THE NORTH BRANCH OF THE POTOMAC RIVER: RESULTS OF TWO YEARS OF LIME DOSING

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INTRODUCTION

The North Branch of the Potomac River (North Branch), from its headwaters to Jennings Randolph Lake, has been adversely affected by acid mine drainage (AMD) from abandoned coal mines since the last decade of the 19th century. This problem is most serious in the upper reaches, where drainage from abandoned coal mines represent a high percentage of the mainstem flow. The North Branch watershed consists of seventy subwatersheds, twenty of which produce AMD. Fifty-two sites produce AMD, with almost ninety percent of the acid loading being produced by fifteen sites from four subwatersheds and two direct discharges (see Attachment 1). The major acid producing sites in Maryland are underground mines in Laurel Run (Kempton Mine) and Three Forks Run (Vindex Mine), and direct discharges to the North Branch at Shalimar and Kitzmiller. Sites located on Abram Creek and Stony River are the major acid producers in West Virginia.

Many streams in the North Branch watershed have historically been completely devoid of aqua life due to high concentrations of acid, dissolved metals and sediments from AMD. The destruction of aquatic habitat and the reduction of aesthetic values has greatly restricted recreational use of the North Branch.

The Bloomington Dam was completed in 198 1, and formed the Jennings Randolph Lake. Bloomington was constructed with the ability to mix different qualities of water from within the lake to achieve a consistently good quality effluent discharging to the mainstem of the North Branch. This "high" quality discharge from the dam allowed for the establishment of a sport fishery below the dam, but due to the input of highly acidic waters into the dam, the dam effluent was often of marginal quality. The establishment of this downstream fishery renewed interest in the problems that still existed in the upper reaches of the North Branch. In 1992, the Maryland Bureau of Mines (BOM) began looking for ways to eliminate the impacts of the AMD on the North Branch above the dam which would also improve the quality of the water in the lake and allow for more consistent, higher quality discharges from the dam. By October of 1993, four lime dosers were installed in the North Branch watershed with the purpose of treating the acid impacts of unabated abandoned surface and deep mine discharges and restoring the river to a recreational fishery.

PROJECT HISTORY

In 1989, each stream in the North Branch watershed above Jennings Randolph Lake was intensively evaluated for water quality by "The North Branch Potomac River Abandoned Mine Drainage Study" (North Branch Study). This study was performed under a joint contract funded by the Federal Office of Surface Mining, the Maryland Department of Natural Resources, and the West Virginia Division of Environmental Protection. The main objective of this study was to locate and evaluate the major sources of AMD in the North Branch watershed. During this study, water quality samples were collected at the nodes of each stream during high, low and normal flow periods.

Additional pre-monitoring data was collected prior to installation of the lime dosers. Sixteen sampling stations were selected for collection of chemical background data (May 1991 through October 1992). Biological background data were collected at fifteen of the sixteen stations (May 1991 and April 1992) (see Attachment 1). These data were used to evaluate the effectiveness of AMD treatment after abatement technologies were implemented in the watershed (see Attachment 2).

In 1991, fishery management objectives were defined for the North Branch, in consultation with both Maryland and West Virginia fisheries management personnel. These objectives were determined based upon biota management potential of each segment of the North Branch, and upon biological tolerance limits for each species of interest as well as human population densities and accessibility to the river.

Available AMD technologies were evaluated to determine their ability to remediate the major AMD sources in Maryland, factoring in funding limitations, and the physical and chemical extremes at each source. Lime dosing was determined to be the best, most cost acceptable alternative for the restoration of a fisheries in the North Branch (International Science and Technology, Inc., 1990).

In 1992, optimum deployment of lime dosers to achieve water quality targets in the North Branch was determined with a model using data from the North Branch Study and the fishery management objectives and running selected treatment scenarios (see Attachment 1). The doser location scenario which met the most water quality targets in Maryland tributaries and the North Branch mainstem, located lime dosers on Laurel Run (Kempton Mine), at Gorman, MD on the North Branch mainstem, on Lostland Run and on Three Forks Run (the Three Forks Run doser was relocated to Kitzmiller, MD - the proximity of one site to the other had little effect on the model).

