Shenandoah National Park
Virginia

US Department of the Interior
National Park Service

Shenandoah National Park

Meadow Run Watershed Restoration Project

ENVIRONMENTAL ASSESSMENT

January 2021

NPS cost associated with developing this document: $469,230

EXECUTIVE SUMMARY

Meadow Run is a stream located in the South District of Shenandoah National Park (the park) in the Commonwealth of Virginia. Like other watersheds in the park, decades of acidic deposition (acid rain) from regional air pollution have negatively affected soil and water quality in Meadow Run's watershed. Acidic soils have altered the water chemistry, impacting species richness and abundance of macroinvertebrates (mostly aquatic insects) and fish such as brook trout. Meadow Run, located in congressionally designated wilderness, is listed as impaired under Section 303d of the Clean Water Act by the Virginia Department of Environmental Quality (VADEQ) because of its elevated acidity (low pH). Acidic deposition has been found to negatively affect songbirds, plants, and forest health in forests similar to the forest in the watershed. These degraded conditions affect ecosystem health and visitor experience.

Because of Meadow Run's underlying bedrock geology, the soil and stream cannot recover naturally to pre-pollution conditions for well over 100 years. Meadow Run specifically has a history of scientific research on acid rain effects and is the ideal size for a restoration effort. Therefore, the park proposes to improve and restore the long-term health of the terrestrial and aquatic ecosystem and mitigate the harmful effects of acidic deposition in the Meadow Run watershed.

Under the no-action alternative (alternative A), current conditions would continue, resulting in long-term, adverse impacts on the ecosystem. Stream macroinvertebrate and fish communities (including brook trout) would likely remain degraded; native plants would remain limited in their growth and health; and the reproduction, growth, and/or abundance of some terrestrial wildlife (e.g., birds, snails, and some salamanders species) may remain adversely affected.

Under the two action alternatives, the park would apply limestone sand by helicopter in park-managed portions of the upper watershed (2,150 acres) to reduce its acidity. Proposed alternative B (split-dose liming) would use a higher liming dose of 3.0 tons per acre (t/acre) on more acidified soils and a lower dose of 2.25 t/acre on less acidified soils. Alternative C (uniform-dose liming) would apply a uniform dose of 2.75 t/acre. While alternative C would be slightly simpler to implement, alternative B (the preferred alternative) would be more closely tailored to site-specific soil conditions.

The application of limestone sand is expected to require two to three months and would occur during the winter (December–February), a period of low visitor use in the park and dormancy for many plants and animals. The project would be staged from areas along Skyline Drive and/or from outside the park. The park would consider multiple staging areas to minimize noise near any given staging area, allow for flexibility to accommodate winter weather conditions, and maximize the efficiency of project implementation, thereby keeping the implementation period as short as practicable. Any staging area outside the park would be located preferentially within a 0.5-mile zone immediately adjacent to the park boundary, although areas up to 1 mile from the boundary may be considered, if suitable. The park would gain permission from landowners for staging areas outside the park and communicate with affected neighbors. The helicopter carrying external loads (limestone sand) would only fly over lands where the park has made arrangements for that activity with the respective landowners.

For visitor safety, Riprap and Wildcat Ridge Trails would be closed, and backcountry camping in the project area would be prohibited during the full application period; closures of sections of Skyline Drive and the Appalachian Trail would be shorter and more intermittent based on project activity. The project implementation plan, to be prepared prior to any work on-site, would include measures for ensuring public safety, as well as a plan for coordination and communication with neighbors and the larger community of park users.

It is highly likely that a single limestone sand application would achieve the desired long-term restoration goal of improving the ecosystem of this watershed. If soil sampling and stream monitoring after the first liming demonstrated that long-term restoration goals were not met, one additional application could be considered in the future, conducted in a similar manner as the first application.

Alternatives B and C would have similar impacts (described below), although beneficial impacts would be more evenly distributed over the project area under alternative B than under alternative C:

- **Soil Chemistry:** Soil acidity and toxic aluminum in the Meadow Run watershed would be reduced. Improvements should be observable within a year and would have beneficial impacts on soils for well over 100 years.
- **Water Quality:** Monitoring data indicate that Meadow Run has poor water quality for brook trout. Liming would have ecologically significant, beneficial impacts on water quality by measurably increasing the acid neutralizing capacity and pH, and decreasing aluminum toxicity. The pH in the stream water is expected to increase to > 6.0, which would allow Meadow Run to be removed from VADEQ's Section 303d list for impaired waters.
- **Aquatic Wildlife (Fish and Macroinvertebrates):** Beneficial changes in stream water quality would result in the likely return or increased abundance of fish species (such as brook trout and blacknose dace) and macroinvertebrates (an important food source for fish).
- **Vegetation:** Changes in soil chemistry would result in long-term improvements of plant growth, improving the overall health of the forest. This includes improved growth of acid-sensitive plants in the project area, giving them a slight competitive advantage over acid-dependent plants. While the spread of non-native invasive plants could occur, the implementation of mitigation measures would minimize adverse impacts.
- **Terrestrial Wildlife (Birds, Salamanders, and Snails):** Birds, especially ground- and understory-foraging species, would benefit in the long term from an increase in calcium-rich food items (e.g., snails) because birds require large amounts of calcium to produce eggshells and raise young. Some salamanders could experience more growth and reproduction because of increased availability of invertebrates and reduced aluminum toxicity. Snails are expected to become more abundant due to calcium additions available for shell growth.
- **Wilderness Character:** Liming would manipulate natural processes in the project area, require the use of a helicopter and vehicles that generate noise and produce visual impacts, and require trail and area closures—all of which would adversely affect wilderness character during the application period. However, liming would help the park meet its wilderness and backcountry management goals by reducing adverse impacts on wilderness resources (soil, stream water, vegetation, and wildlife) and would have long-term, beneficial impacts on the natural quality of wilderness character.
- **Acoustic Environment (audible sound):** Liming would have adverse impacts on the acoustic environment in terms of human and wildlife annoyance during the application period of up to three months. More intense impacts would occur near staging areas with low-elevation helicopter activity and truck deliveries of limestone sand (although specific staging areas outside the park [if any] have not been specified). Impacts would occur during the daytime only. Noise impacts would be mitigated through careful planning of flight paths and staging areas.
- **Visitor Use and Experience:** During the application period, there would be closures of varying duration of trails (Riprap and Wildcat Ridge Trails and a section of the Appalachian Trail), backcountry areas, and a section of Skyline Drive. Closures, along with visual and noise disturbances, would affect visitor use and experience. Over the long term, visitor experience in the project area would improve because opportunities for recreational fishing and experiencing wildlife would benefit from improved natural resource conditions (including fish and wildlife habitats).

CONTENTS

EXECUTIVE SUMMARY .... **I**
CHAPTER 1: PURPOSE OF AND NEED FOR ACTION **1**
INTRODUCTION 1
PURPOSE OF AND NEED FOR ACTION 2
PROJECT AREA FOR RESTORATION 3
ISSUES AND IMPACT TOPICS ANALYZED IN THIS ENVIRONMENTAL ASSESSMENT 3
CHAPTER 2: ALTERNATIVES **5**
INTRODUCTION 5
ALTERNATIVE A: NO ACTION 5
ALTERNATIVE B: SPLIT-DOSE LIMING (NPS PROPOSED ACTION AND PREFERRED ALTERNATIVE) 5
ALTERNATIVE C: UNIFORM-DOSE LIMING 11
MITIGATION MEASURES INCLUDED IN THE ACTION ALTERNATIVES (ALTERNATIVES B AND C) 11
Water Quality 11
Vegetation 11
Terrestrial Wildlife 12
Wilderness Character 12
Acoustic Environment 12
Visitor Use and Experience 13
Historic Resources and Archeological Sites 13
Air Quality 13
Public Health and Safety 14
CHAPTER 3: AFFECTED ENVIRONMENT **15**
INTRODUCTION 15
SOIL CHEMISTRY 15
Bedrock Geology 15
Soil Descriptions 15
Physical and Chemical Characteristics of Soils 17
Trends 19
WATER QUALITY 19
Groundwater 19
Surface Water 19
Trends 21
AQUATIC WILDLIFE (FISH AND MACROINVERTEBRATES) 21
Fish 21
Aquatic Macroinvertebrates 22
Trends 22
VEGETATION 22
Dominant and Codominant Native Vegetation 23
Rare Native Vegetation 26
Non-native Invasive Vegetation 26

Trends and Planned Actions 28
TERRESTRIAL WILDLIFE (BIRDS, SALAMANDERS, AND SNAILS) 28
Birds 28
Salamanders 29
Snails 30
Trends 30
WILDERNESS CHARACTER 31
Trends and Planned Actions 33
ACOUSTIC ENVIRONMENT 34
Sound Levels in the Park 34
Sound Levels Outside the Park 35
Trends 35
VISITOR USE AND EXPERIENCE 35
Skyline Drive 35
Hiking 36
Fishing 37
Trends 37
CHAPTER 4: ENVIRONMENTAL CONSEQUENCES 38
INTRODUCTION 38
SOIL CHEMISTRY 38
Methods and Assumptions 38
Alternative A: No Action 39
Alternative B: Split-dose Liming 40
Alternative C: Uniform-dose Liming 41
WATER QUALITY 41
Methods and Assumptions 41
Alternative A: No Action 42
Alternative B: Split-dose Liming 42
Alternative C: Uniform-dose Liming 44
AQUATIC WILDLIFE (FISH AND MACROINVERTEBRATES) 44
Methods and Assumptions 44
Alternative A: No Action 45
Alternative B: Split-dose Liming 45
Alternative C: Uniform-dose Liming 46
VEGETATION 46
Methods and Assumptions 46
Alternative A: No Action 46
Alternative B: Split-dose Liming 47
Alternative C: Uniform-dose Liming 50
TERRESTRIAL WILDLIFE (BIRDS, SALAMANDERS, AND SNAILS) 50
Methods and Assumptions 50
Alternative A: No Action 50

Alternative B: Split-dose Liming 50
Alternative C: Uniform-dose Liming 52
WILDERNESS CHARACTER 52
Methods and Assumptions 52
Alternative A: No Action 52
Alternative B: Split-dose Liming 53
Alternative C: Uniform-dose Liming 53
ACOUSTIC ENVIRONMENT 54
Methods and Assumptions 54
Alternative A: No Action 56
Alternative B: Split-dose Liming 56
Alternative C: Uniform-dose Liming 59
VISITOR USE AND EXPERIENCE 60
Methods and Assumptions 60
Alternative A: No Action 60
Alternative B: Split-dose Liming 60
Alternative C: Uniform-dose Liming 61
CHAPTER 5: CONSULTATION AND COORDINATION 63
PLANNING 63
CIVIC ENGAGEMENT 63
AGENCY CONSULTATION 63
Section 7 of the Endangered Species Act 65
Section 106 of the National Historic Preservation Act 65
ACRONYMS AND ABBREVIATIONS 66
DEFINITION OF FREQUENTLY USED TERMS 68
REFERENCES 70

LIST OF FIGURES

Figure 1. Meadow Run, a Wild Trout Stream Degraded by Low pH Waters (June 2019) 1
Figure 2. Project Area for Restoration, View from Skyline Drive 3
Figure 3. Meadow Run Project Area 4
Figure 4. Liming by Helicopter in Monongahela National Forest, 2018. Left Loading of Bucket in Staging Area. Right: Spreading of Limestone Sand 6
Figure 5. Potential Staging Areas 8
Figure 6. Limestone Sand on the Forest Floor Immediately after Liming. *Left:* On Hard Surface or Compacted Leaf Litter (Dose of 3-5 t/acre); *Right:* On Loose Leaf Litter Surface (Dose of 2 t/acre) 10
Figure 7. Geological Formations and Structures in the Project Area and Vicinity 16
Figure 8. pH and ANC in Meadow Run, Measured Quarterly During Baseflow Conditions (1987–2018) 20
Figure 9. Dominant and Codominant Vegetation Communities and Known Non-native Invasive Vegetation in the Project Area 25

Figure 10. Vegetation Communities Ranked as Globally Uncommon or at Moderate Risk for Extinction 27
Figure 11. Wilderness Within the Project Area 32
Figure 12. Average Monthly Traffic Counts from 2009 to 2018 at Rockfish Gap Entrance, the Entrance of Skyline Drive Closest to the Project Area 36

LIST OF TABLES

Table 1. Soil Properties of Soil Acidification Metrics for the Project Area from 46 Sites in 2019 (upper 20 cm) and 6 Sites in 2000 (20–80 cm depth) 18
Table 2. Dominant and Codominant Plant Species and Associated Forest Communities for these Plant Species 24
Table 3. Soil pH Ranges for Plant Species Within or Near the Project Area 47
Table 4. Reduction in Listening Area and Alerting Distance Due to Increases in Ambient Sound Levels 55
Table 5. Sound Levels with Distance from Helicopter and Everyday Sounds and Noises 58
Table 6. Science Team Members 64

APPENDICES

Appendix A—Issues, Impact Topics, and Alternatives Dismissed from Detailed Analysis
Appendix B—Technical Information for Liming Meadow Run Watershed
Appendix C—Vertebrate Species of Greatest Conservation Need Potentially Present in the Project Area

CHAPTER 1: PURPOSE OF AND NEED FOR ACTION

INTRODUCTION

Shenandoah National Park (park) encompasses part of the Blue Ridge Mountains in the Commonwealth of Virginia and is bordered by the Shenandoah River valley to the west and the Virginia Piedmont to the east. Almost 40% of the park has been congressionally designated as wilderness, which is managed to preserve its wilderness character. Located just 75 miles from Washington, DC, the park is a popular destination for visitors to enjoy waterfalls, quiet hiking trails, scenic vistas, plants, and wildlife. Each year the park welcomes approximately 1.4 million visitors. Skyline Drive, a scenic roadway, runs through the full length of the park near its highest elevations. As a unit of the national park system, the park's mission is to "...conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (NPS 2020a).

Over many decades, scientists and managers have learned that high levels of acidic atmospheric pollutants emitted by fossil-fuel-burning industrial facilities, power plants, and other sources in the surrounding region have been deposited in the park—this process is referred to as acidic deposition. As a result, some of the park's watersheds have highly acidified soils and streams. In these watersheds, acidic deposition has depleted important elements in the soil, such as calcium and magnesium. These elements help the soil resist acidification and are referred to as base cations.[1] Buffering capacity, a term describing the soil's ability to resist changes in pH (the measurement of acidity in soil and water) due to the addition of an acid, depends on the level of base cations available in the soil. The capacity to buffer against acidification is also known as acid neutralizing capacity (ANC), especially when referring to water. Base cations naturally accumulate in soils through breaking down (weathering) of bedrock (and remain there if not depleted by processes such as acidic deposition). Base cations are nutrients essential for the growth of trees and understory plants.

The effects of acidic deposition vary across the park. The underlying bedrock, or parent geology, of each watershed and the soils that form on top of it contribute to this variation. Most of the park's soils retain the capacity to buffer acidic deposition, which prevents acidic deposition from causing significant impacts on natural resources. However, roughly a quarter of the park's area, including the Meadow Run watershed, is situated on bedrock with low base cation content, and the soils that form in these areas have a low buffering capacity. Therefore, these soils are less resilient to sustained acidic deposition, and the associated watersheds have become acidified.

Meadow Run is a stream located on the west side of the park's South District that is underlain by silica-rich bedrock (figure 1). This type of bedrock is particularly poor in base cations, and the soils that form on it have limited capacity to neutralize acidic deposition as the bedrock naturally weathers.

FIGURE 1. MEADOW RUN, A WILD TROUT STREAM DEGRADED BY LOW PH WATERS (JUNE 2019)

[1] A cation is a positively charged ion (atom or molecule). Base cations are defined as the most prevalent, exchangeable and weak acid cations in the soil, such as calcium or magnesium.

Resulting acidic groundwater flows through those soils and feeds the tributaries of Meadow Run, affecting water quality. Consequently, some fish species (including brook trout), many insect species, and other aquatic organisms struggle to survive in Meadow Run. Acidification also adversely affects songbird, plant, and forest health. Degraded ecosystem health in turn diminishes the visitor experience. Because its low pH is affecting aquatic life, the Virginia Department of Environmental Quality (VADEQ) formally lists Meadow Run as impaired waters under Section 303d of the Clean Water Act (CWA) (VADEQ 2020).

In August 2016, the US District Court for the District of Maryland responded to complaints against Westvaco Corporation over air quality permitting violations at the company's Luke Mill, which resulted in an alleged 200,000 tons of highly acidic "excess" sulfur dioxide emissions (Consent Decree No. MJG 00-CV-2602, US v. Westvaco Corporation). The court approved a settlement agreement where Westvaco Corporation agreed to fund mitigation/restoration projects in the park and nearby US Forest Service (USFS) areas potentially affected by emissions from the Luke Mill. The consent decree and settlement stated that "…Westvaco shall pay $800,000 to the National Park Service to be used in accordance with 54 [United States Code] U.S.C. § 100724 for the restoration of land, watersheds, vegetation, and forests in Shenandoah National Park using techniques designed to improve ecosystem health and mitigate harmful effects from air pollution."

The National Park Service (NPS) proposes to mitigate acidic deposition by dropping limestone sand on the terrestrial watershed (referred to as limestone sand application or liming hereafter) using a helicopter. Watershed liming is a type of project identified in the Consent Decree (2016) as an appropriate use of funds. This environmental assessment (EA) evaluates a no-action alternative (alternative A), a proposed action (alternative B; preferred alternative), and another action alternative (alternative C) that would implement watershed liming in a different manner than the preferred alternative (see chapter 2).

PURPOSE OF AND NEED FOR ACTION

The purpose of the proposed action is to improve the long-term health of the terrestrial and aquatic ecosystems and mitigate the harmful effects from decades of atmospheric acidic deposition in the Meadow Run watershed. Of all the areas with silica-rich bedrock in the park, Meadow Run is one of the most impacted watersheds. This is based on more than 30 years of scientific monitoring of water quality and aquatic life in the stream. Additionally, the size of the Meadow Run watershed makes the action practical given the amount of funding available for restoration projects. The long history of scientific data and the ideal size of the Meadow Run watershed make it the most suitable area for restoration.

Action is needed because acidic deposition has led to reduced ANC and pH in Meadow Run, which has degraded soil and water quality and negatively affected the habitat for fish and aquatic organisms. Recent reductions in regional air pollutant emissions have not led to natural ecosystem recovery in Meadow Run because the system has already lost a significant amount of its natural buffering capacity. The watershed is located on bedrock with comparatively low concentrations of base cations, so base cations lost from the soil from acidic deposition are not replenished naturally. Without restoration, the watershed's aquatic and terrestrial ecosystem would continue to be degraded, and the watershed would remain degraded for well over 100 years.[2]

[2] For a detailed analysis, see "Appendix B: Technical Information for Liming Meadow Run Watershed."

PROJECT AREA FOR RESTORATION

The Meadow Run watershed is located approximately 10 miles northeast of Waynesboro, Virginia. Meadow Run is a tributary to the South River, which flows into the South Fork of the Shenandoah River. The headwaters and most of the upper watershed of Meadow Run are within the park. The lower watershed is west of the park in the town of Crimora in Augusta County.

FIGURE 2. PROJECT AREA FOR RESTORATION, VIEW FROM SKYLINE DRIVE

The 2,150-acre area for the proposed liming project lies entirely within the park boundary, is completely forested, and extends from a steep ridge to the west of Meadow Run, to the Riprap Trail to the north, Skyline Drive to the east, and Wildcat Ridge Trail to the south (figures 2 and 3). The project area allows for a minimum 100-yard buffer between the park boundary and private lands adjacent to it.

ISSUES AND IMPACT TOPICS ANALYZED IN THIS ENVIRONMENTAL ASSESSMENT

This EA analyzes issues and impact topics for the project area, as well as for the staging areas used for the implementation of the project and the flight path between the staging areas and the project area (see “Chapter 2: Alternatives” for details). Issues and impacts topics are related to the following resources and values: soil chemistry, water quality, aquatic wildlife (fish and macroinvertebrates), vegetation, terrestrial wildlife (birds, salamanders, and snails), wilderness character, acoustic environment, and visitor use and experience. Several other issues and impact topics were considered but dismissed for reasons specified in “Appendix A: Issues, Impact Topics, and Alternatives Dismissed from Detailed Analysis.”

Issues analyzed in the EA were identified with support from a science team established for this project. The team consisted of experts familiar with Meadow Run’s acid-impacted systems and watershed liming; these experts are affiliated with federal agencies, state agencies, and universities (see “Chapter 5: Consultation and Coordination” for science team members and their roles).

If an action alternative were selected, an implementation plan would be developed that would contain the logistical details, communication plan, safety measures, and all other aspects relevant for the implementation of the project. In addition, this implementation plan would be evaluated against the National Environmental Policy Act (NEPA) analysis, contained in this EA, to ensure that all potential impacts were considered.

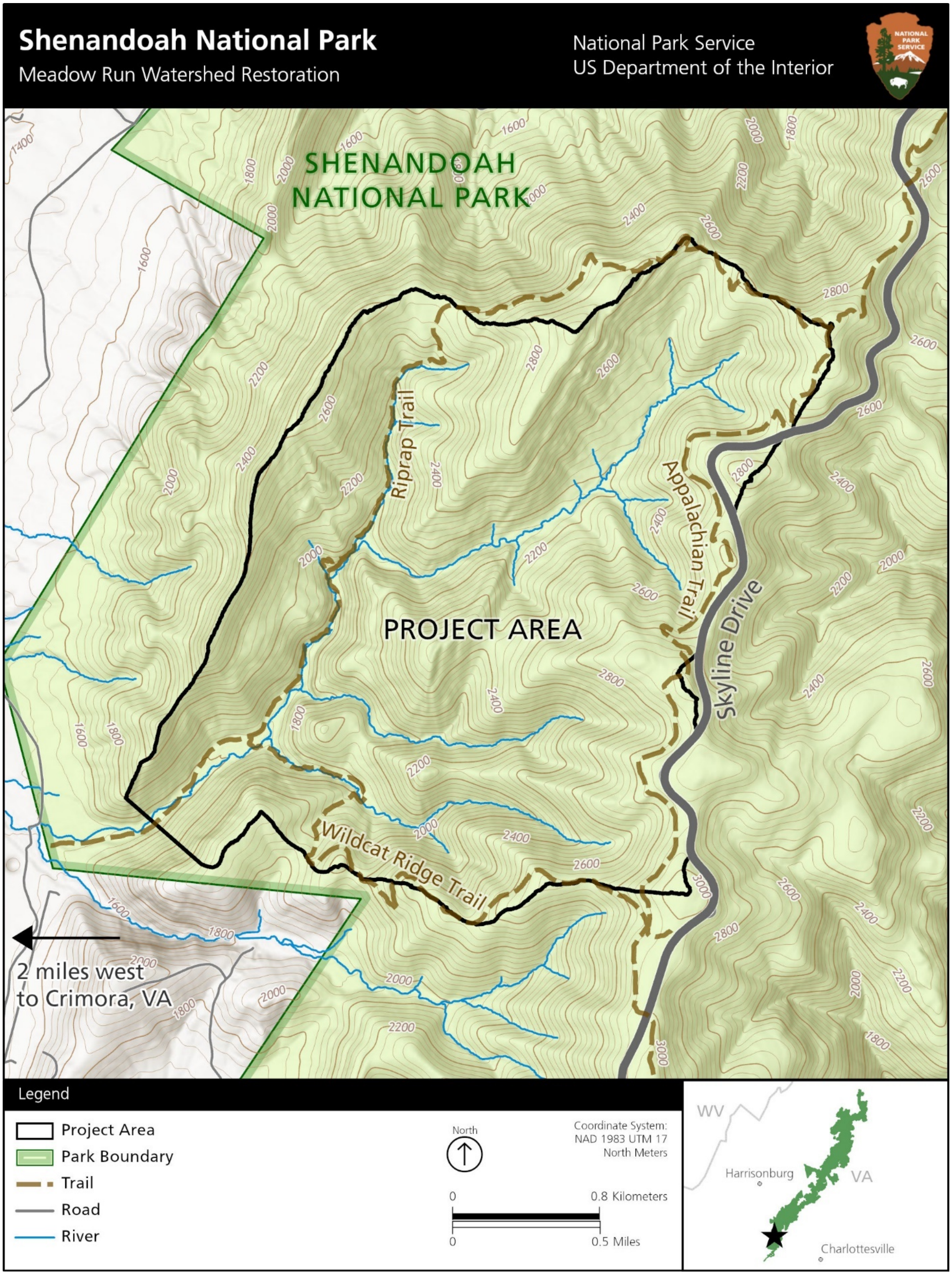


FIGURE 3. MEADOW RUN PROJECT AREA

CHAPTER 2: ALTERNATIVES

INTRODUCTION

This chapter describes alternatives for the restoration of the Meadow Run watershed, consistent with the purpose of and need for action. Three alternatives are analyzed in detail: the no-action alternative (alternative A) and two action alternatives. Alternative B is the NPS proposed action and preferred alternative. This chapter also lists mitigation measures that would apply to both action alternatives. Several other alternatives were identified during internal and public scoping but do not meet the purpose and need, are not feasible, or would result in too great of an environmental impact; therefore, those alternatives were dismissed from detailed analysis in the EA (see appendix A).

ALTERNATIVE A: NO ACTION

Under the no-action alternative, liming of the Meadow Run watershed would not occur. Natural processes would continue to be influenced by acidic deposition, and the high acidity of the soil and water would remain.

ALTERNATIVE B: SPLIT-DOSE LIMING (NPS PROPOSED ACTION AND PREFERRED ALTERNATIVE)

Under alternative B, the park would use a split-dose liming approach to replace base cations lost from soils and ANC lost from the stream as a result of historical acidification. Soils most depleted in base cations would receive a higher dose of limestone sand than soils that are less depleted in base cations. Generally, soils in the eastern half of the Meadow Run project area, closest to Skyline Drive, are most depleted in base cations and would receive the higher dose of limestone sand. Under alternative B, approximately 5,250 tons of dolomitic limestone sand would be applied via helicopter in the project area. A helicopter would provide an efficient and effective way to access the steep terrain and to avoid ground disturbances in a wilderness area, which spans 80% of the project area. The dolomitic limestone sand would be obtained from local quarries.

Limestone Sand Doses. Alternative B would apply two different doses of limestone sand in the project area: a higher dose (3.0 short tons per acre [t/acre]) over soils with a greater deficit of base cations (i.e., soils that are generally more developed and thicker), and a lower dose (2.25 t/acre) over soils with a lower deficit of base cations. Details on how these doses were determined are available in appendix B. Approximately 5,250 tons of limestone sand are expected to be applied across the two subareas based on soil depletion (assuming a 50/50 split). The subareas would be delineated prior to project implementation and would be based on soil analyses, which could change this split and therefore slightly increase or decrease the total weight of limestone sand (perhaps by up to 10%).

Liming Area and Exclusion Zones. Approximately 2,000 acres within the 2,150-acre project area (figure 3) would be limed; the remaining 150 acres of the project area would be excluded from liming to protect rare, threatened, and endangered plants; limit the spread of non-native invasive plant communities; and avoid an area where a predatory beetle (*Laricobius nigrinus*) was released for biological control of hemlock woolly adelgid (*Adelges tsugae*). Buffer areas would be identified around these locations and would be part of the respective exclusion zones. The final size and boundary of the exclusion zones would be specified in the implementation plan to ensure maximum resource protection, following appropriate surveys in the field. In addition, the project area allows for a minimum 100-yard buffer between the park boundary and private lands adjacent to it. Most of the project area is set back one-half mile or more from the park boundary and private lands. Precise positioning capability by the helicopter would avoid identified exclusion and buffer zones from being limed.

Helicopter Service Landing Areas. Suitable helicopter service landing areas would be located outside wilderness areas, and no helicopter landings would occur in wilderness areas. A helicopter would arrive during mobilization. At service landing areas, it would be able to land for downtime periods, refueling operations (from a fuel truck), preventative maintenance activities, and overnight parking. Service landing areas would be located as close to the project area as possible to limit travel times and may include a staging area (see next section), assuming sufficient space was available and permissions from landowners were obtained. A nearby airport could also be used as a service landing area. Helicopter use would follow all Federal Aviation Administration (FAA) regulations and stay within the FAA-managed airspace.

Staging Areas. Implementation of the project requires staging areas for transporting the limestone sand to the project area by the helicopter. While the entire project could be staged from one area, the park would consider multiple staging areas that ideally would be distributed/located closest to the portion of the project area with ongoing application at a given time. This approach—multiple staging areas and close proximity to an actively limed area—would limit the duration of noise near any active staging area, allow for flexibility to accommodate winter weather conditions, and maximize the efficiency of project implementation, thereby keeping the implementation period as short as practicable.

An active staging area (i.e., the staging area where liming operations are underway) requires as a minimum space to accommodate the following (figure 4):

- A large enough stockpile of limestone sand to ensure uninterrupted daily operations by the helicopter.
- Space for filling the liming bucket with a front-loader and/or bobcat. Two buckets would typically be used—one would be refilled with loading equipment, while the other would be used by the helicopter. The helicopter would return the empty bucket and leave with a full bucket.
- Sufficient clearance without overhanging branches or other obstructions to ensure safe lifting of a filled bucket into the air by the helicopter and lowering the emptied bucket back down after a liming run.

Source: USFS staff at Monongahela National Forest

FIGURE 4. LIMING BY HELICOPTER IN MONONGAHELA NATIONAL FOREST, 2018. LEFT LOADING OF BUCKET IN STAGING AREA. RIGHT: SPREADING OF LIMESTONE SAND

The required estimated size of an active staging area is at least approximately 300 square feet, although a larger area is preferred. Active staging areas may require some preparation, including trimming overhanging tree branches, clearing small trees and bushes, and placing wooden construction matting for ground protection (for additional measures, see the “Mitigation Measures” section later in this chapter).

In addition, space would be needed for the following:

- Parking for staff working at an active staging area.
- A small operations trailer for staff for storing equipment and for shelter in case of inclement weather conditions.

If space at an active staging area were inadequate, this need for additional space could be accommodated off a road (e.g., Skyline Drive) or at a nearby staging area (e.g., parking area or overlook).

Finally, the park may decide to build one or several larger stockpiles of limestone sand in advance of liming either at planned active staging areas (if enough space exists) or at one or several other nearby staging areas to ensure uninterrupted limestone sand supply once liming starts.

Staging areas may be paved or unpaved, but truck access for unloading limestone would be required. The limestone sand would be transported to staging areas by quarry trucks with gross vehicle weights dictated by road and site conditions. Weight restrictions on Skyline Drive would result in substantially more truck traffic than on public highways to deliver the same amount of material. As necessary, all staging areas may be fenced, and stockpiles would be protected from precipitation, erosion, and seeds of non-native invasive plant species using plywood, tarps, and other runoff control measures.

The staging areas would be located at overlooks and parking areas along Skyline Drive and/or, with landowner support, at specific (yet to be determined) locations within a zone just outside the park’s western boundary (figure 5). This zone is approximately 9 miles long and generally up to 0.5-mile wide, but the width may extend to 1 mile if necessary. The park would gain permission and coordinate with the landowners and affected neighbors for any staging area(s) outside the park. In addition, the helicopter carrying limestone sand would only fly over undeveloped lands where the park has made arrangements for that activity with the respective landowners. The exact location of the staging areas would be determined well in advance of project implementation, which would include site condition surveys and any appropriate landowner agreements.

Liming Approach. The bucket used for liming would be capable of carrying several tons of limestone sand and would be fitted with a spreading mechanism. The helicopter would lift this bucket, transport it to an area to be limed, drop to a lower flying height, and activate the spreading mechanism (figure 4). Flights would follow precise transects following land contours to systematically apply the limestone sand over the project area at the prescribed liming doses. For transport using a staging area outside the park, appropriate measures would be incorporated through bucket design and/or flight operation to minimize the loss of limestone sand grains over non-park land (after permission for use of land and overflights was received by the landowner[s]).

The helicopter would release the limestone sand approximately 50 to 100 feet above the tree tops. Because of its relatively coarse grain size, the limestone sand would fall quickly to the ground. Rapid settling was observed, for example, during the USFS Lower Williams Terrestrial Liming Project (USFS 2018; Science Team, pers. comm. 2019a).

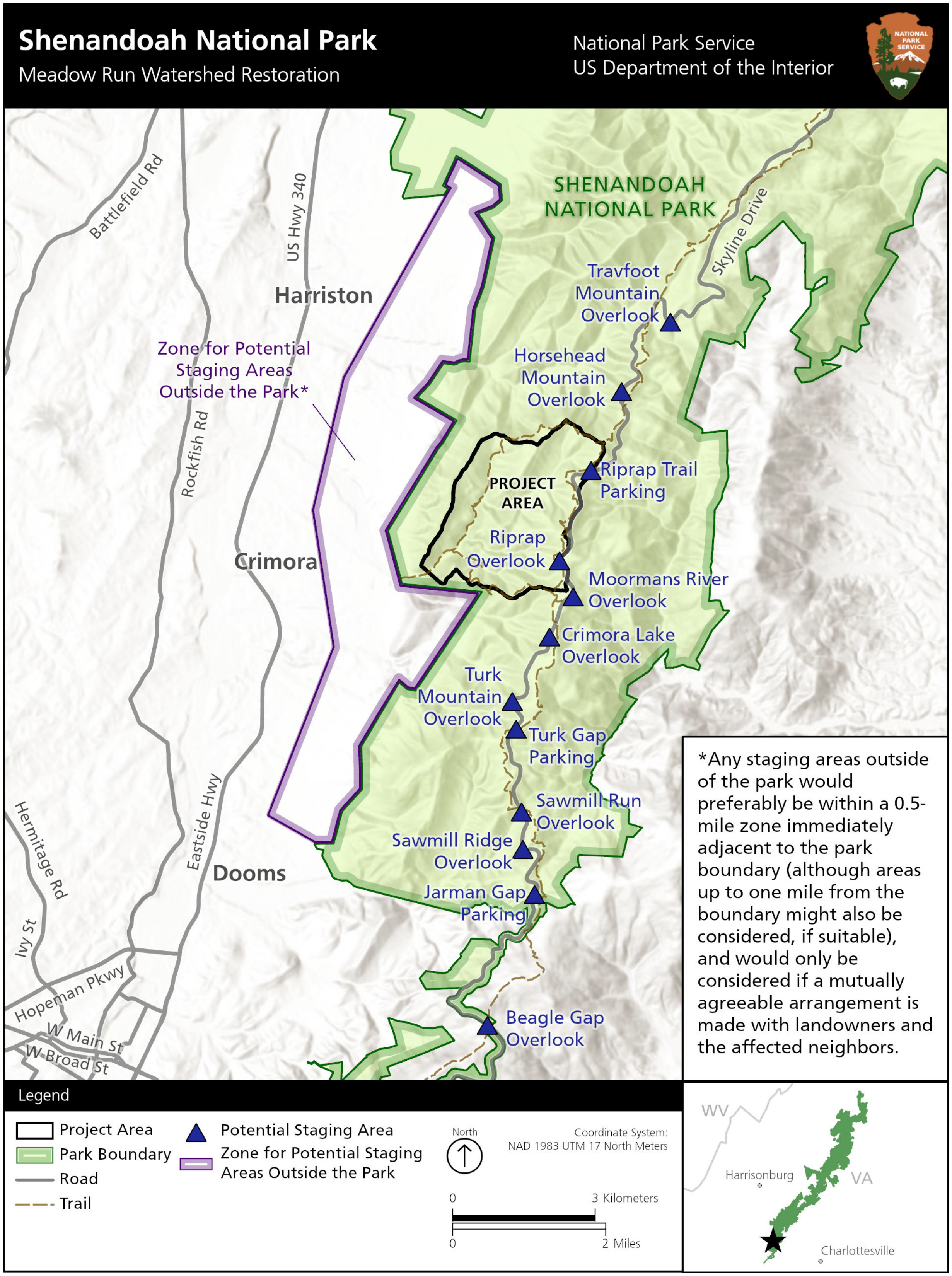


FIGURE 5. POTENTIAL STAGING AREAS

Liming Season and Closures in the Park. Limestone sand application would occur during the winter, a low visitor-use period and leaf-off/dormant season (December–February). Using multiple staging areas close to the project area may allow for completion of liming in two months because of its proximity to the project area. Using staging areas farther away may require up to three months. Liming would be conducted only during daylight hours on weekdays (approximately 8 hours per day), and potentially on Saturdays and Sundays if necessary, because of logistical or weather-related reasons (Sundays would be considered for helicopter liming operations [with loaded bucket] exclusively within park boundaries). No operations would occur on holidays.

Liming would require safety closures of sections of Skyline Drive and the affected backcountry and wilderness areas, and nearby trails in the South District of the park. Examples of closures for safety reasons include the following:

- **Riprap and Wildcat Ridge Trails and Lands in the Immediate Area:** The two trails and lands in the immediate area would likely be closed for the entire duration of liming because the helicopter would cross this area frequently.
- **Appalachian Trail:** The affected section of the Appalachian Trail would be closed for as long as needed to accommodate liming of the eastern part of the project area and to avoid safety concerns from the use of staging areas along Skyline Drive. Hikers on the Appalachian Trail would be rerouted or potentially shuttled to a safe bypass. The Trail could be opened if/when staging areas outside are used, and once the eastern part of the project area has been limed. Therefore, the Appalachian Trail may be closed only for a portion of the implementation period.
- **Skyline Drive:** The affected section of Skyline Drive would also require closures during liming of the eastern portion of the project area and for active use of staging areas along the road. The duration of closures would depend on the selected staging areas for the entire project, and the final logistical approach developed in the implementation plan. For example, Skyline Drive may only be closed for weeks or around a month (if Skyline Drive is not used entirely for staging), could be open during days of non-operation (e.g., on holidays or days of stronger winds or other weather concerns), and perhaps could be open at night (6:00 p.m. to 6:00 a.m.).

The goal would be to limit closures to the minimum number of days feasible to complete the project while providing for visitor safety. Required closures and bypass recommendations would be specified in the implementation plan during project design.

Truck deliveries to stockpile limestone sand at staging areas could start in November but would not result in closures of Skyline Drive or any of the trails. Deliveries may include the closure of a parking area or overlook along Skyline Drive while the stockpile(s) is being built prior to project implementation.

The park expects that a single limestone sand application would achieve the desired long-term restoration goal of improving the ecosystem of this watershed; criteria and targets to achieve this goal are discussed in chapter 4. If soil sampling and stream monitoring after the first application demonstrate that long-term restoration goals were not adequately achieved or that an additional limestone sand application would improve the conditions in the watershed further, a future application could be considered. No more than two applications would be implemented as part of this proposal. A second application, if needed, would be conducted in a similar manner as the first application and would include public notices.

The duration of each limestone sand application period (up to two, as described above) would depend on the location of the staging areas, helicopter service area(s), weather conditions, the total weight of limestone sand to be applied, and other factors, and could last two to three months. Flight time by the helicopter for project implementation could range from 200 to 400 flight hours for 5,250 tons of limestone sand, depending on the locations of the staging areas used. In case of a second liming event, flight times could result in an additional 200 to 400 hours for the second application.

Limestone Sand Mixing with Soil. The limestone sand would be visible on the forest floor for a few months until natural processes (such as biological activity, rain, and wind) mix the sand into the leaf litter (figure 6). By early summer, the sand should no longer be readily visible (Science Team, pers. comm. 2019a, and follow-up communications).

Sources: Left: USFS staff at Monongahela National Forest. Right: Dr. William E. Sharpe, Pennsylvania State University

FIGURE 6. LIMESTONE SAND ON THE FOREST FLOOR IMMEDIATELY AFTER LIMING.
LEFT: **ON HARD SURFACE OR COMPACTED LEAF LITTER (DOSE OF 3-5 T/ACRE);**
RIGHT: **ON LOOSE LEAF LITTER SURFACE (DOSE OF 2 T/ACRE)**

Post-liming Monitoring. The park intends to collaborate with scientists from NPS and other agencies/institutions to monitor the environmental response of the liming. Effectiveness monitoring would be conducted in the project area and potentially in an unlimed control area in a watershed immediately to the north or south of the project area with similar geological and ecological conditions. A monitoring plan, to be developed prior to liming, would be designed to gather new and existing data on conditions before liming occurred and to provide information on the project's effectiveness. Measurable response indicators might include soil base cation saturation, stream water ANC, return of acid-sensitive aquatic organisms, and vegetation monitoring. If funding and support were available, monitoring would include collecting samples for laboratory analysis for soil, stream water quality, and aquatic organisms in the Meadow Run watershed at regular intervals (e.g., quarterly or annually). Any monitoring would use low-impact methods, such as using soil recovery probes (1-inch diameter) or collecting fish in ways that allow for their safe release back to the stream. These monitoring approaches have been in use for years in Meadow Run and other locations by park staff and partners and provided the baseline data to compare pre- and post-liming conditions.

ALTERNATIVE C: UNIFORM-DOSE LIMING

Under alternative C, the park would apply limestone sand via helicopter using a uniform-dose liming approach of 2.75 t/acre. Unlike alternative B, alternative C would not distinguish between more depleted and less depleted soils and would instead distribute the limestone sand evenly across the project area (except over exclusion zones). This dose would result in 5,500 tons of limestone sand applied over 2,000 acres. The total flight time for 5,500 tons under alternative C would be slightly longer (approximately 5%) than the flight time under alternative B (i.e., 210 to 420 hours). All other aspects of alternative C, including size of the project area, size of the exclusion zones, operational logistics, potential staging areas, monitoring plan, and a potential second limestone sand application would be the same as described for alternative B.

MITIGATION MEASURES INCLUDED IN THE ACTION ALTERNATIVES (ALTERNATIVES B AND C)

To protect natural and historic resources, the quality of the visitor experience in the park, and the surrounding community outside the park, this section lists mitigation measures and best management practices that would be included in both alternatives B and C. These actions would be developed in further detail in the implementation plan.

Water Quality

- Comply with and meet all relevant requirements under the CWA, including management of stormwater-related non-point source pollutants under the National Pollutant Discharge Elimination System. Implement best management practices for drainage and sediment erosion control (e.g., VADCR 2020) at staging areas to prevent or reduce non-point source runoff and minimize soil loss from the limestone sand stockpile and any unpaved surfaces. Inspect and clean out erosion control structures periodically and remove them only after unpaved staging areas are restored fully.

- Avoid locating staging areas near wetlands and waterways.

- Develop a refueling and maintenance plan for the helicopter and all construction vehicles to prevent potential contamination of surface waters and groundwater caused by accidental spills.

Vegetation

- Evaluate sensitive areas prior to project design to include new information on rare, threatened, and endangered plants, as well as non-native invasive plant species, as input for the delineation of zones to be excluded from liming (i.e., exclusion zones).

- In addition to excluding locations with documented non-native invasive plant infestations from receiving limestone sand, treat such locations with appropriate herbicide, mechanical, or manual removal methods prior to project implementation, where practical. Take special care to treat infestations in and around selected staging areas.

- Prevent or minimize establishment and spread of non-native invasive plants, noxious weeds, and spread of diseases through the following measures:

  - coordinate with the quarry supplying the limestone sand to cover the sand with a tarp immediately after the sand is generated by crushing limestone source rock;
  - cover each load of limestone sand on trucks with a tarp during transport;
  - cover the stockpile in staging areas when not actively being used;
  - stage equipment and materials on durable paved surfaces where possible;
  - evaluate existing topsoil in and around any unpaved staging area for non-native invasive plant infestations, and place rubber matting or plywood over the soil prior to stockpiling limestone sand to avoid seeds being mixed in with the sand; and
  - minimize disturbance to soils to reduce disturbance to native plants and reduce the potential for introduction or spread of non-native invasive plants.
- Clean all vehicles, heavy equipment, and tools used in staging areas of weeds, seed, debris, and mud prior to entry into the park to prevent the introduction or spread of non-native invasive plants. Allow for NPS inspection for proper level of cleanliness prior to entry into the park or into an active staging area if equipment is being moved from an area where non-native invasive plants are known to occur. Restore any unpaved parts of staging areas disturbed during project implementation to pre-implementation conditions. Ensure that plant species and all materials (e.g., rolled erosion control products) used for revegetation are approved by NPS.

Terrestrial Wildlife

- Properly store and dispose of food, garbage, and potential contaminants at an active staging area until they can be transported off-site to avoid attracting wildlife and causing human-wildlife conflicts.

- Have NPS provide information to contractors and other project staff during the pre-application meeting about any special-status species or other sensitive wildlife in the project area to minimize disturbance to wildlife.

- Use biodegradable matting with a large-diameter natural fiber to prevent entrapment of wildlife if using erosion netting.

Wilderness Character

- Limit management actions (e.g., resource management, resource monitoring, and research) in wilderness areas to the minimum necessary to achieve the objective. For each individual action associated with this project, carefully consider impacts on wilderness character and use Minimum Requirements Analyses, as appropriate, to minimize impacts.

- Direct visitors to other trails in park wilderness where they can still experience this opportunity.

Acoustic Environment

- When carrying loads (i.e., filled or empty bucket attached via cable underneath the helicopter) during flights between a staging area outside the park and the project area, prohibit flying directly over residences and other buildings occupied by people or livestock.

- Carefully select flight paths, hours of operation, and other appropriate best management practices such as limits to idling of engines to minimize noise impacts on wildlife, livestock, neighbors, and the local community, as much as possible and practicable.

- Notify affected neighbors and the local community near the project area and any staging area outside the park, at least a month in advance of the schedule of operations if possible, to allow for factoring helicopter operations into their daily activities. Distribute notifications by newsletter, website, social media posts, emails, or other means to affected neighbors near the project area, specifically near staging areas outside the park staging areas.

Visitor Use and Experience

- Develop and implement a communications plan to inform the public about project-related management activities and any associated closures of Skyline Drive and affected trails. Prepare news and social media releases, signage, websites, and other forms of communication well in advance of project implementation.

Historic Resources and Archeological Sites

Historic resources are dismissed as an impact topic (see appendix A) because impacts can be minimized or avoided by implementing the following mitigation measures:

- Use wooden construction matting on overlook pavements, the vegetative buffer between Skyline Drive, or any overlook (if used) and portion of Skyline Drive used to stockpile limestone sand or maneuver heavy equipment (e.g., wheeled loaders), to prevent pavement surface and structural damage.

- Protect historic guard walls with appropriate barriers in areas of constantly moving vehicles (e.g., the bucket loading area).

- Protect drainage structures (drop inlets, weep holes in walls) at overlooks to prevent filling or clogging with stockpiled limestone sand.

- Maintain loaded truck weights below seasonal weight limits for Skyline Drive by conducting weight monitoring of all loaded trucks–using the scale at the quarry–before transporting the material to the park and requiring regular weight checks by park staff.

- Avoid locating heavy loads (such as large stockpiles) on sections of any overlook built on fill.

Air Quality

Air quality is dismissed as an impact topic (see appendix A) because the emissions contribution from liming activities would be extremely low relative to existing regional emissions. In addition, the following mitigation measures would be implemented to minimize localized impacts:

- Allow for a buffer between the limestone sand application and the park boundary to minimize noise and avoid potential drift of limestone material. Buffers are substantial near most of the boundary (greater than 0.3 miles on the west and well over a mile in the east) with the closest distance at a few points in the souths (100 yards). Ideally, apply limestone sand along the southern and southwestern edges of the project area only on days when wind speeds are low or the wind blows predominately from the south or west to avoid residual limestone sand particles from drifting outside the park boundary.

- If a staging area(s) outside the park is used, minimize the loss of the limestone sand particles from the bucket during transport over non-park land.

Public Health and Safety

Public health and safety is dismissed as an impact topic (see appendix A) because impacts would be minimized or avoided. Appropriate health and safety measures would be detailed in the implementation plan. The plan would include safety measures, e.g., closures for safety reasons and emergency management:

- Prohibit helicopter flights over buildings, vehicles, or other areas potentially occupied by people or livestock when the liming bucket is attached. Close areas during limestone sand application to the extent needed for public safety (see the section entitled “Liming Season and Closures in the Park” above) and provide an alternative route for Appalachian Trail users in that area (along with appropriate signage and directions), in coordination with the Appalachian Trail Conservancy and Appalachian Trail clubs. Close portions of Skyline Drive and work with local jurisdictions to implement closures near the project area and active staging areas as needed for public safety. Work with these jurisdictions if there is a need for alternate vehicle routes for the public as a result of closures. Develop and implement traffic control and safety plans for park and public use prior to project implementation and coordinate with law enforcement rangers, volunteer staff, and other agency staff, who could potentially be working in and around closed areas.

CHAPTER 3: AFFECTED ENVIRONMENT

INTRODUCTION

This chapter presents information about existing conditions of resources that are analyzed in this EA, along with trends observed over recent decades and likely for coming decades if no action is taken. Any planned actions in the project area are included in the section on trends for specific impact topics.

SOIL CHEMISTRY

As noted in chapter 1, Meadow Run is the most acidified stream in the park because of its soils and bedrock geology. Soils are the critical factor in a watershed's sensitivity to acidification, because they serve as the primary store and source for exchangeable base cations, such as calcium and magnesium, that buffer acidic deposition on land and provide acid-neutralizing capacity to streams. Likewise, soils are key to any mitigation effort to improve the long-term health of an acidified watershed's ecosystem.

Bedrock Geology

The primary natural source of base cations to soils is through chemical weathering of bedrock during soil formation. The chemistry of soils and streams and their vulnerability to acidification are thus determined by the underlying bedrock geology (Garrels and Mackenzie 1967; Rice et al. 2006). The park has three major groups of bedrock geology that determine soil and stream water chemistry and susceptibility to acidification: (1) basaltic bedrock formations are typically rich in weatherable base cations and are the least sensitive to acidification; (2) granitic rock units generally have lower base-cation content and are moderately sensitive to acidification; and (3) siliciclastic rock units have very low base cation content and are most sensitive to acidification (Rice et al. 2006; Southworth et al. 2009; Sullivan et al. 2007; Robison et al. 2013; Thornberry-Ehrlich 2014; Riscassi et al. 2019).

Meadow Run formed entirely on siliciclastic bedrock of two formations that help explain why it has become one of the most acidified watersheds in the park (figure 7):

- **Antietam Formation:** This formation underlies the western part of the project area. It consists of thin-bedded metasandstones and quartzites, interbedded with laminated metasiltstone and some iron-bearing layers (Southworth et al. 2009; Thornberry-Ehrlich 2014). This formation has some of the lowest base cation content of all siliciclastic bedrock formations in the region.

