Round 3 Grant

Pennsylvania Growing Greener
Project Number 351358

Mosquito Creek Watershed Restoration Plan

PHASE 3
ALKALINE ADDITION
IMPLEMENTATION PROJECTS
- FINAL REPORT -

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June 29, 2004

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INTRODUCTION

The Mosquito Creek watershed, located in Clearfield, Elk, and Cameron Counties (Figure 1), was once a premier wild trout fishery but has since been severely impacted by acid rain. Acidification effects have eliminated naturally reproducing trout from many of its tributaries, and remaining populations are reduced and isolated. Although upwind acid sources are presumably diminishing with regulation, chronic soil acidification and residual atmospheric deposition are expected to impair the stream for the foreseeable future.

Beginning with a Growing Greener Grant in 2000, the Mosquito Creek Sportsman's Association (MCSA) has been conducting a series of projects to assess the extent of acidification in the watershed and implement innovative acid abatement technologies. The result has been the development of a progressive restoration plan that is already improving the quality of several tributaries and holds promise for the eventual restoration of the entire watershed. Table 1 provides a summary of the project activities associated with the five Grants awarded to date, and Figure 2 shows the distribution of these projects within the watershed. A Round 6 Grant application has also been submitted to implement the alkaline addition projects being designed under Round 5. The results of all these projects will be detailed in a technology assessment to be prepared under Round 4 and completed in 2005.

There were a number of activities conducted under the Round 3 Grant. The primary focus was the design and construction of two alkalinity-generating vertical flow wetlands (VFWs) on the Duck Marsh tributary and Pebble Run. These systems are similar to the VFW constructed on the Ardell tributary under Round 1[1], and are intended to evaluate the cumulative effect of multiple headwaters alkalinity sources on the main stem. The watershed-scale monitoring program begun under Round 2[2] was also extended under Round 3 to continue collecting long-term data on the health of the main stem and major tributaries. Using funds left over from the VFW construction, an aerial lake liming project was undertaken in the headwaters of Beaver Run to assess the benefits of this practice for downstream water quality. Informational kiosks were placed at the three VFW systems, a round of in-stream limestone sand dosing was funded on Gifford Run, and a project was initiated to construct and evaluate limestone-lined open channels for stabilization and runoff neutralization along forest roads. Several maintenance actions were also undertaken on previously constructed projects.

This report summarizes the outcomes of these activities and provides recommendations for future projects within the watershed. A brief project summary for use in PADEP postings is contained in Appendix A, with the Growing Greener Goals and Accomplishments Worksheets contained in Appendix B.

