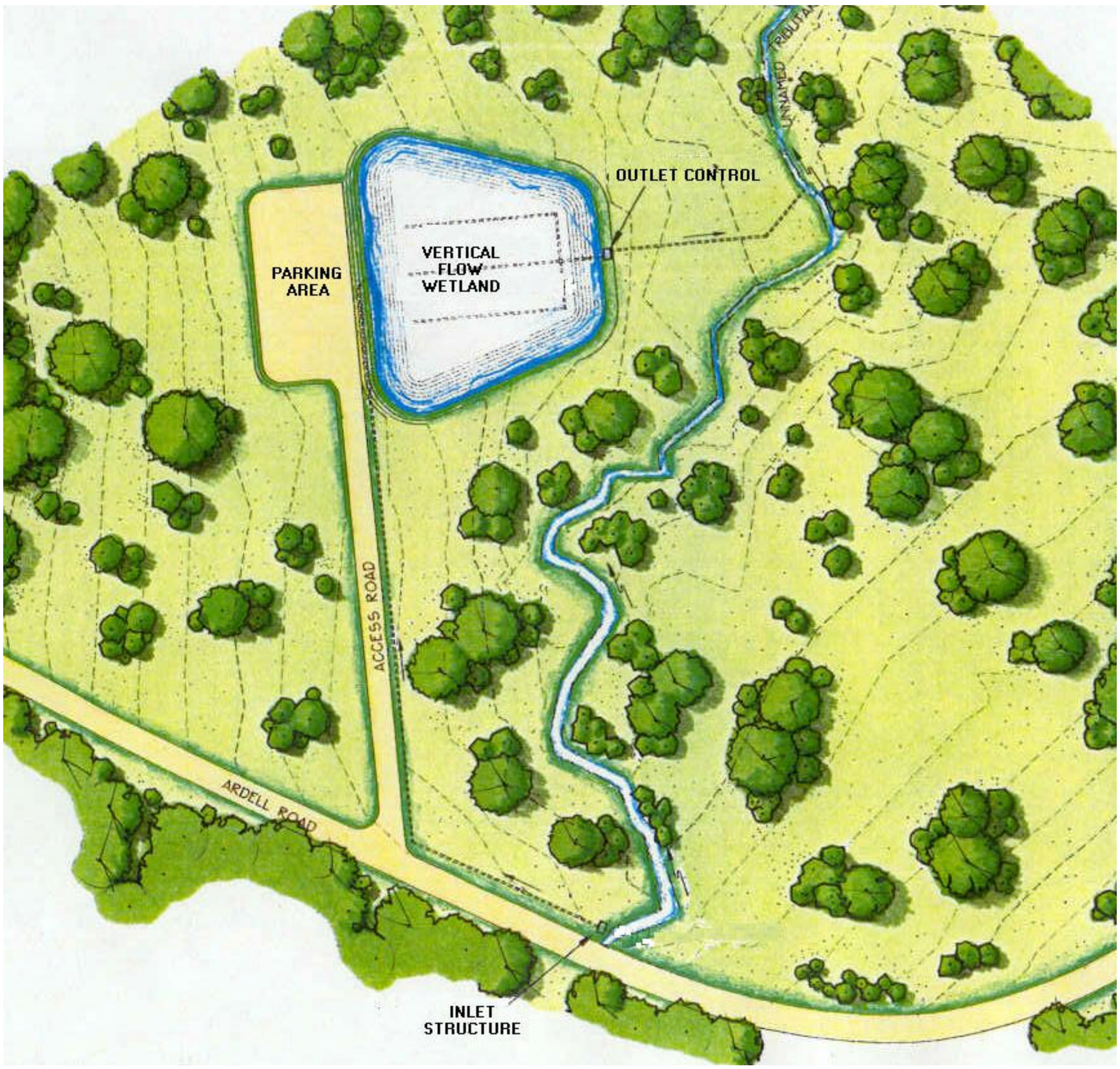
Mosquito Creek Phase 1

ATMOSPHERIC ACIDIFICATION ABATEMENT DEMONSTRATION PROJECTS

FINAL REPORT



Pennsylvania Growing Greener Program

Project No. 3591130

May 17, 2002

Mosquito Creek Phase 1

ATMOSPHERIC ACIDIFICATION ABATEMENT DEMONSTRATION PROJECTS

FINAL REPORT

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INTRODUCTION

The Mosquito Creek watershed, shown by Figure 1, was once a premier trout fishery for Clearfield, Elk, and Cameron Counties, Pennsylvania. Decades of acid rain, however, have severely impacted most of its tributaries and main stem, and remaining populations of trout and other aquatic life are stressed and isolated by acidified runoff. The 90 square mile watershed is dominated by sandstone bedrock, which has no inherent buffering capacity (alkalinity) to neutralize this acidity, and cumulative acidification of the soils is a long-term problem that cannot be immediately corrected by eliminating the source of the acid. Although it is believed that regulation of upwind sources is diminishing atmospheric acid deposition with time, the existing acidification impacts to Mosquito Creek will likely continue for the foreseeable future.

In 2000, the Pennsylvania Growing Greener Grant Program funded the first in a series of projects to develop and implement an organized and long-term restoration plan for Mosquito Creek. This Phase 1 Grant included construction of two demonstration acid abatement projects, including an alkalinity-generating vertical flow wetland (VFW) on an unnamed headwaters tributary crossing Ardell Road, and an experimental lime sand dosing stream ford on the Ardell Dam Road crossing of the Mosquito Creek main stem. Concurrent with this work, Penn State University undertook a separate project to monitor water quality and stream biota before and after these systems were constructed. Construction of the demonstration projects was completed in October 2001, with the water monitoring program continuing until April 2002. This report summarizes the project goals and objectives, design and construction methods, and results and conclusions in reference to the supporting work conducted by Penn State.[1] A short summary narrative of the project is included in Appendix A for Grant program use.

