in 1981, as a flood control and recreational project (Kulp and Pisarski, 1994). Tioga Lake impounds the Tioga River and controls a drainage area of 280 square miles; Hammond Lake impounds Crooked Creek and controls a drainage area of 122 square miles. Due to the degraded state of the water entering Tioga Lake, water from Hammond Lake, which is alkaline, must be mixed with the Tioga Lake water through a 2,700-foot connecting channel and released through multiple-elevation outlet gates before being discharged downstream as the Tioga River (Figure 5b). Studies completed in 1974, before construction, determined that the best abatement alternative would be to implement a suite of preventative measures throughout the watershed to reduce the volume of AMD produced and then build two chemical treatment plants to treat the remaining AMD (U.S. Army Corps of Engineers, 1977). However, this initiative was not funded and implementation was not initiated. To manage the degraded water entering Tioga Lake, a detailed operations plan was created by staff at the complex to ensure that water quality standards were being met downstream of the dam (U.S. Army Corps of Engineers, 1986). However, this plan took many years to develop and multiple fish kills occurred in both the Tioga River and Tioga Lake (U.S. Army Corps of Engineers, 1986). The USACE states that remediation of the mine drainage at its source would produce positive economic benefits for the operation of the Tioga/Hammond Complex by removing the source of impairment to Tioga Lake, while also restoring portions of the Tioga River and its tributaries (U.S. Army Corps of Engineers, 1986).

WATERSHED INVESTIGATION

Methods of Investigation

Initial investigation of the watershed included collection of all preexisting data, identification of mining-related problem areas, and establishment of a stream monitoring network. All pertinent USGS topographic maps, aerial photographs, mine maps, mining permits, and historical reports and records were reviewed. The watershed boundary was outlined and the study area divided into subwatersheds for separate investigation. Areas identified as impaired on Pennsylvania's Section 303(d) list (Pa. DEP, 2003) were delineated and targeted for field sampling. SRBC staff developed a volunteer-oriented problem area identification protocol and training manual for identifying mining-related problem areas for use by local stakeholders. Volunteers from the Tioga River Watershed Reclamation Projects, Inc. were trained in problem area identification. During spring through fall 2001, all AMD-impacted streams and the Tioga River mainstem from Bear Creek to the County Bridge Picnic Area (TIOG6) were walked to define sources of AMD and other mining-related problem areas. Discharge waters were identified and roughly characterized in the field. The field characterization included a test of pH and conductivity using portable meters, flow measurement (using portable flumes or buckets) or estimation, and completion of a problem area inventory checklist. Global Positioning System (GPS) measurements were taken at each problem area identified for entry into a GIS for mapping and analysis. During spring 2001 through fall 2002, field examination and verification of previously documented mining features was conducted.

Figure 5a. Aluminum Hydroxides in Water Column at Southern End of Tioga Lake

Figure 5b. Channel Connecting Tioga Lake and Hammond Lake to Allow Mixing

Water quality sampling points were established at two types of features: (1) instream monitoring stations at various points along streams and the river in the watershed (Figure 4), and (2) AMD discharge monitoring stations located at the groundwater/surface water interface where water was discharging (Figure 6). GPS measurements were taken at each monitoring station for entry into a GIS for mapping and analysis. Instream monitoring stations were chosen based on location above and below major impacted tributaries and discharges, at intervals along mainstem segments, and in areas necessary to show reference conditions and sources of alkaline loads. Instream monitoring stations were sampled six times, at least once in each season from spring 2001 through summer 2002. Discharge monitoring stations were chosen based on the results of the problem area identification inventory. The 20 worst stations, determined by either low pH or high volume or a combination of both, were chosen to be sampled to collect data necessary for use in the Gannett Fleming, Inc. conceptual treatment model. The chosen discharges were sampled at least six times from April through October 2002, including both low and high flow conditions. Discharges known to be major pollution sources based on historical reports were included in the instream sampling as well, allowing these discharges to be sampled up to 12 times. Some discharges were not able to be sampled six times due to: (1) their intermittent nature (only flowed in periods of high groundwater saturation) or (2) their late identification and inclusion in the sampling program. Discharges that were identified through the problem area inventory but not intensively sampled were determined to be contributing very small percentages of the pollutant loads to the watershed.

After the monitoring station network had been established, water quality sampling was initiated. Standard field and laboratory USEPA-approved quality assurance procedures were followed. Field water quality measurements included water temperature, dissolved oxygen, conductivity, and pH. Samples of water from each site were collected for laboratory analysis. Laboratory samples consisted of one 500 ml bottle for whole sample analysis, one 250 ml bottle for metals analysis, and one 250 ml bottle for ferrous iron analysis. The samples for metals analysis were fixed with nitric acid (HNO_3); samples for ferrous iron analysis were fixed with hydrochloric acid (HCl). All samples were chilled on ice and shipped within 24 hours to the Pa. DEP Bureau of Laboratories in Harrisburg, Pa., for analysis. Parameters analyzed for each type of laboratory water quality sample can be found in Table 2; acceptable ranges for selected parameters in AMD-impacted waters can be found in Table 3.

Stream flow was measured at all sampling sites using USGS standard methods for discharge measurement. A Scientific Instruments Pygmy-Type (or AA-Type) current meter was used to measure velocity at all instream stations; a top-set wading rod was used to measure stream depth. Tioga River flows at TIOG1 were recorded at the USGS gauge at Mansfield (#01516350); all other mainstem points (TIOG2-8) were calculated using linear regression based on discharge at TIOG1 and drainage area. A Marsh McBirney Digital Current Meter was used to measure velocity at all discharge stations except DMR001 and DFB100; a top-set wading rod was used to measure stream depth. A Marsh McBirney current meter and customized wading rod were used to measure flow at site DMR001 and a bucket was used to measure flow at site DFB100 due to unique physical features at these sites. Weirs were existent at a few discharge locations, but were not used to measure flow due to disrepair.