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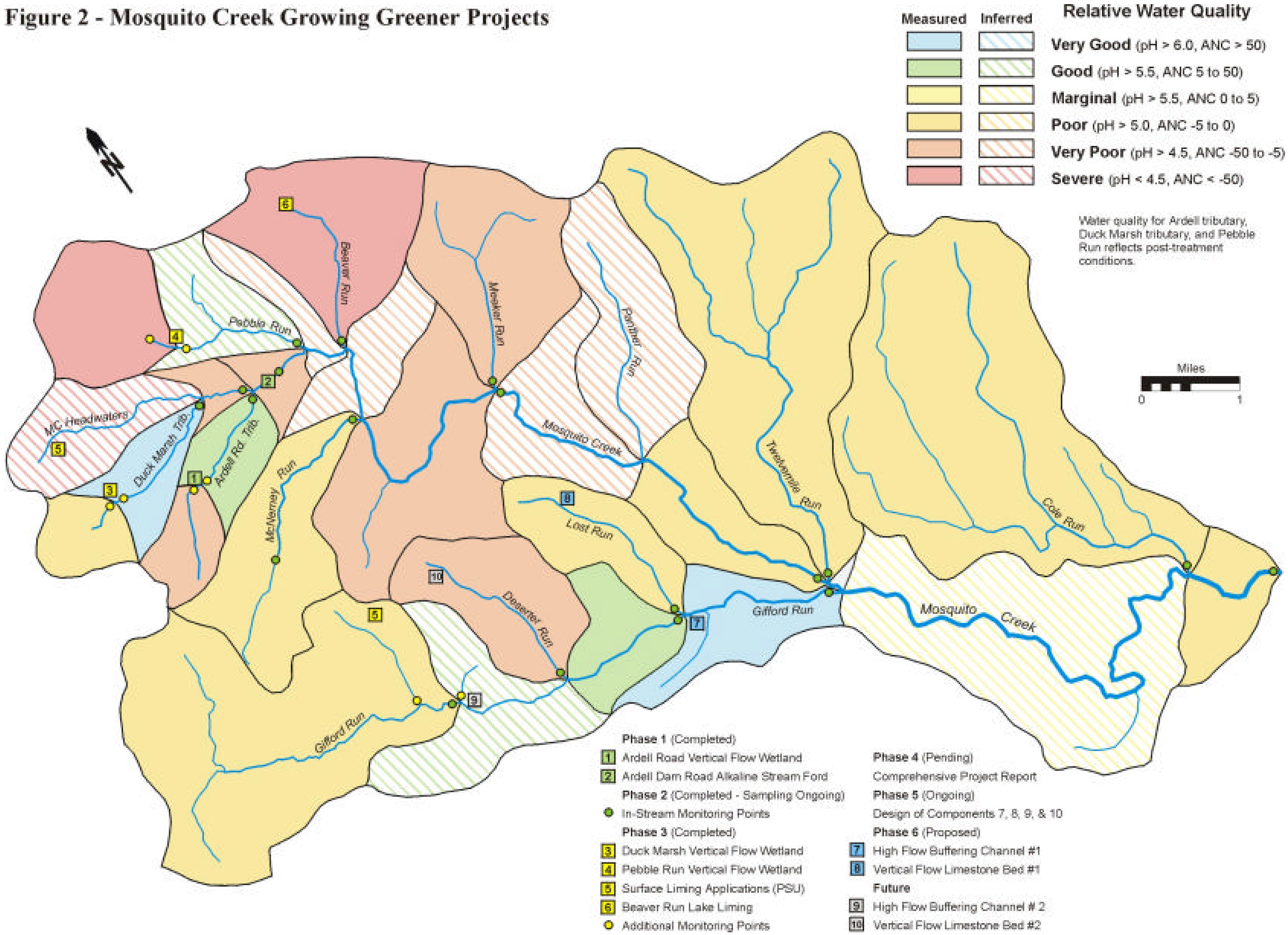
[1] See "Mosquito Creek Phase 1 – Atmospheric Acidification Abatement Demonstration Projects Final Report." Pennsylvania Growing Greener Project No. 3591130. May 2002.
[2] See "Mosquito Creek Phase 2 – Watershed-Scale Assessment for Acidification Abatement Final Report." Pennsylvania Growing Greener Project No. 350344. September 2002.