Project Goals and Objectives

VFWs have been used to neutralize acidity in many acid mine drainage (AMD) treatment applications, but have never before been applied to remediate acid rain impacts. The main objective of this Phase 1 project was to construct a VFW on an acidified tributary of Mosquito Creek and to evaluate whether it generates beneficial increases in pH and acid neutralization capacity (ANC). The overall goal of the project was to determine whether VFWs could be an effective technology for remediation of atmospheric acidification impacts. The lime sand ford was not specifically included in the Phase 1 monitoring program, but will be included in the monitoring of future phases. The initial goal for the lime sand ford was to evaluate technical construction feasibility and physical performance results for this technology. Other summary goals and outcomes for these demonstration projects are provided by the Accomplishment Worksheets in Appendix B.

[1] Happel, A. M, and W. E. Sharpe. Mosquito Creek Watershed: Analysis of Streamwater Chemistry and Fish Populations Pre and Post Installation of a Vertical Flow Wetland. Environmental Resources Research Institute, The Pennsylvania State University, University Park, PA. Final Report, April 30, 2002.

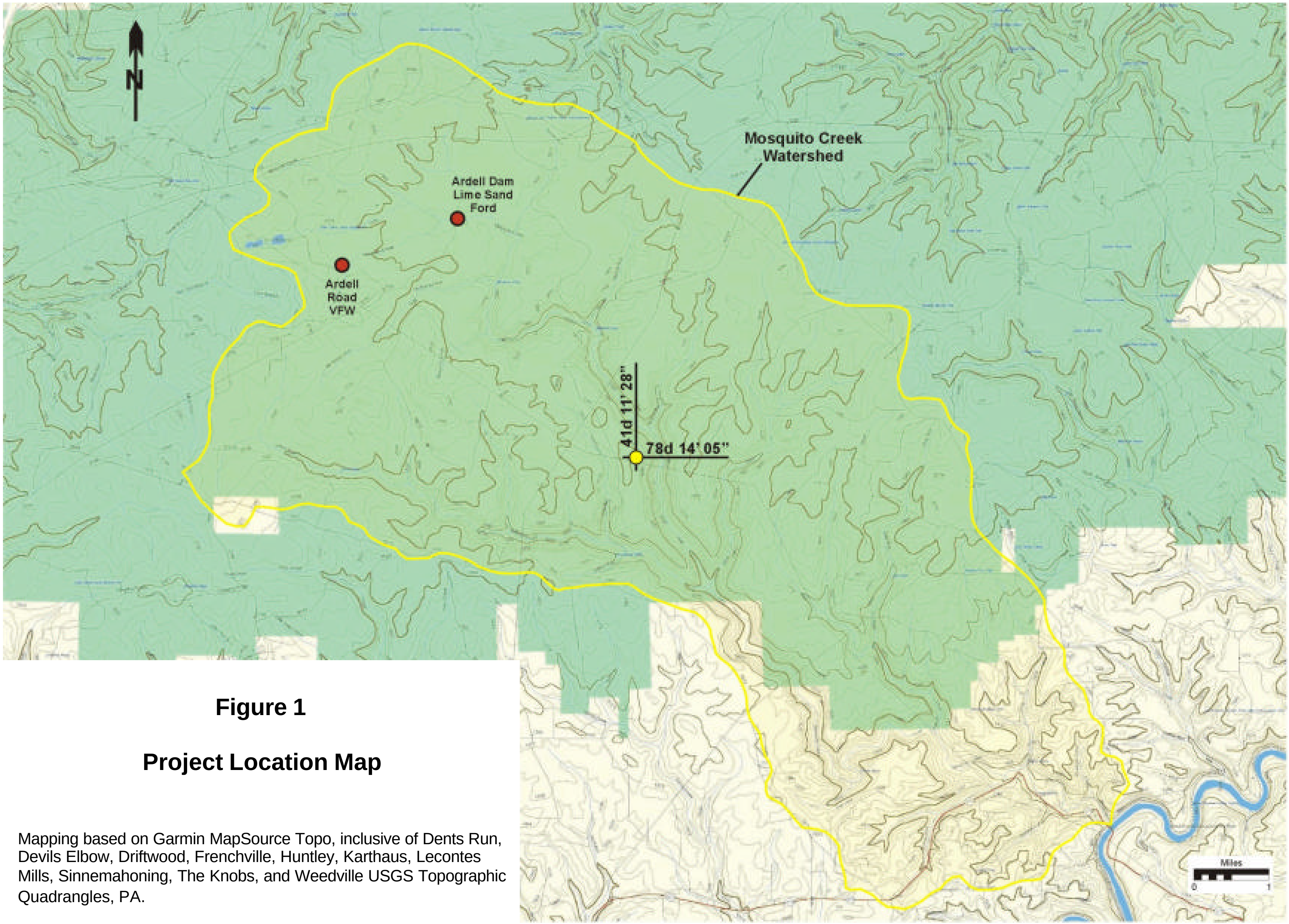


Figure 1

Project Location Map

Mapping based on Garmin MapSource Topo, inclusive of Dents Run, Devils Elbow, Driftwood, Frenchville, Huntley, Karthaus, Lecontes Mills, Sinnemahoning, The Knobs, and Weedville USGS Topographic Quadrangles, PA.

