Michaux State Forest: Recreational Trail Assessment

DRAFT: JUNE 2016

Pennsylvania DCNR FORESTRY

Applied Trails RESEARCH

KAY-LINN

Table of Contents

Executive Summary- TBD

This study was undertaken on the northern portion of the Michaux State Forest to support the goals of Bureau of Forestry in managing current and future recreational trail use. As per the Department of Conservation and Natural Resources 2015 State Forest Resource Management Plan (SFRMP):

> *State forests provide unique opportunities for dispersed, low-density outdoor recreation that can be obtained only through large blocks of forest. Forest recreation is one of the most common ways that people connect with and enjoy the state forest. The state forest system provides bountiful opportunities for citizens to recreate and enjoy the forest. However, state forests cannot sustainably provide unlimited recreational opportunities. Recreational opportunities on state forest land are aimed at those forms of dispersed forest recreation that are compatible with ecosystem management.*
>
> *The Conservation and Natural Resource Act of 1995, P.L. 89, No.18 authorizes the establishment of and provides for the use and control of state forest lands. The act states, in part, that one of the purposes for which state forests are created is "... to furnish opportunities for healthful recreation to the public."*
>
> *Outdoor recreational pursuits are continually changing. Our social structure, affluence, mobility, leisure time, and a multitude of new recreation equipment influence these changes. As opposed to basic human needs for forest products, recreation deals more with attitudes and emotions. Recreation users may not understand their impacts on other resources or the limitations of some forest ecosystems to provide various levels of recreation opportunities. Recreationists feel a sense of ownership over their activity and the places they enjoy this activity, and thus may not agree with constraints on recreation in some places for the sake of sustainability. The bureau strives to be aware of attitudes toward recreation to provide a healthful outdoor recreation experience.*
>
> *Increasing recreational use and the diversity of uses are having a growing impact on other resources and forest ecosystems. With the influx of more individuals and groups in pursuit of recreational activities, it becomes increasingly important for the bureau to develop strategies to provide a quality outdoor experience, minimize conflicts between user groups, and maintain ecological processes.*
>
> *State forest lands provide a unique opportunity for dispersed, low-density, outdoor recreation, but the bureau must balance the desires of various recreation users. Outdoor recreational pursuits are constantly changing, as influenced by a number of social and economic factors. The bureau strives to understand recreational preferences and provide recreation that is compatible with ecosystem management while retaining the wild character of state forest lands.*
>
> *State forest visitors should be assured of a high-quality outdoor experience. As opportunities for recreation on state forest lands have grown, so have the opportunities for conflict between user groups. For example, a hiker who seeks solitude in the forest might be disturbed by the noise of a nearby ATV. Increasing recreational use has the potential to impact recreational resources and forest ecosystems. With the influx of more people pursuing their own preferred types of recreation, it becomes increasingly important for the bureau to implement management strategies to provide quality outdoor experiences that minimize conflicts while maintaining ecological processes and wild character. Localized closures are among the management tools the bureau may use.*

The SFRMP also provides clear direction regarding Goals and Objectives related to Recreation Management. These items were foundational to this trail assessment process, and include:

Recreation Management Principle

Wild character and recreation opportunities and experiences on state forest lands are managed to provide dispersed, low-density recreation activities that are compatible with ecosystem management.

Goals	Objectives
1. To provide and maintain healthful, low-density recreational opportunities and experiences across the landscape.	**1.1** Develop and implement a strategic approach to evaluate and manage recreation.
	1.2 Identify appropriate recreational levels to ensure conservation of ecological resources and minimize user conflict.
	1.3 Direct high-density recreation activities and large groups to appropriate areas.
	1.4 Inventory and assess recreation infrastructure to determine sustainability and maintenance needs.
	1.5 Consider recreational opportunities and experiences during management activities.
	1.6 Continue to monitor visitor use through visitor use monitoring, comment cards, surveys, and other means.
	1.7 Utilize state parks to provide high-density and developed recreation opportunities, and as gateways to primitive low-density dispersed recreation on state forest lands.
	1.8 Maintain the state forests as the largest land base for hunting opportunity in the commonwealth.
2. To develop and promote effective partnerships in managing recreational opportunities and experiences.	**2.1** Collaborate with stakeholders and other state agencies to promote sustainable use of recreational resources.
	2.2 Engage conservation volunteers, recreation groups, and local partners in planning, construction, and maintenance of recreation resources.
	2.3 Consider recreation opportunities that improve experiences by creating connections to adjacent lands.
3. To provide information and assistance to the public while promoting safety.	**3.1** Provide easily accessible information to visitors.
	3.2 Create and maintain facilities that meet visitor use and management needs.
	3.3 Provide public assistance and law enforcement through the Ranger Program and state forest officers.
	3.4 Perform search-and-rescue operations and incident management to promote the safety of state forest visitors.

The Bureau of Forestry and Michaux State Forest management have expressed concerns regarding the sustainability of the recreational trail system and whether it meets the intention of providing low-density, dispersed recreation. This assessment endeavors to provide a benchmark and recommendations relative to the trail system, with the stated goal to:

Develop and formalize a static, manageable trail system that provides for sustainable outdoor recreation use by a diverse set of users and events, while meeting the managerial goals for ecosystem and forest resource management on the Michaux State Forest.

The assessment was conducted relative to three intersecting spheres of sustainability (See Appendix A for greater detail), including:

- **Physical Sustainability**

  The durability of the trails and their ability to handle the trail user and environmental stressors, including a broad assessment of trail conditions relative to location on the landscape, trail grades and the relationship to topography, and the natural or created ability to shed water.

- **Social Sustainability**

  The potential for safety-related incidents between users, navigability of the trail system, quality of trail experiences, use patterns such as modality, residence time, and access locations, and a spatial and comparative assessment of system vs. non-system trail capacities, and likelihood of recreational overcrowding.

