EAST BRANCH FISHING CREEK WATERSHED ACID DEPOSITION ASSESSMENT AND RESTORATION PLAN

COLUMBIA AND SULLIVAN COUNTY, PENNSYLVANIA

FINAL REPORT

FISHING CREEK WATERSHED ASSOCIATION

In Cooperation with

THE COLUMBIA COUNTY CONSERVATION DISTRICT

A PADEP Round 6 Growing Greener Project

EAST BRANCH FISHING CREEK WATERSHED ACID DEPOSITION ASSESSMENT AND RESTORATION PLAN

FINAL REPORT

Prepared for:

Fishing Creek Watershed Association
702 Sawmill Rd., Suite 204
Bloomsburg, PA 17815

In Cooperation With:

The Columbia County Conservation District
702 Sawmill Rd., Suite 204
Bloomsburg, PA 17815

Prepared by:

Water's Edge Hydrology, Inc.
800 Leonard Street, Suite 2
Clearfield, PA 16803

Terry A. Rightnour, PH, PWS, CEP, Project Manager
Kevin L. Hoover, PG, PHGW, PWS, Principal Investigator
Holly Martinchek, Environmental Scientist

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Current Contact Information: Water's Edge Hydrology, Inc. P.O. Box 868, Clearfield, PA, 16830. 814-592-2216.
trightnour@wehydro.com or khoover@wehydro.com – http://wehydro.com

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EXECUTIVE SUMMARY

The East Branch Fishing Creek watershed, located in Sullivan and Columbia Counties, Pennsylvania, is adversely impacted to varying degrees by atmospheric acid deposition, or acid rain. Under a Pennsylvania Growing Greener Grant, a study was conducted by the Fishing Creek Watershed Association in cooperation with the Columbia County Conservation District to identify acidification problem areas and quantify potential alkaline addition requirements to restore impacted reaches. The study consisted of an in-stream water quality and flow monitoring program conducted at 20 sample points between April 2004 and September 2006, including an assessment of forest liming activities performed by Penn State University in the headwaters.

Results show that acidification impacts occur throughout the watershed. The lack of inherent alkalinity of the bedrock geology is a large contributing factor to the acidity of the watershed. Although not assessed as part of this study, tannin (bog) acidity may also be a portion of the overall acidification problem. An assessment was made of the extent of acidification, types of acidification present (sustainable, episodic, and chronic), degree of acidity loading and alkaline deficiency in each stream, and potential downstream effects of alkaline addition activities. Episodically and chronically acidified streams are most in need of alkaline addition.

A review was conducted of potentially applicable alkaline addition technologies, including vertical flow wetlands, high flow buffer channels, forest liming, road liming, and in-stream limestone sand dosing. It was concluded that the majority of the streams have at least one applicable technology capable of improving water quality. A progressive restoration plan was developed to provide a suggested sequence of progressively achievable alkaline addition projects resulting in measurable environmental benefits. Heberly Run was recommended as being the most effective starting point for restoration efforts.

The total cost of implementing the progressive restoration plan for the East Branch Fishing Creek watershed is estimated at approximately $1.8 million over a 15 year period. The annualized cost per mile equates to about $4,700 and is well below the $30,000 in recreational losses estimated for acid-impacted fisheries.

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INTRODUCTION

The East Branch of Fishing Creek is a freestone stream located in Sullivan and Columbia Counties, Pennsylvania. The surrounding region of the North Mountain Plateau and the glaciated portion of the Allegheny High Plateau physiographic provinces have been impacted by atmospheric acid deposition (acid rain) for decades, resulting in stream impairment. As shown by Figure 1-1, the watershed is situated within the 4.5 - 4.6 SU rainfall pH zone. Bedrock in this region is largely deficient in neutralizing alkalinity, and areas of natural tannin-based (bog) acidity are present, leaving watersheds susceptible to long-term acidification and water quality degradation. A study completed by the Pennsylvania Fish and Boat Commission (PFBC) has shown depleted or extirpated fish populations because of this effect. The watershed has also been classified as impaired by atmospheric-deposition metals on the 303d list. Historic sampling indicates that portions of East Branch Fishing Creek and its tributaries have become acidified, but a systematic assessment of water quality and flows was not previously available to quantify these impacts.

To determine existing stream conditions and identify areas where acid abatement activities might be beneficial, a watershed-scale assessment has been undertaken by the Fishing Creek Watershed Association (FCWA) using a Pennsylvania Growing Greener Grant sponsored by the Columbia County Conservation District (CCCD). The monitoring program consisted of 20 in-stream sample points, with 13 to 21 sample rounds collected between April 2004 and September 2006. Eight points collected additional data to characterize water quality before and after an ongoing study by the Pennsylvania State University (PSU) on land application liming in the headwaters of Heberly Run. The study area watershed, streams, and regional topography are shown by Figure 1-2.

East Branch Fishing Creek Watershed Facts

Drainage Basin:	Susquehanna/Elk River
Drainage Area:	19.5 square miles
State Game Lands:	12.5 square miles
Study Area Stream Miles:	34.2 miles
Classification:	High Quality – Cold Water Fisheries

Figure 1-1: East Branch Fishing Creek Location Relative to State Rainfall pH (2003)

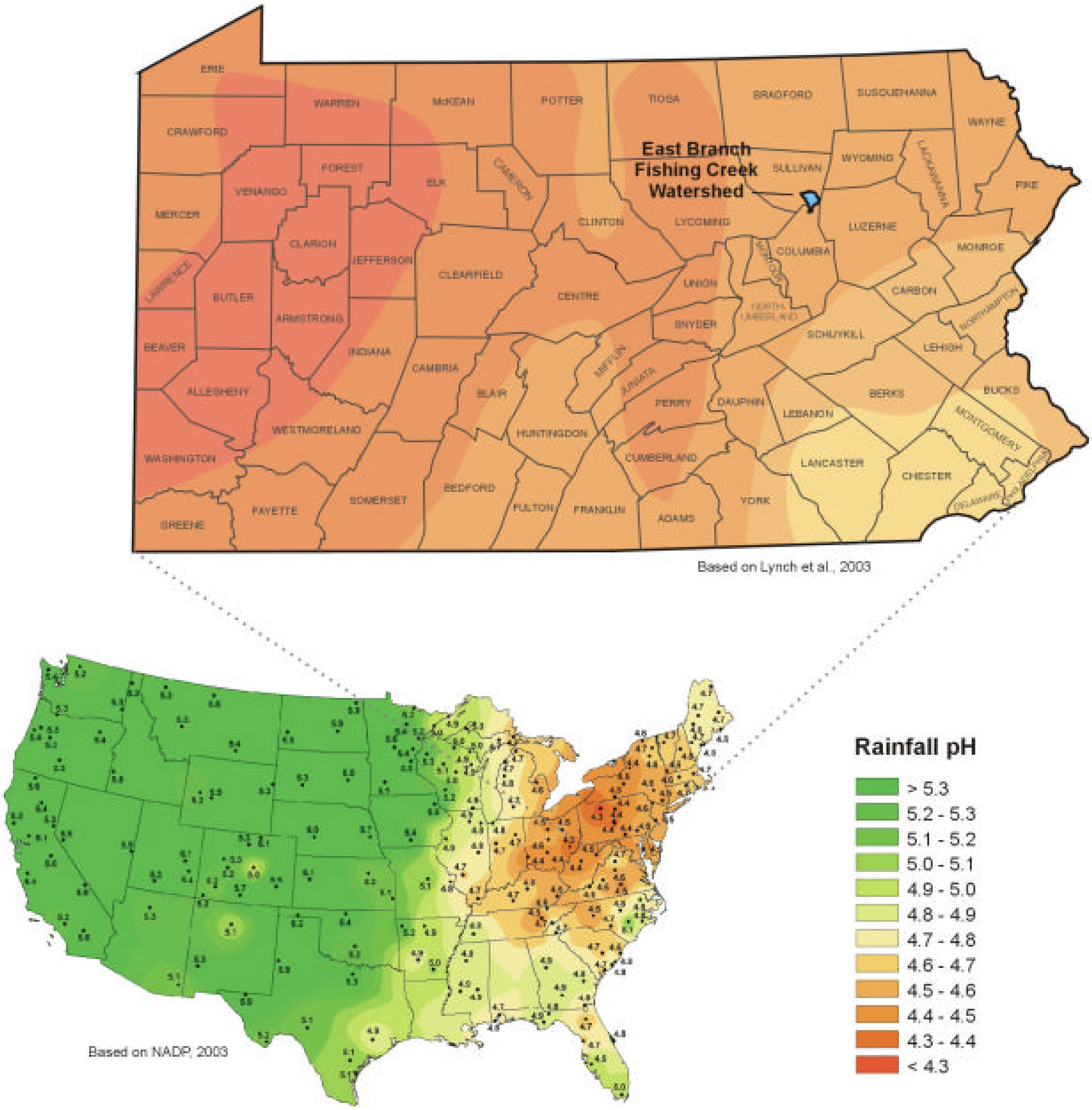
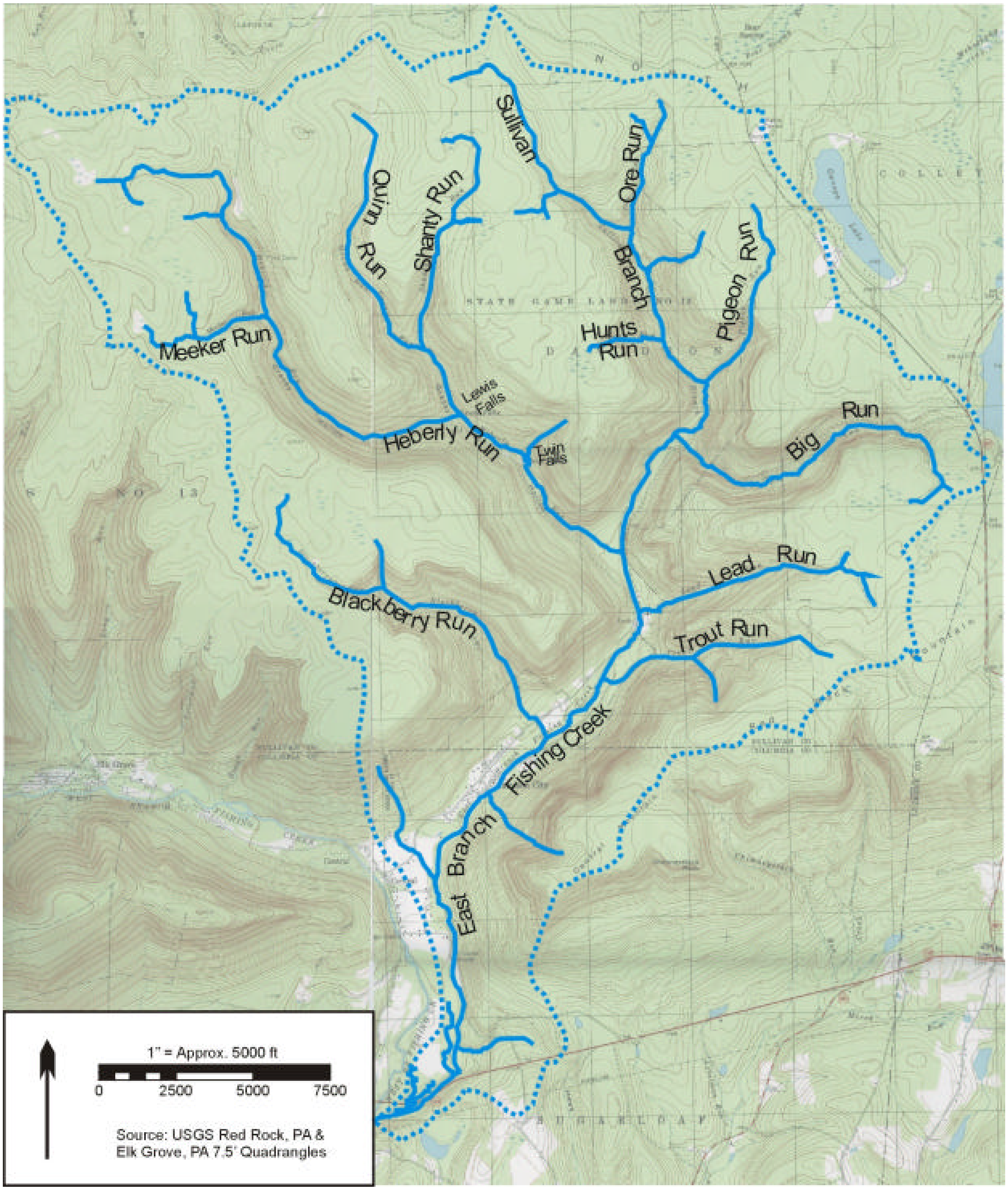


Figure 1-2: East Branch Fishing Creek Watershed Map



The monitoring results were analyzed to determine types of stream acidification impacts (sustainable, episodic, or chronic), influence of bedrock geology, degree of alkaline deficiency in adversely affected streams, and potential effects of acid abatement. Conceptual alkaline addition options were reviewed to address adversely impacted streams, and a progressive restoration plan was developed with a suggested course of acid abatement activities in the East Branch Fishing Creek watershed. This report summarizes the results of this study and provides recommendations for future work in support of the restoration plan.

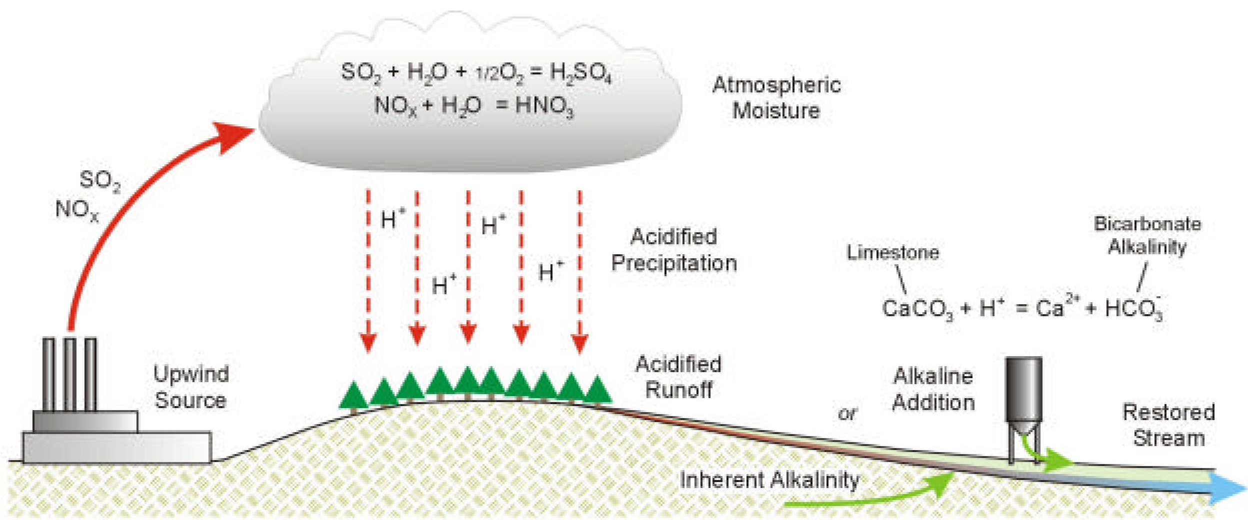
OVERVIEW OF ACID DEPOSITION

Acid deposition, commonly known as "acid rain," occurs when volatile compounds such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are released to the air and react with atmospheric moisture to form dilute sulfuric (H_2SO_4) and nitric (HNO_3) acids. Acid is returned to the ground as rain and snow, where it reduces the pH of soils and streams and can damage aquatic habitats. Some watersheds contain sufficient inherent alkalinity to neutralize the excess acidity and are not significantly impacted. Others, like East Branch Fishing Creek, are poorly buffered and exhibit poor water quality, and are unable to sustain a viable aquatic ecosystem. Figure 1-3 illustrates this basic process.

As shown by Figure 1-1, acid deposition is a widespread problem in the Mid-Atlantic and New England states, particularly in the Appalachian highlands. Northeastern Pennsylvania, including the East Branch Fishing Creek watershed, receives rainfall with some of the lowest pH in the nation. The primary sources of acidity affecting Pennsylvania are electric power generation and other industrial discharges upwind in the Great Lakes region and Ohio River Valley. The Clean Air Act Amendments of 1990 require that 1980 SO_2 emission levels from electric power plants be cut in half by the year 2010, and an increasing trend in rainfall pH has been observed since emission controls were enacted. However, damage to soils and the buffering capacity of watersheds by acidification is a long-term impact that is not readily corrected by eliminating the source alone. In many watersheds, alkaline addition activities will be necessary until such time as a sustainable buffering capacity and rainfall acidity level can be restored.

One characteristic of acid waters is the presence of elevated concentrations of dissolved aluminum. Aluminum is the third most abundant element in the earth's crust and under buffered soil conditions remains essentially immobile. Acid rain, however, can increase the mobility of aluminum and greatly increase the concentration transported into streams. The elevated levels of aluminum can be toxic to fish and other aquatic organisms; the collection of aluminum on their gills limits the intake of oxygen and other important nutrients. To protect aquatic organisms the Environmental Protection Agency recommends that the four-day average concentration of aluminum should not exceed 0.087 mg/L more than once every three years or 0.750 mg/L over one hour when the ambient pH is between 6.5 and 9.0 SU.

Figure 1-3: Acid Rain Formation, Deposition, and Neutralization



The concentration and speciation of aluminum in streams can vary, being dependent on the chemical composition of soils, geology, the pH of infiltrating water, and the presence of natural tannin-based (bog) acidity in the headwaters of a stream. The equilibrium concentration of aluminum in water is inversely proportional to pH below a pH of about 7 SU, such that as pH decreases aluminum concentrations increase. Aluminum concentrations also increase directly above a pH of about 9 SU, but this is seldom a problem in natural waters. The solubility increases dramatically below a pH of 4.5 SU, which is incidentally the approximate pH of acid rain in eastern Pennsylvania and East Branch Fishing Creek. As acidic rain infiltrates soil and exposed bedrock, calcium neutralizes the acidity. Over time the calcium content of soils is reduced and, in the absence of alkaline geologic features, the water remains acidic, and aluminum is dissolved and transported to receiving streams and wetlands.

The addition of alkaline material to a watershed affected by acid deposition is a paramount component of reestablishing water quality conditions. The stream pH must be increased to provide a sustainable environment for aquatic organisms. When alkalinity is increased in a stream containing elevated concentrations of dissolved aluminum, the aluminum precipitates and settles. Care must be taken when choosing and administering alkaline addition due to potential of aluminum precipitate accumulating on sensitive organs of aquatic organisms during the process. The alkaline addition technologies discussed in Section 4, specifically land application liming, high flow buffer channels, and vertical flow wetlands will presumably decrease the acidity of East Branch Fishing Creek and alleviate the potential of harming existing and emerging aquatic organisms.

REFERENCE: ACID/BASE CHEMISTRY

Water is composed of hydrogen and oxygen in the formula H_2O. Water naturally breaks down to some extent into positively charged hydrogen ions (H^+) and negatively charged hydroxide ions (OH^-). The measurement of pH is the negative logarithm of the concentration of hydrogen ions, meaning that as the H^+ concentration goes up, the pH goes down. In the desirable pH range for fish, 6 to 9 standard units (SU), the concentrations of H^+ and OH^- are fairly equal. When the H^+ concentration begins to exceed that of OH^- to a higher degree, water is considered to be acidic, and the pH measurement is lower. Acid mine drainage typically has a pH around 3 SU, and some colas are as low as 2 SU.

$$\mathbf{H_2O \leftrightarrows H^+ + OH^-}$$

$$\mathbf{pH = -\,Log[H^+]}$$

Alkalinity is the chemical opposite of acidity. Alkaline materials generate an excess of OH^- ions, which neutralize H^+ ions by reforming water. Probably the most familiar alkaline material used in stream restoration is limestone ($CaCO_3$). When limestone dissolves in acidic water, it neutralizes acidity as follows:

$$\mathbf{CaCO_3 + H_2O \rightarrow Ca^{2+} + HCO_3^- + OH^-}$$

$$\mathbf{OH^- + H^+ \rightarrow H_2O}$$

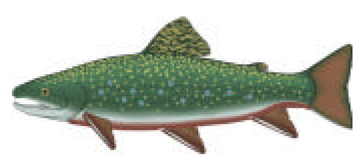
$$\mathbf{CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-}$$

The product is the alkaline bicarbonate ion (HCO_3^-) and dissolved calcium, both of which are benign to aquatic species.

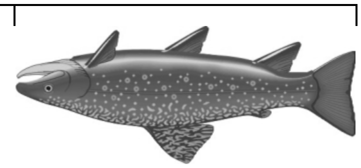
Both acidity and alkalinity are measured as the equivalent concentration as limestone, reported as milligrams of $CaCO_3$ per liter (mg/L). When the acidity concentration is greater than the alkalinity concentration, water is considered to be net acidic, and in the opposite case the water is net alkaline. Net acidity is essentially a measure of the mass of limestone that would need to be added to bring water to a neutral state, or its *alkaline deficiency*. This measure is used in determining alkaline addition rates for stream restoration projects.

Another measure of relative acidity is acid neutralization capacity (ANC). This has the units of microequivalents of $CaCO_3$ per liter (μeq/L) and can be thought of as the ability of water to resist changes in pH resulting from the addition of acid. ANC is a good measure for assessing the health of a stream for supporting fish populations. A positive ANC normally represents survivable conditions for fish, while a negative ANC indicates unhealthy conditions. Water can be slightly net acidic and still have a positive ANC, so correcting an alkaline deficiency in a stream should produce a desirable positive ANC condition.

Alk. > Acid.
$6 < pH < 9$
ANC > 0



Acid. > Alk.
$pH < 6$
ANC < 0



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STUDY PLAN

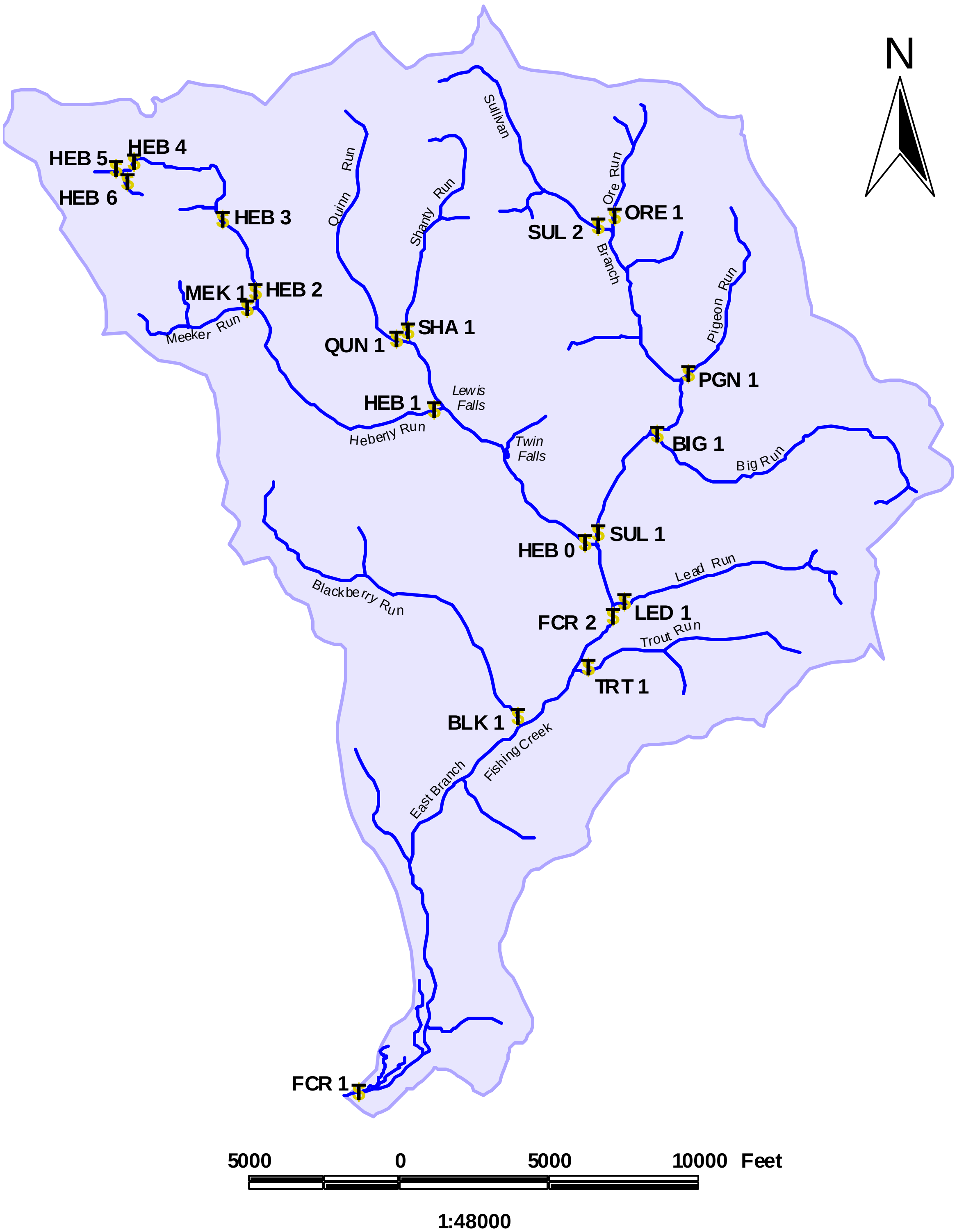
The East Branch Fishing Creek in-stream water quality and flow monitoring program included 20 sample points on representative sections of the main stem and at the mouths of major tributaries. The overall goal of the monitoring program was to assess the current conditions of the watershed resulting from acid deposition and to develop a restoration plan for the stream reaches found to be adversely impacted, with the following specific objectives for the program:

- To establish permanent sampling locations for consistent comparisons with future results
- To collect accurate flow measurements with chemistry samples to allow loading calculations and relevant statistical analysis.
- To monitor throughout seasonal conditions to identify episodic and chronic acidification.
- To determine the degree of alkaline addition required to restore individual tributaries and the main stem.
- To present conceptual alkaline addition methods and recommendations for future actions.
- To provide a historic baseline for future restoration results.