During 1992, the BOM actively pursued a donation from The Conservation Fund, Inc. of Arlington, VA, of four lime dosers (two of the dosers - both water powered, dry powder, $CaC0_3$ dosers -were used in the AMD abatement project, while the remaining two - both small automated, wet slurry dosers - were put into storage for possible use at a later date). In December, 1992, one of the donated dosers was installed on Lostland Run, while the second doser was installed at Kitzmiller, MD to treat AMD that discharges directly into the North Branch. Several months after operation, studies conducted by the U.S. Bureau of Mines showed that the doser located at Kitzmiller did not treat the AMD as well as expected due to AMD chemistry and to the relative flatness of the receiving stream and the lack of agitation or mixing action. In August 1994, at the suggestion of the U.S. Bureau of Mines, the doser located at Kitzmiller was modified to use Pebble Quick Lime, CaO, instead of limestone. This modification was deemed successful, since the pH below the doser, in the channel where the AMD enters the North Branch, has remained near 7.0.

In 1993, the BOM developed specifications for two large automated, dry powder, $CaCO_3$ dosers and solicited bids for these machines. In October, 1993, these large capacity machines were installed on Laurel Run (Kempton Mine) and on the mainstem of the North Branch at Gorman, MD.

One year after installation of the four doser system, post-doser monitoring of water quality was initiated. Post-doser monthly water quality samples were collected during 1995 at the 16 pre-doser monitoring stations and post-doser biological samples were collected at the 15 pre-doser biological monitoring stations in April 1995. These data were compared to the pre-doser data collected in 1991 and 1992. These results are the theme of this paper.

PROJECT RESULTS

The following is a summary by station of the results obtained during this study. With a few exceptions, that will be noted, only the chemical results that are statistically significant will be discussed. Relative doser locations and brief descriptions of their functions are included in this section.

Water Chemistry - General

Sixteen stations were monitored for water quality during the pre-doser and post-doser phases of the project (see Attachment 1). Stream water samples were collected in syringes for closed pH and in cubitainers for analysis of acid neutralizing capacity (ANC), iron, manganese, aluminum, calcium, magnesium, sulfate, sodium, and conductivity.

The pre-doser and post-doser data were subjected to univariate statistics (ANOVA analysis). Multivariate statistics (preliminary factor analysis) were also analyzed but will not be discussed in this paper (Morgan et al., 1996, draft report). The ANOVA analyses indicate significant changes in many water quality parameters over the course of the study at all stations sampled.

Water Chemistry - Station Results

Henry Pond Station

This control station is located on the North Branch above the town of Henry, WV, above any influence of the lime dosers. The pH (6.76 to 6.48) of this station stayed about the same, and ANC (314 to 239 m eq/1) at this station also showed no significant change. A significant decrease in aluminum and a significant increase in magnesium did occur at this station. Mean aluminum was 0.29 mg/l before and 0. 15 mg/l after, and mean magnesium was 4.2 mg/l before and 18.1 mg/l after dosing. Comparison of other analytes showed no significant difference.

Henry Railroad Station

This station is downstream of the Henry Pond station at the town of Henry WV, upstream of the dosers and also served as a control. The pH of this station remained unchanged, 6.75. Significant increases occurred in ANC (263 to 433 m eq/l), iron (0. 19 to 0.50 mg/1), and manganese 0.47 to 0.89 mg/1), while sulfates (843 to 441 mg/1) decreased significantly. These changes may be attributable to upstream AMD treatment at active mining sites. Other analytes showed no significant change.

Doser I at Kempton

The first doser in the system is located on Laurel Run. Laurel Run, which is highly impacted b3 the AMD from the Kempton Mine discharge, enters the North Branch below the Henry Railroad station and above the next mainstream sampling station at Wilson, MD. This doser was sited here to eliminate the impacts that Laurel Run exerts on the North Branch. The doser is located on Laurel Run, approximately 2.5 stream miles below the AMD discharge at the Kempton Borehole and Airshaft, and approximately 2.5 stream miles above the confluence of Laurel Run with the North Branch. This doser delivers the largest quantity of neutralizing agent of the four dosers to the North Branch system.

