TROUT RUN WATERSHED
ACID DEPOSITION ASSESSMENT
AND RESTORATION PLAN

CLEARFIELD COUNTY, PENNSYLVANIA

FINAL REPORT

ALLEGHENY MOUNTAIN CHAPTER OF TROUT UNLIMITED

A PADEP Growing Greener Project

TROUT RUN WATERSHED
ACID DEPOSITION ASSESSMENT
AND RESTORATION PLAN

FINAL REPORT

Prepared for:

Allegheny Mountain Chapter of Trout Unlimited
1510 Village Road
Clearfield, PA 16830

Prepared by:

Water's Edge Hydrology, Inc.
PO Box 868
Clearfield, PA 16803

Terry A. Rightnour, PH, PWS, Project Manager
Kevin L. Hoover, PG, PH-GW, PWS, Senior Environmental Scientist

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EXECUTIVE SUMMARY

Trout Run, located in Clearfield County, Pennsylvania, suffers from acidification due to acid deposition (acid rain). Historic sampling suggests that portions of Trout Run and its tributaries are significantly acidified, and that fish populations have been adversely impacted or eliminated in some reaches. However, there has not previously been a systematic evaluation of the degree or extent of these impacts, or potential means to ameliorate them.

Under a Pennsylvania Growing Greener Grant, the Allegheny Mountain Chapter of Trout Unlimited has undertaken a monitoring program to sample locations in the Trout Run headwaters for an assessment of acidification impacts. With assistance from Water's Edge Hydrology, Inc., the group established six sample points and flow measurement stations: Trout Run headwaters (TR 1A), Alex Branch (TR 2A), Roberts Run (TR 3), an unnamed mid-stem tributary (TR 4), Trout Run mid-stem (TR 5), and Trout Run downstream (TR 6). Between three and nine sample rounds were collected from these points between June 2006 and June 2007, along with concurrent flow measurements.

Using the monitoring data, an assessment was made of the degree of acidification (alkaline deficiency) for the sample points both by concentration and by mass loading. Potential acid abatement project sites were evaluated where alkaline addition could correct these deficiencies. Four passive treatment technologies were identified that would be most applicable in the watershed: open limestone channels, limestone pods, limestone crib walls, and vertical flow wetlands. A loading-based analysis was performed to predict the potential results of treatment from the conceptual project sites. It is estimated that full implementation of all conceptual projects could result in neutral to net alkaline conditions for some distance downstream from the confluence of the Trout Run headwaters and Alex Branch, with beneficial effects extending possibly up to 8 miles downstream. Additional information from unsampled tributaries would be necessary to better predict the full extent of potential restoration.

The results of the assessment were used to develop a progressive restoration plan that divides the conceptual acid abatement projects into four implementation phases. Completion and operation of these phases is estimated to cost approximately $1.1 million over 15 years. Assuming 8 miles of eventual restoration, the annualized cost per restored mile would be about $9,500 per year. This compares favorably to a general estimate of recreational fishing losses due to acidification of about $34,000 per mile per year. This report recommends that planning of acid abatement activities proceed for Trout Run, with additional data collection to refine prediction of the potential results of this treatment.

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INTRODUCTION

Trout Run is a freestone stream located in Clearfield County, 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 4.4 to 4.5 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. Portions of the stream are listed as impaired under Section 303d.[1] Historic sampling indicates that portions of Trout Run 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, an assessment of the headwaters of Trout Run has been undertaken by the Allegheny Mountain Chapter of Trout Unlimited (TU) using a Pennsylvania Growing Greener Grant. The monitoring program consisted of 6 in-stream sample points, with up to 9 sample rounds collected at each point between June 2006 and June 2007. The study area watershed, streams, and regional topography are shown by Figure 1-2.

Trout Run
Watershed Facts

Drainage Basin:	West Branch Susquehanna River
Drainage Area:	32.8 square miles
State Game Lands:	2.9 square miles
Study Area Stream Miles:	50.3 miles
Classification:	HO-CWF

[1] Decision Rationale, Total Maximum Daily Loads, UNT 26051 Trout Run and UNT 26053 Pine Run Watersheds, for Acid Mine Drainage Affected Segments, Clearfield County, Pennsylvania, United States Environmental Protection Agency, Region III, 1650 Arch Street, Philadelphia, Pennsylvania 19103-2029. 2007.

Figure 1-1: Trout Run Location Relative to State Rainfall pH (2003)

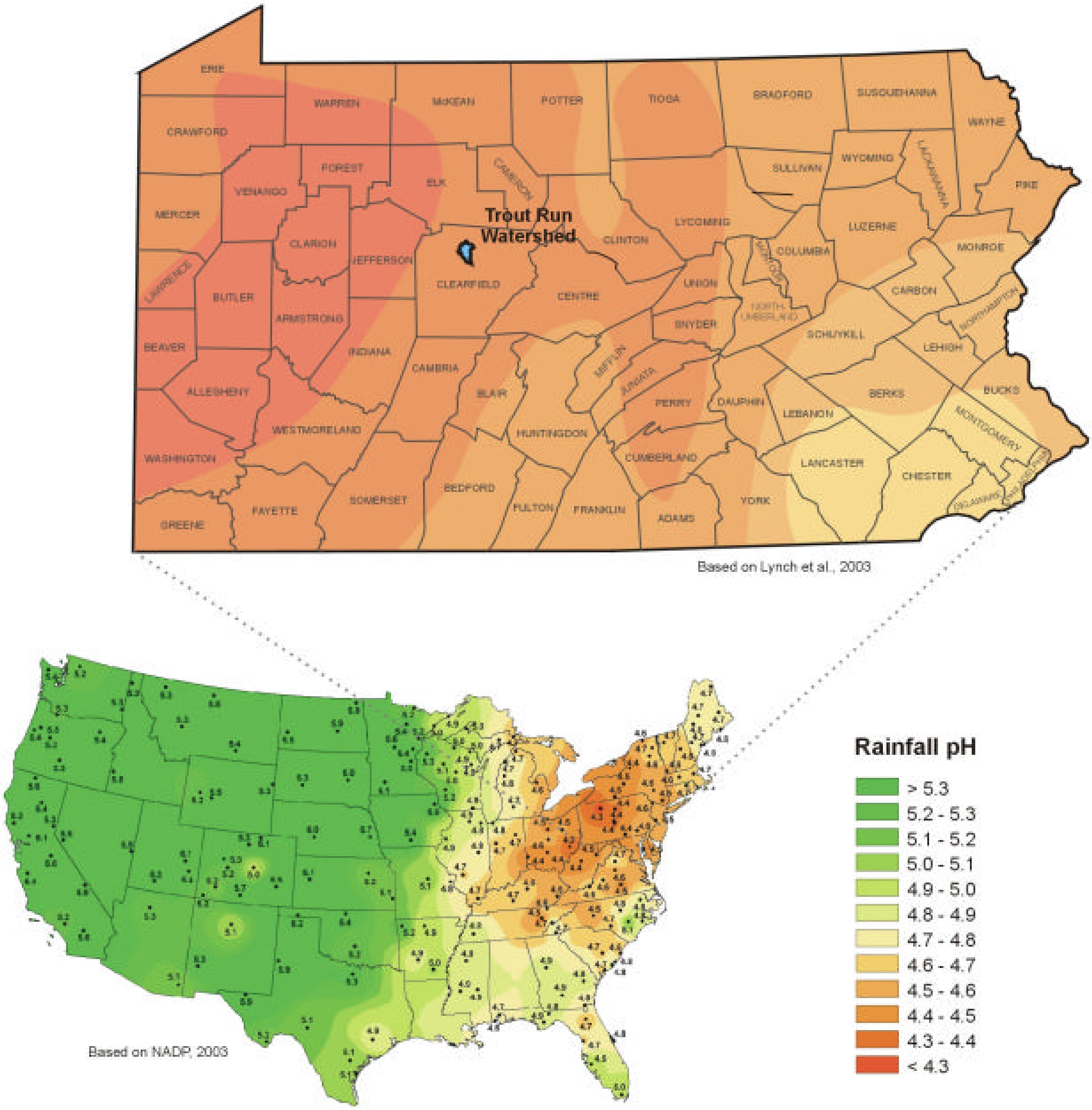
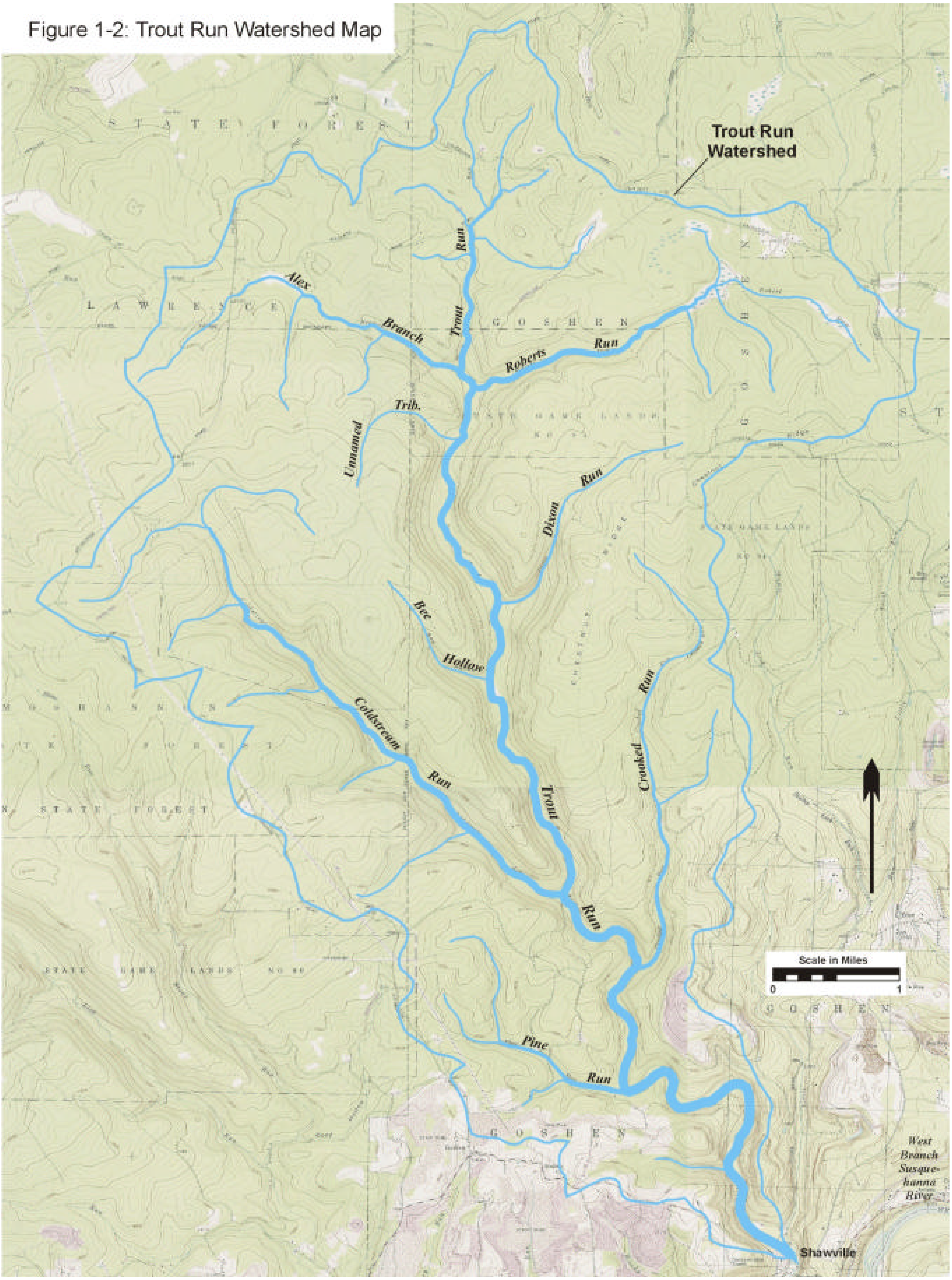


Figure 1-2: Trout Run Watershed Map



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 headwaters of the Trout Run watershed. This report summarizes the results of this study and provides recommendations for future work in support of the restoration plan.

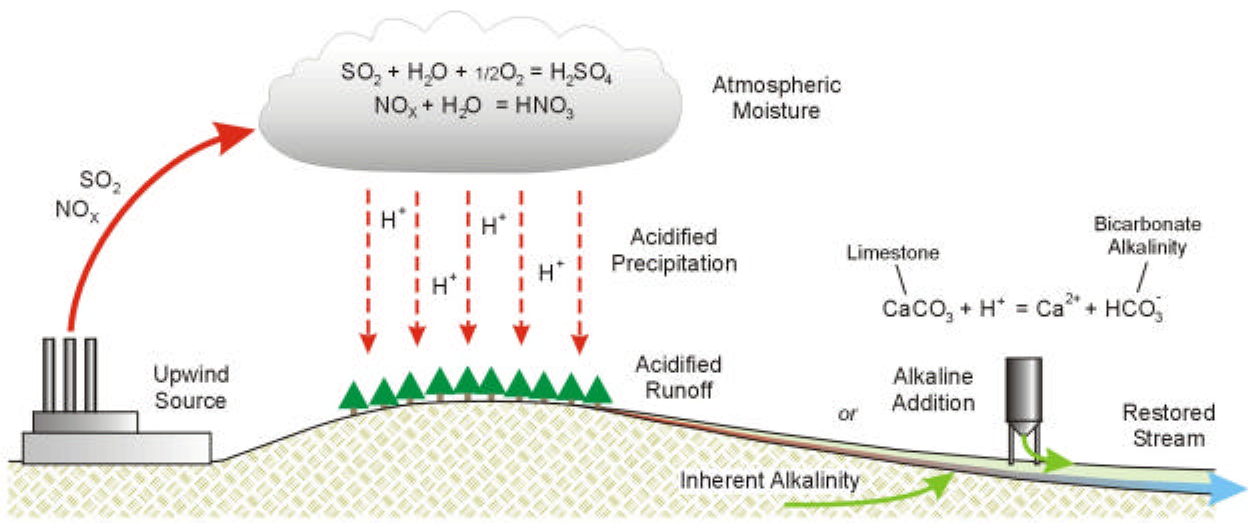
OVERVIEW OF ACID DEPOSITION

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 Trout Run, 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. Northcentral Pennsylvania, including the Trout Run 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 the approximate pH range of acid rain in the Trout Run headwaters. 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 the 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 Trout Run 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:

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

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

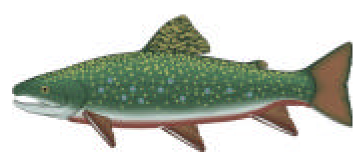
$$\mathbf{CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-}$$

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

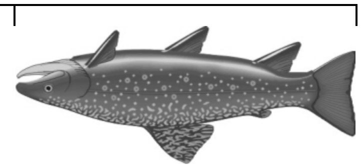
Both acidity and alkalinity are measured as the equivalent concentration as limestone, reported as milligrams of $CaCO_3$ per liter (mg/L). When the acidity concentration is greater than the alkalinity concentration, water is considered to be net acidic, and in the opposite case the water is net alkaline. 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 Trout Run in-stream water quality and flow monitoring program included six sample points on representative sections of the main stem and at the mouths of several tributaries in the headwaters. The overall goal of the monitoring program was to assess the current conditions of the watershed resulting from acid deposition and to provide data for development of a conceptual restoration plan for the headwater stream reaches found to be adversely impacted. The following were the 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 analyses.
- To monitor variations in seasonal conditions to identify episodic and chronic acidification.
- To estimate the quantity of alkaline addition required to restore the monitored 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 the mouths of four headwater tributaries believed to have the greatest acidification impacts, and a midstream and a downstream point on the main stem. Figure 2-1 shows the sample point locations relative to the Trout Run watershed stream network.