- **Managerial Sustainability**

  The capacity of Forest staff and stewards, in terms of skills, knowledge, tools, hours/numbers, budget, fundraising, to manage the trail system, and potential management conflicts related to ecosystem management and facility capacity.

These spheres of sustainability were assessed through field investigation and LiDAR modeling of the entire trail system, and confirmed by quantitative measurements of soil loss (trail cross sectional area analysis) prior to and following a number of large special events. Extensive outreach to stakeholder groups identified by the Forest was conducted to gauge local attitudes and opinions regarding trail conditions, issues and opportunities, desired future conditions, and ability/willingness to engage more deeply in striving to meet those conditions.

Based on the results of the sustainability assessment, recommendations have been created for trail system size, location of trails, use of trails (by group, seasonality, and capacity), alterations in trail location, design, and maintenance regime, and needs for trail-related infrastructure, facilities, and management. This report is intended to be a tool for the Michaux in management decision-making processes and an educational document aimed at increasing the understanding at public and Forest levels on the sustainable design and effective maintenance of trails, dynamics of water and different trail uses on trail condition, and the relationship between trail specifications and desired trail user experiences.

Assessment Area

The Michaux State Forest recreational trail assessment was conducted on the northern portion of the Forest, bound by US HWY 30 in the south and PA HWY 34 in the north. Access to this portion of the Michaux is provided by PA HWY 233, which roughly bisects the Forest in a southwest to northeast direction, as well as Pine Grove Road, Shippensburg/Baltimore Road. Regional access for forest visitors is provided by nearby Interstate Highways 81, 83, and 76.

Potential daily forest visitation population numbers, represented by those living within 45 miles of the Forest, is approximately 1,667,000. Significant cities are located in this radius, including Harrisburg, Carlisle, Chambersburg, York, and Gettysburg, PA, and Frederick, MD. Regional/weekend forest visitation population numbers, represented by those living within 100 miles of the Forest, is approximately 12,000,000 and includes the entire Washington, DC- Baltimore, MD metropolitan region. Major attractions, including Gettsburg National Military Park and the Appalachian Trail, ensure significant seasonal visitation to the area. The Forest is also adjacent to Caledonia and Pine Grove Furnace, and Kings Gap Environmental Education Area.