Dobbin Road Station

This sampling station is located on Laurel Run about I mile downstream of the doser. Comparing pre-doser and post-doser data, dramatic changes in water quality are evident at this site with significant increases in pH (3.24 to 4.2 1), ANC (-871 to 62 m eq/l), calcium (28 to 87 mg/1) and magnesium (16 to 30 mg/l)and significant decreases in iron (7.8 to 3.1 mg/1) and aluminum (8.3 to 2.8 mg/1).

Wilson Station

The next downstream, mainstem station is located approximately 1000 feet below the confluence of Sand Spring Run with the North Branch. Dramatic changes in pH (4.46 to 6.87) and ANC (-28 to 375 m eq/l) were noted as was a significant reduction in aluminum concentrations (1.7 to 0.05 mg/1). These data show the river changing from biologically intolerable conditions to conditions that are more favorable to aquatic life.

Bayard Station

The next downstream sampling station is located at Bayard, WV. At this station dramatic changes in pH were achieved (5.00 to 6.94) and ANC (23 to 392 m eq/1). Aluminum and sulfates also decreased significantly (1.7 to 0.42 mg/l and 692 and 361 mg/l respectively). Iron increased significantly in concentration after dosing was initiated, with a change from an average pre-doser concentration of 0. 17 mg/I to an average concentration after doser operation of 0.47 mg/l.

Gormania Station

This station is located about 3 miles downstream of the Bayard station and about 6 miles below the confluence of the North Branch with Laurel Run. All concentrations of analytes were similar to the concentrations measured at the Bayard Station. Significant changes were measured in pH (5.16 to 7.03), ANC (33.2 to 375.3 m eq/l) and aluminum (1.8 to 0.37 mg/1). Before and after iron concentrations at this station (0. 17 to 0.42 mg/1) were about the same as they were at the Bayard station.

Doser 2 at Gorman

The Gorman doser is the next doser downstream in the doser system. It is located near the town of Gorman, MD, and it discharges directly into the North Branch. Its main purpose is to "level out" pH fluctuations in the river and to add additional ANC to the North Branch.

Steyer Station

The Steyer sampling station is located approximately 2 miles downstream of the Gorman doser. This station is about 300 feet below the confluence of the North Branch with Steyer Run, a very high quality stream. Statistically, only ANC and iron had any significant changes during the study period, with ANC increasing from 265 to 467 m eq/1 and iron increasing from 0.099 to 0.30 mg/l. The relatively high quality of the water at this station before initiation of the doser project may be due, in part, to a sampling error. The close proximity of the sample station to the confluence of the streams may not allow for adequate mixing of the waters prior to sampling.

Bradshaw Station

The next sampling station is located approximately 3 miles downstream of the Gorman doser at Bradshaw, WV, just upstream of the confluence with Snowy River, At this station the pH increased from 5.76 to 7.21 during the study. ANC (92 to 444 m eq/l) and iron (0. 12 to 0.27 mg/1) both increased significantly.

Schell Station

The next sampling station is located at Schell, WV, above the confluence of Trout-Laurel Run with the North Branch. This station exhibited significant increases in pH (6.62 to 7.26), ANC (115 to 377 m eq/1) and iron (0.01 to 0.20 mg/1) and a significant decrease in sulfate (470 to 215 mg/1).

Doser 3 at Lostland Run

The third doser in the system is located on the South Prong of Lostland Run, a slightly AMD impacted tributary to the North Branch. This doser is situated about 2.5 miles upstream of the confluence. Its main purpose is to add buffering ability to Lostland Run and to carry excess ANC into the North Branch.

Lostland Run Station

This sampling station is located on Lostland Run approximately I mile downstream of the doser, below the confluence of the North and South Prongs of Lostland. This station exhibited a significant increase in pH (7.02 to 7.21) and significant decreases in calcium (70 to 36 mg/1), sulfate (226 to 56 mg/1) and conductivity (380 to 154 m S/cm).