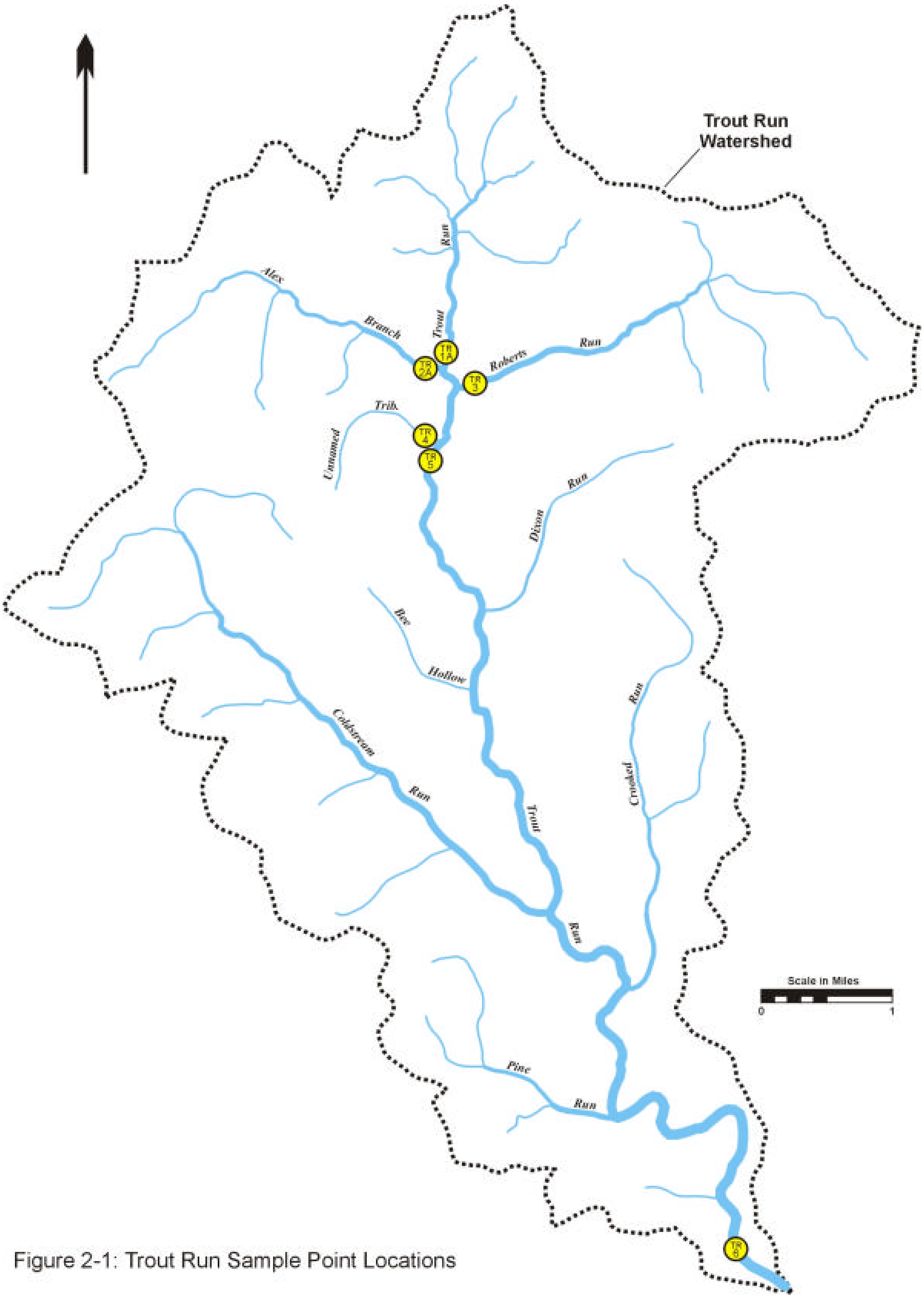


Figure 2-1: Trout Run Sample Point Locations

The sample point pattern used for this acid deposition study is based on a standardized approach developed for similar acidification characterization studies in the region. Sample locations were selected depending on the study needs from four basic categories in their typical order of importance: culmination, confluence, midstream, and upstream. The pattern is efficient for identifying significant sources of acidification and quantifying alkaline addition requirements for progressive downstream restoration. Three basic guidelines for locating points are as follows from Figure 2-2 and Table 2-1:

- 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 (i.e. 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 (i.e. H to E, G to F, E + F to C).

This study focused on the uppermost headwaters tributaries of Trout Run. Because these tributaries terminate in diffuse recharge, the upstream sample point category was not applicable, and samples TR 1A, TR 2A, TR 3, and TR 4 all serve as confluence points. TR 5 serves as a midstream point specific to the headwaters, while TR 6 serves as a culmination point representing the entire watershed.

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

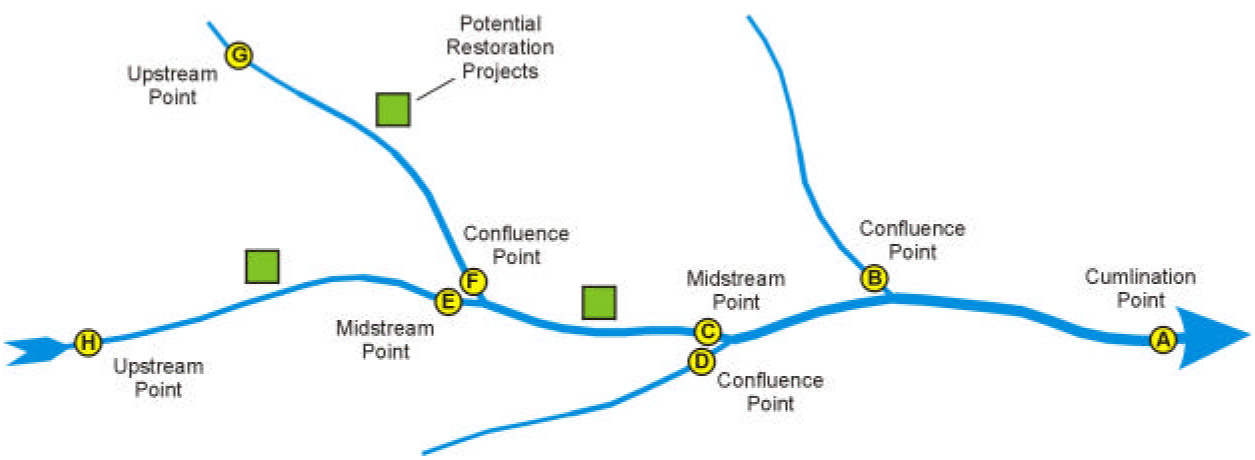


Table 2-1: Sample Points for Acid Deposition Assessment

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.	TR 6
Confluence	Mouths of major tributaries to compartmentalize a watershed for identification of primary acidity sources.	TR 1A, TR 2A, TR 3, TR 4
Midstream	Intermediate points to characterize long reaches of main stem, usually immediately upstream of a confluence point or below alkaline addition projects.	TR 5
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.	Not Applicable

MONITORING PERIOD

Collection of water samples for this study was conducted at intervals of approximately 4 to 6 weeks between June 2006 and June 2007, yielding 9 sample rounds. TR 3, TR 4, TR 5, and TR 6 were sampled for all 9 rounds. The original points TR 1 and TR 2 were sampled for 6 rounds, at which time is was determined that these points were actually located below the full confluence of Trout Run and the Alex Branch. TR 1A and TR 2 A were subsequently established above the confluence of these two streams, respectively. TR 1A was sampled for 3 rounds and TR 2A for 4 fours.

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 TU 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.

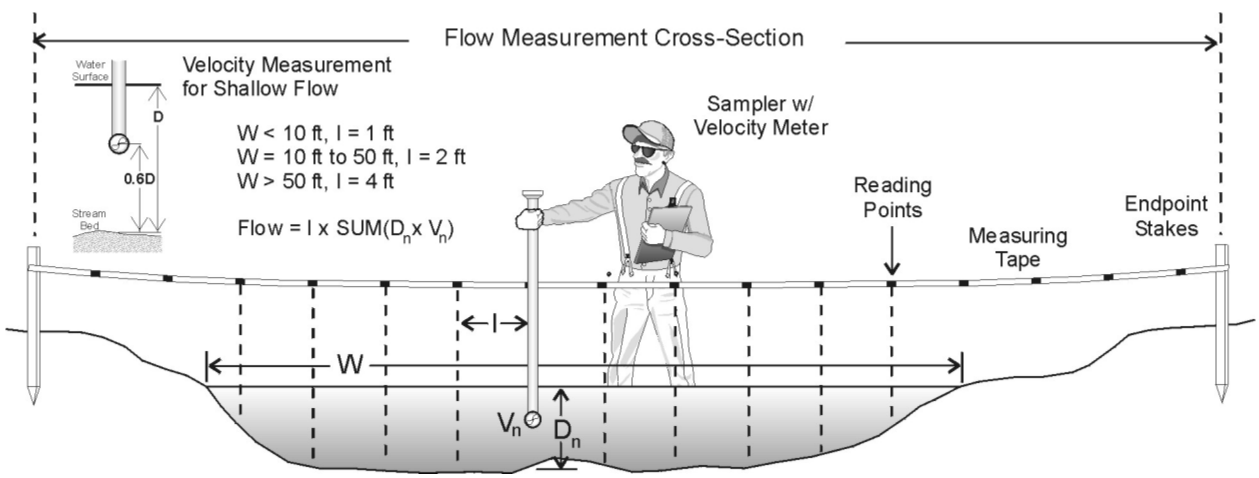
Table 2-2: In-Stream Water Quality Monitoring Parameters

Parameters	Units	Analysis Method
Field		
Flow	gallons/minute (gpm)	Cross-Sectional Velocity
pH	standard units (SU)	pH Meter
Temperature	degrees Centigrade (C^o)	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 TU 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 are contained in Appendix B.

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



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WATERSHED ASSESSMENT

Results from the water quality monitoring were analyzed to assess three primary considerations within the Trout Run 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 ANALYSES

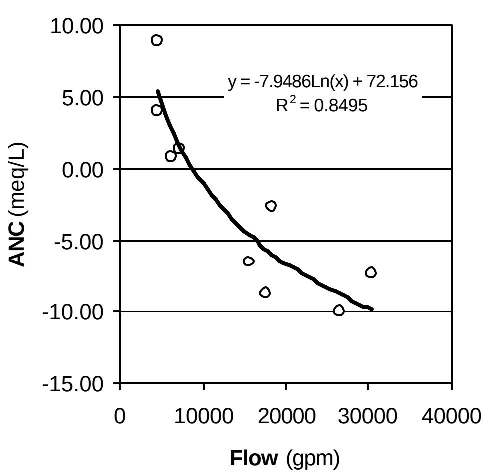
Data from the monitoring program were analyzed to develop average and high flow water quality and quantity conditions for the individual sample points, with results summarized in Table 3-1. The value N in this table represents the number of flow observations for each sample point. Complete data sets are contained in Appendix A. Average values were determined as the arithmetic average of the data. The 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. This approach has proven effective for determining design maximum values in previous acid abatement projects.

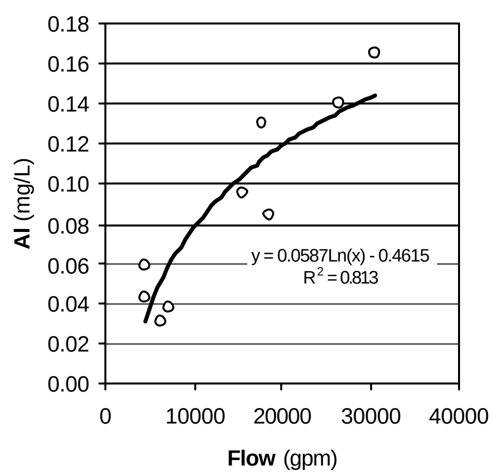
Relationships between parameter concentrations and flows were established graphically and used to predict concentrations at the high flow stage, as shown by the examples in Figure 3-1. The best-fit relationships between flow, ANC, and aluminum were found to be logarithmic. A prediction was also made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

Table 3-1: Summary of Trout Run Monitoring Data

Sample Point		Flow Stage	Flow (gpm)	pH (SU)	ANC (meq/L)	Al (mg/L)
1A	Trout Run Headwaters	Average	4400	5.19	-13.46	0.132
		High Flow	15922	4.86	-26.13	0.161
2A	Alex Branch	Average	4678	5.07	-18.43	0.139
		High Flow	11663	4.73	-31.79	0.162
3	Roberts Run	Average	6319	5.20	-3.75	0.082
		High Flow	13138	5.25	-10.13	0.122
4	Unnamed Tributary	Average	812	5.74	18.69	0.026
		High Flow	2227	5.64	5.69	0.045
5	Trout Run Midstream	Average	14586	5.45	-2.23	0.087
		High Flow	32567	5.25	-10.44	0.148
6	Trout Run Downstream	Average	32231	5.74	1.26	0.047
		High Flow	76057	5.33	-7.04	0.083

Figure 3-1: Example Parameter Relationships to Flow (TR 5 Data)





CHARACTERISTICS OF ACIDIFICATION

ANC is the primary measure of stream health used in this study relative to acidification. 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.