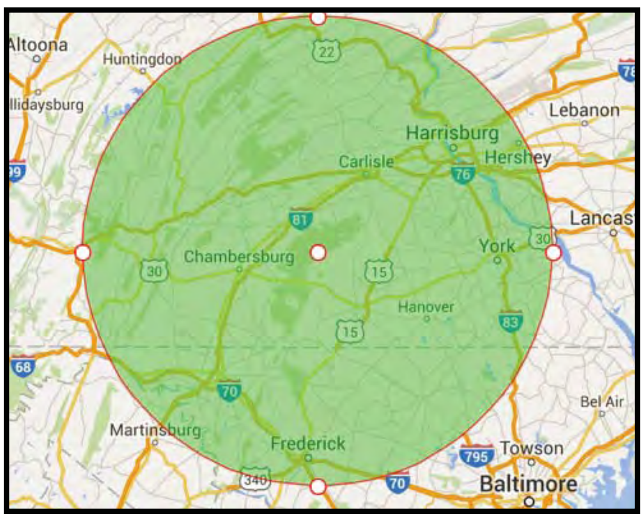


Figure 1. 45-mile radius map

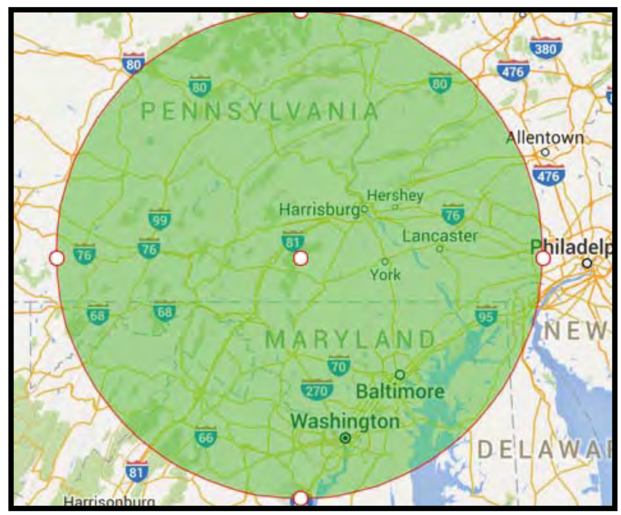


Figure 2. 100-mile radius map

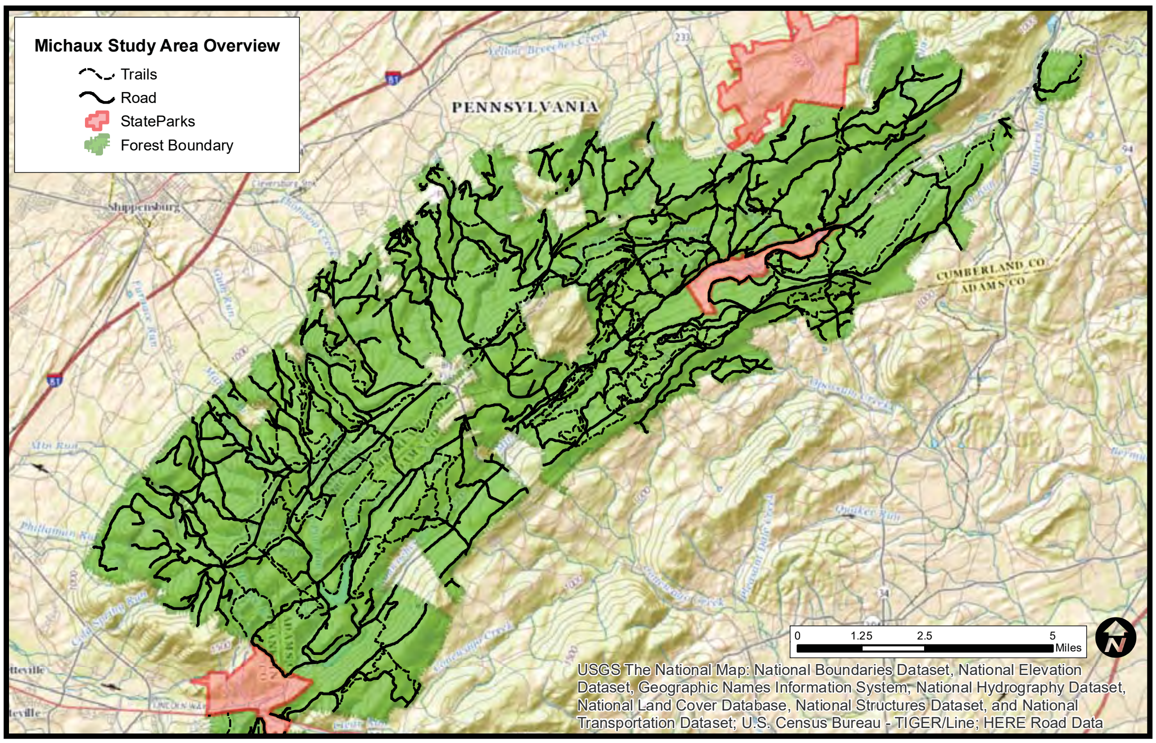


Figure 3. Study Area Overview Map

The Michaux State Forest, relative to other PA State Forests, is medium-sized. At 85,502 total acres, it is larger than nine Forests and smaller than 10 Forests. It is closest in size to the Delaware (82,792 acres), Rothrock (95,911 acres), and Tuscarora (95,650 acres) State Forests. In terms of its level of development, as measured by the Recreation Opportunity Spectrum (ROS), the Michaux is quite developed with 53,897 acres/63% classified as semi-developed and developed, 37% classified as semi-primitive and 0 acres classified as primitive. Compared to the other similarly sized Forests, the Delaware (55% of its acreage classified as primitive or semi-primitive), Tuscarora (55% classified as semi-primitive), and Rothrock (40% classified as semi-primitive) are less developed.

District	Primitive	Semi-primitive non-motorized	Semi-primitive	Semi-developed & developed	Total Acres
Michaux	0	4,493	27,112	53,897	85,502
Buchanan	0	8,532	17,212	43,959	69,703
Tuscarora	0	27,200	25,420	43,030	95,650
Forbes	0	8,753	19,462	30,083	58,298
Rothrock	0	7,815	30,843	57,254	95,911
Gallitzin	0	4,559	7,291	12,413	24,262
Bald Eagle	0	22,202	57,182	114,006	193,390
Clear Creek	0	1,190	2,784	11,990	15,965
Moshannon	528	26,961	47,834	114,710	190,033
Sproul	117	23,115	77,697	204,511	305,440
Pinchot	706	5,111	7,302	16,464	29,583
Tiadaghton	3,994	31,333	40,473	70,772	146,572
Elk	8,225	54,631	54,167	82,922	199,945
Cornplanter	0	0	358	1,131	1,489
Susquehannock	25,253	67,398	63,191	104,272	260,114
Tioga	3,376	35,775	45,903	76,837	161,891
William Penn	0	0	434	373	807
Weiser	127	8,406	8,127	11,396	28,056
Delaware	3,033	18,141	24,262	37,356	82,792
Loyalsock	0	29,729	36,646	48,175	114,550
Total	**45,359**	**385,345**	**593,699**	**1,135,552**	**2,159,953**

Table 1. Recreation Opportunity Spectrum Acreage By Forest (from SFRMP, 2015)