Project Partners

Phase 1 and the other ongoing phases of the overall restoration project have been initiated by the Mosquito Creek Sportsman Association (MCSA), an organization of concerned citizens who have been seeking to restore the quality of Mosquito Creek for over 20 years. With technical support from Gannett Fleming, Inc., the MSCA has completed Phase 1 in partnership with the following agencies and organizations:

Penn State University Environmental Resource Research Institute
Pennsylvania Game Commission
Pennsylvania DCNR Bureau of Forestry
Pennsylvania Fish and Boat Commission
Pennsylvania Department of Environmental Protection
Pennsylvania Department of Corrections Quehanna Boot Camp
Wood Duck Chapter Trout Unlimited
Canaan Valley Institute
Clearfield County Conservation District
USDA Natural Resource Conservation Service

METHODS

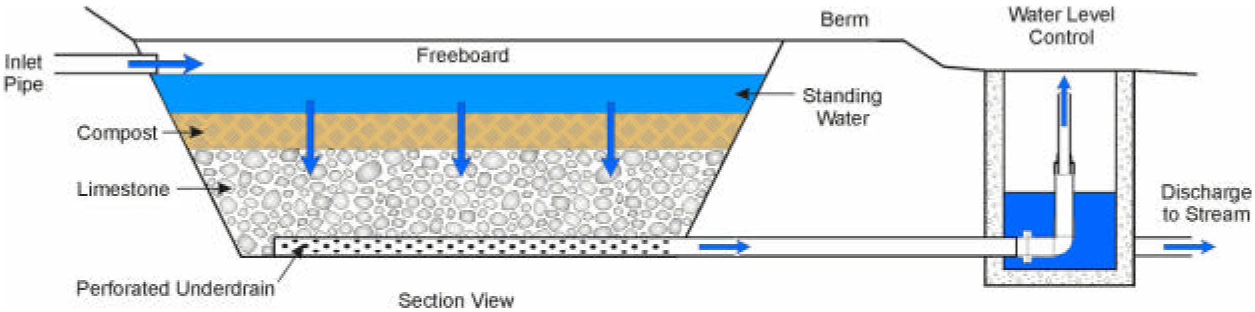
The Ardell Road VFW was designed by Gannett Fleming based largely on methods used for past AMD treatment projects. The Ardell Dam lime sand ford was designed by the Pennsylvania Game Commission based on a conceptual approach for placing and containing lime sand in an in-stream structure. The following summarizes the design and construction approaches used for each of these projects, with representative photographs included in Appendix C, and project design plans in Appendix D.

Ardell Road Vertical Flow Wetland

VFWs are an alkalinity-generating technology originally developed for treatment of AMD discharges. They have also been referred to as vertical flow reactors (VFRs) and successive alkalinity producing systems (SAPS). The Ardell Road VFW is the first known application of this technology to the problem of acidification due to atmospheric deposition.

As shown by Figure 2, a VFW consists of a deep basin filled with a bottom layer of limestone aggregate and a top layer of spent mushroom compost. A foot or more of water then covers the surface of the compost. In AMD treatment systems, the compost serves in part to filter metals precipitates and to inhibit further precipitation by maintaining reducing conditions in the limestone bed. It is also believed that the compost enhances dissolution of the limestone, possibly by increasing dissolved carbon dioxide concentrations. Water is introduced to the top of a VFW and migrates downward through the compost and limestone layers to discharge through a system of underdrain pipes. Dissolution of limestone and bacterial reduction of sulfate in the compost both serve to increase the alkalinity of the water as it passes through the cell. Water levels within the cell are regulated by a control structure at the outlet of the underdrain.

Figure 2 – Typical VFW Section



The Ardell Road site (Photo 1) was selected for the first demonstration VFW based on a screening process that considered many headwaters tributaries throughout the Mosquito Creek watershed. Field screening of sites was conducted in 2000 with the PA DCNR Bureau of Forestry. The primary consideration was selection of a tributary with a stream flow range allowing a reasonable chance of producing environmental benefits from a VFW constructed within the available Grant budget. The site was also required to have ready construction access, avoid existing wetlands to the greatest extent possible, and be positioned to support the cumulative effects of other future restoration activities. The Ardell Road site best met these criteria for the demonstration phase, with the added advantage of having large downstream wetland areas and beaver ponds that could store alkalinity during low flow periods for buffering of higher episodic flows. Background flow monitoring (Photo 2) confirmed the suitability of this site with regards to flow volumes. The Pennsylvania Game Commission was very supportive of the project and approved the use of the site, which is located on State Game Lands.

For design of the Ardell Road VFW, a 4-foot bed of limestone was used with a 2-foot bed of compost and 1-foot cover of open water. Shallow water cover was selected because metals precipitates are not a concern in this setting, and reducing conditions need not be as stringently maintained as for AMD treatment. It was also desired that the cell eventually become vegetated with emergent wetland plants to serve as a long-term source of organic matter as the compost gradually decomposes. The limestone aggregate size corresponds to an AASHTO No. 57 grade (averaging about 1 inch in diameter), which is somewhat smaller than that used for AMD treatment systems. Again, this was in consideration that large volumes of metals precipitates are not anticipated, and that a smaller aggregate size may increase limestone dissolution rates. Results from some previous VFWs treating weakly acidic AMD showed fairly low alkalinity production rates, so it was desired to maximize any production available for the weakly acidic Ardell tributary flows.