Figure 1 – Mosquito Creek Watershed Location

Table 1 – Summary of Mosquito Creek Growing Greener Projects to Date

Grant	Project Scope	Results/Benefits
Round 1	*Phase 1 – Atmospheric Acidification Abatement Demonstration Projects:* Design and construction of a vertical flow wetland (VFW) to generate alkalinity in a tributary crossing Ardell Road, and an experimental limestone sand dosing stream ford on the main stem. Penn State monitored in-stream results under a concurrent Grant.	Demonstrated that VFWs are applicable to acid rain impacts. Water quality improvements extend 1.6 miles downstream to the confluence with Mosquito Creek, and the formerly acidified Ardell tributary now appears capable of supporting fish populations. Provided monitoring results for design of future VFW systems.
Round 2	*Phase 2 – Watershed-Scale Assessment for Acidification Abatement:* Water quality and flow monitoring at 14 permanent stations on major tributaries and the main stem of Mosquito Creek, and evaluation of the results to develop a Progressive Restoration Plan.	Provided data to characterize water quality throughout the watershed and identify the primary sources of acidification. Concurrent flow measurements allowed determination of the point at which episodic acidification begins to impact streams during runoff events. Allows planning of future treatment efforts to produce measurable results.
Round 3	*Phase 3 – Alkaline Addition Implementation Projects:* Design and construction of two VFWs on the Duck Marsh tributary and Pebble Run to evaluate what mutually supportive effects that treating adjacent tributaries would have on the main stem. Also funded continuation of the Phase 2 monitoring to better characterize the watershed. Surface liming is being conducted in other headwaters areas by Penn State under a concurrent Grant.	It is anticipated that the two new VFWs, along with the Ardell VFW and surface liming conducted by Penn State, will significantly benefit water quality in the main stem, possibly as far downstream as Beaver Run. Results will quantify the mutually supportive effects of multiple abatement projects and allow prediction of the ultimate scope of treatment necessary to restore the entire watershed.
Round 4	*Phase 4 – Assessment of Applied Technologies for Acid Abatement:* Preparation of a comprehensive report on the findings of the previous projects. May be extended to include the results from Round 5, if the Round 4 budget period allows.	This report will provide the technology transfer for the results of the Mosquito Creek Grant activities, including an evaluation of treatment and cost effectiveness of the various technologies, and implementation guidelines applicable to other watersheds impacted by acid rain.
Round 5	*Phase 5 - Design of Offline Limestone Sand Application Systems:* Design and permitting of three new alkaline addition technologies at five sites, including high flow buffering channels, vertical flow limestone beds, and road runoff buffering channels.	When implemented, these systems will demonstrate new approaches to using efficient limestone sand for stream buffering without the sedimentation detriments associated with direct in-stream application. The road runoff buffering channels are being constructed using the Round 3 Grant.

Figure 2 - Mosquito Creek Growing Greener Projects



ACTIVITY SUMMARIES

The following summarizes the project activities that were conducted under the Round 3 Grant. Monitoring of performance is ongoing under the Round 5 Grant, with the final results to be reported in the Round 4 technology assessment. This summary is inclusive of project details and results up to the conclusion of the Round 3 funding period.

Vertical Flow Wetlands

Vertical flow wetlands are a passive acid mine drainage treatment technology that have been demonstrated by the Mosquito Creek projects to also be effective for acid rain runoff abatement. They consist of deep basins with a bottom layer of limestone aggregate and a top layer of spent mushroom compost, covered by standing water. As shown by Figure 3, influent to the cell migrates downward through the two substrate layers to an underdrain, acquiring alkalinity during this passage. This also results in a substantial increase in the acid neutralization capacity (ANC) of the water, which is an important indicator of stream health for fisheries and is measured in milli-equivalents per liter (meq/L). A positive ANC will normally support fish populations, while a negative ANC can result in stress or mortality. In the Mosquito Creek VFWs, a portion of an acidic stream is split off to the cell to generate a highly alkaline flow. The split is then returned to the main channel to neutralize acidity and create a positive ANC in the total flow. Figure 4 shows the Pebble Run VFW following construction.

