Sixteen major mine drainage discharges were identified in the 1968 study, six of which were from surface mine or refuse dump sources and 10 of which were from deep mines. Four of the mine discharges were associated with surface mines that have been reclaimed and no longer exist; one was associated with a refuse dump area that has been reclaimed and no longer exists; one discharge exists only as a deep mine opening but no longer discharges any water. An additional two discharges were confirmed that had significantly less impact than in 1968, being identified as intermittent discharges; eight discharges from 1968 were confirmed that are considered major discharges in this study. In addition to confirming the 16 previously identified discharges, 26 additional discharges were identified that were not previously documented. This net gain resulted in a total of 36 mine drainage discharges being identified in this study.

Four of five areas of stream infiltration identified in 1968 were confirmed in this study. One area of stream infiltration identified in 1968 was restored in 1975 through an extensive reclamation project that reclaimed an abandoned surface mine in the headwaters of Morris Run (Miorin and others, 1979). One additional zone of stream flow fluctuation was identified and delineated during this study resulting in a net total of five stream flow fluctuation zones identified in the Upper Tioga River Watershed.

THE WATERSHED RESTORATION PLAN[9]

Gannet Fleming, Inc. was contracted by SRBC to prepare a conceptual AMD restoration plan for the Upper Tioga River Watershed (Rightnour & Hoover, 2003). Thirty-six AMD features were identified by SRBC in the Upper Tioga River Watershed, of which 21 had at least intermittent flow and were able to be sampled within the study period. Based on field reviews, a number of the AMD sources could be combined in common treatment systems for an economy of scale. For each treatment plan developed, conceptual passive and chemical system designs were prepared using the Tarco Technologies, Inc. Watershed Restoration Analysis Model (WRAM v1.2), which generated conceptual component sizing requirements, construction cost estimates, operation and maintenance cost estimates, 15-year present values, and construction area requirement estimates[10]. The more appropriate of the two treatment alternatives was selected based on construction area constraints, cost considerations, and ability of the technologies to meet water quality goals. Of the 10 conceptual treatment plans, four were best addressed by chemical systems and six by passive systems. Following development of the conceptual treatment plans, another component of WRAM was used to predict the downstream water quality improvements that could result from implementing these plans and to guide development of the restoration plan.

Project Benefits/Endpoint

Local stakeholders have expressed a final goal of restoring the Tioga River to a natural ecological condition, with interim water quality and ecological improvements being made to the affected tributaries and contributing to the restoration of the mainstem. While the goal of

[9] The complete restoration plan is contained in the document "Upper Tioga River Watershed: Acid Mine Drainage Conceptual Treatment and Restoration Plan" prepared by Gannett Fleming, Inc., for SRBC.

[10] All costs mentioned are the prices for supplies, labor, operation, and maintenance of systems. They do not include monetary values for benefits from the project(s).

complete ecosystem restoration may take decades to achieve through implementation of the recommendations of this study as funding and new technologies are made available, many other interim benefits would be realized with the progressive treatment of mine drainage pollution. Ecosystem restoration in the watershed would include waters containing both cold and warm water fishery communities (trout waters and nontrout waters). Benefits from the restoration of the aquatic ecosystem will be realized in both ecosystem health and integrity, and in increased recreational use of the Tioga River and its tributaries. Fishing, swimming, canoeing, and other water-based recreational activities will likely all increase with pollution remediation. Another benefit of watershed restoration is to make operations at the Tioga/Hammond Dam Complex easier and more cost efficient. As conditions in the Tioga River improve, additional benefits will be realized at the Complex through increased recreational use due to ecosystem health and integrity. Additional benefits will be realized throughout the watershed in the areas of increased aesthetics of the river corridor system, decreased structural maintenance of bridges and other man-made structures, and improvements to existing and future supplies of potable water for area communities.

