemistry and its importance in designing efficient, effective treatment systems. While polluting discharges from coal mines are ubiquitously referred to as "acid" mine drainage, many are in fact alkaline. The alkaline discharges, particularly common from flooded underground coal mines, are primarily contaminated with ferrous iron and, secondarily, with manganese. Alkaline discharges are effectively treated with sedimentation ponds and constructed wetlands that provide the aeration and retention necessary to naturally precipitate the metal contaminants. No alkaline materials are necessary because the water is already neutralized by naturally occurring bi-carbonate ions.

When mine water is acidic, treatment requires the generation of alkalinity and the precipitation of metals. The most reliable technique for satisfying these requirements is pre-treatment of the acidic water with an appropriate quantity of limestone (which generates alkalinity), followed by flow through ponds and wetlands (which precipitate the metals). Anoxic limestone drains (ALDs) are buried beds of limestone aggregate that generate alkalinity and are increasingly common components of passive systems in the bituminous coal fields. ALDs have proven capable of generating 150 to 300 milligrams per liter (mg/l) alkalinity for eight years (and counting) with minimal operation and maintenance requirements (Turner and McCoy, 1990; Watzlaf and Hedin, 1993; Hedin et al., 1994; Hedin and Watzlaf,1994). ALDs are being constructed that contain enough limestone to theoretically last decades. The drawback of ALDs is that they are primarily appropriate for anoxic acidic water contaminated with dissolved ferrous iron and manganese. Waters containing ferric iron or aluminum (Al) are not appropriate because both ions precipitate within the ALD, potentially decreasing its permeability and reactivity. ALDs constructed to treat acidic water containing these ions in concentrations greater than 20 mg/l have failed within months of their construction.

Unfortunately, many acidic mine waters contain ferric iron and aluminum. Passive treatment of these waters is occurring with innovative systems whose performance records are variable and whose long-term reliability is less certain than ALDs and constructed wetlands. The most common approach is the construction of *vertical flow ponds* (VFP) that contain limestone overlain by an organic substrate. Water flows down through the organic substrate, into the limestone aggregate, and into an underdrain system that discharges to a pond or constructed wetland. As water flows through the organic substrate, microbial activity reduces the ferric iron to ferrous iron and precipitates a portion of the iron. Aluminum precipitates within the organic substrate and the limestone aggregate. Microbial processes in the organic substrate and limestone dissolution generate alkalinity.

The performance of vertical flow ponds can be dramatic – complete removal of Al, substantial removal of iron (Fe), and a discharge with neutral pH. However, the accumulation of metal solids within the organic substrate and limestone is problematic because it eventually armors or plugs the substrates. When this occurs, less water flows through the system, and the water is less effectively treated. Despite uncertainties, VFPs are being constructed by many private companies and public restoration groups throughout Appalachia.

Short descriptions of the primary units utilized in passive mine water treatment systems are presented below.

Passive Treatment Components

Sedimentation Pond A sedimentation pond is intended to collect iron solids. At the iron concentrations observed for Wiconisco Creek discharges (10-20 mg/l), iron solids accumulate in the ponds at a rate of 0.5 to 1.0 inches per year. Sedimentation ponds generally are constructed with depths of 4 to 6 feet, so they have decades of iron oxide sludge storage capacity. Recently, the idea that iron oxides might be recovered from passive systems for sale has attracted attention (Hedin, 1998). If this option is pursued, the ponds can be designed in a manner to facilitate the periodic removal of the iron oxide solids.

Constructed Wetland A wetland is intended to polish the discharge of a sedimentation pond or vertical flow pond. The wetland is constructed with a fertile soil substrate and planted with emergent wetland plant species (typically cattails and bulrushes). Water depths are 3-6 inches. The water level in the wetland is maintained by the effluent structure, which can be gradually raised if the accumulation of organic matter and sludge causes short-circuiting of flow paths. Iron solids accumulate in the wetlands at a rate of approximately 0.2 to 0.5 inch per year. Berms are sized to allow the accumulation of organic matter and iron sludge over the lifetime of the system.

Anoxic Limestone Drain An anoxic limestone drain (ALD) is a buried bed of limestone gravel that generates alkalinity through the dissolution of limestone. The quantity of limestone included in the ALD is calculated from 25 years of expected limestone dissolution plus the targeted performance under the design high flow conditions. Calcitic limestone with at least 85 percent $CaCO_3$ content is preferred. The limestone aggregate is placed in an excavated rectangular pit, covered with plastic, and buried with 2 to 3 feet of soil or spoil. Mine water enters one end of the limestone bed and is collected from the opposite end by a manifold system. The water level in the ALD is maintained at the top of the limestone through proper positioning the effluent pipe.

Vertical Flow Pond A vertical flow pond (VFP) is a combination of limestone and organic substrate that retains metals, decreases acidity and generates alkalinity. Water flows from the surface, downward through the substrate and limestone gravel, and into an underdrain system. The recommended VFP design contains two feet of surface water, overlying one foot of organic substrate, which overlies two feet of limestone aggregate. The organic substrate is sometimes amended with limestone aggregate (25 percent by volume) to increase its acid neutralization capability. An underdrain plumbing system, which is constructed with perforated drainage pipe that feeds into a solid manifold, is placed at the bottom of the limestone aggregate bed. The manifold connects to solid pipe that passes through the berm and rises to an elevation consistent with the designed water level. The emergency spillway is placed 2 to 3 feet above the design water level and provides the capacity for water storage during high flow events and allows the passive development of additional head.

Successive Alkalinity Producing System The successive alkalinity producing system (SAPS) was proposed by Damariscotta, an environmental consulting firm in Clarion, Pa. (Kepler and McCleary, 1994). A SAPS consists of a vertical flow pond, followed by a sedimentation pond. The VFP generates alkalinity and removes Al, while the sedimentation pond precipitates Fe. If more alkalinity generation and Fe removal is required, a second VFP/pond combination is constructed downstream of the first VFP/pond. SAPS can be constructed that, through successive treatment, neutralize many hundreds or thousands of mg/l of acidity. Kepler and McCleary (1994) have recently adapted the SAPS concept to facilitate the flushing and recovery of Al solids that may have marketable value.

BEAR CREEK DISCHARGES

Discharge Characteristics

Water discharges from the Lykens Water Level Tunnel and from several abandoned adits (drift mine entrances). The Operation Scarlift report (Sanders and Thomas, 1973) and November 1998 observations[1] indicate that a majority of the flow is from the northern-most adit (Point #3 in the Scarlift report). The entrance is still open, with water discharging a foot beneath the apparent floor of the adit. The Scarlift Report provides 12 months of flow data for the Lykens Tunnel and five other discharges to Bear Creek. Summary flows are shown below in Table 1. The Lykens Tunnel averaged 760 gallons per minute (gpm), while the adit discharges averaged 3,079 gpm. The total flow averaged 3,839 gpm and ranged as high as 6,672 gpm. The highest flow occurred in March 1971.