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 microequivalents (µeq/L) as follows:

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

Alkalinity (mg/L) = ANC (µeq/L) / 20

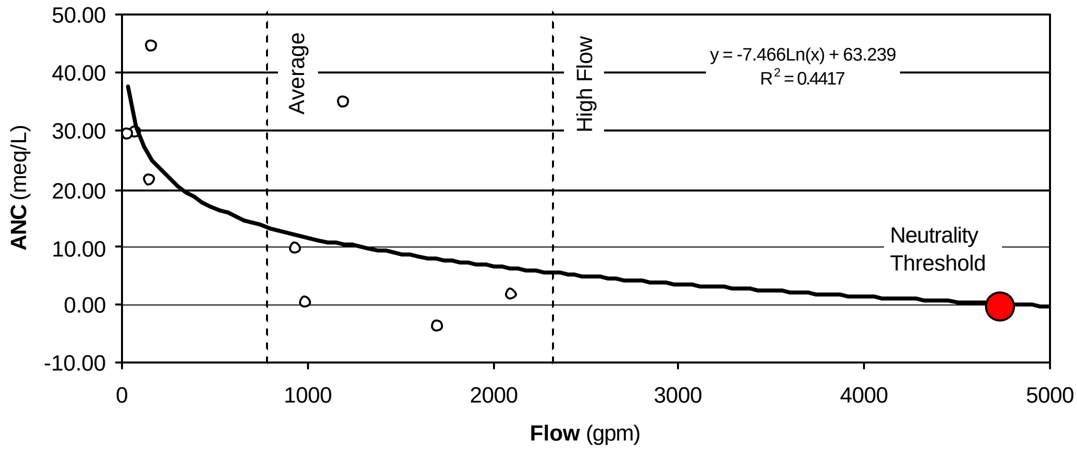
<u>If ANC is negative:</u>

Acidity (mg/L) = -ANC (µeq/L) / 20

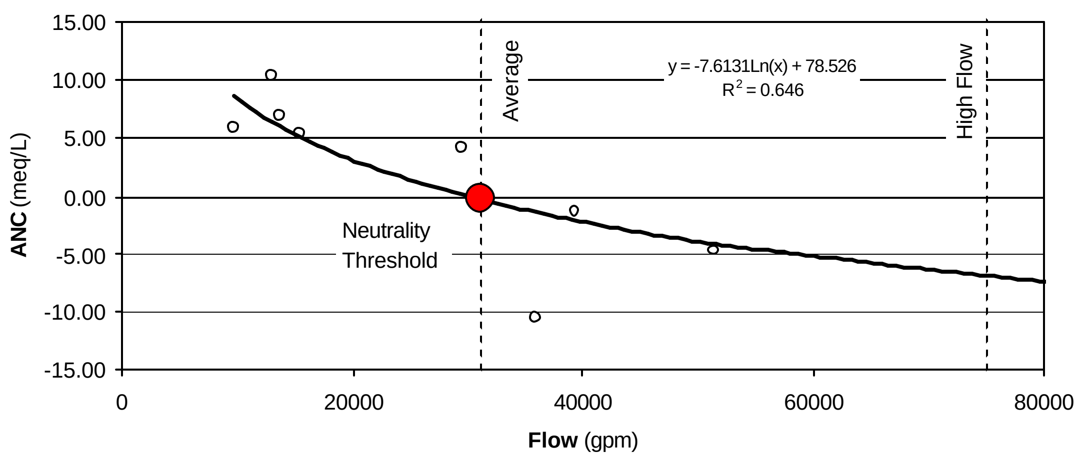
The three basic categories of acid deposition impacts used in this study are *sustainable, episodic*, and *chronic* depending on where acidification begins to occur in a stream's flow range from baseflow to high flow. Sustainable streams contain sufficient alkalinity to neutralize the acid deposition 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.

Figure 3-2: Examples of Applied Acidification Categories

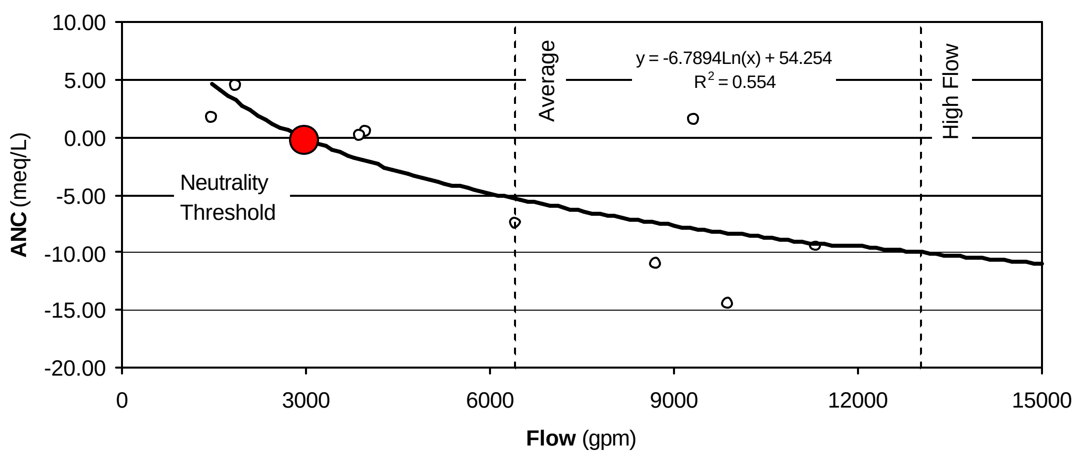
Sustainable Acidification: Unnamed Tributary (TR 4)



Episodic Acidification (marginal): Trout Run Downstream (TR 6)



Chronic Acidification: Roberts Run (TR 3)



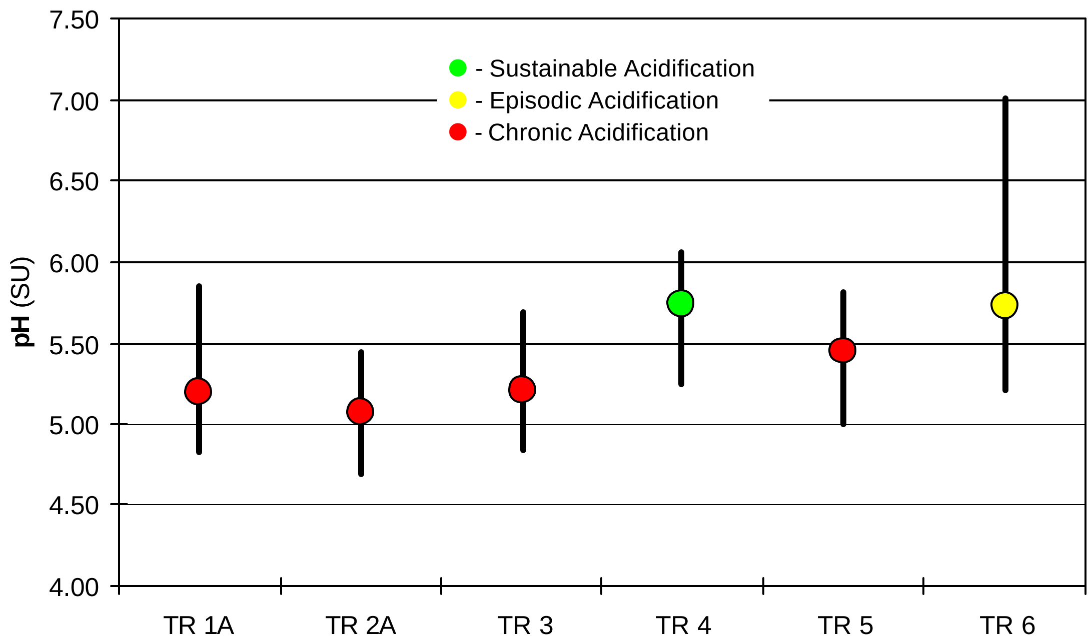
The "Neutrality Threshold" indicated on Figure 3-2 is the predicted flow volume above which the stream will reach a negative ANC and become acidic. It is the flows above this threshold that require some form of alkaline addition to maintain stream health. For this study, streams with a neutrality threshold below the average flow are considered chronically acidified. Threshold values between the average and high flows are considered an indication of episodic acidification. (The example of TR 6 is at the very low end of this range; no sample point in this study shows classic episodic acidification.) A threshold above the high flow is assumed to represent sustainable conditions.

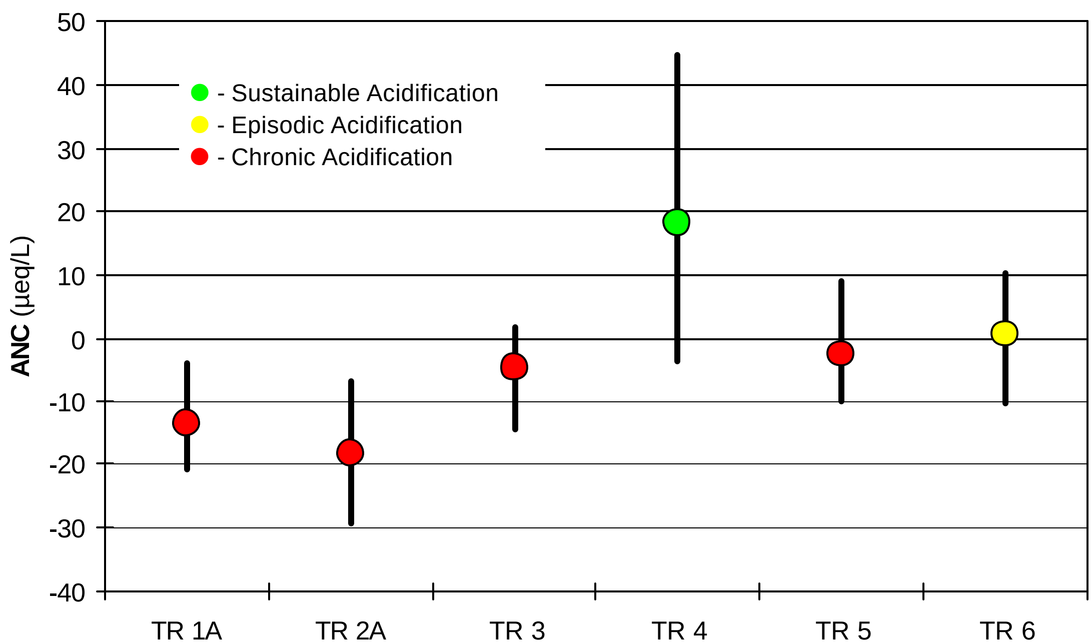
Table 3-2 summarizes the characteristics of acidification monitored in the Trout Run watershed in terms of alkaline deficiency and temporal nature (sustainable, episodic, or chronic). Alkaline deficiency is expressed as pounds per day of calcium carbonate ($CaCO_3$) derived by converting measured ANC into its approximate equivalent value as alkalinity. Negative values indicate an alkaline excess. Values are given for average and 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 to observed ranges of pH and ANC.

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

Sample Point		**Alkaline Deficiency**		**Flow Conditions**			**Acidification Condition**
		Average lbs/day	High Flow lbs/day	Average gpm	Neutral. Threshold gpm	High Flow gpm	
1A	Trout Run Headwaters	36	249	4400	559	15922	Chronic
2A	Alex Branch	52	222	4678	894	11663	Chronic
3	Roberts Run	14	80	6319	2954	13138	Chronic
4	Unnamed Tributary	-9	-8	812	4771	2227	Sustainable
5	Trout Run Midstream	19	204	14586	8759	32567	Chronic
6	Trout Run Downstream	-24	321	32231	30174	76057	Episodic

Figure 3-3: Observed Ranges of pH and ANC Relative to Acidification Conditions





EXTENT OF ACIDIFICATION

Figures 3-4 and 3-5 show the measured extent of acidification within the Trout Run 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. This includes estimated water quality for streams not sampled in this study.