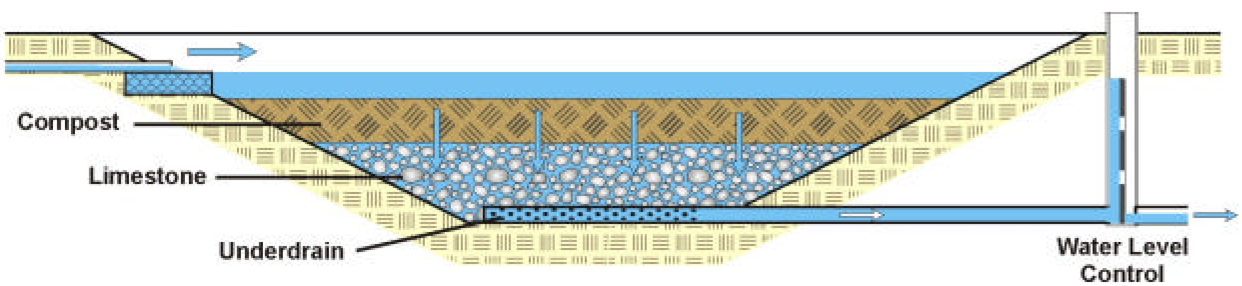


Figure 3 – Typical Vertical Flow Wetland Section

Figure 4 – Pebble Run Vertical Flow Wetland

The two VFWs constructed on the Duck Marsh tributary and Pebble Run are similar in design and size to the Ardell tributary system. The main difference is in the type of inlet control and water level control that were used. The Ardell system used a concrete basin with an orifice plate for inlet flow control, and a concrete basin with an adjustable standpipe for water level control at the outlet of the cell. For the Round 3 projects, it was found that Agridrain brand in-line water level controls were just as effective and much easier to install. These units are rectangular standing boxes with removable stop logs in the center to adjust water levels passing through the box (see outlet on Figure 3). In the inlet control, an orifice is drilled in one of the stop logs to limit the flow. A check dam in the stream with two staged weirs provides a constant water supply to the inlet control and limits the head increase relative to the orifice elevation. This arrangement has proven effective for limiting the influent flow to about 100 gallons per minute (gpm) during storm events, protecting the VFWs from damage and maintaining a fairly consistent detention time within the cell. Figure 5 shows the typical check dam and Agridrain installations used for the two projects.

Another difference in the new designs is the addition of wetland polishing channels at the VFW discharges. The compost substrate of a VFW will tend to leach tannins and foam for a period after system startup. It is intended to filter this residue in the polishing channels prior to returning the flow to the stream. The channels consist of an initial subsurface flow segment followed by a vegetated surface flow segment. At the time of this report the channel vegetation had not become sufficiently established to evaluate the effectiveness of this form of polishing. Figure 6 shows the outlet channel from the Duck Marsh tributary in its current stage of development.

Figure 5 – Typical Check Dam and Agridrain Installations

Figure 6 – Duck Marsh Outlet Wetland Polishing Channel

Performance monitoring has shown both VFW systems to be generating high levels of alkalinity and ANC. The Duck Marsh VFW discharge averages 44 (+/- 9) mg/L of alkalinity and 964 (+/- 270) meq/L of ANC. The Pebble Run VFW discharge averages double that at 87 (+/- 29) mg/L of alkalinity and 1915 (+/- 638) meq/L of ANC. The reason for the difference in performance between the two systems is not known, but may be related to the relative acidity of the influent waters. The Duck Marsh tributary is somewhat less acidic than Pebble Run, and it has been observed with acid mine drainage treatment VFWs that influents with higher acidity tend to produce a greater net alkalinity increase in the unit discharge.[3] The performance of the Duck Marsh system is similar to that of the Ardell system, which has a comparable acidity. If this is the case, then VFWs are to a degree self-regulating with regards to meeting the alkalinity input needs of streams relative to their acidity levels.

In terms of downstream effects, both systems have resulted in the first positive ANC and pH greater than 5 SU recorded for either stream. As shown by Figure 7, the Duck Marsh tributary now has a consistently positive ANC and a pH greater than 5.5 SU. In Figure 8, the more acidic Pebble Run has only been sampled once downstream since its VFW came fully on-line, but this sample indicates a substantial water quality improvement, also to a positive ANC and pH of around 5.5 SU. This is despite the unusually high precipitation and runoff that has occurred during late 2003 and early 2004, which presumably has resulted in a greater degree of episodic acidification than would be present in normal years. Statistically significant improvements in pH and ANC are observed in the Mosquito Creek main stem below its confluence with the Duck Marsh tributary and below the Ardell lime dosing ford downstream of the Ardell tributary, indicating that these systems are providing a combined benefit.

Lake Liming

Lake liming is a common practice in the Scandinavian countries, but has only been applied sparsely in this country, mostly in New York State. The benefit of lake liming is that it creates a large volume of alkaline water to buffer acidic rain events, and the lime is retained in the bottom sediments and riparian shorelines for longer periods than in the beds of flowing streams. This approach can also restore a considerable volume of aquatic habitat with relatively little effort.