- **Harpers Formation:** This older formation underlies the eastern part of the project area. Most of the formation consists of interbedded layers of metasandstone, metasiltstone, and phyllite (Southworth et al. 2009; Thornberry-Ehrlich 2014). In addition to quartz, important mineral constituents include chlorite, micas, and feldspar, which contain modest amounts of base cations and other elements.

Soil Descriptions

The US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) has mapped the soils in the project area as belonging to four major soil series—Hazelton, Drall, Cataska, and Hartleton (USDA-NRCS 2020a). All four series are described as well-drained, stony, coarse-textured soils that typically form in steep forested terrain. Hazelton series soils are deep and sandy. Drall series soils are extremely stony and form on mountain ridges and the upper parts of side slopes. Cataska and Hartleton series are stony silt loams, with Hartleton series soils sometimes found under cultivation.

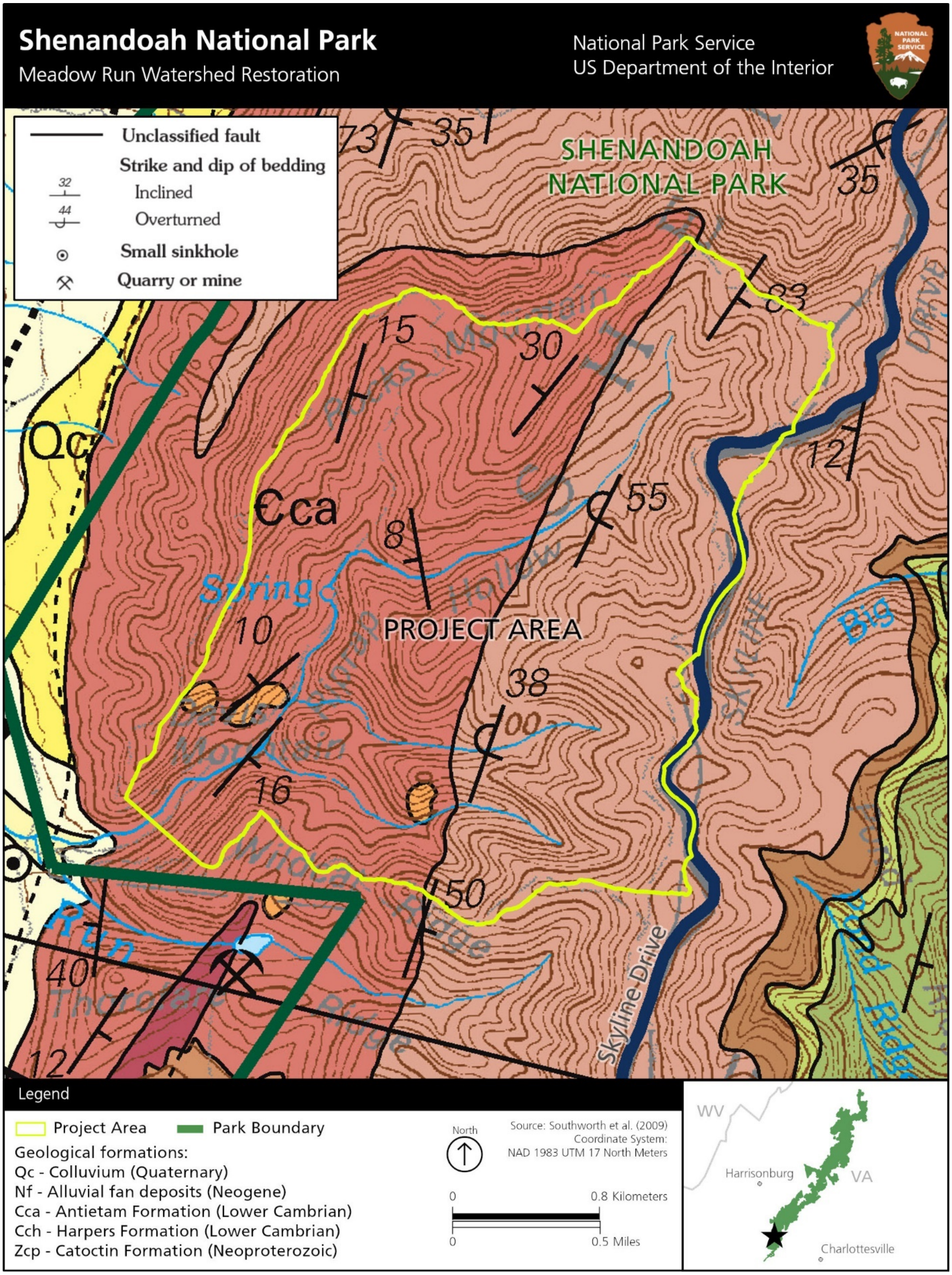


FIGURE 7. GEOLOGICAL FORMATIONS AND STRUCTURES IN THE PROJECT AREA AND VICINITY

Physical and Chemical Characteristics of Soils

The physical and chemical characteristics of the soils in the project area are based on three sets of data: a 2000 University of Virginia study (Welsch et al. 2001); the 2007 NPS long-term ecological monitoring study; and the 2019 NPS quantitative soil study for this project (Sharpe and Cummings 2019; Sharpe et al. 2019). Details of the sampling and analytical methods are provided in appendix B.

Soil chemistry data show that the Meadow Run project area is "extremely acidic" (pH 3.5 to 4.4; USDA-NRCS 2017; table 1). Base cations (calcium, magnesium, potassium, and sodium) are also highly depleted in soils of the Meadow Run watershed, indicating that soils have lost their capacity to buffer against acidification. The best measure of this base cation depletion and reduced buffering capacity is a quantity called base cation saturation.

Soils are a natural ion exchange media, similar to the reusable media in a water softener. Soil particles have a net negative charge, so they naturally attract and temporarily hold positively charged ions from the soil solution (much like opposite poles of a magnet are attracted to one another) to balance the electrostatic charges in the soil. Positively charged ions are called cations. For example, the hydrogen ion that creates acidity is a cation. Cations associated with strong bases that counteract the hydrogen ion are called base cations. The total capacity of soil to attract and hold cations from the soil solution is called the cation exchange capacity (CEC). A soil's CEC is always filled by a combination of the hydrogen ion (acidity), base cations, and a few other cations that are neither strongly acidic nor strongly basic (e.g., aluminum, iron, and other minor and trace metals). The percentage of soil CEC that is occupied by base cations is called base cation saturation, and it is always measured by the charge equivalent, which is the amount of cation multiplied by its ionic charge (i.e., some cations have a charge of +1 while other ions have a charge of +2, +3, or more). These percentages can change over time because high levels of one cation in the soil solution, such as the hydrogen ion from acid deposition, can replace other cations on a soil's cation exchange sites.

These processes describe both the mechanism of how base cations buffer acidity and also how, over time, acidic deposition degrades soil by "stripping" these base cations and flushing them from the system. This base cation depletion is most pronounced for soils overlaying base-poor bedrock that is less able to replenish the flushed base cations quickly enough to counter the losses. Three base cations (calcium, magnesium, and potassium) are also essential plant nutrients, whereas hydrogen and aluminum cations are known to be harmful to plants. Meadow Run soils have base cation saturation values (table 1) far below the 20% threshold at which the soil is functionally acidified, and the forest ecosystem is stressed due to aluminum toxicity and other factors (Sullivan et al. 2013).

Exchangeable aluminum cation concentrations are another indicator of acidification because at low pH and low base cation saturation, aluminum dissolves into the soil solution from insoluble mineral forms in the soil to become exchangeable, bioavailable, and toxic. Exchangeable aluminum concentrations in Meadow Run soils were measured at levels relative to base cations that are considered toxic to soil life and plants for about half of the studied soils (Tomlinson 1990; Sharpe et al. 2019; table 1). Aluminum toxicity changes with soil acidity and is known to increase sharply at soil pH values below 4.2 (Tomlinson 1990). The ratio of exchangeable calcium to exchangeable aluminum (Ca:Al) is a useful indicator of aluminum toxicity, where values below 1.0 are considered toxic.

The underlying geology of the watershed affects the soil chemistry in different portions of the project area differently. Mineral soils formed on the Antietam Formation have lower pH; CEC; and calcium, magnesium, potassium, and phosphorus levels than soils formed on the Harpers Formation (table 1). These differences are especially pronounced for the deep mineral soil horizon (20–80 centimeters [cm]) that is less influenced by biological recycling. A detailed description of the 2019 soil dataset is provided in appendix B; the complete dataset is available in Sharpe et al. (2019).

TABLE 1. SOIL PROPERTIES OF SOIL ACIDIFICATION METRICS FOR THE PROJECT AREA FROM 46 SITES IN 2019 (UPPER 20 CM) AND 6 SITES IN 2000 (20–80 CM DEPTH)

Soil Property	Organic Soil Horizon (Depth of 0–5 cm) [a]	Upper Mineral Soil Horizon (Depth of 5–20 cm) [a]			Deep Mineral Soil Horizon (Depth of 20–80 cm) [b]		
		All Soil Sampling Sites	Antietam Formation	Harpers Formation	All Soil Sampling Sites	Antietam Formation	Harpers Formation
pH	3.77 ±0.35	4.19 ±0.28	4.16 ±0.33	4.23 ±0.20	4.49 ±0.12	4.48 ±0.10	4.50 ±0.17
Base Cation Saturation (%) [c]	11.6% ±7.3%	4.9% ±1.9%	5.3% ±2.0%	4.4% ±1.5%	10.2% ±3.3%	10.0% ±2.5%	10.5% ±4.7%
Ca:Al (molar) [d]	11.3 ±16.6	1.2 ±1.9	1.5 ±2.4	0.9 ±1.1	n/a	n/a	n/a
CEC (meq/100g) [e]	16.6 ±1.2	12.8 ±3.3	10.8 ±3.1	15.0 ±1.6	5.5 ±3.0	3.2 ±0.4	8.4 ±1.7
Calcium (ppm) [c,f]	251 ±249	55.4 ±34.3	55.0 ±36.5	56.9 ±32.1	54.4 ±49.5	30.1 ±18.9	86.8 ±63.7
Magnesium (ppm) [c,f]	44.0 ±18.7	14.9 ±5.9	13.4 ±4.7	16.7 ±6.7	12.3 ±8.1	6.7 ±1.2	19.9 ±6.9
Potassium (ppm) [c,f]	104.1 ±22.7	49.7 ±24.3	35.9 ±16.1	65.5 ±22.4	65.6 ±46.3	34.2 ±3.7	106.9 ±43.2
Sodium (ppm) [c,f]	20.9 ±3.8	16.8 ±4.7	17.8 ±5.7	15.7 ±3.1	5.9 ±1.2	5.8 ±1.3	6.1 ±1.3
Phosphorus (ppm) [c,f]	11.2 ±8.1	7.2 ±7.6	6.1 ±4.7	8.3 ±9.9	n/a	n/a	n/a
Iron (ppm) [c,f]	142 ±62	209 ±79	180 ±74	243 ±72	n/a	n/a	n/a

Notes: [a] NPS sampling sites were selected based on randomized site selection within the catchment of each Meadow Run tributary to capture all soil series.

[b] University of Virginia soil data (Welsch et al. 2001)

[c] Cations and phosphorus were all measured after Mehlich (1943) extraction.

[d] Calcium to aluminum (Ca:Al) ratios were assessed after extraction with 0.01 molar strontium chloride used for Pennsylvania State University's Aluminum Stress Test (https://agsci.psu.edu/aasl/soil-testing/methods). Ca:Al ratios obtained using different extraction methods will yield different results.

[e] meq/100g = milliequivalents of base cations per 100 grams

[f] ppm = parts per million

Trends

Available soils data are insufficient to define past trends, but it is reasonable to assume that soils have become increasingly acidified over time from historical and continuing acidic deposition (i.e., pollutant loading) in Meadow Run (for details see appendix B). Current acidic deposition rates are a third of what they were four decades ago, but acidic deposition would still need to drop in half again to reach balance with the supply rate of base cations from bedrock weathering, which is required for soils to recover from historical acidification (appendix B; Sullivan et al. 2008, 2010, 2012). The effects of climate change, with potentially higher average temperatures, more precipitation, and more extreme storms (NPS 2020b) could lead to increased leaching and loss of soil base cations, which is likely to slow natural recovery from soil acidification.

WATER QUALITY

Acidified soils affect the quality of groundwater, which in turn affects the water quality in the stream after seeping into it.

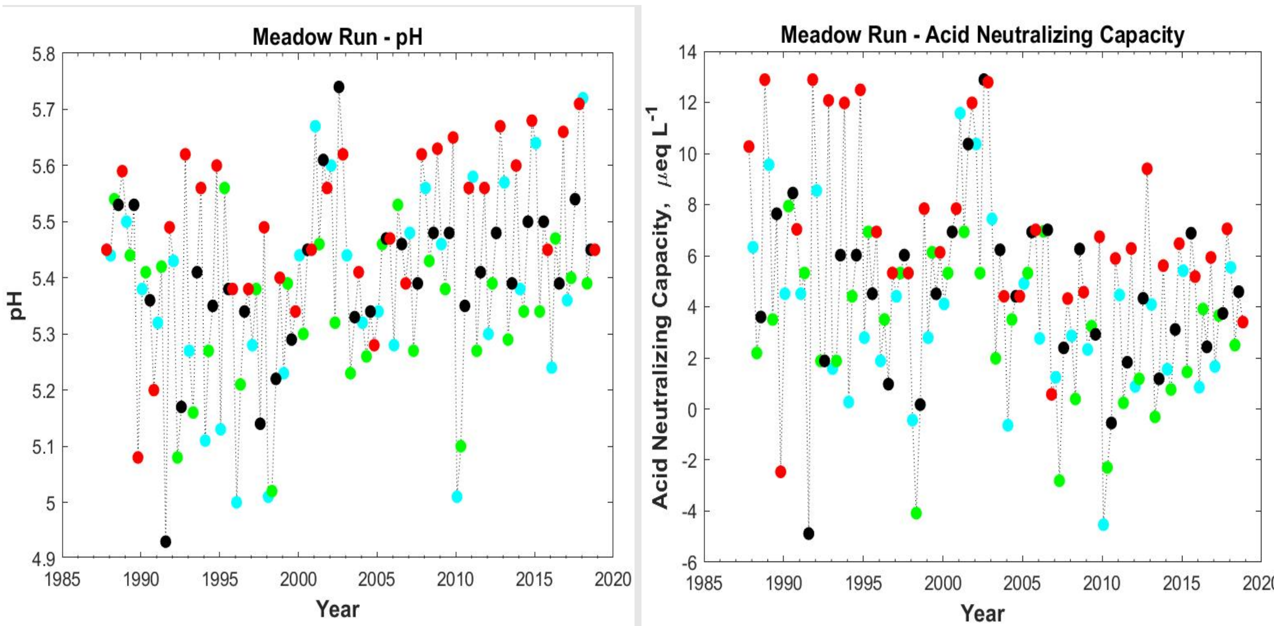
Groundwater

Slopes in the project area dip toward Meadow Run and its tributaries. Bedrock in the project area consists of metamorphic rock types and does not include limestone (and associated karst features) found in the Shenandoah Valley. Since the bedrock in the project area is also typically shallow, the groundwater migrates only over short distances (Plummer et al. 2000, 2001) before it emerges on the surface as a spring or seep and enters Meadow Run and its tributaries. The groundwater quality reflects the watershed's "extremely acidic" (pH 3.5 to 4.4; USDA-NRCS 2017) soils and bedrock geology with low base cation content, described above in the section "Soil Chemistry."

Surface Water

Meadow Run is a perennial stream (i.e., water flows throughout the year). At the point of leaving the park, Meadow Run has an upstream watershed area of approximately 2,200 acres and an estimated average flow rate of 4.4 cubic feet per second.

The water quality of Meadow Run reflects the acidic water quality of the inflowing groundwater. The surface water quality sets the primary conditions for aquatic wildlife, described in "Aquatic Wildlife (Fish and Macroinvertebrates)" below. The park has monitored Meadow Run's water quality and chemistry quarterly during baseflow conditions since 1987 as part of a cooperative program with the University of Virginia Shenandoah Watershed Study and Virginia Trout Stream Sensitivity Study (SWAS-VTSSS) (Webb 2004; Riscassi et al. 2019; Scanlon et al. 2019). Baseflow is the streamflow that is sustained between rain events and fed to streams by delayed pathway such as the groundwater. Stream ecosystems spend most of their time in baseflow conditions, and baseflow water quality is considered an indicator of general stream health. High flow, or stormflow, conditions on the other hand only occur 10%–20% of the time. Although many aquatic organisms hunker down to protect themselves during these conditions, sometimes stormflows can be linked to acute water quality conditions that can harm organisms despite their short duration. Additional information on water quality monitoring sites is provided in appendix B. The collected water quality data for Meadow Run show that it is the most acidified stream in the park (e.g., Scanlon et al. 2019). Measures of stream acidification associated with the health of aquatic organisms, such as pH, ANC, and dissolved aluminum, all demonstrate that Meadow Run is highly acidified. Meadow Run at baseflow has a mean pH of 5.40 ±0.17 and a mean ANC of 4.5 ±3.8 µeq/L (figure 8), reflecting highly acidified conditions that cause injury or mortality to acid-sensitive aquatic biota, such a brook trout (Bulger et al. 1999, 2000). ANC values that existed in in Meadow Run before acidic deposition have been estimated as 69 µeq/L (Sullivan et al. 2004; Sullivan et al. 2008), representing a 15-fold drop in stream ANC over the 20th-century industrial period. During high flows, pH and ANC values are expected to be even lower (pH by as much as 0.4), based on data collected from Paine Run (a watershed to the north of Meadow Run) during storms (Riscassi et al. 2019). In other words, it is reasonable to assume that Meadow Run acidifies even further during high flow events (Jastram et al. 2013). VADEQ has listed Meadow Run since 2004 as Category 5a Impaired Waters for aquatic life due to low pH under Section 303d of the CWA (VADEQ 2020). Specifically, it is listed because baseflow pH values are below the pH criteria of 6.0 to 9.0 set by Virginia for Class IV (mountainous zone waters) and Class VI (natural trout waters) streams. The CWA 303d Category 5a designation for Meadow Run requires that a Total Maximum Daily Load (TMDL) "cleanup" plan or TMDL-alternative plan must be developed and implemented. Presently, VADEQ lists the impaired upper 8.82 miles Meadow Run as medium priority for TMDL development, which will be addressed only after 2022 upon completion of the high priority waters submitted to the US Environmental Protection Agency in 2016.



Source: SWAS-VTSSS 2019

Note: Colors represent sampling season (blue=winter, green=spring, black=summer, red=autumn)

FIGURE 8. PH AND ANC IN MEADOW RUN, MEASURED QUARTERLY DURING BASEFLOW CONDITIONS (1987–2018)

High concentrations of dissolved aluminum are toxic to many organisms. Meadow Run's total monomeric aluminum concentrations (a commonly measured form of dissolved aluminum) averaged 19.7± 11.3 microgram per liter (µg/L) over three decades of baseflow measurements, ranging from 3.1 to 64.6 µg/L. Furthermore, concentrations are likely to increase 2 to 4 times during high flow conditions (Riscassi et al. 2019). Meadow Run therefore often has greater than 54 µg/L of total monomeric aluminum, which causes mortality of brook trout (Baldigo et al. 2007). Lower concentrations cause injuries to fish gills and skin (Baldigo et al. 2007). Base cations and sulfate are metrics of how acidic deposition and soil conditions in the watershed influence the stream quality, and both measurements indicate that Meadow Run is acidified. Water leaching through soils with high base cation saturation produces waters with higher dissolved base cation concentrations, which are in turn a critical component of ANC. Water ANC can be calculated as the sum of dissolved strong base cations (i.e., calcium, magnesium, potassium, sodium) minus the sum of strong acid anions (i.e., chloride, sulfate, and nitrate).

Soils with low base cation saturation result in waters with low dissolved base cations and ANC. Measured concentrations of dissolved base cations in Meadow Run are lower than in any other streams monitored in the park (Scanlon et al. 2019). These values reflect the level of acidification of the watershed, the base cation deficits of its soils, and the ANCs of its surface waters.

Sulfate is one of the strong acid anions found in acidic deposition. The mean sulfate concentration measured in Meadow Run stream water is typical for acidified streams within the park. Overall sulfate deposition (e.g., sulfate concentrations in rainwater and snow) may have decreased over the last decade, but stream water concentrations have only slightly decreased (if at all) because of past sulfate accumulation in the soil.

Other important water quality metrics (water temperature, dissolved oxygen, and nutrients), not related to acidification, all indicate that Meadow Run would be a healthy stream suitable for fish, if acidification were reversed.

Trends

Over the last four decades, improvements to water quality metrics of acidification (i.e., pH and ANC) have been modest and insufficient to improve conditions for aquatic wildlife (figure 8) in Meadow Run. Modeling studies suggest that current acidic deposition loads will not allow for natural recovery for at least 100 years (and probably much longer) even when assuming that regional air pollutant emissions are reduced further (appendix B; Sullivan et al. 2003, 2008, 2010). Climate change is expected to exert additional acidification impacts over time, as large precipitation events increase in frequency and size (NPS 2020b), driving higher flows and more intense episodic acidification events (Robison and Scanlon 2018; Riscassi et al. 2019).

AQUATIC WILDLIFE (FISH AND MACROINVERTEBRATES)

The streams of the park are home to many fish and aquatic macroinvertebrate species (NPS 2020c; Jastram et al. 2013). Macroinvertebrates are organisms without a backbone that are large enough to be observed with the naked eye, such as a water bug. They are an important part of the food chain of streams because they process and cycle nutrients and are major food sources for fish and other aquatic animals.

The abundance and diversity of aquatic wildlife, such as fish and macroinvertebrates, can serve as indicators of overall ecosystem health because many sensitive species respond to the accumulation of a variety of stressors. For this reason, many states and conservation organizations use fish and macroinvertebrate monitoring to assess the health of freshwater bodies. The park has identified native brook trout as a key species of concern in its acidified streams, such as Meadow Run, because of its sensitivity to acidification and because of its historical, cultural, and recreational value (Bulger et al. 1999; NPS 2006a; Rice et al. 2014). There have been two monitoring sites for fish since 1984 and for aquatic macroinvertebrates since 1997 (Wofford and Demarest 2018; Wofford et al. 2018; NPS 2019a; NPS 2020d) (see appendix B for details).

Fish

Fish data have been collected in Meadow Run once every one to two years since 1984 on a single day in June, July, or early August. Only two fish species have been observed repeatedly: brook trout (*Salvelinus fontinalis*) and blacknose dace (*Rhinichthys atratulus*) (NPS 2019a). One individual pumpkinseed (*Lepomis gibbosus*) was captured in 1988.

If the pumpkinseed is considered an outlier, then Meadow Run has a fish species richness (i.e., the number of different species) of 2, which is one of the lowest richness values compared to other streams in the park (Jastram et al. 2013). The median fish species richness is 3 for all streams in the park underlain by siliciclastic bedrock, and 5 for streams underlain by granitic and basaltic bedrock; richness has also been observed as high as 14 in some streams (Jastram et al. 2013). Blacknose dace, an acid-sensitive species, has not been observed since 2010 and may be locally extinct (NPS 2019a; Jessup et al. 2019; Science Team, pers. comm. 2019b).

An analysis by Jastram et al. (2013) of fish surveys in the park between 1996 and 2010 showed that brook trout populations have not changed in Meadow Run during that period, just as fish richness and brook trout abundance have not recovered in other siliciclastic watersheds in the park. Brook trout in Meadow Run weighed less than brook trout of similar length in other park streams, indicating that Meadow Run presents a more stressful environment than other streams in the park.

Aquatic Macroinvertebrates

Aquatic macroinvertebrates have been monitored annually since 1997 on a single day in April or May (Wofford et al. 2018; NPS 2020d). A total of 160 taxa (e.g., mayfly) have been identified and counted in Meadow Run since 1997 (NPS 2020d).

Community metrics derived from these data show that Meadow Run appears to score well when compared to other acidified watersheds in the park (i.e., watersheds with siliciclastic bedrock geologies) but below those from watersheds in the park that have not been as deeply acidified (i.e., watersheds with granitic and basaltic bedrock geologies with higher base cation content). Although this might appear to suggest that Meadow Run has a healthy aquatic macroinvertebrate community, it is likely that none of these widely used macroinvertebrate community metrics adequately reflect the loss of acid-sensitive species because these metrics have been broadly established for the region or nation and generally incorporate degradation by a variety of causes for a wide range of contemporary biological communities (Science Team, pers. comm. 2019b). In addition, it appears that aquatic macroinvertebrate community metrics from siliciclastic watersheds in the park are declining over time, whereas metrics show recovery in streams draining granitic and basaltic bedrock (Jastram et al. 2013). Meadow Run's aquatic macroinvertebrate community is therefore likely degraded from acidification.

Trends

Aquatic wildlife in Meadow Run suffers from the acidic conditions. There is less biodiversity and abundance of aquatic macroinvertebrates and fish, and decreased reproduction of sensitive fish species such as brook trout (Bulger et al. 1999; Jastram et al. 2013; Blum et al. 2018). Although acid deposition has decreased in recent decades, the impacts on aquatic wildlife appear to be getting worse (e.g., blacknose dace has disappeared since 2010) and are not likely to recover as long as water quality remains acidified, which would naturally take well over 100 years without liming. Climate change could add more stress on aquatic wildlife through higher water temperature and increasing episodic acidification as storms increase in frequency and size (Robison and Scanlon 2018; Riscassi et al. 2019).

VEGETATION

Forests are the dominant ecosystem in the eastern United States and are a key ecosystem in the park. Forest vegetation occupies 97% of the park's 199,015-acre land area and is the matrix upon which many other organisms depend (Cass et al. 2012). The park provides habitat to 1,413 vascular plant species. The vegetation communities in the park are relatively young (i.e., most are less than 100 years old) and vary based on factors such as slope, aspect, elevation, geology, moisture, land use history, and natural or human-caused disturbances. Forests dominated by oak (*Quercus* spp.), hickory (*Carya* spp.), and pine (*Pinus* spp.) compose 74% of the park's land cover for vegetation, while rich mixed hardwood forests of maple (*Acer* spp.), birch (*Betula* spp.), tulip tree (*Liriodendron tulipifera*), basswood (*Tilia americana*), and ash (*Fraxinus* spp.) compose 25%. The remaining 1% of the park's land cover for vegetation is composed of wetland and rock outcrop communities (Young et al. 2009; Cass et al. 2012). This section discusses three groups of vegetation in the project area that could be affected by the alternatives under consideration: dominant and codominant native vegetation, rare native vegetation, and non-native invasive vegetation.

Dominant and Codominant Native Vegetation

The entire project area to be limed is forested (figure 2). Dominant and codominant trees are the largest trees and form the main canopy. Dominant trees generally have the largest, fullest crowns in the forest. Codominant trees also grow up to the general level of the canopy but are shorter than dominant trees. Dominant native plant species in the project area include chestnut oak (*Quercus prinus*), sweet birch (*Betula lenta*), and Table Mountain pine (*Pinus pungens*). Codominant species include red oak (*Quercus rubra*), pitch pine (*Pinus rigida*), and yellow birch (*Betula alleghaniensis*).

Though not rare in the project area because of the acidic soil conditions, pitch pine can be rare in forest stands of the Blue Ridge Mountains (Gucker 2007). Pitch pine is also an early successional species that is typically replaced by hardwoods, spruces, or other pines in the absence of fire or other severe disturbance, although it may represent a climax species in some very harsh habitats such as rock outcrops on ridgelines (Gucker 2007). In the project area, pitch pine is associated with soils of pH 3.9 to 4.5 on ridgelines and south-facing rocky slopes. Pitch pine is part of an associated forest community with Table Mountain pine and chestnut oak; the community covers 17% of the project area.

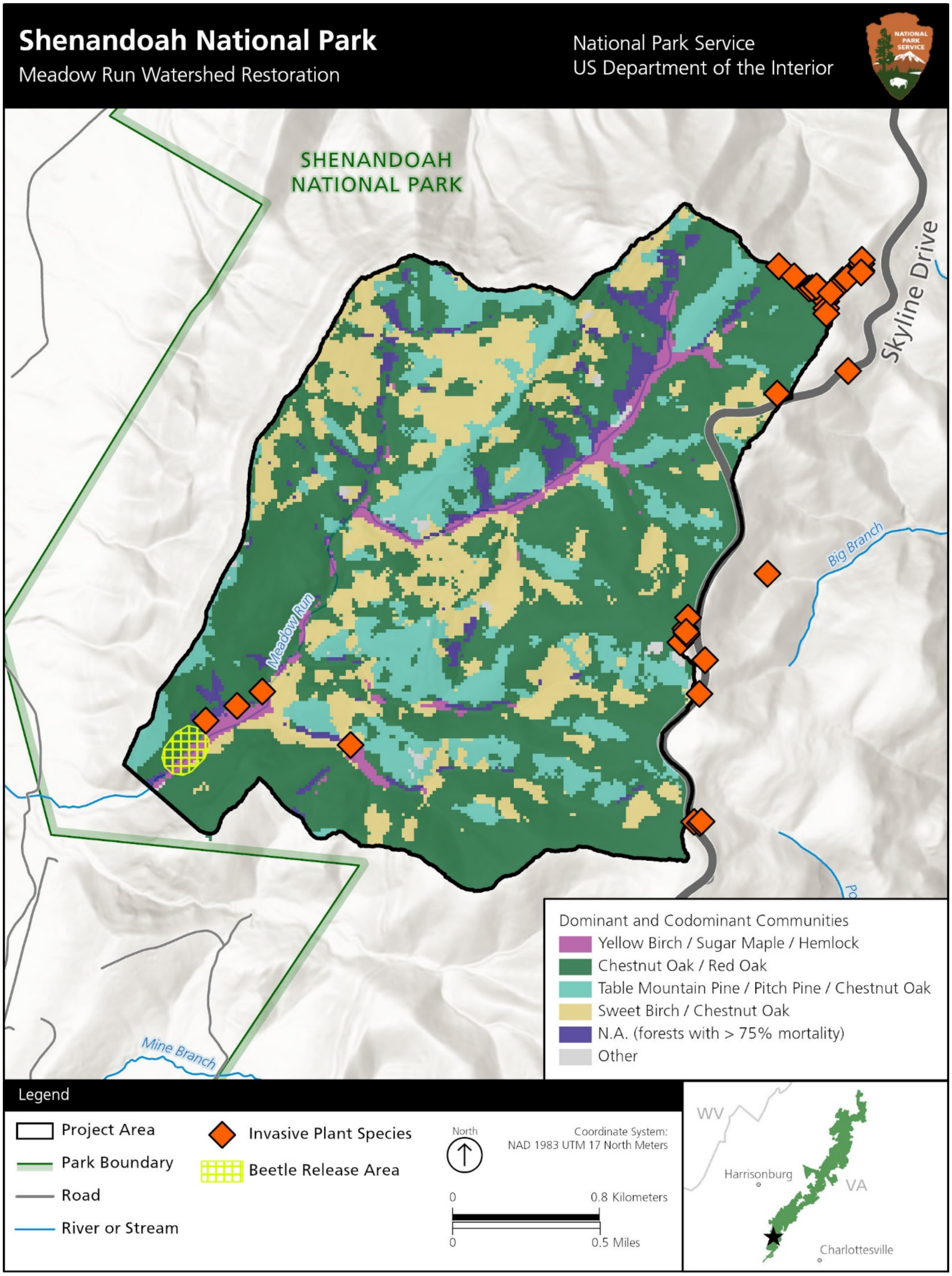
Other plant species found in the project area include sassafras (*Sassafras albidum*), black gum (*Nyssa sylvatica*), bear oak (*Quercus ilicifolia*), mountain laurel (*Kalmia latifolia*), hickory, and tulip tree. The forest floor is typically covered with Blue Ridge blueberry (*Vaccinium pallidum*); black huckleberry (*Gaylussacia baccata*); mountain laurel; and various herbaceous plants, mosses, and lichens (Cass et al. 2012).

Table 2 summarizes the dominant and codominant native vegetation communities found in the project area. The table includes a disturbed vegetation type containing trees with greater than 75% canopy mortality caused by insect infestations (e.g., gypsy moth [*Lymantria dispar*] and hemlock wooly adelgid [*Adelges tsugae*]), fungal pathogens, fire, and drought (Young et al. 2009). Figure 9 shows the spatial distribution of the dominant and codominant native vegetation communities within the project area. The figure also shows a treatment area for hemlock wooly adelgid (via beetle release) that would be excluded from liming.

TABLE 2. DOMINANT AND CODOMINANT PLANT SPECIES AND ASSOCIATED FOREST COMMUNITIES FOR THESE PLANT SPECIES

Dominant and Codominant Plant Species Associated Forest Communities [a]	**Scientific Name**	**Cover in Project Area**	
		Acres	**Percent**
Chestnut Oak / Red Oak	*Quercus prinus / Quercus rubra*	**1,185**	**55%**
Central Appalachian / Northern Piedmont Chestnut Oak Forest (CEGL006299)	*Quercus prinus - (Quercus coccinea, Quercus rubra) / Kalmia latifolia / Vaccinium pallidum* Forest	585	27%
Central Appalachian Dry-Mesic Chestnut Oak - Northern Red Oak Forest (CEGL006057)	*Quercus prinus - Quercus rubra / Hamamelis virginiana* Forest	383	18%
Central Appalachian Montane Oak - Hickory Forest (Acidic Type) (CEGL008516)	*Quercus prinus - Quercus rubra - Carya ovalis / Solidago (ulmifolia, arguta) - Galium latifolium* Forest	32	1%
Central Appalachian Dry Chestnut Oak - Northern Red Oak / Heath Forest (CEGL008523)	*Quercus prinus - Quercus rubra / Vaccinium pallidum - (Rhododendron periclymenoides)* Forest	185	9%
Sweet Birch / Chestnut Oak	*Betula lenta / Quercus prinus*	**438**	**21%**
Sweet Birch - Chestnut Oak Talus Woodland (CEGL006565)	*Betula lenta - Quercus prinus / Parthenocissus quinquefolia* Woodland	438	21%
Table Mountain Pine / Pitch Pine / Chestnut Oak	*Pinus pungens / Pinus rigida / Quercus prinus* Woodland	**370**	**17%**
Central Appalachian Pine - Oak / Heath Woodland (CEGL004996)	*Pinus (pungens, rigida) - Quercus prinus / (Quercus ilicifolia) / Gaylussacia baccata* Woodland	370	17%
Mixed Hardwoods / Yellow Birch / Sugar Maple / Hemlock	*Betula alleghaniensis / Acer saccharum / Tsuga canadensis*	**69**	**3%**
Hemlock - Northern Hardwood Forest (CEGL006109)	*Tsuga canadensis - Betula alleghaniensis - Acer saccharum / Dryopteris intermedia* Forest	6	<1%
Central Appalachian Acidic Cove Forest (Hemlock - Hardwood / Mountain-Laurel Type) (CEGL008512)	*Tsuga canadensis - Quercus prinus - Liriodendron tulipifera / Kalmia latifolia - (Rhododendron catawbiense)* Forest	63	3
Catastrophically Disturbed Forest	Forests with > 75% canopy mortality from gypsy moth, fires, hemlock woolly adelgid.	**81**	**4%**
Catastrophically Disturbed Forest (CEGL00-M1)		81	4%
TOTAL		**2,143**	**100%**

[a] Includes US National Vegetation Classification, Community Element Global (CEGL) number



Source: NPS 2019b

FIGURE 9. DOMINANT AND CODOMINANT VEGETATION COMMUNITIES AND KNOWN NON-NATIVE INVASIVE VEGETATION IN THE PROJECT AREA

Rare Native Vegetation

Two rare native vegetation communities make up 10% of the project area. They are ranked as globally uncommon or at moderate risk for extinction (G3) (NatureServe 2020a, 2020b) and consist of the following (figure 10):

- **Central Appalachian Montane Oak – Hickory Forest (Acidic Type)** (CEGL008516): This community consists mostly of chestnut oak, red oak, Blue Ridge blueberry, and pink azalea (*Rhododendron periclymenoides*). The conservation status of this community is vulnerable because of its relatively small geographic range, although it does cover substantial areas at low to middle elevations of both the Northern Blue Ridge and Ridge and Valley provinces. This community typically occupies middle to upper slopes and narrow ridge crests underlain by various sedimentary and metamorphic rocks, including sandstone, quartzite, siltstone, metasiltstone, phyllite, and acidic shale. Elevations of the community range from 1,800 to 4,200 feet, but the type is most common between 2,500 and 3,600 feet (NatureServe 2020a). The community has been found in the northern and eastern portions of the project area.

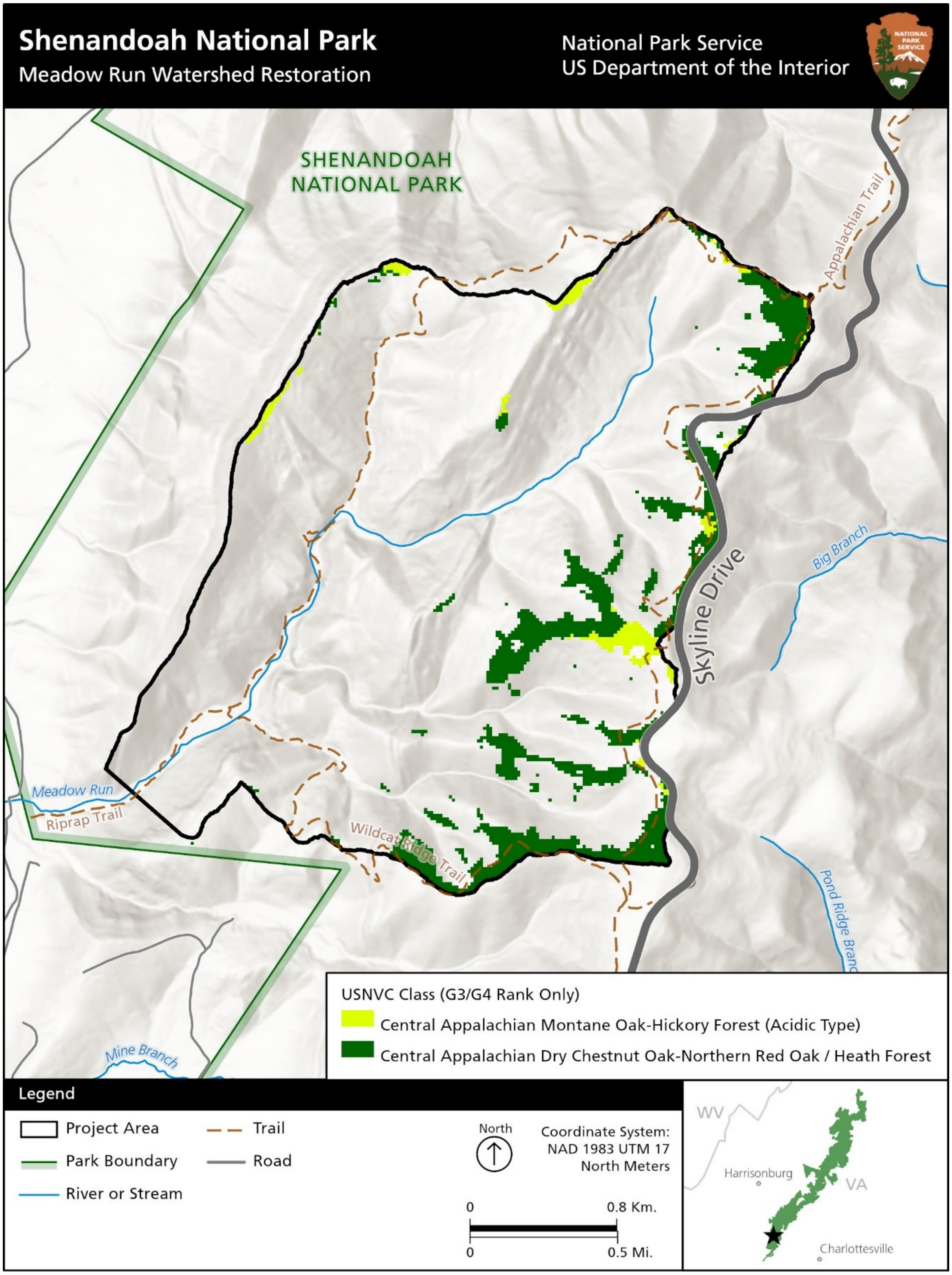
- **Central Appalachian Dry Chestnut Oak – Northern Red Oak / Heath Forest** (CEGL008523): This community consists mostly of chestnut oak, red oak, red hickory (*Carya ovalis*), and Pennsylvania sedge (*Carex pensylvanica*). The community has a conservation status of vulnerable because it occupies a narrow geographic range within the Northern Blue Ridge province but is locally common within the range. This community occupies sites with underlying bedrock such as quartzite, various members of the gneissic granitic complex, and, less frequently, metabasalt. It occurs on chiefly convex, moderately steep middle to upper slopes, ridge crests, and boulder fields with southeastern to northwestern exposures. The community spans a broad range of elevations, from <1,000 to 3,600 feet (NatureServe 2020b). It has been found mostly in the eastern portion of the project area.

Two state rare acidophilic plant species are also known to occur in the project area: bristly sarsaparilla (*Aralia hispida*) (G5 - globally secure / S2 - state imperiled) and sword-leaf phlox (*Phlox buckleyi*) (G2 - globally imperiled / S2 - state imperiled, PT – Proposed Threatened) (Townsend 2020). Acidophilic plants are plants that thrive under highly acidic soil conditions.

No federally threatened or endangered plants are known or expected to occur within the project area (NPS, Cass, pers. comm. 2020e).

Non-native Invasive Vegetation

Non-native invasive plants are plants that thrive outside their natural range and may cause economic or environmental harm to humans, animals, or other plants. The non-native invasive species known to occur within the boundary of the project area (see figure 9) include tree-of-heaven (*Ailanthus altissima*), garlic mustard (*Alliaria petiolata*), Oriental bittersweet (*Celastrus orbiculatus*), Japanese honeysuckle (*Lonicera japonica*), stiltgrass (*Microstegium vimineum*), and wineberry (*Rubus phoenicolasius*). These species have been found at various locations along Skyline Drive and along hiking trails in the project area. In addition, empress tree (*Paulownia tomentosa*) and Oriental lady's thumb (*Persicaria longiseta)* have been found near, but outside, the project area.



Source: NPS 2019b

FIGURE 10. VEGETATION COMMUNITIES RANKED AS GLOBALLY UNCOMMON OR AT MODERATE RISK FOR EXTINCTION

Trends and Planned Actions

Dominant and codominant native vegetation and rare native plant communities in the project area have been and will likely continue to be influenced and degraded from acidic deposition. Acidic deposition also accelerates calcium losses through soil leaching and increases the bioavailability of aluminum (Huntington et al. 2000; Dijkstra 2003). Although most of the species in the project area are tolerant of high aluminum concentrations, the current soil Ca:Al ratios demonstrate that nearly half of the project area vegetation will continue to experience severe aluminum toxicity.

Calcium quantity and availability are important because calcium is an essential nutrient for many plant species and an important element for neutralizing soil acidity. Soils in the project area under current conditions are likely to remain "extremely acidic" (pH from 3.5 to 4.4; USDA-NRCS [2017]), low in calcium, and high in aluminum for well over 100 years. These conditions will limit the growth of native plants by inhibiting cellular function, wood formation by shrubs and trees, and photosynthetic processes (Balter and Loeb 1983; Federer et al. 1989; Boxman et al. 1994; Fromm 2010; Schaberg et al. 2010; Battles et al. 2014). These conditions will also continue to favor species that are typically found in lower pH soils. The trend of climate change, with potentially higher average temperatures and more precipitation, could also affect vegetation within the project area by slowly changing growth patterns of some native plant species (NPS 2020b).

Acidic conditions may continue to limit the spread of non-native invasive plant species to Skyline Drive and trails frequently disturbed by heavy foot traffic because the typical soil pH range for most of these species is above 4.5. Currently, the pH within the organic soil horizon where seeds germinate is on average 3.77 ±0.35, and the pH within upper mineral soil in the project area is 4.19 ±0.28. In addition, the trend of climate change could provide a competitive advantage to non-native invasive plant species given expected increases in precipitation, temperature, and atmospheric carbon dioxide (NPS 2020b).

The park conducted surveys for non-native invasive plants in the project area. Invasive plants were treated just outside the project area to control their spread. For example, oriental bittersweet was treated with herbicide along the Appalachian Trail just north of the junction with Riprap Trail in December 2017. As funding permits, the park plans further treatments of known occurrences of invasive plants along the Appalachian Trail and sections of Riprap Trail and Wildcat Ridge Trail just outside the project/liming area. The areas to be treated cover 49 acres and include various species (e.g., garlic mustard, stiltgrass, oriental bittersweet, tree-of-heaven, and wineberry).

TERRESTRIAL WILDLIFE (BIRDS, SALAMANDERS, AND SNAILS)

A detailed terrestrial wildlife inventory for the Meadow Run project area is not available. Therefore, the NPSpecies database of terrestrial wildlife in the park (NPS 2020c) was used as a proxy for species likely present in the project area. The inventory developed from NPSpecies focused on species that are listed as "present" or "probably present" within the park and those that would potentially be present in the project area based on habitat. The extremely acidic soils in the Meadow Run watershed create a suboptimal habitat for terrestrial wildlife. Based on studies from other acidified watersheds in the Mid-Atlantic region, it is a reasonable assumption that those populations have been adversely affected. If those populations have been adversely affected, these effects would likely continue as long as the habitat remains degraded.

Birds

An estimated 200 species of birds occur in the park (NPS 2020c). Approximately half of these species breed in the park (NPS 2020f). Around 30 bird species are year-round residents such as the barred owl (*Strix varia*), wild turkey (*Meleagris gallopavo*), ruffed grouse (*Bonasa umbellu*), dark-eyed junco

(*Junco hyemalis*), and Carolina chickadee (*Poecile carolinensis*). Around 55 bird species are migratory, 32 species are considered vagrant,[3] and 1 species typically spends only winter months in the park. Nine species are categorized as abundant in the park: northern cardinal (*Cardinalis cardinalis*), indigo bunting (*Passerina cyanea*), American crow, dark-eyed junco, ovenbird (*Seiurus aurocapilla*), American redstart (*Setophaga ruticilla*), veery (*Catharus fuscescens*), and wood thrush (*Hylocichla mustelina*). Among the remaining bird species, 39 are considered common, 64 are considered occasional, 53 are considered uncommon, and 31 are considered rare.

There are 22 bird species categorized as Species of Greatest Conservation Need (SGCN) in the park, 17 of which could occur in the project area (see table in appendix C). Notably, the wood thrush (*Hylocichla mustelina*) is included in this category; wood thrush has been observed to have lower abundances in areas receiving high levels of acidic deposition (Hames et al. 2002).

Birds in the park can be divided into three groups (as relevant for the evaluation of liming impacts in chapter 4) based on their habitat selection and foraging strategies in accordance with Pabian et al. (2012a):

- **Ground-foraging species:** Including veery, wood thrush, hermit thrush (*Catharus guttatus*), ovenbird, eastern towhee (*Pipilo erythrophthalmus*), chipping sparrow (*Spizella passerina*), dark-eyed junco, and indigo bunting.

- **Understory-foraging species:** Including blue-headed vireo (*Vireo solitarius*), chestnut-sided warbler (*Setophaga pensylvanica*), black-throated blue warbler (*Setophaga caerulescens*), and American redstart.

- **Canopy foraging species:** Including eastern wood-pewee (*Contopus virens*), least flycatcher (*Empidonax minimus*), eastern phoebe (*Sayornis phoebe*), red-eyed vireo (*Vireo olivaceus*), black-throated green warbler (*Setophaga virens*), blackburnian warbler (*Setophaga fusca*), scarlet tanager (*Piranga olivacea*), and rose-breasted grosbeak (*Pheucticus ludovicianus*).

In general, bird populations remain diverse in the park, but their abundance appears to be declining (Costanzo et al. 2017).

Salamanders

Amphibians in the park include 14 species of salamanders or newts. The large number of salamanders in the park is important to energy flow and nutrient cycling in forest ecosystems. Their biomass exceeds that of birds and mammals, and they play important roles as both predator and prey (Burton and Likens 1975; NPS 2020f). Species include the following:

- Abundant species of salamander include the eastern red-backed salamander (*Plethodon cinereus*), northern dusky salamander (*Desmognathus fuscus*), and northern two-lined salamander (*Eurycea bislineata*).

- Two species categorized as common include the seal salamander (*Desmognathus monticola*) and white-spotted slimy salamander (*Plethodon cylindraceus*).

[3] Birds that wander beyond the limits of the natural range for the species' natural range.

- Six uncommon salamander species are the eastern newt (*Notophthalmus viridescens*), Jefferson salamander (*Ambystoma jeffersonianum,* a SGCN species), red salamander (*Pseudotriton ruber*), spotted salamander (*Ambystoma maculatum*), three-lined salamander (*Eurycea guttolineata*), and spring salamander (*Gyrinophilus porphyriticus*).
- Two rare salamanders include the four-toed salamander (*Hemidactylium scutatum*) and long-tailed salamander (*Ambystoma macrodactylum*) (NPS 2020c).
- The federally endangered Shenandoah salamander (*Plethodon shenandoah*) occurs in the park but not near the project area.

The state-listed eastern tiger salamander (*Ambystoma tigrinum tigrinum*) occurs in ponds just outside the Meadow Run watershed but is not known to occur in the park (NPS 2020c).

Snails

Land snails are an important part of terrestrial ecology and the soil food web. They provide a food source and calcium supplement to a variety of wildlife. Land snails generally prefer a habitat offering adequate moisture, an abundant food supply, and an available source of calcium for their shell development. Common habitats include locations under leaf litter, rocks, and logs, and under exfoliating bark of standing and fallen dead trees. Although calcium-rich areas have many species, land snails exist across the soil calcium gradient (Carnegie Museum of Natural History 2020). Many small mammals, such as shrews and mice, and several species of salamanders and birds include land snails in their diet. Land snails are especially important to birds that require calcium in their diet to build their shells, and the calcium carbonate in snail shells is critical to female birds for developing their eggs or to parents providing supplemental calcium to growing young (Hames et al. 2002).