SAMPLE POINT SELECTION

Sample points were arrayed within the watershed to monitor East Branch Fishing Creek at the mouths of all major tributaries, several midstream points on the main stem, and specific points of interest associated with a land application liming project conducted by PSU. Figure 2-1 shows the sample point locations for the water monitoring program relative to the East Branch Fishing Creek watershed.

Figure 2-1: East Branch Fishing Creek Sample Point Map



The sample point pattern developed for this acid deposition study is summarized by Figure 2-2 and Table 2-1 based on four categories in their typical order of importance: culmination, confluence, midstream, and upstream. The basic goals were to identify the major sources of acidification, quantify alkaline deficiencies for development of restoration plans, and document pre-existing conditions upstream and downstream of planned restoration reaches. Three basic guidelines for locating points are as follows from Figure 2-2:

- A study needs a culmination point (A) representing the lowermost extent of interest for assessment and restoration planning.
- For any downstream point of interest, the upstream points should provide a sum of the major upstream flow/loading sources (B + C + D = A, E + F = C).
- Any reach planned for restoration requires a downstream point and, if flows occur above the planned alkaline addition site, an upstream point (H to E, G to F, E + F to C).

Figure 2-2: Schematic Sample Point Pattern for Acid Deposition Studies

Table 2-1: Sample Points for Acid Deposition Assessment

Point Type	Criteria	Representative Study Samples
Culmination	A downstream point representing the combined drainage from all upstream sample points, usually the lowermost limit of study or restoration objectives.	FCR 1, HEB 0
Confluence	Mouths of major tributaries to compartmentalize a watershed for identification of primary acidity sources.	MEK 1, QUN 1, SHA 1, SUL 2, ORE 1, PGN 1, BIG 1, LED 1, TRT 1, BLK 1,
Midstream	Intermediate points to characterize long reaches of main stem, preferably immediately upstream of a confluence point or below alkaline addition projects.	FCR 2, SUL 1, HEB 2, HEB 1
Upstream	Points to characterize water entering from upstream of the study area, above planned restoration projects, or the upstream limit of a main stem reach.	HEB 3, HEB 4, HEB 5, HEB 6

MONITORING PERIOD

Collection of water samples for this study was conducted at intervals of approximately 4 weeks between May 2004 and September 2006, yielding 21 sample rounds. Seventeen of these 20 sites were monitored for 13 consecutive sample rounds between May 2005 and June 2006. Five of these sites were observed for all 21 sample rounds. These five sites, grouped in the Heberly Run subwatershed, were sampled to include background data collected prior to the Round 6 Growing Greener Grant application and pre- and post-liming applications by PSU. Three sample locations in the headwaters of Heberly Run were added to the monitoring program in November 2005. Monitoring of these eight points in the Heberly Run subwatershed is ongoing for PSU's study of stream water quality as a result of land application liming.

SAMPLE PARAMETERS

Water samples were collected using the grab method with sample bottles provided by the PSU Institute of the Environments Water Quality Laboratory (PSU Laboratory). Field sampling was conducted by FCWA members with oversight and assistance from the CCCD and training from Water's Edge Hydrology. Field parameters measured at the time of sampling included flow, temperature, pH, and conductivity. Samples were transported in coolers for delivery to the PSU Laboratory, where they were analyzed for pH, aluminum, and acid neutralization capacity (ANC). Table 2-2 provides a summary of the sample parameters and analysis methods used for the water monitoring program.

Table 2-2: In-Stream Water Quality Monitoring Parameters

Parameters	Units	Analysis Method
Field		
Flow	gallons/minute (gpm)	Cross-Sectional Velocity
pH	standard units (SU)	pH Meter
Temperature	degrees Centigrade (C^{0})	Thermometer
Conductivity	microsiemens (*u*ohms/cm)	Conductivity Meter
Laboratory		
pH	standard units (SU)	Standard Methods 4500H Electrometric Method
ANC	microequivalents/liter (µq/L)	Radiometric Triburrette Instrument Guidelines Followed
Aluminum	milligrams/liter (mg/L)	Filtered with 0.1 micron filter Digested with nitric acid (Standard Methods 3030G) Analysis: Standard Method 3113B Electrothermal Atomic Absorption Spectrometric Method

FLOW MEASUREMENTS

Flow measurements were conducted by FCWA members with oversight and assistance from the CCCD and training from Water's Edge Hydrology. Flow measurements were taken by the cross-sectional velocity method (Figure 2-3) using a velocity meter at permanently marked stream sections. Raw data from the in-stream monitoring program are contained in Appendix A, with representative photographs of the sample locations contained in Appendix B.

For some sample points, high flows or other site conditions prevented direct flow measurements on one or more dates. To estimate flows for these occasions, relationships were developed comparing known measured flows at the monitoring points to flows recorded on the same dates for Fishing Creek near Bloomsburg (USGS Gauging Station 01539000). The USGS gauging station is on the main branch of Fishing Creek approximately 20 miles downstream of the confluence of the East and West Branch Fishing Creek. Flows at the East Branch Fishing Creek sample points were found to be linearly related to those in Fishing Creek (see Figure 2-4). Where this relationship was used to estimate flows, the values in Appendix A are shown in italics.

Figure 2-3 – Cross-Sectional Velocity Flow Measurement Method

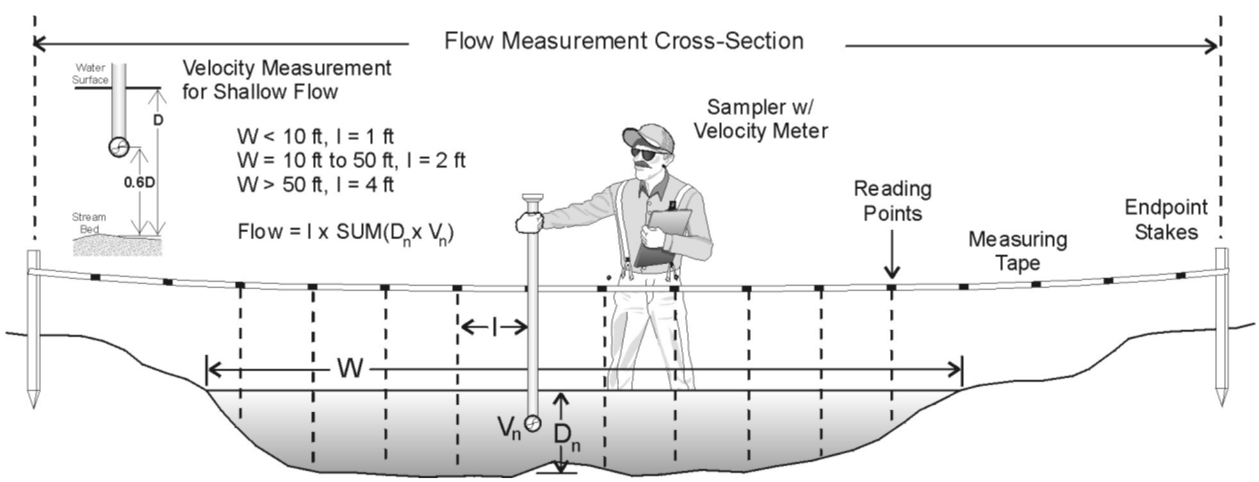
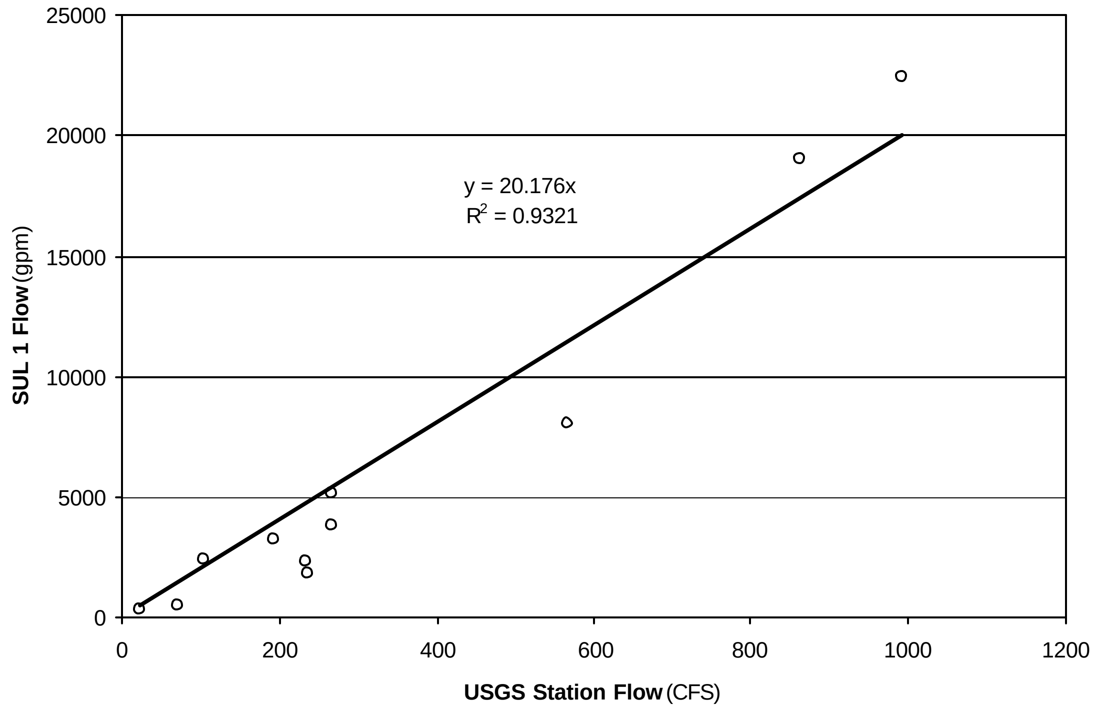
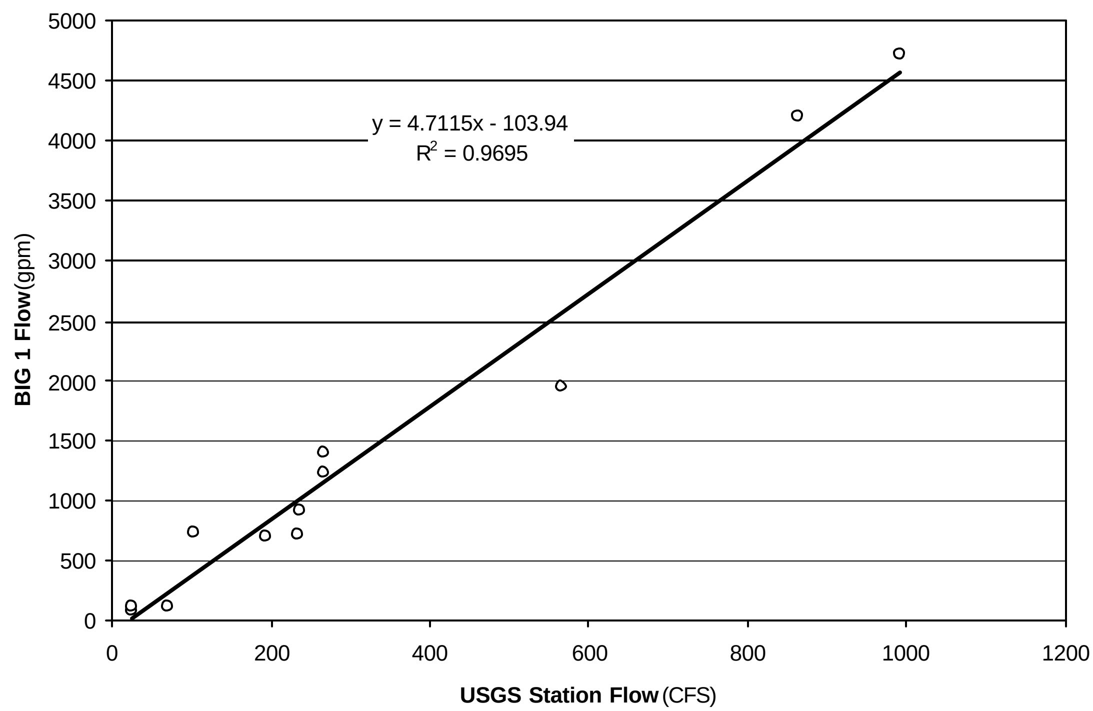


Figure 2-4: Comparison of BIG 1 and SUL 1 Flows with USGS Station 01539000





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WATERSHED ASSESSMENT

Results from the water quality monitoring were analyzed to assess three primary considerations within the East Branch Fishing Creek watershed: (1) the extent and degree of acidification impacts, (2) the temporal nature of acidification and degree of alkaline deficiency in impacted streams, and (3) the water quality improvements that could be realized if the existing alkaline deficiencies were corrected. The following provides a summary of these evaluations as they relate to development of acid abatement strategies and a progressive restoration plan for the watershed.

DATA SUMMARY AND ANALYSIS

Data from the monitoring program were analyzed to develop average and high flow water quality and quantity conditions for individual sample points, with results summarized in Table 3-1. The value N in this table represents the number of flow observations or synthesized flows for each sample point. Complete data sets are contained in Appendix A. Average values were determined as the arithmetic average of the data. Two analysis methods were used to determine potential high flow conditions, referenced as the Standard Deviation (SD) method, and the Standard Error (SE) method.

The SD high flow was determined as the average flow plus the standard deviation of the data set multiplied by the 95% factor of the Students T-distribution for the appropriate degrees of freedom. The SE method was presented by the CCCD in several examples as an alternative to the SD method. The SE method was replicated as being the average of the data set plus the standard error ($SD/N^{\wedge 0.5}$) multiplied by the Students T-distribution for the appropriate degrees of freedom.

The SE method consistently produces lower high flow values than the SD method. The SD high flow appears to better represent expectations for a 95% confidence interval flow (1 chance in 20 of occurrence) than the SE high flow. In past applications, the SD high flow has been found to be an effective maximum design value for balancing performance confidence and implementation costs in acid restoration projects. For these reasons, the SD method is considered to be more conservative and was used for the project high flow values. SE high flow values are also provided in affected tables in this section for comparison.

Sample Calculations of high flow using SD and SE method:

Standard Deviation method :

High flow prediction = Avg. Flow + Standard Deviation (t-dist)

where Standard Deviation = v(?(x-mean)^2 / n-1

x = sample value

mean = average of all samples

n = sample size

t-dist = table calculated value

Standard Error method :

High flow prediction = Avg. Flow + Standard Error (t-dist)

where Standard Error = Standard Deviation /vn

t-dist = table calculated value

FCR 2

Standard Deviation method :

High flow prediction

= 11,463 + 13911 (1.78)

= 36,256*

Standard Error method :

High flow prediction

= 11,463 + 13911/v13 (2.18)

= 19,869*

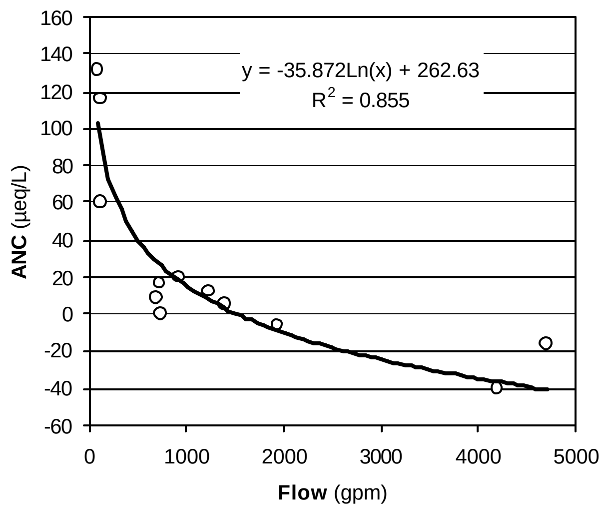
* The equation values have been rounded for display purposes; the resulting value is accurately calculated using the extended values

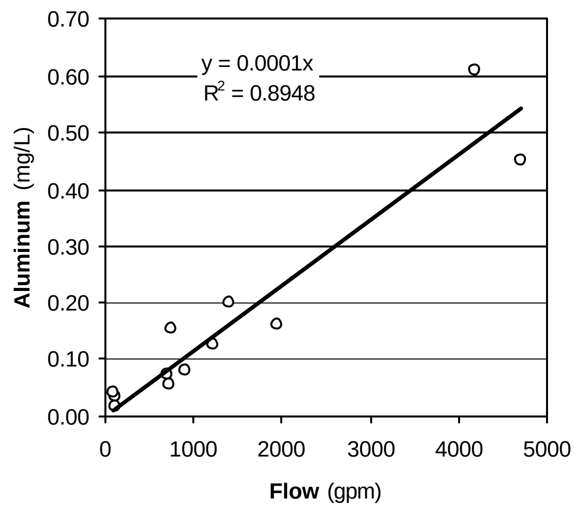
Table 3-1: Summary of East Branch Fishing Creek Monitoring Data

Sample Point		Flow Condition	Parameters: Flow (gpm)	pH (SU)	ANC (μeq/L)	Al (mg/L)	N
BIG 1	Big Run	Average	1404	5.61	28.1	0.167	12
		SD High Flow	4152	4.64	-36.2	0.415	
		SE High Flow	2376	4.99	-16.2	0.238	
BLK 1	Blackberry Run	Average	2113	4.70	-26.9	0.249	12
		SD High Flow	6143	4.72	-31.5	0.553	
		SE High Flow	3539	4.74	-30.2	0.319	
FCR 1	EB Fishing Creek at Confluence w/ West Branch	Average	15498	5.63	40.4	0.024	13
		SD High Flow	38058	5.63	17.9	0.076	
		SE High Flow	23147	5.79	26.7	0.046	
FCR 2	EB Fishing Creek at Lead Run	Average	11463	5.34	4.6	0.093	13
		SD High Flow	36256	5.30	0.3	0.218	
		SE High Flow	19869	5.32	1.3	0.119	
HEB 0	Heberly Run at Mouth	Average	4816	5.62	8.8	0.047	15
		SD High Flow	13127	5.30	0.3	0.092	
		SE High Flow	7429	5.35	3.1	0.052	
HEB 1	Heberly Run at Lewis Falls	Average	1212	5.67	9.4	0.070	19
		SD High Flow	2711	5.20	-5.0	0.163	
		SE High Flow	1629	5.31	1.0	0.098	
HEB 2	Heberly Run at Meeker Run	Average	1037	5.54	5.3	0.075	18
		SD High Flow	2611	5.12	-9.0	0.157	
		SE High Flow	1487	5.20	-4.7	0.089	
HEB 3	Heberly Run Headwaters	Average	1791	5.48	2.9	0.065	18
		SD High Flow	5609	5.11	-9.6	0.112	
		SE High Flow	2883	5.17	-6.4	0.058	
HEB 4	Heberly Run below Confluence w/ HEB 5 & 6	Average	314	5.06	-10.8	0.105	8
		SD High Flow	506	5.11	-9.7	0.152	
		SE High Flow	398	5.11	-9.7	0.120	
HEB 5	Heberly Run Headwaters - North	Average	63	4.76	-24.0	0.180	8
		SD High Flow	176	4.87	-22.7	0.282	
		SE High Flow	113	4.87	-22.7	0.181	
HEB 6	Heberly Run Headwaters - South	Average	140	4.67	-28.5	0.135	8
		SD High Flow	267	4.73	-30.6	0.240	
		SE High Flow	196	4.75	-29.2	0.176	
LED 1	Lead Run	Average	821	4.44	-37.8	0.301	10
		SD High Flow	2946	4.51	-44.4	0.589	
		SE High Flow	1650	4.54	-42.4	0.330	
MEK 1	Meeker Run	Average	320	4.37	-58.8	0.260	18
		SD High Flow	1043	4.20	-69.7	0.417	
		SE High Flow	527	4.23	-67.0	0.211	
ORE 1	Ore Run	Average	481	4.32	-69.1	0.366	12
		SD High Flow	1326	4.16	-75.9	0.663	
		SE High Flow	780	4.17	-74.3	0.390	
PGN 1	Pigeon Run	Average	636	5.11	5.5	0.219	12
		SD High Flow	2118	4.91	-20.3	0.635	
		SE High Flow	1160	5.01	-14.8	0.348	
QUN 1	Quinn Run	Average	1111	5.75	29.3	0.114	10
		SD High Flow	4120	5.01	-15.1	0.247	
		SE High Flow	2285	5.25	-2.3	0.137	
SHA 1	Shanty Run	Average	472	5.76	23.1	0.107	10
		SD High Flow	1125	5.01	-15.1	0.338	
		SE High Flow	727	5.30	0.2	0.218	
SUL 1	Sullivan Branch at Heberly Run	Average	5747	5.26	-1.2	0.163	12
		SD High Flow	19007	5.11	-9.4	0.380	
		SE High Flow	10439	5.15	-7.4	0.209	
SUL 2	Sullivan Branch at Ore Run	Average	1121	4.51	-38.2	0.288	12
		SD High Flow	2932	4.43	-49.5	0.293	
		SE High Flow	1762	4.64	-36.3	0.176	
TRT 1	Trout Run	Average	930	5.29	9.9	0.040	5
		SD High Flow	2625	5.42	6.8	0.079	
		SE High Flow	1917	5.44	7.7	0.058	

Relationships between parameter concentrations and flow were established graphically and used to predict concentrations at the SD and SE high flows, as shown by the examples in Figure 3-1. The best-fit relationship between ANC and flow was found to be a logarithmic function, whereas the relationship to aluminum was evaluated as linear. A prediction was also made of the pH for high flows based on a project-specific relationship between laboratory pH and ANC.