Lostland Run/North Branch Station

The next mainstem station is located below the confluence of Lostland Run with the North Branch. The water quality measurements were the about the same when compared to water quality data collected at the previous upstream mainstem station at Schell. The cause of the water quality improvements at this station are not easy to separate between the doser on Lostland Run and the dosers upstream on the North Branch. This station exhibited significant increases in pH (6.76 to 7.3 1), ANC (160 to 356 m eq/]), iron (0.081 to 0. 18 mg/1) and aluminum (0. 10 to 0.24 mg/l) after operation of the lime dosers.

Shallmar Station

This station is located just above the confluence of the North Branch with Abram Creek. This station exhibited significant increases in pH (6.78 to 7.08), ANC (120 to 350 m eq/1), iron (0.087 to 0.22 mg/1), and aluminum (0.098 to 0.27 mg/1), and a significant decrease in sulfate (423 to 194 mg/1).

Kitzmiller Station

The Kitzmiller station is located along the mainstem of the North Branch, approximately 2 miles below the Shallmar station and the confluence of Abram Creek with the North Branch mainstem. Significant increases in pH (6.67 to 7.02), ANC (78 to 283 m eq/l), and aluminum (0. 13 to 0.33 mg/1) and a significant decrease in sulfate (405 to 186 mg/1) were measured after operation of the dosers.

Doser 4 at Kitzmiller

The Kitzmiller doser is located on an AMD drainage that discharges directly into the North Branch. There are no sample stations below this doser on the North Branch mainstem until Luke, a station 8 miles below the Jennings Randolph Dam.

Luke Station

The last mainstem. station in this study is located near the town of Luke, MD, approximately 8 miles below Jennings Randolph Lake, and above the confluence of the Savage River. Three analytes showed significant increases at this station, ANC (79 to 131 m eq/l), iron (0.093 to 0.28 mg/1) and magnesium (11.5 to 24.8 mg/1). This station is located below the dam which forms Jennings Randolph Lake and the flow is manually controlled. These data may reflect the ability of the dam operator to manipulate the quality of the effluent.

Three Forks Run Station

This sample station serves as an AMD control. It is located on Three Forks Run, a severely degraded, AMD impacted stream, with a pH of 3.13. Three Forks Run is located at the headwaters of Jennings Randolph Lake. This station receives no treatment from the lime dosing system and, as expected, showed no significant changes in water quality during this study.

Savage River Station

The Savage River Station was set up as a chemical and biological control station. This station is located upstream from the North Branch on Savage River, a high quality, recreationally important stream that enters the North Branch near Luke, MD. This station receives no treatment from the lime dosers. This station showed a significant increase in magnesium (4.0 to 19.5 mg/1) and significant decreases in pH (6.69 to 6.27) and sulfate (19 to 13 mg/1) during the study.

Biological Sampling - General

Biological sampling was conducted at the same stations as water sample were collected with the exception of the Luke station. Baseline samples (pre-doser) were collected in May 1991 and April 1992. The doser system was essentially completed and operational by late 1993. By early summer of 1994, the lime doser system was operating smoothly with minimal down time. In April 1995, allowing I year for colonization, the post-doser biological sampling was conducted.

Macroinvertebrates - Results

The initial results for macroinvertebrate response to improved water quality indicate that recolonization is slow, although definitely occurring at some stations, but no consistent pattern of improvement was observed for the mainstem stations from pre-doser sampling to the post-doser sampling

Fishes - Results

The results of the fish collections indicated that recolonization of fish population is also slow. The "Index of Biotic Integrity", IBI, consisting of ten separate metrics, was used to compare changes in fish communities (Jacobson et al. 1992). The Savage River control station did not exceed an IBI of 50, due primarily to the lack of darter species. The uppermost North Branch station showed a decent fish assemblage, with an 1131 of about 45. The remainder of the North Branch mainstem stations showed poor fish communities, with no stations exceeding an IBI of 30. The mainstem stations at Wilson, Bayard, and Steyer exhibited slight decreases in the IBI during the study period. The station on Lostland Run and the mainstem stations below Lostland Run exhibited the same IBI for all three years of sampling, in spite of the of dosing activities. The stations at Bradshaw and Schell both showed slight improvement in the IBI.

