Results/Discussion

AMD is composed of a complex set of elements that interact and affect aquatic life in various ways, but those overall effects are difficult to attribute to its separate, individual components (Earle and Callaghan, 1998). Toxicity is dependent upon many factors including discharge, pH, total acidity, and concentrations of dissolved metals. The overall effect of AMD is also dependent on the alkalinity or buffering capacity of the receiving streams. Unfortunately, the natural buffering capacity of Drury Run and Birch Island Run is quite low, which amplifies the impact of the AMD on the health of both streams.

In streams impacted by AMD, there are several common chemical signatures that indicate AMD pollution is present. Typically, one or more of the metals aluminum, manganese, or iron are found in concentrations far above water quality standards, pH is less than 5, alkalinity is near zero, hot acidity is greater than zero, and sulfate concentrations are greater than 20 mg/l. Some streams, like Birch Island Run, can have a naturally low pH and low alkalinity, and can sometimes be inaccurately assessed as being AMD-impacted.

Water Quality

Drury Run

The Drury Run Watershed originates out of the Tamarack Swamp in Leidy Township, Clinton County. The water quality at the outflow of Tamarack Swamp (DRUR 8.5) was typical for this type of environment, with elevated iron concentrations, a slightly acidic pH (6.1), elevated dissolved organic carbon, and little alkalinity. The acidity measured at this site was likely a product of tannic acids, not AMD, as the water was obviously colored by the presence of tannins in the upper reaches of Drury Run. As additional evidence, the AMD in the rest of the watershed was marked by high aluminum and manganese concentrations, neither of which was detected coming out of the swamp. One mile downstream on Drury Run (DRUR 7.8), water quality was slightly better as the effects of the swamp/bog are lessened. Iron was only above water quality standards during the June sampling event and pH ranged from 6.4 - 6.8.

The next downstream site showed no water quality impairment except for low buffering capacity, but it was net alkaline. Aluminum, iron, and manganese at DRUR 6.5 were below water quality standards year-round, sulfate concentrations were below 20 mg/l, and pH averaged 6.6. However, alkalinity was below the water quality standard of 20 mg/l throughout the sampling period. This was likely a natural condition in Drury Run and other similar nonimpaired streams in this region. The low buffering capacity alone in Drury Run would not be a problem if there were no AMD impairments entering the stream.

The sampling site DRUR 3.7 was directly above the confluence of Sandy Run into Drury Run. This site had the best water quality of any site in the Drury Run Watershed, even though alkalinity remained quite low. No metals exceeded water quality standards, there was no net acidity, and pH was almost neutral with an average of 6.7. Sulfate concentrations at each of the four sites above the confluence of Sandy Run were below 20 mg/l, indicating there was no impairment from AMD. This site is unique in that it is far enough below the Tamarack Swamp that any of those bog-related water quality effects are diluted out, and it is just above all AMD influences so it represents the best water quality in the watershed.

The tributary Sandy Run has one significant AMD discharge in its headwaters that degrades the conditions of Sandy Run itself and also impacts Drury Run. This discharge comes from the remnants of an abandoned deep mine (Discharge No. 5) and, although it is relatively small, does have tangible impacts on water quality and biota. Water samples were taken above and below the discharge as well as from the discharge itself. Another sample was taken at the mouth of Sandy Run to document how the discharge affects the entire tributary. Above Discharge No. 5, water quality met water quality standards for pH and metals, but had little natural buffering capacity with an alkalinity averaging 4 mg/l.

The slight acidity at Tamarack Swamp is likely a product of naturally occurring tannic acids.

Discharge No. 5 flowed year-round even under very low flow conditions in the fall. The maximum flow rate was 85 gallons per minute (gpm) in April. The water coming from Discharge No. 5 was quite polluted, with aluminum concentrations five times greater than the water quality standard, manganese concentrations seven times greater than water quality standards, and sulfate concentrations that averaged 200 mg/l over the four sampling events. Alkalinity was zero and pH was consistently around 4.0.

Although relatively small, AMD Discharge No. 5 has tangible impacts on water quality and biota.

Downstream of Discharge No. 5, Sandy Run became net acidic with zero alkalinity and pH dropped down to the 5.1 - 5.3 range. Aluminum was the only metal that remained above water quality standards downstream of the discharge but sulfate concentrations also reflected the AMD influence at greater than 25 mg/l. Table 3 shows a comparison of average concentrations of key AMD parameters within Drury Run.