Table 1. Flow Rates (gpm) **for the Bear Creek Mine Discharges Between December 1970 and November 1971** (Sanders and Thomas, 1973).

Flow Condition	Lykens	#3	#4	#5	#6	#7	Total
Average (gpm)	760	2,269	155	53	476	126	3,839
50th percentile*	634	2,092	154	50	476	116	3,622
75th percentile	920	2,356	171	58	506	158	4,014
90th percentile	1,006	2,978	203	67	546	171	4,809
Maximum	1,764	4,181	206	80	548	217	6,672

** 50% of the flows are expected to be less than this quantity*

The chemical conditions of the discharges were generally similar in November 1998 to the conditions documented by the Scarlift Report in 1971. The Lykens tunnel was an acidic discharge (pH 3.4 in 1971, pH 4.6 in November 1998), while the adit discharges were alkaline. An analysis of the largest drift discharge is shown in Table 2. The flow of the discharge was estimated in November 1998 as 1,000 gpm. Another sample, collected from a secondary discharge in the same area, had similar chemical constituents (results not shown). Scarlift data for the primary discharge (point #3) also are shown in Table 2. Five other sampling points in the vicinity of Point #3 had similar chemistry (alkaline > acidity, Fe 10 to 12 mg/l). Note that the November 1998 analysis indicates 20 mg/l Fe, while the average for point #3 in 1970-71 was 10 mg/l. Further monitoring of the primary adit discharge would determine whether the November 1998 sample is representative of current average conditions or whether the iron concentration was elevated because of the very dry conditions at the time of sampling.

[1] On November 19, 1995, the Bear Creek site and discharges were inspected and sampled by R. S. Hedin and SRBC personnel.

Table 2. Chemical Composition of the Largest Bear Creek Adit Discharge (1971 values are the average of Point #3 from the Scarlift report (Sanders and Thomas, 1973). 1998 data are the analysis of one sample collected on November 19, 1998 by R. S. Hedin.)

Year	pH	Alkalinity (mg/l)	Iron (mg/l)	Manganese (mg/l)	Aluminum (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Sulfate (mg/l)
1971	6.3	118	10	na	na	na	na	194
1998	6.2	110	20	2	<1	26	10	78

na: not available

The alkalinity contained in the adit discharges is more than sufficient to neutralize the acidity present in the Lykens Tunnel discharge. The adits discharge approximately 1,850 kilograms per day (kg/day) of alkalinity (3,079 gpm @ 110 mg/l alkalinity), while the Lykens Tunnel discharges approximately 195 kg/day of acidity (760 gpm @ 47 mg/l acidity). This condition also is demonstrated by sampling by the SRBC in 1996 and 1997 (Table 3). Bear Creek is an *alkaline* Fe-contaminated stream below the adits. Ten water samples collected between September 96 and July 1997 had pH values > 5.8 and alkalinity concentrations greater than acidity concentrations. Fe concentrations at this point ranged between 2 and 24 mg/l and averaged 10 mg/l

Table 3. Bear Creek Flow and Iron Loadings at State Route 1002 (Stoe, 1998)

Date	Flow Rate (gpm)	Iron (mg/l)	Iron (kg/d)	pH	Alkalinity (mg/l)	Acidity (mg/l)
9/4/96	2,943	4	70	7.1	72	16
5/14/97	3,959	13	270	6.7	68	14
6/2/97	4,211	10	227	6.2	16	16
6/3/97	28,851	9	1,399	6.4	18	16
6/4/97	16,666	6	500	6.5	28	14
6/5/97	11,648	8	482	6.6	38	20
7/16/97	na	15	na	7.1	64	14
7/24/97	3,360	15	277	5.9	36	16
7/25/97	4,928	24	637	5.8	36	22
7/28/97	2,957	2	37	6.7	60	20
Average	8,836	10	433	6.5	44	17

na, not available

Treatment Recommendations

The mixture of the Lykens Tunnel and adit discharges results in alkaline water that contains between 10 and 20 mg/l Fe. The water can be reliably treated with a properly sized constructed wetland. Many wetlands constructed to treat alkaline Fe-contaminated mine water in the bituminous coal fields are effectively decreasing iron concentrations to low levels (<2 mg/l) (Hellier et al., 1994; Hedin et al., 1994). These systems generally remove iron at rates of 5 to30 grams of Fe per square meter of wetland surface area per day (g $m^{-2}d^{-1}$) (Hedin et al., 1994; Hellier et al., 1994). Rates of removal decrease with decreasing iron concentrations. Because iron concentrations in the raw Bear Creek discharges are low relative to discharges in the bituminous fields (which are generally 50 to 100 mg/l Fe) it is recommended that the systems be sized assuming the lower range of observed removal rates. A rate of 6 g $m^{-2}d^{-1}$ is currently recommended. Hedin Environmental bases this rate on empirical observations of iron removal in passive systems that receive water with Fe less than 20 mg/l and consistently discharge less than 1 mg/l Fe. In order to estimate current iron loadings, the 1971 Scarlift flows were combined with the recent mine water analyses (20 mg/l). The use of the Scarlift flows is probably reasonable because the upper Bear Creek Watershed has not been significantly disturbed since 1970 (personal communication, Ed Wytovich). The use of the recently measured Fe concentration may yield an erroneously large wetland size if the iron concentration measured in November 1998 is higher than average.

Comparisons of the estimated discharge loadings (Table 4) to the iron loadings measured in 1996/1997 at a downstream Bear Creek point by the SRBC (Table 3) suggests that the loading assumptions are reasonable. At the SRBC sampling point, flow in Bear Creek is primarily a combination of the Lykens Tunnel discharge, the adit discharges and the Bear Creek Swamp discharge. The SBRC data consist of nine measurements of stream flow and iron concentrations in September 1996, and May, June and July 1997. The data are intentionally biased toward two storm events during which iron oxide solids precipitated in the stream channel were, presumably, flushed from Bear Creek to Wiconisco Creek. The average iron loading measured on the nine sampling dates is 433 kg/day—a value close to the 418 kg/day average calculated from Scarlift flow record and the November 19, 1998, discharge samples.

Table 4. Estimated Iron Loadings and Calculated Wetland Sizes for the Bear Creek Discharges

Flow Conditions	Flow Rate* (gpm)	Iron** (mg/l)	Iron Loading (kg/d)	Wetland Acreage @ 6 g $m^{-2}d^{-1}$ Removal
Average	3,839	20	418	17 acres
50th percentile	3,622	20	395	16
75th percentile	4,014	20	438	18
90th percentile	4,809	20	524	22
Maximum	6,672	20	727	30

** from the Operation Scarlift Report (1970-1971 data)*
*** from the recent analysis of adit discharge chemistry*

Calculated wetland sizes are shown for a variety of flow and loading conditions in Table 4. Acreage recommendations range from 16 acres (median flow) to 30 acres (maximum flow). A reasonable goal would be to target the 75th – 90th percentile conditions, which results in a 20-acre treatment system. When area for berms and roads are considered, the total acreage for the treatment complex is likely to encompass approximately 30 acres.