Land snails are a diverse group. Researchers at Carnegie Museum of Natural History (2020) have documented 232 species of land snail living in Virginia. There is no inventory of land snail species found in the park, but at ecologically similar sites in Great Smoky Mountains National Park, more than 140 species of land snail have been documented (Dourson and Dourson 2006). In addition, in a survey of land snail diversity along the Blue Ridge Parkway, Van Devender et al. (2017) documented 133 species. Similar diversity is expected in Shenandoah National Park.

Trends

Several studies (Graveland et al. 1994; Graveland and van der Wal 1996; Graveland 1998; Hames et al. 2002) have attributed declining bird populations to acidic deposition. The acidic soils in the project area could likely affect the reproduction of birds, particularly for species that forage on the ground, because acidic deposition reduces the quantity or nutritional quality of snails and other soil invertebrates that are main sources of calcium for birds. As a result, birds may not acquire enough calcium to form adequate eggshells (Graveland et al. 1994; Pabian and Brittingham 2007, 2012).

Salamanders are relatively acid-tolerant, but some species are sensitive to even low levels of acidity, and most species experience reduced growth rates and increased developmental abnormalities at low pH values (Pierce 1985; Wyman and Hawksley-Lescault 1987; Wyman and Jancola 1992), increased embryo mortality at a pH between 4 and 4.5, and fail reproduction if the pH is near or below 4 (Pierce 1987; Sugalski and Claussen 1997). Acidic soils may reduce the availability of calcium-rich invertebrate prey, although experimental data are limited (Ormerod and Rundle 1998). The extremely acidic soils in Meadow Run watershed have degraded habitat for salamanders. In summary, based on studies from other acidified watersheds, it is likely that populations have been adversely affected. If salamander populations have been adversely affected, these effects would likely continue.

The abundance and number of land snail species increases with increasing calcium content in soil because snails require substantial amounts of calcium (Johannessen and Solhøy 2001; Hotopp 2002; Hamburg et al. 2003; Beier et al. 2012). Because acidic deposition causes a depletion of soil calcium, it has been identified as a cause of native land snail declines during the past century (Dourson and Dourson 2006; Wäreborn 1992). A lower abundance of snails can have ripple effects through the food chain, as demonstrated for birds in the Netherlands (Graveland and van der Wal 1996; Graveland et al. 1994) and North America (Hames et al. 2002; Beier et al. 2012). Therefore, land snails would likely remain adversely impacted by the extremely acidic soils.

Climate change could have variable effects on terrestrial wildlife, as shifts in temperature and precipitation change preferred habitat. Specifically, species in the park that are currently near the northern limits of their distribution are expected to find climatic conditions more suitable, and species that are currently near the southern limits of their distribution may suffer habitat losses. Furthermore, shifts in seasonal changes and timing of biological processes (e.g., migration and breeding) as a result of climate change, particularly an earlier start to spring, could cause a disconnect between birds and the species they interact with as food sources, predators, and competitors.

WILDERNESS CHARACTER

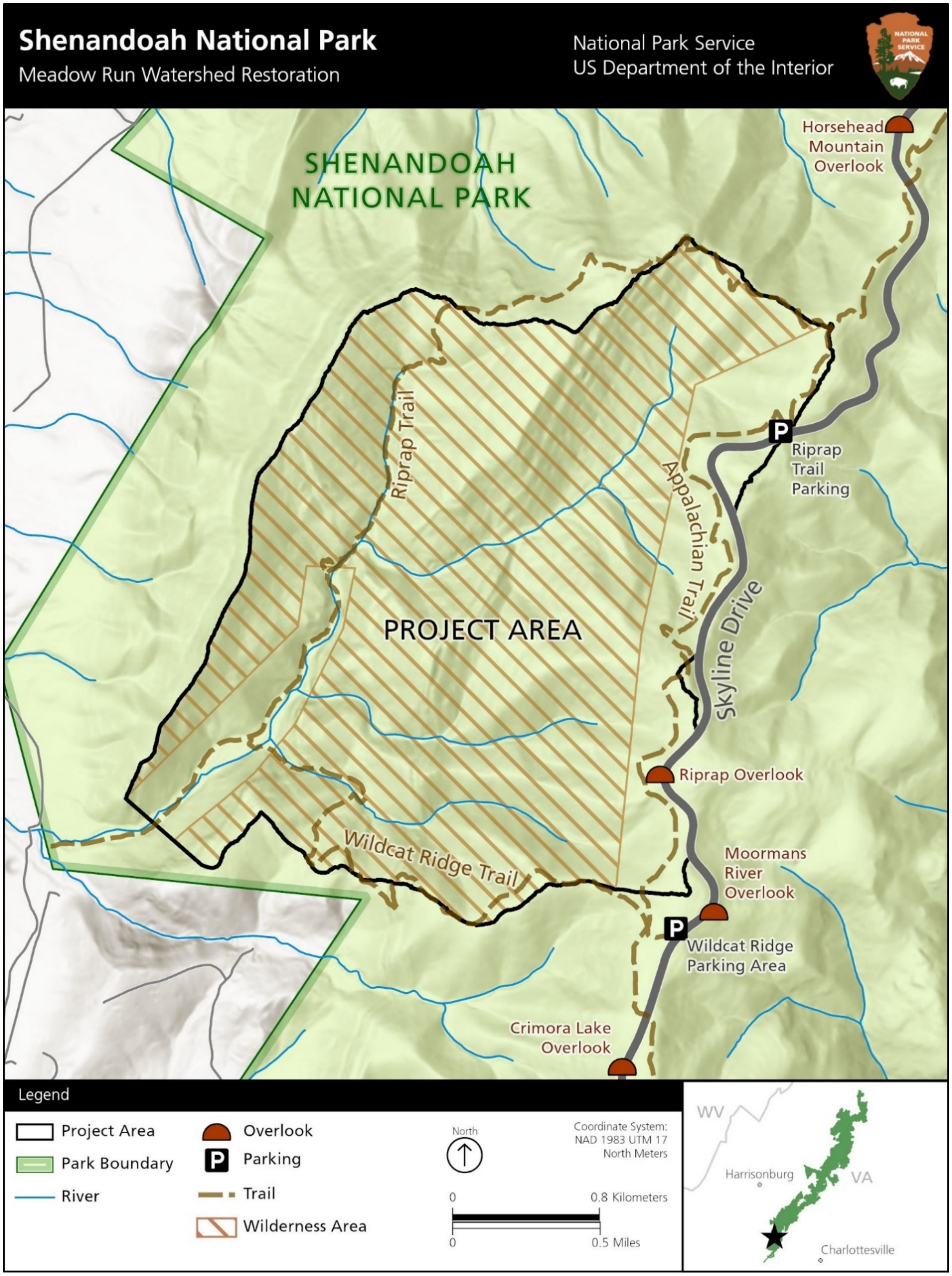
The park contains 79,579 acres of congressionally designated wilderness, which constitutes approximately 40% of the park. The wilderness areas in the park, which were once settled, farmed, and logged, stand as a symbol of the regenerative ability of the deciduous forests of the Appalachian Range (NPS 2015). Approximately 1,711 acres of designated wilderness are included in the project area, which constitutes 2.2% of the designated wilderness parkwide (figure 11). Additionally, designated wilderness occurs within several other watersheds along Skyline Drive in the South District of the park.

The project area is located in the park's Riprap Zone identified in the park's *Backcountry and Wilderness Management Plan* (NPS 1998). The Riprap Zone is designated as a semi-primitive wilderness area containing some non-wilderness areas (NPS 1998). A semi-primitive wilderness is an area that is characterized by a recovered natural environment, with some areas showing disturbance from backcountry users. Any effect on ecological and natural processes by the action of users are within set standards and limits for semi-primitive wilderness areas. Some areas near human-impacted sites may show loss of vegetation or minor erosion. Impacts in some areas often persist from year to year and may be apparent to visitors.

There is access to the wilderness in the project area from Skyline Drive and from the park boundary near the Town of Crimora. Two corridors in the project area are not designated wilderness: a 1-mile-long section along Riprap Trail (starting at the trailhead in the southwestern corner of the project area) and a corridor along Skyline Drive, both with an average width of approximately 0.25 miles (figure 11).

Wilderness areas within the project area are managed in accordance with the *Backcountry and Wilderness Management Plan* and the Wilderness Act of 1964. The primary mandate of the Wilderness Act for the federal agencies administering wilderness is to preserve "wilderness character." Wilderness character is defined by a framework of "qualities," based on the Wilderness Act. Monitoring the condition of these qualities over time allows park staff to assess how attributes of wilderness character may be changing and whether the park is ensuring that wilderness character is preserved in the project area.

Four qualities of wilderness character apply to all wilderness areas, including the project area (Landres et al. 2015): (1) untrammeled, (2) natural, (3) undeveloped, and (4) opportunities for solitude or primitive and unconfined recreation; these qualities are described below. A fifth quality, "other features of value," does not apply to the project area because it does not contain such features.



Source: Wilderness Connect 2020

FIGURE 11. WILDERNESS WITHIN THE PROJECT AREA

- **Untrammeled:** An untrammeled wilderness is unhindered and free from the intentional actions of modern human control or manipulation. Direct site management is sometimes needed to limit adverse impacts associated with use but only as necessary to meet the standards outlined in the park's *Backcountry and Wilderness Management Plan*. Most trammeling actions that occur in the park's wilderness areas focus on removal of developments or impacts of past land uses to improve or restore the undeveloped quality, or intervention to protect, improve, or restore natural processes. For example, some ongoing resource stewardship activities are intentional actions that degrade this quality of wilderness character but enhance others. Such actions include fire management and widespread monitoring and control of non-native invasive plants and forest pests (see "Vegetation").

- **Natural:** A natural wilderness is one where ecological systems are substantially free from the effects of modern civilization. The natural quality of the park's wilderness character is threatened by the surrounding urbanized and agricultural landscape, which serve to isolate the Blue Ridge Mountains and restrict movements of some animals. Although many plants and animals live in the project area, non-native forest pests and disease agents alter the ecological communities and fragment the forest canopy in the project area. Furthermore, changing fire regimes, fire suppression, air pollution, acidic deposition, and climate change have degraded this quality of wilderness character parkwide. Degradation of the natural quality in the Meadow Run watershed is considered severe because the siliciclastic bedrock limits recovery from the legacy effects of decades of acidic deposition.

- **Undeveloped:** An undeveloped wilderness has no permanent improvements or sights and sounds of modern human occupation. In some areas of the park's wilderness, rock walls, foundations, road traces, forest clearings, cemeteries, and stone chimneys remain from old settlements that once occupied the landscape. Even though signs and administrative structures are permitted in the project area, there are no administrative structures within the wilderness of the project area. Motorized equipment, aircraft use, and/or mechanical transport are sometimes authorized for use in park wilderness during emergencies (e.g., search and rescue and wildland fire operations), such type of emergency activities typically only occur approximately a dozen times per year, parkwide.

- **Solitude or Primitive and Unconfined Recreation:** Opportunities for solitude or primitive and unconfined recreation allow park visitors to be in an environment that is relatively free from the effects of modern society and obtain the benefits and inspiration derived from self-reliance, self-discovery, physical and mental challenge, and freedom from societal obligations. The trail network in the project area accommodates visitor access to wilderness, but it also increases the likelihood of encounters on the trail and the establishment of campsites, impacting the opportunity for solitude. Although there is a low to moderate probability of encountering other users or park personnel on the trails in the project area, encounters with other users increase during the peak visitor use period and near Skyline Drive.

Trends and Planned Actions

Ecosystem processes and resources (e.g., soils, water quality, vegetation, and wildlife) in the project area have been and will continue to be influenced and degraded by acidic deposition. Therefore, the natural quality of wilderness character is also expected to remain negatively affected.

Planned routine maintenance actions taken in wilderness may include, but are not limited to, backcountry and wilderness campsite management, signpost installation, and trail maintenance using primitive tools. These activities are designed to preserve the qualities of wilderness and would occur with or without project implementation.

ACOUSTIC ENVIRONMENT

A site's acoustic environment, also referred to as "soundscape," is the combination of acoustic resources and noise from human-induced sources. Acoustic resources are physical sound sources, both natural sounds (e.g., wind, water, wildlife, vegetation) and cultural and historic sounds (e.g., battle reenactments, tribal ceremonies). According to the NPS soundscape management policy (section 4.9 in NPS 2006b), the natural soundscape of a park refers to the combination of all the natural sounds occurring in the park, absent the human-induced sounds, as well as the physical capacity for transmitting those natural sounds.

Natural sounds include those that are within and beyond the range that humans can perceive and can be transmitted through air, water, or solid materials (NPS 2006b). Common natural sounds in the Meadow Run project area include bird calls, insect buzzing, animal calls and sounds, water flowing in streambeds, and weather-related sounds (wind rushing through trees, thunder, and pouring rain). Natural sound and the opportunity to experience uninterrupted solitude are valued components of the visitor experience within the park, particularly in wilderness areas in the park such as the project area.

Noise is generally defined as unwanted or intrusive sound. Noise can adversely affect park resources or values, including but not limited to natural soundscapes, wildlife, wilderness, and visitor experience. Primary sources of human-caused noise in national parks can include cars, buses, and other motorized vehicles and park operations, such as the use of maintenance equipment. A large percentage of the noise sources measured in national parks (such as highways or commercial jet traffic) originates outside park boundaries and beyond the management jurisdiction of NPS (Lynch et al. 2011).

The magnitude of noise is usually described by its sound pressure. The A-weighted decibel (dBA) scale is commonly used to describe sound levels because it reflects the frequency range to which the human ear is most sensitive. Sound levels in national parks can vary greatly, depending on location, topography, vegetation, biological activity, weather conditions, and other factors.

Sound Levels in the Park

Sounds measurements for the Meadow Run project area or the potential staging areas along Skyline Drive are not available. However, NPS conducted acoustic monitoring in the park from August 15 to September 28, 2016, at a site located approximately 5 miles to the north-northeast of the project area. The site was surrounded by designated wilderness; the closest distance to Skyline Drive (a source of noise) was 1.3 miles. The sound levels at this site were low (consistent with a wilderness area) and are considered representative of sound levels in the center of the Meadow Run project area. The metric for sound, L_x, indicates the percentage of time a sound level is exceeded, for example L_{90} indicates the sound level exceeded 90% of the time. During the daytime (7:00 a.m. to 7:00 p.m.), the L_{90}, L_{50}, and L_{10} sound levels at the monitored location were 41 dBA, 44 dBA, and 48 dBA, respectively; during the nighttime (7:00 p.m. to 7:00 a.m.), the L_{90}, L_{50}, and L_{10} sound levels were 47, 49, and 50 dBA, respectively (NPS 2016a).

As stated in Constanzo et al. (2017), the presence of Skyline Drive along the length of the park results in substantial traffic-induced sounds permeating park lands. Approximately 25% of visitor groups in the summer and fall indicated that sounds of motorcycles detracted from their park experience (Manni 2012). In addition to these noise sources, military and commercial overflights introduce noise that is carried into the park.

Sound Levels Outside the Park

Sound levels within the 9-mile zone outside the park (within which staging areas may be located) are expected to be low for developed areas because of to the rural setting.

Trends

Low sound levels are expected to persist in the project area and surrounding area. In the long term, vehicles on Skyline Drive may become less of a source of noise parkwide with the increased use of electric vehicles.

VISITOR USE AND EXPERIENCE

One of the purposes of the park is to provide a broad range of opportunities for public enjoyment, recreation, inspiration, and stewardship (NPS 2015). Many visitors use and experience the park by driving along Skyline Drive.

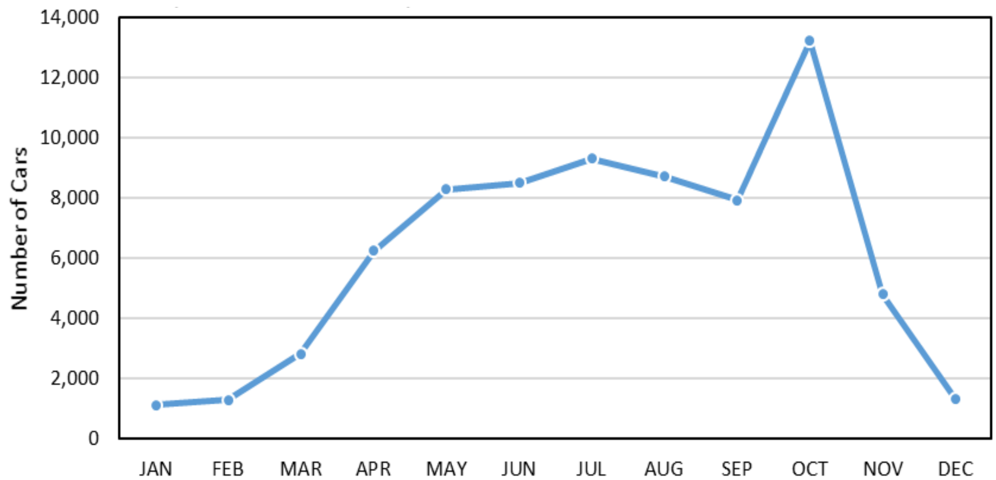
In 2019, the park received approximately 1.4 million recreational visitors (NPS 2020g), ranging on a monthly basis from approximately 10,000 visitors in February to 240,000 visitors in October. Most visitors come to the park between April and November and most arrive by privately owned vehicle. Visitors can enter the park via Skyline Drive at the Front Royal, Thornton Gap, Swift Run Gap, and Rockfish Gap entrance stations (from north to south). Skyline Drive is listed as the Skyline Drive Historic District by the Virginia Department of Historic Resources (VDHR), is listed as a National Historic Landmark, and is also listed in the Virginia Landmarks Register. The road was constructed between 1930 and 1942 along a ridgeline of the Blue Ridge Mountains and is approximately 106 miles long. The Rockfish Gap entrance station is the closest vehicle entrance to the project area.

Some of the most popular activities in the project area include hiking, fishing, enjoying the panoramic views from overlooks, backcountry and wilderness camping, or relaxing in the peaceful surroundings. Other opportunities include backpacking, watching birds and other wildlife, picnicking, and stargazing.

Skyline Drive

Visitor use in the project area includes enjoying views along Skyline Drive and its overlooks. The Rockfish Gap entrance station to Skyline Drive is located 13 miles to the southwest of the project area. The closest entrance station to the northeast of the project area is Swift Run Gap (24 miles away). Over the last 11 years (2009–2019), the Rockfish Gap entrance station received between approximately 70,000 and 83,000 vehicles annually. The lowest traffic occurred from December through February at an average of 1,250 vehicles per month (figure 12). Vehicle traffic started to double in March and reached a peak in October with 13,200 vehicles on average, approximately an order of magnitude more vehicles than during the winter.

During the winter, Skyline Drive may receive snowfall or ice storms that topple trees, block the road, and result in closures until the road can be cleared. In addition, the South District of the park normally has the longest period of each winter closure because snow/damage removal preferentially open the Central and North Districts first. For example, during the 2019–2020 winter, the South District had 6 administrative road closures and 7 emergency road closures, resulting in a total of 55 closed days. During the 2018–2019 winter, the South District had 3 administrative road closures and 1 emergency road closure, resulting in a total of 166 closed days, and during the 2017–2018 winter, the South District had 8 administrative road closures and 7 emergency road closures, resulting in a total of 46 closed days.



Source: NPS 2019c

FIGURE 12. AVERAGE MONTHLY TRAFFIC COUNTS FROM 2009 TO 2018 AT ROCKFISH GAP ENTRANCE, THE ENTRANCE OF SKYLINE DRIVE CLOSEST TO THE PROJECT AREA

Hiking

The park is home to more than 500 miles of trails, including 105 miles of the Appalachian Trail and 200 miles of designated horse trails (NPS 2018a). Approximately 8 miles of hiking trails can be accessed within the project area, including Riprap Trail, Wildcat Ridge Trail, and the Appalachian Trail (figure 11). While these trails are open year-round, access is limited to the entrance near Crimora if Skyline Drive is closed due to snowfall or ice-storms.

Each of these trails weave in and out of the project area and are maintained by the park's trail crews and volunteers from the Potomac Appalachian Trail Club. Key features of each trail are as follows:

- **Riprap Trail:** This trail currently has two entrances, one located near Crimora in the southeastern corner of the project area and one located at the Riprap Parking Area along Skyline Drive in the northeastern corner of the project area. From the entrance near Crimora, the trail follows the mainstem of Meadow Run for approximately 1.5 miles, then continues along Cold Spring Hollow to Chimney Rock and Calvary Rocks at an elevation of approximately 2,800 feet along the northern boundary of the project area, and continues from there to the Riprap Parking Area.

- **Wildcat Trail:** This trail extends from Riprap Trail along the mainstem of Meadow Run in the west, follows the lower section of a tributary to Meadow Run, and then continues along Wildcat Ridge to the Wildcat Ridge Parking Area along Skyline Drive. This trail is close to the southern boundary of the project area.

- **Appalachian National Scenic Trail:** The Appalachian Trail follows along the eastern boundary of the project area for 2.9 miles. It overlaps with Riprap Trail for approximately 0.4 miles in the northeastern corner of the project area. Most hikers who hike the entire trail (referred to as "thru-hikers") start in the south (Georgia) rather than in the north (Maine). The most popular start time in Georgia is between early March and early April, which is considered "a bubble in thru-hikes" (TheTrek 2020). The typical thru-hiker requires 5 to 7 months (ATC 2021a), which implies that the Appalachian Trail segment in the project area is most actively used by thru-hikers in late spring and early summer. Hikers that start somewhere in the middle of the trail (referred to as “flip flop hikers”) are encouraged to start hiking in the park in April (ATC 2021b).

Riprap Trail, Wildcat Ridge Trail, and the Appalachian Trail can be hiked as a loop for a combined 9 miles, which includes sections of the Riprap and Wildcat Ridge Trails located just outside the project area.

Fishing

Fishing in the project area is strictly regulated by the park through its Fishery Management Plan, which has two objectives: (1) to preserve and perpetuate brook trout as a key component of the park’s aquatic ecosystems; and (2) to allow for recreational fishing on those park streams that consistently produce adequate numbers of gamefish for maintaining population stability (NPS 2020h). All streams in the park, including Meadow Run, are open for catch-and-release recreational fishing. Only 17 streams are currently designated for harvest fishing, meaning the angler can keep the fish, as opposed to catch and release. Meadow Run is currently not designated for harvest fishing.

Trends

Activities such as hiking, camping, climbing, and enjoying the park’s landscapes from scenic overlooks are anticipated to continue in or near the project area. Acidic deposition will continue to degrade the ecosystem and water quality of Meadow Run, which may diminish the experience of some visitors expecting a pristine natural environment. As a result of the impaired water quality, the abundance of fish species will remain low, and opportunities for recreational fishing will be limited.

CHAPTER 4: ENVIRONMENTAL CONSEQUENCES

INTRODUCTION

This chapter describes impacts that would occur under each alternative carried forward for detailed analysis. The impact analysis assumes that mitigation measures described in chapter 2 would be implemented.

The preamble to the Council on Environmental Quality (CEQ) regulations implementing the procedural provisions of NEPA states that an agency "may contrast the impacts of the proposed action and alternatives with the current and expected future conditions of the affected environment in the absence of the action, which constitutes consideration of a no-action alternative" (85 *Federal Register* 43304, at 43323). Under the no-action alternative (alternative A), liming of the Meadow Run watershed would not occur, and current conditions and trends of the resources described in chapter 3 would continue. To avoid restating the same information, the impact analysis of alternative A in chapter 4 provides only a brief discussion with the understanding that the reader may refer to chapter 3 for current conditions and trends. This constitutes consideration of the impacts of the no-action alternative, in accordance with the direction from CEQ.

Impacts for action alternatives B and C are described in detail. The duration of impacts would vary for different resources and impact topics. While the duration is specified as applicable, the following general terminology was also used:

- **Short-term impacts during project implementation:** Implementation includes the construction of a stockpile in November and the subsequent limestone sand application period of up to three months in the winter (December–February). Depending on impact topic, impacts may be intermittent (generally lasting seconds, minutes, hours, days, a few weeks, or daytime only) or continuous during the implementation period. For some impact topics, this period also includes the months following limestone sand application (i.e., while the limestone sand is gradually mixed into the forest floor).

- **Long-term impacts following liming:** Beneficial impacts of liming may take years or decades to fully develop as limestone sand gradually dissolves and is integrated fully into the deeper soil horizons. Liming is expected to benefit the project area for well over 100 years. Long-term impacts would reflect the effect of the released cations (i.e., calcium and magnesium) as the limestone sand grains very slowly dissolve in the soil. This long-term release would eventually benefit other resources (stream water, vegetation, and wildlife) in the project area.

SOIL CHEMISTRY

Methods and Assumptions

Liming alters the chemistry of the soil. To assess these changes, NPS examined multiple sources of information, including soil chemistry data for Meadow Run (e.g., 2019 sampling by NPS; Welsch et al. 2001), scientific literature on effects of liming on soils, and information obtained from the science team (Science Team, pers. comm. 2019a).

After review of the literature and consultation with the project's science team, three metrics were used to assess impacts on soils—base cation saturation, pH, and soil exchangeable aluminum.

Base Cation Saturation. Soil base cation saturation is the primary metric because it is a measure of how much of the soil's inherent capacity to hold cations (i.e., CEC) is occupied by base cations rather than acidic hydrogen ions or toxic aluminum ions. Also, liming would directly add base cations (i.e., primarily calcium and magnesium) to the soil, thereby increasing base cation saturation. For these reasons, base cation saturation is the soil property used for determining liming dose recommendations both for agricultural soils and for acidified forest soils. A target of 20% base cation saturation would prevent further aluminum toxicity and stress to plants within the forest ecosystems (Sullivan et al. 2013).

Soil base cation saturation was also selected to be the basis for liming dose recommendations for the action alternatives (B and C); this same metric was also used for other forest liming projects in the eastern United States (George et al. 2018; Millard et al. 2018). The process of developing liming doses sufficient to increase soil base cation saturation to 20% relied on soil chemistry data measured in the project area (table 1) and is described in detail in appendix B.

pH. Soil pH was selected as a secondary, qualitative metric because it is an informative and easily measurable soil parameter to describe acidification. Soil pH was not selected as the primary soil metric because it reflects the combined interactions of a broad range of chemicals within the soil, not just those added or removed by acid deposition or proposed liming. For example, organisms and plant roots in the soil produce carbon dioxide, which turns to carbonic acid in the soil and causes fluctuating soil pH values in response to temperature and precipitation. Soil pH is influenced by biological, chemical, and physical properties of soil, which make it difficult to predict how pH may change within Meadow Run soils in response to liming or to changes in other metrics of soil chemistry.

Presently, Meadow Run soil pH values (table 1) are considered "extremely acidic" (USDA-NRCS 2017). An increase in soil pH to "very strongly acidic" values (4.5 to 5.0) and/or "strongly acidic" values (5.1 to 5.5) would benefit soil health, for the reasons described below.

Soil Exchangeable Aluminum. Exchangeable aluminum was selected as a secondary, qualitative metric because it increases with acidification to levels that are toxic to most soil and plant life (Tomlinson 1990). A high exchangeable aluminum ion concentration in soil, especially relative to base cations, is often described as aluminum toxicity because of its harmful and sometimes lethal impact on most soil organisms and plants. Soil exchangeable aluminum was not selected as the primary soil metric because, similar to soil pH, it reflects complex chemical interactions in the soil that make it difficult to predict a target outcome based on measured soil properties and proposed dosing. However, a decrease in exchangeable soil aluminum concentrations and an increase in the soil Ca:Al ratio would provide a beneficial impact. Within Meadow Run, nearly half the soil sites sampled in 2019 had Ca:Al ratios below the threshold value of 1.0, indicating probable soil aluminum toxicity for most plants at those sites (table 1; Sharpe et al. 2019).

Alternative A: No Action

Under the no-action alternative, the conditions and trends discussed in chapter 3 would continue. Soils in the Meadow Run project area would remain extremely acidic. Soil base cation saturation, pH, and Ca:Al ratios would remain low, and occurrence of aluminum toxicity would remain high. These existing adverse conditions, caused by historical acidic deposition from air pollutant emissions, would continue for well over 100 years and would, in turn, continue to adversely affect other resources throughout the watershed that rely on less acidic soils.

Alternative B: Split-dose Liming

Under alternative B, soils in the project area would be targeted to receive sufficient limestone sand to increase base cation saturation from less than 12% to 20% of CEC (down to a depth of 80 cm). Base cation saturation of 20% is a well-established threshold for terrestrial ecosystem health that has been used as a target for previous terrestrial liming projects (Sullivan et al. 2013; George et al. 2018; Millard et al. 2018). The expected increase to a base cation saturation of 20% leaves the remaining 80% of CEC occupied by acid cations (i.e., the hydrogen and aluminum ions).

Under this split-dose alternative, soils that are more depleted in base cations would receive a higher dose of limestone sand. These more depleted soils generally exist over the Harpers Formation bedrock geology that is found in the eastern half of the Meadow Run project area, closest to Skyline Drive (figure 7). Soils formed on the Harpers Formation have higher CEC values and previously had higher base cation concentrations before acidification. Therefore, more limestone sand is required to increase base saturation to the target of 20%. See appendix B for details on limestone dosing. Soils that are not as depleted in base cations would receive a lower dose of limestone sand.

Liming would provide several intended, measurable, beneficial impacts on soils for well over 100 years. The limestone sand would take less than a year to become physically incorporated into the organic horizon (USFS 2018) but would take longer to mix deeper into the soil. Based on previous studies, measurable improvements to soil base cation saturation, pH, and reduced aluminum toxicity should be observable within a year and would continue to improve for years or decades as limestone sand is gradually integrated fully into the deeper soil horizons (Juice et al. 2006; Pabian and Brittingham 2007; Pabian et al. 2012a; Pabian et al. 2012b; Moore et al. 2012; Melvin et al. 2013; Long et al. 2015; Mizel et al. 2015; Lawrence et al. 2016). A more detailed discussion of these expected benefits and their duration is provided in appendix B.

Under alternative B, the liming doses are intended to increase base cation saturation to 20%, which would in turn likely increase the soil pH throughout the project area by roughly 0.5 to 1.0 units. The soil pH would slowly increase over decades before it plateaus at final pH values likely between 4.4 to 5.1 for most soils in the project area. The soil pH is not expected to increase above 5.5. These estimated ranges are based on (1) measured soil chemistry at 46 sites in the Meadow Run project area (Sharpe et al. 2019); (2) the post-liming target of 20% base cation saturation plus a contingency factor of 1.5 that could result in up to a 30% base saturation if all the limestone sand were to be incorporated in exchangeable cations without any loss (similar to George et al. [2018] and Millard et al. [2018]); and (3) studies that show how pH and base cation saturation vary together in typical soils. Appendix B provides evidence to support these estimated ranges.

Potential secondary beneficial impacts on soils from liming could include increases in soil carbon, bioavailable nitrogen, and bioavailable phosphorus (Groffman and Fisk 2011; Melvin et al. 2013). Calcium additions have increased forest growth and soil carbon storage (Groffman and Fisk 2011) and altered soil microbial communities (Carrino-Kyker et al. 2016; Narendrula-Kotha and Nkongolo 2017) that maintain soil fertility by transforming nitrogen. Another beneficial impact of liming is that soil phosphorus would likely become more bioavailable to plants (Havlin 2005; Carrino-Kyker et al. 2016). Present values of extractable, bioavailable soil phosphorus are very low in the Meadow Run project area (7.2 ±7.6 ppm; table 1); bioavailable phosphorus is expected to increase with liming.

Trends associated with climate change—potentially higher average temperatures, more precipitation, and more extreme storms (NPS 2020b)—may lead to slightly increased dissolution rates of limestone sand into exchangeable base cations. This would lead to a slightly faster recovery from acidic deposition and faster improvements for the terrestrial and aquatic ecosystems. Faster dissolution and leaching rates would not decrease the duration of liming benefits (lasting well over 100 years) under alternative B.

Conclusion. Liming would provide several intended, measurable, beneficial impacts on soils for well over 100 years, including higher soil base cation saturation concentrations and pH values, and reduced occurrence of aluminum toxicity. In turn, improved soil conditions would support recovery of stream water quality, native vegetation, and wildlife. The improved soil conditions should be observable within a year and would continue to improve for years or decades as limestone sand is gradually integrated fully into the deeper soil horizons. Additional benefits to soils would include increased phosphorus bioavailability, increased microbial diversity and activity, and increased organic carbon and nitrogen stocks, all of which contribute to soil fertility and forest health. These benefits would reverse the degradation to soil health caused by decades of acidification and improve the long-term health of the terrestrial and aquatic ecosystems. Adverse impacts on soils are not expected.

Alternative C: Uniform-dose Liming

The overall objective of alternative C is identical to the objective of alternative B, but the implementation plan would be simplified by applying a uniform dose across the project area. Impacts under alternative C would be similar to impacts described for alternative B, except that benefits would be more spatially variable because the liming dose would not be as closely targeted to location-specific soil base cation deficits. Under alternative C, there would be a smaller percentage of sites that would receive the limestone sand needed to achieve the target of 20% base cation saturation. For example, it is estimated that only 77% of soil sampling sites would receive sufficient limestone sand under alternative C to meet targeted base cation saturation, relative to 84% under alternative B (Sharpe et al. 2019; appendix B). Uniform-dosing might therefore modestly reduce the beneficial impacts for about 7% of the project area. Nevertheless, the uniform dosing of alternative C would still reduce acidity and increase soil pH for the entire project area. In cases where sites might receive more limestone sand than needed (i.e., enough limestone sand to increase base cation saturation to as much as 30%), this additional base cation saturation would still likely keep pH values in the soil below 5.5 similar to alternative B.

Conclusion. Similar to alternative B, liming under alternative C would provide numerous long-term, beneficial impacts on soils for well over 100 years, including higher soil base cation saturation concentrations and pH values, increased phosphorus bioavailability, and reduced aluminum toxicity. This would reverse the degradation to soil health caused by decades of acidification and improve the long-term health of the terrestrial and aquatic ecosystems. The primary difference between alternatives B and C is that uniform liming would more likely exceed base saturation targets in some portions of the watershed while other areas would remain modestly below target levels. Therefore, beneficial impacts would be more spatially variable under alternative C. Adverse impacts on soils are not expected.

WATER QUALITY

Methods and Assumptions

The analysis of potential impacts on water quality is based on a review of water quality data collected by SWAS-VTSSS and the park over several decades, literature on effects of liming on stream chemistry from other liming projects, and information obtained from the science team (Science Team, pers. comm. 2019c). Groundwater quality was derived from soil chemistry and stream water quality data collected during baseflow conditions, especially for mountain streams in the park with very shallow groundwater and residence times of zero to three years (Busenberg and Plummer 2014).

After review of the literature and consultation with the science team, three metrics were used to assess impacts on water quality—ANC, pH, and dissolved aluminum.

Acid Neutralizing Capacity (ANC). The primary metric for surface water quality in the project area is ANC, which is the key property that determines a water's ability to neutralize or buffer acidic inputs. ANC has become the basis for distinguishing acidified streams and lakes (Bulger et al. 1999; Jastram et al. 2013; Blum et al. 2018). The target ANC concentration is 50 μeq/L because brook trout populations are believed to be stressed at stream ANC values below 50 μeq/L and injured or killed at stream ANC values below 20 μeq/L (Bulger et al. 2000; Cosby et al. 2006). As stated in chapter 3, pre-industrial ANC values in Meadow Run were estimated to be 69 μeq/L before acidic deposition occurred (Sullivan et al. 2004; Sullivan et al. 2008).

pH. Stream water pH was selected as a secondary, qualitative metric because it is easy to measure and is an important water quality parameter that describes acidification. Stream water pH was not selected as the primary metric because, similar to soil pH, it reflects a broad range of dissolved chemicals, not just those added or removed by acid deposition or proposed liming. For example, dissolved carbon dioxide produced by the activities of aquatic organisms naturally turns into carbonic acid, causing daily and seasonal stream pH fluctuations that are unrelated to acidification or liming. Also, high flows from storms cause decreases in stream pH (Riscassi et al. 2019). VADEQ (2020) sets the pH criteria for water quality as 6.0 to 9.0 for all waters except for swamps.

Dissolved Aluminum. Stream water dissolved aluminum was selected as another secondary, qualitative metric because high concentrations have been shown to increase mortality of brook trout (Baldigo et al. 2007). Dissolved aluminum was not selected as a primary metric because dissolved aluminum depends on many other factors that are not related to acidic deposition or proposed liming, including flow conditions (Riscassi et al. 2019). Total monomeric aluminum is the form of dissolved aluminum measured in Meadow Run, but other forms and analytical methods exist. A decrease in concentrations of any form of dissolved aluminum would have a beneficial impact to water quality.

Alternative A: No Action

Under the no-action alternative, acidic groundwater from the Meadow Run watershed would continue to flow into the stream, keeping the stream water acidic. The water quality in Meadow Run would continue to suffer the adverse impacts of acidic deposition for well over100 years, including ANC values below 5 μeq/L, pH values below 5.5, and total monomeric aluminum concentrations as high as 20 μg/L or more at higher flows. Without taking action to improve water quality, the aquatic habitat would continue to be unsuitable to support fish and other aquatic organisms that are representative of a healthy stream (Bulger et al. 1999, 2000). Meadow Run would also retain its listing as an impaired waterbody under Section 303(d) of the CWA (VADEQ 2020).

Alternative B: Split-dose Liming

Groundwater and Surface Water Quality in the Project Area. Liming would reduce the acidity in the soil and groundwater. As a result, the less acidic groundwater flowing into Meadow Run would improve the stream's water quality. Specifically, liming proposed under alternative B would provide several intended, measurable, beneficial impacts on water quality for well over 100 years. Stream baseflow ANC values are likely to increase to >20 μeq/L and pH to >6.0 within a year of liming, based on reports from previous liming projects (Williams and Downey 2011; Cho et al. 2012; Millard et al. 2018). Episodic acidification during storms would be less intense because runoff would flow through soils treated with limestone sand. In the long term, the stream water would become increasingly buffered and maintain higher stream ANC and pH and lower dissolved aluminum concentrations and toxicity during all flow conditions.

Some studies have identified unintended consequences of liming, such as increased stream sulfate, dissolved organic carbon (DOC), and mercury (Millard et al. 2018). Such changes to sulfate and DOC do not have an adverse impact on water quality (Lawrence et al. 2016), and mercury toxicity is not likely to increase for many reasons, including the fact that the bedrock and soils in the Meadow Run project area have very low mercury content (Rask et al. 2007; Shastri and Diwekar 2008).

Alternative B would also support a water quality restoration plan required under CWA Section 303d due to Virginia listing the upper 8.82 miles of Meadow Run as Category 5a Impaired Waters for aquatic life as a result of low pH. Under federal law, this listing requires a TMDL cleanup plan or TMDL-alternative plan to be developed and implemented for Meadow Run. Currently, VADEQ has listed Meadow Run as medium priority for TMDL development, which indicates that plan development would be scheduled sometime in the next six-year cycle (i.e., from 2023 to 2028; VADEQ 2020). Implementing alternative B could potentially serve as a TMDL-alternative plan or potentially serve to de-list Meadow Run as Impaired Waters because the expected post-liming baseflow pH values would increase in less than a year to within the pH criteria of 6.0 to 9.0 set by Virginia for Class IV (mountainous zone waters) and Class VI (natural trout waters) streams (VADEQ 2020). Park staff coordinates with VADEQ on intensive data collection under the state's Water Quality Assessment program. VADEQ and park staff are monitoring pH every other month, so delisting Meadow Run as 303d Category 5 could potentially occur a few years after liming.

The dose of limestone sand is not expected to cause siltation or change the appearance of the streambed downstream of the project area. The limestone sand at the proposed doses would remain largely on the forest floor; there is no evidence in the project area of runoff erosion caused by concentrated overland flow during rainstorms or snow melt. The limestone sand grains that fall directly into the stream may be visible within the project area for several months, but they would increasingly become less visible as they get mixed into the streambed. Limestone sand is unlikely to be visible in the streambed outside the project area because of dilution and dispersion.

Groundwater Quality outside the Park. Impacts from the proposed action on groundwater quality outside the park would be minimal for two reasons:

- Most of the groundwater is expected to flow into the stream because the slopes in the project area dip toward Meadow Run and its tributaries, and bedrock is typically shallow, which causes groundwater to emerge after only short travel distances.

- Any groundwater that may move along bedding planes and fractures in the bedrock to areas outside the project area would have a slightly higher pH after liming. Specifically, liming would increase the current pH values in the soil and groundwater (approximately 4.0 to 4.4) in the project area to values between approximately 4.5 and 5.5 (see "Soil Chemistry" in chapter 4). While the groundwater would still be very strongly acidic, these pH values would be closer to the secondary drinking water standard for pH of 6.5 to 8.5 (USEPA 2020a). Liming would not introduce any contaminants to the soil or water.

Therefore, should groundwater be tapped as a drinking water source near the project area, its quality would be slightly improved by a higher pH, although considering the slow rate of dissolution of the applied limestone sand into the groundwater and mixing with groundwater from unlimed areas, changes in pH in the groundwater by the time it has migrated to the areas outside the project area may be too small to be measurable.

Stormwater Runoff during Implementation. During limestone sand application, stormwater runoff impacts from any staging areas would be minimal with the use of soil and limestone sand erosion mitigation measures such as placement of haybales, silt fences, and tarps.

Conclusion. Liming would provide several intended, measurable, beneficial impacts on water quality for well over 100 years—beneficial increases in stream ANC and pH and beneficial decreases in stream dissolved aluminum. Baseflow ANC values are likely to increase to more than 20 μeq/L, which would indicate that the stream is no longer acidified (Bulger et al. 1999; Jastram et al. 2013; Blum et al. 2018). Stream pH is expected to increase to more than 6.0, which would bring Meadow Run into a pH range for healthy mountainous streams and natural trout streams as set by VADEQ (2018). This improvement would support removing Meadow Run from Virginia's Section 303d list of Category 5a Impaired Waters and thereby meet requirements under federal law to develop and implement a TMDL mitigation plan. Benefits should be observable within a year and would continue to improve for years or decades as limestone sand is gradually integrated fully into the deeper soil horizons. Adverse impacts on water quality are not expected.

Alternative C: Uniform-dose Liming

The overall objective of alternative C is identical to the objective of alternative B. Impacts on water quality under alternative C would be similar to impacts described for alternative B, especially for the lower reaches of the stream. Compared to alternative B, uniform-dose liming under alternative C might result in greater differences in the responses of tributary streams from the less precise targeting of limestone sand to soil differences. For example, the tributaries that drain the ridge along Skyline Drive to the east all have headwaters in the Harpers Formation, whose soils have a higher base cation deficit than those on the Antietam Formation along the tributary on the western side and along the main Meadow Run channel. Under alternative C, the stream water ANC and pH of the eastern tributaries in the project area might not improve as quickly (or by as much) as the western tributaries.

Conclusion. Similar to alternative B, liming under alternative C would provide numerous long-term, beneficial impacts on the water quality in Meadow Run for well over 100 years, including beneficial increases to stream ANC and pH and beneficial decreases to stream aluminum. The primary difference between alternatives B and C is that beneficial impacts would be more spatially variable with uniform dosing, with some tributary streams improving more slowly or not as much as other tributary streams because their catchments might receive less than the ideal dose to fully reach soil base saturation target levels.

AQUATIC WILDLIFE (FISH AND MACROINVERTEBRATES)

Methods and Assumptions

Analysis of potential impacts on aquatic wildlife is based on a review of existing literature, data, maps, and applicable water quality regulations. This information includes fish and aquatic macroinvertebrate data collected by the park over several decades, information from other liming projects, and information obtained from the science team (Science Team, pers. comm. 2019b).

The key metric selected for fish and macroinvertebrates is the observed presence or absence of acid-sensitive species in studied stream reaches. Repeated non-zero counts of previously absent acid-sensitive species would provide an indicator of some recovery from acidification. For example, blacknose dace (*Rhinichthys atratulus*) appears to be acid-sensitive (Jessup et al. 2019; Science Team, pers. comm. 2019b) and has not been observed in the Meadow Run project area since 2010 despite being commonly found before then. Blacknose dace still occurs in downstream reaches outside the park. Therefore, the return of blacknose dace to the project area (i.e., changing study counts from zero to many) would be considered a metric of a beneficial impact to aquatic wildlife. The return and/or increased abundance of acid-sensitive macroinvertebrate species (e.g., mayfly) may also provide a relevant metric.

Alternative A: No Action

Acid-sensitive fish and macroinvertebrates do poorly in streams with lower pH, such as Meadow Run. Low pH reduces survival, particularly for young individuals. Such effects can cascade through aquatic food webs such that predator species might be indirectly yet severely impacted if their prey organisms are sensitive to acidity at one point in their life cycles. As a result, some species have disappeared from the area because of the extremely acidic environment. Under the no-action alternative, these conditions would continue. The water in Meadow Run and its tributaries in the project area would remain acidified for well over 100 years. Meadow Run within and downstream of the project area would continue to exhibit depressed biodiversity and abundance of aquatic macroinvertebrates and fish and decreased reproduction of sensitive fish species such as brook trout. Blacknose dace have disappeared from the project area since 2010. Brook trout populations in Meadow Run have low body weight at a given length compared to streams with higher pH values. Acid-sensitive aquatic macroinvertebrate species could continue to decline.

Alternative B: Split-dose Liming

Liming would change the stream water pH over several years, which would improve the habitat for aquatic wildlife and potentially lead to an increase in the abundance and diversity of fish and macroinvertebrates in the stream. Specifically, liming would provide several measurable, beneficial impacts on these species for well over 100 years. Improvements in community metrics are expected to occur over time, although exact recovery time is difficult to predict.

Liming aquatic ecosystems has been shown to strongly reverse the adverse impacts on aquatic chemistry and to generally restore the aquatic biological communities by increasing abundance and richness of acid-sensitive invertebrates and fish (Hudy et al. 2000; McClurg et al. 2007; Cho et al. 2012; Mant et al. 2013; Lawrence et al. 2016; Shao et al. 2016). Following stream lime treatments in the Allegheny Plateau ecoregion of West Virginia, McClurg et al. (2007) found improvements in trout biomass, density, and reproductive success, and increases in fish and macroinvertebrate community richness that followed improvements in stream pH, alkalinity, and dissolved calcium after liming, compared to pre-treatments conditions. In the St. Mary's River, Virginia, blacknose dace (*Rhinichthys atratulus*) returned within a year or two after instream liming (Science Team, pers. comm. 2019b; USFS, Kirk, pers. comm. 2019).

Similar improvements are expected in the Meadow Run project area after liming. Specifically, blacknose dace would likely return, and either brook trout abundance or adult body condition (weight/length) would increase. Healthy fish species populations typically put their energy either into storage as body mass or into reproduction, but rarely both at the same time because of a variety of factors that are hard to predict (Science Team, pers. comm. 2019b). In addition, the occurrence and abundance of acid-sensitive aquatic macroinvertebrates, such as mayflies, would likely increase.

Furthermore, the numerous benefits of liming to aquatic wildlife are likely to increase their overall resilience to the future stressors resulting from climate change (Robison and Scanlon 2018). For example, liming would substantially reduce the episodic acidification that is expected from increasing storm size and frequency associated with climate change (Riscassi et al. 2019; NPS 2020b). Other improvements in aquatic species biology, including body condition or overall species abundance, are also expected to increase general resilience of aquatic wildlife populations to other environmental stress factors such as climate change impacts, including episodic high water temperatures during heat waves.

No adverse impacts on aquatic communities are expected in the Meadow Run project area as a result of a split-dose liming strategy. Clair and Hindar (2005) conclude after reviewing liming projects in Europe and North America that the "use of lime or dolomite on either catchment of waterbodies is not deleterious to aquatic ecosystems in the short or long term." Liming is also beneficial for aquatic organisms other than fish and macroinvertebrates; see discussion on salamanders in "Terrestrial Wildlife" below.

Conclusion. Liming would have several long-term, beneficial impacts on aquatic wildlife for well over 100 years. Liming would reverse the adverse impacts from acidic deposition on water quality, which would result in a return or increase in abundance and richness of acid-sensitive fish and macroinvertebrates, such as blacknose dace, brook trout, and mayflies. Expected improvements in aquatic ecological integrity would also increase general resilience of aquatic wildlife populations to climate change impacts. Adverse impacts to aquatic wildlife are not expected.

Alternative C: Uniform-dose Liming

The overall objective of alternative C is identical to the objective of alternative B. Therefore, the beneficial impacts to aquatic wildlife under alternative C are expected to be generally similar to the impacts described for alternative B, especially in downstream reaches. Compared to alternative B, uniform-dose liming under alternative C might result in greater differences in the responses of tributary streams because of the less precise targeting of limestone sand, as described in above under "Water Quality."

Conclusion. Similar to alternative B, liming would provide a number of long-term, beneficial impacts on aquatic wildlife for well over 100 years, including the likely return or increased abundance of acid-sensitive species such as blacknose dace, brook trout, and mayflies. The primary difference between alternatives B and C is that beneficial impacts would be more variable among tributaries of differing types of bedrock within the project area under alternative C. This might result in the aquatic wildlife in some tributaries benefiting more slowly or not as much as in other tributaries. Adverse impacts on aquatic wildlife are not expected.

VEGETATION

Methods and Assumptions

The analysis of impacts on vegetation considers the effects of increased soil pH and nutrient availability over the long term. These impacts were assessed by examining data and information on vegetation for the park, scientific literature, and information obtained from the science team (Science Team, pers. comm. 2019d). This section analyzes the impacts on dominant and codominant native vegetation, rare native vegetation, and the potential for the spread of non-native invasive vegetation as a result of this project.

Alternative A: No Action

Under alternative A, the conditions, trends, and planned actions discussed for dominant and codominant native vegetation, rare native vegetation, and non-native invasive vegetation in chapter 3 would continue. The current acidic soil conditions would favor plant species that are typically found in lower pH soils such as pitch pine (*Pinus rigida*), which is the most acidophilic tree species in the project area (table 3). However, the health, growth, and survivorship of calciphilic plants (i.e., plants that thrive in calcium-rich soils) such as sugar maple (*Acer saccharum*) would remain degraded. The current acidic soil conditions may also continue to limit the spread of non-native invasive plant species.