The mouth of Sandy Run is about 1.5 miles downstream of where Discharge No. 5 enters the creek. At the mouth, visual evidence of aluminum precipitating out of the water column was noticeable with the presence of white-colored substrate. Because of the higher pH values at the mouth of Sandy Run, much of the aluminum that was in the water column upstream precipitated out downstream. Sandy Run had enough buffering capacity that at the mouth, the pH was close to water quality standards. The stream was slightly less acidic with an alkalinity of about 1 mg/l and a hot acidity of 5 mg/l.

Once Sandy Run joins Drury Run, there was an obvious mixing zone where the water from Sandy Run hovered along the left bank and white aluminum precipitate was evident on the substrate. The next sample site on Drury Run (DRUR 3.5) was downstream of this mixing zone and the water from Sandy Run was fully diluted with the non-impacted water from Drury Run. Water quality showed some degradation at this site, which is expected given Sandy Run's AMD influence. Drury Run below Sandy Run was net acidic with low buffering capacity. Sulfate concentrations were double what they were upstream but pH remained above the water quality standard in the range of 6.5 - 6.7.

Woodley Draft is a small tributary that flows through a steep gorge and joins Drury Run from the east, downstream of a small reservoir. This reservoir was created in the 1880s to provide water for railroad stops in the borough of Renovo and was later used as a back-up drinking water supply for the borough until the mid-1980s. Currently, the six-acre area is owned by Renovo as an in-holding within Sproul State Forest but is not being used for any specific purpose (D. D'Amore, personal communication, 2011).

The water quality in Woodley Draft indicated AMD influence, as alkalinity was zero and aluminum and manganese concentrations were greater than water quality standards during all sampling events. The pH of this water ranged from 4.3 - 4.5 and sulfate

Table 3. Average Concentrations of Key AMD Parameters in Drury Run

	Alkalinity mg/l	Hot Acidity mg/l	pH	Aluminum (diss/total) mg/l	Manganese mg/l	Sulfate mg/l
Drury – above all AMD	7.4	-2.3	6.7	PBQ/PBQ	0.0185	5.8
Sandy (mouth)	1.3	5.1	6.1	PBQ/0.217	0.1370	22
Woodley (mouth)	0	19	4.4	2.282/2.477	1.797	106
Whiskey (mouth)	0	45	4.1	4.884/5.039	4.295	186
Stony (mouth)	0	40	4.2	5.528/5.649	4.975	271
Discharge 5 (Sandy)	0	37	4.1	3.960/4.273	7.232	203
Discharge 16 (Stony)	0	36	4.3	4.813/4.849	2.872	175
Drury (mouth)	0.85	15.55	5.3	1.267/1.335	0.871	67

concentrations averaged 105 mg/l. Much of the aluminum was found in the dissolved form because of the low pH levels. However, because the flow was relatively small (270 gpm in high spring flows), Woodley Draft does not account for a large percentage of the AMD loading in Drury Run and should not be the first priority for treatment.

Whiskey Run is another small AMD-influenced tributary to Drury Run that comes in just downstream of Woodley Draft but entering from the west. This small tributary consists almost entirely of AMD as it exits the toe of Drury Ridge South Abandoned Mine Land (AML) site (PA0861). The water quality in this small tributary was worse than Woodley Draft, with pH ranging from 4.0 - 4.2, sulfate concentrations averaging 186 mg/l, and a hot acidity of 45 mg/l (Table 3). Whiskey Run is in a high gradient, steep channel with limited or no access to its headwaters so passive treatment would be quite difficult.

Whiskey Run is a small AMD-influenced tributary to Drury Run. Its steep channel would make passive treatment difficult.

Below both Woodley Draft and Whiskey Run, Drury Run showed some decline in water quality but the pH hovered around 6.0. A small amount of alkalinity remained due to the ratio of Drury Run flows compared to the inputs of Woodley Draft and Whiskey Run.

Stony Run is the last and largest tributary to Drury Run and is the cause of a majority of the AMD to the watershed. The water quality in Stony Run and its tributaries was severely degraded from the headwaters all the way to the mouth. STON 2.2 was net acidic with zero alkalinity. The concentrations of aluminum and manganese ranged from 3-5 times greater than the water quality standards, pH was 4.5, and sulfate concentrations averaged 140 mg/l. Three of the four tributary inputs to Stony Run (Slab Run, Kelly Run, and Discharge No. 16) had similar poor water quality with pH values of 4.1 - 4.5, metal concentrations up to 17 times the water quality standard for aluminum, and more than nine times the water quality standard for manganese. However, the unnamed tributary to Stony Run had considerably worse water quality than any of the other three tributaries. The AMD influence into Stony Run is mainly from groundwater, so pollutants are at their highest when flows are low in the late summer and fall. During September 2010, the unnamed tributary to Stony Run had the highest concentrations of aluminum (33.40 mg/l), manganese (45.0 mg/l), sulfate (1,361 mg/l), hot acidity (248 mg/l), total dissolved solids (1,902 mg/l), and the lowest pH (3.6) seen anywhere in Drury Run Watershed.