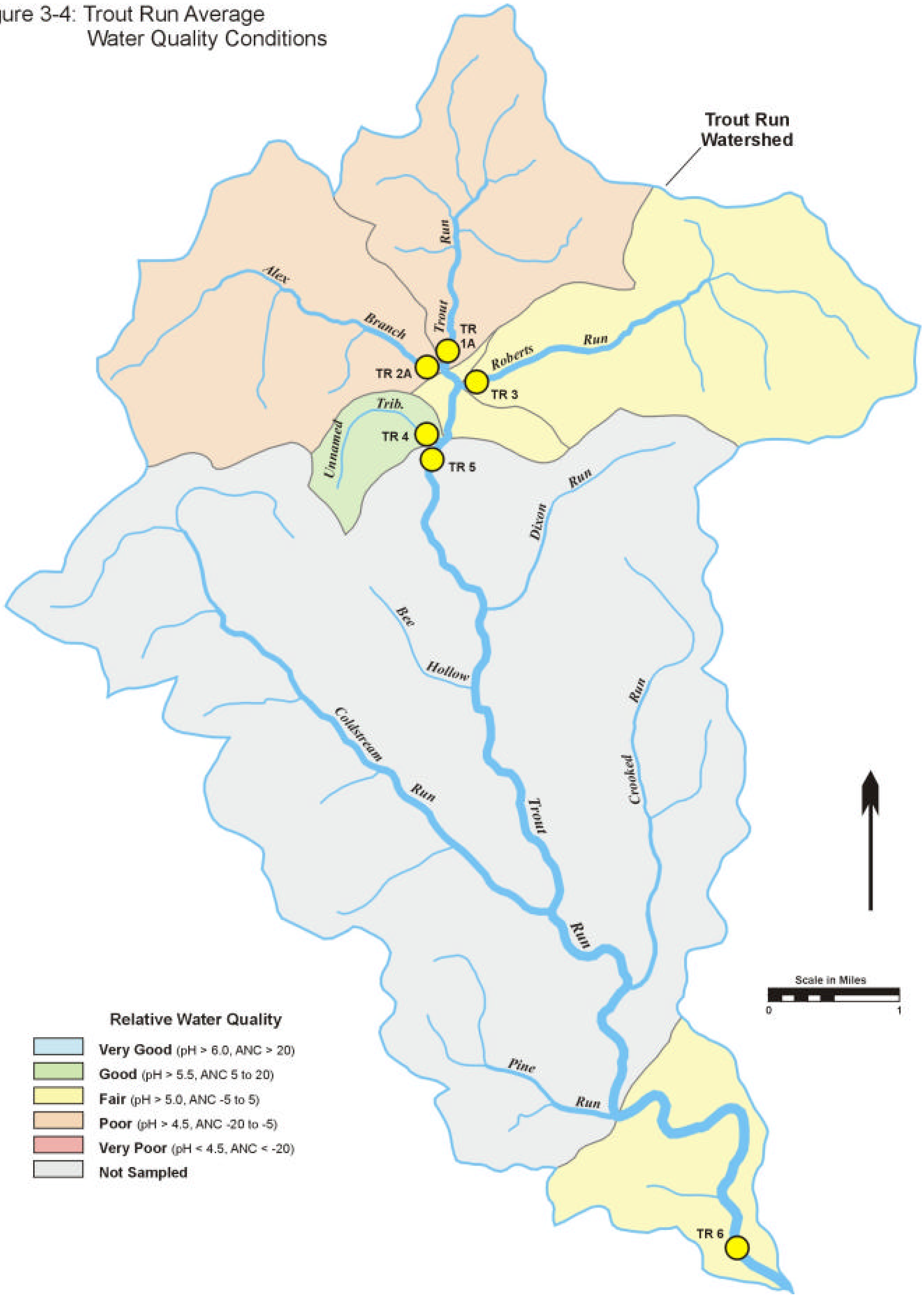
Table 3-3: Summary of Relative Water Quality Categories

Category	**Criteria**	**Comments**
Very Good	pH > 6.0 SU ANC > 20 µeq/L	No significant acidification impacts, should support healthy fish populations. (Not present in this study.)
Good	pH > 5.5 SU ANC 5 to 20 µeq/L	Possible minor impacts, but suitable for fish during short-term storm acidification effects.
Fair	pH > 5 SU ANC -5 to 5 µeq/L	Maintaining a positive ANC, but pH trending towards the low end of sustainability for fish.
Poor	pH > 4.5 SU ANC –20 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 < –20 µeq/L	Consistently negative ANC, likely not supportive of any significant fish 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	12.5	25%	12.5	25%
Fair	26.6	53%	0	0%
Poor	11.2	22%	26.6	53%
Very Poor	0	0%	11.2	22%
Totals	50.3	100%	50.3	100%

Figure 3-4: Trout Run Average Water Quality Conditions



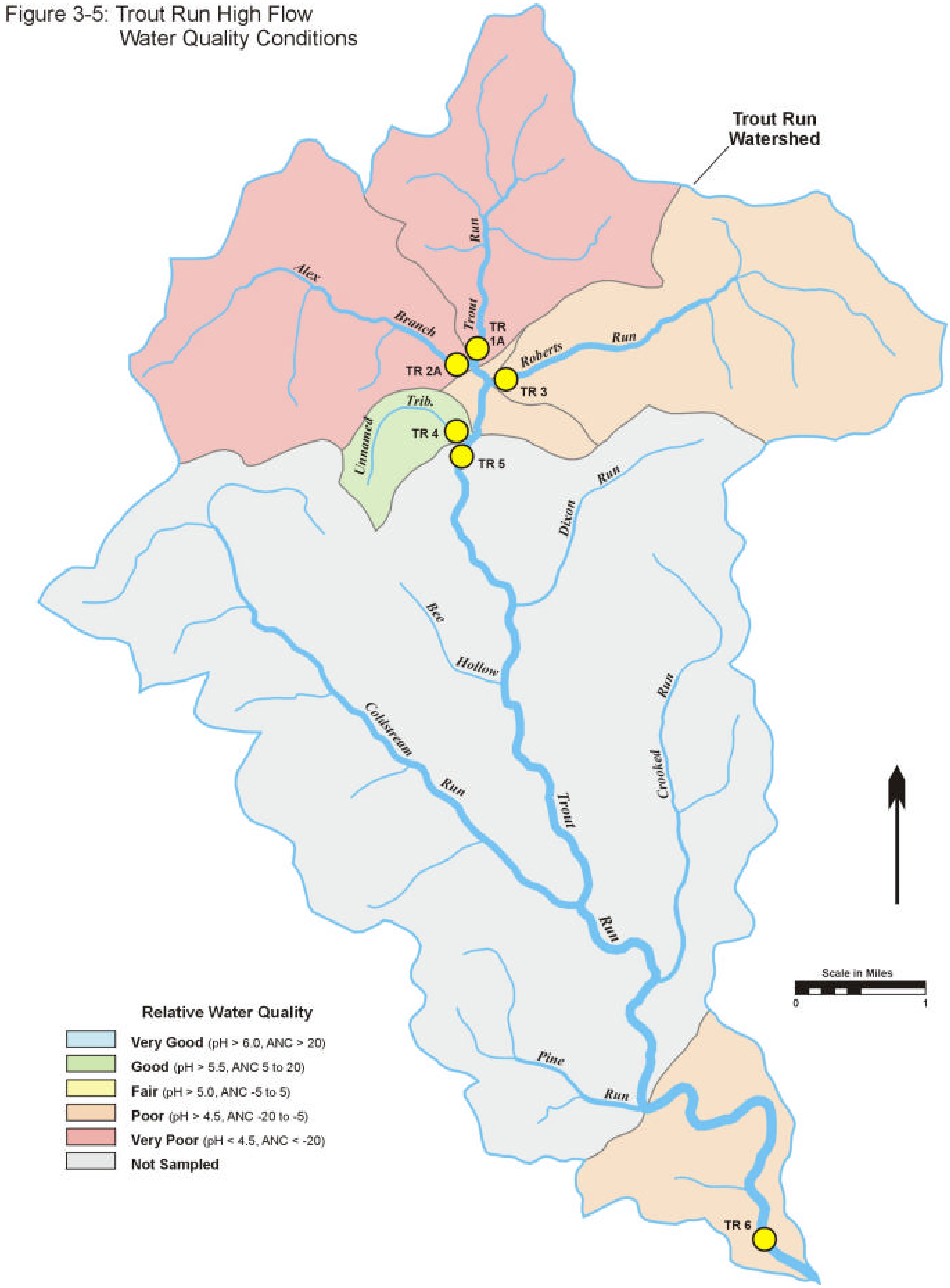


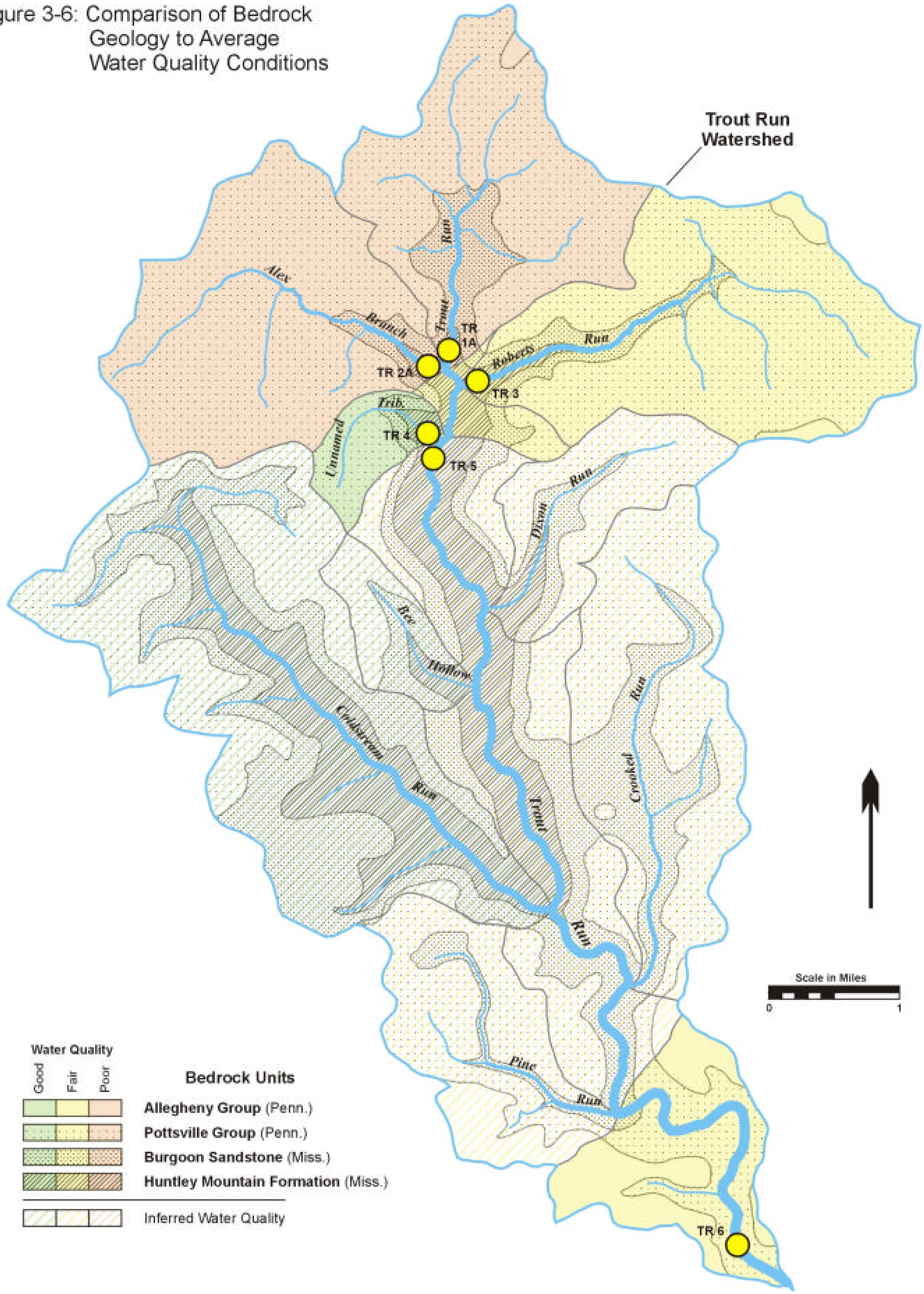
Figure 3-5: Trout Run High Flow
Water Quality Conditions
Trout Run
Watershed
Run
Alex
Branch
Trout
TR
1A
TR 2A
Roberts
Run
TR 3
Trib.
Unnamed
TR 4
TR 5
Dixon
Run
Bee
Hollow
Coldstream
Run
Trout
Run
Crooked
Run
Pine
Run
TR 6
Scale in Miles
0
1
Relative Water Quality
Very Good (pH > 6.0, ANC > 20)
Good (pH > 5.5, ANC 5 to 20)
Fair (pH > 5.0, ANC -5 to 5)
Poor (pH > 4.5, ANC -20 to -5)
Very Poor (pH < 4.5, ANC < -20)
Not Sampled

On Figures 3-4 and 3-5, it is apparent that the worst acidification impacts are present in the upper headwaters of Trout Run and Alex Branch. These tributaries show poor water quality under average conditions and very poor quality under high flow conditions. Adjacent Roberts Run has somewhat better conditions, showing fair quality on average and poor quality at high flows. The main stem at sample point TR 5 also shows improvements over Roberts Run, possibly due to the influent from the UNT to Trout Run, but remains in the fair category at average flow and poor category at high flows. The UNT to Trout Run at sample point TR 4 is anomalous because it shows good water quality under both average and high flow conditions, despite being directly adjacent to the Alex Branch subwatershed. Regression plots of this stream's data suggest that it is at or near a sustainable condition, with positive ANC in six out of seven sample rounds. The culmination point at TR 6 is slightly net alkaline on average, categorizing it as fair under these conditions, but declines to the upper limits of the poor category at high flows.

Assuming that atmospheric deposition is uniformly acidified on average in the Trout Run watershed, the variability of water quality in the subwatersheds is likely due to surface influences, such as soils and geology. Figure 3-6 provides a comparison of average water quality to the major bedrock units underlying the watershed. Exposed units trend upward from the Mississippian Huntley Mountain Formation and Burgoon Sandstone in the deeper southern valleys to the Pennsylvania Pottsville Group on the northern highlands and headwaters areas, with several remnants of the Pennsylvanian Allegheny Group at the highest elevations. The pronounced acidification in the Trout Run headwaters and Alex Branch appears to occur in association with the basal conglomerate member of the Pottsville Group, which contains abundant quartz pebble clasts.

Soils derived from quartz-rich parent materials are expected to have a low natural buffering capacity due to their high silica content. The Burgoon and Huntley Mountain strata contain a greater percentage of shale and siltstone than the basal Pottsville Group, and are described in some localities as having calcareous interbeds. It is presumed that the streams with significant reaches rooted in these units will benefit somewhat from this inherent alkalinity. The Pottsville conglomerate occupies a large portion of the Trout Run headwaters and Alex Branch subwatersheds, with only a small area of Burgoon Sandstone present. Roberts Run has somewhat less exposed Pottsville conglomerate and incises into the Huntley Mountain Formation in its lower reaches, and has a slightly better water quality. The UNT to Trout Run is steeply incised, producing a very limited exposure to the quartz-rich conglomerate. Using these relationships of water quality to bedrock geology, it is inferred that Dixon Run, Crooked Run, and Pine Run may have fair to perhaps slightly poor water quality under average flow conditions due to their relatively broad exposures of Pottsville conglomerate and limited incision into lower units. Coldstream Run and Bee Hollow have large incisions into the Burgoon Sandstone and Huntley Mountain formation, and are expected to have good water quality similar to TR 4. The contrasting water qualities for these mid-stem tributaries are inferred to contribute to the moderate episodic acidification observed at TR 6 for Trout Run.