Alternative B: Split-dose Liming

Dominant and Codominant Native Vegetation. Under alternative B, the dominant and codominant native plant species would remain in the project area over the long term because they are found as seedlings, saplings, young trees, and mature trees within each layer of the forest (i.e., understory, mid-story, and overstory) (Young et al. 2009). Raising the soil pH to levels between 4.4 to 5.1 would maintain the soil conditions in which most of these species typically grow (table 3) (Zobel 1969; Lamson 1990; Tirmenstein 1991a; Carey 1992; Demchik and Sharpe 1998; Reeves 2007; Gucker 2007).

TABLE 3. SOIL PH RANGES FOR PLANT SPECIES WITHIN OR NEAR THE PROJECT AREA

Common Name	Scientific Name	Typical pH Range		Sources; Notes
		Low	High	
Dominant and Codominant Plant Species				
Yellow birch	*Betula alleghaniensis*	4.0	8.0	a, f
Sweet birch	*Betula lenta*	3.6	6.8	a, f
Table Mountain pine	*Pinus pungens*	4.5	7.0	a, f
Pitch pine	*Pinus rigida*	3.5	5.1	a, f
Chestnut oak	*Quercus prinus*	4.5	6.5	a, f
Red oak	*Quercus rubra*	4.3	7.3	a, f
Eastern hemlock	*Tsuga canadensis*	4.2	5.7	a, f
Sugar maple	*Acer saccharum*	3.7	7.9	a, f
Maximum pH range		*3.5*	*8.0*	
Non-native Invasive Plant Species				
Tree-of-heaven	*Ailanthus altissima*	4.1	7.9	a, f
Garlic mustard	*Alliaria petiolata*	5.0	7.2	b
Oriental bittersweet	*Celastrus orbiculatus*	5.0	7.5	a, f
Japanese honeysuckle	*Lonicera japonica*	4.9	7.8	a, f
Stiltgrass	*Microstegium vimineum*	4.6	6.3	c
Empress tree	*Paulownia tomentosa*	4.5	7.5	a
Oriental lady's thumb	*Persicaria longiseta*	4.8	8.0	d, g
Wineberry	*Rubus phoenicolasius*	6.0	8.0	e
Maximum pH range		*4.1*	*7.9*	

Sources: (a) USDA-NRCS 2020b; (b) Anderson 1995; (c) Fryer 2011; (d) Cao 2008; (e) NCSU 2020; Innis 2005.

Notes: (f) USDA-NRCS (2020b) PLANTS website lists pH under "growth requirements" for each tree and states that plant characteristics were compiled "from the scientific literature, gray literature, agency documents, and the knowledge of plant specialists. …The values are best viewed as approximations since they are primarily based on field observations and estimates from the literature, not precise measurements or experiments."
(g) Species not documented within the project area, but nearby.

As noted under alternative A, pitch pine is the most acidophilic of the tree species in the project area. It is typically found on thin, dry, coarse-textured, infertile soils with a pH of 3.5 to 5.1 and is known to be tolerant of soils that are less acidic than its preferred habitats. Several studies indicate that pitch pine would also tolerate soil pH condition higher than 5.1 that may exist in some parts of the project area following liming (Gucker 2007; Plass 1969; Demchik and Sharpe 1998; Hwang 2007). For example, Gucker (2007) found that pitch pine seeds germinated equally well at all studied pH levels from 4.5 to 8.3. Plass (1969) did not observe any negative effect for pitch pine in an experimental liming study for treatments of pH of 3.5, 3.9, and 6.6. Any decreases in pitch pine abundance after liming in the project area would likely be due to natural replacement by other tree species in succession of this disturbance-adapted species. Therefore, liming within the project area is not expected to meaningfully reduce the existing stands of pitch pine.

Although the dominant and codominant native plant species typically grow on sites with low concentrations of calcium and magnesium, current concentrations in the upper mineral soil in the project area are low enough to stress many plants. Liming would increase the concentration and bioavailability of these nutrients in the project area, thereby improving growth and health (i.e., cellular function, wood formation, and photosynthetic processes) in shrubs and trees. Within a year of liming, increases in calcium and magnesium concentrations in the upper soil horizons would become bioavailable and start benefiting plants. However, it may take years to decades for the calcium and magnesium in the limestone sand to fully integrate into the deeper soil horizons and increase the entire exchangeable base cation pool; therefore, the full beneficial impacts from additional nutrients would occur over the long term.

Although most of the species in the project area are tolerant of high aluminum concentrations, the current soil Ca:Al ratios of on average 1.20 ±1.91 (table 1) demonstrate that nearly half of the project area vegetation is likely experiencing severe aluminum toxicity. Liming would reduce the solubility and bioavailability of aluminum and reduce the toxic effects on root cells and root growth of plants (Balter and Loeb 1983; Long et al. 2015; Gu et al. 2017). Some of the native acidophilic vegetation in the project area maintains its dominance by trapping nutrients, preventing the growth of other plants. For example, mountain laurel releases phenolic acid, which may inhibit soil nitrogen mineralization rates (i.e., the process by which organic nitrogen is converted to plant-available inorganic forms of nitrogen) in areas where mountain laurel is abundant (Huebner et al. 2014). Liming could increase nitrogen mineralization and bioavailability by raising the pH and bioavailable calcium in the soil, which would help other native vegetation and herbaceous plants in the project area better compete with species like mountain laurel (Sharpe et al. 1991; Groffman and Fisk 2011; Melvin et al. 2013). Liming has also been shown to increase species diversity among herbaceous plants, despite the high variability in individual plant responses to liming (Sharpe et al. 1991).

Liming could improve the health, growth, and survivorship of calciphilic plants found in the project area, giving them a slight competitive advantage over acidophilic plants. For example, although sugar maple occurs on soils with a pH range of 3.7 to 7.9 (table 3), it grows best on soils with a pH between 5.5 and 7.3 (Tirmenstein 1991b). Calcium fertilization has been shown to improve its foliage and fine root growth (Brandt and Rhoades 1972; Tirmenstein 1991b; Juice et al. 2006). However, sugar maple currently makes up only 0.3% of the spatial distribution of plant species within the project area, and therefore would likely not out-compete the dominant and codominant native plant species present.

Rare Native Vegetation. Due to their relatively small geographic range, the two rare native vegetation communities in the project area (Central Appalachian Montane Oak – Hickory Forest [Acidic Type] and Central Appalachian Chestnut Oak – Northern Red Oak / Heath Forest) are ranked as globally uncommon or at moderate risk for extinction. It is anticipated that the oak and hickory canopy tree species in these two rare communities would benefit from increased pH and nutrients in the soil. However, several of the understory species found within these communities such as Blue Ridge blueberry, pink azalea, and Pennsylvania sedge prefer acidic and infertile soil (Tirmenstein 1991c; Coladonato 1992; Cope 1992). Despite this, adverse impacts are anticipated to be minimal if they occur at all because the liming within the project area is not anticipated to increase the soil pH beyond the range tolerated by these species.

The two rare acidophilic plant species in the project area (bristly sarsaparilla and sword-leaf phlox) would not be affected because areas of their occurrence would be excluded from liming. Federally threatened or endangered plant species would not be affected because none are known to occur within the project area.

Non-native Invasive Vegetation. Eight non-native invasive plant species are known to occur in or near the project area. The response to liming by each species would likely vary according to their soil pH requirements, nutrient demands, and location in, or proximity to, the project area. Generally, the non-native invasive plant species found in the project area prefer acidic to neutral soil, with slightly higher soil pH requirements than native dominant and codominant native plant species (table 3).

Adverse impacts could occur from the spread of non-native invasive plant species in the project area because they would benefit from increased soil pH, calcium, and magnesium that in turn would increase the bioavailability of nitrogen, phosphorus, sulfur, and potentially potassium. In particular, there is a significant positive correlation between higher soil pH and the spread of garlic mustard; sites that are consistently higher in calcium, magnesium, nitrogen, and phosphorus are often invaded by garlic mustard (Anderson 1995; Rodgers et al. 2008).

Garlic mustard accounts for approximately 57% of the known non-native invasive plant occurrences in the project area. Garlic mustard is limited to the northeast section of Riprap Trail and the Appalachian Trail, which may be caused by disturbance from heavy foot traffic, a lack of competition from other plants, and adequate seed dispersal. Although garlic mustard is capable of invading undisturbed, closed-canopied forests, its ability to invade other portions of the project area would be contingent on the level of disturbance in the vicinity of existing populations (Nuzzo 1999). The potential for dispersal of garlic mustard seed depends on the proximity to existing infestations and the average dispersal distance of its seed. Without assistance, seeds disperse only 1 to 2 meters (3.2 to 6.5 feet) from parent plants (Nuzzo 1999). However, long-distance dispersal can occur by vehicle, animal, human, wind, or water transport. Long-distance dispersal could be exacerbated if liming increased forage quality and use of the area by animals such as white-tailed deer (*Odocoileus virginianus*).

Liming under alternative B would occur in the winter when species such as garlic mustard are no longer seeding. Areas with known non-native invasive plant infestations would be excluded from liming or treated with appropriate herbicide or mechanically or manually removed prior to project implementation (see chapter 2 for additional mitigation measures). Therefore, liming is not expected to meaningfully increase the dispersal of non-native invasive plants in the project area because (1) they have slightly higher soil pH requirements than dominant and codominant native vegetation, (2) most non-native invasive plant species (e.g., garlic mustard) are limited to the northeast section of Riprap Trail and the Appalachian Trail, and (3) mitigation measures would be in place to minimize the establishment and spreading of seeds during limestone sand application.

Conclusion. Under alternative B, impacts on vegetation would primarily be beneficial and long-term. Because of higher soil pH levels from liming, the increased bioavailability of calcium, magnesium, nitrogen, and phosphorus would improve plant growth and health over the long term, thereby improving the health of the forest overall. Alternative B would also reduce the bioavailability of aluminum in the soil, aiding the growth of plant roots. Liming could improve the growth of calciphilic plants found in the project area, giving them a slight competitive advantage over acidophilic plants. Acidophilic plants such as pitch pine are expected to tolerate liming at the proposed levels and continue to grow. While non-native invasive plants could spread under alternative B, the implementation of mitigation measures would minimize any adverse impacts.

Alternative C: Uniform-dose Liming

Impacts on vegetation under alternative C would be similar to those described for alternative B for dominant and codominant native vegetation, rare native vegetation, and non-native invasive plants. However, uniform-dose liming across the project area under alternative C—instead of targeting areas with greater base cation deficits under alternative B—could result in a less uniform or slower overall improvement to vegetative health in areas with substantial calcium/nutrient deficits.

Conclusion. Under alternative C, the impacts on vegetation would be similar to those under alternative B, although the approach could result in a less uniform or slower overall improvement to vegetative health in areas with substantial calcium/nutrient deficits, (i.e., a slightly less effective improvement of the health of the forest). Like alternative B, the potential risk of spread of known non-native invasive plant species is expected to be minimal with the use of mitigation measures.

TERRESTRIAL WILDLIFE (BIRDS, SALAMANDERS, AND SNAILS)

Methods and Assumptions

The analysis of impacts to terrestrial wildlife considers activities during limestone sand application (i.e., dropping of limestone sand grains from the air onto the forest floor) and long-term effects on habitat from an increase in base cation saturation of the soil. Impacts are focused on birds, salamanders, and snails. Other sources included relevant scientific literature and information obtained from the science team (Science Team, pers. comm. 2019e).

Alternative A: No Action

Under the alternative A, the conditions and trends discussed in chapter 3 would continue. Birds, salamanders, and snails would continue to experience the effects of extremely acidic soils. Limited calcium availability in such soils and important prey items (e.g., snails) may continue to affect reproduction for birds. Acidic soils may continue to limit growth rates and cause developmental abnormalities in salamanders. Acidic soils would also affect the growth of shells of land snails. They are one of the more acid-sensitive invertebrate groups because they have calcified shells and are sensitive to both pH and calcium availability in their environment (Hotopp 2002).

Alternative B: Split-dose Liming

Potential impacts from liming on birds, salamanders, and snails could occur in the short term (i.e., during the application period of up to three months) and over the long term after liming occurs. In general, because improvements in soil conditions should be observable within a year and would continue to improve for years or decades as limestone sand is gradually integrated fully into the deeper soil horizons (as indicated in the section "Soil Chemistry"), any long-term impacts for birds, salamanders, and snails would follow a similar timeline.

Birds. Approximately 30 species of birds are year-round residents of the park (NPS 2020c, 2020f) and could occur within the Meadow Run project area during the liming period (December–February). Falling limestone sand is not expected to have adverse impacts on birds because of the low falling force of the sand grains, and because birds would likely leave the area during application. Any disturbance from the flying helicopter during the release of limestone sand over specific locations in the project area would be brief (less than a minute). Ingestion of the limestone sand by birds would not result in adverse effects because birds normally ingest stones and other particles (i.e., grit) for essential minerals and improved digestion (Downs 2019), and some birds preferentially ingest limestone or other calcareous grit (Gionfriddo and Best 1999). Grit retention time is typically only from one to a few days (Bennett et al. 2011).

Over the long term, the application of limestone sand would have beneficial impacts for birds, especially for species that forage on the ground and in the understory. Studies on the impacts of liming in forests in the northeastern United States demonstrate that birds generally benefit from increased calcium availability in invertebrate prey items, such as snails and millipedes (e.g., Pabian et al. 2012b; Wäreborn 1992). Birds must acquire calcium in their diets to create eggshells because they store little to no calcium in their skeleton, and many forest songbirds in acidified forests are calcium-limited (Hames et al. 2002). Research indicates that birds are limited by snail abundance in northern hardwood forests, and land snail abundance and/or richness increases with increasing calcium content in soil (Johannessen and Solhøy 2001; Hotopp 2002; Hamburg et al. 2003; Beier et al. 2012; Moore et al. 2015). Following liming in Pennsylvania, Pabian (2010) found that ovenbird (*Seiurus aurocapilla*) abundance, nest density, territory density, and clutch size increased. Pabian et al. (2012b) observed an overall increase in the abundance of ground- and understory-foraging birds; there was no change in the abundance of canopy-foraging birds. Beneficial effects from liming on bird reproductive success have also been reported in Europe (e.g., Tilgar et al. 2002). Ground- and shrub-nesting birds could also benefit because liming could cause an overall increase in herbaceous vegetation cover, diversity, and biomass (Kulmatiski et al. 2007; Sharpe et al. 2006; Pabian et al. 2012b).

Salamanders. Moore (2014) demonstrated that contact with finely ground lime had no adverse impact on the health and survival of the eastern red-backed salamander, a widespread and common species; his findings were based on a 5-month experiment designed to evaluate whether finely ground lime or limestone sand might clog the salamander's pores or otherwise adversely impact its survival or health. Seagle and Curd (1994) also reported no short-term effect of liming on this species. Although these authors only studied one salamander species, their findings suggest that other salamanders might have similar tolerances to direct contact with limestone sand and its effects on their habitat. Considering these results, and the fact that salamanders would be hibernating (dormant) during the application period (December–February), short-term impacts from the limestone sand application are unlikely.

Over the long term, increasing the soil pH would generally have beneficial impacts on terrestrial salamanders (Frisbie and Wyman 1991; Wyman and Jancola 1992). Liming could increase the number of invertebrate prey available for salamanders (Ormerod and Rundle 1998). Beier et al. (2012) observed a connection between the concentration of calcium in northern hardwood forests and the health and size of eastern red-backed salamanders, which could be due to the species' pH sensitivity during reproduction and toxic aluminum mobilized in acidified soils. However, Moore (2020) found no effect of liming on the body condition of eastern red-backed salamanders after five years, and Cameron et al. (2016) found no long-term effect of liming on red-backed salamander population demographics or density of this species, but did suggest that a higher pH may adversely affect arthropods and, thereby alter red-backed salamander prey communities. In summary, although liming is not expected to have adverse impacts on salamanders, the extent of beneficial impacts on the various salamander species is expected to vary and depend in part on how an increase in soil pH would affect prey populations and competition among salamander species.

Snails. There would be no short-term impact during liming because land snails would be hibernating in sheltered places such as in leaf litter or under stones during the application period.

Over the long term, liming under alternative B would increase the abundance and/or species richness of land snails because they have a need for high calcium content in the soil (Beier et al. 2012; Wäreborn 1992). From three to seven years after the addition of calcium to an experimental watershed in New

Hampshire, Skeldon et al. (2007) found snail abundance was 73% higher in a treated watershed than a reference watershed.

Conclusion. Under alternative B, there is little to no potential impact of falling limestone sand on birds, salamanders, or snails because the falling force of limestone sand grains would be low; birds would likely leave the area during application; and snail and salamander species would be sheltered and hibernate beneath the leaf litter, soil, or stones during the application period. This is consistent with observations by researchers during the Lower Williams Terrestrial Liming Project in the Monongahela National Forest in 2018 where no direct effects to wildlife were found (USFS, Connolly, pers. comm. 2020). Liming is expected to have long-term benefits for these animal groups. Birds, especially ground- and understory-foraging species, would benefit from an increase in calcium-rich food items (e.g., snails) because birds require large amounts of calcium to produce eggshells and raise young. They could also benefit from an expected increase in herbaceous vegetation cover, diversity, and biomass. Some salamanders could experience more growth and reproduction because of increased availability of invertebrates and reduced aluminum toxicity. Snails are expected to become more abundant following the calcium addition because snails need calcium for shell development.

Alternative C: Uniform-dose Liming

Impacts on birds, salamanders, and snails under alternative C would be similar to impacts under alternative B. However, the uniform distribution of limestone sand across the project area under alternative C—instead of targeting areas with greater base cation deficits under alternative B—could result in less consistent and slightly less overall beneficial impacts for these animal groups because areas with substantial calcium/nutrient deficits would receive less limestone sand.

Conclusion. Under alternative C, liming would have long-term, beneficial impacts on birds, salamanders, and snails similar to the benefits described for alternative B, with a possibility that the benefits to these animals groups would be slightly lower under alternative C because improvements in soil conditions would be more varied throughout the project area.

WILDERNESS CHARACTER

Methods and Assumptions

The proposed action would affect three of the four tangible qualities of wilderness character that apply to the project area (i.e., untrammeled, natural, and opportunities for solitude or primitive and unconfined recreation). The undeveloped quality would not be affected by the project because there would be no developments in wilderness; therefore, this quality is not evaluated. The analysis applies to the actions taken within or adjacent to the project area under each alternative.

Alternative A: No Action

Under the no-action alternative, the trends and planned actions discussed in chapter 3 would continue. Specifically, the effects of acidic deposition on ecosystem processes would continue to affect the natural quality of wilderness character (e.g., soils, water resources, vegetation, and wildlife). For example, among the many metrics discussed so far, the health, growth, and survivorship of calciphilic plants in the project area would remain degraded, adversely affecting the natural quality of wilderness character. There would be no new impacts on wilderness character under the no-action alternative.

Alternative B: Split-dose Liming

Impacts on wilderness character under alternative B would be as follows:

- **Untrammeled:** Alternative B would intentionally manipulate chemical processes in the project area by replenishing base cations. Trammeling actions would include the aerial helicopter application of limestone sand to the forest floor. Limestone sand would be present on the forest floor for a few months following liming, adversely affecting the untrammeled quality of wilderness character for that period.

- **Natural:** Liming the project area would improve the natural ecosystem processes in soils, stream water, vegetation, and wildlife that have been degraded by acidic deposition. Therefore, liming would have a beneficial impact on the natural quality of wilderness character for well over 100 years.

- **Opportunities for Solitude or Primitive and Unconfined Recreation**: Solitude would be adversely affected by noise from helicopter operations in the project area, in nearby wilderness, and along flight paths from staging areas. Although no staging area would be located in wilderness, 80% of the project area (representing 2.2% of designated wilderness park-wide), as well sections of the park to the east and west of Skyline Drive between potential staging areas and the project area are wilderness. Therefore, most of the flights of the helicopter would occur over wilderness. In general, greater distances between staging areas and project area would increase the helicopter's total flight time over wilderness during the application period. It is anticipated that a maximum of 6 hours of flight time would occur over wilderness throughout a typical 8-hour day of operations. Noise levels would vary in intensity but are likely to be present at some level throughout the application period. Adverse impacts on solitude on wilderness inside and near the project area would last throughout the liming period (December–February). However, because the operations would be scheduled for this low-visitor-use period, the impact on visitors in wilderness areas would be substantially lower than during other times of the year with more visitors.

  Primitive and unconfined recreation, the second aspect of this wilderness quality, would be adversely impacted by safety closures in the project area and its trails, and nearby wilderness and backcountry areas in the South District. The duration of these closures would depend on the location of the staging areas, weather conditions, and other factors (see the section "Liming Season and Closures in the Park" in chapter 2 for details).

Conclusion. Under alternative B, limestone sand application would intentionally manipulate chemical and ecological processes in the project area, require the use of a helicopter and vehicles that generate noise and produce visual impacts, and require trail closures of varying duration during the application period of up to three months. These adverse effects on wilderness character could occur twice—in the event of a second limestone sand application, if necessary, in the future. However, alternative B would help the park meet its backcountry management goals identified in the *Backcountry and Wilderness Management Plan* (NPS 1998) by reducing adverse impacts on wilderness resources from acidic deposition. Wilderness resources that would experience long-term benefits (for well over 100 years) consist of soils, stream water, vegetation, and wildlife, which in turn would have long-term, beneficial impacts on the natural quality of wilderness character.

Alternative C: Uniform-dose Liming

Similar to alternative B, alternative C would intentionally manipulate chemical and ecological processes in the project area, require the use of a helicopter and vehicles that generate noise and other impacts, and require trail closures of varying duration during the period of limestone sand application, which would adversely affect wilderness character during this period. Assuming volumes of 5,250 and 5,500 tons to be applied under alternatives B and C, respectively, alternative C would take slightly longer to implement than alternative B, and the adverse impacts would occur over a correspondingly longer period. However, similar to alternative B, alternative C would reduce adverse impacts of acidic deposition on wilderness resources such as soils, water resources, vegetation, and wildlife and result in long-term, beneficial impacts on the natural quality of wilderness character.

Conclusion. Similar to Alternative B, Alternative C would also intentionally manipulate chemical and ecological processes in the project area, adversely affecting wilderness character during the application period of up to three months (or a total of up to six months if a second limestone sand application was done in another year), but would benefit the natural quality of wilderness character over the long term (i.e., well over 100 years).

ACOUSTIC ENVIRONMENT

NPS *Management Policies 2006* and Director's Order 47 require the agency to manage, preserve, and restore park acoustical environments and soundscapes (NPS 2000, 2016b). An intact natural soundscape enhances visitor experience and allows for natural wildlife communication. These policies require NPS to protect and restore the natural soundscapes of parks, including those that have been affected by unnatural and unacceptable noise. The Director's Order also directs park managers to measure acoustic conditions, differentiate existing or proposed human-made sounds that are consistent with park purposes, set acoustic goals based on the sounds deemed consistent with the park purpose, and determine which noise sources are impacting the parks (NPS 2000). The importance of the natural soundscape is also highlighted in the Wilderness Act of 1964 (16 U.S.C. 1131 et seq.), which states that one of the criteria defining wilderness is whether an area provides "outstanding opportunities for solitude or a primitive and unconfined type of recreation."

Noise from implementing the project could be a concern for park neighbors, particularly if one or more staging areas were located outside the park and were near buildings occupied by people or livestock. (As stated in chapter 2, the park would gain permission from landowners for staging areas outside the park and communicate with nearby landowners and affected neighbors.) Park visitors and wildlife could also be affected by noise within the park's natural soundscape by the intermittent inability to hear natural sounds during the day that would have been audible in the absence of human-caused noise from the project.

Methods and Assumptions

The baseline for evaluating potential impacts on the acoustic environment was developed using the available background sound measurements in the park (NPS 2016b). The ambient sound level exceeding 50% of the time (L_{50}) during the day was measured at 44 dBA (see chapter 3 for a description of soundscapes terminology). Noise levels in the zone for potential staging areas outside the park are also expected to be low for developed areas due to the rural setting. Background noise levels would be higher near Skyline Drive or other roadways but using 44 dBA as the background noise level ensures the potential impact is disclosed.

Truck Noise Levels. Trucks would deliver limestone sand to staging areas for initial stockpiling in November and during liming (December–February). For any staging area(s) outside the park, trucks may pass residences on rural county roads. The maximum noise level of a heavy truck using a full throttle at 25 miles per hour at a distance of 50 feet is approximately 80 dBA (FHWA 1998). The decrease in sound level with distance from the source (referred to as attenuation) depends on site-specific conditions such as the terrain conditions between the source and receiver, vegetation, ground cover, and meteorological conditions. A detailed analysis of truck noise in specific locations that considers these factors would be impracticable; however, a general understanding of the potential for impact can be obtained by assuming free-field attenuation (6 dBA per doubling of distance from the source). Additional intermittent noise from trucks, a bobcat, and/or front-loader would occur near the staging areas (e.g., back-up alarms, tailgate noise when dumping). However, the 80 dBA at 50 feet truck noise level is a reasonable basis for estimating the potential extent of these truck-related staging area noise impacts.

Helicopter Noise Levels. The USFS Lower Williams Terrestrial Liming Project in 2018 used a Boeing Vertol 107-II helicopter. A similar helicopter may be used for the Meadow Run project. The USFS conducted sound measurements for the Boeing Vertol 107-II helicopter during logging operations in Oregon (Harrison et al. 2007). At a horizontal distance of 200 feet from the helicopter, the maximum noise level for the Vertol 107-II was measured at approximately 92.5 dBA (average); the sound level decreased by approximately 6 dBA with every doubling of distance away from the helicopter. To provide context for the predicted helicopter noise levels for the Meadow Run project, the total flying time for limestone sand application was estimated using information provided by Columbia Helicopters, including assumptions for weather-related downtime and use of various staging areas. The predicted helicopter noise levels are provided below.

Noise Impact Criteria. An increase above the ambient sound level affects the ability of humans and animals to perceive other sounds within a certain distance. In general, the higher the ambient sound level, the shorter the distance from which other sounds (for example those of a songbird) can be heard. This concept is expressed in terms of listening area and alerting distance. In terms of impact metrics, a 3 dBA increase above the ambient sound level is an important indicator of potential impact because it results in a 50% reduction in listening area for humans and animals and a 30% reduction in alerting distance, as described below (NPS 2010).

Reduction in listening area quantifies the degradation of hearing performance in humans and animals as a result of an increase in ambient noise level. Under ambient sound conditions, a sound is audible within a certain area around a visitor or animal. If there is an increase over the ambient sound level due to a noise event, the area in which the sound is audible decreases. Table 4 shows the relationship between increases above the ambient sound level and listening area reduction at the frequencies where the increase occurs.

The primary impact criterion is based on the distance at which project impacts would result in a 3 dBA increase over ambient conditions (e.g., the distance at which the project noise level equals 44 dBA). An additional metric used is 60 dBA. This value is the sound level where normal communications at individuals standing 1-meter (3 feet) apart would be interrupted; this represents the sound level at which conversing would be affected (USEPA 1974).

TABLE 4. REDUCTION IN LISTENING AREA AND ALERTING DISTANCE DUE TO INCREASES IN AMBIENT SOUND LEVELS

50% dBA Ambient Increase	Percent Reduction in Listening Area	Percent Reduction in Alerting Distance
3	50%	30%
6	75%	50%
10	90%	70%
20	99%	90%

Alternative A: No Action

Under alternative A, the conditions and trends discussed in chapter 3 would continue. Liming would not occur and there would be no additional impacts on the acoustic environment in the project area and surrounding areas.

Alternative B: Split-dose Liming

Under alternative B, noise would be generated during the application period. The implementation plan to be prepared prior to liming would specify the staging areas to be used. There would be two primary sources of noise during project implementation—limestone sand delivery by truck and helicopter/equipment activity at the staging areas and during flights. Impacts described below pertain to one limestone sand application; in the event of a second application during a subsequent winter, the same impacts would apply.

Noise from Limestone Sand Delivery by Truck. Trucks would deliver limestone sand to the staging areas prior to and during the application period. Alternative B is expected to require 5,250 tons of limestone sand to be delivered to the staging areas over the course of the project:

- **Staging area(s) along Skyline Drive:** Noise receptors along Skyline Drive consist of terrestrial wildlife and park visitors (if limestone sand is delivered to any staging area where the drive is open to visitors). Wildlife and visitors are already sensitized to traffic noise along Skyline Drive, meaning that even with the removal of visitor traffic noise during any closure of a section of the drive, the addition of noise from truck deliveries would reasonably replace the noise levels from visitor traffic. Therefore, on balance, noise impacts from truck traffic on Skyline Drive would be considered minimal.

- **Staging area(s) outside the park:** Trucks would access any staging area (agreed to with landowners and affected neighbors) from Route 340 to the west. Noise impacts from trucks would depend on distance to Route 340, any weight restriction of rural roads that determine the minimum number of truck trips for some amount up to 5,250 tons of limestone sand, and the proximity of receptors (i.e., humans, wildlife, and livestock) along the rural roads between Route 340 and an agreed-to staging area(s). Assuming attenuation of 6 dBA per doubling of distance, truck pass-by noise could travel up to 3,000 feet before reaching the background noise level of 44 dBA. At this distance, the truck noise would increase the total noise level by 3 dBA over the background noise level, resulting in a 50% reduction in listening area. At distances of less than 500 feet from the roadway, truck noise would exceed 60 dBA, which is the sound level where normal communications between individuals standing 3 feet apart becomes difficult. These potential impact distances do not take into account site-specific factors such as the terrain conditions between the source and receiver (e.g., hill, ridges), vegetation, buildings and walls, and meteorological conditions, which could reduce the truck noise level exposure at receptors. If most, if not all, of the limestone sand to be used during liming were stockpiled at staging areas prior to the start of liming, the duration for limestone sand deliveries may be on the order of weeks to a month (to be determined prior to project implementation). However, the total effect of multiple truck trips occurring throughout the day over this period would have the potential for annoyance impacts for residents near affected rural roads.

Noise in Staging Areas and during Helicopter Flight for Liming. During days of operation, noise would be generated (1) at an active staging area, (2) along the helicopter flight path between an active staging area and the liming area, and (3) along the flight path to the helicopter service landing area (i.e., the landing area for periods of non-operation). Operations would occur from Monday to Friday, and on Saturdays and Sundays, if needed. If helicopter operations were to occur on Sunday, flights would only occur within the park boundary. Because multiple staging areas would benefit the efficiency of the operation, noise would likely be centered on and distributed to multiple locations. Operational considerations include the following:

- **Hovering elevation in staging areas:** The hovering distance of the helicopter above the ground during switching of buckets would be approximately 150 feet. For safety reasons, during flight from an active staging area to the liming area and during the limestone sand application itself, the distance between the helicopter and the top of the highest trees would be substantially greater. The duration of helicopter hovering above an active staging area would be approximately 30 seconds per trip.

- **Working time per day for limestone sand transport:** Working hours would depend on several factors, but primarily on weather. On a good-weather day, work would start within an hour after sunrise and last as long as possible until operations are not productive or safe because of insufficient light. Refueling and a lunch break by the pilots would require up to 2 hours each day. Therefore, if a full 8-hour day is possible, a maximum of approximately 6 hours would be available for flights with loaded buckets to lime the project area.

Noise at an active staging area during the limestone sand application period would consist of the following: (1) use of a bobcat or front-loader loading the liming spreader bucket to be lifted by the helicopter, (2) hovering of the helicopter over the staging area while the liming bucket is switched from an emptied bucket to a reloaded one, (3) flights from the staging area(s) to the area to be limed, and (4) potential landing of the helicopter at larger staging areas that have sufficient open space for landing during downtime or in an emergency. Noise from construction equipment on the ground (bobcat, front-loader) would be comparatively low. The largest source of noise would be the helicopter.

Noise from helicopter flights associated with alternative B would affect the acoustic environment of the Meadow Run project area for intermittent periods over the course of an 8-hour day during the application period of up to three months. However, helicopter noise would be localized and transient in nature from the helicopter passing through an area rather than remaining in an area for an extended length of time. Noise impacts from the helicopter would also depend on the location of an active staging area:

- **Staging area(s) along Skyline Drive:** Sections of Skyline Drive would be closed for visitor use if a staging area(s) along Skyline Drive were to be used. However, helicopter noise could affect park visitors in other areas of the park and neighboring communities outside the park. The closest distance of a residence to the project area is 0.3 miles (near the southern border of the project area); the closest distance of a residence to the center of the project area or to Riprap Overlook (a potential staging area along Skyline Drive) is 1.5 miles.

- **Staging area(s) outside the park:** Noise receptors would also include people and animals near any staging area(s) and flight paths outside the park. Flight paths would be over forested areas and open fields only; no flights would occur directly over residences or other buildings occupied by people or livestock. The 9-mile zone considered for a potential staging area(s) directly abuts the park and is not densely developed. Even though the flight paths would be over forested areas and open fields, some residences could be in the general flight path vicinity. Any residents would be contacted prior to project implementation, and arrangements made with the landowners of any staging areas and in the direct flight path between staging area and the park, as described in chapter 2.

Assuming attenuation of 6 dBA per doubling of distance, helicopter noise at an active staging area could travel up to 9.5 miles before reaching the background noise level of 44 dBA. At this distance the helicopter noise would increase the total noise level by 3 dBA over the background noise level, resulting in a 50% reduction in listening area. At distances of less than 8,440 feet (1.6 miles) from an active staging area, helicopter noise would exceed 60 dBA, which is the sound level where normal communications between individuals standing 3 feet apart would start to be affected and wildlife reactions would be likely. These potential impact distances are based on free-field attenuation and do not take into account site-specific factors such as the terrain conditions between the source and receiver, vegetation and other ground cover, buildings and walls, and meteorological conditions, which all would reduce the helicopter noise level exposure at receptor locations.

Helicopter noise would occur at an active staging area intermittently throughout the day when the helicopter switches buckets between each run. Each switch of the bucket is expected to require approximately 30 seconds. Assuming a turn-around time of 10 minutes for each loaded bucket, this would translate into 3 minutes per hour, and 18 minutes total for 6 active hours within each 8-hour day when the helicopter would hover over an active staging area. In total, if 5,250 tons of limestone sand were placed under alternative B, the helicopter would require approximately 1,300 runs; if each switch of the bucket were to last 30 seconds on average, the total time for the helicopter to hover over all active staging areas combined would be approximately 10 hours, spread over the full application period.

Noise Impacts on Humans (Neighbors and Visitors). Noise impacts on residents and visitors would depend on several variables, including distance to any active staging area or flight path and noise of the sources (primarily the helicopter used). For example, assuming a noise level of 92.5 dBA at a distance of 200 feet from the helicopter, noise levels (free-field attenuation without additional site-specific attenuation from factors such as topography, vegetation, or building walls) would be 75 dBA at 0.3 miles (the closest distance of a residence to the closest edge of the project area) and 61 dBA at 1.5 miles (the closest distance of a residence to the center of the project area, or to Riprap Overlook (a potential staging area) (table 5). The table includes a few everyday sounds and noises for reference (CDC 2020).

TABLE 5. SOUND LEVELS WITH DISTANCE FROM HELICOPTER AND EVERYDAY SOUNDS AND NOISES

Distance from Helicopter		Noise Levels	Everyday Sounds and Noises (CDC 2020)	
feet	mile	dBA	dBA	Sound Source
225		92	95	Motorcycle
500		85.5	80-85	Gas-powered lawn movers or leaf blowers, City traffic (inside the car)
1,000		79.0		
1,584	0.3	75.0	70	Washing machine, dishwasher
2,640	0.5	70.6		
5,280	1.0	64.6		
8,448	1.6	60.5	60	Normal conversation, air conditioner
15,840	3.0	55.0		

Noise Impacts on Wildlife. Many animals use auditory clues for predator avoidance, mate attraction, obtaining nesting territories, and finding prey. Human-made sounds may adversely impact wildlife. NPS (2018b) summarized potential impacts on wildlife as follows:

> "A comprehensive review of scientific literature published from 1990 to 2013 on the effects of anthropogenic [human-caused] noise on wildlife found that overall, the range of noise levels documented to induce annoyance in humans and responses in terrestrial wildlife are similar, but that noise sources that are new, unpredictable, or are acoustically similar to biologically relevant sounds would elicit wildlife responses similar to the responses associated with predation risk (startling or flight responses) (Shannon et al. 2015). Additionally, the authors found that these noises do not need to be experienced at a high intensity to elicit anti-predator behavior[4]."

For the Meadow Run project, potential noise impacts from the helicopter on any terrestrial wildlife active during the winter months would be highest (1) in the vicinity of an active staging area and (2) along the flight path between the staging area and the location actively limed during each helicopter run. Overall, the exposure of terrestrial wildlife in the project area would be limited because locations to be limed would shift with each helicopter run. Specifically, the helicopter would spend less than 30 seconds discharging the limestone sand from the bucket over each location to be limed.

Conclusion. Alternative B would result in adverse impacts on the acoustic environment in terms of human and wildlife annoyance during the day in the application period of up to three months. The more intense impacts would occur in the vicinity of active staging areas with low-elevation helicopter activity (although specific any staging area[s] outside the park have not been specified, any area would need to be first negotiated with the landowners and affected neighbors). The duration of impacts would vary. Truck traffic may have impacts from a few weeks to up to three months, depending on the approach used for stockpiling. Staging area activities and the helicopter could have daytime noise impacts also up to three months for a single liming event (i.e., one winter season application). Staging area activities and helicopter flights would occur during daytime hours only. The noise impacts in any one geographic area would be more limited because the helicopter would be traveling on different flight paths to treat different areas with limestone sand (and not fly near people while carrying a load/bucket). In other words, not every overflight would affect every residence to the same extent depending on the flight path. Noise impacts would be mitigated through careful planning of flight paths and the selection of an appropriate staging area(s) in consultation with landowners and the affected neighbors.

Alternative C: Uniform-dose Liming

The type and intensity of impacts on the acoustic environment under alternative C would be similar to alternative B. The primary difference between the two alternatives is the total amount of limestone sand to be applied. For a liming area of 2,000 acres, the total amount of limestone sand to be applied at a dose of 2.75 t/acre would be 5,500 tons. This amount would be slightly greater than the amount proposed under alternative B (i.e., 5,250 tons). A slightly larger amount of limestone sand under alternative C would require a proportionally longer application period, and therefore would result in a proportionately longer period of any noise impacts on wildlife, visitors to adjacent watersheds in the park not closed during this project, and affected neighbors.

Conclusion. Similar to alternative B, alternative C would result in adverse impacts on the acoustic environment in terms of human and wildlife annoyance during the staging area development and during the limestone sand application period, which could last up to three months.

[4] Anti-predator behavior includes running away, hiding, or responding in some other way for self-protection that would differ between animal species.

VISITOR USE AND EXPERIENCE

Methods and Assumptions

The analysis of impacts on visitor use and experience during the application period of up to three months was based on reviewing the visitation records and considered the following elements for implementation: closures of sections of Skyline Drive and the affected backcountry and wilderness areas and nearby trails in the South District; opportunities for outdoor activities such as fishing; and visual and noise disturbances from helicopter use and truck traffic.

For safety reasons, Riprap and Wildcat Ridge Trails within the project area would be closed during the application period. The need and length of closures of sections of Skyline Drive, the Appalachian Trail, and any affected backcountry or wilderness areas and other trails in the South District would depend on the location of any active staging area, weather conditions, and logistical factors, but is estimated to be more intermittent over the course of application period (e.g., days, weeks, daytime only). See chapter 2 for additional details on closures.

The analysis of long-term impacts on visitor use and experience considered the resources in the project area and the effect on these resources from liming.

Alternative A: No Action

Under alternative A, the conditions and trends discussed in chapter 3 would continue. Liming would not occur, and there would be no impacts on recreational activities in the project area and its surrounding area. However, over the long term, the water quality in Meadow Run would remain degraded, adversely affecting fish species and opportunities for recreational fishing. Additionally, visitors would experience a more degraded natural environment given that acidic deposition would continue to adversely affect ecosystem health.

Alternative B: Split-dose Liming

Skyline Drive. Under alternative B, a section of Skyline Drive near the project area and any active staging area along Skyline Drive would be intermittently closed during the period of limestone sand application, as described above and in chapter 2. The maximum length of an intermittently closed section of Skyline Drive would depend on the location of any active staging area and suitable locations for vehicles to turn around on Skyline Drive.

Liming operations would be limited to the low visitor-use period (December–February) and would occur on weekdays, Saturdays and Sundays (if required for logistical and weather-related reasons, with Sundays for liming operations exclusively within park boundaries). No helicopter operations would occur on holidays. Liming operations could prevent any of the 1,250 vehicles per month that generally use Skyline Drive between December and February from travelling on Skyline Drive from the Rockfish Gap entrance at times of road closures. Additionally, visitors driving south from the Swift Run Gap entrance or points north on the drive may be impacted, particularly if they wish to avoid doubling back along the same route to exit the park. The overall impact from closures of Skyline Drive is considered limited, because (1) any closed section of Skyline Drive would only represent a fraction of the 106-mile long scenic roadway available for visitor use, (2) the anticipated implementation approach with multiple staging areas may limit closures to weeks and/or daytime only, and (3) closures of Skyline Drive are common in the winter because of ice, snowfall, and wind (e.g., Skyline Drive was closed 46 days during the winter of 2017–2018 and 166 days during the winter of 2018–2019).

For areas in the park's South District that remain open to the public, visual disturbances and noise from helicopter use and vehicular traffic as trucks supply limestone sand to any staging areas along Skyline Drive would adversely affect visitors. For more information concerning visual and noise-related impacts, see "Wilderness Character" and "Acoustic Environment" in this chapter.

Hiking Trails. The park would ensure that the project area is clear of visitors prior to applying limestone sand. As a result, activities such as hiking, fishing, bird watching, and enjoying the park's landscapes from scenic overlooks would be unavailable to visitors in or near the project area during the application period of up to three months (December–February).

Approximately 9 miles of trails in the project area would be closed during the application period to ensure safety—Riprap Trail and Wildcat Ridge for the full period, and the Appalachian Trail as needed. In addition, area closures would include backcountry and wilderness camping during the application period. Areas adjacent to the project area may also be closed, depending on the flight paths of the helicopter between the staging areas and the project area. This may include parking areas at trailheads, selected trails, and backcountry camping. However, any closed trail would represent only a small fraction of the more than 500 miles of available trails within the park and many other backcountry and wilderness camping opportunities exist. Following reopening of the trails, some residual limestone sand may be visible on the trails until the material is fully integrated into the soil or washed into the leaf litter.

Impacts to Appalachian Trail thru-hikers would be small, as most thru-hikers are not expected to pass through the project area till the late spring or early summer (ATC 2021a). Flip flop hikers that start somewhere in the middle of the Appalachian Trail are encouraged to start hiking in the park in April (ATC 2020b). Nevertheless, alternative routes with associated signage would be established for Appalachian Trail hikers in the implementation plan.

The park would mitigate visitor use and experience impacts by communicating to park visitors the nearby areas where these activities can take place. Communication would occur prior to and during project implementation.

Fishing. Over the long term, alternative B would increase the pH of Meadow Run, resulting in better habitat for aquatic wildlife, including fish species, and consequently a better fishing experience for visitors.

Conclusion. Alternative B would affect visitor use and experience by intermittently closing a section of Skyline Drive, approximately 9 miles of trails in the project area, and some parking areas at trailheads; and by causing visual and noise disturbances for a period of up to three months (or a total of up to six months in event of a second application in another year). The park would mitigate the loss of recreational activities in the project area by early communications about project implementation and by directing visitors to other areas in the park open to recreational activities.

Visitor use and experience would improve over the long term in the project area because better fish habitat is expected to result in an increase of brook trout abundance, improving fishing opportunities for recreational fishermen. Furthermore, improvements to wildlife health and vegetative communities would improve the visitor experience, along with the character of wilderness for visitor enjoyment.

Alternative C: Uniform-dose Liming

The type of impacts on visitor use and experience would be similar to those described for alternative B. The primary difference between the two alternatives is the different total amount of limestone sand to be applied. A slightly larger amount of limestone sand under alternative C would require a slightly longer application period, and therefore would result in slightly longer closures of Skyline Drive, trails, and parking areas as well as slightly longer visual and noise impacts to visitors from helicopter and truck traffic activities. Long-term impacts on visitor use and experience would be beneficial because better fish habitat would increase brook trout abundance, improve fishing opportunities for recreational fishermen, and improve wildlife health and vegetative communities that, combined, would enhance the visitor experience.

Conclusion. Alternative C would result in adverse impacts during the application period of up to three months, but there would be long-term, beneficial impacts on the visitor use and experience, similar to alternative B.

CHAPTER 5: CONSULTATION AND COORDINATION

This chapter describes the civic engagement and agency consultation during the preparation of the Meadow Run Watershed Restoration Project EA. A combination of activities, including internal and public scoping, helped guide NPS in developing this EA.

PLANNING

NEPA regulations require an "early and open process to determine the scope of issues for analysis" (40 CFR 1501.9). The internal scoping process for the project began in December 2018. Internal and external scoping associated with this EA has been extensive and has included dozens of internal interdisciplinary team meetings and reviews.

In addition, NPS convened a science team composed of subject matter experts from federal and state agencies, and universities (University of Virginia, University of Syracuse, James Madison University, and Virginia Tech) (table 6). The science team provided expert advice on specific issues and approaches related to soil chemistry, water quality, aquatic resources, vegetation, and terrestrial wildlife as part of four separate groups. In total, six conference calls were held with science team members in the summer and fall of 2019. In addition, several follow-up calls were made with individual science team members.

CIVIC ENGAGEMENT

The project's civic engagement comment period began with a press release issued on June 5, 2019. The press release pointed interested parties to the NPS Planning, Environment, and Public Comment (PEPC) website, where they could find a newsletter, links to a StoryMap https://nps.maps.arcgis.com/apps/MapSeries/index.html?appid=3ba68fd70b8b4b5eb91ba78dd578a51b, and information on virtual and in-person public meetings. The public comment period closed on July 28, 2019. During the comment period, NPS received eight correspondences. Most of the comments offered potential alternatives and alternative elements. Commenters also provided input on issues concerning fish and wildlife, objectives of taking action, and wilderness character.

A public scoping press release and newsletter were issued for this EA on October 30, 2020. The public comment period closed on November 15, 2020. NPS received 22 correspondences during the comment period. Most of these comments expressed support for restoration of the Meadow Run watershed but also addressed a variety of subjects such as impacts on park resources and support for one or more alternatives. For example, commenters stated that restoring the watershed would benefit fish populations because acid rain has severely destroyed native brook trout habitat. One comment received did not support the project over concerns related to potential impacts on nearby private property.

The EA will be open to formal public and agency review from January 29, 2021, through February 28, 2021 (30 days). It is available on the NPS PEPC website at https://parkplanning.nps.gov/projectHome.cfm?projectID=74048.

AGENCY CONSULTATION

NPS initiated consultation with relevant agencies during the preparation of this EA. This consultation is discussed in more detail below. Copies of correspondence between NPS and other agencies, and responses from the agencies, if applicable, will be provided in the decision document.

TABLE 6. SCIENCE TEAM MEMBERS

Position and Affiliation	Technical Groups*
Universities	
Hydrologist, SWAS-VTSSS, University of Virginia	W
Associate Professor and Principal Investigator for SWAS-VTSSS, Department of Environmental Sciences, University of Virginia	W, V
Professor, Environmental Systems/Biogeochemistry, University of Syracuse	S, W, V
Forest Ecologist, James Madison University	V
Professor of Environmental Soil Science, School of Plant and Environmental Sciences, Virginia Tech	S
US Geological Survey	
Research Hydrologist	S, W
Stream Ecologist	W
Research Fisheries Biologist	W
Hydrologist, Virginia and West Virginia Water Science Center	W
Research Wildlife Biologist, Patuxent Wildlife Research Center	T
US Forest Service; US Department of Agriculture	
Forest Soil Scientist, Monongahela National Forest, US Forest Service	S
Forest Fisheries Biologist for George Washington and Jefferson National Forests, Virginia and West Virginia, US Forest Service	W
Soil Scientist, US Department of Agriculture	S
Virginia Department of Environmental Quality	
Water Monitoring and Assessments Manager	W
Aquatic Biologist	W
TMDL Coordinator	S, W
Water Quality Monitoring Expert	W
US Environmental Protection Agency	
Ecologist	S, W, V
National Park Service	
Biologist, Inventory and Monitoring Division	T

*Key for Technical Groups: S = Soil Chemistry, W = Water quality, fish, and hydrology, V = Vegetation, T = Terrestrial Wildlife

Section 7 of the Endangered Species Act

Section 7 of the Endangered Species Act requires federal agencies to ensure that the actions they authorize, fund, or carry out do not jeopardize the continued existence of listed species or destroy or adversely modify critical habitat. As described in appendix A, the northern long-eared bat and Indiana bat could both potentially occur in the Meadow Run watershed, although liming is not expected to have an adverse effect on either species or on the designated critical habitat of Indiana bat. NPS is coordinating with the USFWS Virginia Field Office to ensure compliance with section 7 of the Endangered Species Act.

Section 106 of the National Historic Preservation Act

Compliance with section 106 of the National Historic Preservation Act is being carried out in coordination with the VDHR, Native American tribes, and the public concurrently during the NEPA planning process. Given that the proposed mitigation measures for the action alternatives would be implemented, VDHR has concurred with NPS' finding of "No Historic Properties Affected."

ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ANC	acid neutralizing capacity
AQRV	air quality related values
BC_w	base cation supply rate from mineral weathering
Bsat	base cation saturation
°C	degrees Celsius
Ca	calcium
Ca:Al	calcium to aluminum ratio
Cca	Antietam Formation (geological formation)
Cch	Harpers Formation (geological formation)
$CaCO_3$	calcitic limestone
$CaMg[CO_3]_2$	dolomitic limestone
$CaSiO_3$	calcium metasilicate
CEC	cation exchange capacity
CEGL	Community Element Global number
cm	centimeter
cfs	cubic foot per second
dBA	A-weighted decibel
DOC	dissolved organic carbon
EA	environmental assessment
°F	degrees Fahrenheit
FAA	Federal Aviation Administration
ft/sec	foot/sec
g/cm^3	gram per cubic centimeter
Hz	hertz
K	potassium
kg/ha	kilogram per hectare
L	sound or noise level
L_{50}	sound or noise level exceeded 50% of the time
L_{90}	sound or noise level exceeded 90% of the time
LTEMS	Long-Term Ecological Monitoring Study

MAGIC	Model of Acidification of Groundwater in Catchments
μeq/L	microequivalent of solute per liter of solution (a measure for acid neutralizing capacity)
μg/L	microgram per liter
meq/100g	milliequivalent of base cations per 100 grams
meq/m^2	milliequivalent per square meter
meq/m^2/y	milliequivalent per square meter per year
Mg	magnesium
mg/L	milligram per liter
mg-N/L	milligram of nitrogen per liter of solution
mm	millimeter
Na	sodium
NADP	National Atmospheric Deposition Program
NEPA	National Environmental Protection Act
NPS	National Park Service
NRHP	National Register of Historic Places
NTN	National Trends Network
park	Shenandoah National Park
PEPC	Planning, Environment, and Public Comment (website)
ppm	part per million
SGCN	Species of Greatest Conservation Need
SWAS	Shenandoah Watershed Study
t/acre	short ton per acre
TDEP	Total Deposition Science Committee
TMDL	Total Maximum Daily Load
TWI	Topographic Wetness Index
U.S.C.	United States Code
USFS	United States Department of Agriculture, United States Forest Service
USFWS	United States Fish and Wildlife Service
VADEQ	Virginia Department of Environmental Quality
VDHR	Virginia Department of Historic Resources
VSCI	Virginia stream condition index
VTSSS	Virginia Trout Stream Sensitivity Study

DEFINITION OF FREQUENTLY USED TERMS

acid neutralizing capacity	buffering capacity, i.e., the ability to resist changes in pH due to the addition of an acid or a base to soil or water
acidophilic	ability of plants that thrive in acidic soils
attenuation	loss of energy from sound waves; i.e., a reduction in noise with distance from the source
base cation	a cation is a positively charged ion (atom or molecule); base cations are defined as the most prevalent, exchangeable and weak acid cations in the soil, such as calcium or magnesium
base cation saturation	measure of depletion of base cations in soils; it is the ratio of total equivalents of base cations (i.e., the sum of ionic charge in exchangeable calcium, magnesium, potassium and sodium) to the total capacity of the soil to store exchangeable cations
Ca:Al ratio	ratio of exchangeable calcium to exchangeable aluminum — a useful indicator of aluminum toxicity, where values below 1.0 are considered toxic
calciphilic	ability of plants that thrive in calcium-rich soils
cation exchange capacity (CEC)	estimate of the soil's ability to attract, retain, and exchange cations, specifically the positively charged cations (e.g., calcium, magnesium, potassium)
exclusion zone	buffer area around non-native invasive plants and rare plants, and/or anything else that is to be excluded from being limed
liming	the application of limestone sand in the liming area (i.e., project area minus exclusion zones)
mast	the fruit of forest trees and shrubs, such as acorns and other nuts – an important source for food for wildlife
monomeric aluminum	a commonly measured form of dissolved aluminum, which is toxic to many aquatic organisms
pH	measure of acidity in soil or water, with lower pH values reflecting more acidic conditions
project area	portion of the watershed within park boundaries where the project is to be implemented (2,150 acres)
receptor	locations or areas of human residences, or wildlife habitats, reachable by sound waves (i.e., noise) from a specific source
service landing area	more permanent base of the helicopter where it would park during downtime and overnight, refuel, and receive maintenance

staging area	site where loading and stockpiling of liming materials, etc. would occur during project implementation. An “active staging area” is an area with ongoing liming operations.

REFERENCES

Aalto, R., L. Maurice-Bourgoin, and T. Dunne

2003 "Episodic sediment accumulation Amazonian floodplain ENSO." *Nature* 425:493–497. https://doi.org/10.1038/nature02002

Anderson, R.

1995 "Growth of garlic mustard *(Allaria petiolate)* in native soils of different acidity." *Transactions of the Illinois State Academy of Science* 88:91–96.

Armstrong, R. A.

1990 "The influence of calcium and magnesium on the growth of the lichens *Parmelia saxatilis* and *Xanthoria parietina* on slate substrates." *Environmental and Experimental Botany* 30(1):51–57.

ATC (Appalachian Trail Conservancy)

2021a Thru-hiking. Accessed December 19, 2020. https://appalachiantrail.org/explore/hike-the-a-t/thru-hiking/

2021b Flip flop thru-hikes. Shenandoah National Park North to Katahdin; Shenandoah National Park, Va., South to Springer. Accessed January 12, 2021. https://appalachiantrail.org/explore/hike-the-a-t/thru-hiking/flip-flop/

Baldigo, B. P., G. Lawrence, and H. Simonin

2007 "Persistent mortality of brook trout in episodically acidified streams of the southwestern Adirondack Mountains, New York." *Transactions of the American Fisheries Society* 136:121–134. https://doi.org/10.1577/t06-043.1

Balter, H. and R. Loeb

1983 "Arboreal relationships on limestone and gneiss in northern New Jersey and southeastern New York." *Bulletin of the Torrey Botanical Club* 110(3):370–379.

Battles, J. J., T. J. Fahey, C.T. Driscoll Jr, J. D. Blum, and C. E. Johnson

2014 "Restoring soil calcium reverses forest decline." *Environmental Science and Technology Letters* 1(1):15—19.

Beattie, R. C. and R. Tyler-Jones

1992 "The effects of low pH and aluminum on breeding success in the frog *Rana temporaria*." *The Herpetological Journal* 26:353–360.

Beattie, R. C., R. J. Aston, and A. G. P. Milner

1993 "Embryonic and larval survival of the common frog (*Rana temporaria*) in acidic and limed ponds." *The Herpetological Journal* 3:43–48.

Beier, C. M., A. M. Woods, K. P. Hotopp, J. P. Gibbs, M. J. Mitchell, M. Dovčiak, D. J. Leopold, G. B. Lawrence, and B. D. Page

2012 "Changes in faunal and vegetation communities along a soil calcium gradient in northern hardwood forests." *Canadian Journal of Forestry Research* 42:1141–1152.

Bellemakers, M. J. S. and H. van Dam

1992 “Improvement of breeding success of the moor frog (*Rana arvalis*) by liming of acid moorland pools and the consequences of liming for water chemistry and diatoms.” *Environmental Pollution* 78:165–171.

Bennett, R., D. Hoff, and M. Etterson

2011 “Assessment of methods for estimating risk to birds from ingestion of contaminated grit particles.” U.S. Environmental Protection Agency, Office of Research and Development, Ecological Risk Assessment Support Center. Cincinnati, OH.

Blosser, D. L. and H. Jenny

1971 “Correlations of soil pH and percent base saturation as influenced by soil-forming factors.” *Soil Science Society of America Journal* 35:1017–1018. doi:10.2136/sssaj1971.03615995003500060044x

Blum, A. G., Y. Kanno, and B. H. Letcher

2018 “Seasonal streamflow extremes are key drivers of brook trout young-of-the-year abundance.” *Ecosphere* 9:1–16. https://doi.org/10.1002/ecs2.2356

Bockheim, J. G. and A. N. Gennadiyev

2000 “The role of soil-forming processes in the definition of taxa in soil taxonomy and the world soil reference base.” *Geoderma* 95:53–72. doi:https://doi.org/10.1016/S0016-7061(99)00083-X

Boxman, A. W., Cobben, P. L., and J. G. Roelofs

1994 “Does (K+ Mg+ Ca+ P) fertilization lead to recovery of tree health in a nitrogen stressed *Quercus rubra L*. stand?” *Environmental Pollution 85*(3):297–303.

Brandt, C. J. and R. W. Rhoades

1972 “Effects of limestone dust accumulation on composition of a forest community.” *Environmental Pollution* 3:217–225.

Brooke, J. M., P. S. Basinger, J. L. Birckhead, M. A. Lashley, J. M. McCord, J. S. Nanney, and C. A. Harper

2019 “Effects of fertilization and crown release on white oak *(Quercus alba)* masting and acorn quality.” *Forest Ecology and Management* 433:305–312.

Buckton S. T. and S. J. Ormerod

1997 “Effects of liming on the Coleoptera, Hemiptera, Araneae and Opiliones of catchment wetlands in Wales.” *Biological Conservation* 79:43–57. https://www.sciencedirect.com/science/article/abs/pii/S0006320796000833.

Bulger, A. J., B. J. Cosby, C. A. Dolloff, K. N. Eshleman, J. R. Webb, and J. N. Galloway

1999 *SNP:FISH, Shenandoah National Park: Fish in sensitive habitats.* Project final report to National Park Service. University of Virginia, Charlottesville, VA. Volumes 1-4: https://irma.nps.gov/DataStore/Reference/Profile/114105, https://irma.nps.gov/DataStore/Reference/Profile/114106, https://irma.nps.gov/DataStore/Reference/Profile/114107, https://irma.nps.gov/DataStore/Reference/Profile/114108

Bulger, A. J., B. J. Cosby, and J. R. Webb

2000 "Current, reconstructed past, and projected future status of brook trout *(Salvelinus fontinalis)* streams in Virginia." *Can. J. Fish. Aquat. Sci.* 57:1515–1523. doi:10.1139/f00-086

Burns, D. A., J. A. Lynch, B. J. Cosby, M. E. Fenn, J. S. Baron, and US EPA Clean Air Markets Division

2011 *National acid precipitation assessment program report to Congress 2011: An Integrated assessment.* National Science and Technology Council, Washington, DC. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/2011_napap_508.pdf

Burton, T. M. and G. E. Likens

1975 "Energy flow and nutrient cycling in salamander populations in the Hubbard Brook Experimental Forest, New Hampshire." *Ecology* 56(5):1068–1080.

Cameron, A. C., C. Hickerson, and C. D. Anthony

2016 "*Plethodon cinereus* (Eastern Red-Backed Salamander) not affected by long-term exposure to soil liming." *Northeastern Naturalist* 23(231):88-99. DOI: 10.1656/045.023.0106 https://www.researchgate.net/publication/297013799_Plethodon_cinereus_Eastern_Red-Backed_Salamander_Not_Affected_by_Long-Term_Exposure_to_Soil_Liming

Cao, L.

2008 *Persicaria longiseta*. US Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, and NOAA Great Lakes Aquatic Nonindigenous Species Information System, Ann Arbor, MI. Last revised October 21, 2008. Accessed May 12, 2020. https://nas.er.usgs.gov/queries/GreatLakes/FactSheet.aspx?SpeciesID=2735

Carey, J. H.

1992 *Quercus michauxii, Q. montana*. In: Fire Effects Information System. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Accessed June 24, 2020. https://www.fs.fed.us/database/feis/plants/tree/quespp3/all.html

Carnegie Museum of Natural History

2020 Land Snails and Slugs of the Mid-Atlantic and Northeastern United States, Virginia Species. Accessed October 27, 2020. https://www.carnegiemnh.org/science/mollusks/va_taxonomic_index.html

Carrino-Kyker, S. R., L. A. Kluber, S. M. Petersen, K. P. Coyle, C. R. Hewins, J. L. DeForest, K. A. Smemo, and D. J. Burke

2016 "Mycorrhizal fungal communities respond to experimental elevation of soil pH and P availability in temperate hardwood forests." *FEMS Microbiology Ecology* 92. https://doi.org/10.1093/femsec/fiw024

Cass, W. B., W. W. Hochstedler, and A. B. Williams

2012 "Forest Vegetation Status in Shenandoah National Park." Long-Term Ecological Monitoring Summary Report. Natural Resource Data Series NPS/MIDN/NRDS—2012/353.

CDC (Centers for Disease Control and Prevention)

2020 What Noises Cause Hearing Loss? Accessed November 14, 2020. https://www.cdc.gov/nceh/hearing_loss/what_noises_cause_hearing_loss.html

Cho, Y., C. T. Driscoll, C. E. Johnson, J. D. Blum, and T. J. Fahey

2012 "Watershed-level responses to calcium silicate treatment in a northern hardwood forest." *Ecosystems* 15:416–434. http://dx.doi.org/10.1007/s10021-012-9518-2

Clair, T. A. and A. Hindar

2005 "Liming for the mitigation of acid rain effects in freshwaters: A review of recent results." *Environmental Review* 13:91–128. https://doi.org/10.1139/a05-009

Coladonato, M.

1992 *Rhododendron periclymenoides*. In: Fire Effects Information System. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Accessed June 24, 2020. https://www.fs.fed.us/database/feis/plants/shrub/rhoper/all.html

Consent Decree

2016 United States of America v. Westvaco Corporation (Civ. No. MJG 00-CV-2602) (filed August 26, 2016)

Cope, A. B.

1992 *Carex pensylvanica.* In: Fire Effects Information System. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Accessed May 28, 2020. http://www.fs.fed.us/database/feis/

Cornell Lab of Ornithology

2020 All About Birds. Accessed April 28, 2020. https://www.allaboutbirds.org/guide.

Cosby, B. J., J. R. Webb, J. N. Galloway, and F. A. Deviney

2006 *Acidic Deposition Impacts on Natural Resources in Shenandoah National Park.* Technical Report NPS/NER/NRTR—2006/066. National Park Service. Philadelphia, PA. https://irma.nps.gov/Datastore/Reference/Profile/662219

Costanzo, S. D., T. Lookingbill, B. Walsh, A. Fries, S. Spitzer, J. Hawkey, V. Vargas, B. Webb, S. Easby, C. Goelst, and M. Rouch

2017 *Shenandoah National Park Natural Resource Condition Assessment.* April 2017 revision. Natural Resource Report NPS/SHEN/NRR—2017/1429. National Park Service, Fort Collins, Colorado.

Cummings, J. and T. Blett

2017 Acid rain: progress and problems. Resource Brief. National Park. https://www.nps.gov/shen/learn/nature/upload/SHEN_Acidification_Resource_Brief_Final-508.pdf

Cummings, J. and P. J. Sharpe

2019 Sampling plan for supplemental surficial soil assessment of the Meadow Run watershed in Shenandoah National Park, VA (unpublished data set)

Curry. K. C. Wollastonite

2019 Wollastonite. US Geological Survey, Mineral Commodity Summaries (February 2019). https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/mcs-2019-wolla.pdf

Demchik, M. C. and W. E. Sharpe

1998 "The effect of calcium/aluminum ratio on root elongation of twenty-six Pennsylvania plants". In: Proceedings of the 1998 PA Acidic Deposition Conference on the Effects of Acidic Deposition on Pennsylvania's Forests, The Pennsylvania State University, University Park, PA, p. 211–217.

Dijkstra, F. A.

2003 "Calcium mineralization in the forest floor and surface soil beneath different tree species in the northeastern US." *Forest Ecology and Management* 175(1-3):185-194.

Dourson, D. and J. Dourson

2006 Land Snails of the Great Smoky Mountains (Eastern Region). Developed for Appalachian Highlands Science Learning Center Purchase Knob Great Smoky Mountains National Park in cooperation with ATBI/ Discover Life in America project. July 2006. Accessed October 27, 2020. https://static1.squarespace.com/static/5804eb039f74569692067655/t/5aeb096b70a6ad7a6072637e/1525352821956/Land+Snails+of+the+Great+Smoky+Mountains.pdf

Downs, C.

2019 "More than eating dirt: a review of avian geophagy." *African Zoology* 54(3):1-19.

Driscoll, C. T., C. P. Cirmo, T. J. Fahey, V. L. Blette, P. A. Bukaveckas, D. A. Burns, C. P. Gubala, D. J. Leopold, R. M. Newton, D. J. Raynal, C. L. Schofield, J. B. Yavitt and D. B. Porcella

1996 "The experimental watershed liming study: comparison of lake and watershed neutralization strategies." *Biogeochemistry* 32:143–174. https://doi.org/10.1007/BF02187137

Federer, C. A., J. W. Hornbeck, L. M. Tritton, C. W. Martin, R. S. Pierce, and C. T. Smith

1989 "Long-term depletion of calcium and other nutrients in eastern US forests." *Environmental Management* 13(5):593-601.

FHWA (Federal Highway Administration)

1998 Federal Highway Administration's Traffic Noise Model (FHWA TNM®), Technical Manual. FHWA-PD-96-010 DOT-VNTSC-FHWA-98-2. https://www.fhwa.dot.gov/environment/noise/traffic_noise_model/old_versions/tnm_version_10/tech_manual/tnm10techmanual.pdf

Fisher, B. A., A. K. Aufdenkampe, K. Yoo, R. E. Aalto, and J. Marquard

2018 "Soil carbon redistribution and organo-mineral associations after lateral soil movement and mixing in a first-order forest watershed." *Geoderma* 319:142–155. https://doi.org/10.1016/j.geoderma.2018.01.006

Frisbie, M. P. and R. L. Wyman

1991 “The effects of soil pH on sodium balance in the red-backed salamander, *Plethodon cinereus*, and three other terrestrial salamanders.” *Physiological Zoology* 64(4):1050–1068.

Fromm, J.

2010 “Wood formation of trees in relation to potassium and calcium nutrition.” *Tree Physiology* 30(9):1140–1147.

Fryer, J. L.

2011 *Microstegium vimineum*. In: Fire Effects Information System. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Accessed May 4, 2020. https://www.fs.fed.us/database/feis/plants/graminoid/micvim/all.html

Garrels, R. M., and F. T. Mackenzie

1967 Origin of the chemical compositions of some springs and lakes, p. 10–222. In: Stumm, W. (ed.), *Equilibrium Concepts in Natural Water Systems,* Chapter 10, American Chemical Society, Washington DC, 222-242. http://dx.doi.org/10.1021/ba-1967-0067.ch010

George, S. D., B. P. Baldigo, G. B. Lawrence, and R. L. Fuller

2018 “Effects of watershed and in-stream liming on macroinvertebrate communities in acidified tributaries to an Adirondack lake.” *Ecological Indicators* 85:1058–1067. https://doi.org/10.1016/j.ecolind.2017.11.048

Gessler, P. E., I. D. Moore, N. J. McKenzie, and P. J. Ryan

1995 “Soil-landscape modelling and spatial prediction of soil attributes.” *International Journal of Geographical Information Systems* 9:421–432. doi:10.1080/02693799508902047

Gionfriddo, J. P. and L. B. Best

1999 ”Grit use by birds: a review.” In Current Ornithology v. 15. Nolan Jr., V., E. D. Ketterson, and C. F. Thompson (eds.), Kluwer Academic/Plenum Publishers. New York. p. 89-148.

Grand, S. and L. M. Lavkulich

2013 “Potential influence of poorly crystalline minerals on soil chemistry in podzols of southwestern Canada.” *European Journal of Soil Science* 64:651–660. https://doi.org/10.1111/ejss.12062

Graveland, J.

1998 “Effects of acid rain on bird populations.” *Environmental Reviews* 6:41–54.

Graveland, J., R. van der Wal, J. H. van Balen, and A. J. van Noordwijk

1994 “Poor reproduction in forest passerines from decline of snail abundance on acidified soils.” *Nature* 366:446–448.

Graveland, J., and R. van der Wal

1996 "Decline in snail abundance due to soil acidification causes eggshell defects in forest passerines." *Oecologia* 105:351–360

Groffman, P. M. and M. C. Fisk

2011 "Calcium constrains plant control over forest ecosystem nitrogen cycling." *Ecology* 92:2035–2042. https://doi.org/10.1890/11-0461.1

Gu, W., C. T. Driscoll, S. Shao, and C. E. Johnson

2017 "Aluminum is more tightly bound in soil after wollastonite treatment to a forest watershed." *Forest Ecology and Management* 397:57–66. https://doi.org/10.1016/j.foreco.2017.04.035

Gucker, C. L.

2007 *Pinus rigida*. In: Fire Effects Information System, [Online]. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Accessed September 14, 2020. https://www.fs.fed.us/database/feis/plants/tree/pinrig/all.html

Hamburg, S. P., R. D. Yanai, M. A. Arthur, J. D. Blum, and T. G. Siccama

2003 "Biotic control of calcium cycling in northern hardwood forests: acid rain and aging forests." *Ecosystems* 6(4):399–406.

Hames, R. S., K. V. Rosenberg, J. D. Lowe, S. E. Barker, and A. A. Dhondt

2002 "Adverse effects of acid rain on the distribution of the wood thrush (*Hylocichla mustelina*) in North America." *Proceedings of the National Academy of Sciences* 99:11235–11240.

Harmon, P.

2017 Revealing the Current Relationship Between Stream Acidification and Fish Species Richness: What is the Status After Two Decades of Recovery? Master of Sciences thesis, James Madison University, VA. https://commons.lib.jmu.edu/cgi/viewcontent.cgi?article=1506&context=master201019

Harper, C. A.

2009 "Fertilizing oaks for more and sweeter acorns: fact or fantasy? *Wildlife Trends Journal*. May/June 2009." Accessed May 30, 2020. https://ag.tennessee.edu/fwf/craigharper/Documents/Fertilizing%20oaks%20for%20acorns--Wildlife%20Trends.pdf

Harrison, R. T., R. Farve, and A. Horcher

2007 *Sound measurements of helicopters during logging operations.* Prepared for the US Department of Agriculture, US Forest Services. Accessed December 31, 2019. https://www.fs.fed.us/t-d/programs/im/sound_measure/helo_index.shtml

Havlin, J. L.

2005 Fertility. In: Hillel, D. and J. L. Hatfield (eds.), *Encyclopedia of Soils in the Environment.* Volume 3. Elsevier. p. 10–19.

Hotopp, K. P.
2002 "Land snails and soil calcium in central Appalachian mountain forests." *Southeastern Naturalist* 1:27-44.

Hudy, M., D. M. Downey, and D. W. Bowman
2000 "Successful restoration of an acidified native brook trout stream through mitigation with limestone sand." *North American Journal of Fisheries Management* 20(2):453–466. https://doi.org/10.1577/1548-8675(2000)020<0453:sroaan>2.3.co;2

Huebner, C. D., J. Steinman, T. F. Hutchinson, T. E. Ristau, and A. A. Royo
2014 "The distribution of a non-native *(Rosa multiflora)* and native *(Kalmia latifolia)* shrub in mature closed-canopy forests across soil fertility gradients." *Plant and Soil* 377(1-2):259–276.

Huntington, T. G., R. P. Hooper, C. E. Johnson, B. T. Aulenbach, R. Cappellato, and A. E. Blum
2000 "Calcium depletion in a southeastern United States forest ecosystem." *Soil Science Society of America Journal* 64(5):1845-1858.

Hutchinson, T. C., M. Scott, C. Soto, and M. Dixon
1987 "The effect of simulated acid rain on boreal forest floor feather moss and lichen species." In: Hutchinson, T. C. and K. M. Meema (eds.), *Effects of Atmospheric Pollutants on Forests, Wetlands and Agricultural Ecosystems*. Springer, Berlin, Heidelberg, p. 411–426.

Hwang, J., Y. Son, C. Kim, M. J. Yi, Z. S. Kim, W. K. Lee, and S. K. Hong
2007 "Fine root dynamics in thinned and limed pitch pine and Japanese larch plantations." *Journal of Plant Nutrition* 30:1821–1839. https://doi.org/10.1080/01904160701628940

Innis, A.F.
2005 Comparative ecology of the invasive Rubus phoenicolasius and the native Rubus argutus (Doctoral dissertation).

Iowa State University
2020 Wind roses. Waynesboro, VA. Accessed December 1, 2020. https://mesonet.agron.iastate.edu/sites/windrose.phtml?station=W13&network=VA_ASOS

Jastram, J. D., C. D. Snyder, N. P. Hitt, and K. C. Rice
2013 "Synthesis and interpretation of surface water quality and aquatic biota data collected in Shenandoah National Park, Virginia, 1979-2009." *US Geological Survey Scientific Investigations Report* 2013-5157, Reston, VA.

Jenny, H.
1946 "Arrangement of soil series and types according to functions of soil-forming factors." *Soil Science* 61: 375-392.

Jessup, B., J. Stamp, M. Paul, and E. Leppo

2019 Biological Condition Gradient (BCG) Attribute Assignments for Macroinvertebrates and Fish in the Mid-Atlantic Region. Prepared by TetraTech for Virginia Department of Environmental Quality.

Johannessen, L. E. and T. Solhey

2001 "Effects of experimentally increased calcium levels in the litter on terrestrial snail populations." *Pedobiologia* 45:234–242.

Johnson, C. E., C. T. Driscoll, J. D. Blum, T. J. Fahey, and J. J. Battles

2014 "Soil chemical dynamics after calcium silicate addition to a northern hardwood forest." *Soil Science Society of America Journal* 78:1458–1468. https://doi.org/10.2136/sssaj2014.03.0114

Juice, S. M., T. J. Fahey, T. G. Siccama, C. T. Driscoll, E. G. Denny, C. Eagar, N. L. Cleavitt, R. Minocha, and A. D. Richardson

2006 "Response of sugar maple to calcium addition to northern hardwood forest." *Ecology* 87:1267–1280. https://doi.org/10.1890/0012-9658(2006)87[1267:ROSMTC]2.0.CO;2

Koenig, W. D. and J. M. Knops

2005 "The mystery of masting in trees: some trees reproduce synchronously over large areas, with widespread ecological effects, but how and why?" *American Scientist* 93(4):340-347.

Kulmatiski, A., K. Vogt, D. Vogt, P. Wargo, J. Tilley, T. Siccama, R. Sigurdardottir, and D. Ludwig

2007 "Nitrogen and calcium additions increase forest growth in northeastern US spruce-fir forests." *Canadian Journal of Forest Research* 37:1574–1585.

Lamson, N. I.

1990 "Betula lenta L. Sweet birch." Silvics of North America 2:148–152.

Landres, P., C. Barns, S. Boutcher, T. Devine, P. Dratch, A. Lindholm, and E. Simpson

2015 Keeping it Wild 2: An Updated Interagency Strategy to Monitor Trends in Wilderness Character across the National Wilderness Preservation System. Gen. Tech. Rep. RMRS-GTR-340. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station, 114p.

Lawrence, G. B., D. A. Burns, and K. Riva-Murray

2016 "A new look at liming as an approach to accelerate recovery from acidic deposition effects." *Science of the Total Environment* 562:35–46. https://doi.org/10.1016/j.scitotenv.2016.03.176

Likens, G. E., C. T. Driscoll, and D. C. Buso

1996 "Long-term effects of acid rain: response and recovery of a forest ecosystem." *Science* 272:[d]244–[d]246. https://science.sciencemag.org/content/272/5259/244

Long, R. P., S. B. Horsley, and T. J. Hall

2011 "Long-term impact of liming on growth and vigor of northern hardwoods." *Canadian Journal of Forest Research* 41(6):1295–1307. https://doi.org/10.1139/x11-049

Long, R. P., S. W. Bailey, S. B. Horsley, T. J. Hall, B. R. Swistock, and D. R. DeWalle

2015 "Long-term effects of forest liming on soil, soil leachate, and foliage chemistry in northern Pennsylvania." *Soil Science Society of America Journal* 79:1223–1236. https://doi.org/10.2136/sssaj2014.11.0465

Lynch, E., D. Joyce, and K. Fristrup

2011 "An assessment of noise audibility and sound levels in US National Parks." *Landscape Ecology* 26:1297-1309. DOI 10.1007/s10980-011-9643-x http://www.edc.uri.edu/nrs/classes/nrs534/NRS_534_readings/SoundsNPS.pdf

Manni, M. F., Y. Le, W. Morse, and S. J. Hollenhorst

2012 *Shenandoah National Park visitor study: Summer and Fall 2011.* Natural Resource Report NPS/NRSS/EQD/NRR—2012/584. National Park Service, Fort Collins, Colorado.

Mant, R. C., D. L. Jones, B. Reynolds, S. J. Ormerod, and A. S. Pullin

2013 "A systematic review of the effectiveness of liming to mitigate impacts of river acidification on fish and macro-invertebrates." *Environmental Pollution* 179:285–293. https://doi.org/10.1016/j.envpol.2013.04.019

McCay, T. S., C. L. Cardelús, and M. A. Neatrour

2013 "Rate of litter decay and litter macroinvertebrates in limed and unlimed forests of the Adirondack Mountains, USA." *Forest Ecology and Management* 304:254–260. https://doi.org/10.1016/j.foreco.2013.05.010

McClurg, S. E., J. T. Petty, P. M. Mazik, and J. L. Clayton

2007 "Stream ecosystem response to limestone treatment in acid impacted watersheds of the Allegheny Plateau." *Ecological Applications* 17:1087–1104. https://doi.org/10.1890/06-0392

McDonnell, T. C., B. J. Cosby, and T. J. Sullivan

2012 "Regionalization of soil base cation weathering for evaluating stream water acidification in the Appalachian Mountains, USA." *Environmental Pollution* 162:338–344. https://doi.org/10.1016/j.envpol.2011.11.025

McGrath, A. L. and K. Lorenzen

2010 "Management history and climate as key factors driving natterjack toad population trends in Britain." *Animal Conservation* 13:483–494.

Mehlich, A.

1943 "Base saturation and pH in relation to liming and nutrient conservation of soil." *Soil Science Society of America Journal* 7:353–361.

Meinrath, G.

2008 "Lectures for chemists on statistics II. the normal distribution: A briefer on the univariate case." *Accreditation and Quality Assurance* 13(4-5):179–192. https://doi.org/10.1007/s00769-008-0359-9

Melvin, A. M., J. W. Lichstein, and C. L. Goodale
2013 “Forest liming increases forest floor carbon and nitrogen stocks in a mixed hardwood forest.” *Ecological Applications* 23:1962–1975. http://doi.org/10.1890/13-0274.1

Millard, G. D., C. T. Driscoll, D. A. Burns, M. R. Montesdeoca, and K. Riva-Murray
2018 “Response of mercury in an Adirondack (NY, USA) forest stream to watershed lime application.” *Environmental Science: Processes and Impacts* 20:607–620. https://doi.org/10.1039/c7em00520b

Mizel, N. L., W. E. Sharpe, and B. R. Swistock
2015 “Efficacy of pelletized lime versus limestone sand for forest regeneration enhancement in Pennsylvania, USA.” *Open Journal of Forestry* 5:221–234. http://dx.doi.org/10.4236/ojf.2015.52020

Moore, J.-D.
2014 “Short-term effect of forest floor liming on eastern red-backed salamander (*Plethodon cinereus*).” *Forest Ecology and Management* 318:270–273.

2020 “No effect of liming on the eastern red-backed salamander (*Plethodon cinereus*).” *Soil Organisms* 92(3): 197–202.

Moore, J.-D., C. Carmiré, and R. Ouimet
2000 “Effects of liming on the nutrition, vigor, and growth of sugar maple at the Lake Clair Watershed, Quebec.” *Canadian Journal of Forest Research* 30(5):725–732.

Moore, J.-D., R. Ouimet, and L. Duchesne
2012 “Soil and sugar maple response 15 years after dolomitic lime application.” *Forest Ecology and Management* 281:130–139. http://doi.org/10.1016/j.foreco.2012.06.026

Moore, J.-D., R. Ouimet, R. P. Long, and P. A. Bukaveckas
2015 “Ecological benefits and risks arising from liming sugar maple dominated forests in northeastern North America.” *Environmental Review* 23:66-77.

Mylavarapu, R.
2020 Essential Nutrients and Ionic Forms. Sustainable Nutrient Systems Program, University of Florida. Accessed June 22, 2020. https://nutrients.ifas.ufl.edu/nutrient_pages/bsfpages/CationExchange.htm

NADP-NTN (National Atmospheric Deposition Program, National Trends Network)
2019 Trend plots for Site VA28: Shenandoah National Park-Big Meadows. Accessed December 15, 2019. http://nadp.slh.wisc.edu/data/ntn/plots/ntntrends.html?siteID=VA28

NAPD-TDEP (National Atmospheric Deposition Program, Total Deposition Science Committee)
2019 Total Deposition Maps, version 2018.02. Accessed April 14, 2020. https://nadp.slh.wisc.edu/committees/tdep/tdepmaps/

Narendrula-Kotha, R. and K. K. Nkongolo

2017 "Microbial response to soil liming of damaged ecosystems revealed by pyrosequencing and phospholipid fatty acid analyses." *PLoS One* 12. https://doi.org/10.1371/journal.pone.0168497

NatureServe (NatureServe Explorer)

2020a *Quercus montana - Quercus rubra - Carya ovalis / Carex pensylvanica - (Calamagrostis porteri)* Forest. Accessed May 4, 2020. https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.686973/Quercus_montana_-_Quercus_rubra_-_Carya_ovalis_-_Carex_pensylvanica_-_(Calamagrostis_porteri)_Forest

2020b *Quercus montana - Quercus rubra / Vaccinium pallidum - (Rhododendron periclymenoides)* Forest. Accessed May 4, 2020. https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.686143/Quercus_montana_-_Quercus_rubra_-_Vaccinium_pallidum_-_(Rhododendron_periclymenoides)_Forest

NCSU (North Carolina State University)

2020 *Rubus phoenicolasius*. North Carolina Extension Gardener Plant Toolbox. Accessed June 24, 2020. https://plants.ces.ncsu.edu/plants/rubus-phoenicolasius/

NPS (National Park Service)

1994 *Report to Congress on the Effects of Aircraft Overflights on the National Park System.* Prepared pursuant to Public Law 100-91, The National Park Overflights Act of 1987. National Park Service. Accessed June 10, 2016. http://www.nonoise.org/library/npreport/intro.htm#

1998 *Backcountry and Wilderness Management Plan.* National Park Service, Shenandoah National Park, Luray, VA. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.693.6010&rep=rep1&type=pdf

2000 Director's Order 47: Soundscape Preservation and Noise Management. US Department of the Interior, National Park Service, Washington D.C. December 1, 2000. https://www.nps.gov/policy/DOrders/DOrder47.html

2006a *A Natural Resource Assessment for Shenandoah National Park.* US Department of the Interior Northeast Region. Philadelphia, Pennsylvania. Technical Report NPS/NER/NRTR—2006/071.

2006b Management Policies 2006. The Guide to Managing the National Park System. (August 31, 2006) https://www.nps.gov/policy/mp/policies.html

2010 *Soundscapes Management Plan for Zion National Park*. National Park Service. http://www.nps.gov/zion/parkmgmt/upload/ZNP-Soundscape-Plan_Sep_2010.pdf

2015 *Foundation Document. Shenandoah National Park*. (April 2015) https://www.nps.gov/shen/getinvolved/upload/SHEN_FD_SP-Full-doc-final-508.pdf

2016a *Shenandoah National Park. Summer 2016 Acoustic Monitoring Snapshot*. Natural Resource Stewardship and Science, Natural Sounds and Night Skies Division, National Park Service.

2016b "Science of Sound." Information on the definition of acoustic resources and soundscapes obtained from NPS Natural Sounds and Night Skies Division website. Accessed October 1, 2016. https://www.nps.gov/subjects/sound/science.htm

2018a Hiking in Shenandoah. Accessed March 30, 2020. https://www.nps.gov/shen/planyourvisit/hiking-safety.htm

2018b *Olympic National Park Mountain Goat Management Plan/Final EIS.* https://parkplanning.nps.gov/document.cfm?parkID=329&projectID=49246&documentID=87542

2019a Shenandoah National Park Fisheries Monitoring Database export (2019). https://irma.nps.gov/Datastore/Reference/Profile/2259912

2019b Forest Vegetation. Spatial Data provided by Shenandoah National Park.

2019c Park Reports. Traffic counts by location. Accessed September 7, 2019. https://irma.nps.gov/Stats/SSRSReports/Park%20Specific%20Reports/Traffic%20Counts

2020a Shenandoah. Management. Accessed December 18, 2020. https://www.nps.gov/shen/learn/management/index.htm

2020b Climate change. Shenandoah National Park, Virginia. Accessed on August 5, 2020. https://www.nps.gov/shen/learn/nature/climatechange.htm#CP_JUMP_5689907

2020c NPSpecies, Information on Species in National Parks – Shenandoah National Park. Accessed February 13, 2020. https://irma.nps.gov/NPSpecies/Search/SpeciesList/SHEN

2020d Shenandoah National Park Aquatic Macroinvertebrate Monitoring Database export (2020-04-15). https://irma.nps.gov/Datastore/Reference/Profile/2260038

2020e Personal communication between Wendy Cass, National Park Service, and Derrick Rosenbach, WSP, concerning threatened and endangered plants within the project area. May 31.

2020f Birds. Shenandoah National Park website. Accessed April 28, 2020. https://www.nps.gov/shen/learn/nature/birds.htm

2020g Annual Park Recreation Visitation for Shenandoah National Park. Accessed March 30, 2020. https://irma.nps.gov/STATS/SSRSReports/Park%20Specific%20Reports/Annual%20Park%20Recreation%20Visitation%20(1904%20-%20Last%20Calendar%20Year)?Park=SHEN

2020h Recreational Fishing. Accessed May 5, 2020. https://www.nps.gov/shen/planyourvisit/fishing.htm

2020i Insects, Spiders, Centipedes, Millipedes. Shenandoah National Park website. Last updated March 5, 2019. Accessed February 12, 2020. https://www.nps.gov/shen/learn/nature/insects.htm

Nuzzo, V.

1999 “Invasion pattern of herb garlic mustard *(Alliaria petiolata)* in high quality forests.” *Biological Invasions* 1(2-3):169-179.

Ormerod, S. J. and S. D. Rundle

1998 “Effects of experimental acidification and liming on terrestrial invertebrates: implications for calcium availability to vertebrates.” *Environmental Pollution* 103:183–191. https://www.sciencedirect.com/science/article/pii/S0269749198001286.

Pabian, S. E.

2010 *Songbirds and soils: relating forest ecosystem quality to nutrient availability.* PhD Dissertation. The Pennsylvania State University, School of Forest Resources. August 2010.

Pabian, S. E. and M. Brittingham

2007 “Terrestrial liming benefits birds in an acidified forest in the Northeast.” *Ecological Applications* 17:2184–2194.

2012 “Soil calcium and forest birds: indirect links between nutrient availability and community composition.” *Ecosystems* 15:748–760.

Pabian, S. E., S. M. Rummel, W. E. Sharpe, and M. C. Brittingham

2012a “Terrestrial liming as a restoration technique for acidified forest ecosystems.” *International Journal of Forestry Research* 2012:10.

Pabian, S. E., N. M. Ermer, W. M. Tzilkowski, and M. C. Brittingham

2012b “Effects of Liming on Forage Availability and Nutrient Content in a Forest Impacted by Acid Rain.” *PLoS One* 7:e39755. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3386234/

Pearse, I. S., W. D. Koenig, and D. Kelly

2016 “Mechanisms of mast seeding: resources, weather, cues, and selection.” *New Phytologist* 212(3):546-562.

Pierce, B. A.

1985 “Acid tolerance in amphibians.” *BioScience* 35:239–243.

1987 “The effects of acid rain on amphibians.” *The American Biology Teacher* 49(6):42–347.

Plass, W. T.

1969 Pine seedlings respond to liming of acid strip-mine soil. USDA Forest Service Research Note DE-103. https://www.fs.usda.gov/treesearch/pubs/19829 Plass, 1969

Plummer, N., E. Busenberg, J. K. Bohlke, R. W. Carmody, G. C. Casile, T. B. Coplen, M. W. Doughten, J. E. Hannon, W. Kirkland, R. L. Michel, D. L. Nelms, B. C. Norton, K. E. Plummer, H. Qi, K. Revesz, P. Schlosser, S. Spitzer, J. E. Wayland, and P. K. Widman

2000 “Chemical and isotopic composition of water from springs, wells, and streams in parts of Shenandoah National Park, Virginia, and vicinity, 1995-1999.” *Open-File Report* 2000-373. https://doi.org/10.3133/ofr00373

Plummer, L. N., E. Busenberg, J. K. Böhlke, D. L. Nelms, R. L. Michel, and P. Schlosser

2001 "Groundwater residence times in Shenandoah National Park, Blue Ridge Mountains, Virginia, USA: A multi-tracer approach." *Chemical Geology* 179:93-111. https://doi.org/10.1016/S0009-2541(01)00317-5

Raduła, M. W., T. H. Szymura, and M. Szymura

2018 "Topographic wetness index explains soil moisture better than bioindication with Ellenberg's indicator values." *Ecological Indicators* 85:172–179.

Rask, M., R. I. Jones, M. Järvinen, A. Paloheimo, M. Salonen, J. Syväranta, and M. Verta

2007 "Changes in fish mercury concentrations over 20 years in an acidified lake subject to experimental liming." *Applied Geochemistry* 22:1229–1240. https://doi.org/10.1016/j.apgeochem.2007.03.015

Reeves, S. L.

2007 *Pinus pungens*. USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory.

Rehm, G.

1994 Soil Cation Ratios for Crop Production. *North Central Regional Extension Publication* 533. Minnesota Extension Service, University of Minnesota. https://store.extension.iastate.edu/product/3151

Rice, K. C., F. A. Deviney, G. M. Hornberger, and J. R. Webb.

2006 "Predicting the vulnerability of streams to episodic acidification and potential effects on aquatic biota in Shenandoah National Park, Virginia." *US Geological Survey Scientific Investigations Report* 2005-5259, 51p. https://pubs.usgs.gov/sir/2005/5259/

Rice, K. C., J. D. Jastram, J. E. B. Wofford, and J. P. Schaberl

2014a "Synthesis of thirty years of surface water and aquatic biota data in Shenandoah National Park: collaboration between the US Geological Survey and the National Park Service." *The George Wright Forum* 31:198–204.

Rice, K. C., T. M. Scanlon, J. A. Lynch, and B. J. Cosby

2014b "Decreased atmospheric sulfur deposition across the Southeastern US: When will watersheds release stored sulfate?" *Environmental Science and Technology* 48:10071−10078. https://dx.doi.org/10.1021/es501579s

Riscassi, A., T. Scanlon, and J. Galloway

2019 "Stream geochemical response to reductions in acid deposition in headwater streams: Chronic versus episodic acidification recovery." *Hydrological Processes* 33:512–526. https://dx.doi.org/10.1002/hyp.13349

Robison, A. L., T. M. Scanlon, B. J. Cosby, J. R. Webb, and J. N. Galloway

2013 "Roles of sulfate adsorption and base cation supply in controlling the chemical response of streams of western Virginia to reduced acid deposition." *Biogeochemistry* 116:119-130, 10.1007/s10533-013-9921-6, 2013.

Robison, A. L., and T. M. Scanlon

2018 "Climate change to offset improvements in watershed acid-base status provided by clean air act and amendments: A model application in Shenandoah National Park, Virginia. *Journal of Geophysical Research: Biogeosciences* 123:2863–2877. https://dx.doi.org/10.1029/2018JG004519

Rodgers, V. L., B. E. Wolfe, L. K. Werden, and A. C. Finzi

2008 "The invasive species *Alliaria petiolata* (garlic mustard) increases soil nutrient availability in northern hardwood-conifer forests." *Oecologia* 157(3):459–471.

Scanlon, T., J. Galloway, A. Riscassi, S. Maben, and J. Atkins

2019 Shenandoah Watershed Study: Shenandoah National Park Water Quality Monitoring 2018 Data Report. University of Virginia, Charlottesville.

Schaberg, P. G., E. K. Miller, and C. Eagar

2010 Assessing the threat that anthropogenic calcium depletion poses to forest health and productivity. In: Pye, J. M., H. M. Rauscher, Y. Sands, D. C. Lee, J. S. Beatty (eds). *Advances in threat assessment and their application to forest and rangeland management*. Gen. Tech. Rep. PNW-GTR-802. US Department of Agriculture, Forest Service, Pacific Northwest and Southern Research Stations: 37-58, 802, p.37-58.

Science Team

2019a Call with Science Team Group A (Soil chemistry) on September 19, 2019.

2019b Call with Science Team Group B2 (Water quality/hydrology – Aquatic biology) on November 4, 2019.

2019c Call with Science Team Group B1 (Water quality/hydrology – Aquatic chemistry) on October 24, 2019.

2019d Call with Science Team Group C (Vegetation) on October 2, 2019.

2019e Call with Science Team Group D (Terrestrial wildlife) on September 25, 2019.

Scott, M. G. and T. C. Hutchinson

1987 "Effects of a simulated acid rain episode on photosynthesis and recovery in the caribou-forage lichens, *Cladina stellaris* (opiz.) brodo and *Cladina rangiferina* (l.) wigg. *New Phytologist* 107(3):567-575.

Seagle, S. W. and S, L. Curd

1994 "Effects of watershed liming on the distribution of terrestrial salamanders." Appalachian environmental laboratory, Center for environmental and estuarine studies, University of Maryland, CBRM-AD-94-5. 42p.

Shannon G., M. McKenna, L. Angeloni, K. Crooks, K. Fristrup, E. Brown, K. Warner, M. Nelson, C. White, J. Briggs, S. McFarland, and G. Wittemyer

2015 *A Synthesis of Two Decades of Research Documenting the Effects of Noise on Wildlife*. Cambridge Philosophical Society, Biological Reviews. https://www.ncbi.nlm.nih.gov/pubmed/26118691

Shao, S., C. T. Driscoll, C. E. Johnson, T. J. Fahey, J. J. Battles, and J. D. Blum

2016 "Long-term responses in soil solution and stream-water chemistry at Hubbard Brook after experimental addition of wollastonite." *Environmental Chemistry* 13:528–540. https://doi.org/10.1071/EN15113

Sharpe, W. E., B. R. Swistock, and D. R. DeWalle

1991 "Response of an Appalachian Mountain soil, soil water and associated herbaceous vegetation to liming." In: McCormick L. H. and K. W. Gottschalk (eds.), *Proceedings, 8th Central Hardwood Forest*, p. 489–499. https://www.nrs.fs.fed.us/pubs/gtr/gtr_ne148%20papers/40sharpe-gtr148.pdf.

Sharpe, W. E., M. C. Brittingham, W. M. Tzilkowski, B. R. Swistock, A. K. Bohnenblust, L. D. Donaldson, H. J. Kim, L. J. MacNeal, S. E. Pabian, S. M. Rummel, and C. R. Voorhees

2006 *Evaluation of Whole Watershed and Riparian Wetland Liming to Mitigate Acidity.* Final report to the Pennsylvania Department of Environmental Protection. Grant no. 41000155481ME352917.

Sharpe, P. J. and J. Cummings

2019 Sampling plan for supplemental surficial soil assessment of the Meadow Run watershed in Shenandoah National Park, VA (unpublished data set)

Sharpe, P. J., J. Cummings, A. K. Aufdenkampe, and M. Bell

2019 Dataset of soil physical and chemical properties at 46 sites in Meadow Run watershed, Shenandoah National Park. (unpublished data)

Shastri, Y., and U. Diwekar

2008 "Optimal control of lake pH for mercury bioaccumulation control." *Ecological Modelling* 216:1–17. https://doi.org/10.1016/j.ecolmodel.2008.03.019

Singh, M. M. and K. C. Curry

2018 "Wollastonite." In: *USGS (US Geological Survey), 2016 Minerals Yearbook Statistics and Information. Wollastonite* (Advance Release). https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/wollastonite/myb1-2016-wolla.pdf

Skeldon, M. A, M. A. Vadeboncoeur, S. P. Hamburg, and J. D. Blum

2007 "Terrestrial gastropod responses to an ecosystem-level calcium manipulation in a northern hardwood forest." *Canadian Journal of Zoology* 85:994–1007. https://core.ac.uk/download/pdf/72050641.pdf.

Southworth, S., J. N. Aleinikoff, C. M. Bailey, W. C. Burton, E. A. Crider, P. C. Hackley, J. P. Smoot, and R. P. Tollo

2009 "Geologic Map of the Shenandoah National Park Region, Virginia." Prepared by US Department of the Interior, US Geological Survey, in cooperation with the National Park Service. *Open-File Report* 2009–1153. https://pubs.usgs.gov/of/2009/1153/

Stankowich, T.

2008 "Ungulate flight responses to human disturbance: A review and meta-analysis." *Biological Conservation* 141:2159–2173.

Swistock, B. and W. E. Sharpe

2016 *Limestone sand: Pros and Cons*. PennState Extension. (May 23, 2016). Accessed August 26, 2019. https://extension.psu.edu/limestone-sand-pros-and-cons

Sugalski, M. T. and D. L. Claussen

1997 "Preference for soil moisture, soil pH, and light intensity by the salamander, *Plethodon cinereus*." *Journal of Herpetology* 31:245–250.

Sullivan, T. J., B. J. Cosby, J. A. Laurence, R. L. Dennis, K. Savig, J. R. Webb, A. J. Bulge, M. Scruggs, C. Gordon, J. Ray, E. H. Lee, W. E. Hogsett, H. Wayne, D. Miller, and J. S. Kern

2003 *Assessment of air quality and related values in Shenandoah National Park*. Technical Report NPS/NERCHAL/NRTR-03/090. US Department of the Interior, National Park Service, Northeast Region, Philadelphia, PA. https://irma.nps.gov/Datastore/DownloadFile/455172

Sullivan, T. J., B. J. Cosby, A. T. Herlihy, J. R. Webb, A. J. Bulger, K. U. Snyder, P. F. Brewer, E. H. Gilbert, and D. L. Moore

2004 "Regional model projections of future effects of sulfur and nitrogen deposition on streams in the southern Appalachian Mountains." *Water Resources Research* 40(W02101). https://dx.doi.org/10.1029/2003WR001998

Sullivan, T. J., J. R. Webb, K. U. Snyder, A. T. Herlihy, and B. J. Cosby

2007 "Spatial distribution of acid-sensitive and acid-impacted streams in relation to watershed features in the southern Appalachian Mountains." *Water, Air, and Soil Pollution* 182:57–71. https://doi.org/10.1007/s11270-006-9320-x

Sullivan, T. J., B. J. Cosby, J. R. Webb, R. L. Dennis, A. J. Bulger, and F. A. Deviney

2008 "Streamwater acid-base chemistry and critical loads of atmospheric sulfur deposition in Shenandoah National Park, Virginia." *Environmental Monitoring and Assessment* 137:85–99. https://doi.org/10.1007/s10661-007-9731-1

Sullivan, T. J., B. J. Cosby, T. C. McDonnell, E. M. Porter, T. Blett, R. Haeuber, C. M. Huber, and J. Lynch

2012 "Critical loads of acidity to protect and restore acid-sensitive streams in Virginia and West Virginia." *Water, Air, & Soil Pollution* 223:5759–5771. https://doi.org/10.1007/s11270-012-1312-4

Sullivan, T. J., G. B. Lawrence, S. W. Bailey, T. C. McDonnell, C. M. Beier, K. C. Weathers, G. T. McPherson, and D. A. Bishop

2013 "Effects of acidic deposition and soil acidification on sugar maple trees in the Adirondack Mountains, New York." *Environmental Science and Technology* 47:12687–12694. https://doi.org/10.1021/es401864w

SWAS-VTSSS (Shenandoah Watershed Study and Virginia Trout Stream Sensitivity Study)

2019 Mountain Stream Database. https://swas.evsc.virginia.edu/POST/scripts/intro_statement.php. Data downloaded October 2019 by following these steps: Select 'Data for individual streams'; select 'Augusta county'; select 'graphical data display'. All primary SWAS-VTSSS data are found within the Project ID entitled 'SHEN_UVA_PRIMARY' on the following USGS/USEPA site: https://www.waterqualitydata.us

Swistock, B. and W. E. Sharpe

2016 *Limestone sand: Pros and Cons*. PennState Extension. (May 23, 2016). Accessed August 26, 2019. https://extension.psu.edu/limestone-sand-pros-and-cons

TheTrek

2020 The 2019 Hiker Survey: General Information. Accessed December 19, 2020. https://thetrek.co/appalachian-trail/2019-hiker-survey-general-information/#:~:text=365%20people%20who%20hiked%20on,in%202019%20took%20the%20survey.&text=59.4%20percent%20of%20hikers%20were,percent%20identified%20as%20non%2Dbinary.