The mouth of Stony Run remains highly impacted by AMD as it accumulates all the upstream influences. The water quality at STON 0.1 was characterized by aluminum concentrations averaging 5.6 mg/l, a pH of 4.2, an average manganese concentration of nearly 5.0 mg/l, and a sulfate concentration of 270 mg/l. With this magnitude of pollution coming into Drury Run, which has already assimilated all the influences of Sandy Run, Woodley Draft, and Whiskey Run, it is easy to imagine why downstream of Stony Run, the cumulative effects are markedly apparent in Drury Run. The mainstem of Drury Run, downstream of Stony Run (DRUR 1.0), is able to assimilate and dilute some of the additional AMD from Stony Run but not all: aluminum concentrations remained double water quality standards, alkalinity was less than 1 mg/l, and the stream was net acidic.

The AMD loading in Drury Run is significant and can be easily attributed to its individual tributaries. The total AMD loading calculations shown below are based on the concentrations of pollutants and the flow of the stream or discharge. Overall, the AMD loading in Drury Run is primarily from Stony Run, which contributes 69 percent of the total loading. See Table 4 for a summary of the loading contributions of each of the four major AMD sources in Drury Run Watershed: Sandy Run, Woodley Draft, Whiskey Run, and Stony Run.

Table 4. Percent Contributions for Each AMD Tributary Source in Drury Run and Total AMD Loading

Tributary	Acidity Loading	Mn Loading	Al Loading	Total AMD Loading
Sandy Run	11	3	4	10
Woodley Draft	5	2	6	5
Whiskey Run	17	11	15	16
Stony Run	67	84	75	69
total lbs/day	**550**	**50**	**58**	**658**

Birch Island Run

The water quality data for the mainstem of Birch Island Run and its tributaries above the Little Birch Island Run confluence seem to indicate little or no influence of AMD but rather, a naturally low pH system with a naturally low buffering capacity. At the two upstream sites on Birch Island Run, pH was between 5.4 and 6.0, and alkalinity was less than 1 mg/l. Metals were below detection limits or else present at very low concentrations, and sulfate concentrations were less than 20 mg/l during every sampling event. Amos Branch and an unnamed tributary to Birch Island Run were also sampled. Both are above the confluence of Little Birch Island Run and both are characterized by low metal concentrations, sulfate concentrations less than 20 mg/l, pH between 5.7 and 6.2, and very low alkalinity.

A small unnamed tributary to Little Birch Island Run had double the water quality standard for total and dissolved aluminum and manganese concentrations, making Little Birch Run the only tributary to Birch Island Run with an identifiable source of AMD impairment.

Little Birch Island Run is the only tributary to Birch Island Run that has an identifiable source of AMD impairment. The upstream site on Little Birch Island Run (LBIR 2.0) is above the influence of AMD, and the water chemistry was similar to the rest of Birch Island Run, with a pH averaging 6.0, low sulfate concentration, low metals, and low alkalinity. About a half-mile downstream, a small unnamed, heavily impaired tributary enters Little Birch Island from the west. Total and dissolved aluminum and manganese concentrations were each more than double the water quality standard. Sulfate concentration averaged 255 mg/l for the year, pH ranged from 3.9 - 4.2, and alkalinity was zero. Downstream of this unnamed tributary, Little Birch Island Run is able to assimilate some of the AMD influences but there are obvious impacts compared to the upstream site. Downstream, numerous impaired seeps and small rivulets enter Little Birch Island between the LBIR 1.0 site and the mouth and only flow after wet weather events. The mining in Birch Island Run Watershed was primarily surface mining and as a result, conditions in Little Birch Island decline during wet weather events, as abandoned mine lands are saturated and overflow down slope into the waterway. Water quality conditions at the mouth of Little Birch Island were indicative of AMD impairment with sulfate concentrations averaging greater than 40 mg/l, no alkalinity, and a pH as low as 4.8.

The mouth of Birch Island Run is the only site along the mainstem that is impaired by AMD. Because of the low buffering capacity of Birch Island Run, the impacts from Little Birch Island can not be fully assimilated into Birch Island despite some dilution. Sulfate concentrations at the mouth averaged 25 mg/l, which is more than double any of the concentrations seen upstream on Birch Island. Overall, metals were below water quality standards but were considerably higher in the wettest sampling month of October, and pH values ranged from 5.6 - 5.9.

Little Birch Island Run