Habitat Assessment

Habitat is a major factor for aquatic community potential, with both quality and quantity of habitat influencing the structure and function of biological communities. Habitat quality was assessed using metrics developed by Plafkin et al. (1989) and modified by Kazyak and Jacobson (1994). Overall habitat scores were very poor at the North Branch mainstream stations, both before and after operation of the dosers. This was due in large part to embeddedness caused by past AMD deposits creating poor substrate habitat. There were no major changes in habitat structure at any station during the study period

DISCUSSION/CONCLUSIONS

Biotic restoration of a disturbed watershed is usually based on the remediation of water quality (Yount and Niemi 1990), and is impossible without adequate water quality. Following water quality restoration, improvements in the biotic community are usually observed, especially if a number of refugia are present within the watershed. Biotic recovery in a lotic system is a function of the availability and accessibility of unaffected upstream and downstream refugia. However, disturbances of a physical nature (such as embeddedness and sediment deposition) are usually more difficult to remediate (Niemi et at, 1990).

There has been an improvement in water quality within the North Branch watershed since the installation and operation of the time dosers. All mainstem stations located below the dosers showed improvement in mean pH values. The monthly sampling showed that the target pH values set forth during the planning stages of the project were met and exceeded at every station on the mainstem. Prior to the doser project, all mainstem stations below the confluence with Laurel Run, except the Steyer Run station (265 m eq/l) had ANC levels less than 200 "q/1 (from 28 to 160 m eq/l), an ANC level indicative of poor buffering capacity in the system and considered by many to be the lower extreme of good quality habitat. After the doser project, all mainstem stations except the Kitzmiller station (283 m eq/l), had ANC levels in excess of 300 m eq/l (350 to 467 m eq/1). All mainstem stations below the dosers also showed increased magnesium and decreased sulfate and conductivity.

The increases in pH and ANC at the mainstem stations are not directly related to increases in calcium in the system, but appear to be driven by reductions in sulfate and increases in magnesium. Preliminary work on the sediments associated with the dosers indicates that the primary mineral formed is ettringite, calcium aluminum sulfate hydroxide [$Ca_6A_{12}(SO_4)_3(OH)_{12}$ $25H_2O$]. The information of this mineral may explain why there is no pattern of calcium increases in the North Branch system, since it is being tied up with sulfate and aluminum, and precipitated out of the water column.

Aluminum concentrations dropped at all mainstem stations except, the Lostland Run/North Branch, Shallmar, and Kitzmiller stations. The decreases in aluminum at most mainstem stations is due to the formation of ettringite and other insoluble aluminum compounds. The increases in concentrations of aluminum at Kitzmiller, Shalimar and below Lostland Run although significant, are very low.

Iron concentrations increased at aft mainstem stations below Laurel Run, with many increases being statistically significant. All mainstem, post doser, mean iron concentrations were 0.50 mg/I or less except for the station at Wilson which was 0.66 mg/l.

Many years of AMD deposits have created an extremely embedded substrate; this situation, will correct itself over time if water quality remains good. The impacts of increased sediment deposition on biotic recovery are currently being studied. The elimination of the sediment deposits from the system, under current conditions, is monetarily impossible. These two characteristics, embeddedness and sediment deposits, may be the two major factors retarding the biotic recovery of the North Branch. Some additional concerns, center on potential temperature and/or gradient limitations that may also inhibit the biotic recovery of the system.

An additional factor to consider in the slow biological recovery of the North Branch is that upstream movement of fishes is blocked and upstream movement of benthic invertebrates is slowed by Bloomington Dam. All colonization of fishes would have to come from present refugia above the darn and most invertebrate colonization will also come from above the dam. An assessment of the refugia resources along the North Branch is necessary to determine the adequacy of the refugia in the watershed.