Figure 3-1: Example Parameter Relationships to Flow (BIG 1 Data)





CHARACTERISTICS OF ACIDIFICATION

ANC is the primary measure of stream health relative to acidification used in this study. A positive ANC represents a buffered, net alkaline condition where the stream pH will normally remain in the circumneutral range and sustain fish populations. A negative ANC indicates an acidified condition, where the pH can drop to levels harmful or fatal to aquatic life. Between these extremes, studies have concluded that episodic acidification (periodic negative ANC) can be both a short-term and long-term detriment to fish populations. While some fish can survive these events by taking refuge in alkaline tributaries or microhabitats, this is not sufficient to maintain the potential population densities that would be implied by the water quality during baseflow periods. Historic data show such a long-term population decline in the East Branch Fishing Creek.

The degree of impact to a stream from acid deposition depends largely on the inherent alkalinity of its baseflow. Alkalinity and acidity can have very low concentrations in weakly acidified streams, and may be difficult to interpret from an alkaline deficiency standpoint. For previous assessments, ANC was found to be the most reliable measure of buffering capacity and potential alkaline addition requirements. Therefore, the concentration of alkalinity and acidity were not analyzed in the laboratory for this study. Alkalinity and acidity as mass concentrations can be approximated from ANC in equivalents as follows:

<u>If ANC is positive:</u>

Alkalinity (mg/L) = ANC (μeq/L) / 20

<u>If ANC is negative:</u>

Acidity (mg/L) = -ANC (μeq/L) / 20

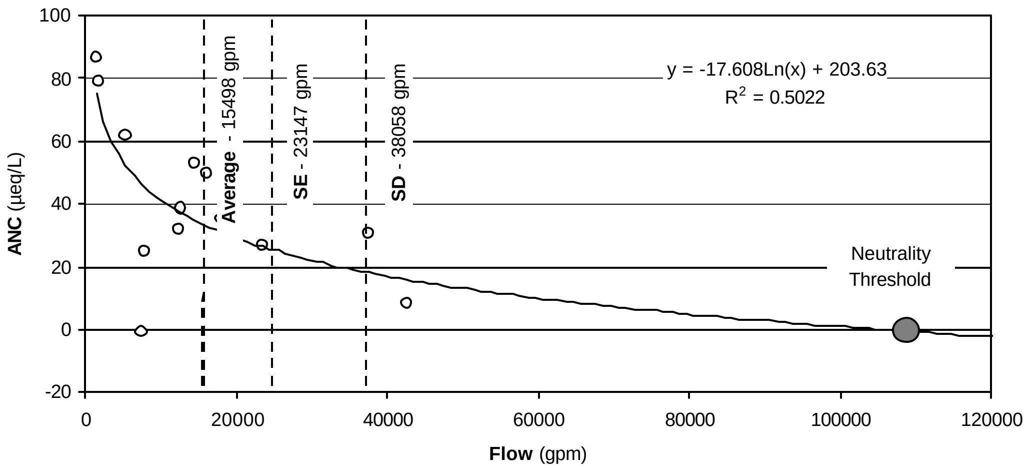
The three basic categories of acid deposition impacts used in this study are *sustainable, episodic,* and *chronic* depending on where acidification begins to occur in a stream's flow range from baseflow to storm flow. Sustainable streams contain sufficient alkalinity to neutralize the acid deposition loading and maintain acceptable water quality for fish populations under all or all but extremely high flow conditions. In episodically acidified streams, the neutralization capacity of alkaline baseflow can be overwhelmed during acidic storm flow or snow melt events, resulting in acidic conditions during moderate to high flows. If the acid deposition loading greatly exceeds the baseflow alkalinity, a stream will be chronically acidified and show poor water quality under most or all flow conditions. Figure 3-2 illustrates these categories using plots of ANC versus flow.

The "Neutrality Threshold" indicated on Figure 3-2 is the predicted flow volume above which the stream will reach a negative ANC and become acidic. It is the flows above this threshold that require some form of alkaline addition to maintain stream health. For this study, streams with a neutrality threshold below the average flow are considered chronically acidified. Threshold values between the average and SD high flows are considered an indication of episodic acidification. A threshold above the SD high flow is assumed to represent sustainable conditions unless the ANC versus flow plots indicate a potential for negative ANC close to the SD high flow volume. In some cases, such as HEB 1, the SE high flow results in streams being predicted as sustainable, but examination of the trends in the data sets suggests episodic conditions instead.

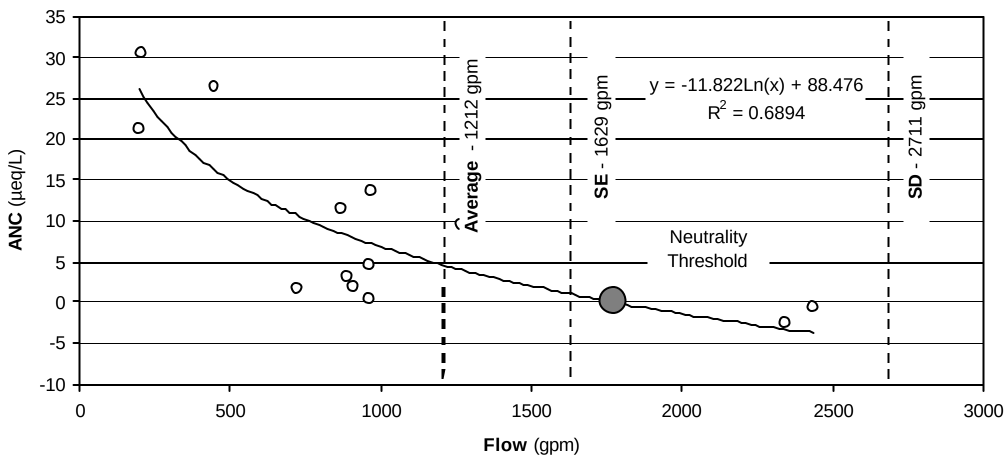
Table 3-2 summarizes the characteristics of acidification in the East Branch Fishing Creek in terms of alkaline deficiency and temporal nature (sustainable, episodic, or chronic). Alkaline deficiency is expressed as pounds per day of calcium carbonate ($CaCO_3$) derived by converting measured ANC into its approximate equivalent value as alkalinity. Negative values indicate an alkaline excess. Values are given for average and SD high flow conditions, including the threshold values calculated from the sample point data sets. Figure 3-3 provides an additional comparison of the acidification conditions predicted from SD high flows to observed ranges of pH and ANC.

Figure 3-2: Examples of Acidification Categories

Sustainable Acidification: E. Branch Fishing Creek above W. Branch Fishing Creek (FCR 1)



Episodic Acidification: Heberly Run at Lewis Falls (HEB 1)



Chronic Acidification: Heberly Run at Meeker (HEB 2)

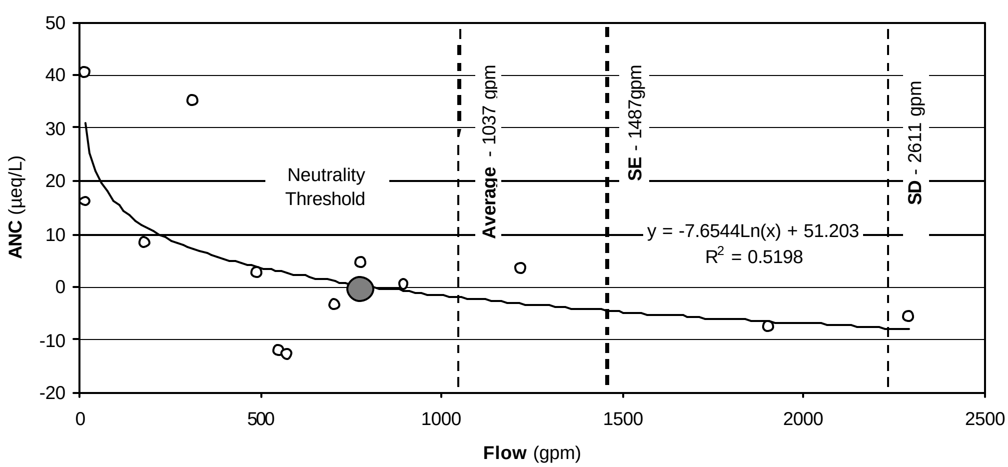


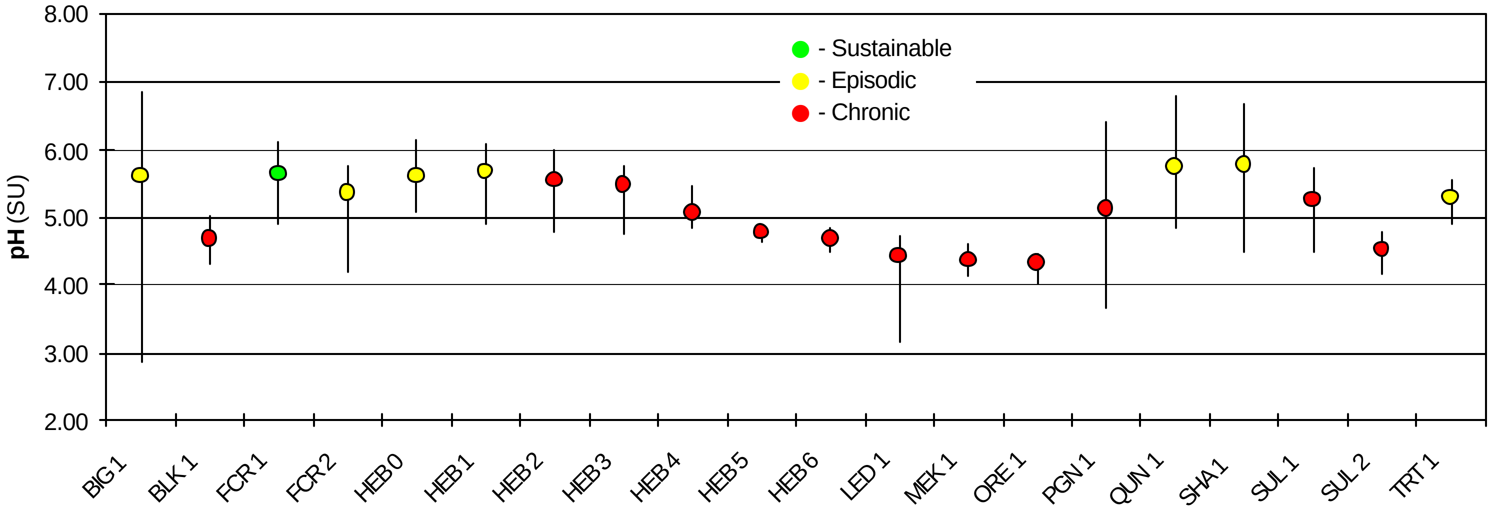
Table 3-2: Summary of Alkaline Deficiencies and Acidification Conditions

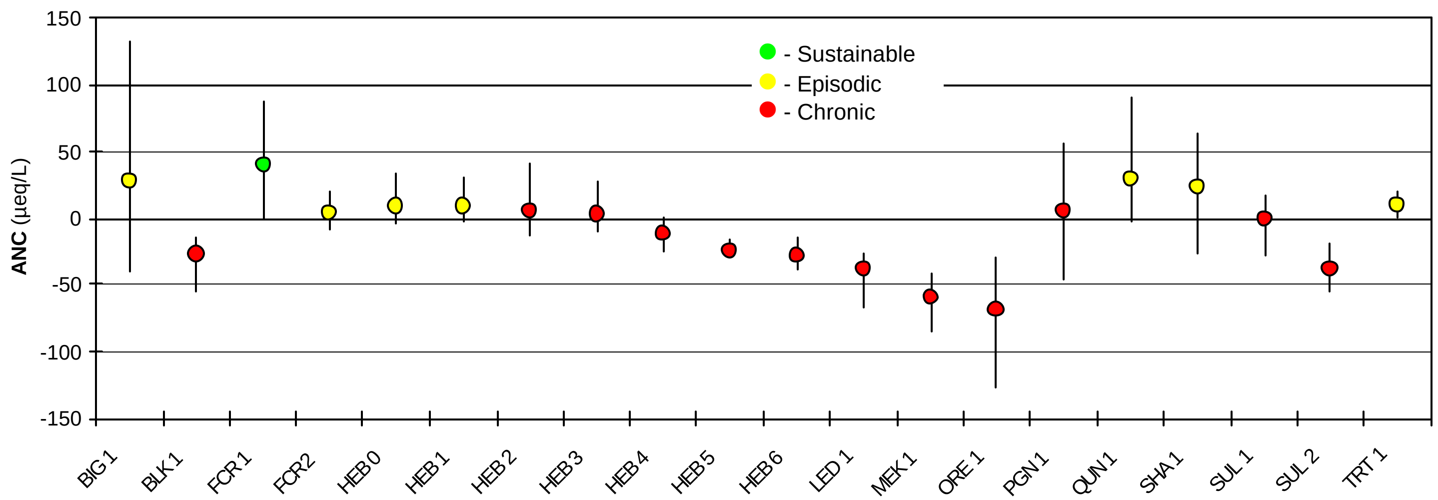
Sample Point		Alkaline Deficiency			Flow Conditions				Inferred Acidification Condition
		Average lbs/day	SD High Flow lbs/day	SE High Flow lbs/day	Average gpm	Neutrality Threshold gpm	SD High Flow gpm	SE High Flow gpm	
BIG 1	Big Run	-24	90	23	1404	1512	4152	2376	Episodic
BLK 1	Blackberry Run	34	116	64	2113	0	6143	3539	Chronic
FCR 1	EB Fishing Creek at Confluence w/ West Branch	-376	-409	-370	15498	105306	38058	23147	Sustainable
FCR 2	EB Fishing Creek at Lead Run	-31	-6	-16	11463	42255	36256	19869	Episodic*
HEB 0	Heberly Run at Mouth	-25	-3	-14	4816	14098	13127	7429	Episodic*
HEB 1	Heberly Run at Lewis Falls	-7	8	-1	1212	1779	2711	1629	Episodic*
HEB 2	Heberly Run at Meeker Run	-3	14	4	1037	804	2611	1487	Chronic
HEB 3	Heberly Run Headwaters	-3	32	11	1791	775	5609	2883	Chronic
HEB 4	Heberly Run below Confluence w/ HEB 5 & 6	2	3	2	314	0	506	398	Chronic
HEB 5	Heberly Run Headwaters - North	1	2	2	63	0	176	113	Chronic
HEB 6	Heberly Run Headwaters - South	2	5	3	140	0	267	196	Chronic
LED 1	Lead Run	19	78	42	821	0	2946	1650	Chronic
MEK 1	Meeker Run	11	44	21	320	0	1043	527	Chronic
ORE 1	Ore Run	20	60	35	481	0	1326	780	Chronic
PGN 1	Pigeon Run	-2	26	10	636	235	2118	1160	Chronic
QUN 1	Quinn Run	-20	37	3	1111	2061	4120	2285	Episodic
SHA 1	Shanty Run	-7	10	0	472	732	1125	727	Episodic*
SUL 1	Sullivan Branch at Heberly Run	4	107	46	5747	1141	19007	10439	Chronic
SUL 2	Sullivan Branch at Ore Run	26	87	38	1121	0	2932	1762	Chronic
TRT 1	Trout Run	-6	-11	-9	930	2002	2625	1917	Episodic*

*Inferred from plots of ANC versus flow due to narrow differences between threshold and high flows.

*According to SE high flow calculations these inferred acidification conditions are sustainable; all other inferred acidification conditions in this table relate to both SE and SD high flow conditions.

Figure 3-3: Observed Ranges of pH and ANC Relative to Acidification Conditions (SD High Flows)





EXTENT OF ACIDIFICATION

Figures 3-4 and 3-5 show the extent of acidification within the East Branch Fishing Creek watershed under average and high flow conditions, respectively. To illustrate the degree of acidification in individual subwatersheds, water quality conditions have been ranked in semi-quantitative categories from very good to severe based on pH and ANC levels. Table 3-3 summarizes these categories with comments relative to their implications for fish populations. Where no sampling data are available, some stream conditions have been inferred from adjacent information. Table 3-4 summarizes the gross impact statistics for the watershed by stream miles per water quality categories and percentage of these stream miles out of the total.

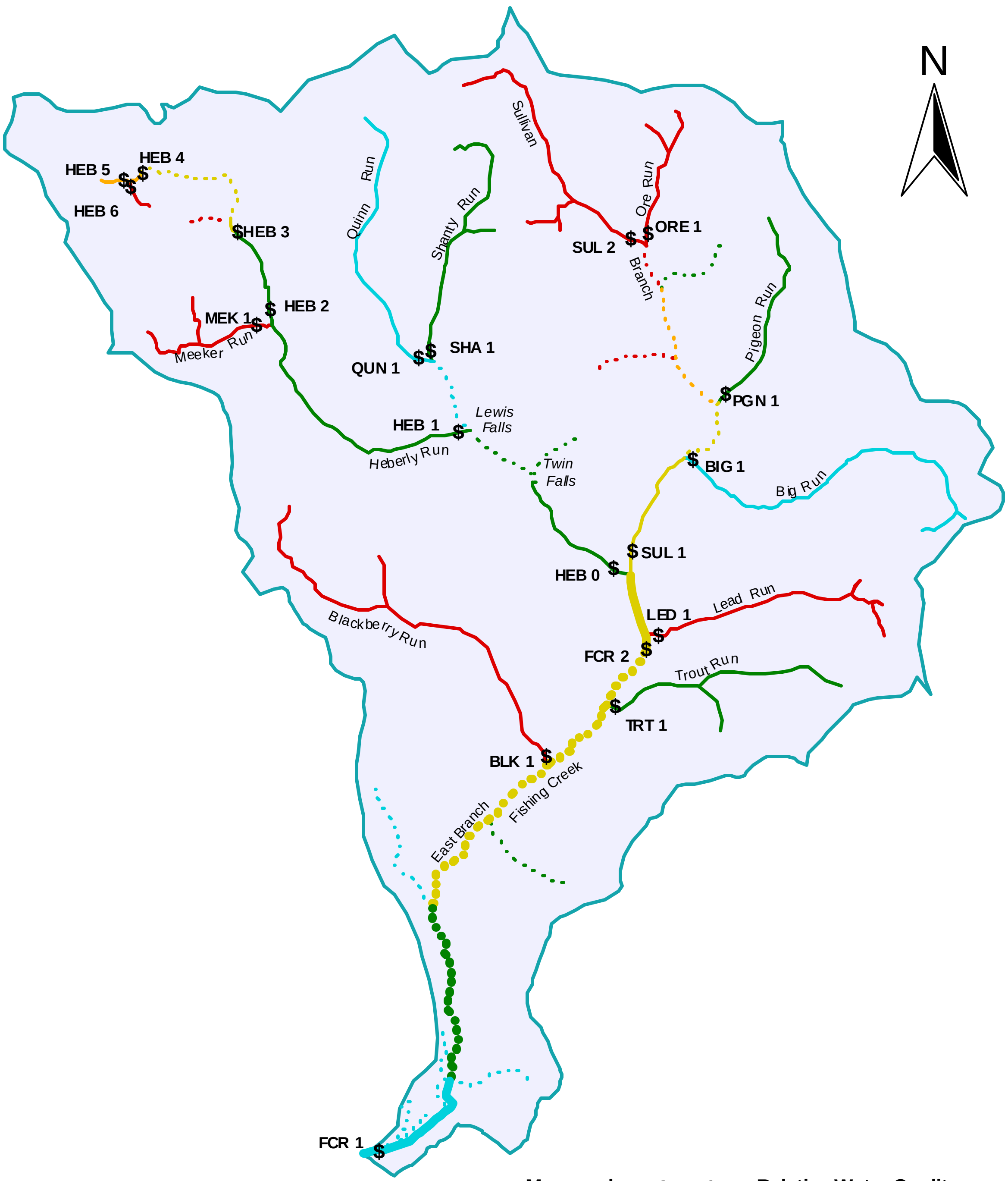
Table 3-3: Summary of Relative Water Quality Categories

Category	**Criteria**	**Comments**
Very Good	pH > 6.0 SU ANC > 50 µeq/L	No significant acidification impacts, should support healthy fish populations.
Good	pH > 5.5 SU ANC 25 to 50 µeq/L	Possible minor impacts, but suitable for fish during short-term storm acidification effects.
Fair	pH > 5 SU ANC 5 to 25 µeq/L	Maintaining a positive ANC, but pH trending towards the low end of sustainability for fish.
Poor	pH > 4.5 SU ANC –10 to 5 µeq/L	Usual negative ANC and reduced pH, poor to no buffering, reduced populations with few tolerant fish.
Very Poor	pH > 4 SU ANC –10 to –25 µeq/L	Consistently negative ANC, likely not supportive of any significant fish populations.
Severe	pH < 4 SU ANC < -25 µeq/L	Consistent and highly negative ANC, likely no fish populations and restricted benthic populations.

Table 3-4: Water Quality Conditions by Stream Miles and Categories

Category	**Average Conditions**		**High Flow Conditions**	
	Miles	Percentage	Miles	Percentage
Very Good	0	0%	0	0%
Good	9.23	27%	0	0%
Fair	10.21	30%	6.95	20%
Poor	4.80	14%	6.38	19%
Very Poor	1.07	3%	9.05	26%
Severe	8.85	26%	11.78	35%
Totals	34.16	100%	34.16	100%

Figure 3-4: East Branch Fishing Creek Average Flow Water Quality Conditions

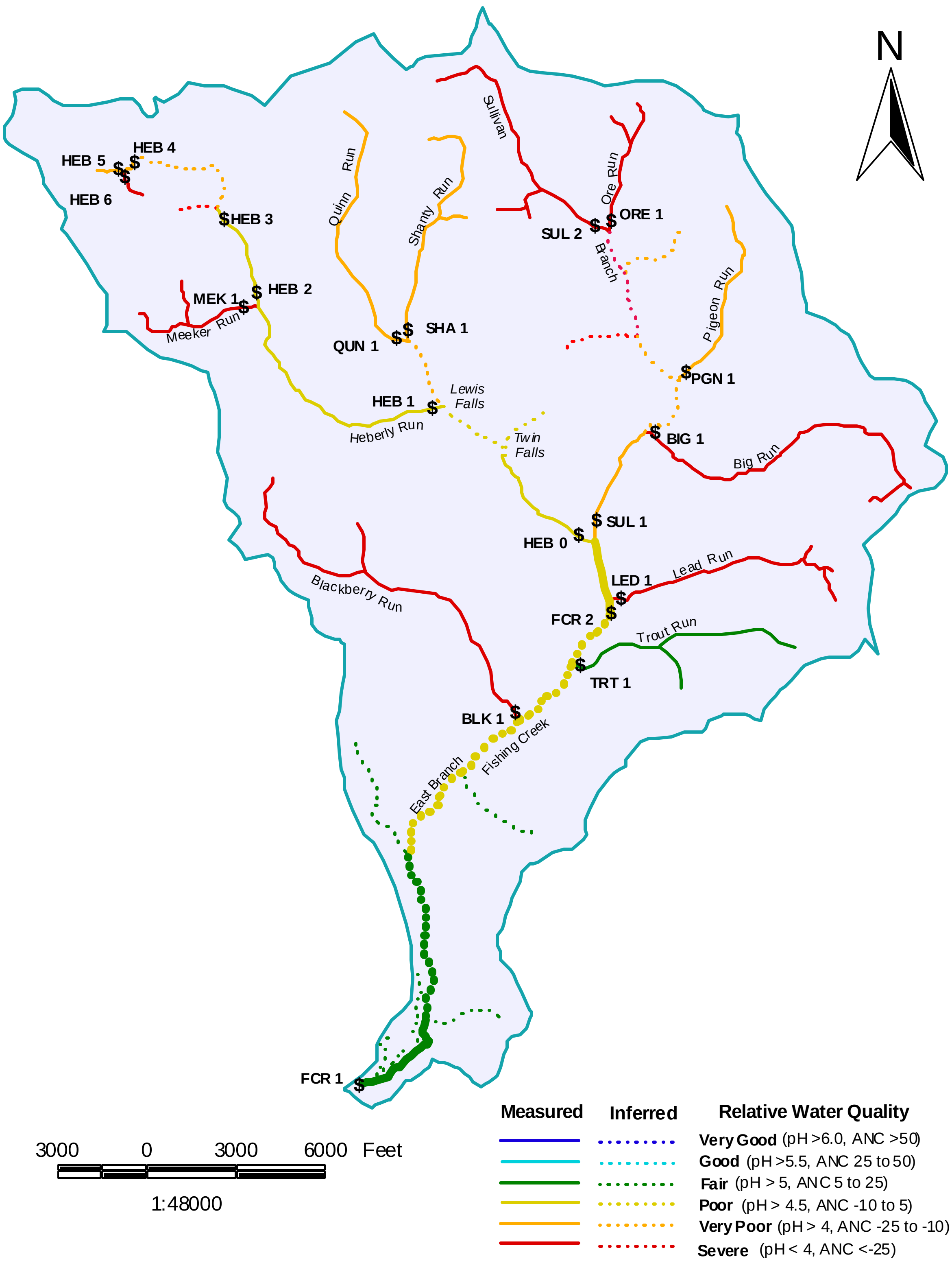


Measured **Inferred** **Relative Water Quality**

Very Good (pH >6.0, ANC >50)
Good (pH >5.5, ANC 25 to 50)
Fair (pH > 5, ANC 5 to 25)
Poor (pH > 4.5, ANC -10 to 5)
Very Poor (pH > 4, ANC -25 to -10)
Severe (pH < 4, ANC <-25)

3000 0 3000 6000 Feet
1:48000

Figure 3-5: East Branch Fishing Creek High Flow (95% CI) Water Quality Conditions



On Figures 3-4 and 3-5, it is apparent that conditions of acidification are present throughout the watershed, and as flow increases water quality conditions decline in all reaches. The poorest quality conditions are generally concentrated around the higher elevation periphery, while the larger, lower elevation reaches are somewhat better. The pattern is not, however, uniformly consistent. The following summarizes the conditions interpreted for the individual subwatersheds, grouped under the Heberly Run and Sullivan Branch drainages, and the main stem of East Branch Fishing Creek. All noted acidification conditions are based on the SD high flow.