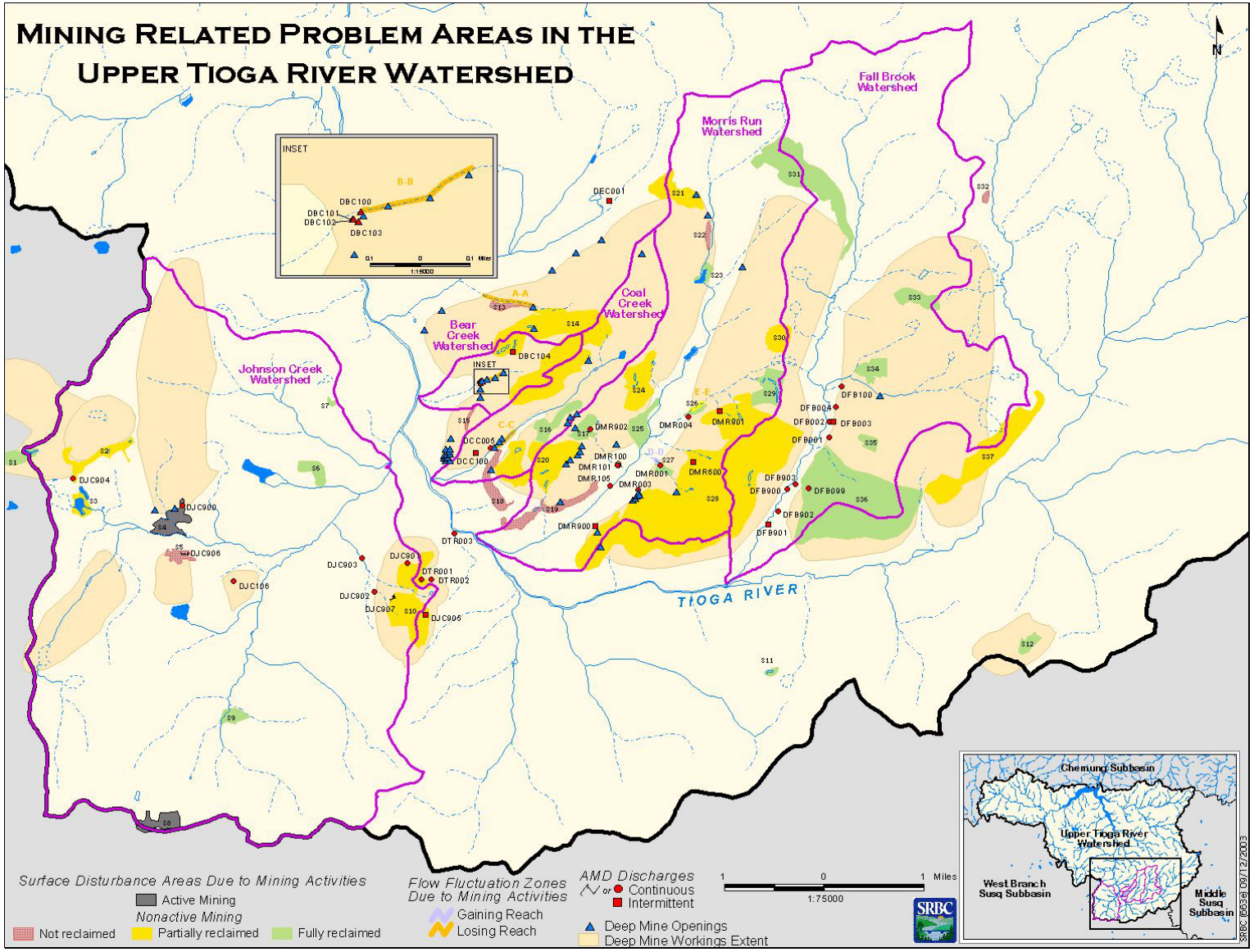

Figure 6. Mining Related Problem Areas in the Upper Tioga River Watershed

Table 2. Laboratory Water Quality Parameters Analyzed

Monitoring Station Type	Parameters Analyzed	Measurement Units
Instream	pH	Standard Units (SU)
	Hot Acidity	Milligrams/liter (mg/l)
	Alkalinity	Milligrams/liter (mg/l)
	Total Iron	Micrograms/liter (μg/l)
	Total Manganese	Micrograms/liter (μg/l)
	Total Aluminum	Micrograms/liter (μg/l)
	Total Sulfates	Milligrams/liter (mg/l)
	Total Calcium	Milligrams/liter (mg/l)
	Total Magnesium	Milligrams/liter (mg/l)
	Total Dissolved Solids	Milligrams/liter (mg/l)
Discharge	pH	Standard Units (SU)
	Hot Acidity	Milligrams/liter (mg/l)
	Acidity	Milligrams/liter (mg/l)
	Alkalinity	Milligrams/liter (mg/l)
	Total Iron	Micrograms/liter (μg/l)
	Ferrous Iron	Micrograms/liter (μg/l)
	Total Manganese	Micrograms/liter (μg/l)
	Total Aluminum	Micrograms/liter (μg/l)
	Total Sulfates	Milligrams/liter (mg/l)
	Total Hardness	Milligrams/liter (mg/l)

Table 3. Significant Physical, Chemical and Biological Parameters Used in Evaluating Mine Drainage Pollution of Streams[5]

Parameter	Range of Values of Concern	Major Water Use(s)	Usual Values in Unpolluted Waters	Pa. DEP Water Quality Standard[6]
pH	Less than 6.0	Aquatic life	6.0-9.0	6.0-9.0
Acidity	Sufficient to lower alkalinity below 20 mg/l	Aquatic life	Less than alkalinity	Less than alkalinity
Alkalinity	20 mg/l	Aquatic life	20 mg/l	20 mg/l (except where naturally lower)
Sulfates	250 mg/l	Domestic, industrial water supply	20 mg/l	250 mg/l
Hardness	250 mg/l	Domestic, industrial water supply	150 mg/l	150 mg/l
Total Iron	1.0 mg/l	Aquatic life, domestic and industrial water supply	0.3 mg/l	1.5 mg/l
Manganese	1.0 mg/l	Aquatic life, domestic and industrial water supply	0.05 mg/l	1.0 mg/l
Suspended Solids	250 mg/l	Aquatic life	100 mg/l (except during storm flow)	

The results of the watershed investigation were interpreted based on the location, concentration, and magnitude of mine drainage discharges; the topographical conditions in the area; and costs. Abatement methods and possible alternatives were considered; evaluation

[5] Source – *Stream Pollution by Coal Mine Drainage in Appalachia*, 1969, Federal Water Pollution Control Administration.
[6] Source – Pennsylvania Code, Title 25. Environmental Protection, Department of Environmental Protection, Chapter 93. Water Quality Standards. 1999, Commonwealth of Pennsylvania

placed emphasis on maximum stream improvement at minimum cost per pound of acid abated. Priorities for abatement were established using the cost-effectiveness ratio as well as other criteria such as: overall cost of reclamation, miles of stream improvement, the probability of abatement success, the potential and probability of future mining, as well as the aesthetics of each project area.

Results of Investigation

The results of the watershed investigation indicate that only three subwatersheds (Coal Creek, Bear Creek, and Johnson Creek) and the Tioga River are being affected by AMD from abandoned surface and underground mining. These watersheds include streams that are listed on the Clean Water Act Section 303(d) list of impaired waters of the Commonwealth (Pa. DEP 2003). Three watersheds (Fellows Creek, McIntosh Hollow, and Taylor Run) are chronically or episodically acidified by non-AMD sources (organic acids, atmospheric deposition). Two watersheds (Fall Brook and Morris Run) are being impacted by a combination of both AMD and non-AMD acidity. AMD impacts alone represent a conservative loss of $287,000 per year of fishery resources in the Tioga River and many of its tributaries (Arway, 1995)[7].

Mining-related problem areas summary

1. *Sources of abandoned mine drainage*
   Thirty-six mine drainage discharge points to surface streams exist in the watershed. The locations of all mine discharge points are shown in Figure 6. A description of each mine discharge point can be found in Table 4.
2. *Deep mine openings*
   Fifty-five deep mine entries exist in the watershed. The locations of deep mine openings are shown in Figure 6. A description of each deep mine opening can be found in Table 5. Also presented in Table 5 are the mine drainage discharge points with which the entries communicate.
3. *Surface mined areas*
   Thirty-seven surface mined areas exist in the watershed. The locations of all surface mined areas are shown in Figure 6. A description of each surface mined area can be found in Table 6.
4. *Stream flow fluctuation zones*
   Five areas of stream flow fluctuation exist in the watershed. Stream fluctuation zones are defined in this report as reaches of stream that are gaining or losing flow based on the influence of mining activities. Gaining reaches are most likely the result of an AMD discharge, while losing reaches are the result of stream flow loss to underground voids created by deep mining activity. The locations of all stream flow fluctuation zones are shown in Figure 6. A description of each fluctuation zone can be found in Table 7.

[7] Economic analysis was completed in 1995 using stream miles known at that time to be impaired by AMD. Since that time, many additional stream miles have been added to the list of AMD-impaired streams. Due to the increase in stream miles from 1995 to the present in the Tioga River Watershed, the loss figures given are a very conservative monetary estimate of the total fishery loss.

Table 4. Abandoned Mine Discharge Points in the Upper Tioga River Watershed

Discharge Point	Source of Drainage	Type of Discharge
DBC100	Deep Mine	Continuous
DBC102	Deep Mine	Continuous
DBC103	Deep Mine	Intermittent
DBC104	Surface Mine	Intermittent
DCC005	Deep Mine	Continuous
DCC100	Deep Mine	Continuous
DEC001	Surface Mine	Intermittent
DFB099	Deep Mine	Continuous
DFB001	Deep Mine	Continuous
DFB002	Deep Mine	Continuous
DFB003	Deep Mine	Intermittent
DFB004	Deep Mine	Continuous
DFB100	Deep Mine	Continuous
DFB900	Groundwater Seep	Continuous
DFB901	Groundwater Seep	Intermittent
DFB902	Groundwater Spring	Continuous
DFB903	Groundwater Seep	Continuous
DMR001	Deep Mine	Continuous
DMR003	Deep Mine	Continuous
DMR004	Deep Mine	Continuous
DMR100	Deep Mine	Continuous
DMR101	Deep Mine	Continuous
DMR105	Groundwater Seep	Continuous
DMR600	Surface Mine	Intermittent
DMR900	Deep Mine	Continuous
DMR901	Surface Mine	Intermittent
DMR902	Deep Mine	Continuous
DTR001	Surface Mine	Continuous
DTR002	Surface Mine	Continuous
DJC106	Deep Mine	Continuous
DJC900	Deep Mine	Continuous
DJC901	Deep/Surface Mines	Continuous
DJC904	Deep Mine	Continuous
DJC905	Deep/Surface Mines	Continuous
DJC906	Deep Mine	Continuous
DJC907	Deep/Surface Mines	Continuous

* DBC101, DTR003, DJC902 and DJC903 (shown in Figure 6) are aggregations of upstream discharge waters and are not locations of actual abandoned mine discharges.