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



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 less than 5.5 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 Trout Run watershed should be an ANC of 20 µeq/L under average flow conditions and 5 µeq/L under high flow conditions. This equates to a pH range of about 5.8 SU on average, with a minimum of about 5.6 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 high flow values being the typical design maximum feed rate. Average and 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 is discussed for specific technologies in Section 4.

In conclusion, Figure 3-7 shows a cumulative loading chart of alkaline addition required to meet minimum restoration goals for the monitored sample point network of the Trout Run 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. This is the case for sample point TR 5, where if alkaline addition is conducted for all four upstream sources, a net excess alkalinity of about 16 tons/yr will occur relative to existing deficiencies at TR 5. However, it is calculated that this excess would be consumed by a predicted 73 ton/yr deficiency at downstream TR 6, requiring an additional 58 tons/yr of alkalinity to offset. The combined estimate for complete restoration of the watershed to minimum goals is an addition of about 112 tons/yr as $CaCO_3$ (roughly 125 tons/yr of high quality limestone).

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

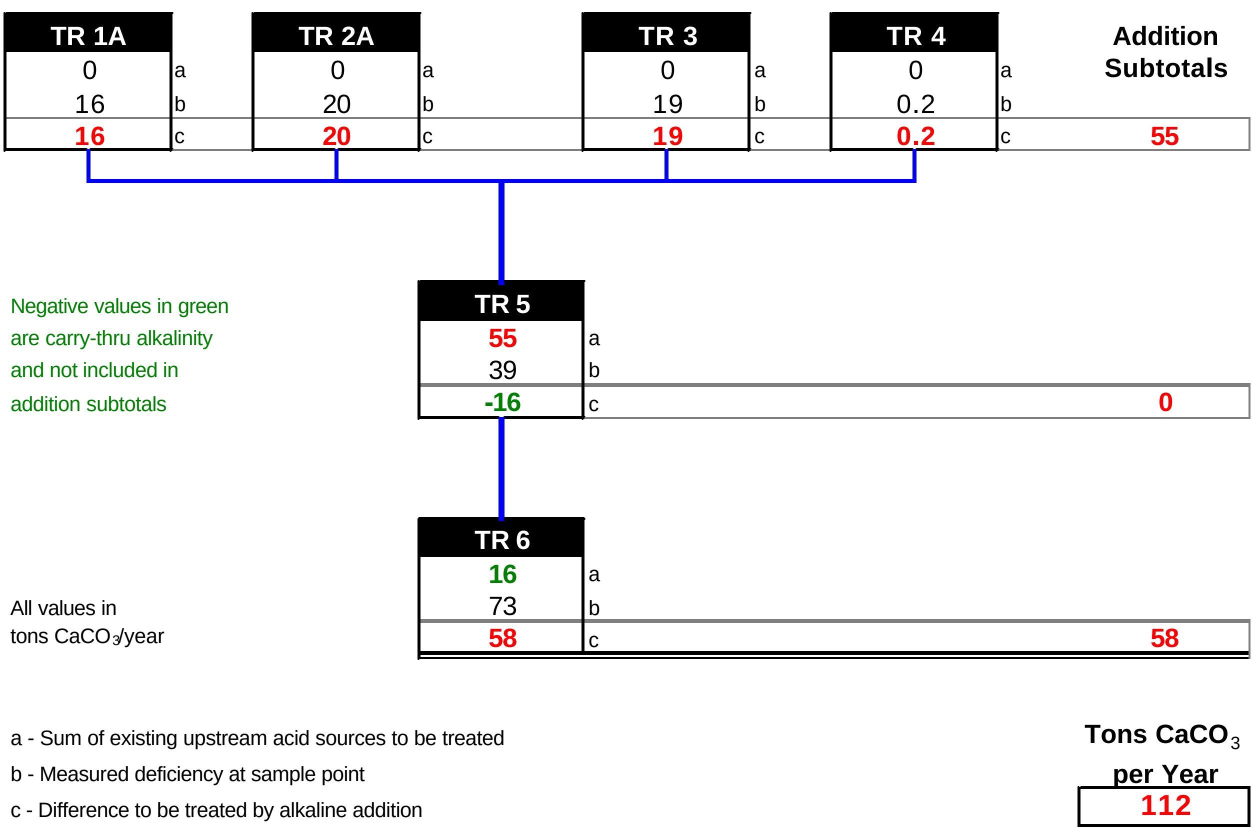
Species	Survival Range																				
pH (SU)	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5
ANC Eq. (meq/L)	-31	-26	-22	-18	-14	-11	-8	-5	-2	1	7	13	19	25	32	40	48	56	66	77	90
Ohio Lamprey																					
Chain Pickerel																					
Golden Shiner																					
White Sucker																					
Brown Bullhead															Target Range						
Pumpkinseed																					
Creek Chubsucker																					
Largemouth Bass																					
Brook Trout																					
Creek Chub																					
Yellow Perch																					
Bluntnose Minnow											Minimum Proposed Restoration Goal										
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																					

Based on Earl & Callaghan, referencing Cooper & Wagner, 1973,
On: HTTP://www.dep.state.pa.us/dep/deputate/ minres/districts/cmdp/chap04.html.

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

Sample Point		**Alkaline Addition Requirement**		
		Average lbs/day	High Flow lbs/day	Annual tons/yr
1A	Trout Run Headwaters	88	297	16.1
2A	Alex Branch	108	257	19.7
3	Roberts Run	102	122	18.6
4	Unnamed Tributary	1	0	0.2
5	Trout Run Midstream	212	326	38.6
6	Trout Run Downstream	403	595	73.5

Figure 3-7: Cumulative Annual Alkaline Addition Required to Meet Minimum Goals



4

ALKALINE ADDITION TECHNOLOGIES

The only practical solution currently available to correct acid deposition impacts is to add neutralizing alkalinity, and limestone is usually 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 Trout Run watershed is deficient in this mineral. 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 related products are considered to be the best means for alkaline addition in the Trout Run 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 common 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 adjacent Mosquito Creek watershed, including development of new approaches and application guidelines for other regional watersheds.[1] This section provides application guidelines for these technologies as they might be used for Trout Run.

Wherever referenced in the following, 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.

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

[1] Rightnour, T. A. and K. L. Hoover. Assessment of Applied Technologies For Acid Abatement (Mosquito Creek Watershed) Pennsylvania Growing Greener Program Project No. ME 352934. June 2006.

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 Systems	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.
Raod 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.
Raod Liming	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.
Raod Liming	Limestone Pods	Sustainable to Mildly Episodic	*	○	○	Easy to construct, low maintenance, provide erosion control below road culverts.	Untested technology, only provides alkalinity during storm flows.
Raod Liming	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.

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		
Direct Water Application	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.
Direct Water Application	Limestone Crib Walls	Episodic to Mildly Chronic	≈ $0.10	○	○	Can stabilize eroded stream banks while providing episodic alkalinity.	Untested technology, may require periodic structure replacement.
Direct Water Application	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 ◉ Moderate cost or effort

○ Low 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. 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

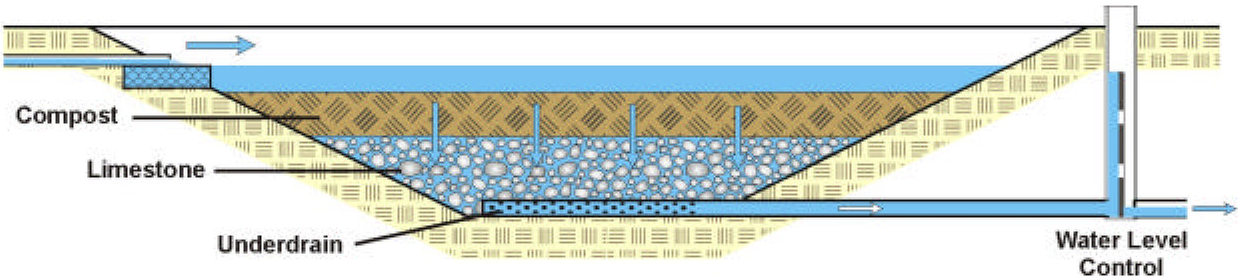


Figure 4-2 shows the layout of a VFW constructed on Pebble Run in the Mosquito Creek watershed. Three of these systems were constructed on sites in Mosquito Creek under Growing Greener Grants and monitored for performance to develop design criteria for acid deposition applications. This led to the development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

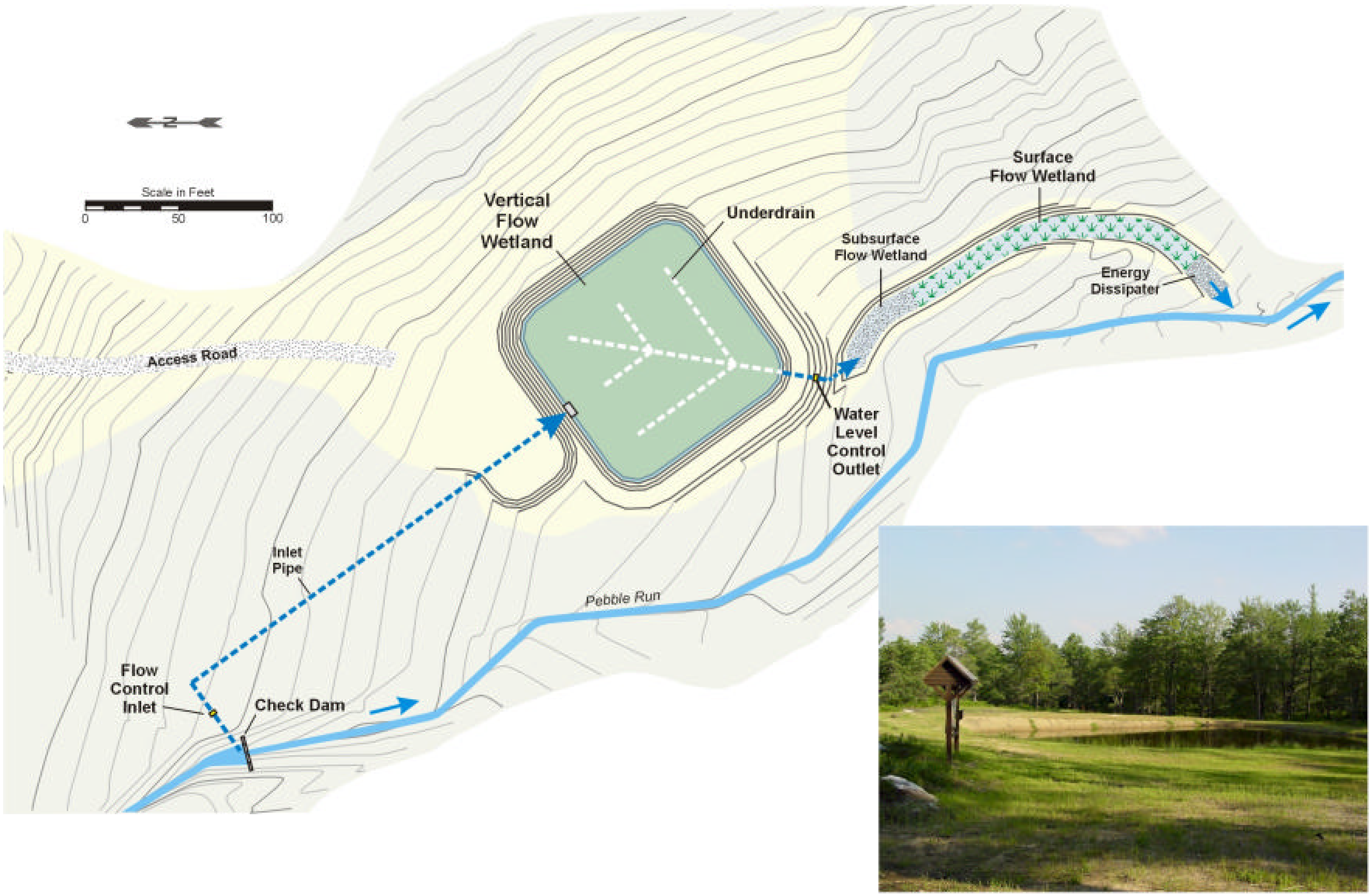


Figure 4-3: Basic Components of a Vertical Flow Wetland for Acid Deposition Treatment