Actual VFW cell construction involved excavation of a rough grade basin configuration (Photos 3 & 4), which was the largest achievable on the site within the constraints of topography and existing wetlands. The interior of the cell was then completed using a bentonite mat liner to prevent leakage. Bentonite mat liners are very convenient for this type of installation and are self-sealing for small punctures. Three perforated underdrain pipes were installed on the cell floor with a solid "T" connection to the cell outlet, and the limestone aggregate then spread over the pipes (Photo 5). As a provision for cleaning, the ends of the perforated underdrain pipes were extended to the surface by 30^o elbow fittings, allowing a pump or pressure line to be inserted into the individual underdrain pipes if ever needed. Hand-drilled PVC pipes were used for the underdrains, as clogging problems have been reported for commercial slotted polyethylene pipes used in some previous AMD systems. A coarse polyethylene geodrain mesh was placed on the completed limestone surface prior to placement of the compost to prevent the compost from falling into and clogging the aggregate bed (Photo 6). The completed VFW cell measures approximately 13,500 ft^2 (0.31 acres) at the compost surface (Photos 7 & 8).

The target detention time for the VFW cell was 24 hours on average in the limestone bed, assuming an aggregate void space of about 40 percent. It was calculated from the final design layout that the limestone bed could accommodate about 90 gallons per minute (gpm) of flow at 24 hours detention. To regulate influent flows to this approximate volume, an inlet flow control structure was designed to divert a portion of the flow from the Ardell tributary into the VFW cell. A check dam was constructed across the tributary with a 6-inch rectangular weir incised in its center, and an adjacent concrete control box was then installed with a pipe connection to the dam pool (Photos 9 & 10). A PVC plate divides the interior of the control box, with a second plate bolted to a large hole in its center and having a 3-inch orifice drilled through (Photo 11). The orifice is set with its centerline level with the bottom of the rectangular weir in the dam. In this configuration, the orifice passes the first 20 gpm of stream flow into the VFW, and splits 90 gpm to the cell under average conditions when the rectangular weir is flowing full. The hydraulics of the orifice effectively limit the maximum split to the VFW to 130 gpm under flood flow conditions, preventing damage to the cell from hydraulic overloads. The orifice plate can be replaced with other plates having different orifice sizes if it is desired to alter the flow split to the system.

Inlet flows enter the VFW cell by passing over a gabion basket to dissipate flow energy when the water level in the cell is low (Photo 12). The cell underdrain discharges to a water level control structure consisting of a flanged standpipe with a second smaller interior standpipe supported by a flexible coupling, creating a standing jet flow (Photo 13). The coupling can be loosened to adjust the second pipe up or down inside the first, and the entire structure can be rotated downward by the flange fitting if needed to generate additional driving head in the cell. The final VFW discharge occurs back to the Ardell tributary through a buried pipe.

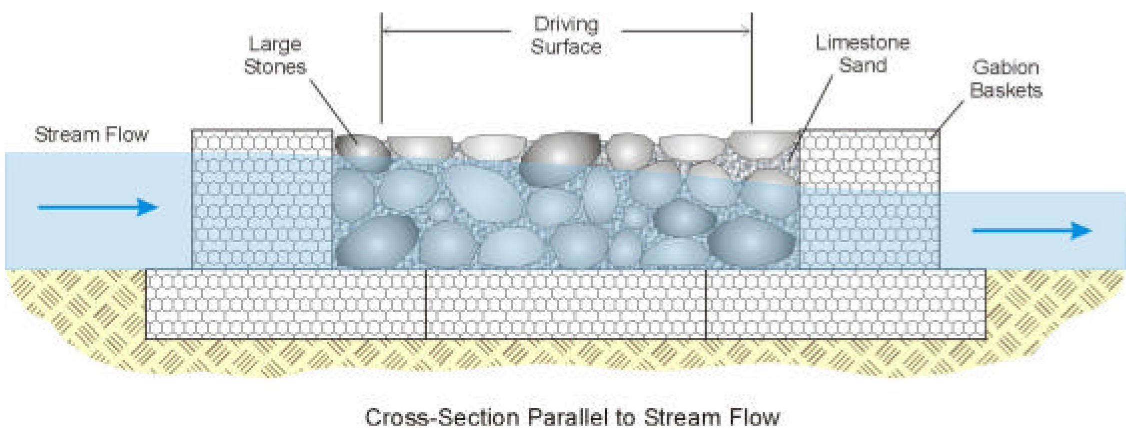
Following completion of construction, the site was stabilized by seeding and planting with a variety of native shrub and tree species. The gravel construction staging area was also improved to provide parking access for the Game Lands (Photo 14), and the overall site forms an attractive, park-like setting along Ardell Road. The final stage of site improvements will include installation of an informational display summarizing the goals, design approaches, and outcomes of the project.

Ardell Dam Lime Sand Ford

The Ardell Dam lime sand ford is based on a simple concept of using gabion structures to stabilize large rock in a stream crossing, allowing finer limestone aggregate or lime sand to be poured into the void spaces in contact with flowing water. Presumably, this would act as a type of dosing structure, with fine limestone periodically flushed out by high flow events. Mechanical abrasion from vehicle traffic would aid in grinding new fines, and limestone could be replaced as needed by simply dumping from a truck and spreading into the voids.