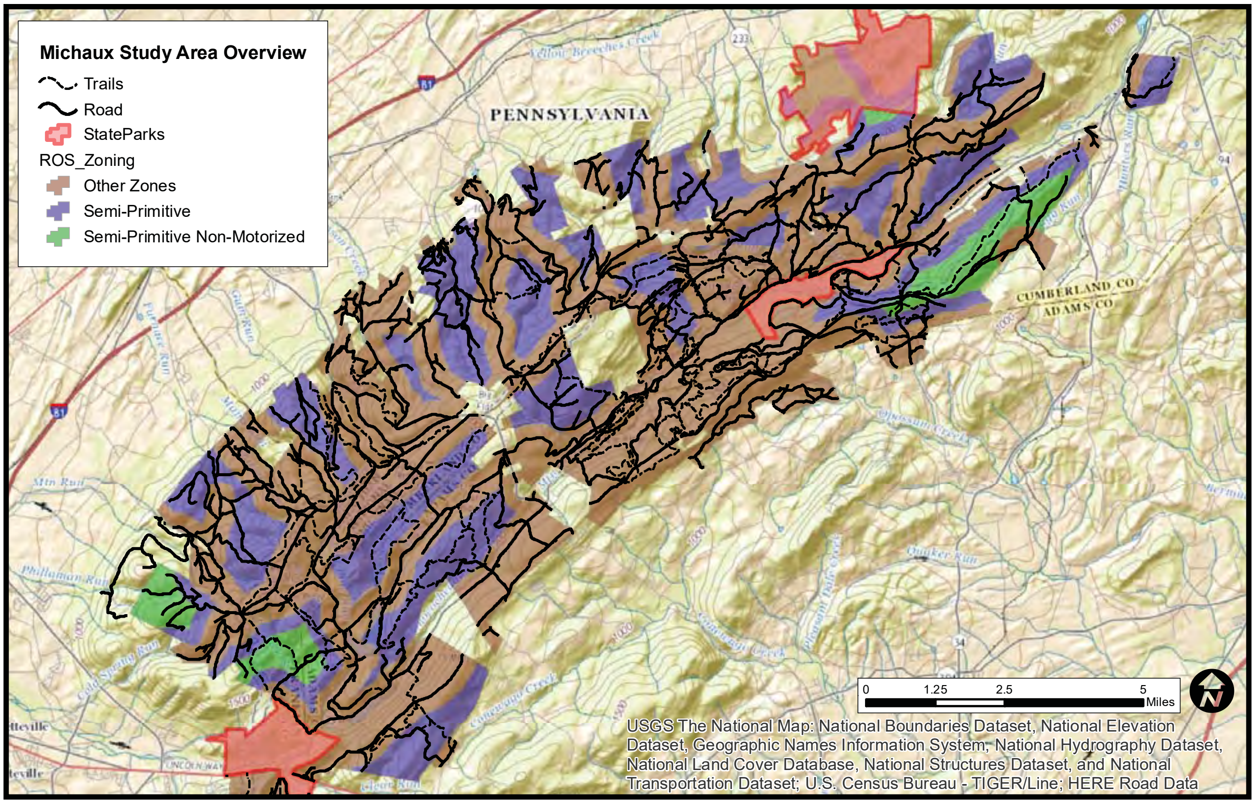


Figure 4. Michaux State Forest Recreation Opportunity Spectrum Zones

The large ATV/Snowmobile Trail System, a long history of road development for purposes of timber management, three State Parks, and bissecting highway all significantly effect the level of development in the Forest.

The Michaux has 477 miles of roads. 350 miles of these are gated, administrative roads, 124 miles of public use roads, and 3 miles of drivable trail. Several of these roads are also qualified as trails. As a measure of road density, the Michaux has 29.4 feet of road/acre. Compared to its three Forest size cohorts, the Rothrock (14.7), Tuscarora (15.6), and Delaware (8.0) Forests have road densities approximately half of Michaux.

Officially, the Michaux has a total of 259 miles of recreational trails. 127 miles of that total are roads that are open to public use. Of the total, 259 miles of trail are open to hikers, 211 trail miles are open to equestrians, mountain bikers, and cross country skiers, 82 miles of trail are open to snowmobiles, and 41 miles of trail are open to ATV riders. These trail mileage totals are similar to the Rothrock (269 miles), Tuscarora (330 miles) and Delaware (260 miles) Forests.

36 miles of the Appalachian National Scenic Trail pass through the Michaux and the three neighboring State Parks host a number of hiking trails within their park boundaries.

Formalized access points in the northern portion of the Michaux are located at the Big Flat and Bendersville Trailheads. These are large dirt/gravel lots with sanitary facilities, connectivity to the ATV/Snowmobile trails, and also contain fields or areas utilized for camping. Smaller, informal access points exist adjacent to Long

District	Public-use roads	Drivable trails	Admin. roads	Total
Michaux State Forest	124	3	350	477
Buchanan State Forest	77	16	125	219
Tuscarora State Forest	99	24	160	283
Forbes State Forest	44	0	85	129
Rothrock State Forest	180	12	76	267
Gallitzin State Forest	17	11	23	51
Bald Eagle State Forest	263	79	208	550
Kittanning State Forest	16	1	56	72
Moshannon State Forest	245	72	138	455
Sproul State Forest	340	106	491	937
Pinchot State Forest	15	1	14	30
Tiadaghton State Forest	167	18	166	350
Elk State Forest	125	9	418	551
Cornplanter State Forest	0	0	2	2
Susquehannock State Forest	163	53	407	624
Tioga State Forest	156	22	292	470
William Penn State Forest	1	0	1	2
Weiser State Forest	29	4	55	88
Delaware State Forest	38	0	87	125
Loyalsock State Forest	124	10	177	311
Total Mileage	**2,224**	**441**	**3,330**	**5,994**

Table 2. Road miles by State Forest (from SFRMP, 2015)

District	Hiking	Biking	Horse	XSkiing	ATV	Snowmobile
Michaux	259	212	211	211	41	82
Buchanan	257	215	215	215	32	34
Tuscarora	330	300	300	305	0	41
Forbes	190	153	153	190	0	39
Rothrock	269	169	169	170	0	27
Gallitzin	83	48	48	83	0	12
Bald Eagle	577	460	462	577	15	98
Clear Creek	4	0	0	0	0	0
Moshannon	11	37	18	12	0	19
Sproul	670	95	95	110	85	42
Pinchot	47	24	24	47	0	25
Tiadaghton	426	228	191	414	18	33
Elk	264	51	48	49	0	6
Cornplanter	11	7	0	7	0	0
Susquehannock	319	228	225	227	45	94
Tioga	372	301	261	345	0	34
William Penn	2	0	0	0	0	0
Weiser	85	82	37	77	0	20
Delaware	260	181	181	200	30	116
Loyalsock	326	260	260	262	0	12
Total Mileage	**4,763**	**3,050**	**2,899**	**3,502**	**267**	**732**