<u>Heberly Run</u>

Heberly Run contains 11 miles of stream reach and receives drainage from approximately 4,149 acres, including the subwatersheds of Meeker Run, Quinn Run, and Shanty Run. During average conditions, the main stem of Heberly Run is of fair quality; however, during high flows upstream tributaries contribute sufficient acidity to reduce the water quality to poor. Ten sample points have been observed and analyzed to characterize Heberly Run and the influence of its subwatersheds, as follows:

Headwaters Areas

Sample points HEB 4, 5, and 6 are located in the uppermost headwaters of the subwatershed. HEB 5 and 6 are receiving tributaries of wetlands and are chronically acidified, with consistently negative ANC values and pH values between 4.5 and 5.0 SU. During average conditions HEB 5 and 6 are of very poor and severe quality, respectively. The functional storage capacity of the wetlands upstream limited the correlation of water quality parameters for high flow conditions; however, water quality is not predicted to improve during high flows. HEB 4, downstream of the convergence of HEB 5 and 6 tributaries, is chronically acidified. During average flow conditions HEB 4 is of very poor quality, with the ANC increasing to a slightly less negative value than upstream. Downstream at HEB 3 conditions slightly improve; during average conditions HEB 3 is of fair quality reducing to poor quality during high flows. Within this section, the neutrality threshold remains below average flows indicating chronic acidification conditions. The quality of the unnamed tributary upstream of this point was assumed to be similar to the severe quality of adjacent tributaries. Further downstream, above the confluence with Meeker Run, sample point HEB 2 is similar in quality to HEB 3 and also exhibits chronic acidification.

The PSU Forestry Department is currently investigating the benefits of land application liming in the northern headwaters of Heberly Run. From May 2006 through August 2006 the Regenerator (see Section 4) was utilized to apply dolomitic limestone to approximately 100 acres at a rate of 4 tons/acre. Post-liming soil samples were obtained and the analysis and conclusions are currently underway. Sample points HEB 5 and HEB 6 do not appear to receive drainage from the area of lime application and serve as controls, while HEB 4 and downstream points may benefit from the application. Current results do not indicate a change in water quality; however, infiltration to the stream is not expected until approximately 12 months post-application. Further details on this study are provided in Sections 4 and 5.

Meeker Run and downstream points

Meeker Run contains 1.2 miles of stream reach and receives drainage from approximately 276 acres. Sample point MEK 1 indicates that Meeker Run is chronically acidified and has consistently severe water quality. The average flows of Meeker Run are relatively low and do not appear to significantly impact Heberly Run; however, high flows contribute high acidity to Heberly run and have a greater impact. Downstream, sample point HEB 1 is considered episodically acidified, indicating the cumulative impact of upstream acidic input during high flows.

Quinn Run, Shanty Run, and downstream points

Quinn Run contains 2.2 miles of stream reach and receives drainage from approximately 1,068 acres. Sample point QUN 1 indicates that Quinn Run is episodically acidified. During average conditions the water quality of Quinn Run is good; however, high flow events reduce the quality of the stream to very poor.

Shanty Run contains 1.8 miles of stream reach and receives drainage from approximately 446 acres. Sample point SHA 1 indicates that Shanty Run is also episodically acidified. During average conditions the water quality of Shanty Run is fair, becoming very poor during high flows. Shanty Run converges with Quinn Run below their respective sample points. Water quality results suggest that Quinn Run below this point may maintain good quality during average conditions, but is reduced to very poor quality during high flows.

Quinn Run discharges into Heberly Run slightly below sample point HEB 1 at Lewis Falls. During average flow conditions this influence does not appear to significantly change the quality of Heberly Run at sample point HEB 0, but does contribute overall acidity during high flows. The lowermost section of Heberly Run shows fair quality during average flows and poor quality during high flows. As indicated for HEB 1, sample point HEB 0 is considered episodically acidified, indicating the cumulative impact of upstream acidic input during high flows. The quality of the tributary leading to Twin Falls was assumed to be similar to the quality of the adjacent Shanty Run.

Sullivan Branch

The Sullivan Branch of East Branch Fishing Creek contains 10.4 miles of stream reach that drains from approximately 3,721 acres, including the subwatersheds of Ore Run, Hunts Run, Pigeon Run, and Big Run. The lower main stem of Sullivan Branch is chronically acidified. Based on sample point SUL 1, during average conditions the quality of Sullivan Branch is poor, reduced to very poor during high flow conditions. The acidity contributions from upstream branches and tributaries strongly degrade Sullivan Branch, which contributes to the poor quality downstream in East Branch Fishing Creek. Five sample points have been observed and analyzed to characterize Sullivan Branch and the influence of subwatersheds, as follows:

Headwaters and Ore Run

The headwaters of Sullivan Branch are chronically acidified. The 2,283 feet of stream reach above SUL 2 contain water of severe quality during average and high flow conditions. According to sample point ORE 1, Ore Run is also chronically acidified. While this tributary is of severe quality during average and high flow conditions, the pH and ANC of ORE 1 are even lower than at SUL 2. It is inferred from these points that the Sullivan Branch maintains chronic acidity and severe quality downstream of the confluence with ORE 1. The unnamed tributary downstream of the confluence is assumed to be of similar quality to Pigeon Run: fair during average conditions and very poor during high flows. Further downstream is another tributary known as Hunts Run. Hunts Run was not investigated during this assessment and contains 0.5 miles of stream reach draining from 268 acres. The quality of Hunts Run was inferred from the adjacent areas of Sullivan Branch as being chronically acidified, with severe conditions during average and high flows.

Pigeon Run

Pigeon Run contains 1.3 miles of stream reach draining from 517 acres. The results from PGN 1 indicate that Pigeon Run is chronically acidified. During average conditions the quality of Pigeon Run is fair, reducing to very poor during high flow conditions.

Big Run

Big Run contains 2.5 miles of stream reach draining from 877 acres. Sample point BIG 1 indicates that Big Run is episodically acidified. During average conditions the quality of Big Run is good, positively impacting Sullivan Branch. Severe quality high flow conditions suggest that Big Run has a negative impact on Sullivan Branch.

Main Stem East Branch Fishing Creek

The main stem of East Branch Fishing Creek is 4.4 miles long and receives drainage from Heberly Run, Sullivan Branch, Lead Run, Trout Run, Blackberry Run, and many unnamed tributaries. East Branch Fishing Creek receives drainage from 4,612 acres in addition to Heberly Run and Sullivan Branch. Based on the water quality at FCR 1, the condition of main stem East Branch Fishing Creek is sustainable. The quality is good during average conditions and reduces to fair during high flows. The ANC remains positive during average and high flow conditions and the pH averages between 5.5 and 6.0 SU. Conditions trend upstream from sustainable to episodic at FCR 2, where water quality is fair on average but poor during high flows.

There are 4 miles of stream and many small tributaries between FCR 2 and FCR 1 that were not observed for this study. Five samples points below the confluence of Heberly Run and Sullivan Branch have been observed and analyzed to characterize the main stem East Branch Fishing Creek and the influence of subwatersheds, as follows:

Lead Run

Lead Run contains 1.8 miles of stream reach draining from 546 acres. Sample point LED 1 indicates that Lead Run is chronically acidified. During average and high flow conditions the quality of Lead Run is severely impacted. During this monitoring period Lead Run was dry for three sample events, alleviating its negative effect on the East Branch Fishing Creek in that time period.

Trout Run

Trout Run contains 1.8 miles of stream reach draining from 511 acres and is considered to be episodically acidified. During both average and high flow conditions the quality of Trout Run is fair, potentially improving the East Branch Fishing Creek. During this monitoring period Trout Run was dry for seven sample events, suggesting that it does not have a strong impact on the receiving stream.

Blackberry Run

Blackberry Run contains 2.9 miles of stream reach draining from 1,232 acres. According to sample point BLK 1, Blackberry Run is chronically acidified and has severe water quality during average and high flow conditions. However, the effect on East Branch Fishing Creek does not appear as great as the relative effects of upstream tributaries, possibly due to the increasing flow volume in the main stem as it descends through the watershed.

INFLUENCE OF SOILS AND GEOLOGY

Figure 3-6 displays the bedrock geology of the East Branch Fishing Creek watershed relative to average water quality conditions. The lowermost exposed units of the Catskill Formation, located in the southern extent of the watershed, are Late Devonian in age. With increasing elevation, the exposed units trend up-section to the north through the Huntley Mountain Formation of Devonian-Mississippian age to the Burgoon Sandstone and Mauch Chunk Formations of the Mississippian period. These sediments were deposited over millions of years by rivers draining from mountain-building events to the east, and generally exhibit a fining-upward trend from oldest to youngest. The exposed units consist of sandstones, siltstones, and shales, and are not reported to contain significant alkaline inclusions. This is lack of bedrock alkalinity is a fundamental reason that East Branch Fishing Creek is poorly buffered and susceptible to systemic acidification.

Figure 3-7 shows the major soil associations within the watershed in comparison to average water quality conditions, and Figure 3-8 summarizes these units into general areas of soil acidification. As indicated by Figure 3-8, large areas of the watershed have soils with strong acidification, suggesting a low calcium/aluminum ratio and low buffering capacity. As acid deposition infiltrates soils, calcium, the main buffering component, is dissolved and leached away. Over years of continuous acid deposition, the buffering capacity of the soils is reduced, and acid runoff is exasperated. Loss of buffering capacity leads to accelerated mobilization of some metals, particularly aluminum, which is of toxic concern for fish. Aluminum mobility rapidly increases with decreasing pH. As previously shown by the example in Figure 3-1, aluminum concentrations are strongly correlated to increasing flow and declining ANC. This effect is observed to some degree in all the project monitoring points, supporting the conclusion that acidified soils are widespread in the watershed.

The general pattern observed for the watershed is that higher degrees of acidification tend to correlate with higher elevations, corresponding to the Burgoon Sandstone. The lowermost reaches floored by the Catskill Formation show the best water quality. The better conditions in the lower main stem of East Branch Fishing Creek are also associated with the less acidic Barbour soil series. There is insufficient overall correlation to definitively point to any one geologic unit as being the source of the acidification problems. Because of the consistently strong aluminum response to flow throughout the watershed, it is interpreted that runoff acidification is primarily related to systemic soil acidification and not a particular bedrock component.

Figure 3-6: Comparison of Bedrock Geology to Average Water Quality Conditions

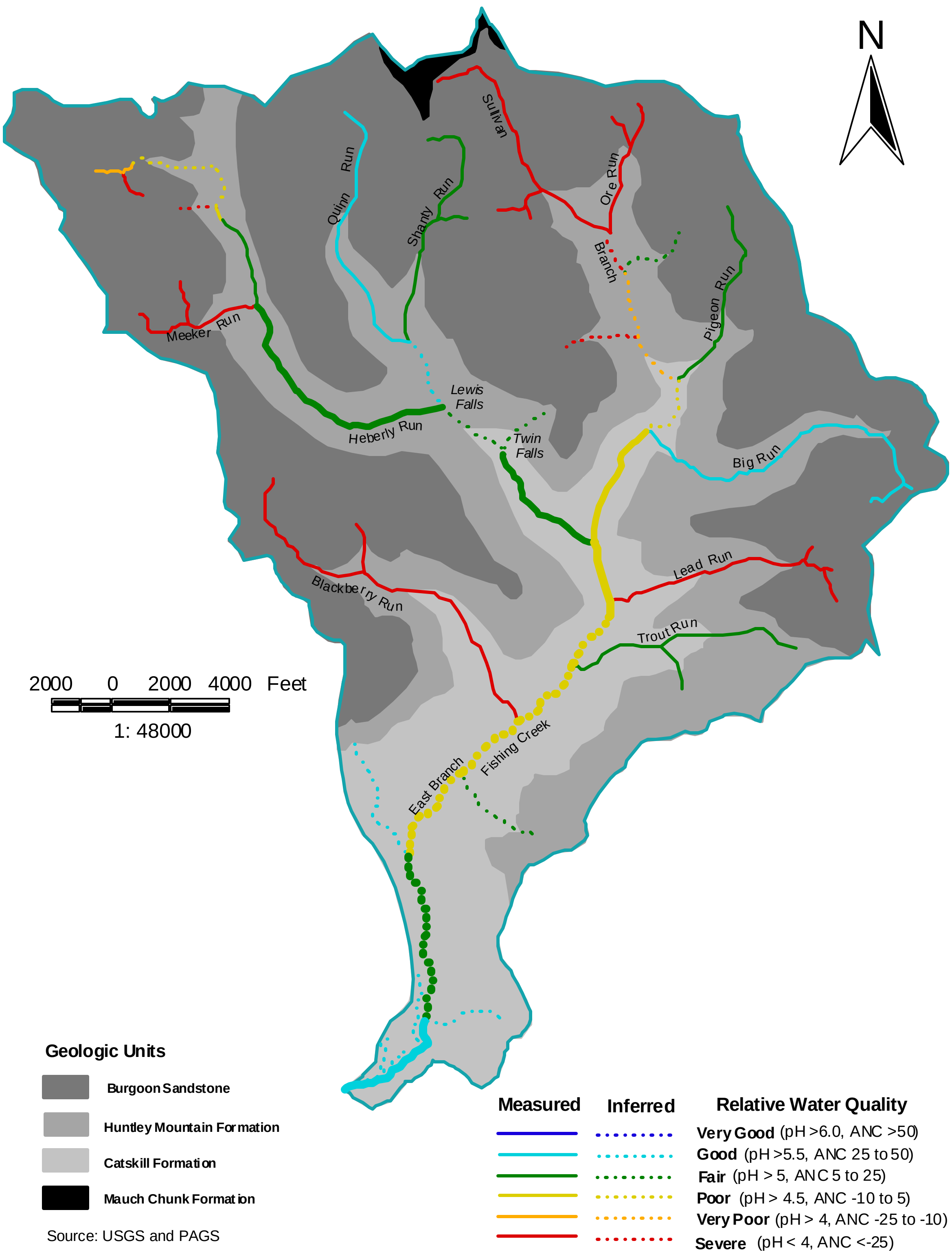


Figure 3-7: Comparison of Soil Associations to Average Water Quality

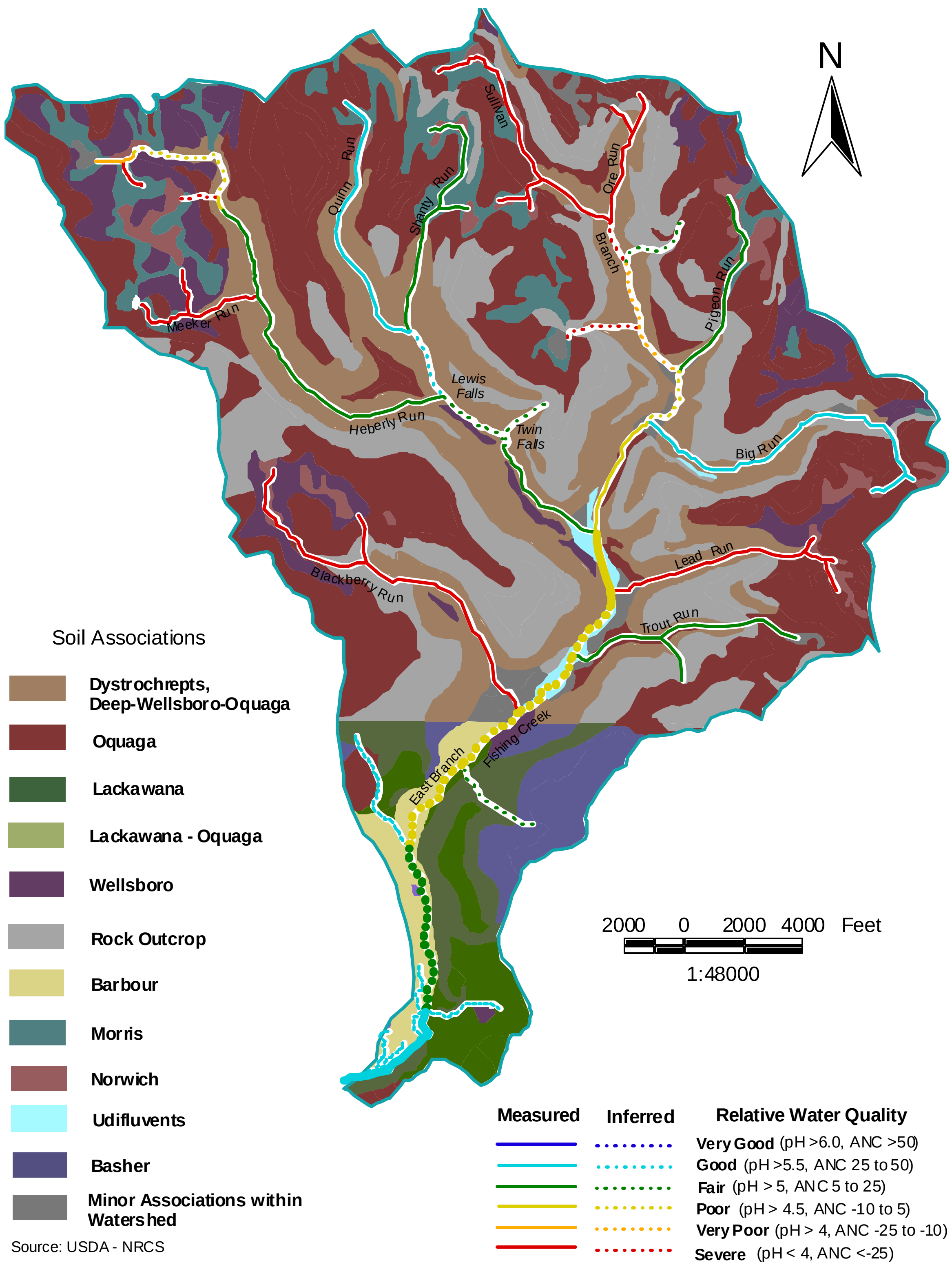
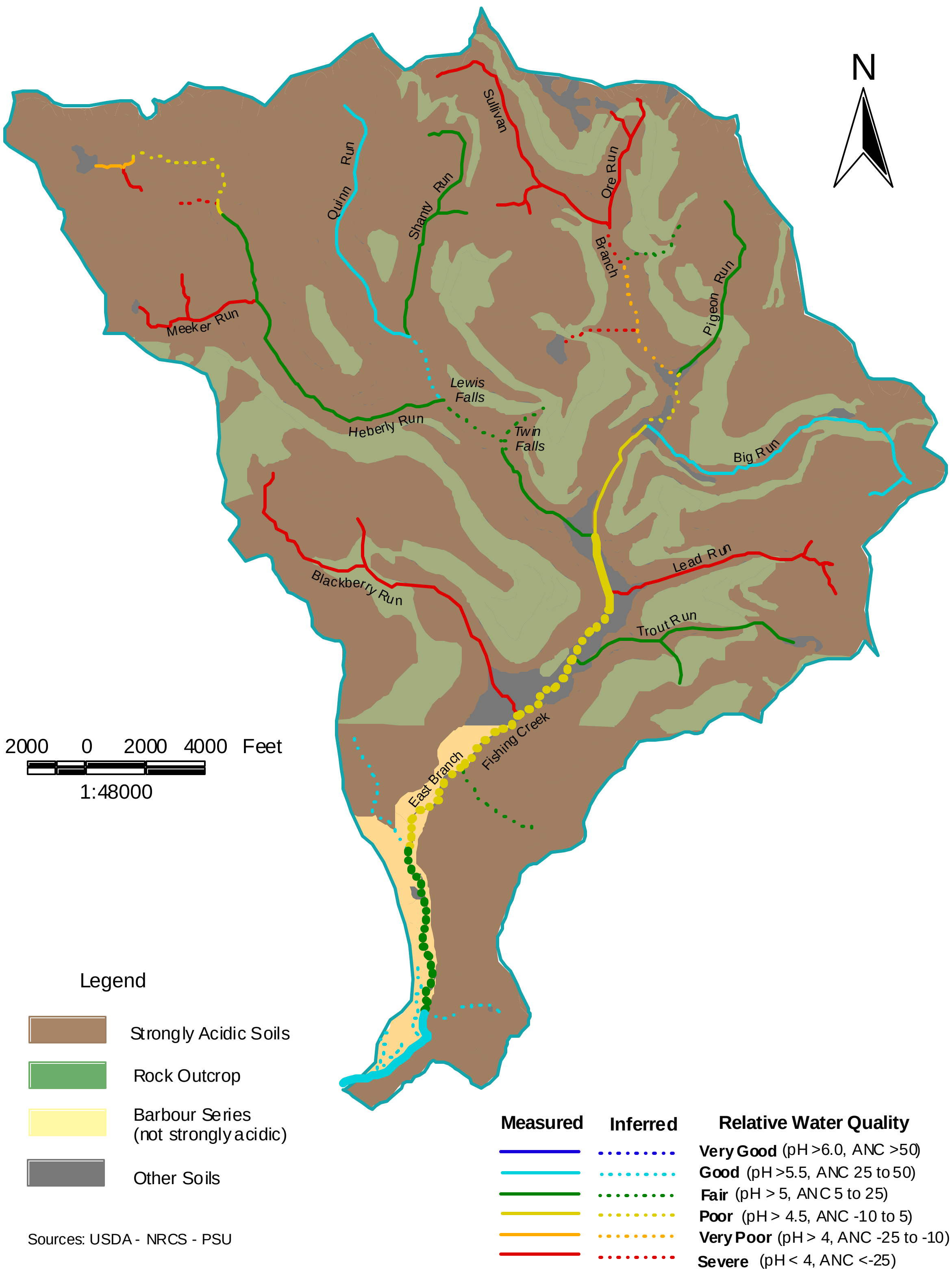


Figure 3-8: Comparison of General Soil Acidity to Average Water Quality



ALKALINE ADDITION REQUIREMENTS

The alkaline deficiencies presented in Table 3-2 represent the alkaline addition required to reach a zero ANC, which is a neutral condition from an analytic standpoint and used for uniform comparison of relative deficiency levels between streams. This is not, however, a desirable condition for sustainable fish populations, since zero-ANC waters have no buffering capacity and equate to a pH of about 5.3 SU in this study. A minimum pH of 5.5 SU is desirable for sustaining fish species such as brook trout, requiring a positive ANC.