Using excess construction funds from the VFW projects, a liming experiment was conducted on a 25-acre man-made lake at the headwaters of Beaver Run, one of the most acidic streams in the watershed. High-calcium lime was applied at 2 tons per acre using a specially modified airplane (Figure 9). Field readings indicate that the lake discharge pH increased from less than 5 SU before liming to greater than 6.5 SU after liming. Monitoring will continue into 2005, with laboratory results to be reported in the Round 4 technology assessment. The DCNR Bureau of Forestry is considering placing the lake in an annual liming program if these results are maintained for a sufficient period to allow fish stocking. The cost of the initial liming was $27,000.

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[3] Rose. A. W. & J. M. Dietz. Case Studies of Passive Treatment Systems: Vertical Flow Systems. 2002 National Meeting of the American Society of Mining and Reclamation, Lexington, KY, June 9-13, 2002.

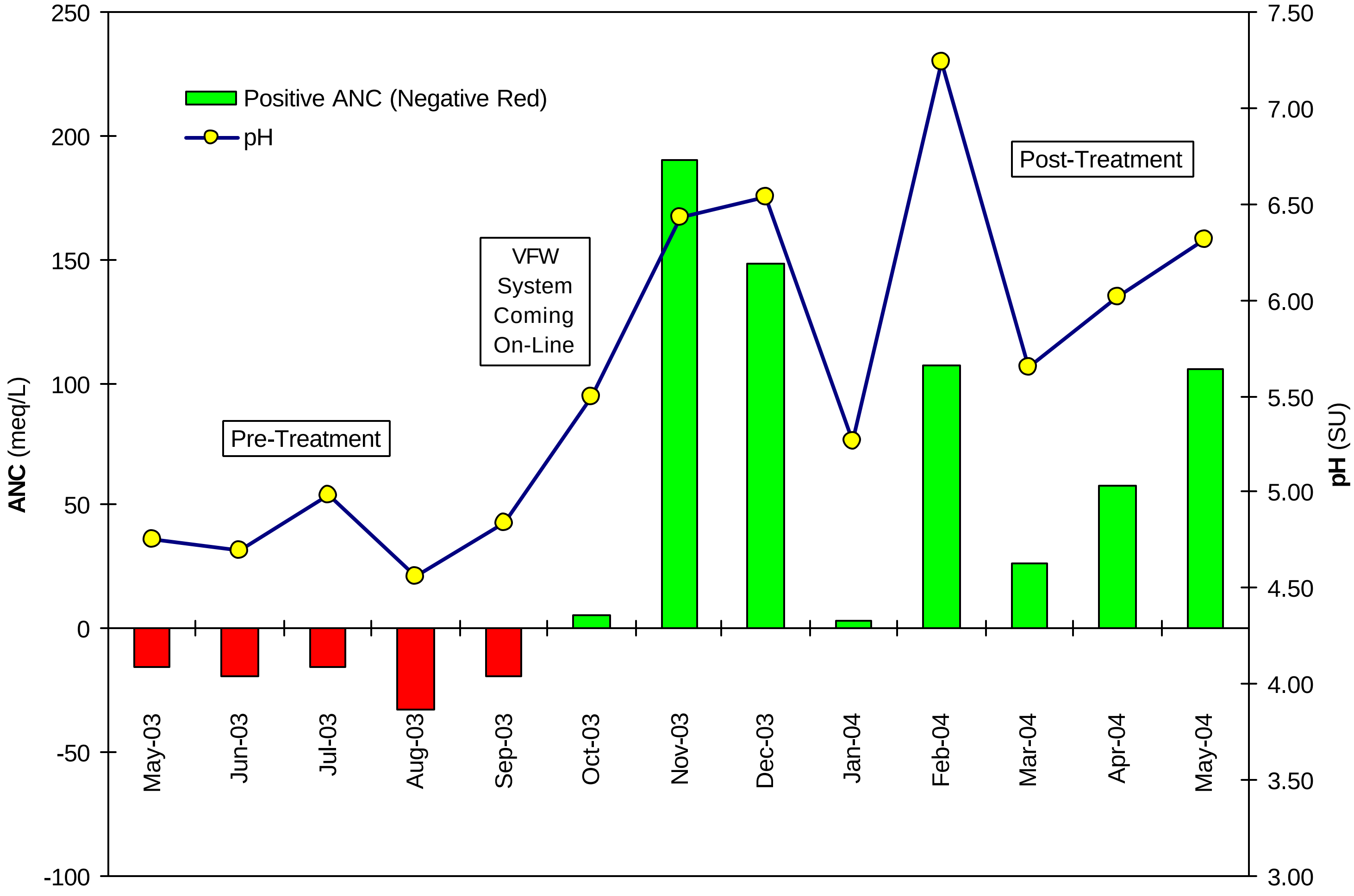

Figure 7 – Downstream ANC and pH Trends in the Duck Marsh Tributary

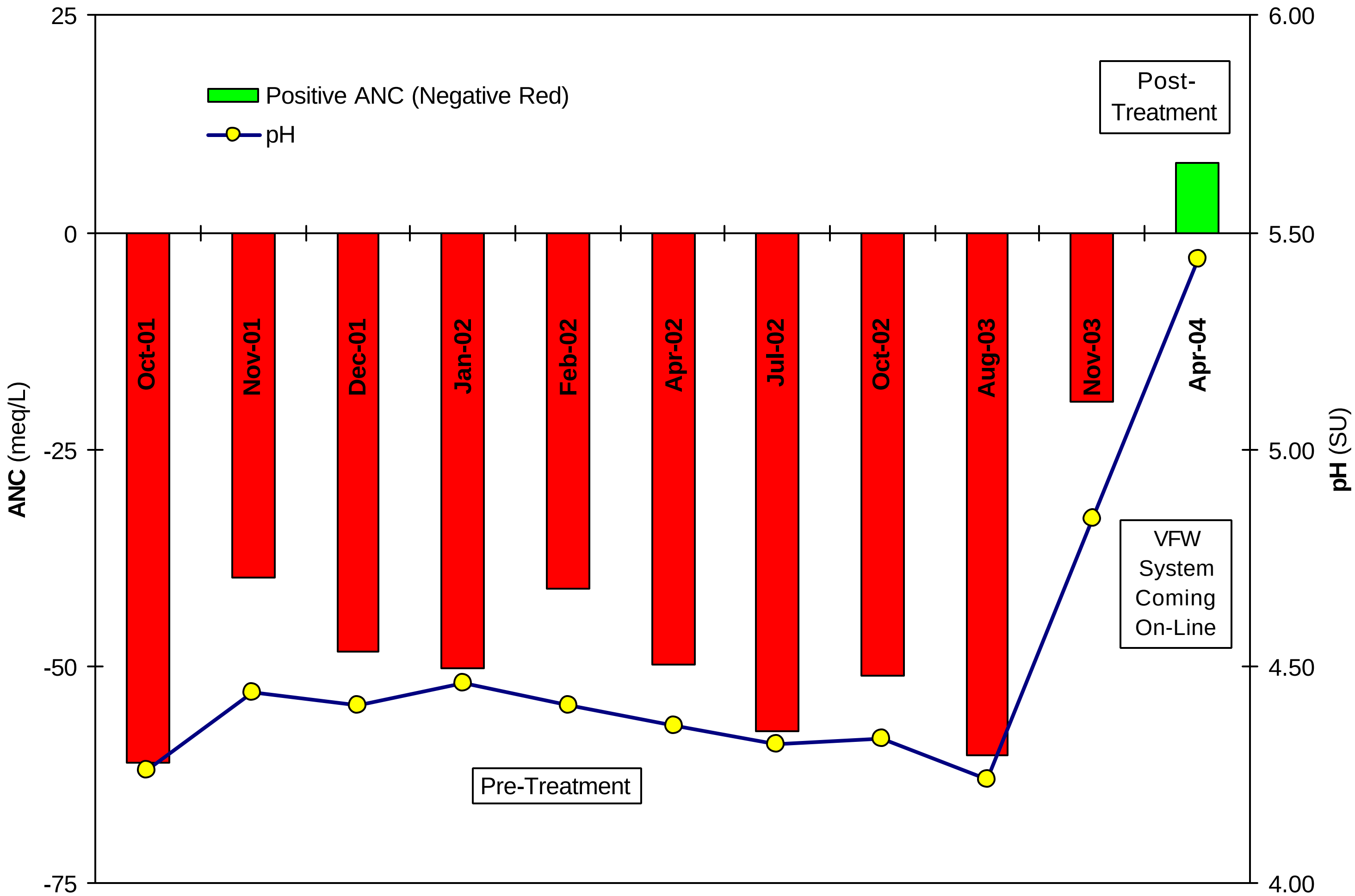

Figure 8 – Downstream ANC and pH Trends in Pebble Run

Figure 9 – Aerial Liming at the Beaver Run Lake

Water Monitoring

As part of Round 3 activities, the watershed-scale monitoring program established under Round 2 was extended to continue the collection of long-term water quality data for prioritization of future acid abatement projects. Fifteen in-stream monitoring points