As shown by Figure 3, the completed Ardell Dam lime sand ford consists of a basal gabion mat with two parallel rows of gabions leaving an open core channel. This channel was filled with coarse rock (6 to 12 inch diameter) to form the rough crossing surface. Lime sand was then spread on the coarse rock and worked into the void spaces to form the travel surface. A stockpile of lime sand was left by the construction contractor adjacent to the ford for future applications. Photos 15 – 18 show the Ardell Dam site before, during, and after construction.

Figure 3 – Typical Section of Ardell Dam Lime Sand Ford



RESULTS

In conjunction with the water quality and aquatic life monitoring conducted by Penn State, the two demonstration projects have been closely monitored during and after construction with regards to practicality of design approaches and physical performance results. The following summarizes the water quality results and performance inferences available at the conclusion of the Phase 1 activities.

Water Quality Improvements

The monitoring program conducted by Penn State indicates that the Ardell Road VFW is producing significant water quality improvements in the Ardell tributary from the system discharge to the confluence with Mosquito Creek. The pH in the tributary immediately below the system discharge has increased to 6.5 SU on average compared to 5.3 SU prior to treatment, with ranges between 6.2 SU and 7.1 SU observed. At its confluence with Mosquito Creek, the tributary pH has increased to 6.0 SU on average compared to 4.7 SU prior to treatment, with ranges of 5.6 SU to 6.9 SU observed. A slight, but still significant improvement is noted in the Mosquito Creek main stem as far downstream as the Ardell Dam Road crossing (5.0 SU versus 4.7 SU prior to treatment), despite poor quality contributions from other headwaters tributaries.

In terms of ANC improvements, a positive ANC is now consistently observed in the Ardell tributary from the VFW discharge to the confluence with Mosquito Creek. ANC has averaged 317 meq/L immediately below the system discharge since its construction, with ranges of 136 meq/L to 688 meq/L observed, compared to an average of 18 meq/L prior to treatment. At its confluence with Mosquito Creek, the tributary ANC now averages 37 meq/L, with ranges of 9 meq/L to 98 meq/L observed, compared to –22 meq/L prior to treatment. Again, a slight, but still significant increase in ANC has been observed in the Mosquito Creek main stem above the Ardell Dam Road crossing (-9 meq/L versus –22 meq/L prior to treatment), although the ANC at that location remains negative on average. It is generally assumed that a positive ANC will support aquatic life, even if the pH temporarily decreases below 6 SU. In that case, and if the observed improvements continue over time, this project will have restored aquatic life habitat in approximately 8,500 feet (1.6 miles) of the Ardell tributary, and provided preliminary improvements in approximately 3,500 feet (0.7 miles) of the Mosquito Creek main stem.

No specific water quality monitoring has been conducted yet for the Ardell Dam lime sand ford, although sampling is planned under Phase 3. The one monitoring point on Mosquito Creek downstream of Meeker Run does show a very slight increase in average pH relative to pre-treatment conditions, but this is not statistically significant and cannot be differentiated between treatment effects or normal annual fluctuations. It is not assumed that either of these projects have restored aquatic life habitat in any portions of the Mosquito Creek main stem, but they are believed to provide low level improvements that could augment future alkaline addition projects in the watershed.

Aquatic Life Improvements

Electrofishing population surveys were conducted by Penn State before and after VFW construction at the six water quality sampling points: the Ardell tributary above Ardell Road, immediately below the VFW discharge, and at its confluence with Mosquito Creek; and Mosquito Creek above its confluence with the Ardell tributary, above the Ardell Dam Road, and below Meeker Run. Before treatment, no brook trout were found at any of the points, and only six fish were found overall: one chain pickerel above the Ardell Dam Road, and two chain pickerel and three bullhead catfish below Meeker Run. Both species are fairly tolerant of acidic conditions. After installation of the VFW, a chain pickerel and two bullhead catfish were found in the Ardell tributary at its confluence with Mosquito Creek. Eleven brook trout (eight young-of-the-year) and sixteen white suckers were also found below Meeker Run, but these are not believed to be related to any effects of the treatment projects. It was concluded that although the water quality has improved in the Ardell tributary, more time is needed for sustainable fish populations to develop. However, the presence of fish where none were previously observed in the tributary is a positive indication that such populations could develop in the future.

Vertical Flow Wetland Performance

Input/output monitoring of the Ardell Road VFW will be conducted under Phase 3 of the project once the cell has had time to mature and the most soluble alkaline materials have been flushed out. A preliminary sample collected from the cell discharge after eight months of operation showed an alkalinity of 85 mg/L and an ANC in excess of 1700 meq/L, indicating that the VFW is producing alkalinity on a par with previous AMD applications. The influent acidity on this date was 24.5 mg/L, equating to a net alkalinity production of approximately 110 mg/L.

The inlet flow control structure has been remarkably efficient at regulating the system input despite wide variations in the main stream flow. System flows have been observed to average 96 +/- 12 gpm for a main stream flow range of 200 gpm to over 3,500 gpm. This control will allow for very accurate measurement of system performance over time. The only complication with the flow system to date is the adjustable water level control for the system outlet. Following construction, it was found that the slip-fitting pipe was rather difficult to adjust while water was passing through the cell. Future designs will use a commercial water level control structure that employs removable stop logs instead of adjustable pipes.

Assuming that the Ardell Road VFW produces a net alkalinity increase of about 110 mg/L at average flows of 96 gpm, this equates to an average alkalinity generation rate of about 127 lbs/day as $CaCO_3$ (limestone). Assuming that the limestone used in the system is about 85 percent pure and weighs about 90 lbs/ft^3, this equates to 1.66 ft^3 of limestone consumed every day. The VFW cell contains about 47,250 ft^3 of limestone, so it would take nearly 80 years to completely dissolve it at this rate. The actual project intent was to provide at least 15 years of treatment, so the system has the capacity to meet this goal and beyond.