Restoration Technologies

Two general categories of restoration technologies are employed when abating AMD: active treatment and passive treatment. Active treatment-treatment of the AMD with a chemical (sodium hydroxide, calcium hydroxide, calcium oxide, sodium carbonate, ammonia)-is used extensively in the regulated coal industry to treat AMD to meet federally mandated effluent criteria. However, it is labor and maintenance intensive and is thus not a favored alternative for abandoned sites. Passive treatment technologies for AMD treatment have emerged in the past 20 years as the favored technology at abandoned sites due to decreased operation and maintenance costs and responsibilities (Hedin and others, 1989). In general, passive treatment systems have been shown to have a lower unit cost than treatment at the same sites with active treatment (Ziemkiewicz and others, 2000). However, some sources of severe AMD, especially those sources with large flow volumes and high metals concentrations, are not able to be adequately treated using current passive treatment technologies. For the conceptual restoration plan, both treatment (active, passive) approaches were evaluated to determine the requirements, cost and feasibility of each. Three general types of passive treatment technologies exist and were evaluated based on their appropriateness for the chemical conditions present at each discharge: aerobic wetlands, organic substrate wetlands, and anoxic limestone drains (Hedin and others, 1989).

In addition to active and passive treatment technologies, other techniques, often termed preventative techniques, can be used in the Tioga River Watershed where feasible (Gardener in Brady and others, 1998). These include such activities such as re-mining, land capping to limit infiltration on disturbed sites, alkaline addition to abandoned surface and deep mine workings, installation of underground drains, streambed sealing or lining to prevent infiltration into mine workings, or indirect treatment, such as increasing the alkalinity of reaches upstream of AMD sources. These measures will work to reduce the amount of AMD produced and provide additional treatment that cannot be accomplished at the AMD discharge site.

Prioritization for Restoration

The 20 discharges deemed to be the most severe in the Upper Tioga River Watershed were ranked by the average of the discharge's rank for loads of iron, manganese, aluminum, and acidity (Table 12). The single worst discharge, DCC005, contributes an average 42 percent of the total acidity and 38 percent of the total sulfates to the Tioga River (Rightnour and Hoover 2003; Figure 13). Seven discharges (DCC005, DMR004, DFB099, DMR001, DJC900, DBC101, and DMR003) contribute 94 percent of the total sulfate contribution to the watershed (Rightnour and Hoover 2003; Figure 14).

The recommended sequence of restoration begins in the Fall Brook and Johnson Creek Watersheds. These watersheds were chosen first because: (1) Fall Brook is the most upstream AMD-impacted tributary in the watershed; (2) Johnson Creek has marginal water quality and small amounts of reclamation would have a large effect; and (3) Morris Run, Coal Creek, and Bear Creek all presently require active treatment systems. The Fall Brook Watershed is the most upstream AMD-impacted tributary to the Tioga River; abatement of AMD sources in the watershed will not only treat the 4th worst-ranking discharge and restore Fall Brook, but also will restore a three-mile section of the Tioga River (to the confluence with Morris Run). Although the next AMD-impacted tributary downstream would be Morris Run, Johnson Creek also was chosen as a watershed in which to begin abatement measures. Water quality data for the Johnson Creek Watershed show the mainstem to be of marginal quality; however, with the installation of treatment systems for the discharges in the watershed, especially DJC900, and the surface reclamation of South Mountain, Johnson Creek will have sufficient water quality to support a recreational fishery. Brook trout were documented in the Johnson Creek Watershed in 1999 by the PFBC (Moase and others, 1999) and populations would likely increase with the abatement of AMD pollution.

Table 12. Severity Rank Based on Pollutant Load for the 20 Most Severe Discharges in the Upper Tioga River Watershed

Discharge	Iron Load Rank	Manganese Load Rank	Aluminum Load Rank	Acidity Load Rank	Overall Rank
DFB099	9	3	4	4	4
DFB001	19	18	19	19	20
DFB002	5	10	15	14	T-10
DFB100	14	20	20	20	19
DFB003	20	16	18	18	18
DFB004	17	11	13	13	14
DMR003	10	5	6	7	6
DMR001	3	4	3	3	3
DMR004	2	1	2	2	2
DCC005	1	2	1	1	1
DBC100	6	9	7	8	8
DBC101	4	6	5	6	5
DBC102	11	13	10	10	T-10
DBC103	12	15	11	11	12
DJC106	13	19	16	15	16
DJC900	7	8	9	5	7
DJC902	8	7	8	9	9
DJC903	15	12	12	12	13
DJC904	18	17	17	16	17
DTR003	16	14	14	17	15