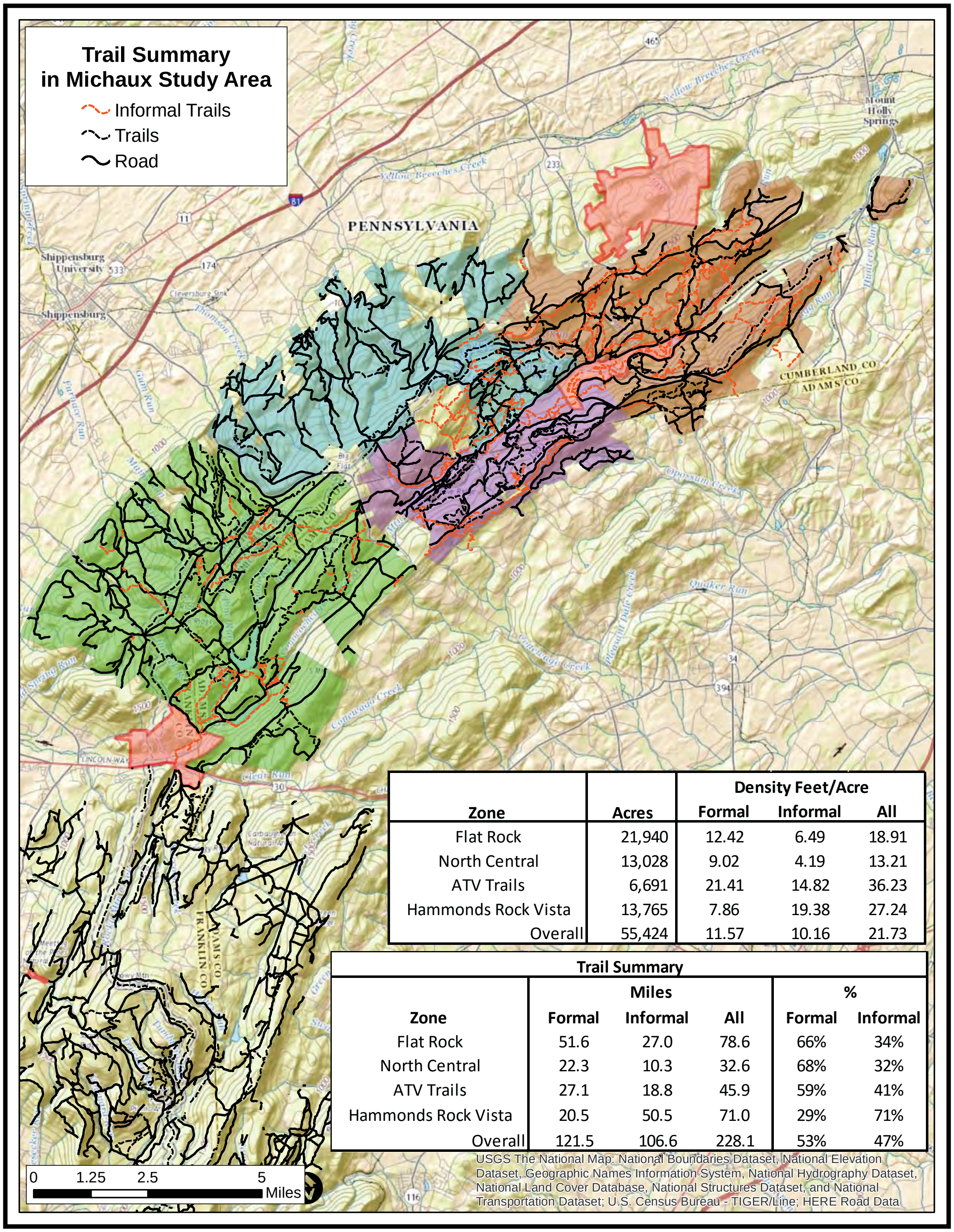
Table 3. Trail miles by State Forest (from SFRMP, 2015)

Pine Run Reservoir, Conococheague Creek, two locations on Ridge Road, and on 233 near Tumbling Run Preserve. These locations generally are small, holding five or fewer vehicles, do not have roadside signs, maps/kiosks, or sanitary facilities. The notable exception is the Long Pine Run Reservoir lot, which has capacity for approximately 20 vehicles.

The State Parks have developed day-use parking areas that can be utilized to access the nearby Forest trail network.

A number of scenic vista and special interest sites are also denoted throughout this portion of the forest, including Dark Hollow, Buzzards Rock, Pole Steeple, Hammonds Rocks, and Spruce Run. These sites are generally located near open roads and accessed by informal paths that are not included in the official trail system inventory.

The vast majority of trails managed by Michaux State Forest are located centrally and southeast of HWY 233 (the core of the ATV/Snowmobile trail system) and southerly and west of HWY 233 (the core of the shared-use, non-motorized trail system). Outside of the Appalachian National Scenic Trail, Pole Steeple Trail, and Buck Ridge Trail, there are few official trails in the northeast portion of the forest.



Zone	Acres	Density Feet/Acre		
		Formal	Informal	All
Flat Rock	21,940	12.42	6.49	18.91
North Central	13,028	9.02	4.19	13.21
ATV Trails	6,691	21.41	14.82	36.23
Hammonds Rock Vista	13,765	7.86	19.38	27.24
Overall	55,424	11.57	10.16	21.73

Trail Summary

Zone	Miles			%	
	Formal	Informal	All	Formal	Informal
Flat Rock	51.6	27.0	78.6	66%	34%
North Central	22.3	10.3	32.6	68%	32%
ATV Trails	27.1	18.8	45.9	59%	41%
Hammonds Rock Vista	20.5	50.5	71.0	29%	71%
Overall	121.5	106.6	228.1	53%	47%

Figure 5. Overview, Formal and Informal Trails

Physical Sustainability Assessment

The physical sustainability assessment was undertaken from Fall 2015 through Spring 2016. The official non-motorized, shared-use trail system was investigated by bicycle and foot and the special event enduro routes and ATV/snowmobile trail system was investigated by motorcycle. A large number of unofficial/informal trails were also investigated during the physical sustainability assessment. The locations of these trails were developed primarily from internet-based resources such as Strava, as well as from personal communication offered by forest trail users during the stakeholder outreach.

Noting these relatively different management and use regimes, the assessment has been segmented geographically to provide depth and site-specificity for the general observations regarding the:

- durability of the trails and their ability to handle the trail user and environmental stressors,
- trail conditions relative to location on the landscape,
- trail grades and the relationship to topography, and
- the natural or created ability to manage water.