Twenty acres of constructed wetlands are expected to discharge alkaline water with Fe concentrations <1 mg/l whenever the total mine drainage flow rate is less than 4,500 gpm. When flows are higher than 4,500 gpm, particulate iron will be discharged. At the maximum Scarlift flow rate, 6,672 gpm, the system effluent will likely contain 3 to 5 mg/l Fe. Water with this Fe content has a slight orange tint.

Figure 1 is a map showing the lower Bear Creek Watershed and the principle mine discharges. The highlighted area below the discharges that is designated as Tracts A, B, C, and D comprise approximately 143 acres. Portions of Tract A are unavailable because of recent housing development and a waste water treatment plant has been constructed in a portion of Tract B. All of the tracts contain refuse that would

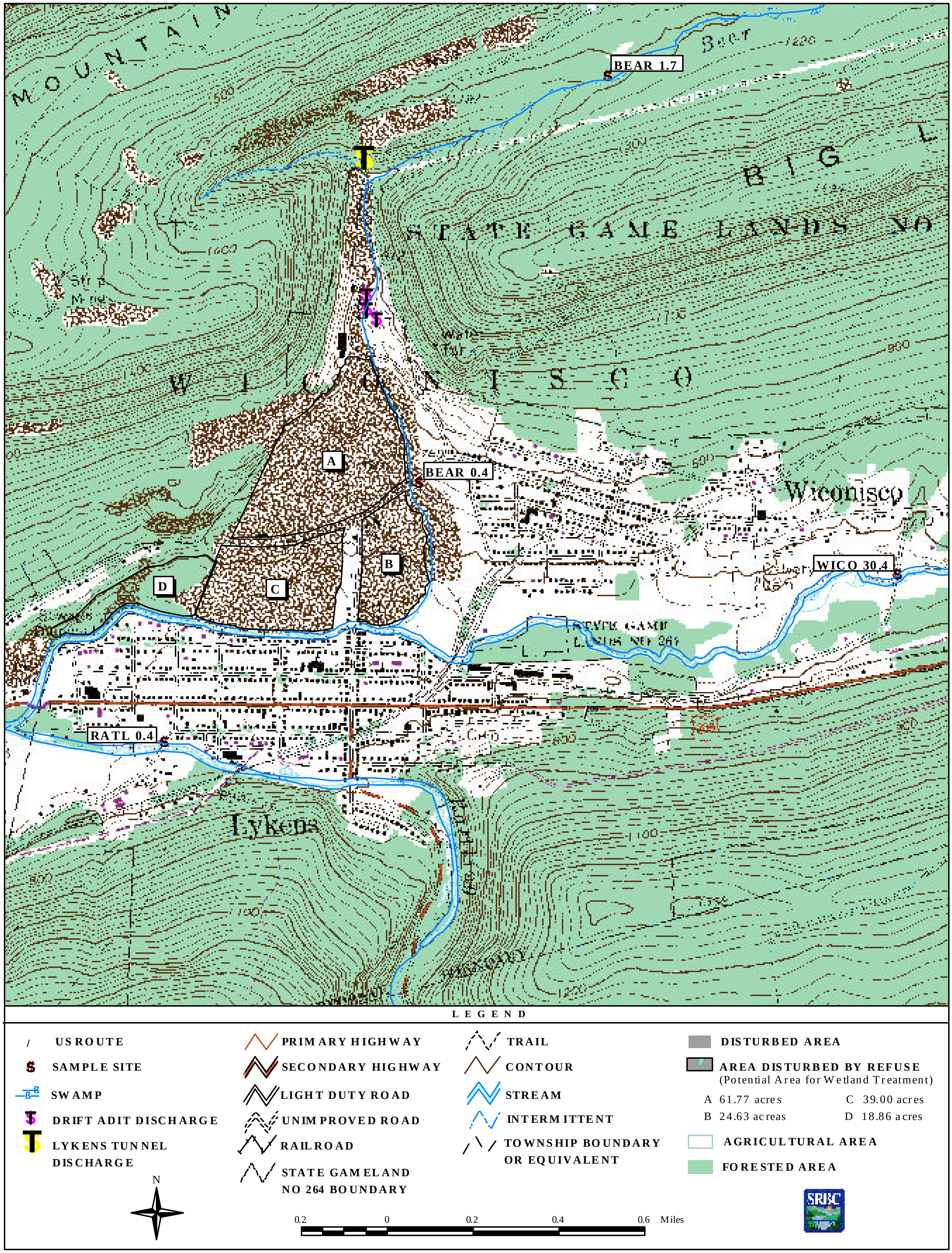

Figure 1. Mine Drainage Discharges and Potential Wetland Treatment Areas in the Bear Creek Watershed

need to be moved or removed. A detailed investigation of the current condition of these tracts is warranted. It appears likely that 30 acres of suitable land can be identified in this area.

It is recommended that the passive system be constructed to receive only contaminated mine water. The mine water should be separated from the flow of Bear Creek and directed to the passive treatment system. Mine discharges are commonly collected and gravity piped to treatment systems. Because of the close proximity of Tract A to the discharges, it would not be unduly expensive to separate the mine water and uncontaminated stream flow.

Estimated Cost

Constructed wetlands can be constructed in undisturbed ground for approximately \$1 per ft^2. This cost includes excavation, berm and road construction, wetland planting, and appropriate influent and effluent structures. This cost does not include the installation of an artificial liner, the removal of refuse, or the acquisition of land. An estimated cost for the passive system, assuming it can be constructed in Tracts A, B, C or D is shown in Table 5.

Table 5. Estimated Cost to Construct a Passive System for the Bear Creek Discharges

Mine discharge collection system (estimate)	\$ 75,000
20 acres of constructed wetland at \$1/ft^2	900,000
Subtotal	**975,000**
Design, engineering, permitting, construction oversight (15% of subtotal)	146,250
Total	**\$1,121,250**

Comparison to Existing Passive Systems

The size of the proposed system is large, but consistent with existing passive systems. A private mining company in Tennessee has treated a 700 to 1,200 gpm flow of alkaline water containing 40 mg/l Fe with ten acres of ponds and wetlands for five years. The final discharge has always contained less than 1 mg/l Fe (Hedin, 1998). In Latrobe Pennsylvania, the Monastery Run Improvement Project has facilitated the construction of wetlands for the treatment of 1,000 gpm (average) of alkaline water contaminated with 90 mg/l Fe. A complex of three treatment systems comprising a total of 19 acres has been constructed by St. Vincent College (using US EPA 319 funds), The Natural Resource Conservation Service, and the Pa. DEP Bureau of Abandoned Mine Reclamation. The total cost of the Monastery Run Improvement Project has been approximately \$1 million. Fact sheets for the project are attached to this report.