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

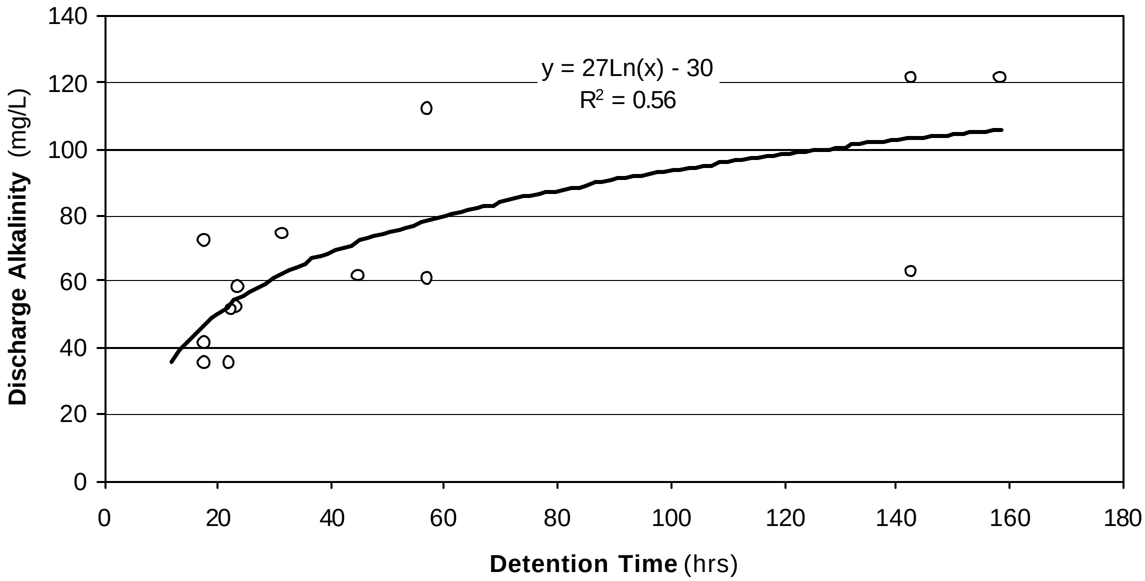
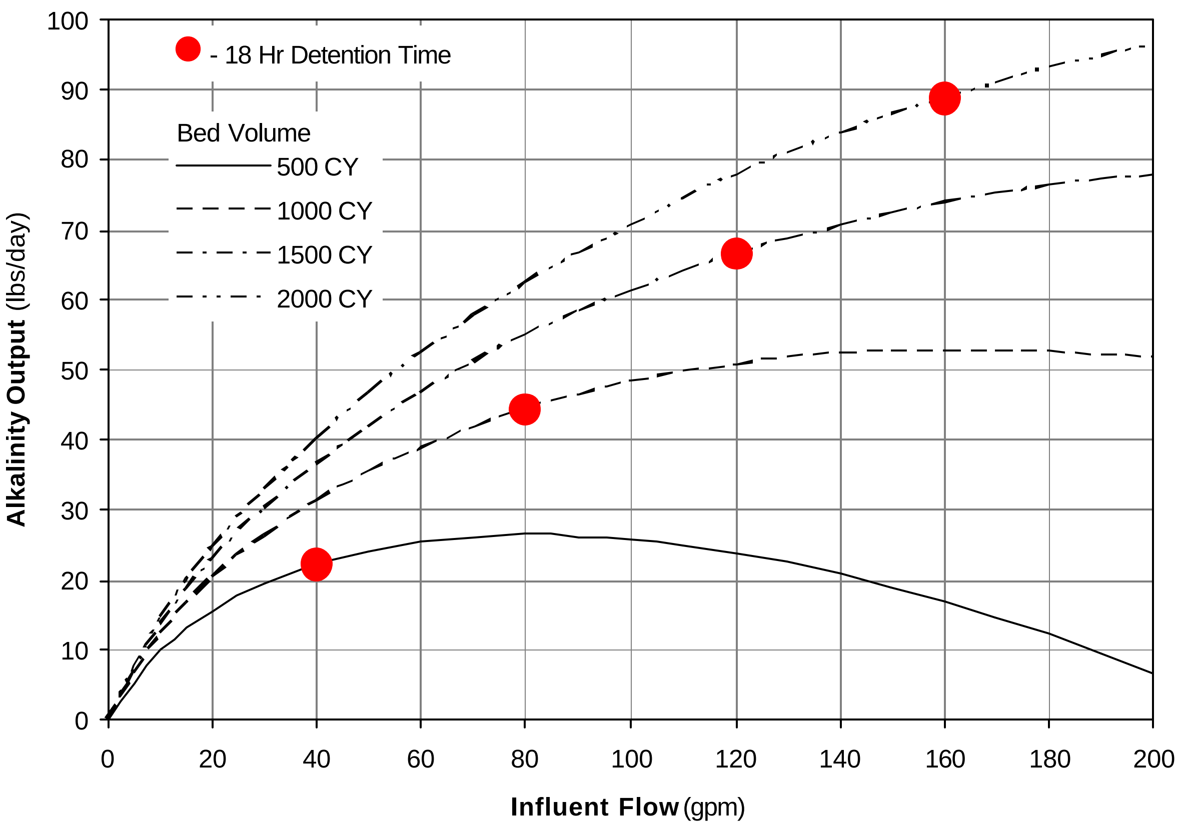


Figure 4-5: Relationship of Alkalinity Output, Influent Flow, and Bed Volume in VFWs



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 ultimate 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.

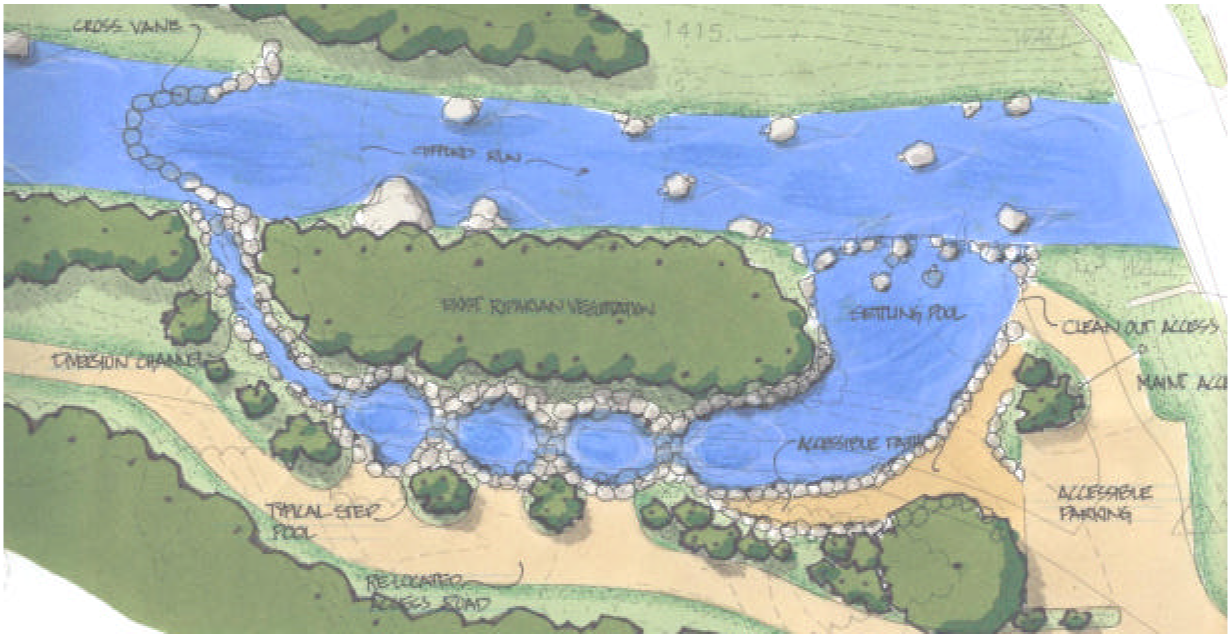
In a variation of the VFW design, vertical flow limestone beds (VFLBs) have been conceptually planned for application in acid deposition settings. VFLBs are simply VFWs without the compost bed. Although compost appears to be required to maintain alkalinity generation for mine drainage treatment, it may 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, and 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 minimize earthwork requirements. This type of construction will require stream encroachment permitting and other permits as described for VFWs.

Construction of a first demonstration HFBC is planned in the Mosquito Creek watershed in the near future, 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 2 tons per acre is generally used as a starting point rule-of-thumb. 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 $25 per ton, and agricultural limestone can be obtained for about $30 per ton.

The Penn State University Forestry Department is currently investigating the benefits of land application liming in several areas of the Mosquito Creek watershed. (Please contact Dr. William Sharpe at Penn State for more information regarding this study.) For their forest liming projects, Penn State 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, but has been made available for use on other restoration projects in the central Pennsylvania region.

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.

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

ROAD LIMING

Application of limestone 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. Several basic approaches to road-related liming are road surface application, open limestone channels, limestone pods, and roadside lime 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 alkalinity generation could make the difference between episodic and sustainable conditions for a receiving stream with a significant watershed portion affected by roads.

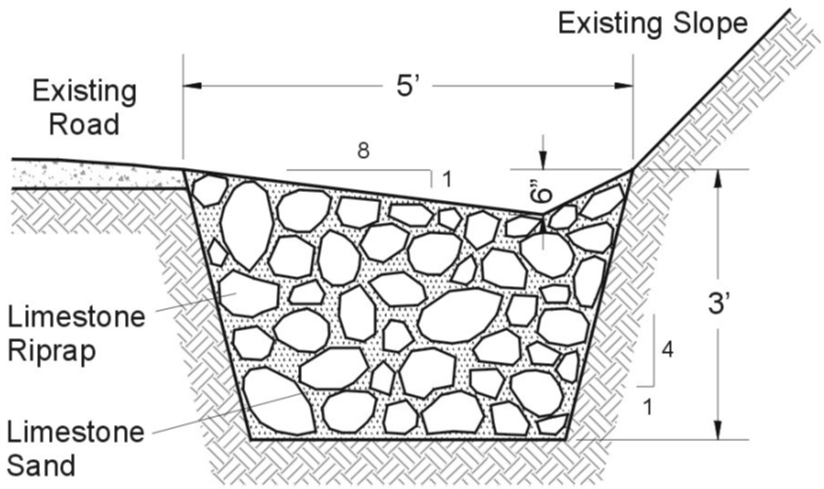
Figure 4-8 shows a completed limestone road surfacing project (note also an open limestone channel to the right). Costs of limestone road surfacing depend greatly on the nature of the road, including width, thickness of cover, and coarseness of the aggregate applied. Basic crushed limestone road cover 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

Open Limestone Channels

Open limestone channels (OLCs) 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 OLC is shown by Figure 4-9.

Figure 4-9: Typical OLC Section

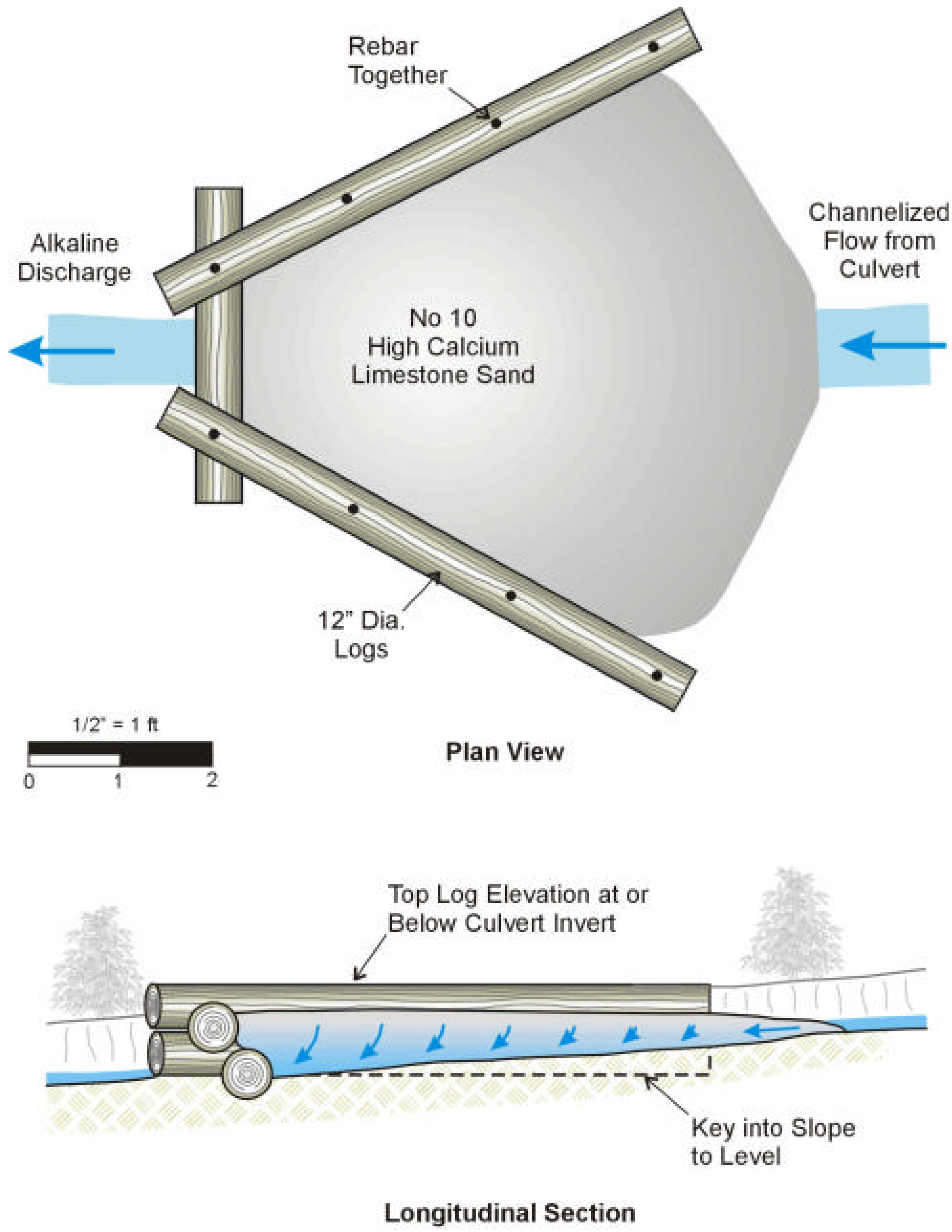


There are insufficient data to date to develop a prediction model for alkalinity output from OLCs. One demonstration project was measured as discharging an alkalinity of 19.8 mg/L, an ANC of 459 meq/L, and a pH of 7.63 SU. As with limestone road surfacing, OLCs are currently targeted at unspecified improvements in acidified watersheds. Costs of OLC construction will vary depending on the channel size and depth. Riprap for constructing roadside ditches typically costs about $35 per ton. The Mosquito Creek OLC was constructed for about $10 a linear foot using labor and equipment from the Moshannon State Forest. 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. OLCs are also suitable for use beside paved as well as unpaved roads.

Limestone Pods

Road culverts provide additional opportunities to passively apply limestone. As shown by Figure 4-10, a simple log cribbing structure, or "pod," containing limestone can be placed below culvert outlets to intercept storm water, temporarily retaining flows and neutralizing acidity by migration through the aggregate. This approach can also be applied to other ephemeral channels where access is available, and the units are easily constructed with volunteer labor. Limestone pods have not been tested to date, but are planned for preliminary applications in northeastern Pennsylvania in the near future. Sizing at this time is based on field observations of existing flow channels and estimates of stability requirements for the structures. The performance of the pods is expected to be similar to that of OLCs. Depending on labor, their construction costs should be in the range of about $2,500 each.

Figure 4-10: Basic Limestone Pod



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 roadsides 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 of roadside lime casting would likely be comparable to forest liming, while the costs should be lower due to greater ease of machine operation. This approach has not been tested to date, but is presented as an option for unpaved public roads in the Trout Run watershed.