Table 5. Deep Mine Entries Identified in the Upper Tioga River Watershed

Deep Mine Entry Number	Type of Entry	Coal Seam Mined	Discharge Point With Which Entry Communicates
1	Slope	Bloss	DCC005
2	Drift	Bloss	DCC005
3	Drift	Bloss	DCC005
4	Drift	Bloss	DCC005
5	Drift	Bloss	DCC005
6	Drift	Bloss	DBC100, DBC102
7	Drift	Bloss	DBC100, DBC102
8	Drift	Bloss	DCC005
9	Drift	Seymour	DCC005
10	Drift	Seymour	DBC100, DBC102
11	Drift	Cannel	DBC100, DBC102
12	Drift	Bloss	DBC100, DBC102
13	Drift	Bloss	DBC102
14	Drift	Bloss	DCC005
15	Drift	Morgan	DCC005
16	Drift	Bear Creek	DCC100
17	Drift	Bear Creek	DCC100
18	Drift	Bear Creek	DCC100
19	Drift	Bloss	DCC005
20	Drift	Bloss	DCC005
21	Drift	Cannel	DCC005
22	Drift	Bloss	DCC005
23	Drift	Bloss	DCC005
24	Drift	Cannel	DCC005
25	Drift	Bloss	DCC005
26	Drift	Cannel	DCC005
27	Drift	Bloss	DCC005
28	Drift	Cannel	DCC005
29	Drift	Bloss	DCC005
30	Drift	Bloss	DCC005
31	Drift	Rock	DCC005
32	Drift	Rock	DCC005
33	Drift	Rock	DCC005
34	Drift	Rock	DCC005
35	Drift	Bloss	DCC005
36	Drift	Bloss	DCC005
37	Drift	Bloss	DMR004
38	Drift	Morgan	DCC005
39	Drift	Bloss	DMR003
40	Drift	Morgan	DMR003
41	Drift	Morgan	DMR003
42	Drift	Morgan	DMR003
43	Drift	Morgan	DMR003
44	Drift	Bloss	DCC005
45	Drift	Bloss	DMR900
46	Drift	Bloss	DMR900
47	Drift	Seymour	DMR001
48	Drift	Bloss	DFB004
49	Drift	Bloss	DJC900
50	Drift	Bloss	DJC900
51	Drift	Morgan	DCC005, DMR100-101
52	Drift	Morgan	DCC005, DMR100-101
53	Drift	Morgan	DCC005, DMR100-101
54	Drift	Morgan	DCC005, DMR100-101
55	Drift	Bloss	DCC005

Table 6. Areas of Surface Disturbance Due to Mining Activities Identified in the Upper Tioga River Watershed

Area Number	Coal Seam(s) Affected	Area Affected, square miles	Connection to Deep Mines	MD Discharge Point With Which Surface Area Communicates
S-1	Seymour	0.04	Indirect	In Babb Creek Watershed
S-2	Seymour	0.06	Indirect	DJC904, DJC900
S-3	Refuse Pile	0.04	*	DJC904
S-4	Refuse Pile	0.07	*	DJC900
S-5	Refuse Pile	0.02	Precipitation	DJC906
S-6	?	0.04	*	*
S-7	?	0.01	*	*
S-8	None Gravel Mine	0.06	*	*
S-9	?	0.03	*	*
S-10	Bloss, Morgan	0.22	Direct, Indirect	DJC901, DJC903, DJC907?, DTR001, DTR002
S-11	?	0.01	Precipitation	*
S-12	?	0.03	Precipitation	*
S-13	Bloss	0.02	Direct	DBC100, DBC102, DCC005
S-14	Morgan, Seymour, Rock	0.57	Direct, Indirect	DBC100, DBC102, DBC104, DCC005
S-15	Morgan	0.01	Direct	DCC005
S-16	Seymour, Rock	0.06	Precipitation	DCC005
S-17	Seymour, Rock	0.04	Precipitation	DCC005
S-18	Bloss	0.06	Indirect	DCC005
S-19	Bloss	0.08	Direct	DCC005
S-20	Morgan, Seymour, Rock	0.24	Precipitation	DMR100-101, DCC005
S-21	Bloss	0.09	Direct	DCC005
S-22	Bloss	0.01	Precipitation	DCC005
S-23	Bloss	0.02	Precipitation	DCC005
S-24	Seymour	0.12	Precipitation	DCC005
S-25	Bloss, Cannel	0.06	Precipitation	DCC005
S-26	Refuse Pile	0.01	*	*
S-27	Refuse Pile	0.01	*	*
S-28	Bear Creek, Bloss, Cannel, Morgan, Seymour	1.53	Precipitation	DMR004, DMR901, DMR001, DMR003, DMR900
S-29	Seymour	0.08	Precipitation	UNT3.0
S-30	Seymour	0.06	Precipitation	UNT3.0
S-31	Bloss, Cannel, Morgan	0.29	Precipitation	DMR004
S-32	Seymour	0.01	Indirect	*
S-33	Cannel, Morgan	0.06	*	*
S-34	Cannel, Morgan	0.05	*	*
S-35	Morgan, Seymour	0.02	Precipitation	DFB001, DFB002
S-36	Bloss, Morgan, Seymour	0.77	Precipitation	DFB099
S-37	Seymour	0.27	Indirect	DFB002, DFB003

* Direct connection - deep mine workings visible; indirect connection–apparent infiltration from bottom of pit; precipitation–groundwater infiltration into underlying deep mine workings

Table 7. Areas of Stream Flow Fluctuation Due to Mining Activities in the Upper Tioga River Watershed

Infiltration Area	Length, Feet	Losing or Gaining Reach	MD Discharge Point with Which Infiltration Area Communicates
A-A	2,700	Losing	DBC100
B-B	1,255	Losing	DBC100, DCC005
C-C	1,465	Losing	DCC005
D-D	390	Gaining	DMR001
E-E	772	Losing	DMR004

Subwatershed conditions

Streams in the Upper Tioga River Watershed can be classified into three different categories: (1) non-AMD acidified streams; (2) AMD acidified streams; and (3) non-acidified streams. Streams in the non-AMD acidified category are those streams which are average net acidic but have low levels of conductivity, metals, and sulfates, indicating a non-AMD acidity source. Streams in the AMD acidified category are those streams which are average net acidic with high levels of conductivity, metals, and/or sulfates, indicating an AMD acidity source. Streams in the non-acidified category are those that are not contained in the other two categories. These streams are generally net alkaline with low levels of metals and sulfates.

Non-AMD Acidified Streams - Fellows Creek, McIntosh Hollow, Taylor Run

Fellows Creek is a medium sized watershed that has been minimally impacted by past mining activities. Small areas of surface mining, one unreclaimed, are located in the middle and lower reaches of the stream. However, field investigation of the watershed found no water quality impacts to Fellows Creek from mining. Despite the absence of mine drainage impacts, Fellows Creek is a chronically acidified stream year-round and does not support a healthy macroinvertebrate or fish community (Moase and others, 1999). The acidity in the Fellows Creek Watershed is attributable to two sources: tannic acid and acid deposition. Large portions of the Fellows Creek Watershed are plateau wetlands with beaver activity. Beaver dams impound the water in Fellows Creek, creating large wetland areas. Decaying organic materials in these wetlands break down into organic acids causing a lowering of pH and an increase in total organic carbon (TOC), giving the water a reddish-orange hue. Past studies have noted that the upper Tioga River and its tributaries are naturally low pH, low conductivity, and high TOC streams, sometimes with a deep orange color, especially during times of low flow (Hughey, 1993; Moase and others, 1999). This condition was observed during the summer of 2002 when Fellows Creek appeared visually to be impacted by AMD due to its color but did not show the chemical characteristics of AMD. USEPA documented that rain in Pennsylvania can have a pH of as low as 4.3 due to acidification from atmospheric pollution originating from anthropogenic sources (power-plants, automobile exhaust, etc.) (U.S. Environmental Protection Agency, 1999). Rains with these low pH levels falling on soils that contain very little buffering capacity create acidic groundwater recharge to streams and cause stream pH levels to become chronically acidified (U.S. Environmental Protection Agency, 1999; Sharpe and Drohan, 1999). The acid inputs from these two sources are enough to create and maintain a chronically acidified condition in the Fellows Creek Watershed. Remediation activities directed at increasing stream pH levels would be necessary for Fellows Creek to establish and maintain a healthy aquatic community.

McIntosh Hollow and the unnamed tributary to Taylor Run (UNT4.0), although much smaller streams, are very similar in chemical characteristics to Fellows Creek. Similar remediation techniques would be necessary for a healthy aquatic community to exist in these streams. However, due to their size and the extremely high gradient of the unnamed tributary to Taylor Run, it is unlikely that they would support a fish community even with remediation.

AMD Impacted Streams - Fall Brook, Morris Run, Coal Creek, Bear Creek, Johnson Creek

Fall Brook

Fall Brook (Figure 7), an 8.9-square-mile watershed, is largely forested but was intensively deep and surface mined in its lower two-thirds, with small areas of residential development in the upper one-third. There are multiple major sources of AMD in the watershed, with a few additional minor sources. These discharges cause severe to very severe impacts from monitoring station FALL2.5 to the mouth. Above FALL2.5, there are no AMD impacts; however, the upper portions of Fall Brook are impacted by tannic acids and acid deposition. Due to this combination of impacts, Fall Brook is net acidic along its entire length and supports no fish (while the upper portions above FALL2.5 may be able to support acid-tolerant macroinvertebrate communities) (Moase and others, 1999).