were sampled and measured for flow on five occasions from 2002 to the present. Influent and effluent performance monitoring was also conducted on the two new VFW systems following their construction, and continued for the Ardell system. Penn State is concurrently monitoring six other in-stream points in the headwaters area.

Additionally, pre- and post-liming monitoring was conducted on the Beaver Run lake discharge, and on a culvert draining from a limestone-surfaced road to evaluate water quality improvements resulting from that surfacing practice. The latter indicates that limestone surfacing can result in a considerable ANC increase (459 meq/L) in road runoff despite a relatively short contact time, and an experimental limestone runoff ditch project is being developed in cooperation with the DCNR Bureau of Forestry to further quantify this improvement.

Other Activities

In addition to the lake liming project, the leftover funds from the VFW construction budgets were sufficient to complete the following beneficial activities within the Mosquito Creek watershed:

- An information kiosk was placed at each of the Ardell, Duck Marsh, and Pebble Run VFW sites to explain the function and purpose of the systems and the overall progressive restoration plan. ($2,700)

- Maintenance was conducted on the Ardell lime dosing stream ford to add fresh limestone sand and make minor repairs to the crossing. ($2,200)

- Repairs were made to the culvert at the Ardell VFW site. ($2,750)

- Limestone sand was purchased for the annual in-stream lime dosing by the MCSA on Gifford Run at the Lost Run Road and Merrill Road bridge crossings.($8,000)

- Limestone aggregate and sand will be purchased to construct open limestone stabilization channels along Lost Run Road to evaluate the effectiveness of this approach for runoff neutralization, with in-kind installation labor to be provided by the DCNR Bureau of Forestry. ($15,000)

DISCUSSION

The following provides an analysis of the project costs and discusses the lessons learned and public outreach program.

Cost Analysis

Experience gained from construction of the Ardell VFW under Phase 1 allowed several cost-saving design changes in the Round 3 VFWs. Use of Agridrain water controls simplified plumbing and reduced installation costs. A less expensive MDPE pre-assembled liner was also used in place of a geosynthetic clay liner. Standardization of the design between the two systems provided additional savings. The final costs to construct the systems were $141,123 at the Duck Marsh site and $128,806 at the Pebble Run site, for a total of $269,929. The higher cost for the Duck Marsh system was due to the need to construct a longer access road on that site. In comparison, the Ardell system of equal size cost $212,431 to construct. Construction costs will vary depending on the local site conditions, and the contractor in this case indicated that he had underbid the job to some degree, but it is expected that systems of this scale can be constructed for between $125,000 and $150,000 in most cases.