BIG LICK TUNNEL

Discharge Characteristics

On November 17, 1998, the discharge from the Big Lick Tunnel flowed less than 1 gpm. The low flow was unusual. SRCB personnel had never seen the flow this low (2 years of observations). The lowest flow reported in the Scarlift report (1970-1971) was 67 gpm (Table 6). The Scarlift study reports an average flow of 664 gpm, with a range of 67 to 4,874 gpm. The discharge was chemically variable. Under lower flow conditions the discharge was marginally acidic with low concentrations of sulfate and metal. Under two higher flow conditions (1,600 gpm and 4,900 gpm), the flow was alkaline with concentrations of Fe 3 to 8 mg/l and sulfate 120 to 235 mg/l. A single sample collected by the SRBC in July 1997 was alkaline with 9 mg/l Fe and low sulfate concentrations (41 mg/l).

Table 6. Big Lick Tunnel Discharge Flow and Chemical Characteristics (Data for 1970-1971 are from the Operation Scarlift report (Sanders and Thomas, 1973). Data for July 1997 are from SRBC (Stoe, 1998).)

Date	Flow Rate (gpm)	pH	Alkalinity (mg/l)	Acidity (mg/l)	Iron (mg/l)	Sulfate (mg/l)
12/17/70	110	5.2	0	6	<1	42
1/19/71	161	4.4	0	10	<1	70
2/17/71	217	5.2	0	8	<1	70
3/18/71	4,874	6.5	72	0	8	120
4/16/71	1,593	6.9	66	0	3	235
5/18/71	161	4.6	0	14	2	48
6/16/71	135	5.0	10	0	<1	90
7/21/71	67	6.8	12	0	<1	42
8/19/71	67	5.6	0	0	<1	60
9/21/71	188	4.2	0	14	3	70
10/21/71	217	5.4	0	0	<1	50
11/23/71	188	4.6	0	6	1	70
7/16/97		8.1	92	6	9	41

Treatment Recommendations and Cost Estimate

Treatment of the Big Lick Tunnel discharge is problematic because of the highly variable flow and chemistry. The primary recommendation is to implement a monitoring program that would determine whether the Scarlift results are still representative. These data, combined with SRBC *instream* monitoring data, should allow a determination of the conditions under which the Big Lick Tunnel discharge degrades Wiconisco Creek. Treatment options should be developed to target these conditions.

A review of the SRCB *instream* data for sampling station WICO 08 (revised WICO 30.4) suggests that the Big Lick discharge periodically has a detrimental effect on Wiconisco Creek (Table 7). Under base flow conditions, *instream* iron concentrations were <1 mg/l. However, concentrations appeared to increase substantially in conjunction with two rainstorm events. If the cause of the degradation is storm-related flushing of the Big Lick Creek discharge channel, it would be useful to implement a management plan that prevented these flushing events. A system consisting of a sedimentation pond(s) followed by constructed wetlands would lessen the impact of these flushing events on Wiconisco Creek.

Table 7. Water Quality in Wiconisco Creek at WICO 08 (new ID WICO 30.4) (from Stoe, 1998).

Date	pH	Iron (mg/l)	Manganese (mg/l)	Sulfage (mg/l)
9/4/96	6.6	0.5	0.4	55
5/14/97	6.7	0.4	0.4	50
6/2/97	6.3	2.5	0.3	43
6/3/97	6.3	1.0	0.2	37
6/4/97	6.4	0.9	0.1	41
6/5/97	6.5	0.6	0.2	26
7/16/97	6.9	0.8	0.5	49
7/24/97	6.2	14.0	0.4	35
7/25/97	5.9	1.8	0.3	50
7/28/98	5.9	1.2	0.3	64

A passive system designed to treat high flows of alkaline, Fe-contaminated water would encompass 3 to 10 acres in the area shown in Figure 2. This range is size is based on an assumption that the system is sized to remove iron at a rate of 6 g $m^{-2}day^{-1}$ from a flow of 1,600 to 4,900 gpm containing 9 mg/l Fe (the most recent SRBC Fe analysis). The cost of the system would likely be $150,000 to $500,000. Because the discharge flows through State Gamelands, there would not be land acquisition costs (assuming it could be benched into the hill below the discharge). The treatment system would be unnecessary during base and low flow periods when, according to the Scarlift Report, iron concentrations are <1 mg/l. Between December 1970 and November 1971, treatment was only needed during two months. If a large treatment system was constructed, it would act a retention basin and flow-dissipater during storm events, and would eliminate most of the *instream* problems suggested by Table 7. During low and base flow conditions, when Fe contamination may be less significant, the system would discharge high quality water and would provide wildlife values.