Deep mining was conducted in the Fall Brook Watershed from 1859 to the early 1900s, with an estimated 4.95 million tons of coal removed from the watershed by 1904 (Swinsick, 1994). The town of Fall Brook, which exists as a few seasonal camps today, once supported a population of 2,300 (Swinsick, 1994). Mine drainage emerges from six sources in the watershed, all draining deep mine workings located below FALL2.5. In addition, contaminated stream recharge from impacted groundwater sources adds additional small amounts of AMD to Fall Brook in its lower reaches (DFB900-903). In addition to deep mining, surface mining was conducted extensively throughout the watershed. This surface mining sometimes cut into the abandoned deep mine workings below, causing them to form a hydraulic connection, increasing infiltration and thus the volume of AMD produced. If the surface mining did not directly connect the deep and surface mine workings, it significantly increased the rate of infiltration of precipitation into groundwater and, subsequently, into deep mine workings. All of the surface mined areas in the watershed have been at least minimally reclaimed (pits filled in, surfaces regraded, and vegetation planted). One surface mined area discharges AMD to Fall Brook during periods when the groundwater table is elevated; however, this discharge was only sampled once during the course of this study due to the absence of water and is considered a very minor source of AMD (sampled at monitoring station UNT2.0). Between FALL2 and FALL1, Fall Brook receives input from the largest and most severe discharge in the subwatershed, DFB099, which likely drains from or close to the abandoned Fall Brook Drift #1.

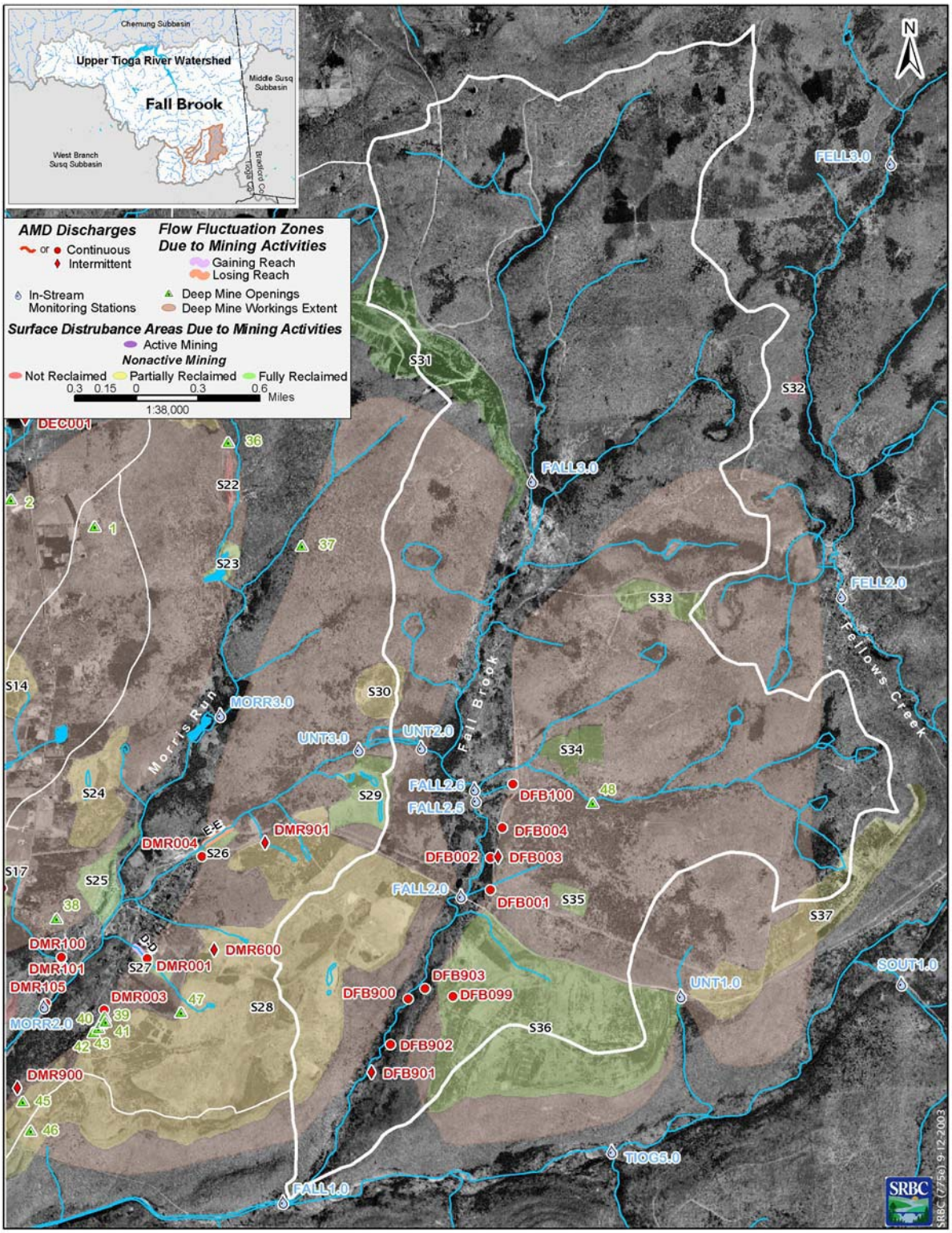

Figure 7. Mining Problem Area Features in the Fall Brook Watershed

Morris Run

Morris Run (Figure 8), a 7-square-mile watershed, is largely forested in its headwaters, with residential development in the village of Morris Run in its lower reaches. There are multiple major sources of AMD in the watershed, with additional minor sources also identified. Above MORR3 (above the Morris Run Reservoir), AMD impacts are not present; however, the upper portions of Morris Run are impacted by acid deposition and possibly tannic acid which causes them to be chronically acidified. USACE documented in the early 1970s that Morris Run above the reservoir lost significant amounts of its flow into underground mine workings through an unreclaimed surface mine, which was subsequently discharged as AMD at DCC005 (U.S. Army Corps of Engineers, 1972). Reclamation done in 1975 reclaimed the surface mine and restored the stream channel, resulting in a 15 percent reduction in flow and 10 percent reduction in acid loads at DCC005 (Miorin and others, 1979). During periods of low flow, Morris Run above the confluence with the DMR004 unnamed tributary is sometimes dry. Due to the combination of acidic impacts, Morris Run is net acidic along its entire length, often dry above the influence of large mine discharges in its lower reaches, and supports no fish (Moase and others, 1999), while Morris Run above MORR3 may be able to support acid-tolerant macroinvertebrate communities.

Deep mining was conducted in the Morris Run Watershed from 1853 to 1962, with an estimated 25 million tons of coal removed by 1931 (Wellsboro Gazette, 1932). Many entrances into the deep mines were located along both the eastern and western hillsides around the village of Morris Run. Due to the geological dip and the configuration of the deep mine workings, precipitation falling on sections of the western Morris Run Watershed contributes to mine drainage in the Coal Creek Watershed through DCC005. Between the Morris Run Reservoir and the SR2024 bridge, Morris Run receives drainage from three major deep mine discharges: the Lake Mine Discharge (DMR004), the East Mine Discharge (DMR001) and the Tioga Mine Discharge (DMR003). The Lake Mine Discharge drains the Lake Mine deep mine complex which underlies the watershed from eastern Morris Run to western Fall Brook. It is located behind the pallet factory in the village of Morris Run and is the largest volume discharge in the Morris Run Watershed. The unnamed tributary to Morris Run that runs parallel to the boundary of the reclaimed area near the Lake Mine loses flow as it travels the length of the reclaimed area (stream flow fluctuation zone E-E). It is assumed that this water contributes to the AMD volume at DMR004. The East Mine Discharge drains the East Mine deep mine complex underlying portions of the Morris Run and Fall Brook Watersheds. Historical reports document two mine openings and a refuse dump present in the area behind Saint Joseph's Catholic Church (U.S. Army Corps of Engineers, 1972; Gannett Fleming Corddry & Carpenter, Inc, 1968; U.S. Environmental Protection Agency, 1979). The discharge presently originates from a pipe in the reclaimed area (completed in 1990) behind the church. Downstream of the piped outlet, the discharge channel is lined with rip-rap. Flow volumes increase from the pipe opening to the end of the reclaimed area (stream flow fluctuation zone D-D). The increase in volume is most likely caused by fractures in the stream bottom allowing flow from the second mine opening that was in the area prior to reclamation to be added to the stream. This flow fluctuation zone was not discovered until late in the study, so the water quality data collected characterize only the discharge from the piped opening. The Tioga Mine Discharge drains the Tioga Mine deep mine complex underlying portions of the Morris Run and Fall Brook Watersheds. It originates from the bottom of a refuse pile below a series of mine openings at the end of Tioga Street in the village of Morris Run. Morris Run also receives drainage from some other minor