By pooling the data for the three VFWs, average influent flows are about 80 gpm, and the discharge alkalinity is about 50 mg/L. This equates to approximately 50 pounds of alkalinity generated per day. The ultimate longevity of VFWs receiving clean water is not known, but based on the results from acid mine drainage applications it is estimated to be at least 15 years. Spreading a nominal construction cost of $125,000 over this period yields a cost of alkalinity generated or acidity removed of about $0.46 per pound. The VFW cells contain about 1,650 tons each of limestone. At the current dissolution rates, it would take 90 years for one half of the limestone to be consumed, so a 15-year life expectancy is likely conservative. The alkalinity generation cost for a 50-year system life drops to only $0.14 per pound. Long-term treatment using a chemical system of comparable capacity would cost between $0.50 and $0.80 per pound of acidity removed or alkalinity produced depending on the technology employed[4], so the VFW is a cost-effective alternative.

Lessons Learned

In addition to leaching tannins and foam, there is some concern that VFWs with compost substrates may also generate hydrogen sulfide, with possible adverse effects on aquatic life for a short distance downstream. Vertical flow cells using limestone alone are currently being designed under Round 5, with construction funding requested for Round 6. If found to be effective, elimination of the compost component would improve the quality of the unit discharges and reduce construction costs for similar applications on otherwise "clean" streams.

A second problem noted is the tendency for leaves and debris to be sucked into the inlet pipe at the stream and clog the orifice control. The Pebble Run system is being modified for this reason to place the pipe inlet under a scour pool slightly upstream of the check dam. For the systems being designed under Round 5, an artificial scour pool will be placed below the dam weir, and the inlet pipe will draw from this pool on the downstream side of the dam rather than the upstream side. This and addition of trash guards are expected to eliminate the problem.

Public Outreach

The MCSA holds monthly meetings at the Frenchville clubhouse with presentations regarding the status of these projects and new developments. Informational kiosks have been placed at each of the three VFW systems explaining their purpose and the overall scope of restoration efforts in the watershed. The group also maintains a Web site detailing project activities and outcomes.

CONCLUSIONS AND RECOMMENDATIONS

Additional monitoring is needed to confirm the results achieved by the Round 3 VFW systems and lake liming; however, initial results are very promising. This monitoring will be continued under Round 5 and reported in the Round 4 technology assessment to be completed in 2005. The existing VFW applications have already provided sufficient performance data that application has been made to fund designs of VFWs in the headwaters of Fall Brook, a tributary to the Tioga River that is similarly impacted by acid rain and bog tannin acid. All of the funded technologies applied for the Mosquito Creek projects will eventually be transferable to other Pennsylvania watersheds impaired by non-mine drainage acidity. The following are several specific recommendations related to this work:

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[4] Based on an analysis of 20-year annualized costs for soda ash, ammonia, caustic soda, and hydrated lime treatment contained in Phipps, T. T., J. J. Fletcher, and J. G. Skousen. "Costs for Chemical Treatment of AMD." In: Skousen, J. G. and P. F. Ziemkiewics. Acid Mine Drainage Control & Treatment. West Virginia University and the National Mine Land Reclamation Center. 1995.

- It is recommended that the off-line alkaline addition systems currently being designed under Round 5 be funded, such that the proposed new technologies may become available as alternatives to existing compost-based VFWs and in-stream limestone sand dosing.

- It is recommended that the in-stream water quality monitoring and system input/output monitoring proposed under Round 6 be funded to allow continuation of a long-term database of the watershed characteristics and system performance over time.

- It is recommended that other alkaline addition projects be undertaken in the final headwaters portion of Mosquito Creek to extend the synergistic improvements in pH and ANC in the main stem, potentially creating stockable conditions in the headwaters area downstream to Beaver Run.

APPENDIX A

Project Summary Narrative

Mosquito Creek Phase 3 – Alkaline Addition Implementation Projects

This project involved construction of two vertical flow wetlands to add alkalinity and abate acid rain impacts to the Duck Marsh tributary and Pebble Run in the Mosquito Creek watershed, along with aerial lake liming on Beaver Run and continuation of a watershed-scale monitoring program on other tributaries.

APPENDIX B

Goals and Accomplishments Worksheets