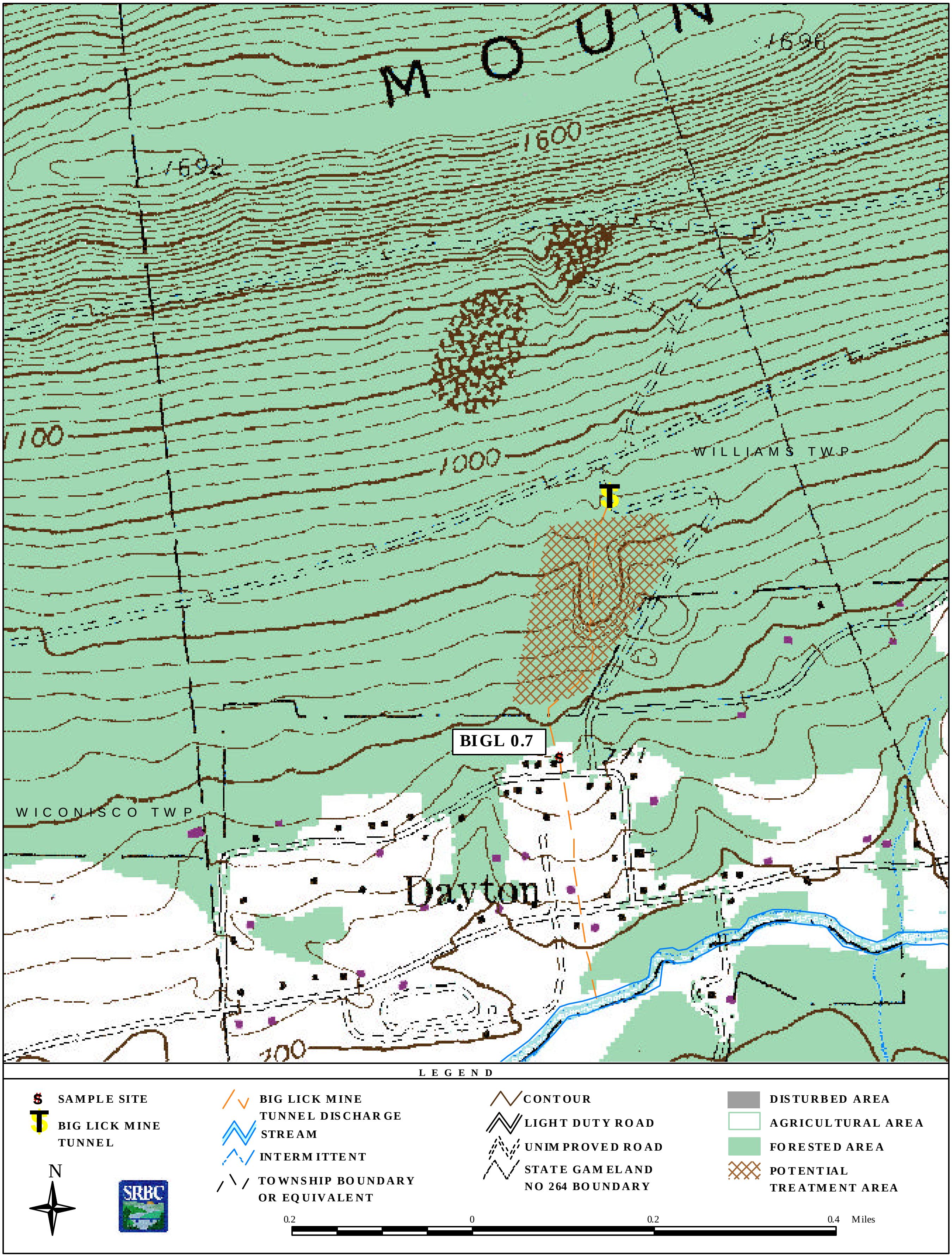

Figure 2. Big Lick Mine Tunnel Discharge and Potential Area for Settling Ponds and Wetland Treatment System

PORTER TUNNEL

Discharge Characteristics

Acidic water flows from the Porter Tunnel near Muir. Samples collected in 1971 by the Scarlift effort (Sanders and Thomas, 1973) and in 1997 by SRBC (Stoe, 1998) revealed similar flow rates and chemical conditions (Table 8). The discharge averages ~540 gpm of flow, containing approximately140 mg/l acidity, 20 mg/l Fe and 4 mg/l Al. The discharge currently flows across an inactive mine yard and down to a limestone diversion well before discharging to the headwaters of Wiconisco Creek. On November 17, 1998, the diversion well was not functioning because the intake was clogged with debris and the well was not full of limestone.

Table 8. Porter Tunnel Discharge Flow and Chemical Characteristics (Data for 1970-1971 are from the Operation Scarlift report (Sanders and Thomas, 1973). Data for 1996-1997 data from SRBC (Stoe, 1998).)

Date	Flow Rate (gpm)	pH	Acidity (mg/l)	Iron (mg/l)	Aluminum (mg/l)	Manganese (mg/l)	Sulfate (mg/l)	Acidity (g/day)
12/17/70	529	3.1	180	35	na	na	450	518,949
1/19/71	529	3.0	200	40	na	na	525	576,610
2/17/71	1,065	3.0	200	50	na	na	300	1,160,850
3/18/71	873	3.1	180	28	na	na	210	856,413
4/20/71	610	3.1	130	20	na	na	900	432,185
5/18/71					na	na		
6/18/71	345	3.3	140	6	na	na	100	263,235
7/21/71	278	3.0	130	6	na	na	525	196,963
8/19/71	490	3.0	240	6	na	na	475	640,920
9/21/71	380	2.9	100	12	na	na	350	207,100
10/21/71	345	3.0	110	9	na	na	475	206,828
11/23/71	490	2.8	100	26	na	na	500	267,050
9/5/96	744	2.5	140	17	4.4	4.5	324	567,672
5/15/97	450	2.3	120	16	3.8	3.9	161	294,300
6/2/97	426	2.2	122	17	3.7	3.7	213	283,247
6/3/97	450	2.4	126	16	3.6	3.6	345	309,015
6/4/97	469	2.5	140	15	3.9	3.9	247	357,847
6/5/97	473	3.0	124	16	3.9	3.8	232	319,653
7/16/97	na	2.3	112	16	3.7	3.8	260	na
7/24/97	na	2.8	96	12	3.3	3.7	291	na
7/25/97	na	3.0	116	16	4.1	4.6	262	na
7/28/97	na	2.9	128	17	4.5	4.4	278	na

According to SRBC personnel, the owner of the tunnel and coal reserves, Reading Anthracite, is considering reopening the mine. Active mining complicates treatment of the discharge using public funds, because, to our knowledge, Section 319, 10 percent set-a-side or AML funds cannot be spent on sites where there is an active mining permit.

Treatment Recommendations

Treatment of the discharge requires the generation of alkalinity and the precipitation of Fe and Al. An anoxic limestone drain is not recommended because the water is aerated, contains aluminum, and the iron is likely present in the ferric state. One passive treatment option currently used for low pH oxidized water is vertical flow ponds, followed by constructed wetlands (see technology description). One pass through a vertical flow pond would result in the generation of alkaline water with low concentrations of metals (<1 mg/l Al and < 2 mg/l Fe). (Several vertical flow ponds could be built, but they should be arranged in a parallel manner in the area shown in Figure 3. There is no value to arranging VFPs in a "successive" manner.) Because the discharge of vertical flow ponds generally contains objectionable amounts of volatile organic compounds, hydrogen sulfide, and BOD, a wetland is recommended to polish the water before it discharges to Wiconisco Creek.

Vertical Flow Ponds are generally sized based on the targeted flow and contaminant loadings and the measured acidity removal rates at existing VFPs. Experiences by Hedin Environmental suggest that VFP's generate an average of 40 grams of alkalinity per m^2 per day. This rate is used to size VFPs for the Porter Tunnel discharge. The wetlands are sized based on either retention time (12^+ hours) or iron loading (6 g $m^{-2}d^{-1}$ removal), whichever is larger. Several VFP and wetland configurations for the Porter Tunnel discharge are shown below.

Table 9. Passive Treatment Scenarios for the Porter Tunnel Discharge

Flow Condition	Flow Rate (gpm)	Acidity (mg/l)	Acidity (kg/day)	VFP (acres)	Wetland (acres)
Average	539*	125**	411	2.3	2.4
75th percentile	570	125	435	2.4	2.5
90th percentile	873	125	666	3.7	3.8
Maximum*	1,065	125	813	4.5	4.7

** based on the Scarlift study (December 1970-November 1971)*
*** based on recently collected SRBC data*

Estimated Cost

The cost of vertical flow ponds averages approximately \$5 per ft^2 (installed). Assuming that engineering costs are 15 percent, then the costs of the systems in Table 8 range from \$700,000 to \$1,400,000. This cost assumes that sufficient flat land exist below the discharge and Wiconisco Creek. It does not include land acquisition costs.