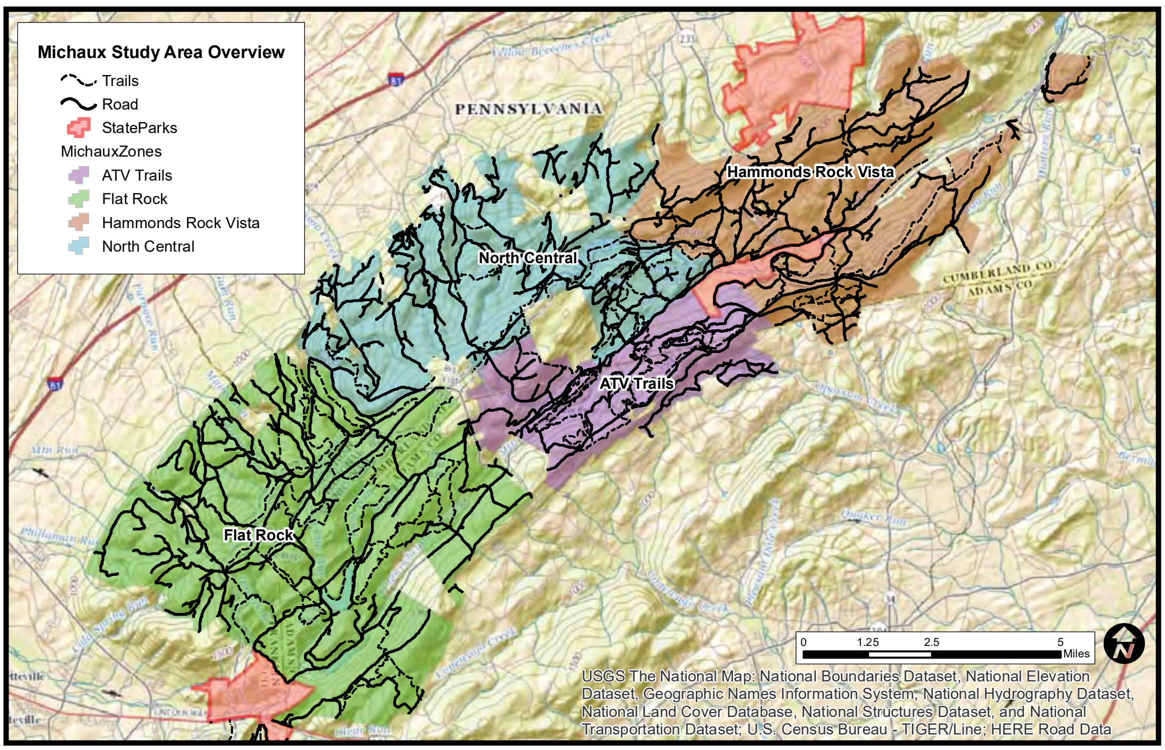
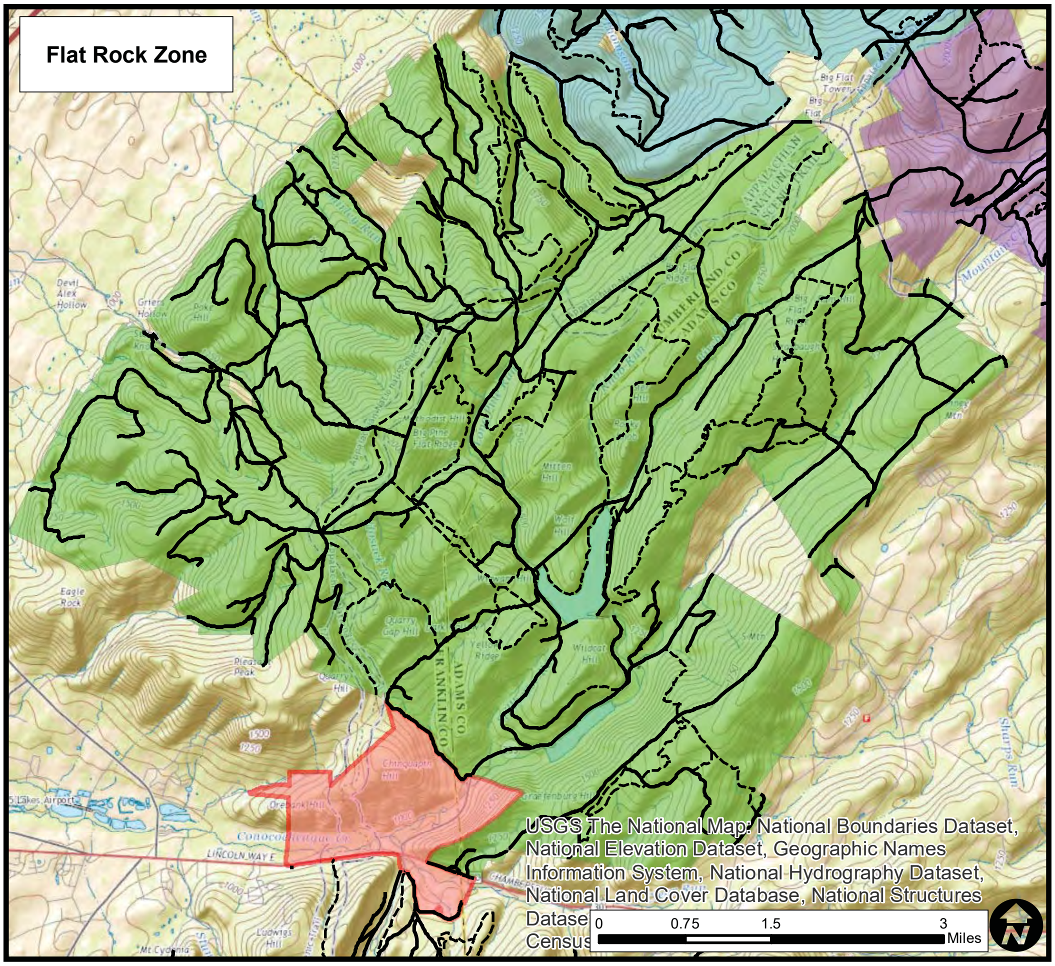