Thornberry-Ehrlich, T. L.

2014 *Shenandoah National Park.* Geologic Resources Inventory Report. Natural Resource Report NPS/NRSS/GRD/NRR—2014/767.

Tilgar, V., R. Mand, and M. Magi

2002 "Calcium shortage as a constraint on reproduction in great tits *Parus major*: a field experiment." *Journal of Avian Biology* 33:407–413.

Tirmenstein, D. A.

1991a *Quercus rubra*. USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory.

1991b *Acer saccharum*. USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory.

1991c *Vaccinium pallidum*. USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory.

Tomlinson, G. H.

1990 *Effects of Acid Deposition on the Forests of Europe and North America*, Taylor & Francis. ISBN: 9780849347207. https://books.google.com/books?id=oyHKu0pBQwMC

Townsend, J. F.

2019 *Natural Heritage Resources of Virginia: Rare Plants.* Natural Heritage Technical Report 19-15. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, Virginia. Unpublished report. March 2019. 58p, plus appendices.

UCAR (University Corporation for Atmospheric Research)

2020 Accessed November 24, 2020. (http://kejian1.cmatc.cn/vod/comet/mesoprim/at_dust/navmenu.php_tab_1_page_2.1.2_type_text.htm#:~:text=Particles%20smaller%20than%2020%20micrometers,transported%20across%20oceans%20without%20settling

USDA-NRCS (US Department of Agriculture, Natural Resource Conservation Service)

2017 Title 430 – National Soil Survey Handbook (430-618-H, 1st Ed., Amend. 25, Nov 2017) 618-A.1 Part 618 – Soil Properties and Qualities. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=41981.wba

2020a Soil Survey. Accessed March 31, 2020. https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/

2020b The PLANTS Database. National Plant Data Team, Greensboro, NC 27401-4901 USA. Accessed October 3, 2020. http://plants.usda.gov

USEPA (US Environmental Protection Agency)

1974 *Information on levels of noise requisite to protect the public health and welfare with an adequate margin of safety.* Report No. 550/9-74-004. Prepared by the EPA Office of Noise Abatement and Control. Washington, D.C. https://nepis.epa.gov/Exe/tiff2png.cgi/2000L3LN.PNG?-r+75+-g+7+D%3A%5CZYFILES%5CINDEX%20DATA%5C70THRU75%5CTIFF%5C00000239%5C2000L3LN.TIF

2000 Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria Lakes and Reservoirs in Nutrient Ecoregion IX. Office of Water. Washington DC. EPA 822-B-00-020.

2020a Secondary Drinking Water Standards: Guidance for Nuisance Chemicals. Accessed December 11, 2020. https://www.epa.gov/sdwa/secondary-drinking-water-standards-guidance-nuisance-chemicals

2020b Virginia nonattainment/maintenance status for each county by year for all criteria pollutants. Accessed May 15, 2020. https://www3.epa.gov/airquality/greenbook/anayo_va.html

USFS (US Department of Agriculture, US Forest Service)

2011a *Lower Williams Terrestrial Liming Project. Environmental assessment.* Gauley Ranger District, Monongahela National Forest, Webster County, West Virginia. (July 2011). http://a123.g.akamai.net/7/123/11558/abc123/forestservic.download.akamai.com/11558/www/nepa/42897_FSPLT2_054176.pdf

2011b *Lower Williams Terrestrial Liming Project. Decision notice and finding of no significant impact*. Gauley Ranger District, Monongahela National Forest, Webster County, West Virginia. (July 2011). US Department of Agriculture, US Forest Service. http://a123.g.akamai.net/7/123/11558/abc123/forestservic.download.akamai.com/11558/www/nepa/42897_FSPLT2_054175.pdf

2018 “2018 Lower Williams Terrestrial Liming Project, logistics and details.” The Monongahela National Forest, Gauley Ranger District, Dyer, West Virginia. Presented by Stephanie Connolly, Forest Service Soil Scientist and Project Manager. Accessed September 7, 2019. http://www.uvm.edu/~nesmc/2018/LW_Liming_Presentaton_031518.pdf

2019 Personal communication between Dawn Kirk, US Forest Service, and Anthony Aufdenkampe, LimnoTech, concerning liming in the St. Mary’s River, Virginia.

2020 Personal communication between Stephanie Connolly, US Forest Service, and Derrick Rosenbach, WSP, concerning liming approach for the 2018 Lower Williams Terrestrial Liming Project in the Monongahela National Forest. August 5.

USFWS (US Fish and Wildlife Service)

1994 Shenandoah salamander (*Plethodon shenandoah*) Recovery Plan. USFWS Region 5. Hadley, Massachusetts.

USGS (US Geological Survey)

2019 “Wollastonite.” In: *2016 Minerals Yearbook Statistics and Information*. USGS National Minerals Information Center. Accessed September 10, 2019. https://www.usgs.gov/centers/nmic/wollastonite-statistics-and-information

UVA (University of Virginia)

2014 Shenandoah Watershed Study, 2014 Data Report. Shenandoah Watershed Study (SWAS) and Virginia Trout Stream Sensitivity Study (VTSSS). Todd Scanlon/James Galloway (Principal Investigators. Ami Riscassi, Project Coordinator. Suzanne Maben, Laboratory Manager.

VADCR (Virginia Department of Conservation and Recreation)

2020 Nonpoint Source Pollution Best Management Practices. Accessed December 10, 2020. https://www.dcr.virginia.gov/soil-and-water/npsbmp

VADEQ (Virginia Department of Environmental Quality)

2020 Final 2020 305(b)/303(d) Water Quality Assessment Integrated Report. Accessed January 14, 2021. https://www.deq.virginia.gov/water/water-quality/water-quality-assessments/most-recent-year-305b-303d-integrated-report

Van Devender, A., W. Van Devender, and D. Furr

2017 Final Report on Snail Survey. December 11, 2020. Memorandum to Bambi Teague, Supervisor Biologist at National Park Service, regarding preliminary results of a survey of Land Snails and Millipedes on the Blue Ridge Parkway. Provided via email from Paul Super, Science Coordinator of the Appalachian Highlands Science Learning Center at Great Smoky Mountains National Park, to Phillip Baigas, WSP Wildlife Biologist, on November 11, 2020.

VDGIF (Virginia Department of Game and Inland Fisheries)

2015 Virginia State Wildlife Action Plan, Appendix A. Virginia Species of Greatest Conservation Need. Accessed February 12, 2020. http://bewildvirginia.org/wildlife-action-plan/pdf/Final%20SGCN%20List%20Appendix%20A%20July%202016.pdf

Virginia Cooperative Extension

2009 *Liming acidified lakes and pond*. Prepared by L.A. Helfrich, R.J. Neves, and J. Parkhurst. Publication 420-254. https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/420/420-254/420-254_pdf.pdf

Virginia DCR (Department of Conservation and Recreation)

2020 Natural Heritage Data Explorer. Virginia DCR – Division of Natural Heritage website. Accessed April 28, 2020. https://vanhde.org/

Wäreborn, I.

1992 "Changes in the land mollusc fauna and soil chemistry in an inland district in southern Sweden." *Ecography* 18:177–180.

Walker, J. T., G. M. Beachley, H. M. Amos, J. S. Baron, J. Bash, R. Baumgardner, M. D. Bell, K. B. Benedict, X. Chen, D. W. Clow, A. Cole, J. G. Coughlin, K. Cruz, R. W. Daly, S. M. Decina, E. M. Elliott, M. E. Fenn, L. Ganzeveld, K. Gebhart, S. S. Isil, B. M. Kerschner, R. S. Larson, T. Lavery, G. G. Lear, T. Macy, M. A. Mast, K. Mishoe, K. H. Morris, P. E. Padgett, R. V. Pouyat, M. Puchalski, H. O. T. Pye, A. W. Rea, M. F. Rhodes, C. M. Rogers, R, Saylor, R. Scheffe, B. A. Schichtel, D. B. Schwede, G. A. Sexstone, B. C. Sive, P. H. Templer, T. Thompson, D. Tong, G. A. Wetherbee, T. H. Whitlow, Z. Wu, Z. Yu, and L. Zhang

2019 *Science needs for continued development of total nitrogen deposition budgets in the United States.* U.S. Environmental Protection Agency, Washington, DC, EPA 601/R-19/001. https://nadp.slh.wisc.edu/committees/tdep/reports/nrDepWhitePaper.aspx or https://nadp.slh.wisc.edu/committees/tdep/reports/NADP_TDep_Nr_Deposition_White_Paper_v3.pdf

Weather Spark

2020 Average Weather in Waynesboro Virginia, United States. Accessed November 18, 2020. https://weatherspark.com/y/20256/Average-Weather-in-Waynesboro-Virginia-United-States-Year-Round

Webb, J. R., B. J. Cosby, F. A. Deviney Jr., J. N. Galloway, S. W. Maben, and A. J. Bulger

2004 "Are brook trout streams in western Virginia and Shenandoah National Park recovering from acidification?" *Environmental Science and Technology* 38:4091−4096. https://doi.org/10.1021/es049958a

Welsch, D. L., J. R. Webb, and B. J. Cosby

2001 Description of Summer. 2000. Field Work. Collection of Soil Samples and Tree Corps in the Shenandoah National Park with Summary. Soils Data. Charlottesville, VA: Department of Environmental Science, University of Virginia.

Wendt, J. W. and S. Hauser

2013 "An equivalent soil mass procedure for monitoring soil organic carbon in multiple soil layers." *European Journal of Soil Science* 64:58–65. https://doi.org/10.1111/ejss.12002

Wilderness Connect

2020 Wilderness Areas of the United States. Accessed March 30, 2020. https://umontana.maps.arcgis.com/apps/webappviewer/index.html?id=a415bca07f0a4bee9f0e894b0db5c3b6

Williams, N. C. and D. M. Downey

2011 *St. Mary's Acid Mitigation Project: Is it time for another dose of medicine?* Project Report on the Cooperative Project between The US Forest Service, VA Department of Game and Inland Fisheries and James Madison University. https://www.srs.fs.usda.gov/airqualityportal/assets/stmarys.pdf

Wofford, J. E. B., and E. D. Demarest

2018 Shenandoah National Park Fish Monitoring Protocol: Version 5.0. Natural Resource Report NPS/SHEN/NRR—2018/1646. National Park Service, Natural Resource Stewardship and Science. Fort Collins, CO.

Wofford, J. E. B., E. D. Demarest, and J. R. Voshell Jr.

2018 Shenandoah National Park Benthic Macroinvertebrate Monitoring Protocol. Version 3.0. Natural Resource Report NPS/SHEN/NRR—2018/1621. National Park Service, Natural Resource Stewardship and Science. Fort Collins, CO. https://irma.nps.gov/Datastore/Reference/Profile/2252925

Wyman, R. L. and D. S. Hawksley-Lescault

1987 "Soil acidity affects distribution, behavior, and physiology of the salamander *Plethodon cinereus*." *Ecology* 68(6):1819–1827.

Wyman, R. L. and J. Jancola

1992 "Degree and scale of terrestrial acidification and amphibian community structure." *Journal of Herpetology* 26(4):392–401.

Yoo, K., B. Fisher, J. Ji, A. Aufdenkampe, and J. Klaminder

2015 "The geochemical transformation of soils by agriculture and its dependence on soil erosion: An application of the geochemical mass balance approach." *Science of the Total Environment* 521–522: 326-335. https://doi.org/10.1016/j.scitotenv.2015.03.084

Young, J., G. Fleming, W. Cass, and C. Lea

2009 Vegetation of Shenandoah National Park in relation to Environmental Gradients, version 2.0. Technical Report NPS/NER/NRTR—2009/142. National Park Service. Philadelphia, PA. https://irma.nps.gov/DataStore/DownloadFile/440196

Zobel, D. B.

1969 "Factors affecting the distribution of *Pinus pungens*, an Appalachian endemic." *Ecological Monographs* 39(3):303–333.

APPENDIX A
ISSUES, IMPACT TOPICS, AND ALTERNATIVES DISMISSED FROM DETAILED ANALYSIS

ISSUES AND IMPACT TOPICS DISMISSED FROM DETAILED ANALYSIS

Several issues and impact topics were considered during the development of the environmental assessment (EA) but were dismissed from detailed analysis for one or both of the following reasons:

- potential environmental impacts associated with the issue are not central to the proposal or of critical importance; or
- a detailed analysis of environmental impacts related to the issue is not necessary to make a reasoned choice between alternatives.

More details about the dismissal for these issues and impact topics are provided below. Note that literature citations for appendix A are included in the "References" section of the EA.

Hydrological Processes

Liming of the project area would have no impact on the hydrology in the stream because the limestone sand would not be placed in large quantities into the streambed (where it could temporarily dam flowing water and/or silt the streambed); instead the limestone sand would be applied as a thin layer of sand grains over the entire project area. Therefore, this topic was dismissed from further analysis in the EA.

Vegetation (Mast Production and Lichen)

Two topics related to vegetation (mast production and lichen) were not considered because meaningful impacts are not expected.

Mast Production. Mast is the fruit of forest trees and shrubs, such as acorns and other nuts, and is an important source for food for wildlife. There are no published data that support the notion that the application of fertilizer to oak trees influences mast production. However, masting may be difficult when nitrogen and phosphorus are already depleted in plant tissues (Harper 2009; Pearse et al. 2016; Brooke et al. 2019). Potential beneficial effects on trees from improved soil fertility would likely be minimal unless the soil pH is above 5.5 (Harper 2009). Present values of plant available soil phosphorus are very low in the Meadow Run watershed (7.2 ±7.6 parts per million), and bioavailable phosphorus is expected to increase with liming by releasing phosphate ions currently bound in insoluble forms with aluminum and iron. Similarly, potassium and sulfur bioavailability are likely to increase, because increased leaching and therefore plant availability has been observed after liming (Pabian et al. 2012b; Mizel et al. 2015). Producing a large seed crop during a masting event requires an abundance of these nutrients, and the low nutrient content and soil pH in the project area may currently compel trees to invest their resources into growth rather than seed or fruit production (Koenig and Knops 2005; Pearse et al. 2016). Therefore, mast production was dismissed from further analysis in the EA because adverse impacts are not expected, and the literature available to determine the extent of any beneficial impact is limited.

Lichen. Lichen species are sensitive to changes in soil pH and changes in calcium levels, so liming could affect their overall health (Scott and Hutchinson 1986; Hutchinson et al. 1987; Armstrong 1990). For example, treating common orange lichen *(Xanthoria parietina)* with calcium carbonate enabled the thalli to survive and grow (the thallus [plural thalli] refers to the body of a plant that does not have leaves, stems, or shoots). However, calcium carbonate treatment of shield lichen *(Parmelia saxatilis)* resulted in low growth rates and fragmentation of the centers of the thalli (Armstrong 1990). Although a list of lichen species in the project area is not available, any potential impacts on lichen in the project area may be short term because liming would occur during their dormant period and rain and snow could quickly remove limestone sand from rocks and other surfaces that support lichen. Therefore, lichen were dismissed from further analysis in the EA because the available information about the potential impacts from liming is limited, and potential adverse impacts are expected to be minimal or unlikely.

Terrestrial Wildlife (Mammals, Reptiles, Amphibians other than Salamanders, and Invertebrates other than Snails)

Several animal groups (mammals, reptiles, amphibians other than salamanders, and invertebrates other than snails) were not considered because meaningful impacts are not expected.

Mammals. Approximately 50 mammals are found in park, including large carnivores such as the coyote (*Canis latrans*), omnivores like the black bear (*Ursus americanus*), and large herbivores such as the white-tailed deer (*Odocoileus virginianus*) (NPS 2020c). Approximately 20 small mammal species occur in the park, including the eastern chipmunk (*Tamias striatus*) the eastern cottontail (*Sylvilagus floridanus*), meadow vole (*Microtus pennsylvanicus*), and deer mouse (*Peromyscus maniculatus*). Impacts of liming on mammals would be related to changes in vegetation. Expected increases in plant production and nutrient content following liming could improve forage quality and quantity for white-tailed deer and other herbivores (Pabian et al. 2012b). This change, however, is not anticipated to have population-level effects on deer and other mammals. Also, while liming could increase the fruiting or nutrition of mast-seeding of trees and affect the mammalian community that rely on both hard and soft mast, the dynamics of mast seeding depend largely on soil nutrients, and there is limited research on the effect of liming on mast seeding, as described above.

In addition, the risk of falling limestone sand particles actually injuring any active mammals during the application period (December–February) is considered low. Falling sand is of short duration and falls at a rate that would not cause harm to mammals. It is unlikely to be of sufficient volume to cause irritation for animals that remain in the flight path and do not disperse. During the Lower Williams Terrestrial Liming Project in the Monongahela National Forest in 2018 (e.g., USFS 2018a, 2018b), no impacts were observed during implementation, which occurred in winter when there was approximately a foot of snow on the ground (USFS, Connolly, pers. comm. 2020a). Helicopters spreading limestone sand in the project area could also disturb mammals, including the possible arousal of hibernating animals. Possible wildlife responses to these disturbances can range from an alert posturing (e.g., raised head or body) to a very energetic, stressed escape response (NPS 1994; Stankowich 2008). However, any disturbance from the helicopter over specific locations in the project area would be brief (less than a minute) and occur during daylight hours for up to three months during the winter. There would be no long-term impacts on the health and abundance of mammal populations in Meadow Run watershed. Therefore, mammals were dismissed from further analysis in the EA because population-level impacts from liming are not expected.

Reptiles and Amphibians (other than Salamanders). Aside from salamanders, amphibians in the park include 10 species of frogs and toads. There are at least 26 species of reptiles within the park, including 19 snakes, 3 lizards, and 4 turtles (NPS 2020c). These animals would likely be in a state of dormancy (e.g., brumation) during the period of limestone sand application (December–February), so liming would not directly affect them. With the exception of salamanders, there has been no published research in the United States regarding impacts of liming on these groups of reptiles and amphibians, although several studies in Europe have shown a beneficial effect of liming on the breeding success and/or abundance of frogs and toads (Beattie and Tyler-Jones 1992; Beattie et al. 1993; Bellemakers and van Dam 1992; McGrath and Lorenzen 2010). Therefore, reptiles and amphibians, except salamanders, were dismissed from further analysis in the EA because the available information about the potential impacts from liming is limited, and population-level impacts are unlikely.

Invertebrates (other than Snails). Invertebrates are the least conspicuous and most poorly understood terrestrial wildlife in the park. The process of liming would not likely have direct impacts on invertebrates (such as crushing from the falling limestone sand particles or desiccation from physical contact with it on the ground) because invertebrates would be inactive and sheltered beneath soil, leaf litter, or bark during the application period (December–February). Although invertebrates are the most abundant and diverse group, the number of species present in the park is not known (NPS 2020i; Costanzo et al. 2017).

Invertebrates include spiders (Arachnida); crayfish, fleas, and lice (Crustacea); centipedes (Chilopoda); millipedes (Diplopoda); and insects (Insecta). Native invertebrate communities evolved in ecosystems with less acidic soil conditions than the current conditions in the Meadow Run watershed, so liming is expected to have an overall beneficial impact on most native species. For example, effects on tree growth and physiology from liming could increase available nutrients in soil and litter, which could promote more diverse and abundant assemblages of native invertebrate species. Beier et al. (2012) found that major types of soil arthropods (i.e., invertebrates that inhabit the soil) do not appear to be sensitive to soil chemistry or plant nutrition, whereas McCay et al. (2013) showed declines in the abundance of millipedes and spiders following liming, which may in turn contribute to a reduction in the rate of litter decay. Buckton and Ormerod (1997) found that certain spider families increased while others decreased in limed upland mire in Wales. They also found that although there were significant differences in abundance for various taxa at limed and unlimed sites, there were no differences in the relative abundance or diversity of species at the community level.

In summary, available research findings about the effects of liming on invertebrates are limited and conflicting for some taxa. Overall, considering that conditions in the Meadow Run project area would be improved to conditions that existed prior to acidic deposition, the overall impact on invertebrates is considered beneficial. For these reasons, impacts on invertebrates other than snails were dismissed from further analysis in the EA.

Special-Status Species (Including Threatened and Endangered Species)

Special-status species are those protected by federal or state law, regulation, or policy. Included in this category are species designated as threatened or endangered at the federal and/or state level.

Threatened and Endangered Species. Four bat species could potentially occur in the project area: the federally listed endangered Indiana bat (*Myotis sodalis*) and threatened northern long-eared bat (*Myotis septentrionalis*), and the state-listed little brown bat (*Myotis lucifugus*) and tri-colored bat (*Perimyotis subflavus*). Although the project area provides possible roosting habitat, liming would occur during winter when bats are hibernating. Because there are no suitable hibernacula within the project area, there is little to no potential for adverse impacts to these species. A third state-listed species, the peregrine falcon (*Falco peregrinus*), is unlikely to forage in the project area and its suitable nesting habitat on high cliffs is limited. Also, peregrine falcons leave the park during winter and would not likely occur in the project area during the period of limestone sand application.

The Shenandoah salamander (*Plethodon shenandoah)* is federally listed as endangered and only occurs in the park, but it does not occur within the Meadow Run watershed (USFWS 1994).

Because adverse impacts are not expected, threatened and endangered species were dismissed from further analysis in the EA.

Other Special-status Species (Other than Birds). Information regarding other special-status species was obtained by reviewing species categorized as Species of Greatest Conservation Need (SGCN) in the Virginia State Wildlife Action Plan (VDGIF 2015). Nine mammals, six reptiles, and one amphibian, the eastern spadefoot (*Scaphiopus holbrookii*), are categorized as SGCN and could occur in the project area, but these species were dismissed from further analysis for reasons provided above for each group under "Terrestrial Wildlife (Mammals, and Other Reptiles, Amphibians and Invertebrates)." On the other hand, 17 bird species and the Jefferson salamander (*Ambystoma jeffersonianum*) are categorized as SGCN and are analyzed as part of the terrestrial wildlife topic in chapter 3 of the EA.

Historic Resources and Archeological Sites

Four archeological sites have been recorded within the project area. All are presently listed as unevaluated for the National Register of Historic Places (NRHP) in the Virginia Department of Historic Resources (VDHR) Cultural Resources Information System, although two sites have had NRHP recommendations of “not eligible” made by archeologists. The four sites include three small prehistoric lithic scatters or camp sites of unknown temporal period, and an early-twentieth century check dam. However, the proposed action would not affect these sites because there would be no ground disturbance other than placement of a thin layer of scattered limestone sand grains from the air.

Historic resources in the project area consist of the Appalachian Trail and Skyline Drive and its associated waysides and overlooks that may be used as staging area(s). VDHR determined the trail to be eligible and nominated it to the NRHP in 2018. However, the proposed action would not physically impact the Appalachian Trail. Skyline Drive and its adjoining overlooks and waysides were designated a National Historic Landmark in 2008.

Potential impacts to the historic overlooks and waysides could come from physical damage to the road surface, guard walls, underpasses, drainage structures, and other elements of the built environment from the weight of the limestone sand and movement of equipment. However, weight restrictions on Skyline Drive would be followed and monitored. Damage to overlooks would be avoided by appropriate planning during project implementation. Such steps could include using wooden construction matting on surfaces used to stockpile limestone sand or to maneuver heavy equipment, protecting of historic guard walls with appropriate barriers, and avoiding overlook sections built on fill for stockpiling heavy loads. Therefore, this topic was dismissed from further analysis in the EA.

Air Quality, Air Quality Related Values, and Climate Change

The park is designated a Class I area under the Clean Air Act. Class I status provides the park with an additional measure of protection for park air quality (criteria pollutant ambient concentrations) and resources sensitive to air pollution (referred to as air quality related values [AQRVs]), such as visibility, plants, animals, soils, water, and ecosystems. Existing air quality is affected primarily by power plants, industrial facilities, and urban areas within surrounding regions, as opposed to emissions sources located within the park (Sullivan 2003).

The proposed action would have a localized impact on air quality from engine emissions during the limestone sand application period of up to three months, and during November while the limestone sand stockpile is being constructed. Emissions would come from the helicopter, trucks, and other construction vehicles used in the staging areas. The emissions contribution of these activities would be extremely low relative to existing regional emissions. In addition, the helicopter emissions would be geographically dispersed over the flight path and would not result in concentrated emissions in any particular area due to the short duration of helicopter hovering over an active staging area during switching of buckets. The project area is in attainment status with respect to the National Ambient Air Quality Standards (USEPA 2020b).

Most of the released limestone sand would settle quickly to the floor of the project area after its release from the bucket underneath the helicopter. The accidental drift of some residual fine limestone sand particles into the neighboring properties can be avoided through appropriate planning. Data from the Waynesboro Airport indicate that at the project area the wind blows two-thirds of the time from the west and south during the December–February period (and one third of the time from the north and east), and on 32% of the days throughout the year the atmosphere is “calm” (i.e., winds speeds are lower than 2 miles per hour) (Iowa State University 2020; Weather Spark 2020). In combination, this implies that approximately 77% of the time there are either calm conditions or the wind blows to the east or north in the project area (i.e., away from the nearest properties and communities outside the park). The helicopter would only operate during moderate wind conditions, limiting travel distances of the finest grains in the limestone sand. Accordingly, liming along the southern and southwestern edges of the project area would be planned for times when wind speeds are low or when the wind blows predominantly from the south or west to avoid or minimize residual limestone sand particles from drifting outside the park boundary. Details of the liming approach would be determined in the implementation plan, which would include additional grain size analyses of the limestone sand to be used. For these reasons, air quality was dismissed from further analysis in the EA.

The proposed action would have beneficial effects on AQRVs that are affected by the historical and continuing acidic deposition of sulfate and nitrate ions. These beneficial effects are addressed in other impact topic sections, including soil, water, vegetation, and wildlife. The temporary truck and helicopter emissions associated with the proposed action likely would not cause measurable visibility degradation or increases in ozone concentrations. Therefore, AQRVs were dismissed from further analysis in the EA.

Although climate change is expected to affect the resources in the Meadow Run project area (NPS 2020b), the proposed project is not expected to affect climate change. While the helicopter and trucks used during liming would consume fossil fuel, greenhouse gas emissions associated with these activities would be negligible because of the limited number of anticipated flights and truck trips. As a result, impacts on climate change from greenhouse gas emissions were dismissed from detailed analysis in the EA.

Public Health and Safety

Health and safety risks could be associated with the movement of construction equipment and the flight of the helicopter with a suspended bucket, and noise and dust and sand grains stirred up by the hovering helicopter in an active staging area when an emptied bucket is switched for a reloaded full one.

Movement of Helicopter and Vehicles. The project could potentially impact public safety during the movement of construction equipment to and from an active staging area. The helicopter would also fly overhead with a loaded bucket of limestone sand (and an empty bucket on return flights) suspended from the helicopter on a wire cable. Limestone sand would be released over the project area, which would affect three trails. Injury from moving equipment and helicopters would be avoided through (1) careful selection of staging areas and flight paths (this would include close coordination and approval from landowners and affected neighbors for staging area[s] outside the park), (2) full or partial closures of affected trails and Skyline Drive, and (3) communication with neighbors and potential visitors.

Hovering of Helicopter. The helicopter hovering directly over an active staging area during the switching of buckets would be loud and could stir up dust and sand grains on the ground through “rotor wash.” Appropriate personal protective equipment to protect ears from noise and exposed skin from mobilized particles would be required for employees working on the project during liming.

Any risks to public health and safety from the helicopter and construction equipment and the hovering helicopter at active staging areas for a period of up to three months (or a total of up to six months in the event of a second application in another year) would be minimized and avoided through maintaining safety distances from the operation, appropriate planning, and suitable mitigation measures. Details on health and safety measures (including emergency management procedures) would be specified within the implementation plan. For these reasons, this impact topic was dismissed from further analysis in the EA.

ALTERNATIVES CONSIDERED BUT DISMISSED FROM DETAILED ANALYSIS

Several alternatives described below were identified during internal and public scoping but did not meet the purpose and need, are not feasible, or would result in too great of an environmental impact. Therefore, they were dismissed from detailed analysis.

Liming by Ground Transport

The National Park Service (NPS) considered transporting limestone sand or lime into the watershed by non-motorized means or by motor vehicles and distributing the material evenly over the surface of the liming area.

Non-motorized methods for transporting liming material into the project area include people or transport animals (e.g., horse, mule). Non-motorized transport would involve many trips. For example, transporting 5,000 tons of limestone sand would require 250,000 person-trips, assuming each person carried a net load of 40 pounds. A larger load could be carried by pack animals, but the use of animals would result in greater wear of the trail. Assuming a mule could carry 150 pounds, it would require 67,000 mule trips for 5,000 tons of limestone sand. In addition, the limestone sand would need to be spread evenly in the liming area, well beyond the few existing trails. Volunteers would have to cross all parts of the forest floor. The terrain is steep, rugged and rocky, posing a safety risk to pack animals and people in some areas. Leaving the trails would also result in considerable resource impacts in wilderness areas in the form of soil compaction by trampling, destruction of vegetation, and erosion triggered by soil disturbance on slopes, even more so by a pack animal than by a person. The number of people and pack animals required under this alternative would result in extensive impacts to solitude and unconfined recreation because it would take significantly longer than liming by helicopter; require many people in wilderness at one time; and leave impacts on soil, vegetation, and trails that would be noticeable and not consistent with wilderness character. Therefore, NPS deemed this alternative infeasible, and it was dismissed from further analysis in the EA.

Motorized transport could include four-wheelers and tractors or log skidders fitted with a spreader. However, the use of motorized equipment in designated wilderness is prohibited under the Wilderness Act unless an analysis demonstrates that it is necessary and is the minimum tool needed to accomplish the project goals. Therefore, motorized ground transportation could only be considered for non-wilderness corridors that exist in approximately 20% of the project area. Even in these small non-wilderness parts of the project area, dense vegetation and steep topography would make this approach unsuitable. In addition, because other alternatives (i.e., liming by helicopter under alternatives B and C) do not require on-the-ground motorized equipment in the project area, there are options that are consistent with the Wilderness Act. Therefore, NPS dismissed this alternative because it is not the minimum tool necessary to achieve the purpose and need of this project.

Liming by Fixed-wing Aircraft

NPS also explored applying limestone sand using fixed-wing aircraft (aircraft). However, application by aircraft would have a low accuracy and application would be uneven compared to helicopter placement because an aircraft needs to release the sand during a brief moment while in flight. Accurate aircraft placement is further complicated by the steep and complex topography of the project area; the mountain side facing the approaching aircraft would receive a higher dosage of the liming material than the side of the mountain opposing the approaching aircraft. As a result, impacts to the soil and vegetation in the project area would be highly uneven. Also, the higher velocity of the sudden discharge of a large amount of limestone sand may have a “sand-blasting” effect on vegetation and any wildlife, unless released higher in the air, which would further reduce the accuracy of sand placement. For these reasons, this alternative would not meet the purpose and need of the project.

Gravity-based Application from Skyline Drive

Gravity-based approaches would involve dispersing liming material into the watershed using motorized vehicles from Skyline Drive and then allowing stormwater runoff and/or the groundwater to gradually transport base cations through the soil and bedrock to lower elevations in the watershed and eventually into Meadow Run waters. For example, liming material could be applied using a power sprayer, releasing lime or lime slurry through pipes or hoses, or simply placing carbonate sand along the side slopes of Skyline Drive. However, while applying liming material from Skyline Drive would likely be less expensive than helicopter liming per ton of material applied, gravity-based applications could only cover a very small portion of the project area and would be very uneven in this small area, and would therefore not meet the purpose and need for this project.

Instream Liming

NPS considered using a lime dosing system or adding limestone sand directly to Meadow Run. A combination of terrestrial liming and targeted instream liming was also considered.

Lime dosing systems automatically release a prescribed amount of lime to the stream, based on regular monitoring of the chemistry and flow. Using a dosing system would require a physical structure (or several structures for multiple tributaries) that would house the lime and the equipment to prepare the appropriate dose to be added to the stream. It may also include equipment for frequent monitoring of the flow and chemistry of the stream to maintain accurate calibration. Lawrence et al. (2016) stated that monitoring of an automated dosing system requires a site visit at least several times a week. This system would need to be set up for year-round operation to provide consistency in the pH of the stream water. In most parts of the Meadow Run project area, placement of a structure would be inconsistent with the wilderness character. Non-wilderness parts of the watershed either have no stream flow or would have limited benefits to Meadow Run. Furthermore, the need for frequent monitoring in a remote area would make this approach labor intensive for park staff.

Direct limestone sand application consists of depositing a pile of dry limestone sand into the streambed by truck or helicopter. Rainfall and flow then gradually distribute the material down the stream where it slowly dissolves. As summarized by Swistock and Sharpe (2016), advantages of this approach are its simplicity with maintenance requirements, low costs, and effectiveness; disadvantages are inconsistent results especially at high stream flows, unclear dosage requirements, the need for frequent applications to achieve long-term effects, and the potential of sand deposits covering the stream bottom and negatively affecting aquatic macroinvertebrates. In addition, only helicopter placement of limestone sand would be suitable in the Meadow Run project area given the lack of access and wilderness status.

Both instream liming approaches would only address the symptom and not the source of the acidity, which is the acidified soil and groundwater. The park is planning terrestrial application of limestone sand only, because the treatment lasts longer and provides benefits to both the terrestrial and aquatic environments, thereby benefiting the entire ecosystem. While instream liming results in immediate water quality improvements (i.e., increased acid-neutralizing capacity and pH), it must be repeated every few years to remain effective, whereas the documented effectiveness of terrestrial applications is decades to centuries. In addition, under the proposed terrestrial liming included in alternatives B and C, a small amount of limestone sand would fall into the narrow streambed, providing some level of immediate response.

Therefore, instream liming alone would not meet the purpose and need of the project. Adding instream liming to the proposed terrestrial liming as a hybrid approach was also not considered sufficiently beneficial to justify the added complexity and cost to the project.

APPENDIX B
TECHNICAL BACKGROUND FOR LIMING MEADOW RUN WATERSHED

CONTENTS

SECTION 1: INTRODUCTION **1**
SECTION 2: WATERSHED ACIDIFICATION IN THE PARK **2**
HISTORY OF ACIDIC DEPOSITION 2
EFFECTS OF ACIDIC DEPOSITION 3
RECOVERY FROM ACIDIC DEPOSITION 5
SECTION 3: LIMING AS A RESTORATION TOOL AND LIMING DOSE DETERMINATION FOR MEADOW RUN WATERSHED **10**
OVERVIEW 10
ECOSYSTEM EFFECTS AND EFFECTIVENESS OF LIMING AS A RESTORATION TOOL – EXPERIENCE FROM OTHER WATERSHEDS 10
LIMING MATERIALS 13
Types 13
Quarries 14
Liming Material Appropriate for Meadow Run Project Area 17
LIMING DOSES FOR MEADOW RUN PROJECT AREA 18
Methodology 18
Proposed Liming Doses for Meadow Run Watershed Restoration 24
SECTION 4: MEADOW RUN RESPONSE TO LIMING **26**
RESPONSE TIME 26
SOIL PH 26
SOIL CALCIUM AND MAGNESIUM 29
SOIL POTASSIUM 29
HEALTHY STREAM CONDITIONS 29
SECTION 5: SUMMARY **31**

LIST OF FIGURES

Figure B-1. Total Sulfur Deposition in and around Shenandoah National Park, Comparing Average Data from 2000–2002 to 2016–2018 2
Figure B-2. Atmospheric Wet Deposition of Sulfate at Big Meadows in the Park (1980–2018) 3
Figure B-3. pH and ANC in Meadow Run, Measured Quarterly during Baseflow Conditions (1987–2018) 4
Figure B-4. Bedrock Geology and SWAS Stream Sampling Sites 6
Figure B-5. pH and ANC in Streams of the Park, Based on SWAS Data (1986–2009) 7
Figure B-6. Fish Biodiversity (Measured in Richness) and ANC, Measured in 13 Streams in the Park 9
Figure B-7. Bedrock Geology and Soil Sampling Sites in the Project Area 11
Figure B-8. Pelletized Lime 14
Figure B-9. Limestone Sand Products available at Frazier’s North Quarry 15
Figure B-10. Grain Size Distribution of Limestone Sand from Frazier’s North Quarry 16
Figure B-11. Meadow Run Baseflow Stream Water Concentration Trends for Four Base Cations Measured Quarterly from January 1986 to March 2018 17
Figure B-12. Profile-averaged Base Cation Saturation (left) and Cation Exchange Capacity (right) 20
Figure B-13. Base Cation Need (in t/acre of Limestone Sand) for the 0-20 cm Soil Interval for all 46 Soil Sites together (left) and for the different Geological Formations (right) 21
Figure B-14. Cumulative Probability of the Standardized Normal Distribution 23
Figure B-15. Soil pH as a Function of Cation Base Saturation for Clay Mineral End Members 27
Figure B-16. Soil pH as a Function of Base Cation Saturation (Bsat) Measured in Soils by Horizon 27
Figure B-17. Distributions of Soil pH measured in the Upper Mineral Soil (~5 to 20 cm deep) 28

LIST OF TABLES

Table B-1. Stream Conditions in the Park for Different Bedrock Types 8
Table B-2. Terrestrial Liming Projects in Appalachia 12
Table B-3. Chemical Composition of Liming Materials 16
Table B-4. Soil Acidification Metrics from 46 Sites in Meadow Run Watershed in 2019 19
Table B-5. Base Cation Need to Achieve Base Cation Saturation of 20% (from Limestone sand), Calculated from Measured Base Cation Deficit 22

SECTION 1: INTRODUCTION

The National Park Service (NPS) is proposing to improve the long-term health of the terrestrial and aquatic ecosystem and mitigate harmful effects of acidic deposition in the Meadow Run watershed, located in the South District of Shenandoah National Park (park). Aside from considering the effects of taking no action, the environmental assessment (EA) analyzes the potential impacts from two action alternatives that would apply limestone sand over the project area via helicopter. The project area covers approximately 2,150 acres. Applying liming material (i.e., ground limestone in the form of lime or limestone sand) to watersheds has been effective in restoring impaired ecosystems and counteracting the adverse consequences of acidic deposition.

This appendix provides technical background developed prior to the preparation of the EA. Specifically, the appendix contains the following sections:

- **Section 2 - Watershed Acidification in the Park.** This overview summarizes the history of acidic deposition in the park and provides the justification for selecting the Meadow Run project area as one of the most suitable areas in the park for restoration.
- **Section 3 - Liming as a Restoration Tool and Liming Dose Determination for Meadow Run Watershed.** This overview includes case studies of successful liming in other watersheds in the United States. It also lists different types of liming materials and reviews their suitability and availability for the project area. Finally, it determines liming doses that would be appropriate for a successful project in the Meadow Run watershed based on site-specific conditions of soils and other natural resources. These doses are used for alternatives B and C.
- **Section 4 - Meadow Run Response to Liming.** This section contains details about the expected response to liming, providing additional information to support the findings described in "Chapter 4: Environmental Consequences" of the EA.
- **Section 5 – Summary.** This section summarizes key technical information provided in this appendix.

Please note the following:

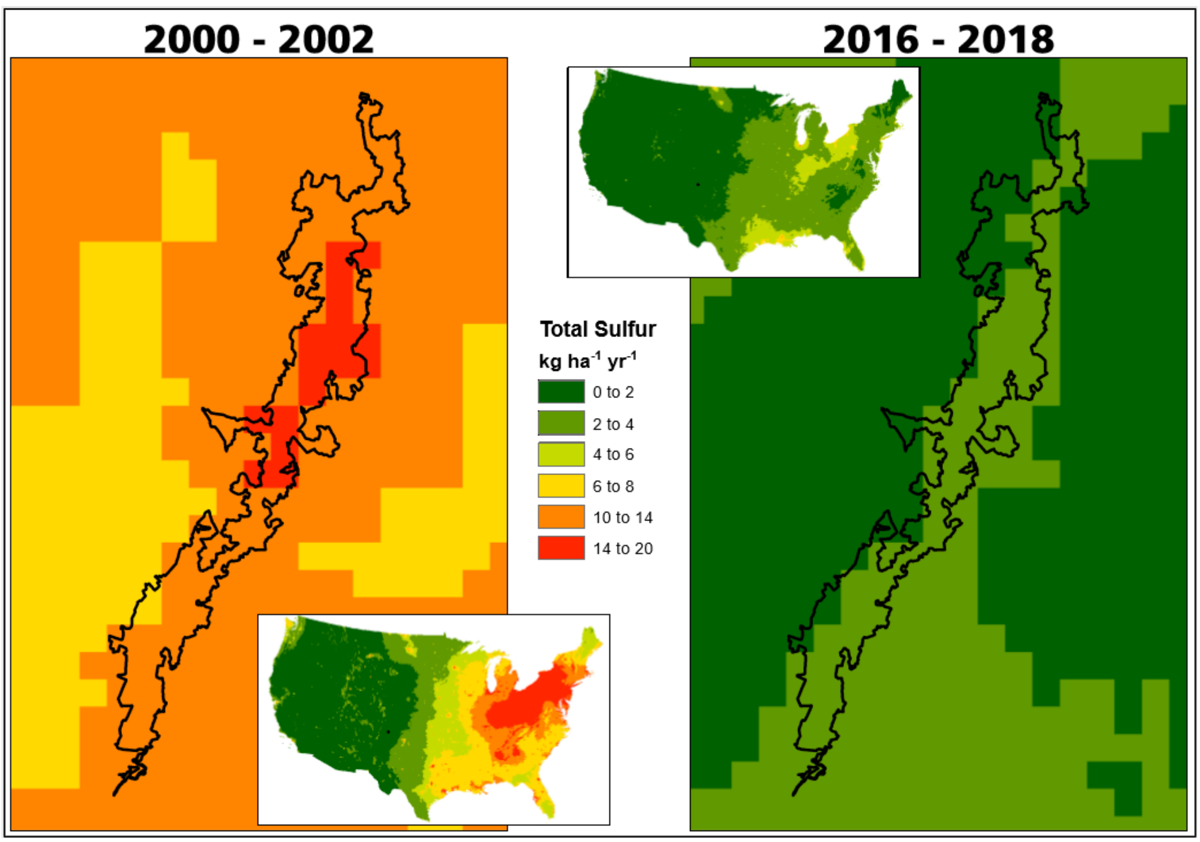
- **Acronyms and Abbreviations and Definition of Frequently Used Terms:** Such terms used in appendix B are included in the so-named lists above, following chapter 5 of the EA.
- **References:** Literature citations in appendix B are included in the chapter "References" above, following the main body of the EA.

SECTION 2: WATERSHED ACIDIFICATION IN THE PARK

The park encompasses part of the Blue Ridge Mountains, which form the eastern rampart of the Appalachian Mountains between Pennsylvania and Georgia. The park rises above the Virginia Piedmont to its east and the Shenandoah Valley to its west. The park's highest two peaks exceed 4,000 feet (1,210 meters) above sea level. More than 95% of the park is forested, dominated by hardwoods. It has diverse habitats as a result of its range of elevation, slopes and aspects, rocks and soils, precipitation, and latitude. The park is home to more than 1,400 species of vascular plants, 200 birds, 50 mammals, 30 fish, and 50 amphibians and reptiles (NPS 2020c). These species include several federally listed endangered and state-designated threatened species of animals and plants. In addition, the park contains globally rare plant communities and several state-designated rare plant species.

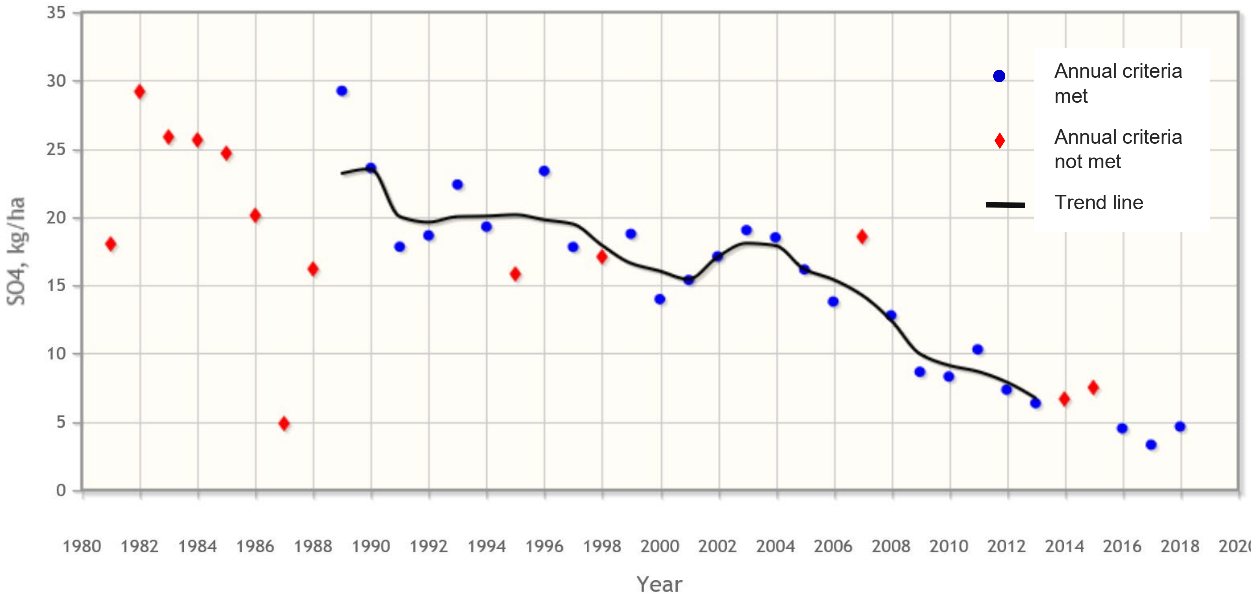
HISTORY OF ACIDIC DEPOSITION

The park's location downwind from industrial facilities has resulted in chronic, high levels of acidic deposition of atmospheric pollutants such as sulfate and nitrogen oxides over many decades (Sullivan et al. 2008; figures B-1 and B-2). Such acidic deposition leaches calcium and other base cations from soils, depleting the natural acid neutralizing capacity (i.e., the ability of the system to buffer acidic input) of soils, groundwater, and surface waters that they feed. Acidification of streams in turn reduces habitat quality for fish and aquatic invertebrates (e.g., Bulger et al. 1999; Harmon 2017).



Source: NADP-TDEP 2020, adapted by NPS

FIGURE B-1. TOTAL SULFUR DEPOSITION IN AND AROUND SHENANDOAH NATIONAL PARK, COMPARING AVERAGE DATA FROM 2000–2002 TO 2016–2018



Source: NADP-NTN 2019

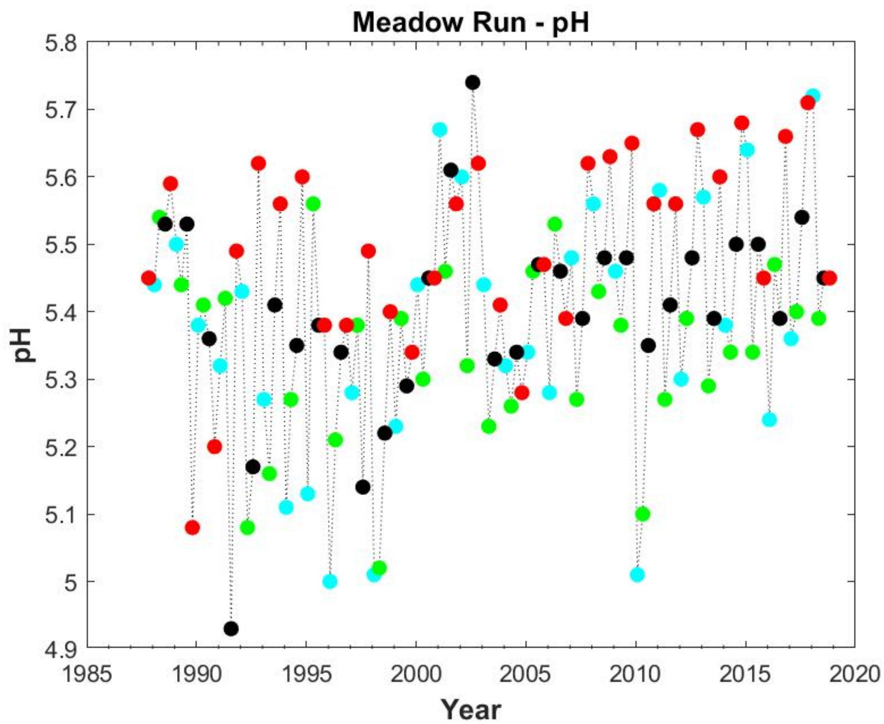
Notes: The Big Meadow NADP-NTN monitoring site (VA28) is at an elevation of 3,514 feet (1,072 meters. The trend line on the figure is smoothed over years to reduce noise associated with annual variability and is only drawn over periods when data (in kilogram per hectare [kg/ha]) were collected for enough weeks to allow for a reasonably complete record for each year.