DIRECT WATER APPLICATION

Several methods are available for directly applying limestone to flowing streams or other water bodies, including in-stream limestone sand dosing, limestone crib walls, and lake liming. Each has advantages and limitations, as discussed in the following:

In-Stream Limestone Sand Dosing

The simplest form of direct addition is in-stream limestone sand dosing. This involves periodically dumping a quantity of limestone sand in a stream channel or on its 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 4-11 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 a fourth 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 addition rate in the first year of treatment. In the absence of ANC data prior to alkaline addition, the Clayton Method appears to best predict an effective addition rate for regional streams. For the Empirical Method, the dosing requirement is the actual 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.

Figure 4-11: 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 is preferable 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 steer 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.

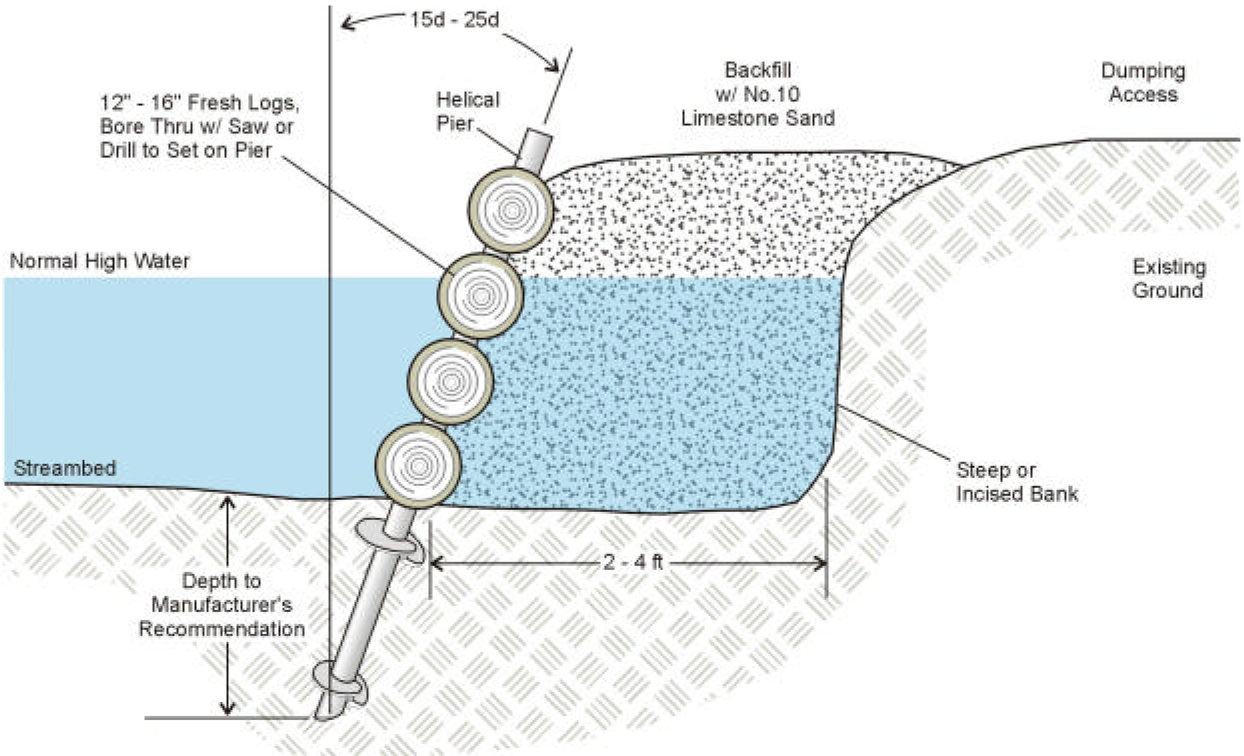
There are concerns that long-term dosing can degrade streambeds by clogging cobble bottoms with finer-grained sand, reducing the quality of habitat for benthic macroinvertebrates. A buildup of aluminum precipitates has also been noted downstream of dosing sites in some cases, where increased pH renders 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.

Limestone Crib Walls

A somewhat more controlled option for applying limestone in direct contact with flowing water is to contain it within a bank-side crib wall constructed of loose-fitting logs. Limestone sand is the most effectively sized material for this. During low-flow periods, the sand will dissolve to provide a low but steady source of alkalinity, while during high flows some sand will be washed directly into the channel similar to direct limestone sand dosing. As sand is lost to both processes, it can be replenished by backfilling more sand behind the crib wall. This approach has the advantage of focusing sand application more towards the high flow periods. Crib walls can also be used for erosion control and prevention on incised stream banks.

Figure 4-12 shows an example crib wall installation using helical piers for the log wall anchoring. These types of piers are driven into the streambed by a specially-equipped track hoe. They provide exceptionally strong support and can be driven into streambeds containing large cobbles to small boulders. Wall logs are bored out with a drill or chainsaw sufficiently to slide over the piers, and then stacked to the required height. When the logs require eventual replacement, they can be easily cut free and new logs slid into place. The current estimate for this type of construction is about $150 per linear foot of crib wall placement, equating to about $0.10 per pound of limestone placed. Their performance should be fairly comparable to in-stream dosing, but no direct measurements or sizing criteria are currently available.

Figure 4-12: Limestone Crib Wall Using Helical Piers



Completed Helical Pier Crib Wall

Lake Liming

Lake liming and other forms of riparian lime addition 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 on open water bodies, creating a large reservoir of alkaline water that is progressively flushed out to neutralize downstream reaches. Aerial liming also has the advantage of being able to reach sites that are inaccessible by ground equipment or otherwise protected from ground disturbance. Figure 4-13 shows a typical aerial liming operation.

Figure 4-13: Example of Aerial Lake Liming

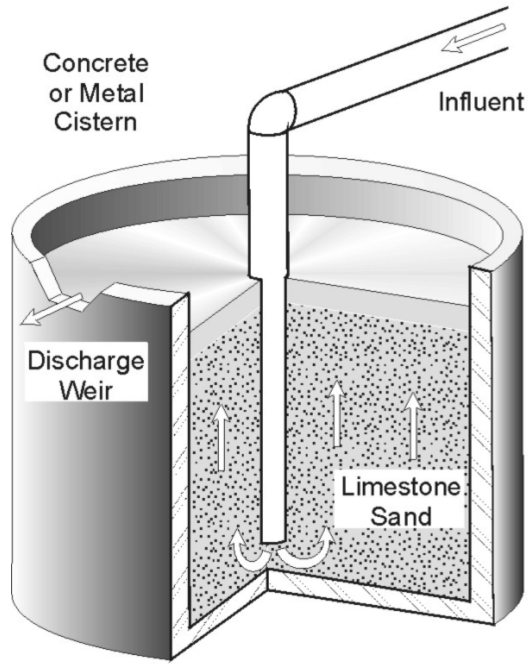
The initial rule-of-thumb approach to aerial liming is the same as for forest liming: 2 tons of limestone per acre of surface area. Alkalinity generation results will depend on the nature of the application surface, with flow-through wetlands providing more immediate benefits than non-inundated areas. 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/ton.

LIMESTONE DIVERSION WELLS

Limestone diversion wells originated in Scandinavia as methods for treating acid rain, and were later adopted in the United Stated for treating mine drainage. As shown by Figure 4-14, 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 diversion of a portion of a stream flow to the well (hence the name “diversion well”). There have been numerous applications of diversion wells in the Appalachian states, 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.

Figure 4-14 – Typical Diversion Well



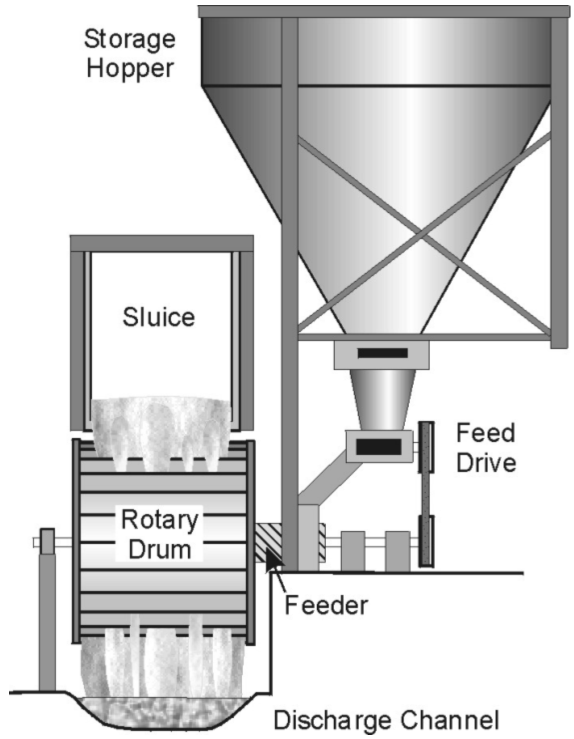
LIMESTONE ROTARY DRUMS & BASKET WHEELS

Limestone rotary drums and basket wheels offer a more aggressive dosing option by enclosing limestone aggregate in a rotary wheel, usually consisting of a drum with slots, perforations, or external screening (Figure 4-15). 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.

Crushed limestone is either manually loaded into each drum or automatically fed through a reciprocating feeder at the bottom of a hopper. Flow volume through the sluiceway determines the speed at which the drums rotate, the amount of aggregate supplied to the drum, and the amount of neutralization supplied to the stream. Abrasion of the 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. Various screens and meshes can be used to control the discharge size of the fines. Several drums can be operated in series, with increased flow initiating movement of progressively more drums, 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. 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 these systems.

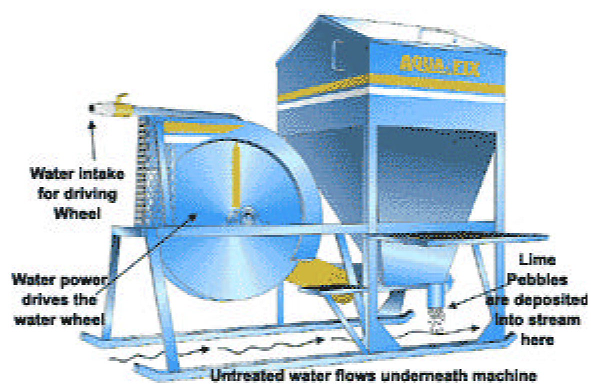
Figure 4-15: Typical Rotary Drum



PEBBLE QUICKLIME ADDITION

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 4-16), 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 4-16: 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 4-17) or an integral hopper unit (Figure 4-18). The driving water flow for the waterwheel mechanism is taken from a diversion upstream of the addition site. This allows the systems to provide a material 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.

Figure 4-17: Silo-Type Aquafix Unit

Figure 4-18: Hopper-Type Aquafix Unit

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 35 ton or larger silo can be 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 35 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 designs. Construction of the diversion and outfall structures will usually require a stream encroachment permit.

5

PROGRESSIVE RESTORATION PLAN

As discussed in Section 3, the Trout Run 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 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 this watershed assessment. This section discusses the latter considerations and presents a progressive restoration plan for Trout Run, including an estimate of conceptual implementation costs.

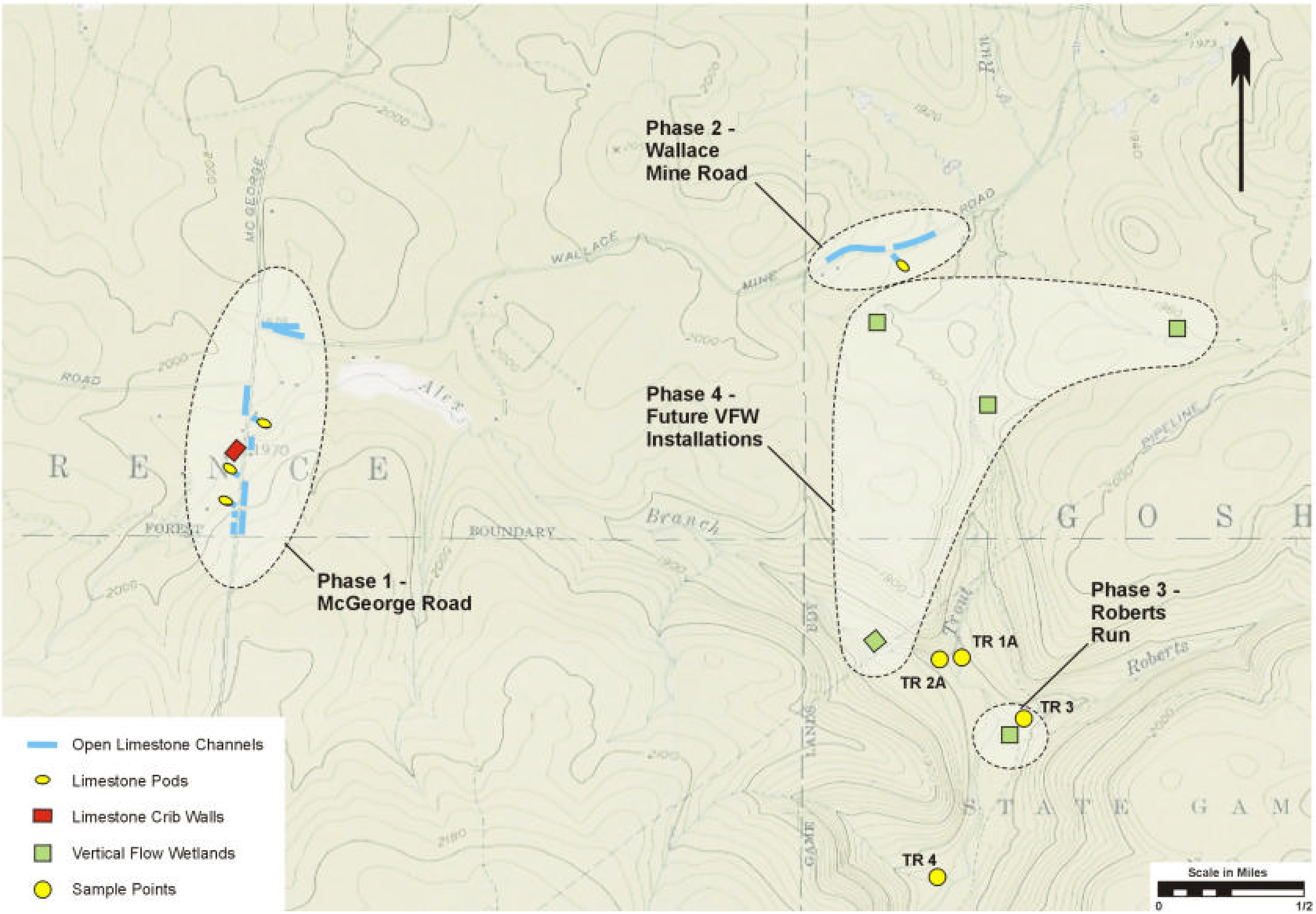
CONCEPTUAL PROJECT SITE FEASIBILITY

A primary review of potential alkaline addition project sites was conducted by field investigation of readily accessible areas for such factors as topographic suitability, construction feasibility, and access requirements. A secondary review was conducted using USGS mapping to conceptually assess sites that are currently inaccessible. Both reviews focused on the headwaters area above sample TR 5 where data were collected to allow assessment of potential treatment results. It is noted that private lands are interspersed with public lands in this area, and the actual ownership of conceptual project sites was not determined as part of this study. The feasibility of applying the technologies discussed in Section 4 was evaluated according to the general criteria presented in Table 5-1. It was determined that the most applicable technologies for the headwaters area are limestone pods, limestone crib walls, open limestone channels, and vertical flow wetlands. Figure 5-1 shows conceptual locations for these projects.