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Variable (Mean)	Henry Pond	Henry Rail Road	Laurel Run Station	Wilson	Bayard	Gormania	Steyer Run	Bradshaw	Schell	Lostland Run	Lostland Run/North Branch	Shallmar	Kitzmiller	Three Forks Run	Luke	Savage River
pH-[H+]																
Pre-Doser	6.76	6.76	3.24	4.46	5.0	5.16	6.82	5.76	6.62	7.02	6.76	6.78	6.67	3.13	6.20	6.69
Post-Doser	6.48	6.75	4.21	6.87	6.94	7.03	7.07	7.21	7.26	7.21	7.31	7.08	7.02	3.17	6.24	6.27
ANC (µeq/L)																
Pre-Doser	314.1	263.3	-871	-27.5	22.7	33.2	264.9	91.8	115.1	229.3	160.3	119.5	78.3	-1335	78.9	283.9
Post-Doser	239.4	432.9	62.1	374.8	392.1	375.3	466.8	444.3	376.6	201.7	356.1	350.4	283	-1554	130.6	263.8
Iron (mg/L)																
Pre-Doser	0.31	0.19	7.8	0.39	0.17	0.17	0.099	0.12	0.1	0.072	0.081	0.087	0.083	27.9	0.093	0.44
Post-Doser	0.42	0.5	3.1	0.66	0.47	0.42	0.3	0.27	0.2	0.1	0.18	0.22	0.4	12.2	0.28	0.38
Manganaese (mg/L)																
Pre-Doser	0.11	0.47	3.3	1.1	0.93	0.86	0.52	0.58	0.37	0.22	0.25	0.2	0.61	2.1	0.33	0.043
Post-Doser	0.12	0.89	3.0	1.1	0.87	0.76	0.58	0.51	0.37	0.14	0.29	0.27	0.58	2.2	0.38	0.051
Aluminum (mg/L)																
Pre-Doser	0.29	0.14	8.3	1.7	1.7	1.8	0.15	0.52	0.15	0.24	0.1	0.098	0.13	15.9	0.2	2.1
Post-Doser	0.15	0.17	2.8	0.5	0.42	0.37	0.25	0.26	0.17	0.25	0.24	0.27	0.33	5.4	0.29	0.27
Calcium (mg/L)																
Pre-Doser	19.2	188.5	27.6	192.1	192.1	179.4	127.9	145	132.8	69.5	109.1	107.1	116.1	75.0	52.8	22.6
Post-Doser	20.1	178.2	87.2	160.4	155.9	161.5	132.5	132.8	116.3	35.8	112.8	99.7	103.3	83.9	69.9	13.1
Magnesium (mg/L)																
Pre-Doser	4.2	32.9	15.9	25.7	24.8	24.1	20.3	20.5	19.6	16.4	18.5	18.9	19.7	22.3	11.5	4.0
Post-Doser	18.1	43.1	30.0	34.9	34.5	30.7	28.7	29.6	25.9	19.1	27.9	26.3	26.1	29.7	24.8	19.5
Sulfate (mg/L																
Pre-Doser	34.8	842.9	325.6	679.6	692.1	662.2	451.7	552.6	469.8	225.8	403.0	422.6	405.5	670.0	165.7	18.8
Post-Doser	55.3	440.9	246.4	374.8	361.3	350.7	260.8	236.4	215.1	56.0	190.0	194.2	186.1	285.0	134.0	13.0
Sodium (mg/L)																
Pre-Doser	1.5	14.0	6.0	16.7	19.1	16.4	9.5	20.4	10.5	2.6	8.0	8.9	8.1	6.2	5.1	3.6
Post-Doser	1.4	9.7	6.7	9.7	9.7	8.0	6.7	7.0	6.0	1.0	8.3	8.0	8.7	7.7	3.4	2.9
Conductivity (µS/cm)																
Pre-Doser	104.4	1009.6	631.0	946.5	898.3	856.5	643.6	709.8	638.8	380.4	574.3	617.7	599.7	908.8	324.5	80.8
Post-Doser	143.2	832.8	453.5	750.5	711.0	678.4	578.6	534.9	477.9	154.2	425.1	435.1	418.5	679.4	290.1	80.0

NORTH BRANCH SAMPLING STATIONS