Figure 6. Trail Zones

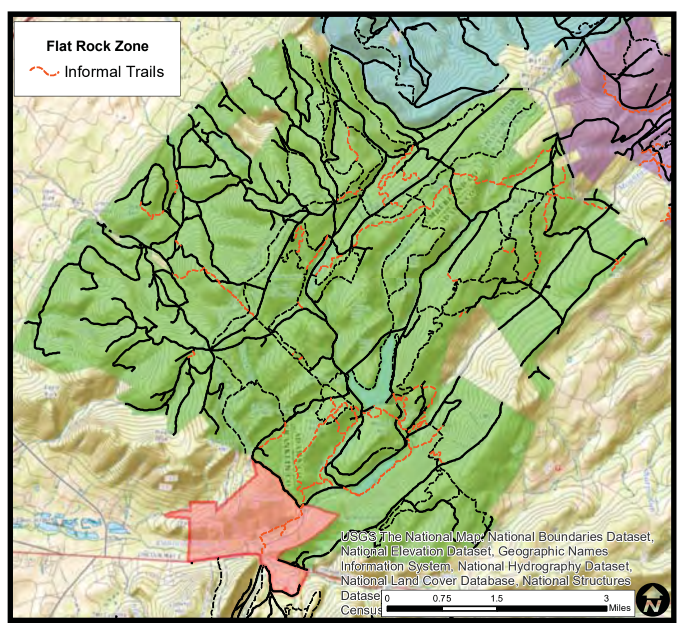
Flat Rock Zone



General Description

The Flat Rock Zone of approximately 22,000 acres contains the vast majority of the official, shared-use, non-motorized trails in the assessed portion of the Forest. 51.6 miles of official trail are located in this area, representing 42% of the total formal trail system. 27 miles of informal trail were catalogued in the assessment. 66% of the trails in this zone are part of the formal trail system and 34% are informal trails.

This equates to a trail density of 12.42 feet/acre of formal trail, 6.49 feet/acre of informal trail, and 18.91 trail feet/acre of for the total trail network. This is slightly lower than the overall trail density of 21.73 feet/acre.



Trail Durability

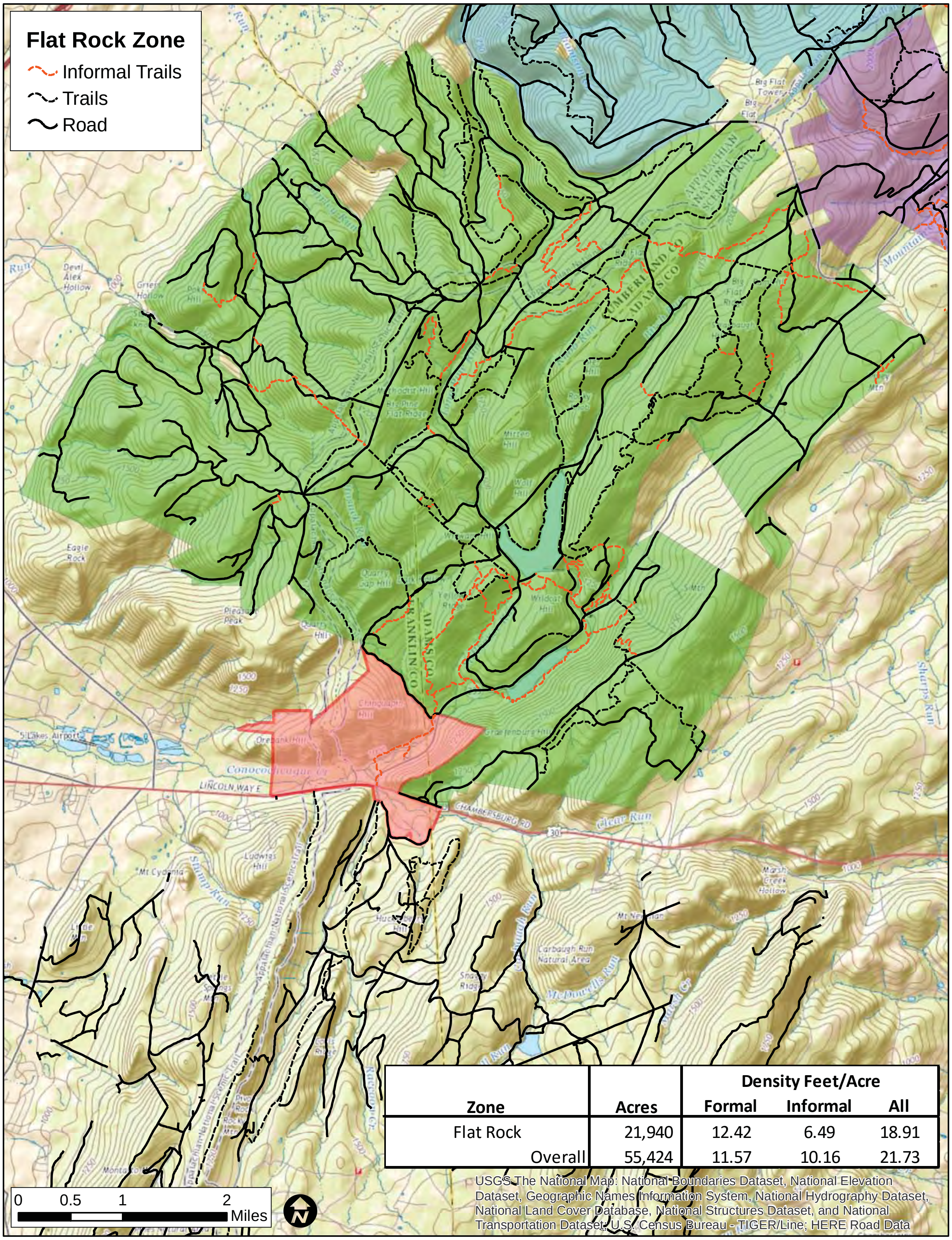
The potential durability of the trail tread is relatively high with a highly rocky soil matrix and well-draining soils. Many of the highest use trails are located on caplands. The current trail design does not respond well to motorized use, with significant erosion and entrenchment generated during special events which allow motorized use.