It is proposed that the minimum restoration goals in the East Branch Fishing Creek watershed should be an ANC of 25 µeq/L under average flow conditions and 10 µeq/L under SD high flow conditions. This equates to a pH range of about 5.8 SU on average, with a minimum of about 5.5 SU during high flows. Table 3-5 provides a comparison of this target range to the observed pH and ANC equivalent short-term survivability ranges of fish species living in waters acidified by mine drainage. These ranges may guide future adjustments to restoration goals if reintroduction is desired for more sensitive species.

Table 3-6 provides a summary of the predicted alkaline addition requirements to meet the proposed restoration goals at each of the sample points. Average values would represent the normal daily feed rate of an addition system, with SD high flow values being the typical design maximum feed rate. Average and SD high flow alkaline addition requirements are presented as pounds per day as $CaCO_3$ as estimated from ANC deficiencies. Actual addition rates will depend on the purity and type of alkaline addition material selected. Annual figures are also provided as an estimate of the yearly addition commitment. Determination of actual addition requirements will be discussed for specific technologies in Section 4. Values for SE high flows are provided for comparison, but the SD high flow values are used in further discussions as being the more conservative estimates. As indicated by Table 3-6, use of SE high flows makes essentially no difference in annual addition requirements because most of these requirements are dependent on average flows rather than high flows.

In conclusion, Figure 3-9 shows a cumulative loading chart of alkaline addition required to meet minimum restoration goals throughout the sample point network of the East Branch Fishing Creek watershed. Where the sum of the upstream addition is greater than the downstream deficiency, the alkalinity greater than the deficiency is assumed to carry to the next downstream point. Ultimately, downstream-progressing, long-term restoration will likely require a minimum of about 49 tons per year of alkaline addition as $CaCO_3$ (roughly 50 tons per year of high-quality limestone). Essentially identical figures result when applying this analysis to the estimated annual SE addition rates. As discussed in Section 5, it may not be possible to treat all headwaters sources, so greater quantities of addition may be necessary to compensate at points that are treated.

Table 3-5: Observed Survival Ranges of Fish Species in Mine Drainage Waters

Species	Survival Range																				
pH (SU)	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5
ANC Eq. (µeq/L)	-31	-26	-22	-18	-14	-11	-8	-5	-2	1	7	13	19	25	32	40	48	56	66	77	90
Ohio Lamprey																					
Chain Pickerel																					
Golden Shiner																					
White Sucker																					
Brown Bullhead																					
Pumpkinseed																					
Creek Chubsucker																					
Largemouth Bass																					
Brook Trout																					
Creek Chub																					
Yellow Perch																					
Bluntnose Minnow																					
Blacknose Dace																					
Brown Trout																					
Longnose Dace																					
Margined Madtom																					
Tessellated Darter																					
Slimy Sculpin																					
Stoneroller																					
Silverjaw Minnow																					
River Chub																					
Common Shiner																					
Silver Shiner																					
Rosyface Shiner																					
Mimic Shiner																					
Northern Hogsucker																					
Rock Bass																					
Smallmouth Bass																					
Greenside Darter																					
Fantail Darter																					
Johnny Darter																					
Banded Darter																					
Blackside Darter																					
Cutlips Minnow																					
Fallfish																					
Redbreast Sunfish																					
Rainbow Darter																					
Variegated Darter																					
Mottled Sculpin																					
Redside Dace																					
Spotfin Shiner																					
Spottail Shiner																					
Pearle Dace																					
Green Sunfish																					

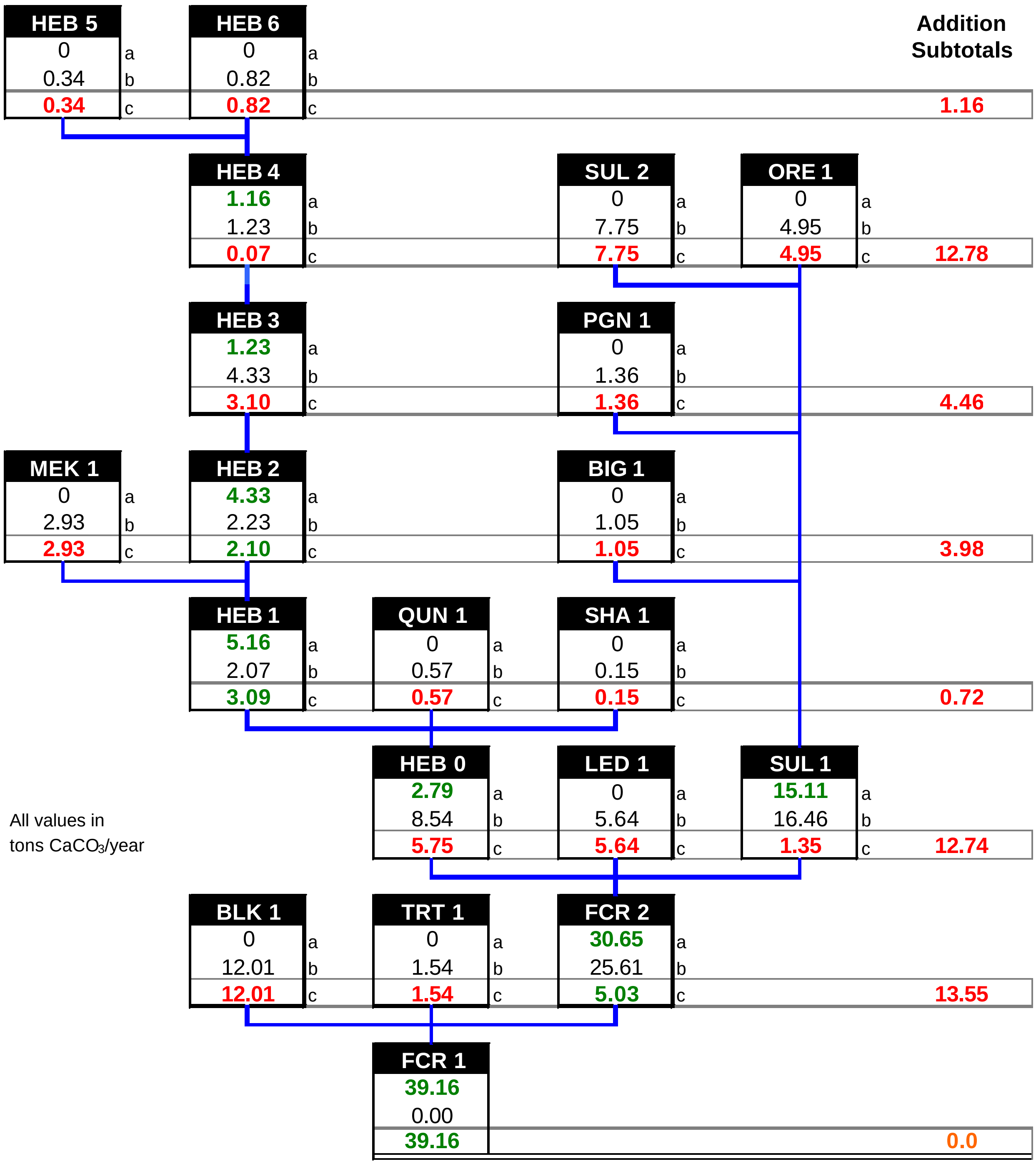
Target Range

Minimum Proposed Restoration Goal

Table 3-6: Alkaline Addition Requirements to Meet Minimum Restoration Goals

Sample Point		Alkaline Addition Requirement				
			High Flow		Annual	
		Average lbs/day	SD Value lbs/day	SE Value lbs/day	SD Value tons/year	SE Value tons/year
BIG 1	Big Run	0	115	37	1.05	0.34
BLK 1	Blackberry Run	66	153	85	12.01	12.01
FCR 1	EB Fishing Creek at Confluence w/ West Branch	0	0	0	0.00	0.00
FCR 2	EB Fishing Creek at Lead Run	140	211	103	25.61	25.61
HEB 0	Heberly Run at Mouth	47	76	31	8.54	8.54
HEB 1	Heberly Run at Lewis Falls	11	24	9	2.07	2.07
HEB 2	Heberly Run at Meeker Run	12	30	13	2.23	2.23
HEB 3	Heberly Run Headwaters	24	66	28	4.33	4.33
HEB 4	Heberly Run below Confluence w/ HEB 5 & 6	7	6	5	1.23	1.23
HEB 5	Heberly Run Headwaters - North	2	3	2	0.34	0.34
HEB 6	Heberly Run Headwaters - South	4	6	5	0.82	0.82
LED 1	Lead Run	31	96	52	5.64	5.64
MEK 1	Meeker Run	16	50	24	2.93	2.93
ORE 1	Ore Run	27	68	39	4.95	4.95
PGN 1	Pigeon Run	7	39	17	1.36	1.36
QUN 1	Quinn Run	0	62	17	0.57	0.15
SHA 1	Shanty Run	1	17	4	0.15	0.10
SUL 1	Sullivan Branch at Heberly Run	90	221	109	16.46	16.46
SUL 2	Sullivan Branch at Ore Run	42	105	49	7.75	7.75
TRT 1	Trout Run	8	5	3	1.54	1.54
Comparison of Annual Totals					**100**	**98**

Figure 3-9: Cumulative Annual Alkaline Addition Required to Meet Minimum Goals



a - Credit or carry through for upstream alkaline addition

b - Measured deficiency at sample point

c - Green: Net excess alkalinity not requiring alkaline addition

Red: Net alkalinity deficiency requiring alkaline addition

Total Alkaline Addition Requirement: **Tons $CaCO_3$ per Year** **49**

4

ALKALINE ADDITION TECHNOLOGIES

The only practical solution currently available to correct acid deposition impacts is to add neutralizing alkalinity. Limestone is the alkaline material of choice for stream restoration projects. The calcium ion (Ca^{2+}) released by dissolving limestone is naturally occurring in most waters and is benign to fish. Many streams in Pennsylvania are buffered by limestone bedrock, whereas the East Branch Fishing Creek watershed is deficient of limestone bedrock. Stronger neutralizing chemicals, including caustic soda (NaOH) and ammonia (NH_3), are used in severe cases of acid mine drainage, but these can introduce less beneficial cations to streams and may involve special handling precautions due to their reactive properties. Limestone and limestone-related products would be the most practical form of alkaline addition for the East Branch Fishing Creek watershed.

A number of technologies have been developed in recent years for applying limestone to acid-impaired streams. Table 4-1 provides a summary of the characteristics of the more commonly applied alkaline addition methods in the North Atlantic states. The Growing Greener Program recently funded an extensive series of assessments and demonstration projects for alkaline addition technologies in the Mosquito Creek watershed, including development of new approaches and application guidelines for other regional watersheds. (See Rightnour & Hoover, 2006 in References for complete details of this study). Of these, five appear most applicable to East Branch Fishing Creek: vertical flow wetlands (VFWs), high flow buffer channels (HFBCs), forest liming, road liming, and in-stream limestone sand dosing. This section provides application guidelines for these technologies, and an overview of other common methods.

Where referenced, limestone used for restoration projects should be specified as *high calcium limestone,* having a $CaCO_3$ content of 90% or greater. Products with a lesser $CaCO_3$ content have not proven as effective in past applications. The alkalinity deficiencies presented in Section 3 represent deficiencies as pure $CaCO_3$. The actual mass of impure limestone that needs to dissolve to correct a deficiency is greater than the mass of the deficiency. As shown by the equation below, this mass is determined by dividing the mass of alkalinity required by the purity of the limestone product in percent.

$$\text{Limestone Required (lbs)} = \text{Alkalinity Required (lbs)} / \text{Limestone Purity } (CaCO_3\ \%)$$

Table 4-1: Summary of Common Alkaline Addition Technologies

Technology	**Applicable Acidification Conditions**	**Approx. Alkalinity Addition Cost** ($/lb)	**Relative Costs & Effort**		**Advantages**	**Limitations**
			Construct.	O & M		
Vertical Flow Systems						
Vertical Flow Wetlands	Chronic to Mod. Episodic	≈ $0.75	●	⊗	Large alkalinity reservoir, very low maintenance, one-time expenditure.	Relatively high capital cost, long-term performance not known, compost discoloration.
Vertical Flow Limestone Beds	Chronic to Mod. Episodic	*	●	⊗	May not require compost or wetland outfall channels, less expensive than VFWs.	Performance untested, may be subject to substrate armoring.
High Flow Buffer Channels	Sustainable to Mod. Episodic	*	●	○	Saves limestone for when needed in episodic events, prevents streambed degradation.	Performance untested, requires suitable floodplain construction site.
Forest Liming	Sustainable to Mildly Episodic	≈ $0.05 – $0.30	●	⊗	Long-term improvements to soil condition, runoff neutralization, and vegetative cover.	Can be difficult to apply with high initial cost, improvements not immediate.
Road Liming						
Limestone Road Surfacing	Sustainable to Mildly Episodic	≈ $0.01 – $0.05	◉	⊗	Can be incorporated with existing surfacing programs, no new earth disturbance.	Limited intercept area for runoff, net alkaline output relatively small.
Alkaline Road Runoff Channels	Sustainable to Mildly Episodic	≈ $0.05	◉	⊗	Can be used to stabilize existing ditches, intercepts surrounding land runoff.	Requires ditch reconstruction, only generates alkalinity during storm flows.
Roadside Lime Casting	Sustainable to Mildly Episodic	≈ $0.05	◉	⊗	Lower cost than forest liming due to easier equipment access.	Limited area affected, requires specialized equipment.
In-Stream Limestone Sand Dosing	Episodic to Mildly Chronic	≈ $0.01	⊗	○	Very simple, low cost, little or no capital investment.	May degrade streambed, effectiveness variable, dosage difficult to estimate.

Table 4-1: Summary of Common Alkaline Addition Technologies (Continued)

Technology	Applicable Acidification Conditions	Approx. Alkalinity Addition Cost ($/lb)	Relative Costs & Effort		Advantages	Limitations
			Construct.	O & M		
Lake Liming	Episodic to Mildly Chronic	≈ $0.10 – $0.30	⊗	**○**	Creates large alkaline water reservoir, may restore lacustrine fisheries.	Relatively high application cost, must be re-applied ever 1 to 2 years.
Diversion Wells	Episodic to Mildly Chronic	**	**○**	●	Simple to construct, proven in existing applications, unskilled maintenance.	High frequency of maintenance, no current criteria for alkalinity output.
Rotary Drums & Basket Wheels	Episodic to Mildly Chronic	**	**○**	●	Allows a degree of dosage control and response to flow changes.	High frequency of maintenance, mechanical systems can malfunction.
Pebble Quicklime	Chronic to Mod. Episodic	≈ $0.05 – $0.10	**○**	●	Rapid neutralization and controllable dosage, small construction footprint.	Frequent maintenance and skill in quicklime handling required, higher material cost.

*Technology not yet applied.
**Varies considerably depending on site conditions.

⊗ Little or no cost or effort
○ Low cost or effort
○ Moderate cost or effort
● High cost or effort

VERTICAL FLOW WETLANDS

As shown by Figure 4-1, VFWs consist of deep basins filled with a basal layer of limestone aggregate topped by a bed of spent mushroom compost. Water diverted from an acidified source or stream is introduced into the top of the basin and migrates down through the two layers, acquiring excess alkalinity through sulfate reduction and limestone dissolution before being returned to the stream through an underdrain system to neutralize the source or stream. VFWs were originally developed to treat acid mine drainage based on observations that use of compost in conjunction with limestone improved alkalinity generation and reduced armoring by metals precipitates compared to use of limestone alone. The advantage of VFWs is that they provide a large reservoir of limestone and require little maintenance and no material replenishment for many years after construction. They are particularly effective where maintenance labor is limited or where restoration funding requires a one-time investment without provision for ongoing material replacement.

Figure 4-1 – Schematic Section of a Vertical Flow Wetland

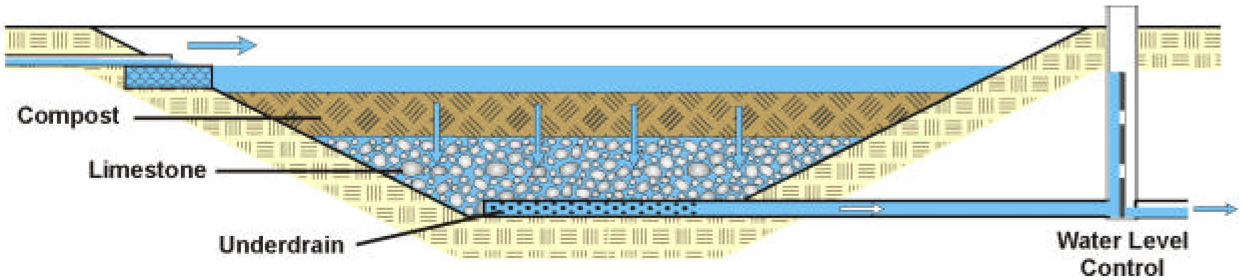


Figure 4-2 shows the layout of a VFW constructed on Pebble Run in the Mosquito Creek watershed. Three of these systems were constructed on sites in Mosquito Creek under Growing Greener Grants and monitored for performance to develop design criteria for acid deposition applications. This led to the development of a standardized design that is readily modified to application in other watersheds, and which has a predictable alkalinity output expectation. Figure 4-3 shows the basic components of this design.

A fundamental feature of the standard VFW plan is the controlled inlet structure, which is designed to admit baseflow from a stream while limiting high flow events that could damage the cell. A stepped-weir check dam is placed across the stream with a baseflow notch measuring 6 inches square, and a high flow crest with a width as needed to carry the design storm event. An inlet pipe is installed along the upstream side of the dam with the centerline of the pipe level with the bottom of the baseflow notch. A 6-inch pipe is adequate for the range of flows that can be handled by a practical VFW cell sizing. An inverted elbow is placed on the end of the pipe to exclude leaves and debris.

The level inlet pipe is connected to an in-line water level control manufactured by Agri Drain Corporation. This control features removable PVC stop logs set in brackets. A round hole is drilled in one of the stop logs and set center-to-centerline with the inlet pipe to act as an orifice, hydraulically limiting inlet flows even with relatively large head increases at the dam structure. A 3-inch orifice will divert the first 20 gpm of stream baseflow, with high flow passage of 80 gpm and maximum storm flow passage of 100 gpm. The inlet pipe then drains to the VFW cell across the top of a gabion basket to dissipate flow energy.

For substrates, 3 feet of limestone and 1.5 feet of spent mushroom compost are used. Some systems have used blended compost and limestone sand for the upper substrate, but there is no definite evidence that this improves performance. The limestone is typically placed by a track hoe to avoid damage to the underdrain. Compost may then be spread on the limestone using a small bulldozer or skid loader.

Figure 4-2: Typical Vertical Flow Wetland Site Plan (Pebble Run – Mosquito Creek)

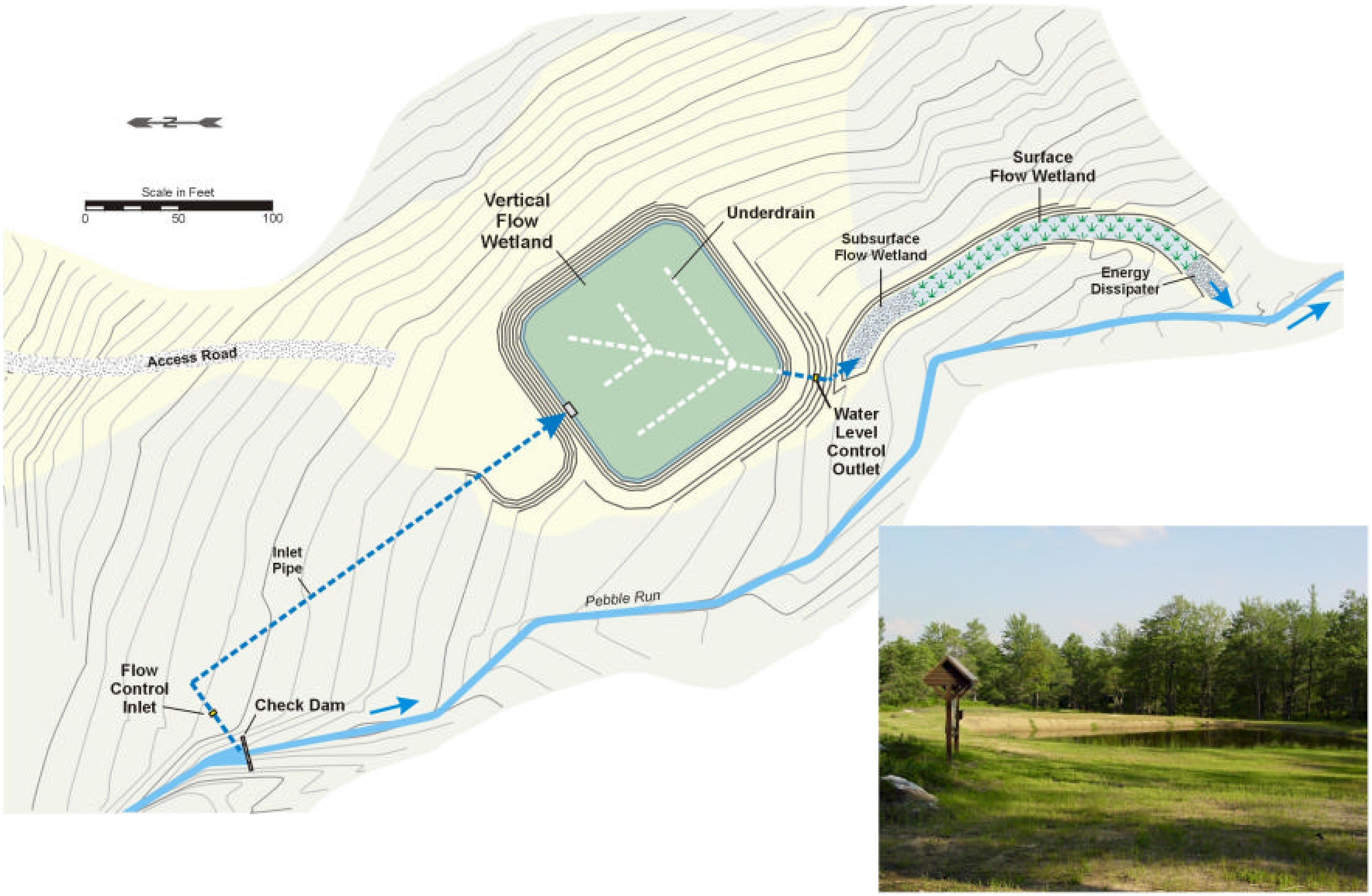


Figure 4-3: Basic Components of a Vertical Flow Wetland for Acid Deposition Treatment

Influent water is diverted to an inlet pipe by a staged check dam.

An in-line water level control with an orifice allows baseflow to enter the pipe, but limits high flows to prevent damage to the VFW.

An underdrain of perforated pipes is placed on the lined floor of the VFW cell.

A 3-foot bed of limestone aggregate is spread on top of the underdrain.

An 18-inch blended compost and limestone sand substrate is spread on top of the limestone bed.

The underdrain discharges through an in-line water level control, entering a wetland channel for discharge polishing.

The underdrain consists of 6 inch PVC pipe with ½ inch perforations drilled on 6 inch centers. A crows-foot pattern has been found convenient for uniform infiltration spreading. The underdrain is connected to another Agri Drain in-line water level control at the cell outlet, which is initially set to provide a minimum standing water level of 1 foot above the compost, and can be adjusted later to account for settling and gradual decreases in hydraulic conductivity. The cell is lined using a medium density polyethylene (MDPE) liner up to the design water level to prevent leakage, with a perimeter liner anchor extending to the freeboard elevation and covered with topsoil to allow revegetation to the waterline.