The vertical flow pond technology is innovative and still evolving. The long-term performance of VFP systems is uncertain. It is recommended that the passive treatment of the Porter Tunnel discharge be delayed until the discharge is better characterized (flow and chemistry), the status of renewed mining activity is resolved, and passive technologies for low pH acidity water are better developed.

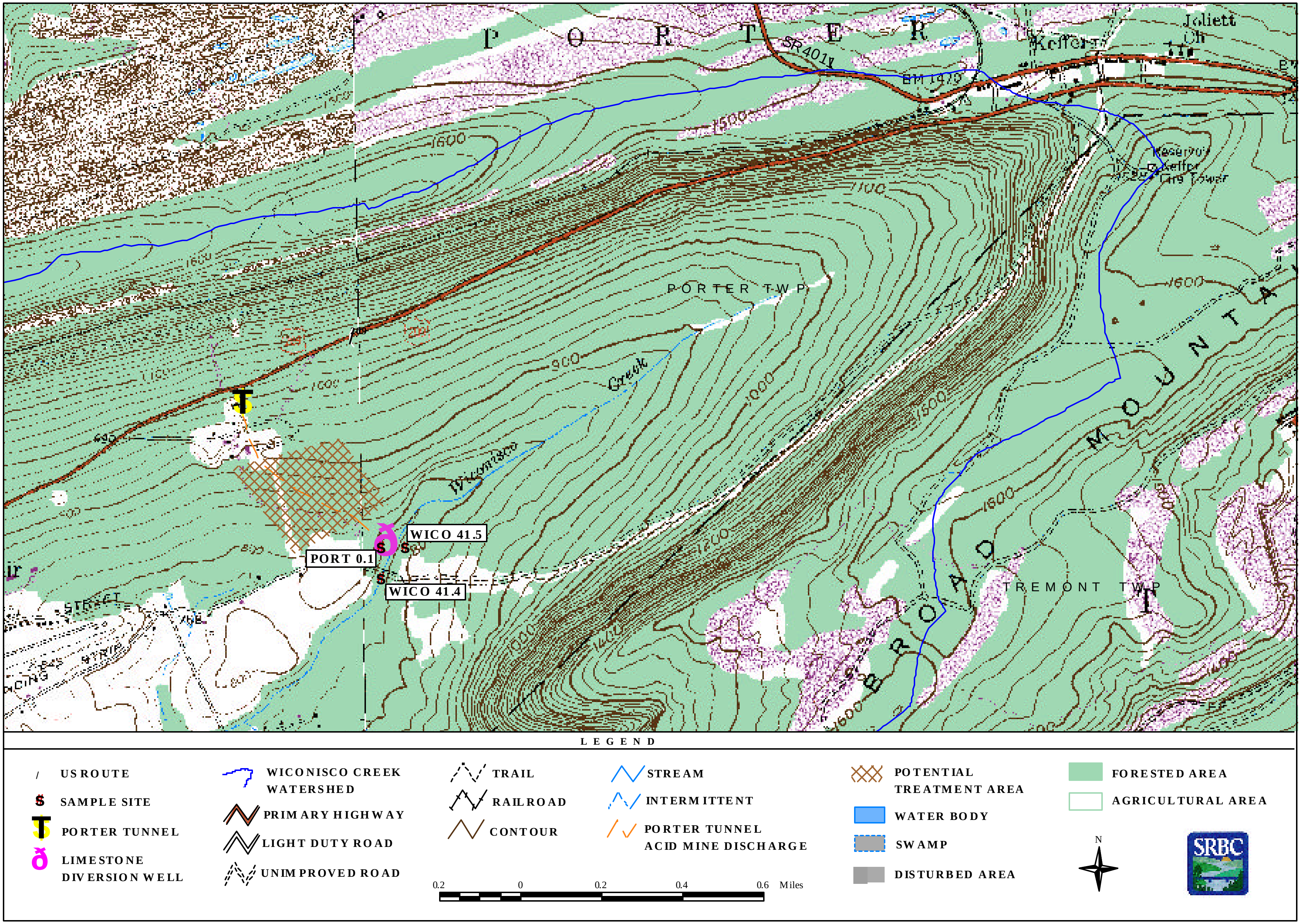

Figure 3. Porter Tunnel Acid Mine Discharge and Location of Land Suitable for a Treatment System

RECOMMENDATIONS REGARDING FUTURE DATA COLLECTION EFFORTS

Most of the biological and chemical data collected thus far for Wiconisco Creek describe *instream* conditions. In order to develop remediation plans that target specific pollution sources, it is necessary to characterize individual pollution sources. Characterization involves the measurement of flow rates and the analysis of water samples collected at the discharge sources. Data should be collected on a 4 to 6 week schedule for at least one year. Water samples should be analyzed for pH, alkalinity, acidity, iron, aluminum, manganese and sulfate. Samples collected for metal analysis should be acidified in the field. Filtration is only required (for characterization) if a clear sample cannot be collected. Samples should be analyzed by a laboratory with mine water experience. The data should be reviewed by a chemist with mine drainage experience so that analytical or sampling problems can be quickly identified and rectified. Flows are most conveniently measured from a properly installed weir, flume, or pipe (using a bucket and stopwatch). A good reference for the proper installation and use of weirs and flumes is "ISCO Open Channel Flow Measurement Handbook," available from Isco, Inc. in Lincoln, Nebraska. Measurements using a flow velocity meter and cross sectional area measurements are certainly adequate, but this method requires an instrument that not all monitoring personnel own.

SUMMARY OF RECOMMENDATIONS FOR THE RESTORATION OF MINE DRAINAGE POLLUTION IN THE WICONISCO CREEK WATERSHED

Mine drainage in the Wiconisco Creek Watershed is chemically diverse. Bear Creek is primarily polluted by alkaline Fe-contaminated discharges, while the Porter Tunnel discharges acidic water contaminated with ferric iron and Al. The flow rates are also highly variable. The Big Lick Tunnel, which in March of 1971 had a measured discharge of 4,874 gpm, discharged less than 1 gpm in November 1998. This variability in mine drainage characteristics makes remediation similarly variable. The Bear Creek and Big Lick Tunnel discharges can be treated using tested passive treatment techniques at a cost of $1.5 to $2.0 million. While the size of the treatment systems and the total cost is high, it is far from unprecedented. With unified commitments from watershed residents, the Eastern Pennsylvania Coalition for Abandoned Mine Reclamation, a local Pa. DEP office, and the SRBC, it is reasonable to expect that substantial remediation of mine drainage could occur.