Table 13. Summary of Treatments and Costs to Implement Technologies to Remediate AMD Impacts in the Upper Tioga River Watershed

Implementation Stage	Recommended Treatment Type By Area	Cost Factors		Stream Improvements		Annualized Cost/Mile Improved	
		Individual	Cumulative	Individual	Cumulative	Individual	Cumulative
Stage 1 Fall Brook	Upper Fall Brook-active or passive Lower Fall Brook-active	Construction $1,300,000 Operation $170,000 15-Year PV $3,500,000	Construction $1,300,000 Operation $170,000 15-Year PV $3,500,000	Tributaries 1.84 miles Main Stem 3.06 miles Total 4.90 miles	Tributaries 1.84 miles Main Stem 3.06 miles Total 4.90 miles	Total $48,000	Tributaries $48,000 Main Stem $48,000 Total $48,000
Stage 2 Johnson Creek	DJC904-passive DJC900-passive DJC106-passive South Mountain West-passive	Construction $2,600,000 Operation $10,000 15-Year PV $2,700,000	Construction $3,900,000 Operation $180,000 15-Year PV $6,200,000	Tributaries 4.01 miles Main Stem 0 miles Total 4.01 miles	Tributaries 5.85 miles Main Stem 3.06 miles Total 8.91 miles	Total $45,000	Tributaries $46,000 Main Stem $48,000 Total $46,000
Stage 3 Morris Run & DTR003	Morris Run-active DTR003-active	Construction $2,100,000 Operation $520,000 15-Year PV $8,500,000	Construction $6,000,00 Operation $700,000 15-Year PV $15,000,000	Tributaries 1.06 miles Main Stem 0.80 miles Total 1.86 miles	Tributaries 6.91 miles Main Stem 3.86 miles Total 10.77 miles	Total $300,000	Tributaries $85,000 Main Stem $100,000 Total $93,000
Stage 4 Coal Creek & Bear Creek	Bear and Coal Creeks-active	Construction $3,300,000 Operation $1,900,000 15-Year PV $26,000,000	Construction $9,300,00 Operation $2,600,000 15-Year PV $41,000,000	Tributaries 1.48 miles Main Stem 9.27 miles Total 10.75 miles	Tributaries 8.39 miles Main Stem 13.13 miles Total 21.52 miles	Total $160,000	Tributaries $99,000 Main Stem $140,000 Total $130,000

Table 13 modified from Table 7 – Summary of Stream Restoration Gains and Costs for the Tioga River Conceptual Progressive Restoration Plan in Rightnour and Hoover, 2003

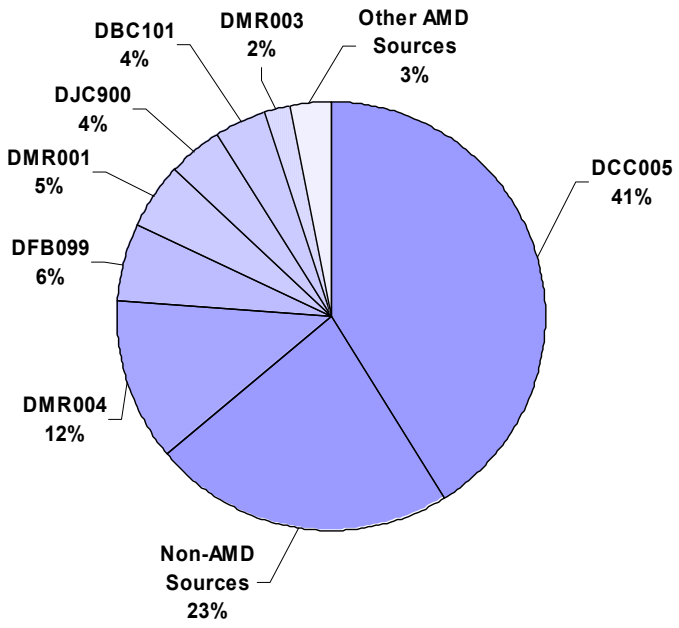

Figure 13. Acidity Contribution from AMD and Non-AMD Sources to Acid Load at TIOG2 in the Upper Tioga River Watershed