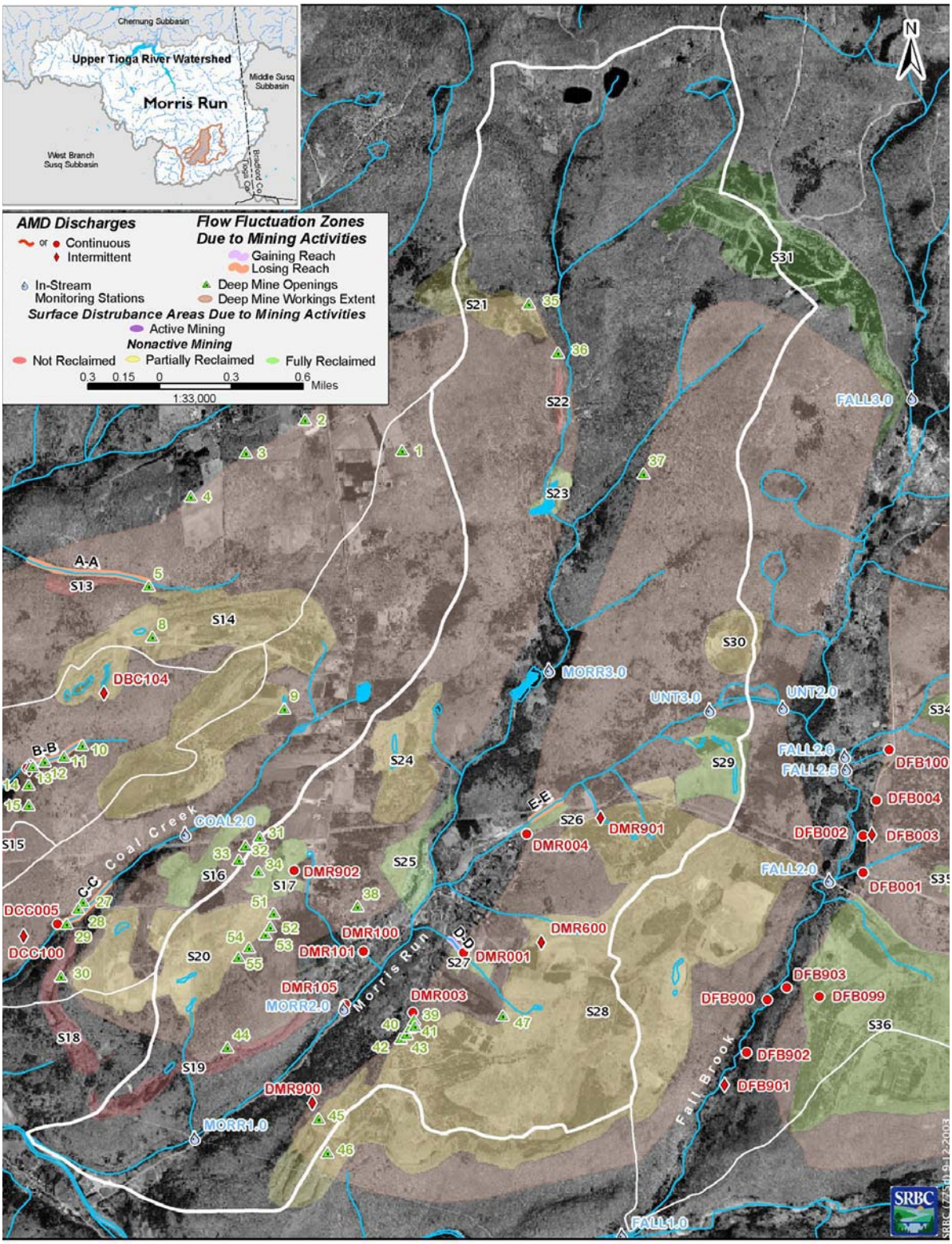

Figure 8. Mining Problem Area Features in the Morris Run Watershed

discharges in this segment, mostly along its western hillsides. Under low flow conditions, Morris Run is made up entirely of mine discharge water downstream of the confluence with the DMR004 unnamed tributary.

In addition to deep mining, surface mining was conducted extensively throughout the watershed. This surface mining sometimes formed a hydraulic connection to the abandoned deep mine workings below, increasing infiltration and thus the volume of AMD produced. If the surface mining did not directly connect the deep and surface mine workings, it significantly increased the rate of infiltration of precipitation into groundwater and subsequently into deep mine workings. Most of the surface mined areas in the watershed have been at least minimally reclaimed (pits filled in, surfaces regraded); however, many are still in need of more complete reclamation, including vegetation establishment. Two surface mined areas discharge AMD to Morris Run during periods when the groundwater table is elevated; however, these discharges were only sampled once during the course of this study due to the absence of flow and are insignificant sources of AMD (sampled at monitoring stations UNT 3.0 and DMR600).

Many projects have been conducted in the Morris Run Watershed to reclaim abandoned surface mined areas. Extensive surface reclamation of 27 acres was conducted to seal an existing mine opening, stabilize stream banks, and grade, shape, and vegetate an abandoned area near the Lake Mine entry (DMR004). Reclamation was completed by the Rural Abandoned Mine Program (RAMP) through the U.S. Department of Agriculture in 1982 at a cost of $138,000. Extensive surface reclamation of 21 acres was conducted to seal an existing mine opening, install subsurface drainage to create one discharge area, remove a refuse area, and grade, shape, and vegetate an abandoned area near the East Mine entry (referred to by USDA as the Church Site) (DMR001). Reclamation was completed by the RAMP program in 1990 at a cost of $133,000. Extensive surface mine reclamation of 40 acres was conducted to remove the Morris Run Coal Company tipple and remaining buildings, stabilize stream banks, and grade, shape, and vegetate a site in the middle of the village of Morris Run (referred to by USDA as the Jones Foundation Site). Reclamation was completed by the RAMP program in 1981 at a cost of $332,000. Surface mine reclamation of 7 acres was conducted to stabilize grades with structural timber cribbing and rock fill, stabilize stream banks, install subsurface drainage, and grade, shape, and vegetate another site in the middle of the village of Morris Run. Refuse banks at this site had previously burned and pieces of "red dog" (burnt refuse materials) the size of large cars were eroding from the site into Morris Run. Reclamation was completed by the RAMP program in 1981 at a cost of $192,000. In addition to the RAMP reclamation, additional pre-Act surface mined areas in the watershed were reclaimed by the Jones & Brague Mining Company.

Coal Creek

Coal Creek (Figure 9), a 1.6-square-mile subwatershed, is largely disturbed due to past mining activities. Much of the upper half of the watershed has been extensively surface and deep mined. Although most of the surface mines have been reclaimed, areas of pre-Act surface mining still exist. Almost the entire Coal Creek Watershed has been undermined, including portions of Coal Creek itself, allowing infiltration of stream water into underlying mine workings, contributing to AMD. Coal Creek above COAL2 represents the watershed area upstream of the Mohawk Lane crossing. Water quality data at this point show Coal Creek to be