In recent systems, a wetland outfall channel has been added to remove organic matter and discoloration that can leach from the compost for several years after construction. The upper part of the channel is a subsurface flow wetland containing limestone aggregate, and the lower part is a surface flow wetland with a topsoil substrate. The aerobic wetlands also serve an important secondary function to dissipate hydrogen sulfide gas (H_2S) that is generated in the VFWs, reducing potential adverse effects on downstream biota in the effluent mixing zone. A flow measurement device, such as an H-flume, is typically installed at the end of the channel for performance monitoring.

As shown by Figure 4-4, discharge alkalinity from VFWs is primarily a function of detention time in the limestone substrate. The trend is asymptotic at greater detention times as the limestone approaches dissolution equilibrium in the VFW environment. Alkalinity diminishes more rapidly as detention times fall below about 24 hours. Although longer detention times create higher discharge alkalinities, they also imply lower flow rates through a fixed volume of substrate. Actual alkalinity output as a mass loading is a function of both the flow volume and the concentration, so reducing flows to increase detention time can also reduce output loadings. Figure 4-5 illustrates this relationship with plots of predicted alkalinity output (pounds per day) versus input flow for several example limestone bed volumes in cubic yards (CY). Due to the logarithmic nature of the discharge alkalinity concentration function in Figure 4-4, alkalinity loading output reaches a peak at moderate flows for a given bed volume before diminishing again at higher flows. This is most apparent for the 500 CY example, but will occur for all bed volumes at sufficiently high flows.

By this analysis, an 18 hour detention time appears to provide the most efficient alkalinity output rate for a VFW. Figure 4-5 serves essentially as a nomogram to estimate the 18 hour detention limestone bed volume for a desired average alkalinity output rate, and for estimating the input flow volume required to achieve that rate. Because of the potential for daily output variability, a design margin of error is advisable. The bed volume range shown on Figure 4-5 is probably the practical construction limit for VFWs. Systems smaller than 500 CY will have higher per-pound costs because of fixed construction costs, such as inlet structures, and those greater than 2,000 CY will occupy several acres and be more difficult to construct and maintain. For projects requiring greater alkalinity output, the required bed volume can be divided among multiple cells.

Figure 4-4: Relationship of Discharge Alkalinity to Detention Time in VFWs

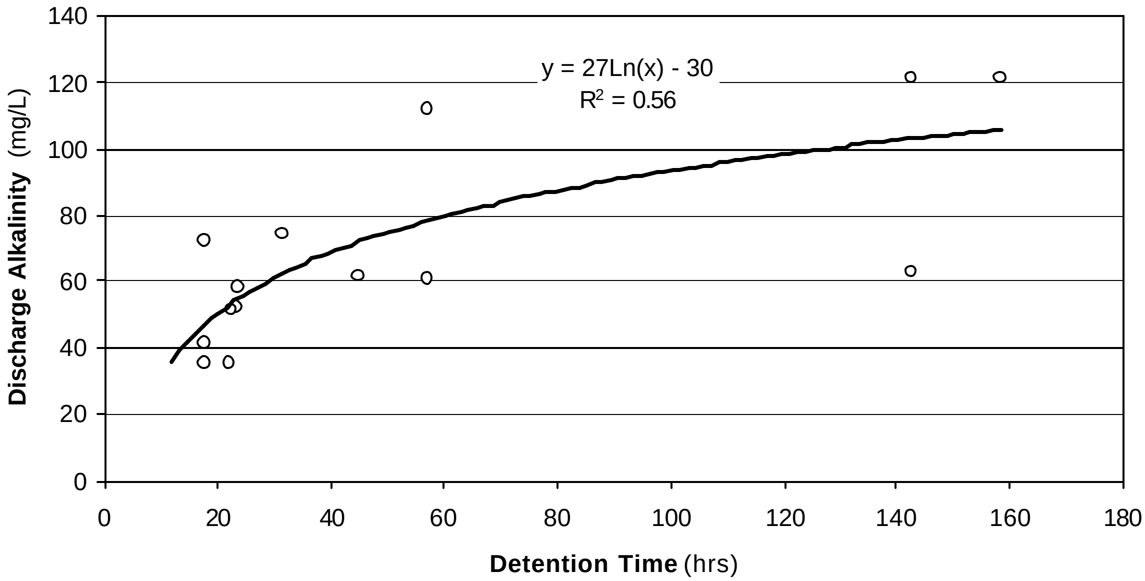
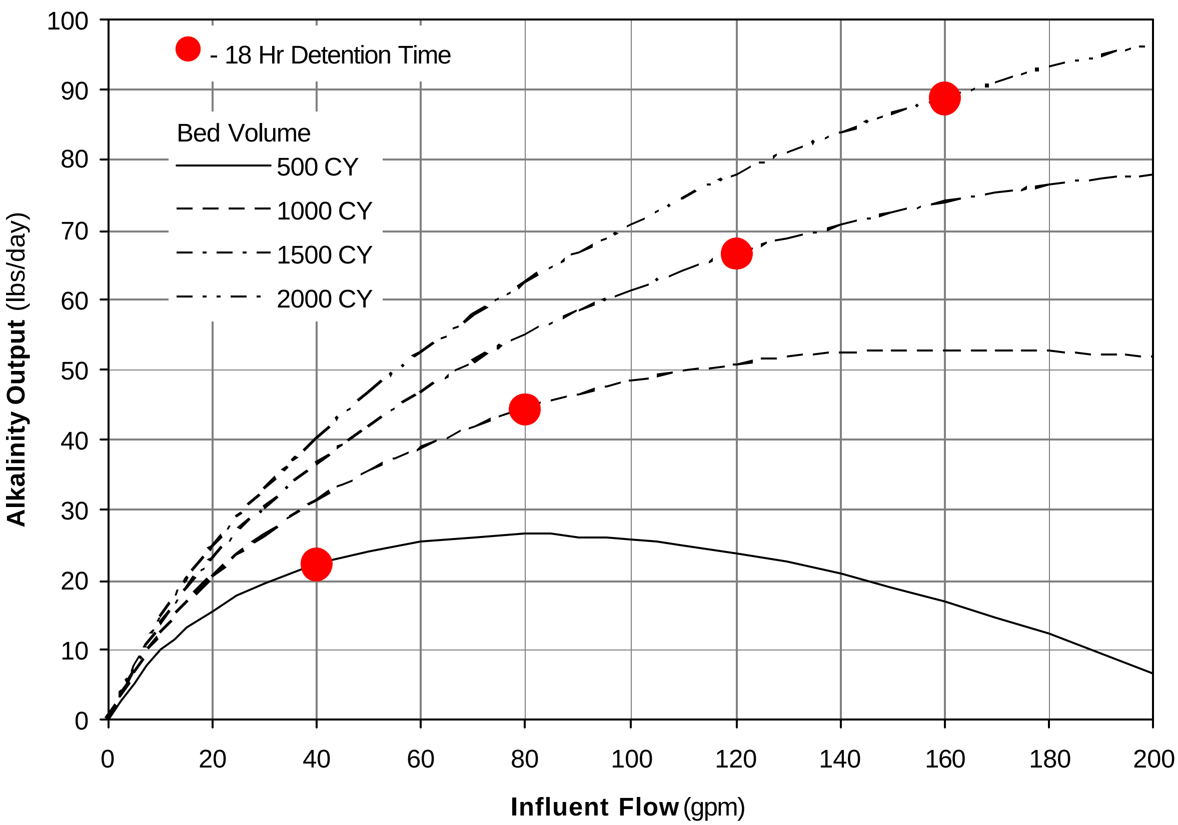


Figure 4-5: Relationship of Alkalinity Output, Influent Flow, and Bed Volume in VFWs



The standard VFW design measures 120 feet square at the freeboard level, with 1.5 feet of freeboard, 1 foot of standing water, 1.5 feet of compost, and 3 feet of limestone, for a total depth of 7 feet. Inside slopes are 2 to 1, with outside slopes varying depending on the stability recommendations of the designer. This configuration results in a bed volume of approximately 1,000 CY, with an influent capacity of 80 gpm and typical alkalinity output of about 50 lbs/day. In the Appalachian region, most watersheds of 250 acres or greater will produce sufficient runoff to adequately supply this size VFW with influent.

Depending on access development and other site-specific project factors, the standard VFW design will currently cost about $200,000 to construct. The actual longevity of VFWs in acid deposition settings is not yet known. At the observed output rates, the standard design hypothetically contains over 100 years of consumable material; however an operational life of 15 years is a more conservative estimate. VFWs are fairly substantial earthwork structures and require an engineering design for stability and hydraulic sizing. The inlet and outfall structures will normally require stream encroachment permits, and earth disturbance and National Pollution Discharge Elimination System (NPDES) permits may also be required depending on the project size. For these reasons, VFW designs are usually contracted to a specialized design firm. Base costs for design and permitting will normally be about $35,000 per site.

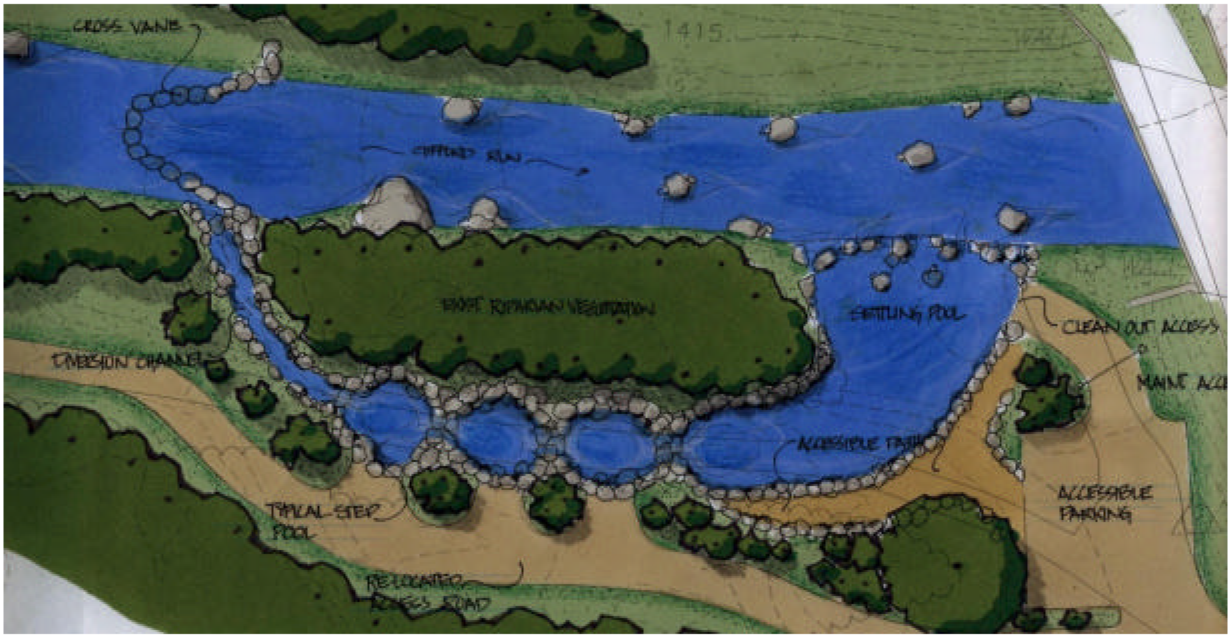
In a variation of the VFW design, vertical flow limestone beds (VFLBs) have been conceptually planned for application in acid deposition settings. VFLBs are simply VFWs without the compost bed. Although compost appears to be required to maintain alkalinity generation for mine drainage treatment, it may not be as necessary in “clean water” applications such as acid rain runoff. If results from future projects are favorable, VFLBs may be used in place of VFWs for acid deposition, saving the costs of compost and outfall polishing wetlands.

HIGH FLOW BUFFER CHANNELS

HFBCs are an innovative concept intended to address two concerns involved with in-stream limestone sand dosing: the placing of fine materials in natural stream channels, and the wasting of limestone by dissolution during low flow periods in episodically acidified streams. The concept is to create a “stream beside a stream” in which limestone sand can be placed and retained in a controlled flow regime outside of the natural channel. Figure 4-6 shows the conceptual layout of an HFBC designed for Gifford Run in the Mosquito Creek watershed.

An in-stream structure, such as a cross vane, is designed to direct a portion of high flow events into the HFBC. Diverted waters flowing through the HFBC acquire alkalinity from migrating limestone sand in a series of step pools, much as with sand dosing in a natural channel. In this plan, however, a settling pool traps the sand, preventing the accumulation of fine materials in the natural stream channel. The settling pool also serves as a temporary alkaline refuge for fish during acid runoff events.

Figure 4-6: Typical High Flow Buffer Channel Site Plan



The current design approach for HFBCs is to size the inlet structure to begin diversion at or below the predicted neutrality threshold flow for negative ANC. As flows increase, a progressively greater percentage of the total flow passes through the HFBC for return to neutralize the main stream flow. The HFBC sizing requirement is established through channel hydraulics based on the maximum intended diversion flow. A construction site is necessary on a floodplain or other low-lying area capable of receiving flows diverted from a stream. Minimum construction lengths are estimated at about 350 feet, although longer lengths will likely yield greater alkalinity output. The construction area should be less than 4 feet above the adjacent stream level at the upstream end to minimum earthwork requirements. This type of construction will require stream encroachment permitting and other permits as described for VFWs.

Construction of the first demonstration HFBC is anticipated in the Mosquito Creek watershed in 2007, with performance criteria to be developed thereafter. Current construction costs for HFBCs are estimated at about $90,000 per unit, although this will vary on other sites depending on access requirements and site constraints. The only anticipated maintenance for HFBCs after construction is periodic recycling of limestone sand from the settling pool back to the step pools using a loader, and replenishing the sand by truck delivery as it dissolves. Maintenance costs will be approximately the same as for in-stream limestone sand dosing.

FOREST LIMING

Liming of forest floors and other catchment areas has been used as an alkaline addition strategy in the Scandinavian countries for many years. The concept is to both neutralize acid deposition in the runoff stage and to restore acidified soils in the hydrologic source areas. Acid rain is thus neutralized as it reaches the surface and before entering the stream. Although the effects may not be immediately observed in receiving streams, land application liming can produce long-term improvements lasting for decades.

There are as yet no established criteria for land application liming rates to treat acid deposition, although the 2 tons per acre rule-of-thumb is generally used as a starting point. The methods and costs of land application liming vary depending on the type of surface cover in the application area. Open fields present the easiest areas and can be limed by common agricultural equipment, such as a tractor and an agricultural lime spreader. With volunteer labor and equipment, this type of liming can be conducted for essentially the cost of materials. Scrubland and forests require more specialized equipment to navigate between obstacles. The type of lime product applied depends on the nature of the spreading equipment used. Pelletized lime is available for about $100 per ton, agricultural limestone can be obtained for about $30 per ton, and limestone sand about $20 per ton.

The PSU Forestry Department is currently investigating the benefits of land application liming in the headwaters of Heberly Run. Composite soil samples were collected and analyzed to determine soil deficiencies and to quantify limestone application rates. From May 2006 through August 2006 dolomitic limestone sand was applied to approximately 100 acres at a rate of 4 tons/acre. Dolomitic limestone was applied for its magnesium carbonate ($MgCO_3$) content in addition to calcium carbonate ($CaCO_3$). Calcium and magnesium enrich soil conditions and provide a healthier growth environment for vegetation. Post-liming soil samples were obtained, and the analysis and conclusions are currently underway. Alkalinity generation results are not expected to be as great as if calcitic limestone (majority calcium carbonate) had been applied. Higher calcium content would have a greater direct benefit for acid-impacted streams and is suggested for liming applications specific to the goal of improving water quality.

For their forest liming projects, PSU purchased and outfitted a log skidder with a liming hopper, the "Regenerator" shown by Figure 4-7. The operation also involves a dedicated loader to fill the hopper from on-site stockpiles. Basic costs are $1,000 for mobilization, $29 per hour for the skidder, $25 per hour for the operator, $200 per day for the loader, and the cost of limestone delivered. On projects greater than 100 acres, this amounts to costs on the order of $150 for 2 tons per acre of application, or about $0.05 per pound of potential alkalinity. The "Regenerator" is currently a unique piece of equipment, and has been used for other restoration projects in the central Pennsylvania region. For more information on the forest liming project or using the "Regenerator," please contact Dr. William Sharpe at the PSU.

Figure 4-7: The Penn State “Regenerator” Lime Application Skidder

Problems with forest liming include difficulty of application in wooded areas, slow dissolution of applied material under the forest canopy, and potentially long periods until effects appear in receiving streams. There are no current criteria for predicting what percentage of the alkalinity will eventually reach a stream as runoff, or at what rate. It has also been noted that liming may have adverse effects on existing plant communities adapted to acidic conditions, especially bryophytes and lichens. Some areas may not be accessible for practical ground application of lime, such as dense forests, steep slopes, sensitive riparian corridors, and wetlands. If direct application is required for these areas, the only solution may be aerial liming using methods much as described for lake liming.

ROAD LIMING

Application of limestone for on or around roads may provide an alkaline benefit to acidified watersheds during precipitation events. Although the surface area of roads is usually a very small percentage of a given watershed, they often affect a significant portion of the total runoff volume. While studies to document this effect are in the early stages, preliminary observations indicate that this could be a worthwhile practice to pursue, especially in cases where surfacing and stabilization are required in any case. Three basic approaches to road liming are road surface application, alkaline road runoff channels, and roadside casting, described as follows.

Limestone Road Surfacing

Over the course of the Mosquito Creek projects, a number of field measurements were taken during storm events along limestone-surfaced forest roads maintained by the Moshannon State Forest and Pennsylvania Game Commission. The cumulative field observation was that overland flows from untreated forest areas would gain about one full unit of pH on contact with limestone-surfaced roads and ditches. This ANC generation could make the difference between episodic and sustainable conditions for a receiving stream with a significant watershed portion affected by roads.

Figure 4-8 shows a completed limestone road surfacing project (note also an alkaline road runoff channel to the right). Costs of limestone road surfacing depend greatly on the nature of the road, including width, thickness of cover, and coarseness of the aggregate applied. Basic crushed limestone road cover is available for about $20 per ton. In many cases this type of surfacing can be incorporated into existing road maintenance programs for essentially the cost of materials. There are no current criteria for estimating alkalinity generation rates from limestone road surfacing, other than it creates positive increases in pH and ANC. This technology is also only applicable to unpaved roads.

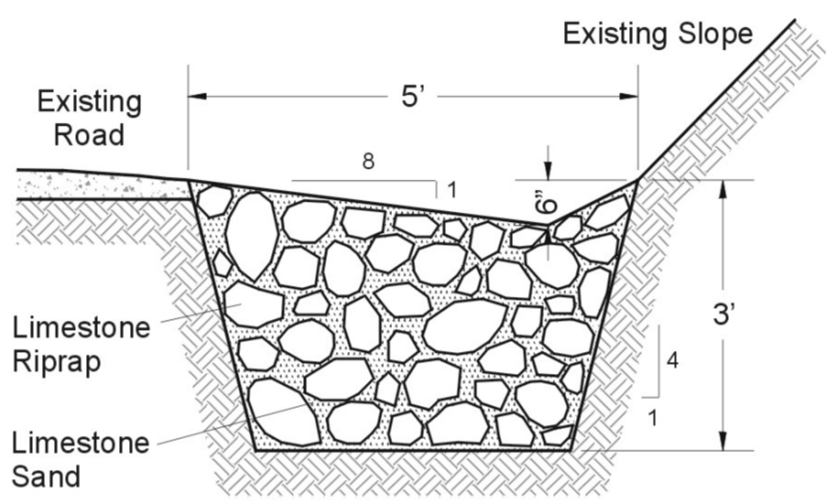
Figure 4-8: Example of Limestone Road Surfacing

Alkaline Road Runoff Channels

Alkaline road runoff channels, or ARRCs, can involve nothing more than using limestone in place of inert riprap when lining roadside ditches. This enhances the performance of limestone road surfacing by maintaining contact between runoff and alkaline material during channelized flow to streams. In an approach developed for the Mosquito Creek projects to enhance performance, limestone sand was added to the interstitial riprap voids to provide finer alkaline material with a greater reactive surface. While the riprap provides stability, the sand can migrate to some extent on the surface and in the voids. A deeper trench plan can also provide water retention between storm events, with longer-term dissolution yielding a higher alkalinity dose during the next storm flush. A typical section for this type of ARRC is show by Figure 4-9.

There are insufficient data to date to develop a prediction model for alkalinity output from ARRCs. One demonstration project was measured as discharging an alkalinity of 19.8 mg/L, an ANC of 459 μeq/L, and a pH of 7.63 SU. As with limestone road surfacing, they are currently targeted at unspecified improvements in acidified watersheds. Costs of ARRC construct will vary depending on the channel size and depth. Riprap for constructing roadside ditches typically costs about $35 per ton. Unless volunteer labor and equipment are available, additional costs will be incurred for the actual installation of the material. The lowest cost projects will be those where limestone can be used in place of another type of channel lining material for already planned road maintenance. ARRCs are also suitable for use beside paved as well as unpaved roads.

Figure 4-9: Typical ARRC Section



Roadside Lime Casting

Mechanical abrasion by traffic on limestone-surfaced roads tends to keep the particle surfaces fresh and generates fine limestone dust, which then is blown into surrounding areas during dry periods and creates a wider alkaline corridor. Conceptually, this corridor could be enhanced by casting lime from roads using a spreader. The PSU Regenerator can cast lime 20 to 30 feet to a side, depending on the density of vegetation. The area of alkaline influence for a given road could conceivably be tripled or more by simply driving a machine of this type along it and casting to the sides. This approach would only be applicable to unpaved roads, as spreaders usually are not sufficiently directional to keep material from falling on pavement. The effects roadside lime casting would likely be comparable to forest liming, while the costs should be lower due to greater ease of machine operation. The approach has not been tested to date, but is presented as an option given the extent of unpaved public roads in the East Branch Fishing Creek watershed.

IN-STREAM LIMESTONE SAND DOSING

Probably the simplest form of alkaline addition is in-stream limestone sand dosing. This involves periodically dumping a quantity of limestone sand in a stream channel or on the banks where high flows will wash it away. While imprecise as far as addition quantity versus momentary need, this method does appear effective over a broad range of flows because higher flows tend to mobilize the sand and increase its rate of dissolution by entrainment contact and surface abrasion. Figure 4-10 provides an example of a limestone sand dosing project.

Several generic formulae have been developed for determining the required limestone sand dosing rate, using the variables of watershed area and pH. Table 4-2 provides a summary of three published methods based on Schmidt & Sharpe (2002) and an Empirical Method developed for the Mosquito Creek project. Where used as a factor, pH is taken as the spring (high) flow measurement to represent worst-case conditions. All methods recommend doubling the predicted addition rate in the first year of treatment, and it is best to err on the high side of estimates. In the absence of ANC data prior to alkaline addition, the Clayton Method appears to best describe an effective addition rate for regional streams. Because ANC data are available for East Branch Fishing Creek, the Empirical Method is recommended for sizing limestone sand dosing projects in this watershed. The dosing requirement in this case is the difference between the average target restoration ANC and the existing average measured ANC, multiplied by the measured average flow and a conversion factor. The Empirical method is presumably not affected by regional rainfall variations because it uses measured flow instead of watershed area, and it also allows a scalability of restoration goals by changes to the target ANC value.

Figure 4-10: Example of In-Stream Limestone Sand Dosing

Table 4-2: Common Calculations for In-Stream Limestone Sand Dosing

Method	Calculation
West Virginia	Annual Application (tons/yr) = 0.05 x Watershed Area (acres)
Clayton	Annual Application (tons/yr) = 0.4 x Watershed Area (acres) x 10.3 $e^{-1.15pH}$
Virginia (Downey)	Annual Application (tons/yr) = Watershed Area (acres) x [0.028 - 0.015 Ln(pH)]
Empirical	Annual Application (tons/yr) = 0.00012 x (Target ANC – Existing ANC) x Flow (gpm)

Limestone sand dosing is best suited to moderately sized streams with low to moderate acidification impacts. It appears more effective to dose several points along a stream to prevent excessive sedimentation at a single point and limit aesthetic impacts. A sufficient flow velocity is required to cause migration and abrasion of the sand under average and higher flow conditions. A minimum thalwag velocity of 2 ft/s is recommended under average conditions. Dosing requires a dumping access point, such as a bridge abutment, but no other appreciable capital investment. Depending on site conditions, it may be necessary to use a small loader or skid loader for spreading. The preferred limestone sand material corresponds to an AASHTO No. 10 aggregate size (about 1/8” to 3/8” dia.), which is typically available for about $20 per ton delivered.