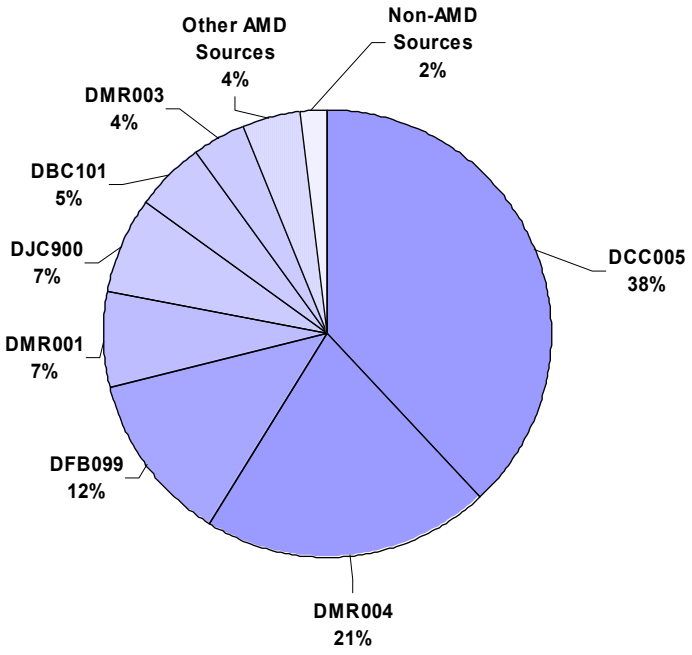

Figure 14. Sulfate Contribution from AMD and Non-AMD Sources to Sulfate Load at TIOG2 in the Upper Tioga River Watershed

Gannett Fleming determined that treatment efforts on Fall Brook and Johnson Creek would yield the greatest benefit/cost ratio, and would be the best starting points for restoration efforts (Table 13). Chemical treatment of sources along Fall Brook would produce significant water quality improvements for 1.8 miles of that tributary and 3 miles of the mainstem Tioga River, at an initial construction cost of $1.3 million, annual operating cost of $170,000, and 15-year present value of $3.5 million[11]. About 4 miles of stream in Johnson Creek, while already of relatively good quality, would benefit from passive treatment of five source areas, with a construction cost of $2.6 million, annual operating cost of $10,000, and 15-year present value of $2.7 million. Treatment costs in both tributaries would equate to about $46,000 per stream mile per year. In Morris Run, three large sources and several smaller sources would require a common chemical treatment system. The mainstem would also benefit from concurrent passive treatment of several small sources on the east side of South Mountain. These two projects would have a construction cost of about $2.1 million, annual operating cost of $520,000, and 15-year present value of $8.5 million. This work would improve 1 mile of Morris Run and an additional 0.8 miles of the mainstem, equating to about $300,000 per stream mile per year. The final two major AMD sources in Coal Creek and Bear Creek could be treated together in a large chemical system, with a construction cost of $3.3 million, annual operating cost of $1.9 million, and 15-year present value of $26 million. This would likely improve water quality downstream to the Tioga/Hammond Dam Complex, restoring 1.5 miles of the two tributaries and 9.3 miles of the mainstem at a cost of about $160,000 per stream mile per year. If fully implemented, the conceptual treatment activities would cost $9.3 million to construct, $2.6 million per year to operate, and have a 15-year present value of $41 million. This equates to about $130,000 per stream mile per year for 8.4 miles of tributaries and 13.1 miles of mainstem, or 21.5 miles of total stream improvements.