Lime Sand Ford Performance

As with the VFW, performance monitoring around the Ardell Dam lime sand ford will be conducted under Phase 3. Observations following construction indicate that this type of delivery system may not be as efficient as originally intended. The initial cover of lime sand was washed out of the crossing by high flows during the first winter following construction, leaving little fine limestone in contact with flowing water. Also, a dense growth of algae has covered the upstream face of the gabion baskets, preventing flows from passing through the structure in contact with residual limestone. The algae has colonized the downstream channel as well, suggesting that its growth is promoted by the local alkalinity increase, and that this may be a problem encountered by other structures of this nature. Overall, the Ardell Dam lime sand ford is performing below design expectations, but is believed to still provide some acid neutralization benefit.

DISCUSSION

The following provides a summary of the project costs, public outreach program, and ongoing phases of the overall restoration plan being conducted for Mosquito Creek under the Growing Greener Program.

Cost Analysis

The original construction budget for the Phase 1 Grant was $250,000. Actual construction costs were $212,431 for the Ardell Road VFW and $10,604 for the Ardell Dam lime ford, for a project total of $224,835. Because of the lower construction costs, it was possible to transfer $20,000 from the original construction budget to the contractual budget to cover additional analyses and management of project aspects. Overall, the project budget was found to be reasonable for completion of the intended work. However, it is recognized that the associated Penn State monitoring project should have had additional funding for input/output monitoring of the VFW cell immediately following construction to better document system maturation.

As discussed, the Ardell Road VFW is predicted to produce an average of 127 lbs/day of alkalinity for at least 15 years, equating to nearly 700,000 pounds (350 tons) of alkalinity over the intended system life. Dividing the total VFW construction cost by this figure yields a treatment cost of about $0.30 per pound of acidity removed or alkalinity produced using this technology. 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[2], so the VFW is a very cost-effective alternative. In terms of stream restoration length, if it is assumed that aquatic life conditions have been restored in 1.6 miles of the Ardell tributary, the restoration cost equates to about $8,850 per mile of stream per year over 15 years. A 1995 Pennsylvania Fish Commission study[3] valued losses to recreational fishing from AMD impacts on wild trout streams at approximately $23,400 per mile per year, so the cost of restoration of comparable habitat in the Mosquito Creek watershed is substantially on the positive side of the cost/benefit balance.

No formal cost analysis has been conducted regarding the Ardell Dam lime sand ford, pending collection of monitoring samples under Phase 3. However, the cost of constructing the ford was very minor for creation of a stabilized, long-term crossing structure. The costs of utilizing limestone in future crossings would be relatively small, and may yield environmental benefits outweighing the costs of importing materials.

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[2] 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. <u>Acid Mine Drainage Control & Treatment</u>. West Virginia University and the National Mine Land Reclamation Center. 1995.

[3] Arway, John. A. "Scope of Nonpoint Source Pollution Problem." Presented at the Mine Drainage & Watersheds Conference, Clarion University of Pennsylvania, Clarion, PA. June 1 – 3, 1995.

Public Outreach Program

With assistance from Gannett Fleming, the MCSA has initiated an active information dissemination progress to keep the public informed of the progress of these projects and other phases of the ongoing restoration efforts. This has included participation in meetings with the public and elected officials, and development of informational fliers for general distribution. Samples of these informational materials are contained in Appendix E. As noted, an informational display (Figure 4) will be constructed at the Ardell Road VFW site to summarize the goals and technologies of that system. A Phase 4 Grant application has also been submitted to prepare a comprehensive project report for this and other project phases. If funded, this report will provide perhaps the most important form of information dissemination by providing permanent project documentation and guidance for future projects of this nature in other watersheds impacted by atmospheric acidification.

Ongoing Project Phases

Since initiation of activities in 2000, the Mosquito Creek watershed has received two additional Growing Greener Grants, and another application is currently under review. Phase 2 of the ongoing project has involved water quality and flow monitoring on major tributaries throughout the watershed to determine the true extent of acidification impacts and provide reliable data for siting and design of future restoration projects. Results from this phase, to be completed in 2002, will be used to develop a progressive restoration plan for the Mosquito Creek watershed to prioritize restoration activities for the maximum environmental benefit. Figure 5 provides an example of the progressive restoration plan conceptually developed for the Mosquito Creek headwaters.

Phase 3 activities will begin in 2002 with determination of the next most appropriate restoration projects in the watershed, followed by construction of two treatment systems in 2003. Current conceptual activities include construction of one or two additional VFWs in the Mosquito Creek headwaters, and possibly a high flow limestone diversion channel elsewhere in the watershed. Penn State will be participating again in an expanded performance monitoring program, and will oversee an experimental project to evaluate the effects of surface lime applications to forest soils and riparian wetlands. Monitoring of these projects will continue until 2004.

The Phase 4 application currently under review would fund development of a comprehensive project report to detail the activities and outcomes of the previous phases. This would include assessment of the effectiveness of the remediation approaches used for Mosquito Creek, guidelines for the design and implementation of these technologies in this and other acidified watersheds, and an analysis of remediation costs and benefits for the respective approaches. If funded, this report would be completed by 2005.