There are concerns that long-term dosing can degrade streambeds by clogging cobble bottoms with finer-grained sand, reducing the quality of habitat for benthic macroinvertebrates. A buildup of aluminum precipitates has also been noted downstream of dosing sites in some cases, where increased pH renders aluminum less mobile in solution. During high flow events, reduced pH can re-dissolve these deposits, potentially causing aluminum concentrations locally in excess of those existing prior to treatment. Limestone sand dosing is still an inexpensive and successful approach and readily implemented by watershed interest groups and volunteer labor. Because limestone sand dosing involves placement of material within a stream channel, this activity may be regulated by state and federal agencies.

OTHER TECHNOLOGIES

Several other common alkaline addition technologies are available that may or may not eventually be found applicable in the East Branch Fishing Creek watershed. These include lake liming, limestone diversion wells, limestone rotary drums and basket wheels, and pebble quicklime addition. All four are relatively high maintenance compared to the previously discussed technologies, but are summarized here for future consideration as restoration planning progresses.

Lake Liming

Lake liming and other forms of riparian lime addition for acid abatement are widely used in Norway and Sweden, and have also shown favorable results in North America. The concept is to spread fine limestone material by air or by boat to open water bodies, creating a large reservoir of alkaline water that is progressively flushed out to neutralize downstream reaches. Figure 4-11 shows a typical aerial liming operation. Because there are no significant open water bodies present in the East Branch Fishing Creek watershed, this technology is not considered to be directly applicable. However, the concept of aerial liming may eventually be of use to reach riparian or wetland areas that otherwise cannot be accessed by ground equipment.

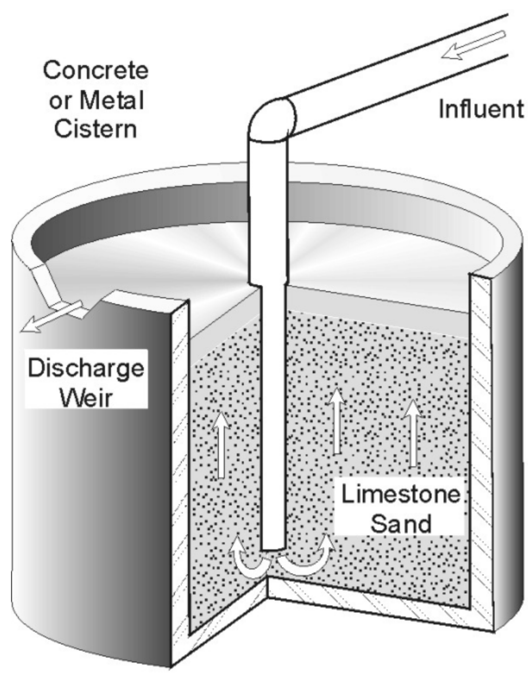
The rule-of-thumb approach to aerial liming is the same as for forest liming: 2 tons of limestone per acre of surface area. Alkalinity generation results will depend on the nature of the application surface, with flow-through wetlands providing more immediate benefits than non-inundated areas. Aerial liming requires a specially equipped airplane or helicopter, and costs about $1,000 per acre, assuming that an airstrip is available within about 10 miles. A free flowing pelletized lime works better for aerial application, costing approximately $100 per ton.

Figure 4-11: Example of Aerial Lake Liming

<u>Limestone Diversion Wells</u>

Limestone diversion wells originated in Norway and Sweden as methods for treating acid rain, and they were adopted for mine drainage treatment in the United States during the 1990s. As shown by Figure 4-12, a diversion well typically consists of a 4 to 6 foot circular concrete culvert section or metal cistern set on end at 6 to 9 feet in depth and filled with crushed limestone. A central pipe introduces flow to the bottom of the well under a hydraulic head slightly greater than the discharge elevation of the culvert section, causing the limestone particles to become fluidized like quicksand. Continuous agitation in the fluidized bed prevents armoring of the limestone and maximizes its contact with the influent water. Hydraulic head may be developed by damming and diversion of a portion of a stream flow to the well (hence the name "diversion well").

Figure 4-12 – Typical Diversion Well



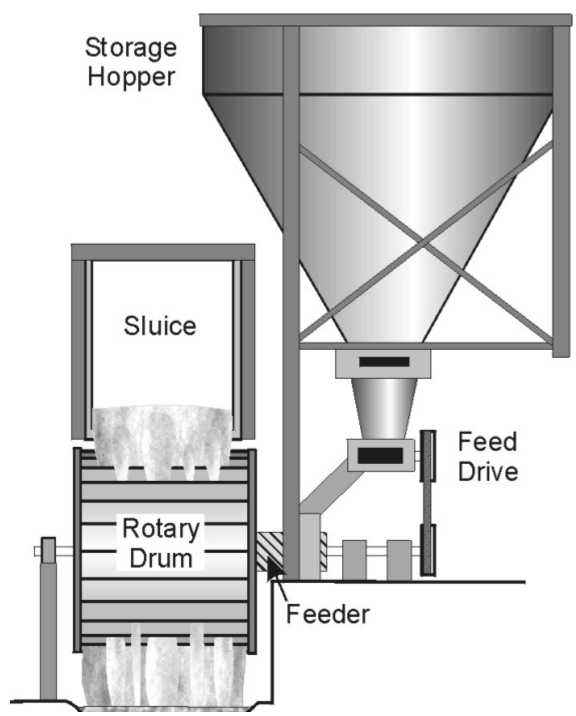
There have been numerous applications of diversion wells in the Appalachian states since their introduction, but there are as yet no specific criteria for their design or determining their performance results. A typical diversion well will cause a pH increase of 1 to 2 units in the water passing through it, along with some release of alkalinity. The amount of alkaline increase has not been adequately modeled to allow sizing of diversion wells to meet specific alkaline deficiency needs. At their current state of development, diversion wells are best suited for improvements to sustainable or mildly episodic streams where an unspecified alkaline addition would be beneficial.

Diversion wells also require frequent replenishment of limestone lost to dissolution and washout, sometimes on a weekly basis. One project on Swatara Creek in Pennsylvania reported two diversion wells consuming approximately one ton of limestone per week, although the flow and influent acidity loading were not provided. Ready truck access is necessary to maintain diversion wells at this rate of consumption. Sizing of a diversion well requires careful regulation of hydraulic head pressures to keep the limestone sand in motion without sweeping it out of the well. This can be approximated using fluidized bed mechanics, with the minimum fluidizing velocity and terminal velocity setting the lower and upper flow thresholds, respectively, for a given well configuration. Assistance from experienced persons is recommended in designing and installing diversion wells to assure proper performance.

Limestone Rotary Drums & Basket Wheels

Limestone rotary drums and basket wheels seek to overcome armoring and material loss problems by enclosing limestone aggregate in a rotary wheel, usually consisting of a drum with slots, perforations, or external screening (Figure 4-14). Typical installations are powered by water diverted from the stream and directed to a sluiceway. In the bottom of the sluice are openings located directly above each drum. As water falls through the openings in the sluice, blades attached to the exteriors of the drums initiate their rotation, as in a waterwheel.

Figure 4-13: Typical Rotary Drum



Crushed limestone is either manually loaded into each drum or automatically fed to the drums through a reciprocating feeder at the bottom of a hopper. Volume through the sluiceway determines the speed at which the drums rotate, the amount of aggregate supplied to the drum, and, ultimately, the amount of neutralization supplied to the stream. The grinding of the limestone aggregate within the drum liberates fine limestone powder and retards armoring. Water enters the drum from the sluiceway through small holes in its exterior, and exits through the bottom through the same holes, mixing with and carrying away the limestone fines. Output of the produced fines is controlled by aggregate size and rotation rate of the drums, with various screens and meshes used to control the discharge size of the fines. Several drums can be operated in series, with increased flow increasing the number of drums in operation, or multiple drums may be operated in parallel for large flows.

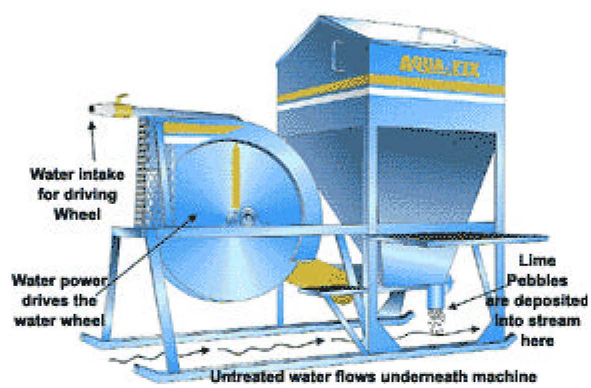
Limestone rotary drums and basket wheels are typically custom-built facilities and can vary greatly in size and complexity. Self-feeding types require the most mechanical complexity and may need frequent inspection. The Toby Creek project in Pennsylvania is such a large-scale example and includes water-powered limestone crushers to prepare bulk limestone for delivery to the rotary drums. Smaller types, true basket wheels, are based on simple mesh cylinders or perforated drums. These non-fed systems require that the wheel be periodically stopped and opened to replenish the limestone content.

There are no specific design criteria for limestone rotary drums and basket wheels. Each must be sized to provide an acceptable balance of limestone containment volume relative to the motive energy of the influent flow. Too large a drum will not rotate, and too small a basket wheel will exhaust its limestone rapidly in a high-volume flow, requiring frequent maintenance. Large-scale rotary drums and self-feeding systems can involve complex engineering design. Assistance from experienced persons is recommended in designing and installing rotary drums and basket wheels to assure proper performance.

<u>Pebble Quicklime Addition</u>

In recent years, an effective alkaline addition system has been developed using pelletized pebble quicklime (CaO), which has approximately twice the alkalinity generation rate per pound as limestone. This material is much more soluble than limestone, allowing more controlled delivery and neutralization results. The Aqua-Fix addition unit (Figure 4-14), manufactured by Aqua-Fix Systems, Inc. in West Virginia, combines a substantial reagent storage capacity with a simple, low maintenance rotary delivery unit driven by waterpower.

Figure 4-14: Aqua-Fix Unit



Courtesy of Aquafix Systems, Inc.

The Aquafix system is scalable for differing addition requirements based on its constructed storage capacity, either as an overhead silo (Figure 4-15) or an integral hopper unit (Figure 4-16). The driving water flow for the waterwheel mechanism is taken from a diversion upstream of the addition site. This allows the systems to provide an addition feed scaled to increasing flow. For conceptual sizing, it is recommended that the lime storage capacity be at least sufficient to operate between inspections at the highest design delivery rate, such that the system will not be depleted by a major storm event. The units should be inspected at least weekly to check for mechanical problems and add fresh material as needed.

For silo systems, there is little difference in construction cost between a small silo and a large silo. The standard delivery truck size is about 20 to 25 tons, and for single site applications a 25 ton silo is just as economical in the long run in terms of cost and effort as a smaller silo. With multiple systems operating in one watershed, it may be possible to arrange for a scheduled bulk delivery to all the systems using smaller and somewhat less expensive silos. Pebble quicklime is available in 50 pound bags for hopper-based systems (about $160 per ton at the plant) or in bulk for silo-based systems (about $120 per ton delivered). A 25 ton silo system costs about $100,000 to construct, while a hopper system up to 1 ton capacity is about $20,000. Over a 15-year operational life, these equate to a range of about $0.05 to $0.10 per pound of alkalinity generated, respectively.

Aquafix systems will require site-specific designs for hydraulic calibration of addition rates, diversion structures, building foundations and storage structure supports, and the chemical mixing zone. Professional assistance is recommended for site-specific design. Construction of the diversion and outfall structures will usually require a stream encroachment permit.

Figure 4-15: Silo-Type Aquafix Unit

Figure 4-16: Hopper-Type Aquafix System

5

PROGRESSIVE RESTORATION PLAN

As discussed in Section 3, the East Branch Fishing Creek watershed shows acidification to varying degrees throughout its extent. While the ultimate restoration goal would be to correct all of these impacts simultaneously, the scale and expense of such a project is likely not feasible in a single effort. Instead, it will be necessary to address local impacts in a series of smaller, more practical steps that provide immediate and mutually supporting improvements leading up to full restoration. This approach is referred to as a *progressive restoration plan*, and it has been successfully applied to other watersheds impacted by acid deposition in Pennsylvania.

The primary components of a progressive restoration plan are identification and quantification of alkaline deficiencies, an assessment of feasibility and potential effect for conceptual alkaline addition projects, and a prioritization of projects by value of benefits and community goals. The former has been completed as part of the watershed assessment. This section discusses the latter considerations and presents a progressive restoration plan for East Branch Fishing Creek, including an estimate of conceptual implementation costs.

CONCEPTUAL PROJECT SITE FEASIBILITY

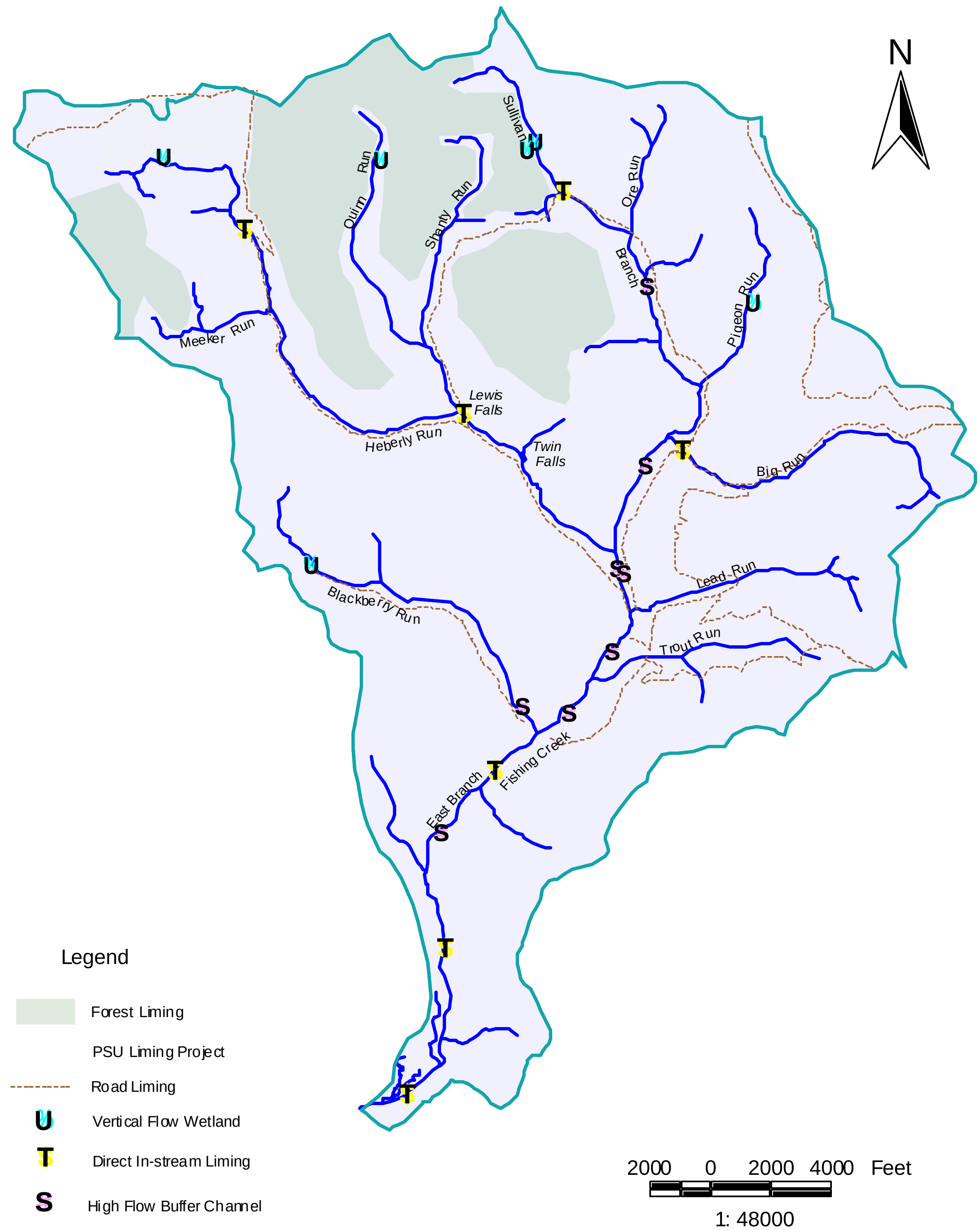
A GIS map analysis was conducted to identify conceptual sites within the watershed for application of five alkaline addition technologies: vertical flow wetlands (VFWs), high flow buffer channels (HFBCs), forest liming, road liming, and in-stream limestone sand dosing (ILSD). Road liming includes the aspects of limestone road surfacing, alkaline road runoff channels, and roadside lime casting, as discussed in Section 4. The general criteria used for site feasibility evaluations are summarized in Table 5-1.

Figure 5-1 shows the results of the GIS analysis, with the conceptually applicable quantities for each technology summarized in Table 5-1. As indicated, all five technologies have multiple potential application points. VFWs are probably limited to five application sites because of the generally steep slopes in the headwaters areas, with few suitable construction sites with sufficient upstream drainage area to provide a usable influent. Forest liming is also mostly restricted by steep slopes to the northwestern third of the watershed. Unpaved public roads and 4x4 trails are not numerous, but do parallel most of the tributaries. These can provide access for road liming, sand dosing, and construction of HFBCs. Some tributaries have no practical existing access for alkaline addition.

Table 5-1: Feasibility Criteria and Results for Application of Addition Technologies

<table>
<tr><th colspan="2">Alkaline Addition Technology</th><th>Site Feasibility Criteria</th><th>Conceptual Applicability</th></tr>
<tr><td colspan="2">Vertical Flow Wetlands</td><td>A relatively flat area (0 – 5% slope) of 1 acre or more adjacent to stream
A drainage area of approx. 250 acres or more above potential construction site to provide 100+ gpm of baseflow</td><td>5 Headwaters Sites:
Blackberry Run
Heberly Run
Quinn Run
Sullivan Run
Pigeon Run</td></tr>
<tr><td colspan="2">High Flow Buffer Channels</td><td>A relatively flat area (0 – 5% slope) within 50 feet of stream
Greater than 350 feet of construction area parallel to stream
Construction area estimated at less than 4 foot elevation above stream</td><td>8 Lower Reach Sites:
Sullivan Branch – 2
Blackberry Run – 1
EB Fishing Creek – 5</td></tr>
<tr><td colspan="2">Forest Surface Liming</td><td>Applicable to land areas with < 30% slope
USGS-mapped wetland areas were avoided</td><td>1,925 Potential Acres Affecting:
Meeker Run – 86 acres
Heberly Run – 434 acres
Quinn Run – 716 acres
Shanty Run – 253 acres
Sullivan Branch – 436 acres</td></tr>
<tr><td rowspan="3">Road Liming</td><td>Limestone Road Surfacing</td><td>Applicable along non-paved public roads</td><td rowspan="3">24.9 Potential Miles Affecting:
Blackberry Run – 1.8 miles
Heberly Run – 6.4 miles
Quinn Run – 0.5 miles
Shanty Run – 1.0 miles
Sullivan Branch – 3.2 miles
Ore Run – 0.1 miles
Pigeon Run – 1.6 miles
Big Run – 3.7 miles
Lead Run – 1.2 miles
Trout Run – 3.2 miles
EB Fishing Creek – 2.2 miles</td></tr>
<tr><td>Alkaline Road Runoff Channels</td><td>Applicable along non-paved public roads (also on paved roads, but not included in study)</td></tr>
<tr><td>Roadside Lime Casting</td><td>Applicable along non-paved public roads</td></tr>
<tr><td colspan="2">In-Stream Limestone Sand Dosing</td><td>Dosing sites were located at bridges and other stream crossings.
Applicable to moderate- to large-sized streams</td><td>7 Sites Affecting:
Heberly Run – 2
Sullivan Branch – 1
Big Run – 1
EB Fishing Creek – 3</td></tr>
</table>

Figure 5-1: Conceptual Sites for Alkaline Addition Technologies



CONCEPTUAL EFFECTS OF TREATMENT

Of the selected alkaline addition technologies, VFWs have the most predictable alkaline output rates, typically about 9 tons per year for the standard design. Their cost per pound of alkalinity generation is normally higher than that of the other technologies, so they can be used as a simplified benchmark when estimating alkaline addition requirements and costs on a conceptual basis. The cost per pound of higher-cost, higher reliability VFW alkalinity is probably roughly equivalent to achieving the same results with a lower-cost, lower reliability technology that must be scaled up for equal confidence in treatment.

Using this assumption, Figure 5-2 shows the potential results of treatment using VFWs alone in the five conceptually suitable construction locations. Other technologies without predictable alkaline addition rates are indicated where conceptually applicable. The following are the basic conclusions of this analysis:

- A single VFW in the headwaters of Heberly Run appears capable of restoring alkaline conditions downstream to HEB 2. Restoration downstream to Heberly Run at Lewis Falls will require additional alkaline addition to overcome the acidity input by Meeker Run.

- The small alkaline deficiency in Quinn Run may not warrant a VFW on that tributary; forest liming and local sand dosing may be sufficient to correct any remaining alkaline deficiencies in the lower portion of Heberly Run.

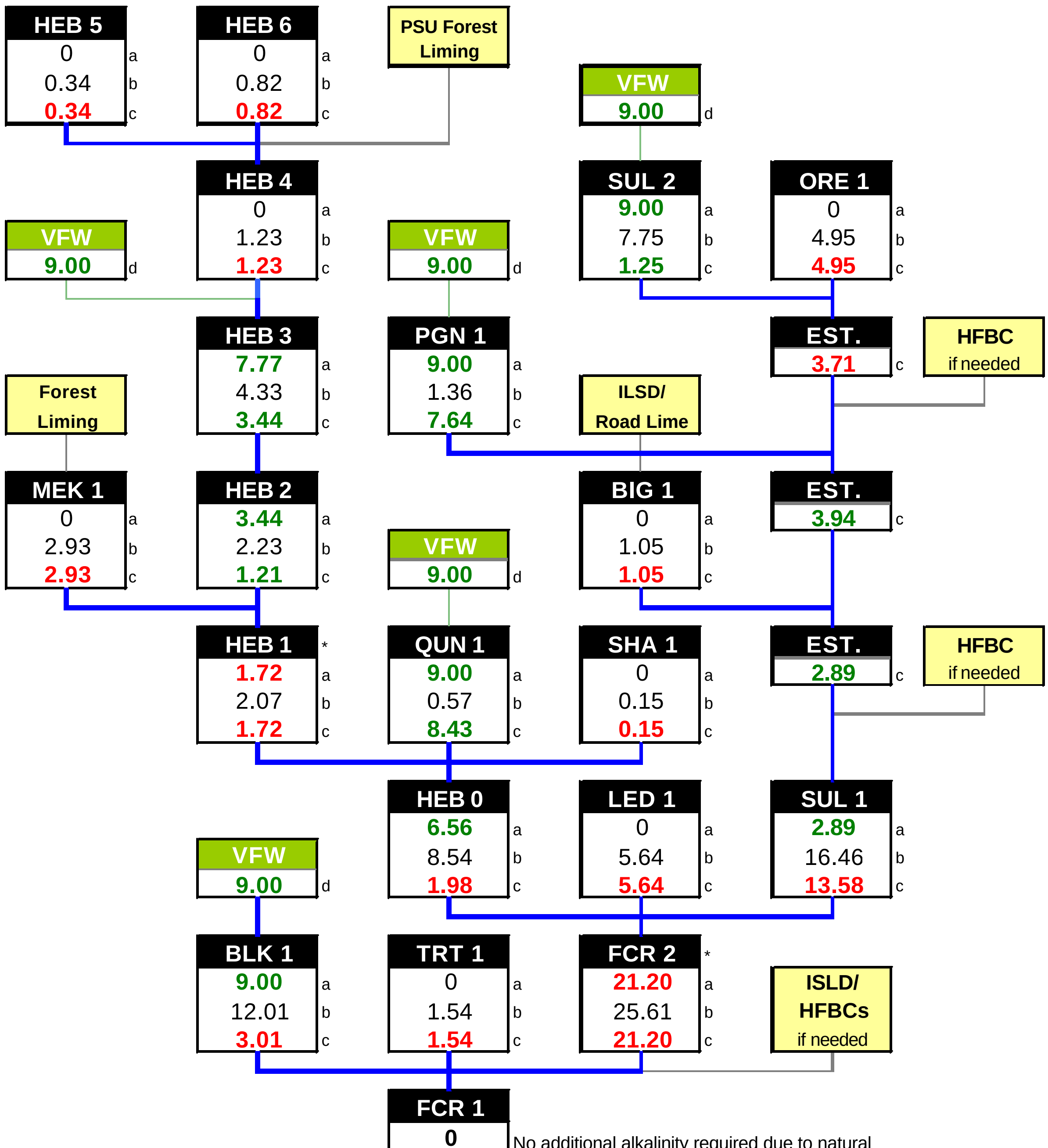
- A single VFW in the headwaters of Sullivan Branch does not appear capable of fully overcoming the acidity associated with Ore Run. Sand dosing or a HFBC may be required in the vicinity of Ore Run.