Recognition of the contribution of non-AMD acidity to the Tioga River is essential for restoration of the watershed. Almost one quarter of the acidity contribution in the watershed is due to non-AMD sources such as tannic acid and acid deposition (Rightnour and Hoover, 2003). It is critical to note that even if all AMD acidity sources were treated, the mainstem of the Tioga River and some tributaries in the headwaters of the watershed would still not be able to support viable fisheries due to limited buffering capacity to neutralize episodic acid inputs and toxic aluminum concentrations. The slightly acidic, low-metals flows in the headwaters of Fall Brook and Morris Run, and found in Fellows Creek, McIntosh Hollow, and Taylor Run, are ideal for passive treatment, which would benefit the overall restoration efforts at a comparatively low cost. Based on findings from other projects conducted by Gannett Fleming, net alkaline conditions could be restored in these streams using vertical flow wetlands and other passive technologies that may become available in the near future. Current estimates are that it would cost $560,000 to implement vertical flow wetland treatment in the headwaters of Fall Brook and $340,000 on Morris Run. Abatement of this non-AMD acidity is an integral component of the restoration of the Tioga River Watershed.

Implementation of AMD remediation technologies has already begun in the watershed. The Arnot Sportsmen's Club, in conjunction with the Babb Creek Watershed Association, is

[11] The costs presented above and in the report are specific to the construction, operation, and maintenance of the selected treatment alternatives over a 15-year projection period. There are a number of other factors that could not be predicted at this level of assessment, including property acquisition, access development, electric service, and design and permitting costs. The conceptual construction costs include a 25 percent contingency to estimate these factors, but the ultimate costs of implementing the individual treatment projects may be greater than stated.

installing a treatment system in the Johnson Creek Watershed at site DJC904. The Tioga County Concerned Citizens Committee (TCCCC), in conjunction with the Hillside Rod and Gun Club, will be submitting a proposal for funding to install passive treatment systems on discharges in the middle Fall Brook Watershed, as well as to treat non-AMD acidity in the watershed. These efforts should be encouraged and funding made available to support them.

RECOMMENDATIONS

The Upper Tioga River Watershed is severely impacted by AMD from Fall Brook to Bear Creek, impairing or eliminating aquatic life in about 13 miles of the mainstem extending downstream to the Tioga/Hammond Dam Complex. Staining from precipitating metals and high acidity also limit the river's socioeconomic value to the local community. Other tributaries in the watershed show reduced pH due to non-AMD acidity sources, including tannins from natural headwaters wetlands and acid precipitation. Although AMD production will decline over time by depletion of the acid-forming minerals, this is a very slow process, particularly for underground mines, and significant impacts could continue for centuries without some form of abatement. The most common form of abatement is direct treatment of the AMD discharges by either active (chemical) or passive (wetland) systems. Other alternatives may include re-mining or land capping to limit infiltration on disturbed sites, alkaline addition to abandoned surface and underground mine works, streambed sealing to prevent infiltration to mine pools, or indirect treatment, such as increasing the alkalinity of reaches upstream of the AMD sources. The scope of the mine drainage problem in the Upper Tioga River Watershed is large, with some extremely severe sources of AMD.

SRBC and Gannett Fleming, Inc. constructed the following recommendations for the Upper Tioga River Watershed based on data collected and conclusions made during the present study, the areas in which additional study should be conducted, current and relevant literature, and professional experience. These recommendations should be viewed as dynamic as implementation efforts proceed in the watershed and additional needs are discovered that are beyond the scope of this assessment and restoration plan.

1. Support the efforts of local stakeholder groups working on AMD abatement in the watershed. Continue to provide funding for implementation of proposed restoration activities. Encourage stakeholders to establish interim restoration goals, focusing on the concerns of the community. Coordinate restoration activities with goals in the Tioga River TMDL.
2. Implement an initial, modestly sized demonstration project. The project would be beneficial for organizing stakeholders into a working team and will provide justification for future, larger scale efforts.
3. Develop GIS coverage of surface property ownership and underground mineral rights for problem areas identified. Locate and digitize deep mine maps for the area. Use geophysical techniques, if necessary, to map extent of deep mine workings throughout the study area.
4. Prior to AMD treatment for selected discharges, determine feasibility and estimated effectiveness of implementing source reduction techniques in the watershed to reduce the volume and possibly increase the quality of AMD. These actions would include reclaiming select pre-Act surface mined areas identified as high priority areas for