Figure 4 – Ardell Road VFW Public Information Display

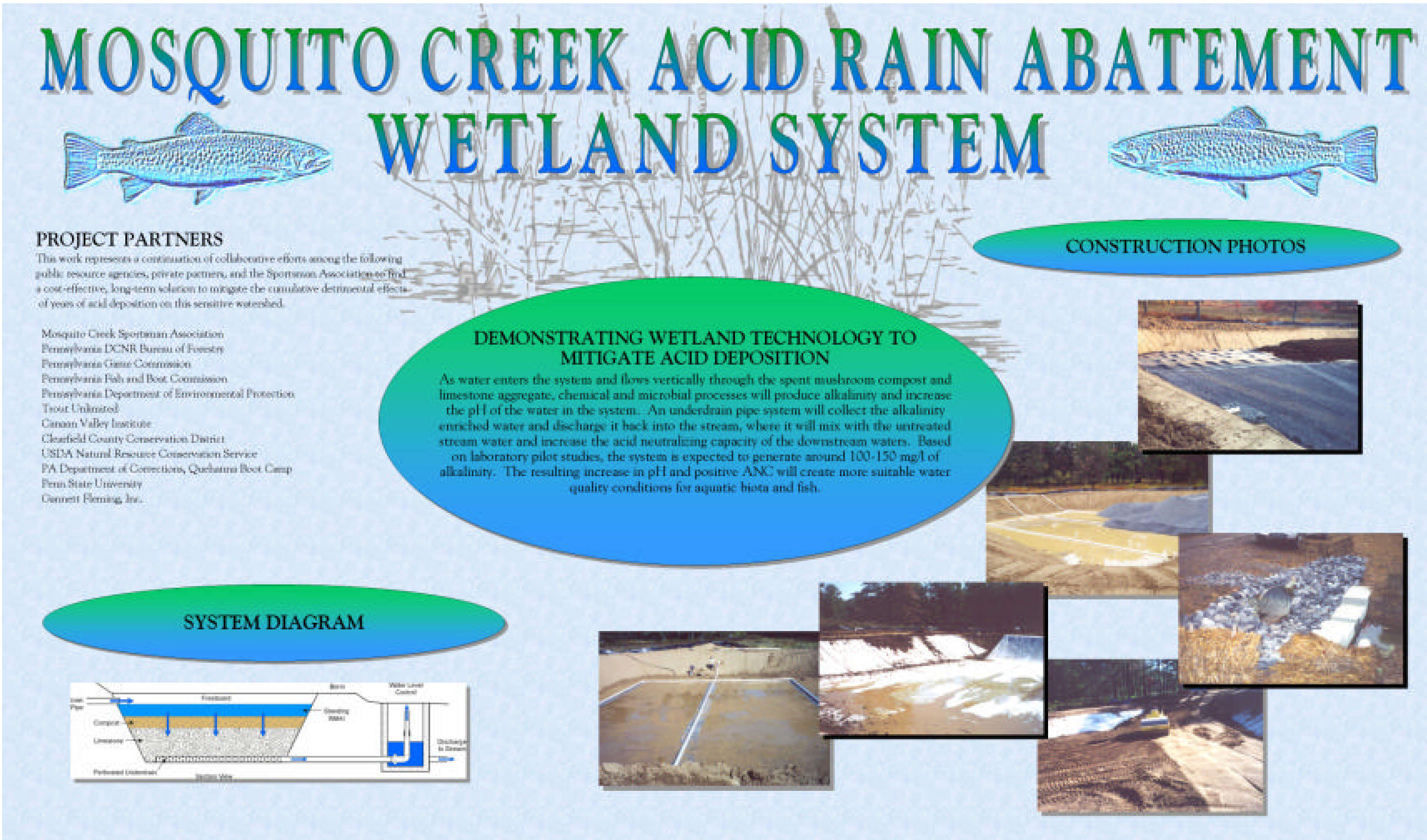
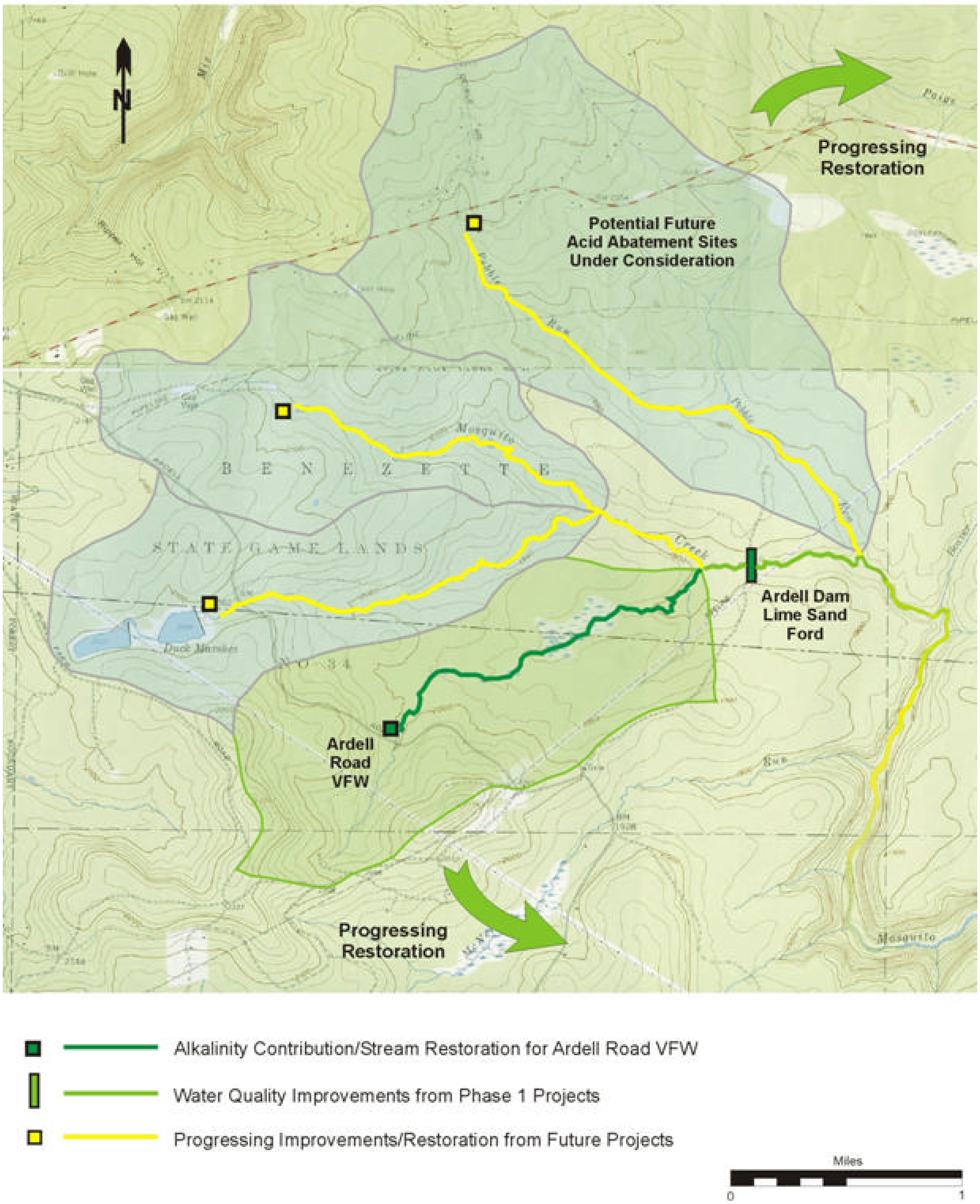