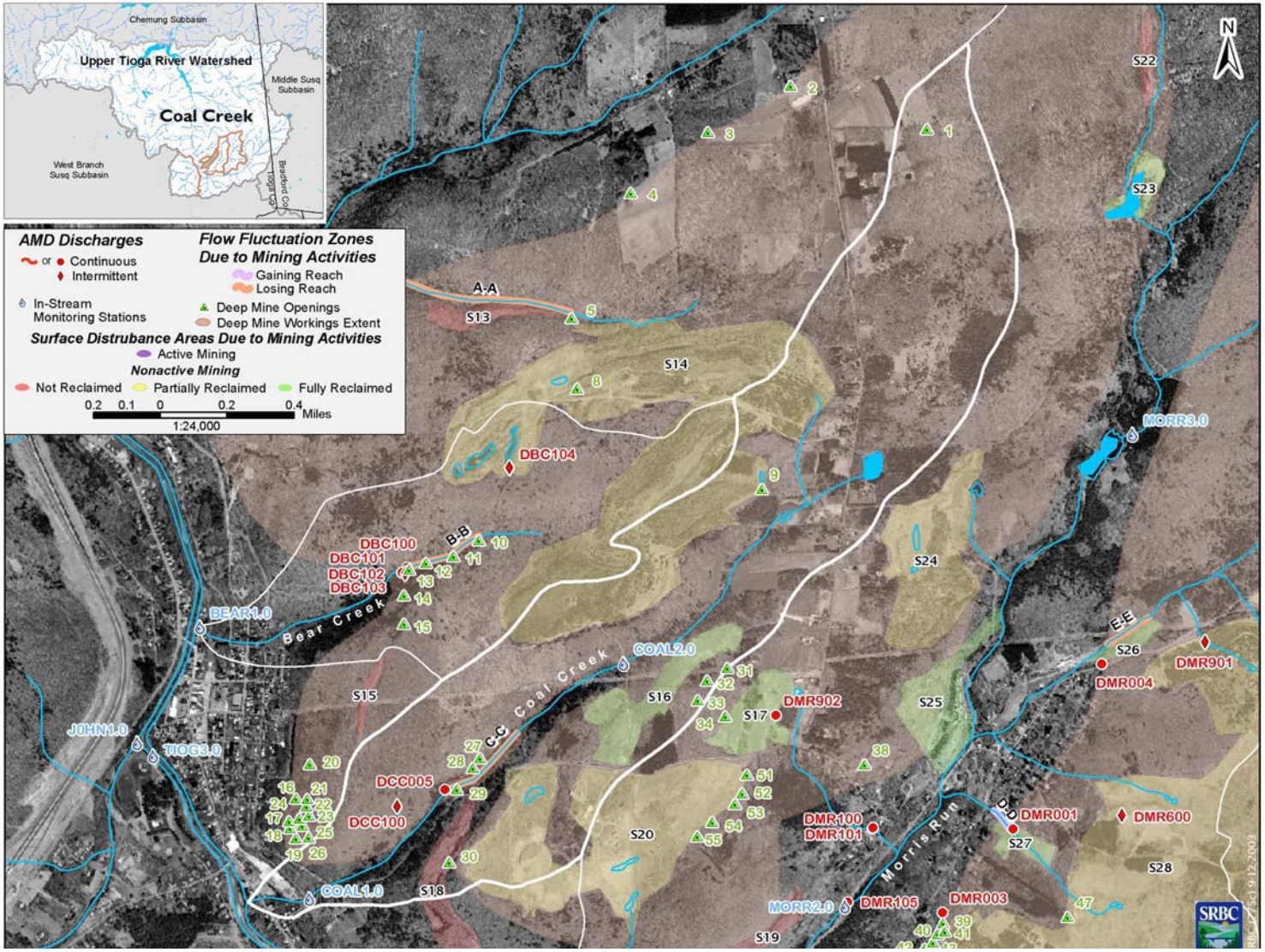

Figure 9. Mining Problem Area Features in the Coal Creek Watershed

minimally impacted by AMD. Approximately one-half mile downstream, DCC005 drains into Coal Creek. DCC005 is the largest volume discharge in the Tioga River Watershed and has the most degraded water quality; it is responsible for an average 45 percent of the total acidity load to the Tioga River (Rightnour and Hoover, 2003). It drains from an opening at the end of a railroad spur into a deep, steeply-sided ravine. According to historical reports, the underground watershed created by the deep mine workings for this discharge is almost twice the area of the topographical watershed, and extends significantly into the neighboring Morris Run Watershed (U.S. Army Corps of Engineers, 1972). Between points COAL2 and DCC005, Coal Creek loses most of its flow into underlying mine workings through fractures in the streambed and often is dry (stream flow fluctuation zone C-C). Much of the flow lost in this segment is assumed to re-emerge as AMD at DCC005. Below DCC005, Coal Creek receives drainage from one other small deep mine discharge (DCC100).

In addition to deep mining, surface mining was conducted extensively throughout the watershed. This surface mining sometimes cut into the abandoned deep mine workings below, increasing infiltration and thus the volume of AMD produced. If the surface mining did not directly connect the deep mine and surface mine workings, it significantly increased the rate of infiltration of precipitation into groundwater and, subsequently, into deep mine workings where it becomes AMD. A large portion of the surface mined areas in the watershed have been at least minimally reclaimed (pits filled in, surfaces regraded and vegetation planted).

Coal Creek is severely impaired below DCC005 by AMD and supports no fish or macroinvertebrate life (Moase and others, 1999; Hughey, 1993). Coal Creek above COAL2.0 is vulnerable to the affects of acid deposition and episodic acidification, likely able to support no fish and only acid-tolerant macroinvertebrates.

Johnson Creek

Johnson Creek (Figure 10), a 17-square-mile watershed, is largely forested with the town of Arnot in its headwaters. There is one major source of AMD in the watershed, with multiple minor sources also identified. Above JOHN3 (upstream of the town of Arnot), AMD impacts are minimal, although the landscape has been significantly altered by past mining activities. The Johnson Creek Watershed and the neighboring Babb Creek Watershed are almost connected through wetlands in their headwaters. In addition, two deep mine complexes (Arnot #1 and #2) straddle the watershed boundaries and each has discharges into both watersheds. The wetland substrates in this area are composed largely of coal fines and refuse material. Three mine discharges drain into Johnson Creek in this area. One drains from the north and drains portions of the Arnot #2 Mine (DJC904); two drain from the south and drain portions of the Arnot #1 Mine (Boyer Kantz & Associates, 1976). One of the southern discharges is used by the Arnot Sportsman's Club to feed a co-operative trout nursery and is also used as a public water supply for the village of Arnot; the second southern discharge was not identified during this study. Both discharges contribute minimally to AMD impacts in the Johnson Creek Watershed and need no remediation; therefore, they are not addressed further. The second largest volume discharge in the Tioga River Watershed, the #5 discharge, makes up the entire flow of the unnamed tributary to Johnson Creek measured at UNT7.0; however, it has relatively mild chemical characteristics.

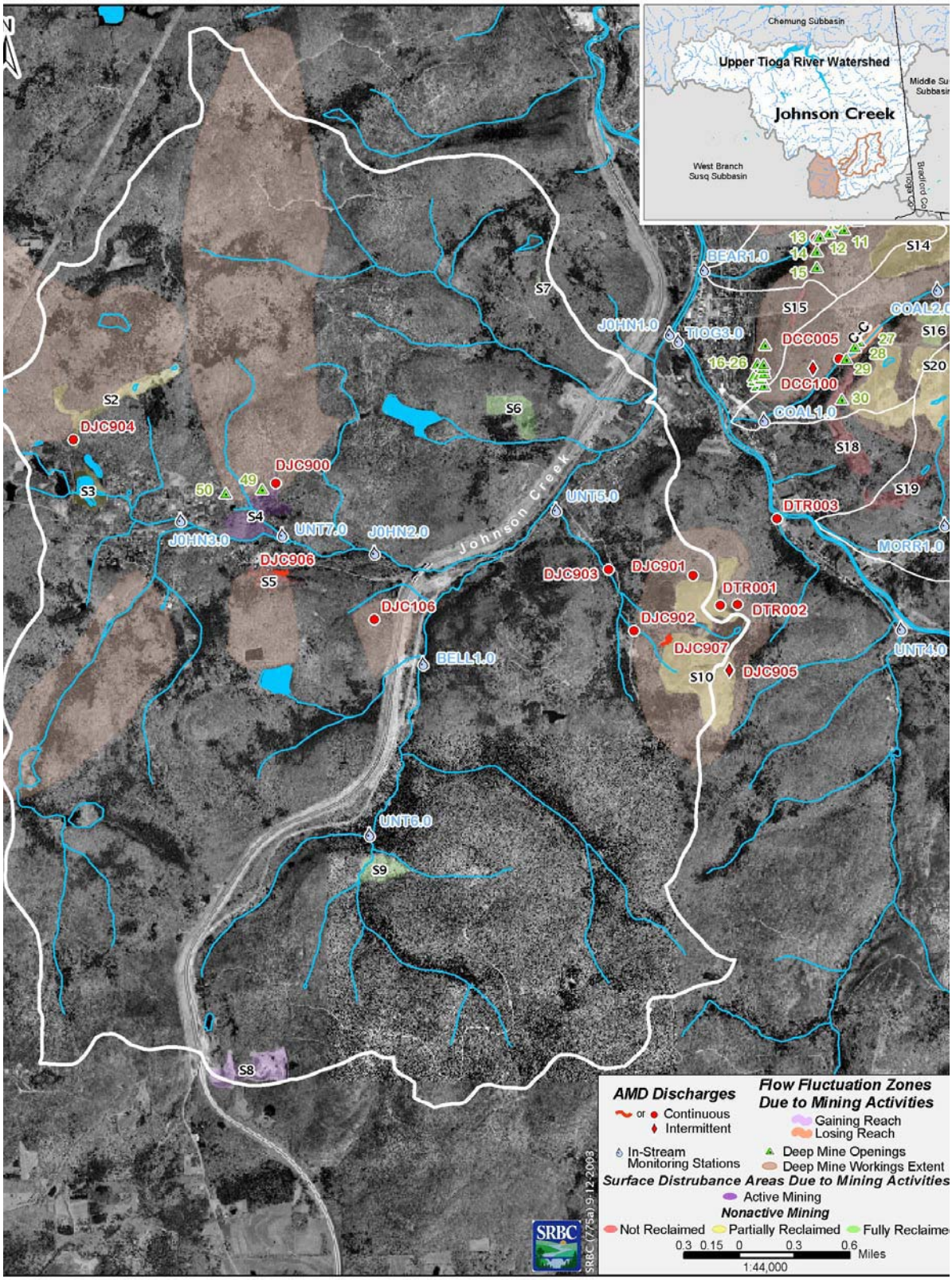

Figure 10. Mining Problem Area Features in the Johnson Creek Watershed

Additional discharges drain into Johnson Creek from: (1) a large abandoned refuse pile on state forest land just outside the village of Arnot, and (2) the Flower Run deep mine, a low flow but very low pH discharge that currently drains into a small wetland built by the Pennsylvania Department of Transportation (PennDOT) along the new Route 15 overpass. The last source of AMD to Johnson Creek is the South Mountain unnamed tributary, measured at monitoring station UNT5.0. South Mountain was both deep and surface mined, most recently surface mined by John Percival (Pa. DEP Mining Permit #4772SM7). However, after mining was completed on the permitted area, reclamation was not completed and bonds were eventually forfeited, leaving the area as a liability to the Commonwealth. Approximately half of the disturbed areas on the mountain have had surface reclamation completed; however, the other areas are not reclaimed. This includes large areas of acid-producing overburden material with no vegetation, an open dry pit with a dangerous highwall, and hazardous water-filled pits. In addition, along the edges of the surface mined area are toe-of-spoil discharges of mine drainage; the aggregated drainage from these sources are characterized at monitoring stations DJC902 and DJC903. The monitoring station DTR003 characterizes an additional small amount of drainage from South Mountain to the east (flows into the Tioga River). Johnson Creek is weakly net acidic along its entire length, but supports a small brook trout fishery (Moase and others, 1999).