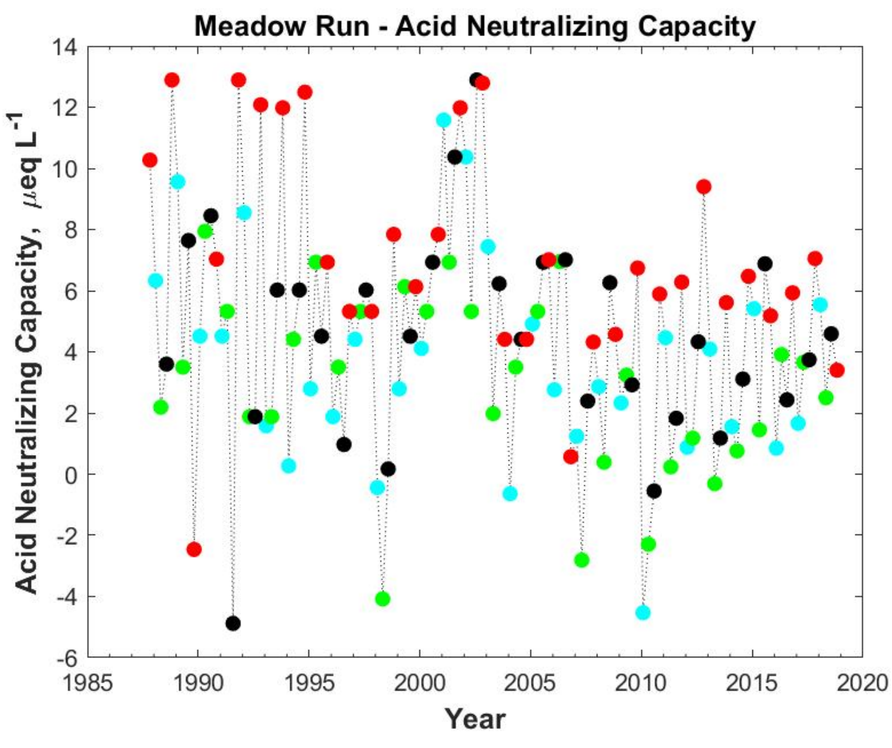
FIGURE B-2. ATMOSPHERIC WET DEPOSITION OF SULFATE AT BIG MEADOWS IN THE PARK (1980–2018)

EFFECTS OF ACIDIC DEPOSITION

Acid neutralizing capacity (ANC) and pH are the two primary indicators of stream acidification. ANC measures the ability of a stream to neutralize a strong acid; pH is a quantitative measure of the acidity or basicity of aqueous or other liquid solutions. Low ANC is associated with reduced overall fitness in most fish species and loss of stream biodiversity due to the disappearance of acid-sensitive fish and some common invertebrate species (e.g., Jastram et al. 2013). Pre-industrial stream ANC values in Meadow Run exceeded ANC values of 50 microequivalents per liter (µeq/L) (Sullivan et al. 2003). The average ANC value of today's stream is around 4 µeq/L based on monitoring data by the Shenandoah Watershed Study and Virginia Trout Stream Sensitivity Study (SWAS-VTSSS) (figure B-3; Scanlon et al. 2019). Many of the affected streams in the park, including Meadow Run, have been formally listed by the Virginia Department of Environmental Quality as impaired waters under Section 303d of the Clean Water Act because of low pH that affects aquatic life (VADEQ 2018).

The effects of acidic deposition vary across the park. The severity of stream acidification is tied to watershed characteristics, most notably elevation, underlying bedrock geology, and soil properties. High elevation areas in the park (e.g., ridge tops) receive higher levels of acidic deposition through increased rain, fog, and cloud deposition than lower elevation areas. Bedrock geology and soils are critical factors because they serve as the watershed's primary source and storage of acid neutralizing capacity.





Source: SWAS-VTSSS 2019
Note: Colors represent sampling season (blue=winter, green=spring, black=summer, red=autumn)

FIGURE B-3. PH AND ANC IN MEADOW RUN, MEASURED QUARTERLY DURING BASEFLOW CONDITIONS (1987–2018)

RECOVERY FROM ACIDIC DEPOSITION

Although acidic deposition has dramatically decreased over the last four decades, natural systems recover slowly (Likens et al. 1996; Rice et al. 2014b). Studies in the park provide a clear example. In the region in and around the park, the total sulfur deposition rate decreased by a factor of more than four from the period of 2000–2002 to 2016–2018 (figure B-1). The atmospheric sulfate deposition rate specifically measured in the park at the Big Meadow monitoring station (elevation 3,514 feet) decreased by a factor of more than five since 1981 (figure B-2). Despite these reductions in acidic deposition, pH and ANC concentrations in Meadow Run have not improved and remain below levels considered healthy for aquatic systems (figure B-3).

Recovery rates vary and are dependent on watershed characteristics (Lawrence et al. 2016). The primary natural mechanism for recovery is through chemical weathering of bedrock during soil formation processes. The chemistry of soils and streams and their vulnerability to acidification are thus determined by the underlying bedrock geology (Garrels and Mackenzie 1967; Rice et al. 2006).

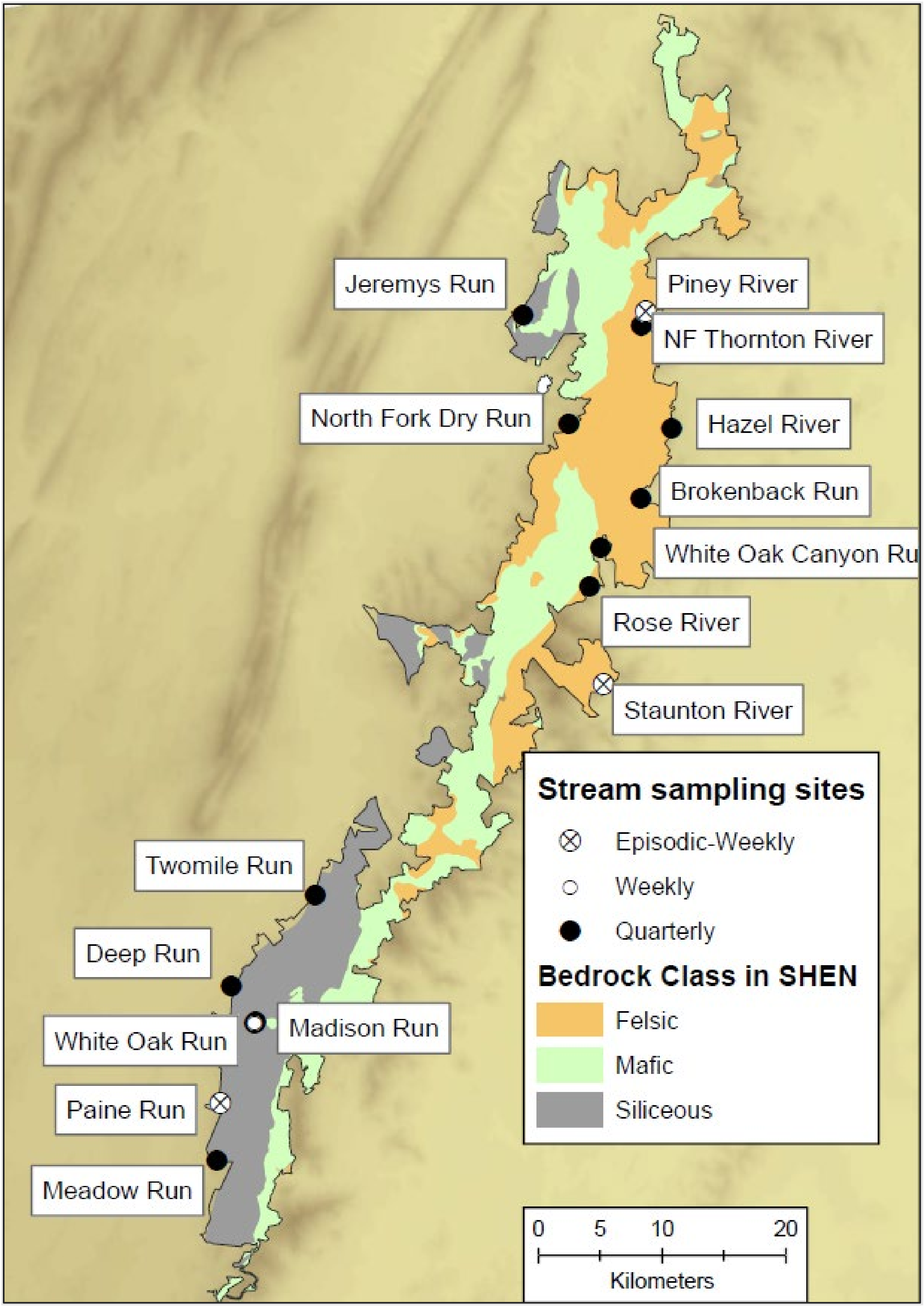
The park has three major groups of bedrock geology (figure B-4) that determine the soil and stream water chemistry and susceptibility to acidification (Rice et al. 2006; Southworth et al. 2009; Sullivan et al. 2007; Robison et al. 2013; Thornberry-Ehrlich 2014; Riscassi et al. 2019):

- **Basaltic (or mafic)** (both terms are used in the literature): Basaltic rock units in the park include Neoproterozoic metasedimentary rocks of the Swift Run Formation and metabasalt of the Catoctin Formation. These rock units are typically rich in weatherable base cations, such as calcium and magnesium, and are the least sensitive to acidification.

- **Granitic (or felsic)**: Granitic rock units in the park are made up of Mesoproterozoic granitic gneisses and granitoids. These rock units generally have lower base cation content and are moderately sensitive to acidification.

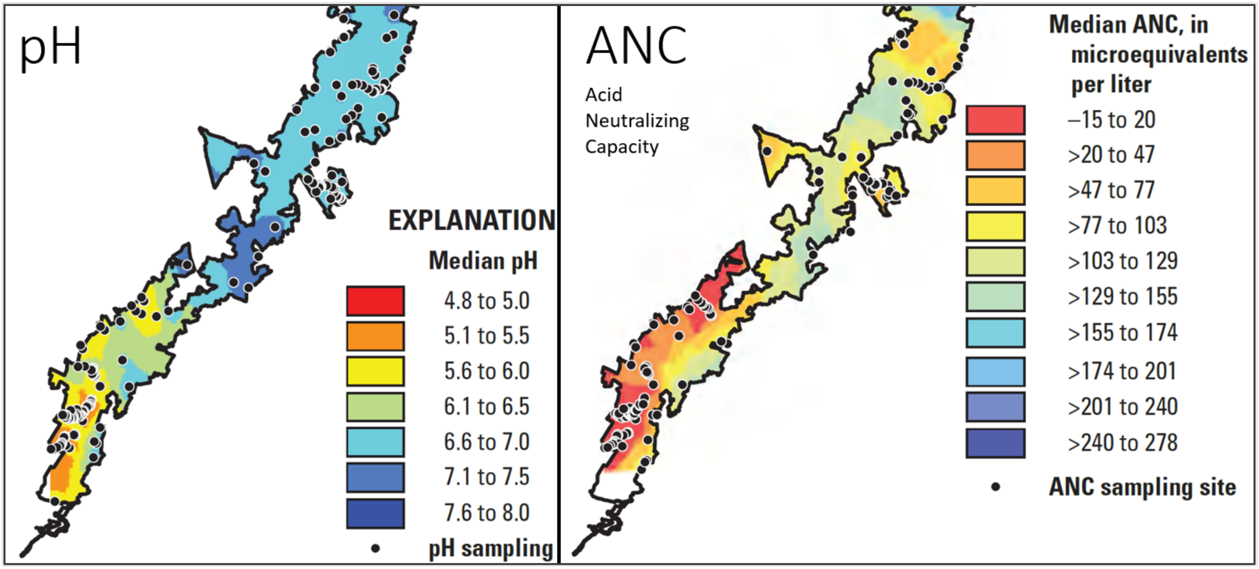
- **Siliciclastic (or siliceous)**: Siliciclastic rock units in the park are of the Lower Cambrian Chilhowee Group, including the Harpers Formation of meta-sandstone, meta-siltstone, and phyllite; the Weverton Formation of metamorphosed siltstone, coarse-grained metamorphosed greywacke, and quartzite; and the Antietam Formation of metamorphosed sandstones and quartzite. Siliciclastic rock units have very low base-cation content and are most sensitive to acidification.

Chronically acidified streams in the park occur in locations where underlying bedrock lacks natural buffering capacity, particularly in areas with siliciclastic bedrock. This is reflected in the low pH and ANC levels in streams of these areas, based on SWAS-VTSSS program water quality data from 1986 to 2018 (Jastram et al. 2013; Scanlon et al. 2019; figure B-5). Spatial patterns in water quality throughout the park, particularly those associated with acidification, largely follow a north-south gradient that coincides with geologic variation. Overall, Jastram et al. (2013) found that water quality in watersheds with higher mean elevations, areas with more gentle slopes, larger watershed areas, and lower proportions of siliciclastic bedrock are least affected by acidification and tend to improve over time. In contrast, watersheds with higher proportions of siliciclastic and granitic bedrock, smaller watershed areas, and higher minimum watershed elevation tend to be more affected by acidification and experience continued degradation.



Source: UVA 2014; geological mapping information based on Thornberry-Ehrlich 2014

FIGURE B-4. BEDROCK GEOLOGY AND SWAS STREAM SAMPLING SITES



Source: Jastram et al. 2013

FIGURE B-5. PH AND ANC IN STREAMS OF THE PARK, BASED ON SWAS DATA (1986–2009)

Many fish species (including brook trout), as well as insects and other organisms upon which they feed, can no longer survive in the park's acidified streams such as Meadow Run (e.g., Bulger et al. 1999; Burns et al. 2011; Jastram 2013). Brook trout populations are believed to be stressed at stream ANC values below 50 µeq/L and experience reduced reproduction and/or growth at stream ANC values below 20 µeq/L (Bulger et al. 2000; Cosby et al. 2006). Similarly, the health of the macroinvertebrate community is low in streams with siliciclastic bedrock (table B-1). Based on the 14-year monitoring data record, the fish biodiversity (species richness) in areas of siliciclastic bedrock has remained low. The low fish species richness and lack of species recovery in streams with siliciclastic bedrock was also shown by Harmon (2017), who compared data from 13 streams in the park collected in 1995 and 2016 (figure B-6). Areas with basaltic and granitic bedrock that are more resilient to acidic deposition showed improved fish species richness between 1995 and 2016.

The natural recovery time for Meadow Run, in the absence of liming, has been estimated by a series of related modeling studies to go well beyond 2100 (Sullivan et al. 2003, 2004, 2008, 2010, 2012; McDonnell et al. 2012). These studies used the Model of Acidification of Groundwater in Catchments (MAGIC) to simulate stream water ANC values for watersheds throughout the park and Appalachian region. A key parameter for predicting recovery time for a given watershed is the base cation supply rate from mineral weathering (BC_w) estimated from bedrock geology and other watershed properties (McDonnell et al. 2012; Sullivan et al. 2012). Meadow Run's estimated BC_w was 36 milliequivalents per square meter per year (meq/m^2/y) (Sullivan et al. 2010), which was one of the lowest in the region. The second key parameter for these estimates is the total acidic deposition load from sulfur and nitrogen wet and dry deposition, which has varied over time historically (figures B-1 and B-2), increasing over the 20th century to peak values in the 1990s and decreasing since then. At present, total acidic deposition for Meadow Run is estimated to be about 75 meq/m^2/y (NADP-NTN 2019; NADP-TDEP 2020), which appears to be the threshold to maintain current stream ANC of approximately 4 µeq/L, based on the last decade of observations (figure B-3) and on modeling (Sullivan et al. 2003, 2008, 2010). The critical load of total acidic deposition for Meadow Run (to maintain ANC values greater than 50 µeq/L) has been estimated as 32 meq/m^2/y (Sullivan et al. 2010, 2012), or about half of current deposition and similar to cation supply rates from bedrock weathering.

TABLE B-1. STREAM CONDITIONS IN THE PARK FOR DIFFERENT BEDROCK TYPES

Measure of Stream Condition[1]	Basaltic (Mafic)[a]	Granitic (Felsic)[b]	Siliciclastic (Siliceous)[b]
Stream water quality – ANC and sulfate			
Condition	High	Intermediate	Low
Trend (20 years)	Improving	Mixture of improving and degrading	Degrading
Aquatic macroinvertebrate metrics			
Condition	Intermediate	High	Low
Trend (20 years)	Degrading	Degrading	Degrading
Fish species richness			
Condition	Intermediate	Intermediate	Low
Trend (14 years)	Improving	Improving	No trend
Brook trout			
Condition: Mean abundance of adults (age 1+)	Intermediate	Intermediate	Low
Trend (14 years): Adults (age 1+)	Mixture of improving and degrading	Improving	Improving

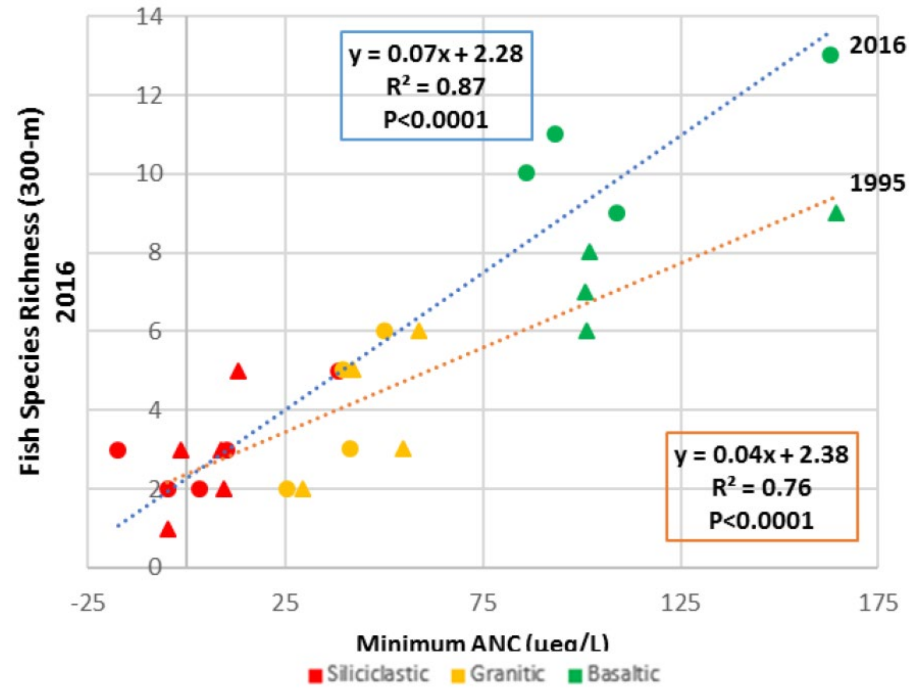
Source: Cummings and Blett 2017, adapted it from Rice et al. 2014a

Notes: [a] Stream water quality, summarized by combining ANC and sulfate concentrations and trends. High/increasing ANC and low/decreasing sulfate indicate high ranking and/or improving trends; low/decreasing ANC and high/increasing sulfate indicate low ranking and/or degrading trends.

[b] Both terms are used in the literature for the same bedrock groups.

Predictions of recovery time must rely on assuming different scenarios of future acidic deposition. These scenarios depend primarily on policy decisions, implementation of emissions mitigation approaches, and economic factors that are together the largest source of uncertainty for any prediction of future outcomes. Sullivan et al. (2003, 2008) simulated four different emissions scenarios to estimate Meadow Run stream ANC values from 1990 to 2100. Scenarios 1 and 2 were based on regulations that had already been passed, resulting in predicted ANC values of 10 and 13 µeq/L by 2100. Scenarios 3 and 4 were based on presumptions that additional emissions regulations and reductions would take place by 2020, predicting ANC values of 37 and 42 µeq/L, respectively, by 2100. The modeled trajectories under scenarios 3 and 4 predict that stream ANC would not reach the 50 µeq/L target until 2160 and 2140, respectively, and the pre-industrial Meadow Run ANC of 69 µeq/L not until 2250 and 2220, respectively.

The actual acidic deposition over Meadow Run in the last 20 years has been different from any of these scenarios, in that total sulfur deposition has dropped much more than expected (about 60% lower than scenario 4) but total nitrogen deposition has dropped less than any of the scenarios (Walker et al. 2019; NADP-TDEP 2020). Combined, it appears that current acidic deposition trends are somewhat of a blend of scenarios 2 and 4 (Sullivan et al. 2003, 2008, 2010), but much depends on future emissions, which is highly uncertain because (1) of the effects of future regulations and (2) unknowns regarding nitrogen deposition (Walker et al. 2019). Regardless, it is safe to say that in the absence of liming, the terrestrial and aquatic ecosystems of Meadow Run would take well over 100 years (and possibly over 200 years) to recover from historic and continuing acidic deposition.



Source: Harmon 2017

Note: Data were collected in 1995 (triangles) and 2016 (circles). The graph demonstrates that fish richness is closely tied the type of bedrock underlying each stream's watershed.

FIGURE B-6. FISH BIODIVERSITY (MEASURED IN RICHNESS) AND ANC, MEASURED IN 13 STREAMS IN THE PARK

SECTION 3: LIMING AS A RESTORATION TOOL AND LIMING DOSE DETERMINATION FOR MEADOW RUN WATERSHED

OVERVIEW

For acidified watersheds to recover and support thriving aquatic ecosystems, the watershed's soils must be resupplied with base cations to restore buffering capability. As stated in section 2, for watersheds with siliciclastic geology, natural bedrock weathering processes will not supply sufficient base cations for well over 100 years (Sullivan et al. 2008; McDonnell et al. 2012; Sullivan et al. 2012; Rice et al. 2014b). Management actions aimed at base cation restoration can accelerate the recovery of degraded surface waters and soils and improve the overall health of aquatic and terrestrial ecosystems. In other words, active management would allow recovery to occur more quickly to achieve resource management and restoration goals.

Research regarding effective watershed restoration strategies considered experiences from similar watershed restoration efforts in conjunction with site-specific information about the target watershed. For example, Meadow Run is the most acidified stream in the park because its geology limits recovery from acidic deposition. Not only is Meadow Run entirely formed on siliciclastic bedrock, but it is predominantly underlain by the Antietam Formation, which consists of sandstones and quartzite (figure B-7). With the added effect of acidic deposition, this formation has some of the lowest baseline ANC values of all siliciclastic bedrock formations in the region. No other watershed in the park is predominantly on the Antietam Formation, which explains Meadow Run's extreme and persisting acidification.

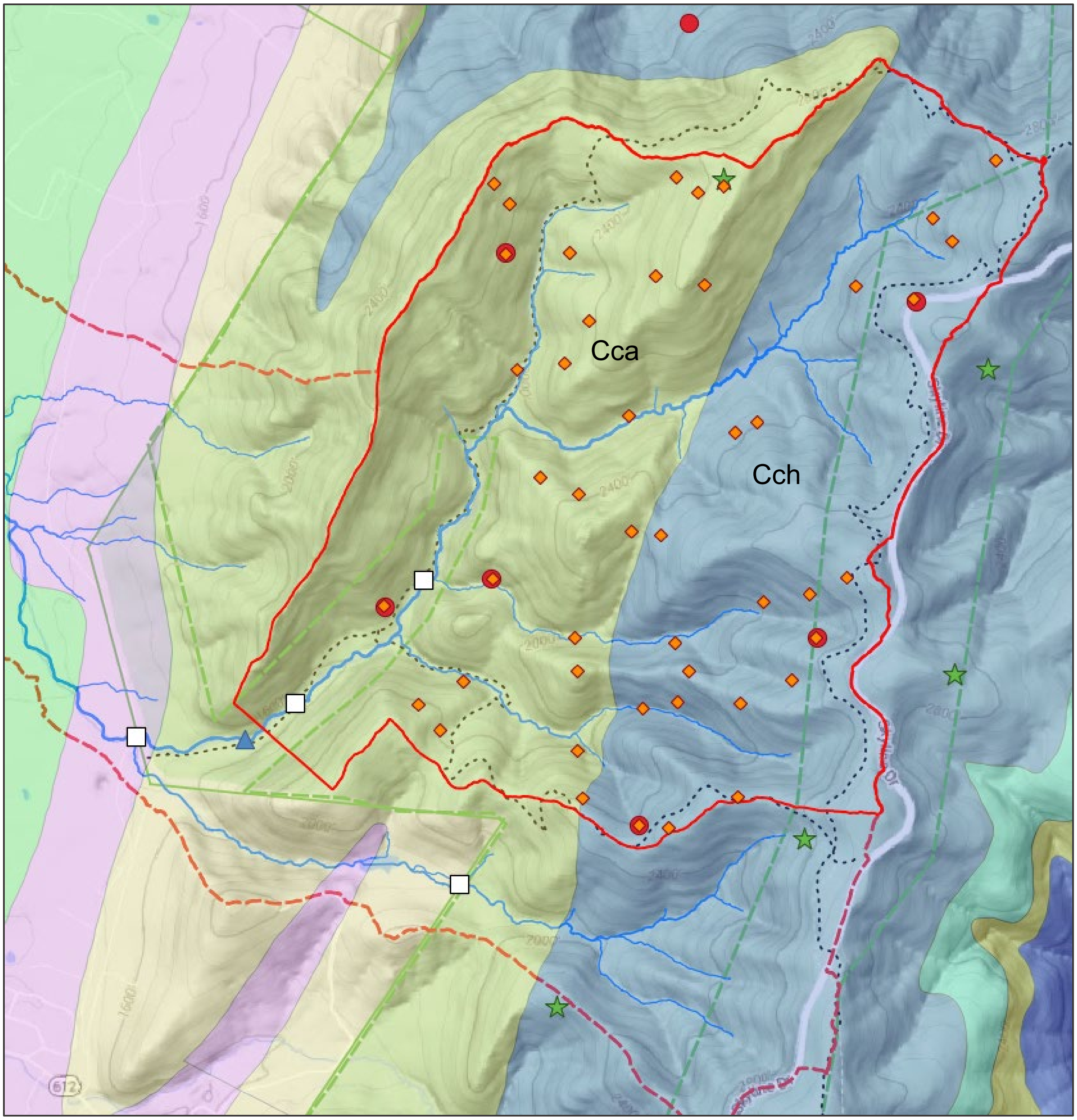
Section 3 reviews the literature on the effectiveness of liming to mitigate natural ecosystems, summarizes relevant site-specific data, and describes how literature and site-specific information were combined to develop optimal liming dose recommendations for the Meadow Run watershed.

ECOSYSTEM EFFECTS AND EFFECTIVENESS OF LIMING AS A RESTORATION TOOL – EXPERIENCE FROM OTHER WATERSHEDS

Humans throughout the world have a long history of restoring lost base cations to soils by applying ground limestone, starting centuries ago for improving fertility for agriculture, and beginning decades ago for restoring forests, streams, and lakes degraded by acidic deposition. The scientific literature on the approaches and outcomes of liming acidified natural ecosystems is extensive. The effectiveness of liming treatments has been well documented through decades of published research and technical monitoring reports.

The broad consensus is that liming is effective at reversing acidification in aquatic and terrestrial ecosystems and at restoring overall ecosystem health (e.g., Lawrence et al. 2016). Recent studies focus on sharing and refining approaches and outcomes as a function of differing ecosystem characteristics, with a goal toward optimizing benefits over expense, given that the largest concern is the cost of scaling such efforts to meet regional and global restoration needs (Mizel et al. 2015; Lawrence et al. 2016).

The benefits of liming acidified natural ecosystems are numerous. Acidified soils have decreased bioavailability of biological nutrients such as calcium and magnesium, increased toxicity of many metals such as aluminum, and decreased microbial activity. Terrestrial liming has a demonstrated record of reversing these long-term negative consequences of acidification, and restoring other metrics of forest ecosystem health such as tree growth and resilience, foliar nutrient content, snail and songbird abundance, and increased soil carbon content (Juice et al. 2006; Pabian and Brittingham 2007; Pabian et al. 2012a; Pabian et al. 2012b; Moore et al. 2012; Melvin et al. 2013; Long et al. 2015; Lawrence et al. 2016).



Source: Adapted from Cummings and Sharpe 2019

Sampling sites:	Small orange diamonds	2019 Meadow Run Soil Study
	Red dots	Soil sites sampled by Welsch et al. (2001)
	Green stars	NPS Long-Term Ecological Monitoring Study
	Blue triangle	SWAS water quality station VT36
	White squares	NPS aquatic biology stations

Geology:	Cca	Antietam Formation: Quartz sandstone with some quartzite and quartz schist
	Cch	Harpers Formation: Meta-sandstone, meta-siltstone, and phyllite

FIGURE B-7. BEDROCK GEOLOGY AND SOIL SAMPLING SITES IN THE PROJECT AREA

Acidified streams and lakes have decreased ANC, increased toxicity of many metals such as aluminum, decreased biodiversity and abundance of aquatic macroinvertebrates and fish, and decreased reproduction of sensitive fish species such as brook trout (Bulger et al. 1999; Jastram et al. 2013; Blum et al. 2018). Liming these aquatic ecosystems, either directly or indirectly by treating hydrological source area soils, has been shown to strongly reverse the negative impacts on aquatic chemistry and to generally restore the aquatic biological communities by increasing abundance and richness of acid-sensitive invertebrates and fish (Hudy et al. 2000; McClurg et al. 2007; Cho et al. 2012; Mant et al. 2013; Lawrence et al. 2016; Shao et al. 2016).

Terrestrial liming projects have been successfully completed throughout the greater Appalachian Mountain range by United States and Canadian agencies and researchers from the Carolinas to Quebec. The proposed Meadow Run Watershed Restoration Project can draw on implementation cost estimates from these regionally relevant liming projects. Examples include the Hubbard Brook Experimental Forest (New Hampshire), the Woods Lake watershed in the Adirondacks (New York), Mosquito Creek and Rolling Rock forests (Pennsylvania), and US Forest Service (USFS) projects in the St. Mary's wilderness of the George Washington National Forest (Virginia) and in the Lower Williams watershed of Monongahela National Forest (West Virginia). Table B-2 lists these terrestrial liming reference projects by treatment year, treatment material, application method, and dose rate, and provides selected references. Note that the USFS St. Mary's project only treated the streams and is thus not listed in the table but is referenced in the discussion of potential alternatives. Some studies used multiple doses for different experimental plots.

TABLE B-2. TERRESTRIAL LIMING PROJECTS IN APPALACHIA

Site	Year	Liming Material Used*	Application Method	Liming Dose (tons/acre)	References
Susquehannock State Forest, Pennsylvania	1985	dolomitic lime, pulverized	tractor with spreader	10	Long et al. 2011; 2015
Woods Lake watershed, New York	1989	dolomitic/calcitic lime, pelletized	helicopter	4.5	Driscoll et al. 1996; Melvin et al. 2013
Lake Clair watershed, Quebec, Canada	1994	dolomitic lime, pulverized	manual	1, 2, 5, 10, 20, 50	Moore et al. 2000; 2012
Hubbard Brook Watershed 1, New Hampshire	1999	wollastonite, pelletized	helicopter	1	Johnson et al. 2014
Mosquito Creek and Rolling Rock, Pennsylvania	2003	dolomitic limestone sand	tractor with spreader	1, 2	Pabian 2007; 2012a; 2012b; Mizel et al. 2015
Mosquito Creek and Rolling Rock, Pennsylvania	2003	dolomitic lime, pelletized	tractor with spreader	1, 2	Mizel et al. 2015
Honnedaga Lake watershed, New York	2013	calcitic lime, pelletized	helicopter	1.1	Millard 2018
Lower Williams, Monongahela National Forest, West Virginia	2018	limestone sand, AASHTO #9	helicopter	3-5	USFS 2011a; 2011b; 2018

* See the "Liming Material Appropriate for Meadow Run Project Area" section for more information on types of liming materials.

LIMING MATERIALS

Types

Cost-effective implementation of large-scale liming requires availability of suitable materials. Liming materials vary by their grain size and chemical composition. The primary ingredients of limestone are base cations and the carbonate anions at various concentrations. Sources of all liming materials are based on carbonate rocks, mined in quarries. Liming materials commonly used include the following:

- **Calcitic Limestone Sand:** This limestone sand[1] consists of ground calcitic limestone rock primarily consisting of calcite, a calcium carbonate mineral ($CaCO_3$). Calcitic limestone is the most common type of limestone, so it is often referred to simply as "limestone." The grain size distribution varies depending on product specifications, but the dominant grain size is sand and very fine gravel (i.e., 0.0625 to 4.75 millimeters [mm]).

- **Dolomitic Limestone Sand:** This type of limestone primarily consists of dolomite, a calcium magnesium carbonate mineral ($CaMg[CO_3]_2$). Magnesium is an essential mineral for healthy soil. Dolomitic limestone is sometimes referred to as dolostone. Like calcitic limestone sand, the grain size distribution varies depending on the product specifications of the quarry.

- **Lime:** Lime consists of pulverized (i.e., fine-grained) calcitic or dolomitic limestone. Grain sizes may vary; for example, for liming lakes and ponds, Virginia Cooperative Extension (2009) recommended the use of agricultural lime (aglime), which consists of pulverized limestone with a calcium content of greater than 70% and a grain size smaller than 0.020 mm.

- **Pelletized Lime:** Lime may also be applied as pelletized lime, produced by granulating fine agricultural lime (figure B-8). The small granular lime particles are bound together with a water-soluble (and environmentally benign) binding compound into small pellets with a diameter typically between one and two millimeters. The pellets are designed to disintegrate and return to a granulated powder form once they come in contact with moisture. Applied from the air, lime pellets drop faster to the ground than the fine-grained lime, allowing the application area to be more tightly controlled. Pellets also coat vegetation to a lesser degree than unpelletized lime during airborne application. On the ground, pelletized lime dissolves faster than limestone sand and has a more immediate effect on the soil chemistry (Mizel et al. 2015). While the total load of cations on a per ton basis is the same for both liming materials, in their comparative study of both liming materials, Mizel et al. found that dissolution of the limestone sand was substantial enough to create conditions similar to those observed on the pelletized lime test plots approximately nine months after liming.

  Compared to limestone sand, pelletized lime is more expensive. Mizel et al. (2015) used pelletized lime at a cost of $200/ton and limestone sand at a cost of $12/ton. It is noted that the three quarries closest to the Meadow Run watershed (Frazier Quarry [two locations] and Rockydale Staunton Quarry; see "Quarries" section) do not produce pelletized lime; therefore, the transportation costs for pelletized lime would likely be higher than the transportation costs for limestone sand from those local quarries.

[1] Unless specifically qualified, the single term "limestone" or "limestone sand" refers to both calcitic limestone and dolomitic limestone.

Another factor to consider is handling of pelletized lime for large-scale projects. For liming of large project areas, such as for the Meadow Run project with 2,150 acres, pelletized lime would require more specialized handling than limestone sand for stockpiling prior to use by helicopter. Such handling would need to ensure that the material remained completely dry to avoid disintegrating or clumping.

- **Wollastonite:** Wollastonite is a calcium metasilicate ($CaSiO_3$) with a nominal composition of 48% calcium oxide and 52% silicon dioxide, but it may also contain minor to trace amounts of aluminum, iron, magnesium, manganese, potassium, and sodium (USGS 2019). It was only mined in New York State by two companies during 2018, one located in Essex County and the other in Lewis County (Singh and Curry 2018; Curry 2019). Wollastonite was applied in 1999 in the Hubbard Brook Experimental Forest in New Hampshire with good results (Lawrence et al. 2016; Johnson et al. 2014; Cho et al. 2012). However, prices per ton appear to be substantially higher than for other liming materials (Curry 2019). In addition, transportation costs from the quarry in New York State to the Meadow Brook project area would be high.

In general, all these liming materials neutralize soil acidity and increase the soil's capacity to buffer changes in pH. The liming material gradually gets physically incorporated and mixed into the soil by entrainment with rainwater, bioturbation, and other means, where it gradually dissolves to become bioavailable and leachable into the subsoil and groundwater. The dissolution of liming material is a slow process that depends on several variables, including the grain size of the applied liming material, the acidity of precipitation, and the moisture content and acidity of the soil.

Source: farmersassociation.com

FIGURE B-8. PELLETIZED LIME

Quarries

Considering the large quantity of liming material to be applied in the Meadow Run watershed, distance to the project area is a relevant cost factor. Quarries in the vicinity of the project area consist of the following:

- **Frazier Quarry:** Frazier operates two quarries in Virginia, one located in Harrisonburg (North Quarry) and one located in Elkton.

- *North Quarry:* This quarry mines the Ordovician Beekmantown Formation and part of the overlying New Market Formation. North Quarry products include lime, American Association of State Highway and Transportation Officials (AASHTO) gradations (including AASHTO #10 aggregate), and sieved aggregates (referred to by Frazier Quarry as LS, FS, and ¼-inch S). Figure B-9 contains photographs of these aggregates; figure B-10 presents their grain size distributions. The source rock is limestone with a low magnesium content (table B-3).
- *Elkton Quarry:* Elkton Quarry source rock has a higher magnesium content than source rock from the North Quarry and is a dolomitic limestone. The Elkton quarry products include lime and AASHTO #10 aggregate; the quarry does not produce sieved aggregates.

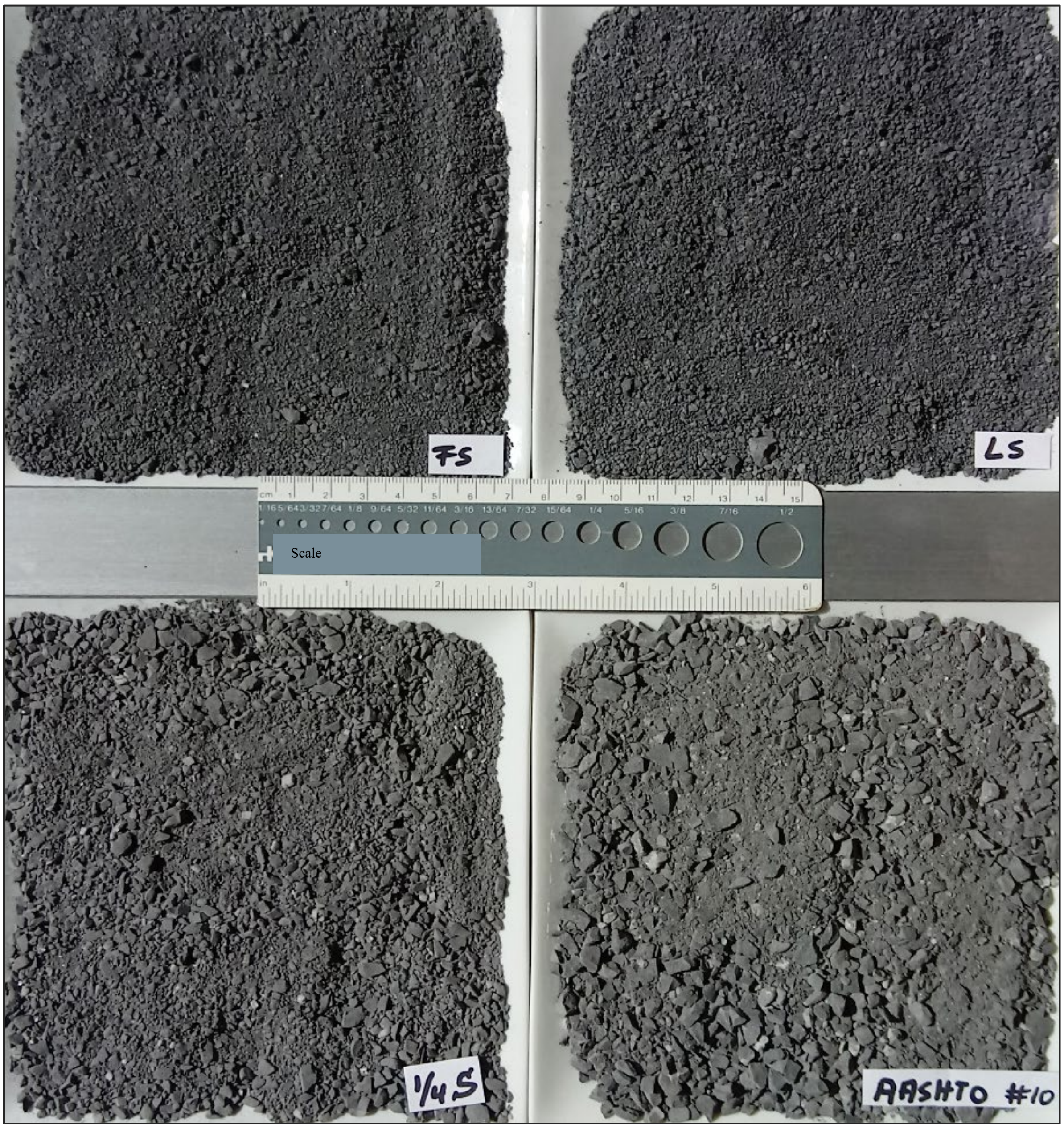
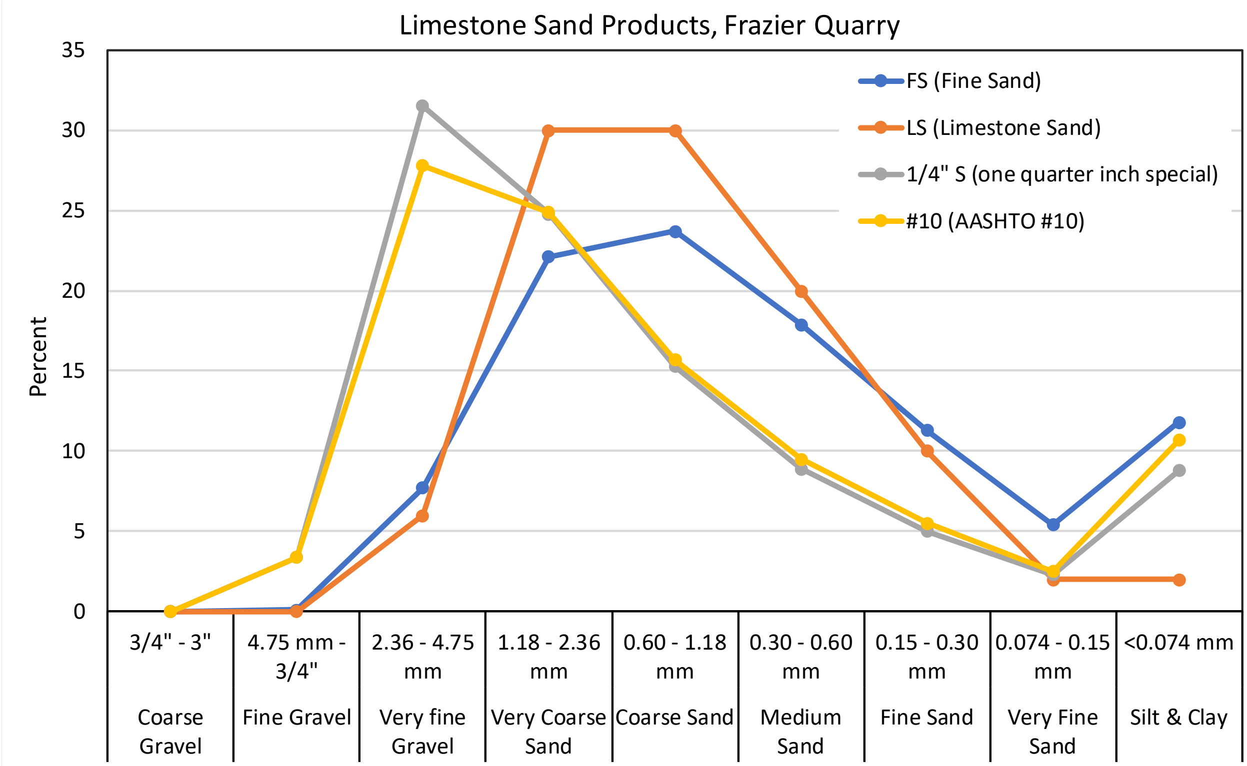


FIGURE B-9. LIMESTONE SAND PRODUCTS AVAILABLE AT FRAZIER'S NORTH QUARRY



Source: Based on data provided by Frazier Quarry

FIGURE B-10. GRAIN SIZE DISTRIBUTION OF LIMESTONE SAND FROM FRAZIER'S NORTH QUARRY

TABLE B-3. CHEMICAL COMPOSITION OF LIMING MATERIALS

Compounds		Frazier Quarry		Rockydale Staunton Quarry
		Elkton Quarry	North Quarry	
		Percent	Percent	Percent
Calcium	Ca	29	38	25
Magnesium	Mg	7.5	1.8	9
Calcium carbonate	$CaCO_3$	72	95	62
Magnesium carbonate	$MgCO_3$	26	6	31

Source: Data provided by the Frazier Quarry and Rockydale Staunton Quarry (June 2019)

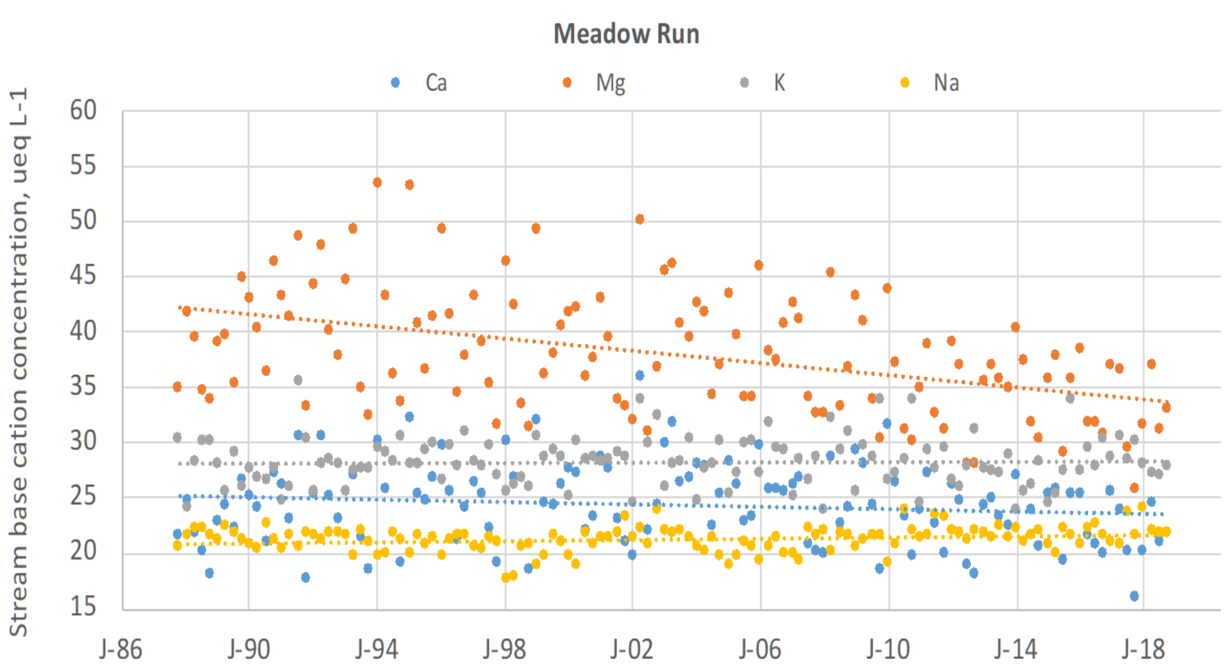
- **Rockydale Staunton Quarry:** The source rock is also from the Ordovician Beekmantown Formation; it is a dolomitic limestone based on its magnesium content, similar to the dolomitic limestone at Frazier's Elkton Quarry. Rockydale Staunton Quarry products include lime and AASHTO #10 aggregate. The quarry does not produce sieved aggregates. "Guaranteed screen analysis" data from Rockydale Staunton Quarry suggest that the grain size is more similar to the sieved grain sizes from the Frazier Quarry.

All grain size analyses from the three quarries are considered estimates at this time. Considering the range of grain size data from the three quarries, multiple samples from the actual products considered for the Meadow Run Restoration Project should be obtained during the more detailed project implementation design.

Liming Material Appropriate for Meadow Run Project Area

For terrestrial liming of a watershed as large as the Meadow Run project area (2,150 acres), the choice of liming material is largely determined by practical considerations, given that any of the options used elsewhere (table B-2) would be effective at reversing acidification of the ecosystem. Transportation costs from a quarry to the project area can be greater than the purchase cost of the material. The three quarries are within a viable distance to Meadow Run and provide options for both dolomitic and calcitic limestone that can be crushed to a variety of products of varying grain size.

When available, dolomitic limestone, with a magnesium (Mg) content greater than 6% by weight, is generally preferred over calcitic limestone because magnesium is an important base cation nutrient that is depleted along with calcium (Ca) during acidification. In Meadow Run in particular, stream magnesium concentrations have declined more substantially than calcium concentrations over the last three decades, while the remaining base cations, potassium (K) and sodium (Na), show no depletion (figure B-11).



Source: SWAS-VTSSS 2019
Note: J = January

FIGURE B-11. MEADOW RUN BASEFLOW STREAM WATER CONCENTRATION TRENDS FOR FOUR BASE CATIONS MEASURED QUARTERLY FROM JANUARY 1986 TO MARCH 2018

The selection of grain size is also primarily constrained by practical considerations. Although pulverized lime dissolves into the soil and restores pH more rapidly, it cannot easily be applied from a helicopter. Pelletized lime, which is pulverized lime that is bound into pellets that are easy to handle yet readily dissolve, is not practical because of its high cost, lack of nearby availability at required quantities, and challenges to maintain dry at temporary storage and helicopter staging areas.

Therefore, limestone sand remains the only viable option. Of the four available grades of limestone sand, AASHTO #10 is less expensive than other grain sizes with narrower grain size distribution ranges.

LIMING DOSES FOR MEADOW RUN PROJECT AREA

Liming doses were developed for both action alternatives (split-dose and uniform-dose) to meet the project goal of restoring the long-term health of the terrestrial and aquatic ecosystem and mitigating the harmful effects from decades of atmospheric acidic deposition in the Meadow Run watershed.

The objective was to find an optimal liming dose that could be applied over the soils of the project area (minus exclusion zones) to produce a measurable, long-term, beneficial impact of restoring both terrestrial and aquatic ecosystems. After a review of the scientific literature and consultation with the project's science team, the following potential metrics of success were selected:

- Soil chemistry: base cation saturation *(the goal is to identify an increase)*
- Stream chemistry: water ANC *(the goal is to identify an increase)*
- Stream biology: acid-sensitive aquatic organisms *(the goal is to identify their return)*

The liming dose calculation is primarily based on soil chemistry data from samples collected throughout the Meadow Run watershed. Specifically, the target dose for the Meadow Run Watershed Restoration Project is the amount of limestone sand required to increase the base cation saturation to around 20% over the entire soil profile, similar to previous liming projects (George et al. 2018; Millard et al. 2018). A target of 20% base cation saturation—where extractable base cations represent 20% of the available cation exchange capacity—was selected because below this value, soils would remain functionally acidified, aluminum toxicity would be likely, and forest ecosystems would be stressed (Sullivan et al. 2013).