Figure 5
Mosquito Creek Headwaters
Conceptual Progressive Restoration Plan



CONCLUSIONS AND RECOMMENDATIONS

The Ardell Road VFW has demonstrated that this passive treatment technology is applicable and effective for the abatement of stream acidification related to atmospheric deposition. The project restoration costs are less than for comparable chemical treatment alternatives, and very economical in consideration of the potential rewards to the community through increased recreational functionality of the affected stream. VFWs installed in these types of acid rain impact settings can be long-lived, require little maintenance, and blend well with natural surroundings. It is recommended that additional study be undertaken to better quantify alkalinity generation versus flow as a possibly means of optimizing VFW sizing. The breakeven point is not yet known between decreasing alkalinity concentration with decreasing detention time, and increased alkalinity loading production with increased flow through the system. Although such studies are currently unfunded, the Ardell Road VFW has the capability for inlet flow variation with very good volumetric control, and would make an excellent test bed for future performance studies.

It is noted that VFWs do have limitations to application, and that they may not be sufficient for complete watershed restoration as a stand-alone technology. The largest practical VFW to construct is about one acre in size, equating to a treated flow capacity of about 250 gpm on average. Dilution factors must be determined on an individual site basis to size actual treated flow splits, but for water of the quality seen at the Ardell site, a one-acre VFW would only be capable of reliably treating a stream flow averaging about 1,000 gpm. Restoration of larger flows would require multiple VFWs, possibly spaced throughout the watershed rather than concentrated at one point. Phase 3 of the ongoing restoration project plans to test this concept by constructing another VFW system in the headwaters of Mosquito Creek to evaluate any synergistic effects of multiple, small treatment projects on the combined downstream flow. If funded, an in-depth development of sizing constraints, unit treatment costs, and prediction of results will be conducted under Phase 4.

The Ardell Dam lime sand ford shows less conclusive results, but is interpreted to represent a benefit to the stream environment. Although not included as part of this current study, Penn State has observed that use of limestone in general road surfacing projects can produce alkaline runoff and locally improve water quality. Modifications to the lime sand ford concept may yet produce an efficient in-stream lime sand delivery system, and use of limestone is recommended for all stream crossing and road surfacing projects within the Mosquito Creek watershed. This approach may be evaluated further in future phases of the ongoing project.

Operation and maintenance plans for the two Phase 1 demonstration projects are included in Appendix F. In addition to the observations made regarding the specific technologies evaluated, there are several general conclusions and recommendations that have developed over the course of the Phase 1 project, summarized as follows:

- Treatment projects should be mutually supportive within the overall scope of a watershed restoration program, preferably creating progressive contiguous habitat improvements rather than isolated cases of restoration.

- Costs in general for remediation of acid rain impacts will be less than those of treating AMD impacts due to the lower overall alkalinity deficit and metals concentrations associated with acidification from atmospheric sources. Greater extents of stream restoration may be achievable for the same investment by focusing on areas of acid rain impacts.

- Treatment projects should be constructed by experienced contractors and monitored during construction by qualified individuals. Effective return on investment of restoration dollars requires tight quality control during the construction stage.

- Monitoring parameters for streams acidified by atmospheric deposition should include alkalinity as well as ANC and acidity. Alkalinity is a better measure for use in physical sizing of systems and design performance predictions, while ANC appears to be a better measure of overall stream health.

- All monitoring programs <u>must</u> include concurrent flow measurements with collection of water quality samples. Sizing of acid abatement systems is based on flow capacity and required acid loading reductions in streams, both of which require flow data to determine.