Several reclamation projects have been completed in the Johnson Creek Watershed. The Arnot Sportsman's Club, in cooperation with the Babb Creek Watershed Association, have recently completed construction of a passive system to treat discharge from the #2 mine that flows into the Babb Creek Watershed (Zug, 2001); they are also designing a treatment system to treat discharge water from the #2 mine flowing into the Tioga River Watershed (shown as DJC904). One remining operation is active in the Johnson Creek Watershed. The Berguson Operation (Pa. DEP Mining Permit #6662-59-01-01) is a remining permit to remove 5 acres of refuse piles that are the waste from two abandoned deep mines (#4 and #5) located north of the piles. The last mining on this area was in 1924 by the Blossburg Mining Company. Surface reclamation at the #4 mine site was conducted by the RAMP program (Hensel project); the #5 mine currently is the second largest volume discharge of AMD in the Tioga River Watershed (measured at monitoring station DJC900). Reclamation of this site through remining, which would cost the Commonwealth $25,000 to complete itself, will reduce sedimentation to Johnson Creek and will remove the refuse pile; an unsightly landscape feature easily viewed from Arnot, but will not treat the discharging water. Another RAMP project was completed to remove a surface water supply reservoir on Saw Mill Creek that was hazardous and leaking water into underlying deep mine workings. The reservoir was originally built in the early 1900s by the Blossburg Coal Company, and included an earthen and timber dam; deterioration of the structure made it hazardous to the downstream community of Arnot. Currently, the town of Arnot uses one of the discharges from the #1 mine (South Drift Spring) as a potable water supply for 128 customers.

Bear Creek

The Bear Creek Watershed (Figure 11), a 0.7-square-mile watershed, is impacted by abandoned deep mine discharges in its mid-reaches. Mining in the Upper Tioga River Watershed was started in this subwatershed. At least five discharges impact the watershed, all occurring within a very small area. The largest in volume is an artesian discharge that emerges in the stream bottom (DBC100). Multiple collapsed drift entries, some with a discharge

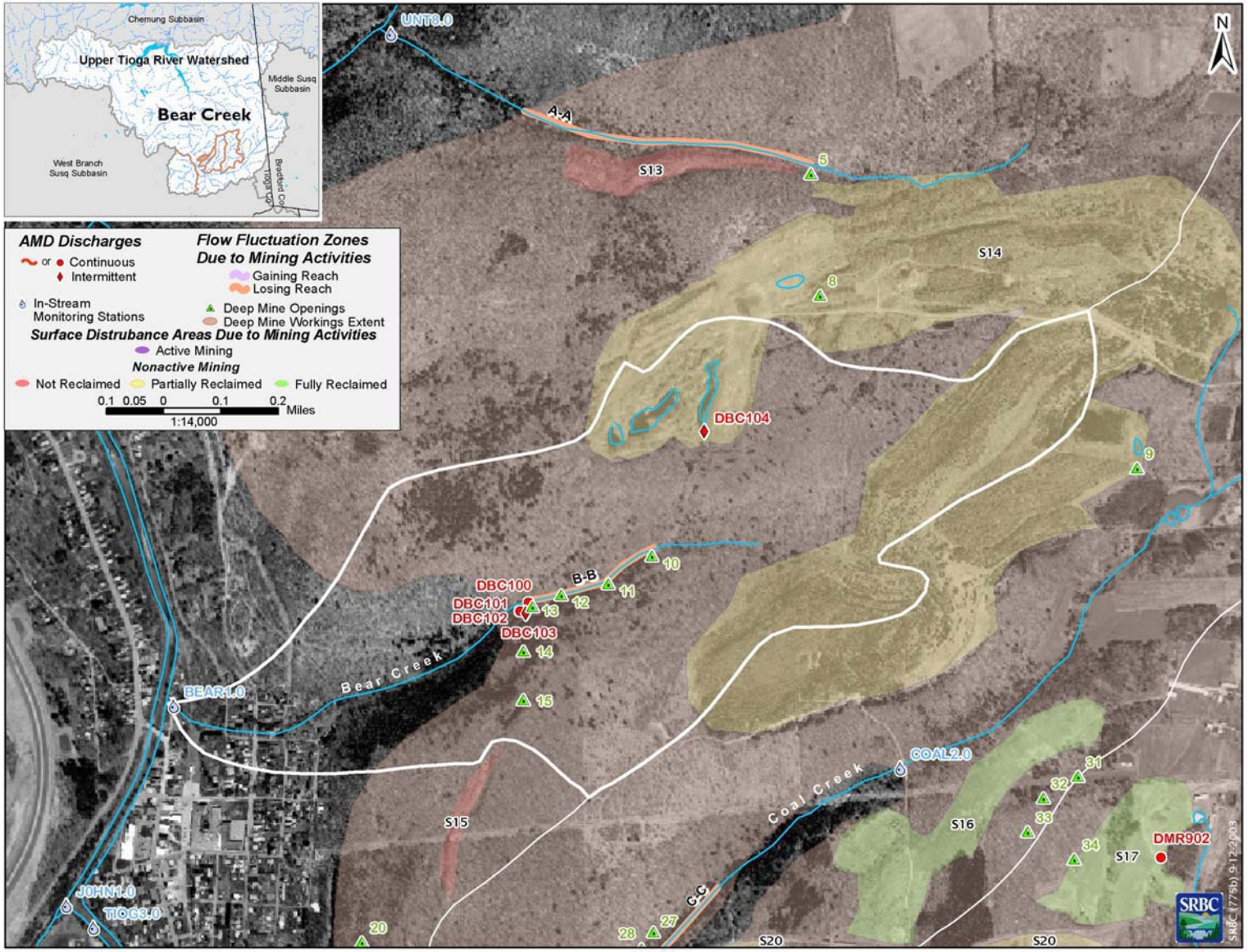

Figure 11. Mining Problem Area Features in the Bear Creek Watershed

(DBC102-103), line the steeply-sided valley. Upstream of DBC100, Bear Creek is dry due to infiltration of stream flow into underlying deep mine workings (stream flow fluctuation zone B-B). In the headwaters of the stream, above the fractured zone, water flows in the channel. In this reach (above the fractured zone), Bear Creek receives AMD from the surface overflow of a water-filled pit (DBC104) on a large, abandoned surface mine on the hilltop between the Bear Creek and East Creek Watersheds. In total, four unreclaimed pits are located on the surface mine, only one of which has a surface discharge (DBC104). Reclamation of this surface mine would likely have significant impact on the water quality of Bear Creek as a large portion of the water in the pits infiltrates into underlying deep mine workings and likely emerges as AMD in Bear Creek. In addition, the rolling topography of this area attracts ATV and other off-road vehicles and is used heavily as a recreational area. Large drops from refuse piles into water-filled pits and abrupt cliffs pose significant threats to public health and safety.

Non-Acidified Streams - Rathbone Creek, South Creek, Elk Run, Corey Creek, Lambs Creek, Canoe Camp Creek, Ellen Run, Marvin Creek, Crooked Creek, Mill Creek

Rathbone Creek (RATH1.0) and South Creek (SOUT1.0) are small streams located in the headwaters of the Tioga River Watershed that drain into the river from the southeast. They are clean streams with circumneutral pH, net alkalinity, and low levels of metals, conductivity, and sulfates. They are not impacted by AMD, tannic acids, or acid deposition. Surveys conducted by the PFBC in 1999 documented Class A wild brook trout fisheries in these watersheds and recommended that their designated use be upgraded from cold water fishes (CWF) to high quality-cold water fishes (HQ-CWF) to protect the fishery resources (Moase and others, 1999).