The remediation of the Porter Tunnel is made more difficult by its highly acidic chemistry and its ownership by a viable mining company. It is unlikely that public funds can be used to treat the discharge as long as further mining is anticipated. The mining company may be willing to construct a passive treatment system as part of its mining plan. This opportunity should be explored, but with the caveat that all parties understand that the Porter Tunnel discharge is a highly oxidized acidic water whose passive treatment is less certain than the alkaline Bear Creek discharges. The mining and reclamation industries are constructing passive treatment systems for waters like the Porter Tunnel discharge, but performance problems exist and the technology is still evolving. It is advisable to delay major expenditures on the Porter Tunnel discharge until the vertical flow pond and SAPS technologies are more thoroughly evaluated.

This quick assessment of mine drainage problems and treatment opportunities in the Wiconisco Creek Watershed should facilitate the development of a restoration plan. The substantial increase in public funding for stream restoration projects that has occurred during the last five years has been accompanied by increasing demands for planning documents. The Pa. DEP, which disburses funds through the AML and 319 Programs, will soon require an approved *rehabilitation plan* for all projects. The Office of Surface Mining, which approves Pa. DEP's expenditures for the 10 percent set-aside Program, requires an approved *hydrologic unit plan*. U.S. Army Corps of Engineers requires the all projects be preceded by a *feasibility study* that addresses watershedwide issues. Before the Natural Resource Conservation Service can commit funding to its PL 566 Program, a watershed plan must be prepared and reviewed. Hedin Environmental believes that the SRBC is already in a good position to produce a viable restoration plan. The plan would be strengthened by the collection of flow and chemical data for the discharges that are especially damaging (Bear Creek and the Big Lick Tunnel, in particular). However, because the current mine discharge characteristics appear similar to those documented by Operation Scarlift in 1970/71, it is reasonable to proceed with restoration planning.

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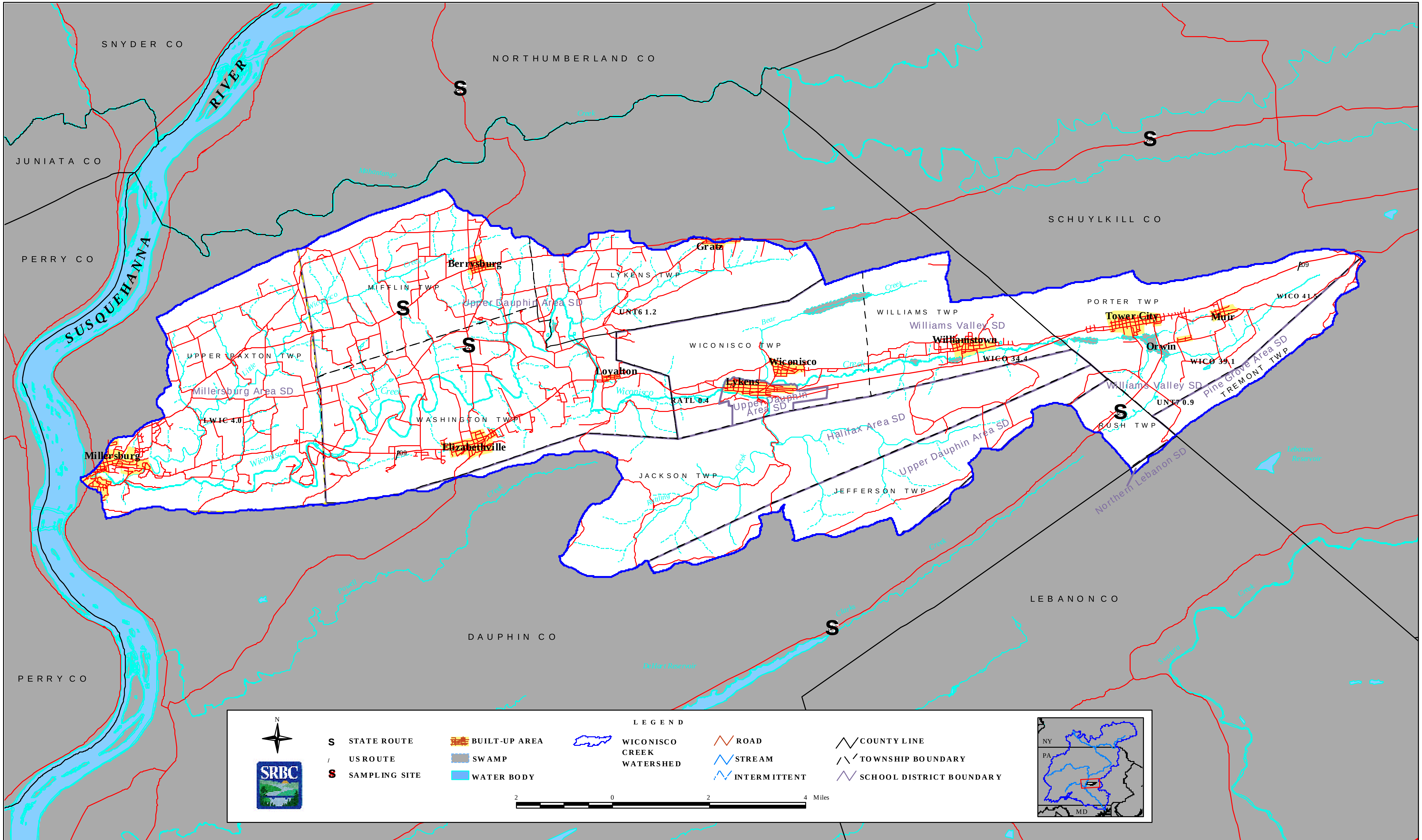