- Moving the capacity of the Pigeon Run VFW to the headwaters of Sullivan Branch would obviate the need for a HFBC or sand dosing around Ore Run.

- Deficiencies are predicted to remain in East Branch Fishing Creek below Sullivan Branch even if all five VFWs are implemented; HFBCs or sand dosing may be required in this reach.

As a modified analysis, Figure 5-3 shows the predicted results if the VFW is omitted from Quinn Run, and the VFW on Pigeon Run is moved to the headwaters of Sullivan Branch for a double-VFW installation. The only substantial change in this configuration is that a HFBC or sand dosing would not be required in the vicinity of Ore Run, but sand dosing might be required on the lower reaches of Heberly Run. The need for HFBCs or sand dosing would also increase in East Branch Fishing Creek below Sullivan Branch. This is the general configuration that has been used in developing the progressive restoration plan.

Figure 5-2: Preliminary Analysis of Potential Treatment Results



All values in
tons $CaCO_3$/year

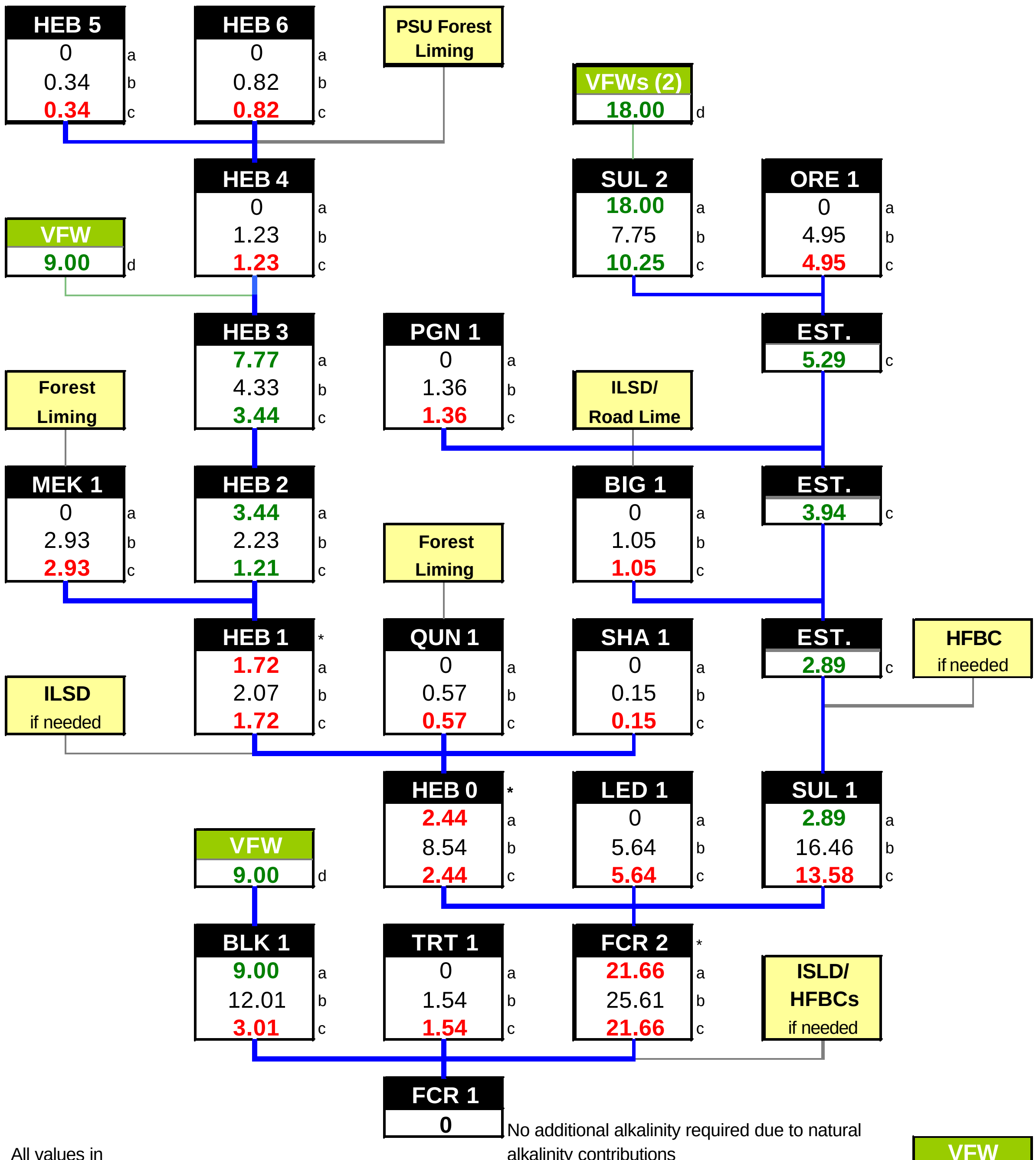
VFW — Vertical Flow Wetland

Alkalinity Generation Uncertain

a - Residual acid deficiencies to be treated or alkaline excess from treatment
b - Projected deficiency at sample point
c - Green: Net excess alkalinity not requiring alkaline addition
Red: Net alkalinity deficiency requiring alkaline addition
d - Typical annual alkalinity output for standard VFW design

*Due to the effects of upstream treatment, the lower acid deficiency is to be treated by akaline addition.

Figure 5-3: Secondary Analysis of Potential Treatment Results



All values in tons $CaCO_3$/year

VFW Vertical Flow Wetland

Alkalinity Generation Uncertain

a - Residual acid deficiencies to be treated or alkaline excess from treatment
b - Projected deficiency at sample point
c - Green: Net excess alkalinity not requiring alkaline addition
Red: Net alkalinity deficiency requiring alkaline addition
d - Typical annual alkalinity output for standard VFW design

*Due to the effects of upstream treatment, the lower acid deficiency is to be treated by akaline addition

PROGRESSIVE RESTORATION PLAN

The purpose of a progressive restoration plan is to divide a large stream improvement project into manageable phases for funding and implementation. The basic goal is that each new phase should show a meaningful result and/or build on improvements from previous phases. The following presents a series of suggested phases based on results from the monitoring program and the analysis of potential treatment results. Phases may be completed concurrently if resources are available, and the order may be altered to meet specific community wishes. Figure 5-4 shows the general location of these phases in the watershed.

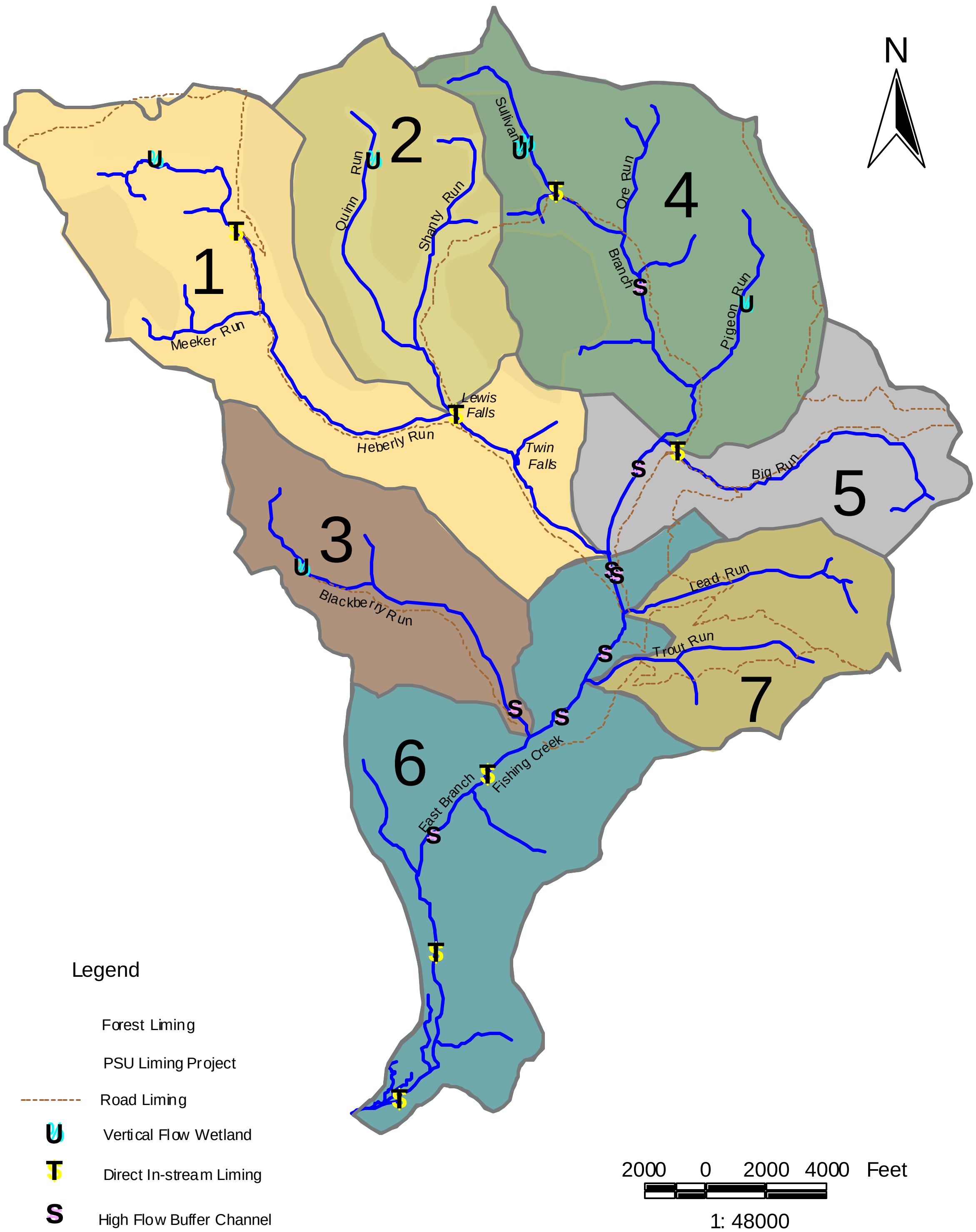
Phase 1 – Heberly Run

From sample point HEB 3 downstream to its mouth, Heberly Run shows fair water quality during average flows and poor water quality during high flows, but actual alkaline deficiencies are relatively low compared to other tributaries in the watershed. Implementation of a single headwaters VFW is predicted to result in substantial improvements and possibly a positive ANC throughout this reach, a length of approximately 4.2 miles. The stream is fully contained within State Game Lands and is easily accessible to the public. PSU has initiated forest liming in the uppermost headwaters and conducted monitoring to assess the effects of application, representing a substantial preliminary investment in this subwatershed. For these reasons, Heberly Run is proposed as the first priority for restoration. Although Meeker Run is not predicted to adversely affect the results from a VFW system on Heberly Run, this tributary is a significant source of acidity and may impair long-term downstream performance. Meeker Run has no existing access for construction equipment or other forms of alkaline addition except for forest liming. It is recommended that forest liming be extended south from the existing PSU sites to include the headwaters of Meeker Run. Eventual improvements on Meeker Run would affect approximately 1.2 miles of stream reach.

Phase 2 – Quinn Run & Shanty Run

Quinn Run shows good quality under average flow conditions, while Shanty Run shows fair quality. Both streams show very poor quality under high flow conditions. They are fully contained on State Game Lands, but only a portion of Shanty Run is currently accessible by any form of road. It is conceptually possible to locate a VFW in the Quinn Run headwaters, but this would require new access construction, and the annual deficiency of 0.9 tons/year is not a great justification for a 9 ton/year addition system. The majority of the upper subwatersheds of both streams appear conceptually accessible for forest liming, with possible road liming adjacent to Shanty Run. As with Meeker Run, the best approach in this area may be forest liming followed by monitoring of long-term results. The acid input from these streams is not an immediate concern for Heberly Run if VFW addition is undertaken on that stream. When addressed, Quinn Run has about 2.2 miles of restoration potential, and Shanty Run about 1.8 miles.

Figure 5-4: Phase Areas of Progressive Restoration Plan



Phase 3 – Blackberry Run

Blackberry Run shows very poor quality under average flow conditions and severe quality at high flows. It is a significant acidity source to the lower main stem of East Branch Fishing Creek. Monitoring data suggest that a single VFW system should be capable of correcting this deficiency, potentially improving quality in East Branch Fishing Creek below the confluence, where fair to poor quality currently exist. The stream is mostly enclosed in State Game Lands, and a forest trail is indicated as present that could be upgraded for construction access. Approximately 2.4 miles of Blackberry Run should be restorable.

Phase 4 – Sullivan Branch Headwaters & Pigeon Run

The upper reaches of Sullivan Branch and Ore Run show very poor quality under average flow conditions and severe quality at high flows. The headwaters of Sullivan Branch appear amenable to VFW construction, with existing access and sufficient drainage area. Sullivan Branch is also fully contained on State Game Lands. As previously discussed, a single VFW may not fully improve the reach upstream of Pigeon Run given the excess acidity discharging from Ore Run. Ore Run itself does not appear accessible for convenient alkaline addition, other than the possibility of sand dosing at its mouth. Although it is conceptually possible to construct a VFW in Pigeon Run as indicated by the GIS analysis, in practicality Pigeon Run does not have any construction access. It is suggested that the capacity of two VFWs be placed in the headwaters of Sullivan Branch rather than splitting the capacity between that and Pigeon Run. As indicated by the results analysis, this should generate alkaline conditions downstream to at least Big Run without need for supplemental treatment. Ore Run and Pigeon Run would require treatment by non-specific means thereafter, and are not included in overall restoration expectations. Improvements on Sullivan Branch downstream to Big Run with a double VFW system would amount to about 3.5 miles.

Phase 5 – Sullivan Branch Lower Reach & Big Run

Modeling suggests that even with two VFWs in the Sullivan Branch headwaters there may be a residual deficiency below Big Run. If monitoring indicates this to be the case after completion of upstream activities, the option may exist to create a HFBC on Sullivan Branch near the Big Run confluence, or a sand dosing site at the trail crossing near its mouth. Big Run itself does not appear very amenable to the available alkaline addition approaches, and a portion of it is on non-public lands. A combination of road liming and development of a sand dosing site in the upper reaches may be the only current options for improving Big Run. When completed with upstream addition, the remainder of Sullivan Branch has about 1.5 miles of potential restoration, and Big Run has 2 miles.

Phase 6 – East Branch Fishing Creek

As upstream alkaline addition activities progress, the quality of East Branch Fishing Creek should steadily improve. There are several potential HFBC construction sites and sand dosing points in the reach from Heberly Run to the confluence with West Branch Fishing Creek that may be used to support water quality in the interim. It is expected that one and possibly two permanent HFBC sites will be required to maintain long-term quality in East Branch Fishing Creek. These can be implemented concurrently with the other phases, but it may be more efficient to observe results from progressing upstream restoration before committing to constructed sites. One approach would be to use sand dosing to maintain water quality in the interim and replace this practice with HFBCs as long-term addition requirements become apparent in the main stem. East Branch Fishing Creek has about 4.4 miles of improvable reach below Heberly Run.

Phase 7 – Trout Run & Lead Run

Lead Run shows severe quality under average and high flow, while Trout Run shows fair quality under these conditions. The majority of both streams are located on non-public lands. The only readily-available alkaline addition approach in these drainages is road liming on several forest trails that parallel and cross the streams. Both Lead Run and Trout Run were observed as being dry on several occasions during the monitoring program, particularly during the summer months, and they are not major contributors of acidity to East Branch Fishing Creek. It would be of benefit to eventually correct their alkaline deficiencies, but their continued acidity loading is not expected to be a detriment as restoration work progresses elsewhere in the watershed. For these reasons, Lead Run and Trout Run are currently considered to be low priorities in the progressive restoration plan. If addressed, these streams each have about 1.5 miles of restorable reach.

Other Supporting Projects

Essentially any limestone-based alkaline addition will benefit the East Branch Fishing Creek watershed. There are numerous opportunities to add limestone in addition to those outlined in this section, including smaller forest liming areas, additional road liming segments, and local sand dosing sites. These activities can be undertaken at any time in the progressive restoration program, but would best be associated with other active addition projects to provide meaningful mutual support.

COST ANALYSIS

Table 5-2 provides a summary of the estimated basic costs and benefits for the suggested projects in the progressive restoration plan. Approximate stream miles to be restored are given for the individual projects and as a cumulative total assuming that this order of projects is followed; actual cumulative miles restored will depend on the final selected sequence. Ultimately, there are about 26 miles of stream that could be improved in the East Branch Fishing Creek watershed.

Individual project costs are estimated based on comparable alkaline addition activities in other Pennsylvania watersheds, including construction (implementation) and annual maintenance costs. These costs have been annualized over a general 15 year operational life expectancy for passive alkaline addition technologies. A cumulative annual cost is given for the phases in the presented order, and an annual cost per mile of stream improvement is given for individual projects.

Returns to the community on benefits of restoration have been assessed in many ways by previous studies, but two basic measures are available with a reasonable degree of justification: direct dollar returns from recreational use, and community willingness-to-pay for water quality improvements. There has been no willingness-to-pay study for Columbia or Sullivan Counties, so no justified valuation on that issue currently exists. In 1995, the Pennsylvania Fish & Boat Commission valued the losses to recreational fishing on wild trout streams from acid mine drainage impacts at $23,400 per mile per year (about $30,000 in 2006 dollars). Although an average figure, this is probably a reasonable value for acid deposition impacts to East Branch Fishing Creek given its overall amenities versus its remoteness.

The synopsis of the cost analysis is that it will probably take on the order of $1.8 million over the next 15 years to treat acid deposition in East Branch Fishing Creek on a whole. This amounts to an annualized investment of about $120,000 per year, or about $4,700 per stream mile improved. This compares with conceptual recreational returns of $30,000 per stream mile improved. The conceptual valuation of restoring all major tributaries of East Branch Fishing Creek is about $800,000 per year, compared to a cumulative investment annualized at about $120,000 per year.

Table 5-2: Summary of Estimated Project Costs and Benefits

Phase/Projects	**Stream Miles Restored**		**Project Costs**		**15-Year Annualized Costs**			**Annual Recreat. Benefit**
	Direct	Cumulative	Capital Construct.	Annual O&M	Project	Cumulative	Proj. $/Mile	
Phase 1 - Heberly Run								
One VFW system in vicinity of HEB 3	4.2	4.2	$200,000		$13,000	$13,000	$3,100	$130,000
Forest liming on Meeker Run - 4 tons/acre on up to 100 acres at $300/acre	1.2	5.4	$30,000		$2,000	$15,000	$1,700	$40,000
Phase 2 - Quinn Run & Shanty Run								
Forest liming - 4 tons/acre on up to 970 acres at $300/acre	4.0	9.4	$300,000		$20,000	$35,000	$5,000	$120,000
Phase 3 - Blackberry Run								
One VFW system in the headwaters of Blackberry Run	2.4	11.8	$200,000		$13,000	$48,000	$5,400	$70,000
Phase 4 - Sullivan Branch Headwaters								
One VFW system on Sullivan Branch and one on Pigeon Run, or two VFWs on Sullivan Branch	3.5	15.3	$400,000		$27,000	$75,000	$7,700	$110,000
Phase 5 - Sullivan Branch Lower Reach								
HFBC near mouth of Big Run	1.5	16.8	$100,000	$3,000	$10,000	$85,000	$6,700	$50,000
Limestone sand dosing in Big Run, with access dev. and road liming on 3 miles at $30,000/mile	2.0	18.8	$100,000	$3,000	$10,000	$95,000	$5,000	$60,000
Phase 6 - East Branch Fishing Creek								
Temporary limestone sand dosing until HFBCs installed*	4.4*			6000*	$6,000	$101,000	$1,400	$120,000*
Two HFBCs as needed	4.4	23.2	$200,000	$6,000	$19,000	$114,000	$4,300	$140,000
Phase 7 - Lead Run & Trout Run								
Road liming on 4 miles at $30,000/mile	3.0	26.2	$120,000		$8,000	$122,000	$2,700	$90,000

Total All Projects: $1,650,000 $12,000

*Not included in project totals.

15-Year Phase Total Cost: $1,830,000 Total Annual Cost/Mile: $4,656

15-Year Annualized Cost: $122,000 **Annual Recreational Benefit $810,000**

Revised 3-16-07

6

CONCLUSIONS & RECOMMENDATIONS

The overall conclusion of this study is that restoration is technically feasible for much of the East Branch Fishing Creek watershed, and that stream improvements to restore fisheries would be of positive socioeconomic value to the surrounding communities. This Growing Greener project has proved the information needed to proceed with the planning and implementation stages for multiple alkaline addition projects. Other specific conclusions and recommendations are presented as follows:

CONCLUSIONS

- East Branch Fishing Creek can have significant recreational value due to its low level of development and containment of most of its tributaries on public land.

- Acidification impacts are long-term and will not be immediately remedied by upwind acid source reductions; however, the degree of impacts in this watershed is not as severe as some Pennsylvania streams.

- Multiple demonstrated and conceptual alkaline addition technologies are applicable throughout the watershed.

- The local watershed association (FCWA) has undertaken substantial efforts as a "grass-roots" organization to initiate restoration activities, and wishes to continue this work until quality fisheries are restored.

- The estimated annual costs per stream mile for the individual restoration phases are justifiable in comparison to existing losses to recreational use due to acidification.

- The conceptual restoration projects are reasonable in scale for progressive funding and implementation, and can produce meaningful improvements individually as well as in combination.

- The total estimated restoration cost for the watershed of $1.8 million is a reasonable level of investment for a potential return of up to 26 connected stream miles.

RECOMMENDATIONS

- Continue studies by PSU to quantify alkalinity generation from forest liming compared to addition quantities, and to determine the response time for streams.

- Investigate the condition of construction access for the conceptual project sites.

- A design and permitting phase should be funded to initiate the VFW on Heberly Run.

- Consider initiating limestone sand dosing in the fairly good quality lower reach of East Branch Fishing Creek for relatively inexpensive initial improvements while the other projects progress.

- Work with the PA Game Commission to determine how road liming can be incorporated in their road maintenance plans.

- Sampling budgets should be included in future funding efforts to continue the in-stream monitoring program to develop long-term trends and document the effects of alkaline addition activities. Sampling and assessment budgets should also be included with each new alkaline addition project to improve the data records and efficiencies of the technologies over time.