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

Alkaline Addition Technology		Site Feasibility Criteria	Conceptual Applicability
Vertical Flow Wetlands		Relatively flat area (0 – 5% slope) of 1 acre or more adjacent to stream Drainage area of approx. 250 acres above potential construction site to provide 100+ gpm of baseflow	5 Potential Sites: Roberts Run (1) Alex Branch (1) Trout Run Headwaters (3)
High Flow Buffer Channels		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	Not particularly applicable – headwaters channels either too small or suitable locations are inaccessible for construction
Forest Surface Liming		Areas with < 30% slope USGS-mapped wetland areas are likely inaccessible	Potentially applicable, but access to suitable areas is limited, and may be complicated by land ownership
Road Liming	Limestone Road Surfacing	Applicable on non-paved public roads	Most area roads already receive limestone surfacing
Road Liming	Open Limestone Channels	Applicable along paved and non-paved public roads	2 Potential Sites: McGeorge Road – 1950 ft Wallace Mine Road – 1450 ft
Road Liming	Limestone Pods	Applicable at culvert discharges and other runoff concentrations	2 Potential Sites: McGeorge Road (3) Wallace Mine Road (1)
Road Liming	Roadside Lime Casting	Applicable along non-paved public roads	Potentially applicable, but not a priority, and may be complicated by land ownership
Direct Water Application	Limestone Sand Dosing	Dosing sites located at bridges and other stream crossings. Applicable to moderate- to large-sized streams	Not particularly applicable – most headwaters streams are too small for adequate lime migration
Direct Water Application	Limestone Crib Walls	Particularly applicable to steep or eroded banks. Requires access for lime sand replenishment.	One usable site located along McGeorge Road
Direct Water Application	Lake Liming	Open water body > 10 acres with a flowing discharge	No applicable water bodies in the watershed

Figure 5-1: Conceptual Sites for Alkaline Addition Technologies



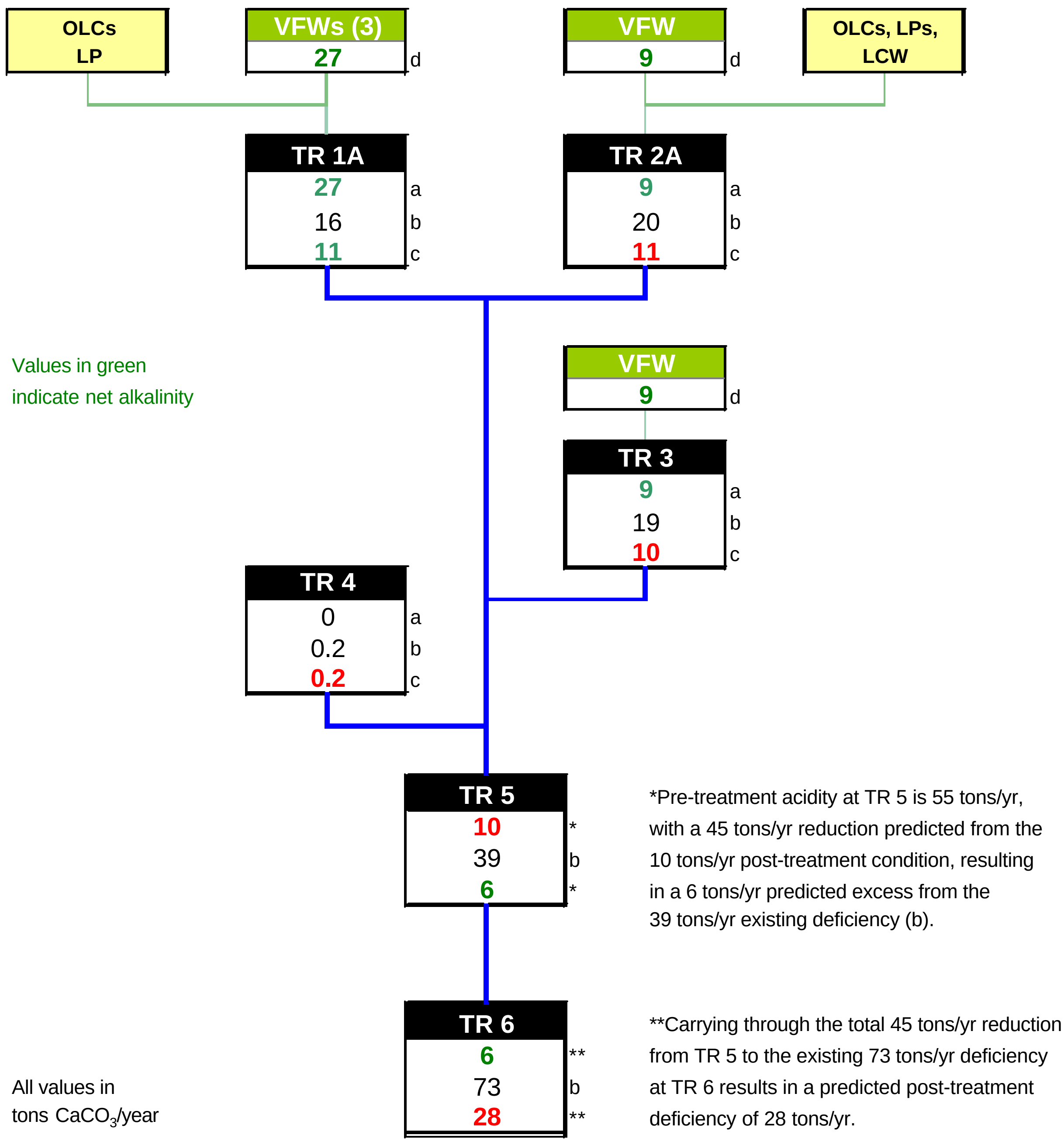
CONCEPTUAL EFFECTS OF TREATMENT

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 conceptual construction locations. Other technologies without predictable alkaline addition rates are indicated where conceptually applicable. The following are the basic conclusions of this analysis:

- Three VFWs in the Trout Run headwaters should result in a net excess alkalinity of approximately 11 tons/yr at TR 1A.
- One VFW on Alex Branch should result in a residual alkaline deficiency of approximately 11 tons/yr at TR 2A.
- Trout Run below the confluence of the headwaters and Alex Branch should be essentially neutral after treatment above TR 1A and 2A.
- One VFW on Roberts Run should result in a residual alkaline deficiency of approximately 10 tons/yr at TR 3.
- The sum of the alkaline excess at TR 1A and the residual deficiencies at TR 2A, TR 3, and TR 4 should result in a residual alkaline deficiency of approximately 10 tons/yr and TR 5.
- From Figure 3-7, the sum of the upstream pre-treatment deficiencies at TR 5 is 55 tons/yr. Subtracting the predicted post-treatment deficiency of 10 tons/yr from this value results in a predicted net acidity reduction of 45 tons/yr for the upstream projects. Subtracting this from the measured existing deficiency at TR 5 of 39 tons/yr results in a net carry-through alkaline excess of 6 tons/yr.
- Similarly, the removal of 45 tons/yr of upstream deficiency from the existing 73 tons/yr deficiency at TR 6 should result in a residual alkaline deficiency of 28 tons/yr at TR 6 after treatment.

Figure 5-2: Preliminary Analysis of Potential Treatment Results



a - Sum of treated upstream alkalinity or acidity

b - Measured existing deficiency at sample point

c - Treated alkaline excess or deficiency

d - Typical annual alkalinity output for standard VFW design

PROGRESSIVE RESTORATION PLAN

The purpose of a progressive restoration plan is to divide a large stream improvement obligation 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 5-1 shows the general locations and components of these phases in the watershed.

Phase 1 – McGeorge Road

Fairly simple and inexpensive alkaline addition can be provided to the headwaters of Alex Branch by working off McGeorge Road. As shown by Figure 5-1, a number of open limestone channels can be constructed on both sides of the crossing of the main stem of Alex Branch, with three limestone pods located in association with existing culverts. An opportunity is also available to construct about 20 feet of limestone crib wall upstream of the crossing. Additional open limestone channels can be installed at the intersection with Wallace Mine Run to affect an ephemeral drainage to Alex Branch. Results from this work should be monitored to determine actual future alkaline addition needs should a VFW be implemented downstream on Alex Branch.

Phase 2 – Wallace Mine Road

As shown by Figure 5-1, a segment of Wallace Mine Road is suitable for installation of two OLCs and a limestone pod near the confluence of the multiple drainages forming the Trout Run headwaters. This work would serve to augment future VFW installations downstream, and could be conducted concurrently with the McGeorge Road projects to save on mobilization costs.

Phase 3 – Roberts Run

The downstream VFW location indicated for Roberts Run on Figure 5-1 is the only readily accessible construction site for this technology in the upper Trout Run area. Access is possible via an existing Game Lands trail, although improvements would be necessary to admit construction and hauling equipment. This work would not result in an immediate development of downstream alkaline reaches, but would improve water quality in the main stem and support future alkaline addition projects in the headwaters.

Phase 4 – Future VFW Installations

The remaining four conceptual VFW sites shown on Figure 5-1 are not currently accessible for construction without new access development, and complications may exist with land ownership. From the predicted conceptual effects of treatment, at least four VFWs would be necessary to achieve a neutral condition below the confluence of the Trout Run headwaters and Alex Branch. In combination with the Phase 1 and 2 activities, these VFW installations may also achieve a net alkaline condition for some distance below the confluence, potentially through the 8 miles to TR 6. Phase 4 should include a detailed site selection analysis and an evaluation as to whether multiple VFWs could be applied at one construction site to reduce the overall cost of access development.

Other Supporting Projects

Essentially any limestone-based alkaline addition will benefit the Trout Run watershed. There are numerous potential opportunities to add limestone in addition to those outlined in this section, including smaller forest liming areas, additional road liming segments, local limestone crib walls, and limestone pods in ephemeral channels. 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. Where a net alkaline result in stream mileage is not anticipated for the proposed work, the mileage is designated as undetermined (UND). Ultimately, there are about 8 miles of stream that could be improved in the Trout Run watershed by the current progressive restoration plan, assuming that the proposed headwaters improvement projects achieve a net alkaline condition in the main stem downstream from the confluence with Alex Branch to sample TR 6.

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. 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 $34,000 in 2008 dollars). Although an average figure, this is probably a reasonable value for acid deposition impacts to Trout Run given its overall amenities versus its remoteness.

The synopsis of the cost analysis is that it will probably take on the order of $1.1 million over the next 15 years to treat acid deposition in the Trout Run headwaters sufficiently to restore net alkaline conditions below the confluence with Alex Branch. This amounts to an annualized investment of about $76,000 per year, or about $9,500 per stream mile improved assuming results continue to TR 6. This compares favorably with conceptual recreational returns of $34,000 per stream mile improved.

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 - McGeorge Run								
1950 ft of OLCs	UND	UND	$25,000		$2,000		UND	UND
Three limestone pods (3)	UND	UND	$7,500		$1,000		UND	UND
One limestone crib wall	UND	UND	$3,000	$500	$1,000	$4,000	UND	UND
Phase 2 - Wallace Mine Road								
1450 ft of OLCs	UND	UND	$15,000		$1,000	$5,000	UND	UND
One limestone pod	UND	UND	$2,500		$0	$5,000	UND	UND
Phase 3 - Roberts Run VFW								
One VFW system near the mouth of Roberts Run	UND	UND	$200,000	$1,000	$14,000	$19,000	UND	UND
Phase 4 - Future VFW Systems								
Three VFWs in the Trout Run headwaters and one on Alex Branch	apprx. 8	apprx. 8	$800,000	$4,000	$57,000	$76,000	$7,100	270000
		Total All Projects:	$1,053,000	$5,500				
		15-Year Phase Total Cost:		$1,135,500	Total Annual Cost/Mile:		$9,463	
		15-Year Annualized Cost:		**$75,700**	**Annual Recreational Benefit**			**$270,000**

6

CONCLUSIONS & RECOMMENDATIONS

The overall conclusion of this study is that restoration is technically feasible for the Trout Run watershed, and that stream improvements to restore and improve 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 in the Trout Run headwaters. Other specific conclusions and recommendations are presented as follows:

CONCLUSIONS

- The Trout Run watershed can have a significant recreational value due to its low level of development and containment of many 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.
- Trout Unlimited 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 cumulative restoration phases appear justifiable in comparison to generally estimated losses to recreational use due to acidification.
- The conceptual restoration projects are reasonable in scale for progressive funding and implementation.
- The total estimated restoration cost for the watershed of about $1.1 million is a reasonable level of investment for a potential return of up to 8 main stem stream miles.

RECOMMENDATIONS

- Collect additional data from the other major tributaries (Dixon Run, Coldstream Run, Crooked Run, and Pine Run) to evaluate the full extent of acidification impacts and need for abatement projects.

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

- Begin the design and permitting stages for the Phase 1 and 2 projects.