Methodology

Soil Data Collection

In 2019, NPS conducted an extensive quantitative study of physical and chemical properties of the soils in the Meadow Run watershed (Cummings and Sharpe 2019; Sharpe et al. 2019). The study was designed to allow for optimizing the liming dose and to provide a pre-project baseline for soil restoration. Specifically, the purpose was to quantify the depth-integrated soil inventories of cation exchange capacity (CEC), base cations (calcium, magnesium, sodium, potassium), aluminum, and other relevant properties to (1) determine a base cation deficit at each location as the basis for liming dose calculations, and (2) detect future changes to soil pH, base cation saturation (Bsat), calcium to aluminum ratios (a metric of aluminum toxicity stress to plants), and other properties after liming.

In summer 2019, NPS collected soil samples from 46 sites selected throughout Meadow Run watershed to span a range of geology, topographic position, vegetation, solar aspect, and other soil-forming factors (figure B-7). At each site, soils were quantitatively sampled with soil recovery probes (manufactured by AMS) at six points, each 3 feet (1 meter) apart at the site, to capture spatial variability in soil properties for each site. Soil cores were directly collected into plastic liner tubes, removed from the probe, cut to sampled lengths, and capped for transport to the laboratory. Soil recovery probes were used rather than dug soil pits because several studies have demonstrated that soil recovery probes are much more effective at quantifying soil inventories than soil pits. Specifically, soil cores can be efficiently collected in sufficient numbers and distances with a soil recovery probe to provide statistically robust results given the high levels of spatial variability found in all soils (Aalto et al. 2003; Wendt and Hauser 2013; Yoo et al. 2015; Fisher et al. 2018). Furthermore, the use of soil recovery probes substantially reduced disturbance within the Meadow Run federally designated wilderness areas. For this reason, and to preserve potentially buried cultural artifacts, soil probe coring was limited to the upper 20 centimeters (cm) of depth.

In the laboratory, each soil core was inspected through the clear plastic liner (to determine the transition point from organic horizons to mineral horizons), measured, and cut to separate the horizons. For the six cores collected at each site, all organic horizon core sections were physically composited into a single plastic bag for oven drying at 105 degrees Celsius (°C), then weighed for the calculation of bulk density. All six mineral horizon core sections from a single site were composited, dried, and weighed in the same manner.

The following chemical analyses were performed on composited samples at Pennsylvania State University's Agricultural Analytical Services Laboratory (https://agsci.psu.edu/aasl):

- Soil fertility and micronutrient test:
    - pH in water
    - Exchangeable aluminum, calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, sulfur, zinc by Mehlich 3 extraction
    - CEC and exchangeable acidity by summation method
- Aluminum stress test:
    - Bioavailable calcium and aluminum after extraction with 0.01 molar strontium chloride

Seven of the 46 sites sampled in 2019 had also been sampled in previous studies (sampling sites are included in figure B-7):

- In 2000, Welsch et al. (2001) sampled six sites in the Meadow Run watershed by sampling soil down to a depth of 80–120 cm, dividing the profile into shallow (0–20 cm) and deep (>20 cm) depth intervals, and analyzing for pH, CEC, base cations, aluminum, organic carbon, and nitrogen.
- In 2007, NPS sampled one site in Meadow Run as part of its Long-Term Ecological Monitoring Study, Forest Vegetation Monitoring, soils data collection. The collected surface soils were analyzed for pH, CEC, and exchangeable elements (same elements as listed under soil fertility and micronutrient test in the bullet point just above).

Soil Data Analysis

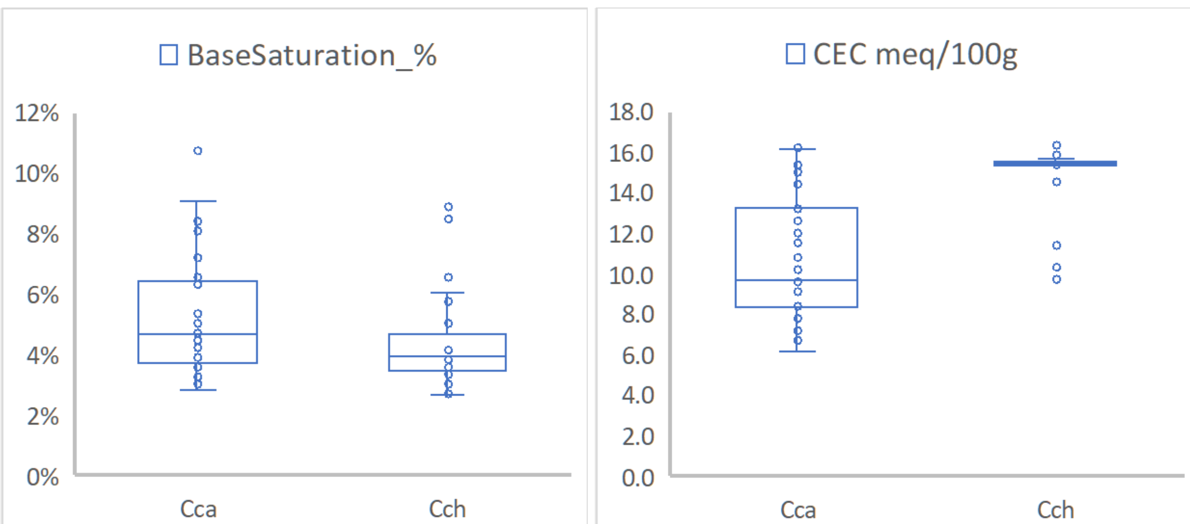
The 2019 soil data showed clear signs of acidification (table B-4).

TABLE B-4. SOIL ACIDIFICATION METRICS FROM 46 SITES IN MEADOW RUN WATERSHED IN 2019

Depth Horizon	pH	Base Cation Saturation
Organic, 0 to ~5 cm	3.77 ±0.35	11.6% ±7.3%
Upper Mineral, ~5 to 20 cm	4.19 ±0.28	4.9% ±1.9%
Deep Mineral, 20 to 80 cm	4.49 ±0.12	10.2% ±3.3%

Depth-integrated cumulative inventories of soil properties (quantity per unit land area) were calculated by multiplying the bulk density (soil mass per volume) of each depth interval by its depth (length) to convert depth profiles into cumulative soil mass profiles (soil mass per land area), which were in turn multiplied by the concentrations (quantity per unit soil mass) of CEC, base cations, and other elements (Wendt and Hauser 2013; Yoo et al. 2015; Fisher et al. 2018). Depth-integrated cumulative soil inventories depend in part on the total soil depth used in the calculations; thus integrating, or summing, to greater depths results in greater inventories. Soil property inventories can be divided by soil mass inventories to produce mass-weighted concentration averages for the soil profile.

The resulting inventories down to the 20-cm depth were dominated by the mineral horizon. Organic horizons extended 5.3 ±1.2 cm deep with a bulk density of 0.34 ±0.13 gram per cubic centimeter (g/cm^3), compared to bulk densities of 1.13 ±0.13 g/cm^3 for the mineral soil horizons down to the 20-cm depth. Thus, the profile-average base cation saturation calculated from 0–20 cm cumulative inventories was 5.7% ±2.5% (figure B-12). All calculations were performed explicitly for each site down to 20 cm; the presented means and standard deviations describe the distribution of values from the 46 sites. This enables exploration of how these soil inventories vary by geology, topographic position, vegetation, solar aspect and other soil forming factors, similar to the analysis done by McDonnell et al. (2012). For example, as shown in figure B-12, the CEC was strongly related to geology.



Source: Adapted from Sharpe et al. 2019

Notes: The box and whisker plots show median and quartile values (based on the 46 soil sites sampled in 2019) and are categorized by geology: Cca – Antietam Formation; Cch – Harpers Formation.

FIGURE B-12. PROFILE-AVERAGED BASE CATION SATURATION (LEFT) AND CATION EXCHANGE CAPACITY (RIGHT)

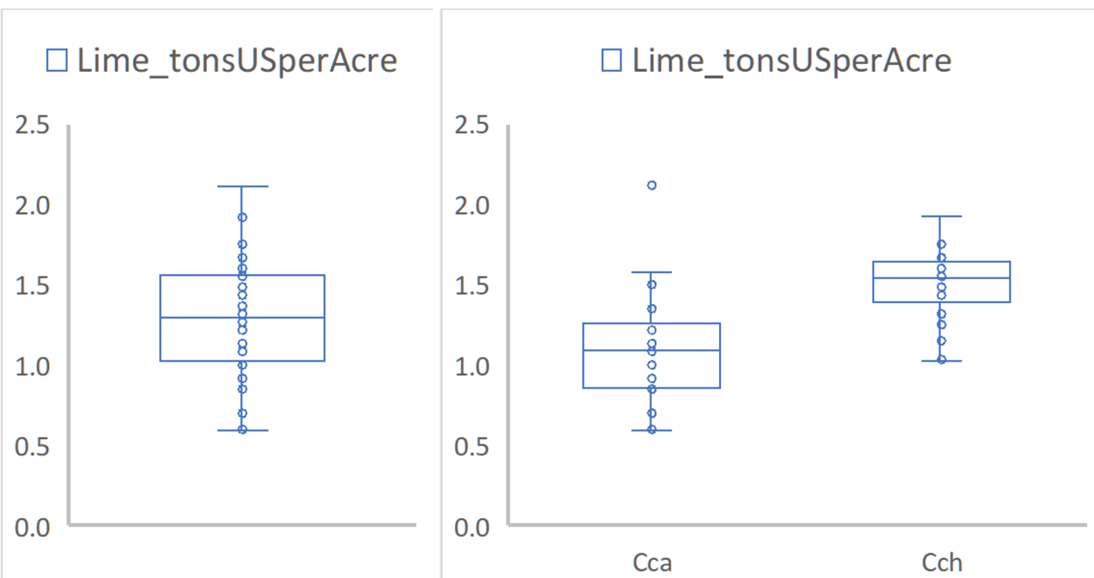
Welsch et al. (2001) found Meadow Run soils to extend to depths of 80–120 cm. Although the deeper soils (>20 cm) measured by Welsch et al. (2001) had half the CEC concentrations, higher Bsat, and higher rock content than the shallower soils, they nevertheless contribute to the base cation deficits from soil acidification. Therefore, the project team estimated watershed-averaged lower mineral horizon inventories for the purposes of calculating the target liming dose. Welsch et al. (2001) did not report bulk density values, so a value of 1.2 g/cm^3 for the lower mineral horizons for all six sites was assumed. Welsch et al. (2001) described that deeper soils contained many rocks that were removed prior to collecting samples for analysis, so the project team assumed 40% of the soil volume consisted of rocks in the lower mineral horizons.

Liming Dose Calculations

The target liming dose was determined for each of the 46 sites as the amount of limestone sand required to increase the base cation saturation to around 20% over the entire soil profile. The base cation deficit for a given site is therefore defined as the difference between the measured base cation soil inventory and the base cation inventory equivalent to a 20% base cation saturation over the entire soil profile. The units for base cation deficit are equivalents of base cations per unit land area.

To calculate the base cation need for each site, a contingency factor of 1.5 was added to account for slow dissolution and incorporation in the soil, losses due to leaching and erosion, and spatial variability in the concentration of applied limestone sand, similar to previous liming projects (George et al. 2018; Millard et al. 2018). The base cation need at a site is functionally equivalent to the ideal liming dose at that site to achieve the target base cation saturation, because limestone provides about 2,000 milliequivalents of base cations per 100 grams (meq/100g). Base cation needs are therefore presented in units of short tons per acre (t/acre). For these calculations, it was presumed that the project would use dolomitic limestone sand from the Frazier Elkton quarry (29% Ca; 7.5% Mg), which has 4% more base cation equivalents per ton than dolomitic limestone sand from the Rockydale Staunton Quarry (25% Ca; 9.0% Mg), although either would be suitable.

From measured soil inventories, the project team calculated the base cation deficit down to the 20-cm depth explicitly for each of the 46 sites sampled in 2019. These base cation deficits directly translate to target liming doses for each site, without the need for any additional assumptions. The mean base cation need for the 0–20 cm soil interval is 1.29 ±0.34 t/acre of dolomitic limestone sand, which, when categorized by geology, corresponds to a liming dose of 1.09±0.32 t/acre for sites on the Antietam Formation (Cca; quartz sandstone with some quartzite and quartz schist) and 1.51±0.21 t/acre for sites on the Harpers Formation (Cch; meta-sandstone, meta-siltstone, and phyllite) (figure B-13).



Source: Adapted from Sharpe et al. 2019
Note: The box and whisker plots show median and quartile values (based on the 46 soil sites sampled in 2019) and are categorized by geology: Cca – Antietam Formation; Cch – Harpers Formation.

FIGURE B-13. BASE CATION NEED (IN T/ACRE OF LIMESTONE SAND) FOR THE 0-20 CM SOIL INTERVAL FOR ALL 46 SOIL SITES TOGETHER (LEFT) AND FOR THE DIFFERENT GEOLOGICAL FORMATIONS (RIGHT)

For the lower mineral soil horizons, from 20–80 cm, an additional base cation need was calculated from the six sites sampled by Welsch et al. (2001) (table B-5). The mean 20–80 cm base cation need was 0.99±0.55 t/acre for all six sites, or, when categorized by geology, 0.60±0.08 t/acre for the three sites on the Antietam Formation (Cca) and 1.51±0.45 t/acre for the three sites on the Harpers Formation (Cch). Note that Welsch et al. (2001) reported that many soils extended deeper than 80 cm to as deep as 120 cm. Unfortunately, depth records for each soil pit were not available.

TABLE B-5. BASE CATION NEED TO ACHIEVE BASE CATION SATURATION OF 20% (FROM LIMESTONE SAND), CALCULATED FROM MEASURED BASE CATION DEFICIT

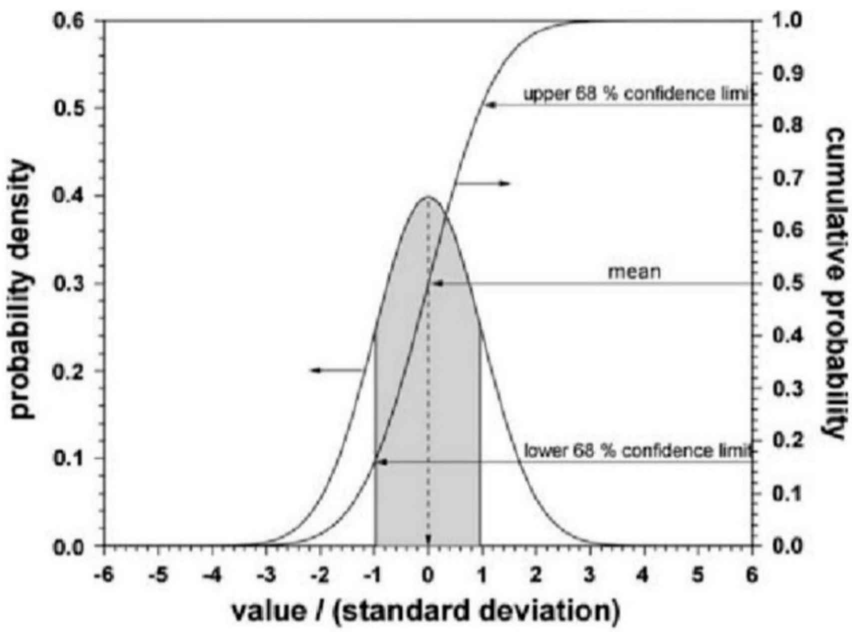
Soil Interval	Base Cation Need (t/acre)					
	All Sites		Antietam Formation (Cca) Sites		Harpers Formation (Cch) Sites	
0-20 cm	1.29	±0.34	1.09	±0.32	1.51	±0.21
20-80 cm	0.99	±0.55	0.60	±0.08	1.51	±0.45
Total soil profile	**2.27**	**±0.65**	**1.69**	**±0.33**	**3.01**	**±0.50**

Combining base cation needs for upper (0–20 cm) plus lower (20–80 cm) soil horizons and propagating standard deviations by quadrature provides a mean of 2.27±0.65 t/acre for all the sites over the 0–80 cm soil profile. When separated by geology, base cation needs are 1.69±0.33 t/acre for Antietam Formation (Cca) sites and 3.01±0.50 t/acre for Harpers Formation (Cch) sites.

Liming dose recommendations for this project must consider the practical considerations of helicopter application, where individual soil needs cannot be targeted, and where helicopter application rates are likely to vary around dose targets (USFS 2018). With this in mind, a liming dose that would meet or exceed the base cation need for the majority of sites was targeted. Fortunately, the base cation need values are normally distributed (figure B-14, n = 46; Sharpe et al. 2019), which allowed the project team to estimate what percentage of sites have a base cation need that would be exceeded or met by any given dose of limestone sand. For example, if limestone sand was applied at dose of 2.27 t/acre (i.e., the mean need) to the entire project area, then only 50% of the sites would get a dose that would adequately meet the local need at those sites. For any other potential liming dose, the cumulative normal probability distribution function could be used (figure B-14) to calculate the percentage of sites that would receive an adequate dose to meet base cation needs.

Therefore, if a liming dose of 2.75 t/acre were selected as a uniform dose for the entire project area, it would exceed the base cation need for 77% of the sites (where 2.75 - 2.27 = 0.48, which is 0.72 standard deviations). Considering that +2.0 standard deviations would include essentially all the soils (97.7% of sites), then the soils with the greatest base cation deficit and highest base cation need (2.27 +2*0.65 = 3.57 t/acre of need) would still get 77% of their base cation need filled with a 2.75 t/acre application rate. This is well within the margins of the built-in contingency factor of 1.5 (1/1.5 = 66.7%).

A more efficient dosing approach would be to apply two different liming doses over the project area. This could potentially result in better meeting soil base cation needs over a greater number of sites for similar or lower total project costs. A split-dosing approach might be developed from a multivariate statistical relationship between base cation need measured for each site and geospatial characteristics of those sites. Parent material (i.e., bedrock geology) is clearly a major factor, but a final implementation plan might also consider other mappable characteristics based on the classic soil forming factors: climate (which varies by elevation within the Meadow Run watershed), topography (i.e., slope, slope curvature, aspect), biological factors (i.e., vegetation), and time since the beginning of soil formation (Jenny 1946; Blosser and Jenny 1971; Bockheim and Gennadiyev 2000). Of particular potential value to this project is the use of slope curvature metrics, such as the Topographic Wetness Index (TWI). Slope curvature metrics are not only excellent predictors of soil moisture but also soil depth, texture, organic content, cation exchange capacity, phosphorus concentration, and other soil properties because of downslope soil creep accumulation in concavities (Gessler et al. 1995; Radula et al. 2018). TWI is higher at concave portions of the landscape with larger upslope contributing areas, such as swales, the toe of hillslopes, and lower portions of valleys.



Source: Meinrath 2008

FIGURE B-14. CUMULATIVE PROBABILITY OF THE STANDARDIZED NORMAL DISTRIBUTION

A split-dose liming recommendation for this project might be 2.25 t/acre for half the area with less depleted soils and 3.0 t/acre for the remaining area with more depleted soils. This conservative approach to split-dosing would provide 86% of the sites with limestone sand that adequately meets their site-specific base cation needs, using a cumulative normal distribution approach similar to that employed above for the uniform-dose approach. Furthermore, soils with the greatest base cation need (i.e., 3.57 t/acre, which is the mean + 2 standard deviations) would still get 84% (3.0/3.57) of their base cation need. If project implementers develop strong geospatial statistical predictions of soil base cation needs, they could potentially split the doses further to doses similar to 2.0 t/acre for half the area and 3.25 t/acre for the remaining area. This would have the benefit of meeting the base cation need for a greater number of sites within the watershed while using less limestone sand over the project area.

Duration of Benefits of Liming

The duration of the benefit of liming can be roughly calculated from estimates of the acidic deposition rate and the base cation supply from bedrock mineral weathering. One ton of limestone sand per acre adds about 4,500 milliequivalents per square meter (meq/m^2) of base cations to the soil, depending slightly on limestone chemistry. Current total sulfur and nitrogen acidic deposition rates over Meadow Run were estimated to average approximately 75 meq/m^2/y from 2017 to 2019 by the Total Deposition Science Committee of the National Atmospheric Deposition Program (NADP-TDEP 2020). Current base cation supply from bedrock mineral weathering was estimated at approximately 36 meq/m^2/y for the Meadow Run watershed (Sullivan et al. 2010, 2012). Therefore, the current net acidification of the Meadow Run watershed is approximately 40 meq/m^2/y. Assuming those net rate acidification rates remain constant, the buffering capacity of 1.0 t/acre of limestone sand would take approximately 110 years to be neutralized by acid deposition. Considering that proposed liming doses range from 2.25 to 3.0 t/acre and that acidification rates are likely to continue to decrease, limestone sand neutralization times are likely to be at least 250 to 350 years or more. This is slightly longer than predicted natural recovery times. Therefore, benefits of the proposed liming would last well over 100 years and well into the timeframe in which the ecosystem would have naturally recovered.

Proposed Liming Doses for Meadow Run Watershed Restoration

The proposed liming doses for the two potential action alternatives are considered most appropriate to increase the base cation saturation and buffering capacity in the soil and increase the pH and ANC in the stream.

Alternative B (Split-dose Liming)

The split-dosing alternative is designed to provide targeted limestone material doses that meet cation needs for a greater percentage of the soils in the Meadow Run project area than uniform-dose alternative C. Soils in the Meadow Run project area exhibit a wide range of base cation deficits depending on location. More depleted soils have a greater cation exchange capacity (in part inherited from type of underlying bedrock), are thicker (i.e., areas with a deeper soil layer above bedrock), and are generally more developed as a result of a combination of other soil forming factors.

Based on these calculations, proposed liming doses for alternative B (split-dose liming) are identified below. For each dose, an average and a range are provided. A range is needed for realistic implementation, given inaccuracies introduced from the aerial positioning of the helicopter and air movement. For the USFS Lower Williams Terrestrial Liming Project conducted in the nearby Monongahela National Forest, a liming dose range of 3-5 t/acre was achievable (USFS 2018). This translates to a ±25% range in application rates, which would be acceptable for Meadow Run given the built-in contingency factor of 1.5.

- **High dose:** 3.0 t/acre on average would be applied over more depleted soils. An acceptable application range would be 2.25 to 3.75 t/acre.

- **Low dose:** 2.25 t/acre on average would be applied over less depleted soils. An acceptable application range would be 1.7 to 2.8 t/acre.

As a first-order estimate for planning purposes, the project area may be separated into 50% more depleted soils and 50% less depleted soils to be limed under alternative B. Assuming a liming area of 2,000 acres (i.e., a 2,150-acre project area, minus 150 acres reserved for exclusion zones), this split-dose approach would result in a total weight of 5,250 tons of limestone sand to be applied.

This first-order approach, for example, might roughly follow the geological map (figure B-7), applying the high dose over the Harpers Formation (Cch) and the low dose over the Antietam Formation (Cca). The split-dose approach could further be refined and mapped in more detail prior to the implementation. Delineation of the liming area into subareas with greater versus lower base cation needs would be based on geospatial statistical analysis of measured soil properties versus multiple landscape metrics, as described under “Liming Dose Calculations,” above. One additional key soil property that could be measured is soil depth at each sampling site; soil depth can be quickly measured by replicate insertions of a soil tile probe (3/8-inch diameter to ensure negligible soil disturbance). Once the detailed multivariate analysis and mapping of soil base cation needs is completed, practical liming dose boundaries should be straightened enough to allow for realistic operation of liming by the helicopter.

Alternative C (Uniform-dose Liming)

The uniform-dosing alternative is designed to simplify the implementation of the liming project. However, the uniform-dose approach would have the drawback of providing optimal limestone sand doses to a smaller percentage of the soils in Meadow Run. Also, the headwaters and eastern tributary streams, which originate on soils over Harpers Formation (Cch) geology, would likely have a reduced response to uniform-dose liming because of their greater base cation deficit.

Based on calculations for this project, a recommended liming dose for alternative C (uniform-dose liming) would be 2.75 t/acre. The range for applying the limestone sand could be 2.1 to 3.4 t/acre. The dose for alternative C would result in a total weight of 5,500 tons of limestone sand to be applied in the 2,000-acre liming area.

SECTION 4: MEADOW RUN RESPONSE TO LIMING

This section contains more details on the expected response to liming, providing additional information to support the findings described in “Chapter 4. Environmental Consequences” of the EA.

RESPONSE TIME

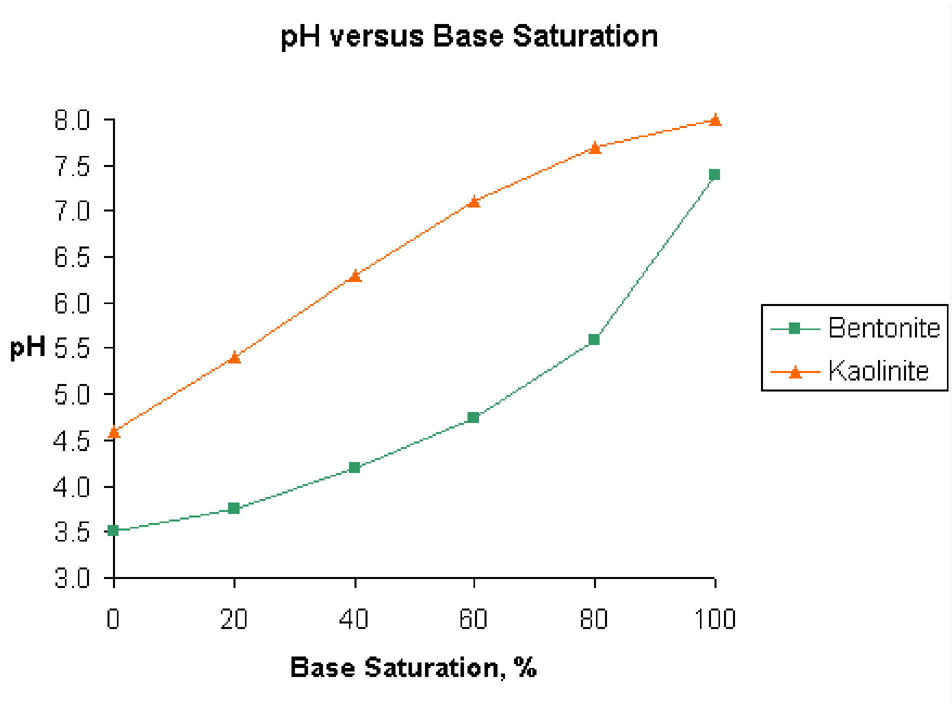
Limestone sand would take less than a year to become physically incorporated into the organic horizon (USFS 2018). However, it would take years to decades to get more deeply mixed through bioturbation and dissolution and be fully integrated into the soil’s exchangeable base cation pool (Pabian et al. 2012a; Long et al. 2015). A 21-year study of soil chemistry responses after liming with 10 t/acre of pulverized dolomite showed that for the upper 0–5 cm of soil, exchangeable calcium and pH increased for 8 years, exchangeable magnesium increased for 11 years, and exchangeable aluminum decreased for 11 years before all metrics reached steady values that did not decrease for the duration of the study (Long et al. 2015). For the 10–15 cm depth, these soil properties were continuing to change after 21 years with no sign of plateauing (Long et al. 2015). Coarser-grained limestone sand, as proposed under action alternatives B and C, would take much longer to fully incorporate into the exchangeable cation pool compared to the pulverized lime used by Long et al. (2015). Other studies of shorter duration all support these findings that soil impacts would begin to be measurable within a year of liming but would take decades to fully develop (Juice et al. 2006; Pabian and Brittingham 2007; Pabian et al. 2012a; Pabian et al. 2012b; Moore et al. 2012; Melvin et al. 2013; Mizel et al. 2015; Lawrence et al. 2016).

SOIL PH

The proposed liming doses for action alternatives B and C would likely increase the soil pH throughout the project area by roughly 0.5 to 1.0 units over the course of decades, with final pH values likely between 4.4 to 5.1 for most soils in the project area. These estimated ranges are based on (1) the post-liming target of 20% base cation saturation plus a safety factor of 1.5 that could result in up to a 30% base saturation if all the limestone sand were to be incorporated in exchangeable cations without loss, and (2) studies that show how pH and base cation saturation vary together in typical soils. This section describes the evidence for arriving at these estimated ranges.

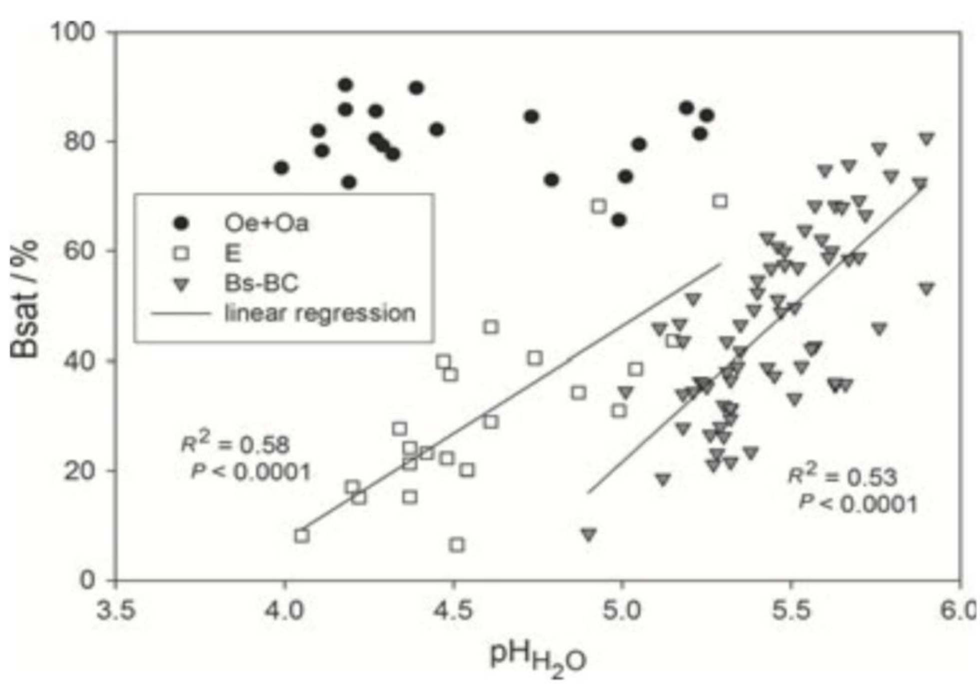
Although the post-liming base cation saturation for each sampled soil site within the Meadow Run project area can be precisely predicted, it is not possible to predict the final pH values because of complex geochemical reactions with unmeasured soil properties. To constrain the full range of pH values possible over the full range of base cation saturation, an early study measured common soil clay minerals that represent endmembers of the range of potential CEC values (figure B-15; Mehlich 1943). For the high CEC mineral endmember (i.e., bentonite), an increase of base saturation from 5% to 30% (i.e., similar to the maximum possible change for Meadow Run upper mineral soils) might increase pH from 3.6 to 3.9 (i.e., an increase in pH by 0.3); for the low CEC mineral endmember (i.e., kaolinite), pH might increase from 5.0 to 5.9 (i.e., an increase in pH by 0.9) (Mehlich 1943).

A field study of more than 20 different naturally acidic soils with mineral mixtures (figure B-16; Grand and Lavkulich 2013) showed that a 5% to 30% increase in base cation saturation corresponded to a pH increase from 3.9 to 4.6 (an increase of 0.7) on average for the upper mineral horizon (the E horizon) and from pH 4.7 to 5.2 (an increase of 0.5) on average in the lower mineral (Bs-BC) horizons, based on their respective regression lines (Grand and Lavkulich 2013). This study also suggests that more acidified soils would experience a larger pH change than less acidified soils.



Source: Adapted from Mehlich (1943) by Mylavarapu (2020)

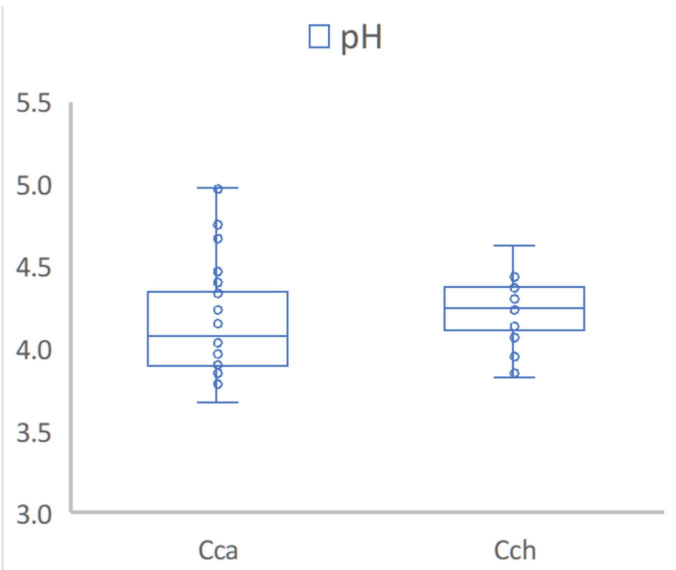
FIGURE B-15. SOIL PH AS A FUNCTION OF CATION BASE SATURATION FOR CLAY MINERAL END MEMBERS



Source: Grand and Lavkulich (2013)

FIGURE B-16. SOIL PH AS A FUNCTION OF BASE CATION SATURATION (BSAT) MEASURED IN SOILS BY HORIZON

Estimating the final post-liming pH values soils in the Meadow Run project area requires understanding the distribution of present pH values (figure B-17). The remainder of this discussion focuses on the upper mineral soil (approximately 5 to 20 cm deep) for simplicity and because it contains base cation deficit of about 10 times more than the organic horizons and is also more biologically active than the lower mineral soil horizons (20–80 cm deep) that are outside the primary rooting zone. Measured pH values for these upper mineral soils in the Meadow Run project area span a full range of 3.67 to 4.99, with 80% of soils in the range of 3.84 to 4.48, and 50% of the soils in the range of 3.97 to 4.37 (Sharpe et al. 2019). Soil pH values are slightly higher and less variable (4.23 ±0.20) in soils on the geologic Harpers Formation (Cch) with higher and less variable CEC (15.0 ±1.6) relative to soils on the Antietam Formation (Cca) (pH = 4.16 ±0.33; CEC = 10.8 ±3.1 meq/100g) (figures B-12 and B-17). Based on these current pH ranges and the relationships between pH and base cation saturation from other studies, most of the less acidified soils (pH of 4.2 to 4.5) that are primarily but not exclusively on the Harpers Formation might increase by 0.5 to 0.6 pH units to final values of 4.7 to 5.1. More acidified soils (pH of 3.7 to 4.1) with lower CEC might increase in pH by 0.7 to 1.0 to final pH values of 4.4 to 5.1.



Source: Adapted from Sharpe et al. 2019

Note: The box and whisker plots show median and quartile values (based on the 46 soil sites sampled in 2019) and are categorized by geology: Cca – Antietam Formation; Cch – Harpers Formation.

FIGURE B-17. DISTRIBUTIONS OF SOIL PH MEASURED IN THE UPPER MINERAL SOIL (~5 TO 20 CM DEEP)

Combined, it is reasonable to estimate that most soils (about plus or minus a standard deviation [i.e., approximately 68% of soils]) would reach a final pH of 4.4 to 5.1, and that 90% of soils would likely reach a final pH of 4.2 to 5.3. Only 4 of 46 soil sampling sites had a current pH between 4.6 and 5.0, and these would unlikely increase by more than 0.5. No soils would likely increase to a final pH of more than 5.5. In summary, although liming would measurably increase pH of all soils in the Meadow Run project area, most soils would have a final pH that the US Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) considers “very strongly acidic” (pH = 4.5 to 5.0), with a small percentage of soils classified as “strongly acidic” (pH = 5.1 to 5.5) (USDA-NRCS 2017).

SOIL CALCIUM AND MAGNESIUM

Calcium and magnesium are base cations that also serve as plant nutrients. The addition of limestone sand, which contains calcium and magnesium, would directly increase total exchangeable calcium and magnesium in soils by factors of three to five for the proposed doses, depending on geology and other variables. Specifically, liming doses of 2.25 t/acre and 3.0 t/acre would yield 1,500 to 2,000 kilograms per hectare (kg/ha) of calcium and 375 to 500 kg/ha of magnesium. This would represent a substantial addition to the 140 ±100 kg/ha of calcium and 33 ±14 kg/ha of magnesium that are currently present in the upper 20 cm of soils in the project area. The deeper mineral horizon (depth of 20–80 cm) contains an additional 390 ±360 kg/ha of calcium and 89 ±59 kg/ha of magnesium; the large ranges are primarily caused by differences in bedrock geology.

Following incorporation of these nutrient base cations into the soil, exchangeable calcium and magnesium concentrations in the upper mineral horizon (depth of approximately 5–20 cm) would be at levels that would improve the soil and benefit vegetation.

SOIL POTASSIUM

Potassium is a base cation and a key plant nutrient. Although the action alternatives would not directly add potassium, it is important to understand if there might be unintended effects on potassium or if potassium would become a limiting nutrient after liming.

Potassium concentrations are relatively high in Meadow Run soils, with 104 ±23 parts per million (ppm) in the organic horizon, 50 ±24 ppm in the upper mineral horizon (<20 cm depth), and 65 ±46 ppm in the lower mineral horizon (20–80 cm depth). Soil potassium is therefore unlikely to be limiting to plant growth or be substantially reduced with increased leaching from liming, especially given that post-liming base saturation would be <30%, which would not force a competition with calcium and magnesium for available cation exchange sites. Another potentially adverse effect on potassium could be a “nutrient antagonism,” where calcium and magnesium compete with potassium for uptake by plants (Tomlinson 1990; Havlin 2005). However, calcium-to-potassium ratios over the entire (0–80 cm) soil profile would increase from approximately 2:1 presently to approximately 11:1 after liming. Liming would therefore move soils closer to the “ideal soil” range of 13:1 to 22:1 calcium to potassium ratios claimed by proponents of the basic cation saturation ratio concept—although recent studies show that soil nutrient ratios are much less important than total concentrations (Rehm 199494; Kopittke and Menzies 2007). In summary, it is unlikely that liming would have an adverse impact on potassium bioavailability, either via leaching or nutrient antagonism.

HEALTHY STREAM CONDITIONS

Water temperature, dissolved oxygen, and nutrients are important water quality metrics that are not related to acidification, but all indicate that Meadow Run would be a healthy stream if acidification were reversed.

The low water temperatures and high dissolved oxygen concentration in Meadow Run are ideal for aquatic wildlife, especially brook trout. Summer water temperatures have been measured as high as 20 to 23°C for short periods in some recent years, which could temporarily increase mortality rates in brook trout fingerlings (Costanzo et al. 2017; VADEQ 2018). Water temperatures are expected to be lower farther upstream during the summer (from proximity to springs and other groundwater sources), so headwaters would likely provide sufficiently low temperatures year-round for brook trout because groundwater temperatures during the summer are substantially cooler than air temperatures. Dissolved oxygen concentrations measured by the park in water of Meadow Run averaged 10.8 milligrams per liter (mg/L) during spring monitoring and 9.1 mg/L during summer monitoring (Wofford and Demarest 2018; Wofford et al. 2018). These concentrations are ideal for trout and reflect low biological oxygen demand from the clear waters and the steep and shallow stream channels that provide high levels of turbulence and reaeration. Low dissolved nutrient concentrations measured in Meadow Run also reflect water quality conditions ideal for a healthy stream. In particular, stream nitrate has dropped over the last decade to values below the National Ambient Water Quality Criteria for rivers and streams in this ecoregion (USEPA 2000). Such concentrations are not likely to produce algal blooms that can lead to anoxia, even when sunlight or other nutrients are not limiting.

SECTION 5: SUMMARY

In summary, this appendix provides the following additional technical information:

- **Acidic Deposition in the Park:** Modeling studies have predicted that Meadow Run cannot recover naturally for a long time; specifically, existing degraded conditions would persist for well over 100 years.

- **Effectiveness of Liming as a Restoration Tool:** The effectiveness of liming watersheds has been well documented through decades of published research and technical monitoring reports, including studies and reports from multiple projects in the northeastern United States.

- **Liming Material:** The most appropriate liming material for the proposed Meadow Run restoration is limestone sand, which is available from local quarries near the project area.

- **Liming Doses:** Based on soil data from the project area and other constraints, recommended liming doses consist of (1) a split-dose liming approach with a high dose of 3.0 t/acre over more depleted soils and a low dose of 2.25 t/acre over less depleted soils (alternative B), or (2) a uniform-dose liming approach applying 2.75 t/acre over the entire project area (alternative C).

- **Response Time Following Liming:** Limestone sand would take less than a year to become physically incorporated into the organic horizon, but it would take years to decades to be fully integrated into the soil's exchangeable base cation pool. However, the benefits of liming are estimated to last well over 100 years (and possibly over 200 years) with a liming dose of 2 t/acre or higher.

- **Soil pH:** Following liming, the pH of soils in the Meadow Run project area would improve from currently "extremely acidic" (pH = 3.5 to 4.4; classification of USDA-NRCS [2017]) to mostly "very strongly acidic" (pH = 4.5 to 5.0). A small percentage of soils would improve to "strongly acidic" (pH = 5.1 to 5.5).

- **Potassium:** Potassium is a base cation and a key plant nutrient. Although the action alternatives would not directly add potassium, it is unlikely that liming would have an adverse impact on potassium availability for plants.

- **Water Quality of Meadow Run for Successful Restoration:** Water temperature, dissolved oxygen, and nutrients are important water quality metrics that are not related to acidification, but past measurements of these metrics all indicate that Meadow Run would be a healthy stream if acidification were reversed.

APPENDIX C
VERTEBRATE SPECIES OF GREATEST CONSERVATION NEED POTENTIALLY PRESENT IN THE PROJECT AREA

TABLE C-1. VERTEBRATE SPECIES OF GREATEST CONSERVATION NEED POTENTIALLY PRESENT IN THE PROJECT AREA

Common Name	Scientific Name	Abundance [1]	SWAP Tier / Opportunity Ranking [2, 3]	Habitat
Birds				
American woodcock	*Scolopax minor*	Uncommon	II / a	Young forest and abandoned farmland mixed with forested land, often in forest openings and wet areas near forest edges
black-and- white warbler	*Mniotilta varia*	Uncommon	IV / a	Deciduous forest and mixed forest of various ages and a variety of foraging substrates
black-billed cuckoo	*Coccyzus erythropthalmus*	Uncommon	II / b	Forest edge and open woodland, both deciduous and coniferous, with dense deciduous thickets
brown thrasher	*Toxostoma rufum*	Uncommon	IV / a	Shrub thickets and brushy areas in deciduous forest clearings and forest edges
Canada warbler	*Cardellina canadensis*	Occasional	IV / b	Mixed conifer and deciduous forest and woodlands with shrubby undergrowth, often along streams or near swamps, and deciduous second growth
cerulean warbler	*Setophaga cerulea*	Uncommon	II / a	Structurally mature hardwood forest in a mesic or wetter conditions with tall, large-diameter trees and relatively little undergrowth, favoring relatively mesic north- and east-facing slopes
eastern towhee	*Pipilo erythrophthalmus*	Common	IV / a	Forest and swamp edges, regenerating clearcuts, open-canopied forests, particularly those with a well-developed understory, reclaimed strip mines, mid-late successional fields, riparian thickets, overgrown fence rows, shrub/small-tree thickets, open-canopied forests, and other brushy habitats
eastern whip-poor-will	*Antrostomus vociferus*	Uncommon	III / a	Open deciduous or evergreen forest and woodlands with little or no underbrush, close to open areas
golden-winged warbler	*Vermivora chrysoptera*	Uncommon	I / a	Various types of open shrublands, especially in wetland areas, near edges of mature forest within a broader forested matrix
Kentucky warbler	*Geothlypis formosa*	Uncommon	III / a	Dense undergrowth of deciduous forest near creeks and rivers, and ravines in upland woodlands

Common Name	Scientific Name	Abundance [1]	SWAP Tier / Opportunity Ranking [2, 3]	Habitat
northern flicker	*Colaptes auratus*	Rare	IV / b	A wide variety of tree-covered areas, including deciduous and coniferous forest and woodlands, but tends to avoid dense unbroken forest and requires some open ground for foraging
northern saw-whet owl	*Aegolius acadicus*	Rare	I / c	Mature forest with and open understory, but also a wide range of deciduous and coniferous woodlands
red crossbill (Type I)	*Loxia curvirostra*	Rare	III / c	Mature coniferous forests, especially spruce, fir, pine, or hemlock forests
ruffed grouse	*Bonasa umbellus*	Occasional	III / a	Dense forest with some deciduous trees, in both wet and relatively dry situations, especially those with scattered clearings and dense undergrowth
wood thrush	*Hylocichla mustelina*	Abundant	IV / b	Deciduous or mixed forests with a dense tree canopy and a fairly well-developed deciduous understory, especially in moist sites with water nearby
yellow-billed cuckoo	*Coccyzus americanus*	Uncommon	III / a	Open woodland, especially where undergrowth is thick, parks, and deciduous riparian woodlands
yellow-breasted chat	*Icteria virens*	Occasional	IV / a	Dense shrubby areas, including clearcuts, old pastures, thickets, woodland undergrowth, and forest edges, often in wet places near streams
Mammals				
Allegheny woodrat	*Neotoma magister*	Uncommon	IV / a	Rocky areas in deciduous forests, including caves, rock shelters, cliff faces, talus slopes, and rock outcrops
eastern small-footed myotis	*Myotis leibii*	Uncommon	I / a	Heavily forested, mountainous areas, often but not exclusively near caves and rocky outcrops within and near hemlock forests; hibernates in caves and mine tunnels; roosts in hollow trees, rock crevices, under rocks, or in rocky outcrops; forages near forest edges and over ponds and streams
eastern spotted skunk	*Spilogale putorius*	Uncommon	IV / c	Rock piles, rock slides, and cliffs surrounded by forest

Common Name	Scientific Name	Abundance [1]	SWAP Tier / Opportunity Ranking [2, 3]	Habitat
fisher	*Martes pennanti pennant*	Rare	IV / c	Spruce/fir forests, northern bogs and swamps, or mixed northern hardwood forests
hoary bat	*Lasiurus cinereus*	Uncommon	IV / a	Primarily deciduous and coniferous forests and woodlands, including areas altered by humans
long-tailed shrew	*Sorex dispar*	Unknown	IV / c	Talus slopes, rock slides, and cliffs surrounded by forest
red bat	*Lasiurus borealis*	Common	IV / a	Wide range of forested and semi-forested areas, including developed areas with large trees (e.g., city parks) and some areas subject to intensive forest management
silver-haired bat	*Lasionycteris noctivagans*	Unknown	SGCN IV / a	Forested (frequently coniferous) areas adjacent to lakes, ponds, or streams, including areas altered by humans
Virginia northern flying squirrel	*Glaucomys sabrinus fuscus*	Unknown	I / a	Spruce/fir and mixed conifer/northern hardwood forests
Amphibians				
Jefferson salamander	*Ambystoma jeffersonianum*	Uncommon	IV / a	Moist deciduous hardwood forests with suitable breeding ponds nearby
eastern spadefoot	*Scaphiopus holbrookii*	Unknown	IV / c	Forest and upland habitat generalist but requires fish-free breeding sites and soils suitable for digging
Reptiles				
eastern box turtle	*Terrapene carolina*	Common	III / a	A variety of areas including forests, wetlands, and interdunal areas
eastern hog-nosed snake	*Heterodon platirhinos*	Uncommon	IV / c	Areas with sandy soils, and have been found in fields, open grassy areas adjacent to woodlands, and various forest types
queen snake	*Regina septemvittata*	Unknown	IV / a	Crayfish obligate; clear streams with rock or sandy bottoms and vegetated shorelines
spotted turtle	*Clemmys guttata*	Rare	III / a	Swamps, bogs, fens, marshes, woodland streams, and wet pastures

Common Name	Scientific Name	Abundance [1]	SWAP Tier / Opportunity Ranking [2, 3]	Habitat
smooth green snake	*Opheodrys vernalis*	Rare	III / a	Moist meadows or grassy areas at the edges of bogs or small streams
timber rattlesnake	*Crotalus horridus (timber)*	Common	IV / a	Hibernates in fissures in rock ledges or talus slopes. When active, utilizes various forest and open habitats.

Sources: NPS (2020c); VDGIF (2015); Virginia DCR (2020); Cornell Lab of Ornithology (2020)

[1] NPSpecies (NPS 2020c) categorizes species abundance as:

Abundant: May be seen daily, in suitable habitat and season, and counted in relatively large numbers.
Common: May be seen daily, in suitable habitat and season, but not in large numbers.
Uncommon: Likely to be seen monthly in appropriate season/habitat. May be locally common.
Rare: Present, but usually seen only a few times each year.
Occasional: Occurs in the park at least once every few years, but not necessarily every year.
Unknown: Abundance unknown.

[2] The Virginia State Wildlife Action Plan (SWAP) (VDGIF 2015) assigns SGCN a Tier ranking (I to IV) as:

Tier I: Critical Conservation Need. Faces an extremely high risk of extinction or extirpation. Populations of these species are at critically low levels, face immediate threat(s), or occur within an extremely limited range. Intense and immediate management action is needed.
Tier II: Very High Conservation Need. Has a high risk of extinction or extirpation. Populations of these species are at very low levels, face real threat(s), or occur within a very limited distribution. Immediate management is needed for stabilization and recovery.
Tier III: High Conservation Need. Extinction or extirpation is possible. Populations of these species are in decline, have declined to low levels, or are restricted in range. Management action is needed to stabilize or increase populations.
Tier IV: Moderate Conservation Need. The species may be rare in parts of its range, particularly on the periphery. Populations of these species have demonstrated a declining trend, or a declining trend is suspected which, if continued, is likely to qualify this species for a higher tier in the foreseeable future. Long-term planning is necessary to stabilize or increase populations.

[3] The Virginia SWAP (VDGIF 2015) has assigned SGCN a Conservation Opportunity Ranking (a, b, or c), as follows:

a: Managers have identified “on the ground” species or habitat management strategies expected to benefit the species, at least some of which can be implemented with existing resources and are expected to have a reasonable chance of improving the species’ conservation status.
b: Managers have only identified research needs for the species or managers have only identified “on the ground” conservation actions that cannot be implemented due to lack of personnel, funding, or other circumstance.
c: Managers have failed to identify “on the ground” actions or research needs that could benefit this species or its habitat or all identified conservation opportunities for a species have been exhausted.

Note: Literature citations are included in the “References” chapter above, following the main body of the EA.