Marvin Creek (MARV1.0), Elk Run (ELKR1.0), Canoe Camp Creek (CANO1.0), Corey Creek (CORY1.), Ellen Run (ELLN1.0), Lambs Creek (LAMB1.0), and Mill Creek (MILL1.0) are streams of varying sizes that drain into the Tioga River between Bear Creek and Tioga Lake (Table 8). Most of the streams drain watersheds that are a mosaic of agricultural, forested, and residential lands; no abandoned mine lands are present in any of the watersheds. These streams maintained a net alkaline load and low levels of metals and sulfates through all seasons during the sampling period of the study. None of them are impacted by AMD, tannic acids, or acid deposition; however, some of them may be impacted by agricultural activities.

Table 8. Net Alkalinity Contribution from Monitored Tributaries to the Tioga River Mainstem Downstream of Blossburg

Stream Name	Average Net Alkaline Load, pounds per day	Net Alkalinity Range, pounds per day	Net Alkalinity Rank
Mill Creek	11,810	1,006-23,694	1
Crooked Creek	11,421	1,851-23,676	2
Elk Run	3,280	52-5,833	3
Corey Creek	2,510	27-5,880	4
Canoe Camp Creek	1,481	706-2,814	5
Lambs Creek	880	143-1,551	6
Marvin Creek	486	79-817	7
Ellen Run	288	41-661	8

Crooked Creek[8] is a large stream located in the lower Tioga River Watershed. Crooked Creek is impounded in the Hammond Lake portion of the Tioga/Hammond Complex. It is an agricultural and forested watershed, with some residential development. It is a net alkaline stream with circumneutral pH (6.83), net alkalinity, and low levels of metals, conductivity, and sulfates. It is not impacted by AMD, tannic acids, or acid deposition; however, higher levels of nutrients from agricultural sources in the watershed are suspected of causing nuisance algal blooms in Hammond Lake (U.S. Army Corps of Engineers, 2002). Alkaline water from Hammond Lake is drawn through a connecting channel to Tioga Lake and is mixed with the Tioga Lake water to improve water quality leaving the complex. The mixed, circumneutral pH water is released from the complex as the Tioga River.

Tioga River conditions

The Tioga River begins as a small stream on Armenia Mountain in Bradford County. Chemically, it possesses a near-neutral pH and net alkalinity when sampled near its origin at TIOG8 (Figure 12). From TIOG8 to TIOG6, the river receives drainage from many tributaries from both the north and the south. The tributaries from the south possess net alkalinity and near neutral pH levels; however, the tributaries from the north drain areas with headwater wetlands and possess net acidity and low natural pH. These tributaries, such as McIntosh Hollow and Fellows Creek, begin to erode at the small amount of net alkalinity the river possesses. This section of the Tioga River is stocked by the PFBC with brown trout. All sources of acidity upstream of TIOG5 are due to organic acids and atmospheric deposition.

The Tioga River begins to show adverse conditions from AMD acidity downstream of its confluence with Fall Brook. The Tioga River between points TIOG5 and TIOG4 changes drastically in its chemical composition due to AMD impacts in Fall Brook, including decreases in pH and increases in acidity, conductivity, sulfates, and metals. Sites in the watershed impacted by AMD are ranked according to concentration for each metal in Tables 9-11. Fall Brook at its confluence with the Tioga River is impaired by AMD and causes the Tioga River downstream of their confluence to be impaired as well. The bottom substrate in Fall Brook at its mouth is stained orange from iron hydroxide precipitates. When Fall Brook water mixes with the higher pH water of the Tioga River, it causes aluminum to precipitate, giving the Tioga River a white color downstream from Fall Brook to the confluence with Morris Run below point TIOG4. Point TIOG4 represents the Tioga River approximately one half mile upstream of the confluence with Morris Run, the next downstream AMD-impacted tributary. The Tioga River between TIOG4 and TIOG3 receives drainage from the Morris Run and Coal Creek Watersheds. These two watersheds are the most severely impacted tributaries to the Tioga River, containing most of the top five major AMD discharges in the Tioga River Watershed. This segment of the Tioga River travels through the town of Blossburg. The river is straightened and leveed for flood control and is usually a bright orange color from the mine drainage in the Morris Run and Coal Creek Watersheds. Point TIOG3 represents the Tioga River upstream of the confluence with Johnson Creek, a moderately impacted subwatershed. The Tioga River between TIOG3

[8] Loads at the mouth of Crooked Creek (CROO1.0) include contributions of upstream alkaline tributaries including Hills Creek (HILL1.0), Norris Creek (NORR1.0), and Catlin Hollow (CATL1.0).

and TIOG2 receives drainage from the Bear Creek and Johnson Creek Watersheds. Bear Creek is the most downstream source of AMD to the Tioga River.

After Bear Creek, the Tioga River flows out of the Blossburg area and into the agricultural section of the watershed; the river enters another physiographic province at this point, causing a significant difference between the upper and lower sections of the watershed. The Tioga River begins to receive inputs of alkaline water without AMD constituents, beginning the process of AMD neutralization that continues downstream and in Tioga Lake. TIOG2 represents the Tioga River downstream of the confluence with Bear Creek. The Tioga River between TIOG2 and TIOG1 is a long segment that stretches from below Blossburg to below Mansfield where the Tioga Lake begins to pool. Sampling using wadeable techniques is not feasible in this area. Many tributaries, some large and most of which flow through largely agricultural lands, drain into the river in this reach. TIOG1 represents the Tioga River below Mansfield where Tioga Lake begins, effectively the end of the flowing segment upstream of the complex. Precipitating metals (iron and aluminum hydroxides) can be observed in this segment that functions as the recovery zone for the upstream AMD impacts.

Table 9. Rank of Monitoring Stations Exceeding Pa. DEP Water Quality Criterion for Total Iron

Site Name	Average Total Iron Concentration, mg/l	Severity Rank
COAL1*	34.32	1
BEAR1*	6.54	2
MORR2	5.07	3
MORR1*	4.19	4

*Sites are at the mouths of tributaries that drain into the Tioga River

Table 10. Rank of Monitoring Stations Exceeding Pa. DEP Water Quality Criterion for Total Manganese

Site Name	Average Total Manganese Concentration, mg/l	Severity Rank
MORR2	17.45	1
MORR1*	16.95	2
UNT5	9.05	3
COAL1*	7.61	4
BEAR1*	6.62	5
FALL1*	6.15	6
UNT3	5.83	7
UNT2	4.64	8
TIOG3	3.96	9
TIOG2	2.56	10
TIOG1	2.02	11
FALL2	1.91	12
FALL2.6	1.57	13
FALL2.5	1.46	14
TIOG4	1.03	15

*Sites are at the mouths of tributaries that drain into the Tioga River

Table 11. Rank of Monitoring Stations Exceeding Pa. DEP Water Quality Criterion for Total Aluminum

Site Name	Average Total Aluminum Concentration, mg/l	Severity Rank
COAL1*	27.38	1
MORR2	15.85	2
BEAR1*	15.63	3
MORR1*	15.50	4
UNT5	10.22	5
TIOG3	5.75	6
FALL1*	4.36	7
UNT3	3.95	8
TIOG2	3.75	9
TIOG1	2.87	10
UNT2	2.54	11
FALL2	0.99	12
FALL3	0.98	13

*Sites are at the mouths of tributaries draining into the Tioga River

COMPARISON TO HISTORICAL ACCOUNTS

The most pronounced change in the Tioga River Watershed in comparison to historical accounts is in the reclamation of surface mined areas. Previous to this project, the most comprehensive assessment was completed by Gannett Fleming Corddry & Carpenter in 1968 for the Federal Water Pollution Control Administration. At that time, 41 surface mines were identified, 39 of which were abandoned and five of which had intermittent discharges of AMD to surface streams. Active surface mining was producing 300,000 tons of coal per year. However, surface mining ended in 1990 when the remaining mining company, Jones and Brague Coal Company, finished reclaiming its active surface mines, as well as some pre-Act surface mines. Since that time, no new surface mining has been conducted and further mining, with the exception of remining, is not anticipated in the watershed in the future. Thirty-seven areas of surface disturbance were identified in this study, including 18 new surface disturbance features not identified in the 1968 study. This increase was largely due to the expansion of the study area to include the entire Upper Tioga River Watershed, not just the Morris Run/Coal Creek/Bear Creek area. These areas not only included abandoned and reclaimed surface mines, but also problem refuse piles and a gravel mining operation. Many of the areas of surface disturbance are classified as partly reclaimed; these areas are still in need of some type of surface reclamation on at least part of their area. For this reason, a net gain/loss of square miles was not computed for disturbed surface areas between this study and historical reports.

Seventy-two deep mine entries were identified in the 1968 study; however, one of them was not identified on a map, so it was not included in the historical total. Many of these deep mine entries were visible in highwalls of abandoned surface mines, creating direct access for water accumulating in the pits to abandoned deep mine workings. Twenty-two of the openings identified in 1968 were no longer present during this study. The loss of these openings is due to reclamation of abandoned surface mines where openings were visible in the highwall. However, because of the larger scope of this project compared to the 1968 study, six additional mine openings were identified in this study that were not previously documented. Fifty-five deep mine entries were identified in this study, resulting in a net loss of 16 mine openings.