Plate 1. Wiconisco Creek Watershed Location

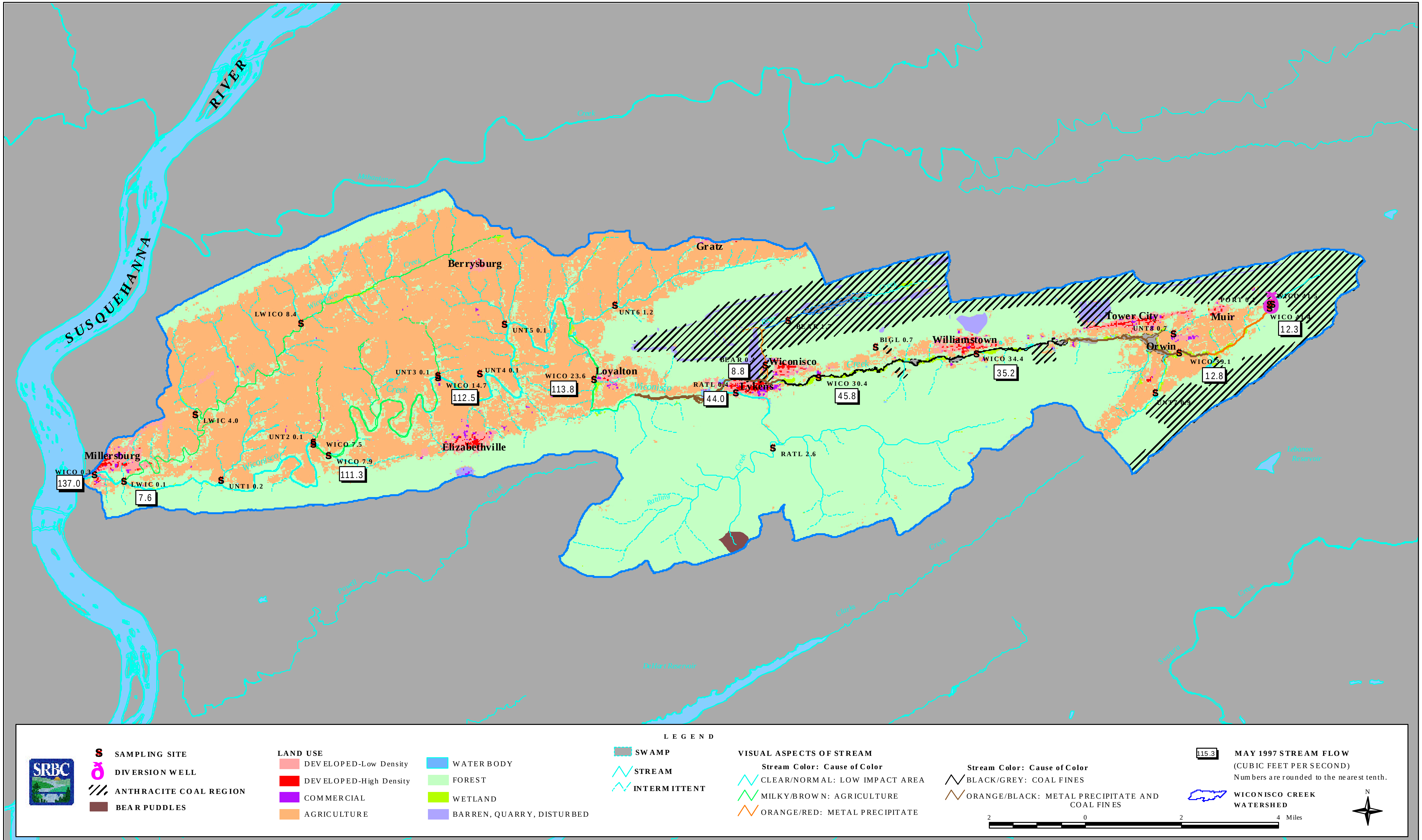

Plate 2. Susquehanna River Basin Commission Sampling Sites, Land Use, and Stream Characteristics in the Wiconisco Creek Watershed

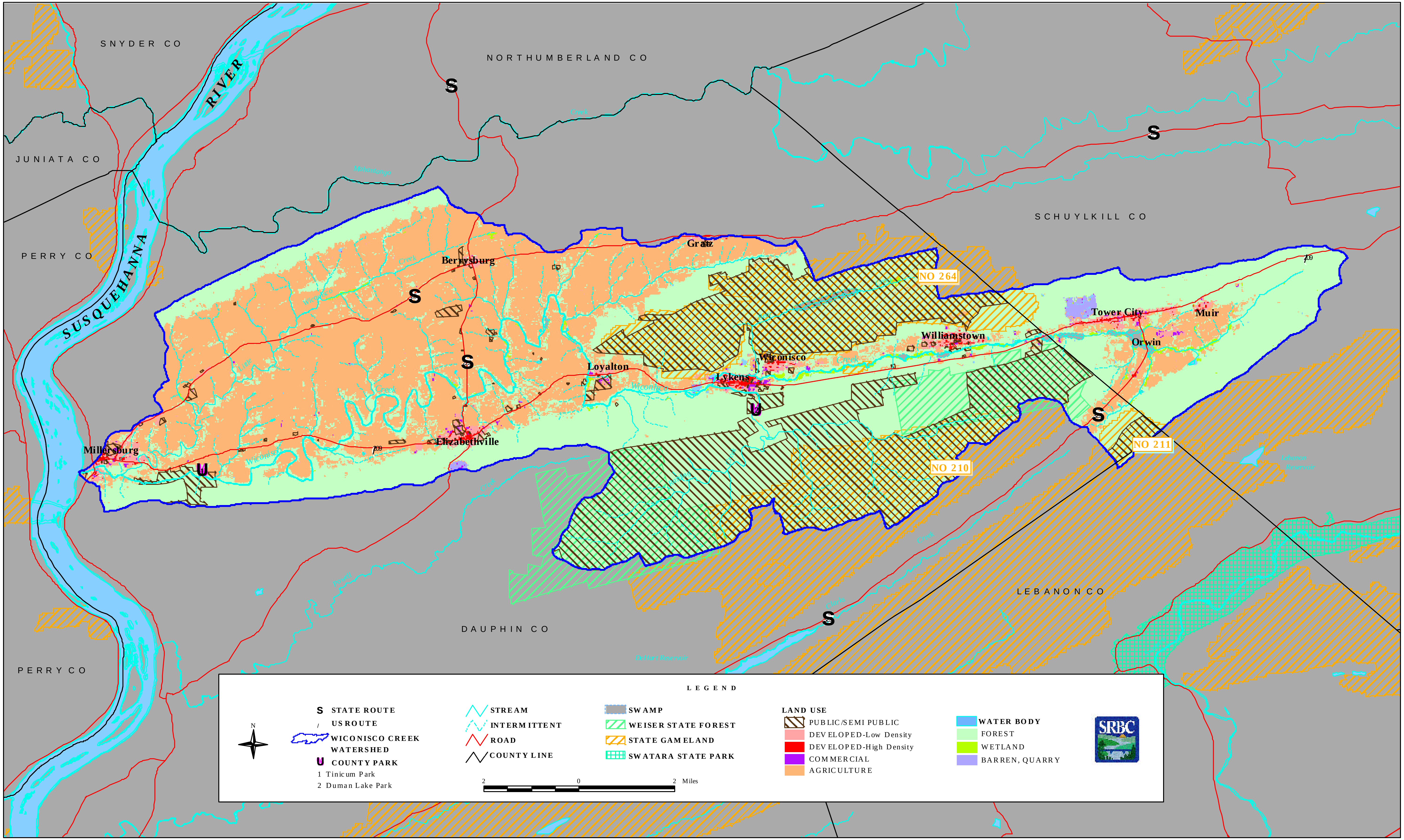

Plate 3. Land Use and State Lands in the Wiconisco Creek Watershed