Trail Conditions

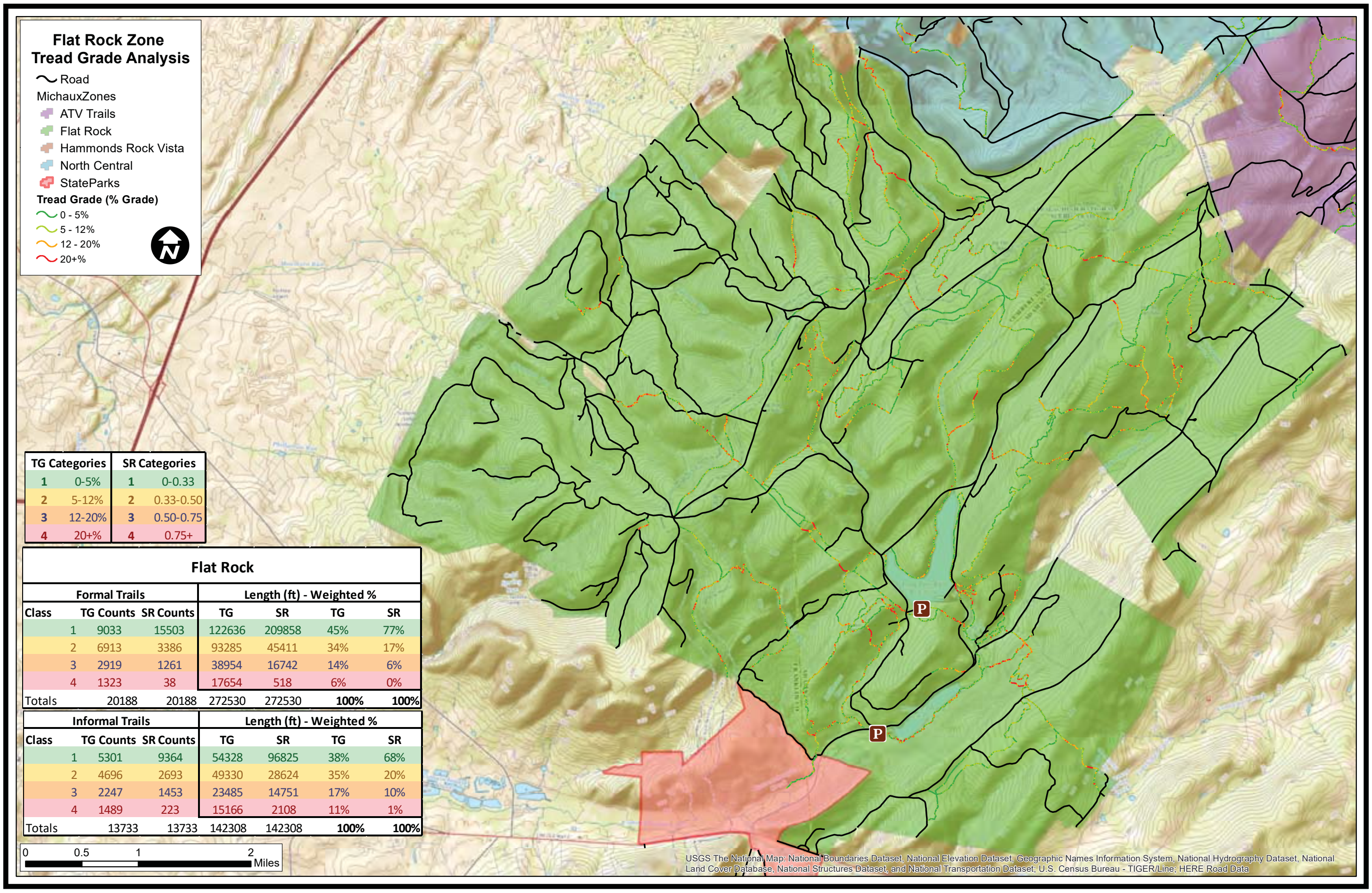
Historic corridor routes, such as old roads and powerlines, show evidence of tread amendments (i.e. the addition of gravel or rock), and/or significant erosion. There is evidence of significant equestrian use throughout the area, with rock scrapings from shod hooves and numerous overturned rocks remaining within the trail tread. Sinuous, mountain bike-focused trail design is present on many of the singletrack routes. However, these trails are often straightened or braided, entrenched on steeper slopes, and expanded on corners by enduro use during motorcycle special events. Trail conditions are generally manageable on narrow routes with slight entrenchment, but significant design flaws on many of the historic open corridors have developed widening tread with significant erosion problems present.

Water Management Capacity

Capland-located trails have high water management capacity but almost no formal, water-shedding design, construction, or maintenance. Trails in lower lying cupland-locations have a higher level of entrenchment, often due to a lack of proper trail drainage management.



Zone	Acres	Density Feet/Acre Formal	Informal	All
Flat Rock	21,940	12.42	6.49	18.91
Overall	55,424	11.57	10.16	21.73



TG Categories		SR Categories	
1	0-5%	1	0-0.33
2	5-12%	2	0.33-0.50
3	12-20%	3	0.50-0.75
4	20+%	4	0.75+

Flat Rock

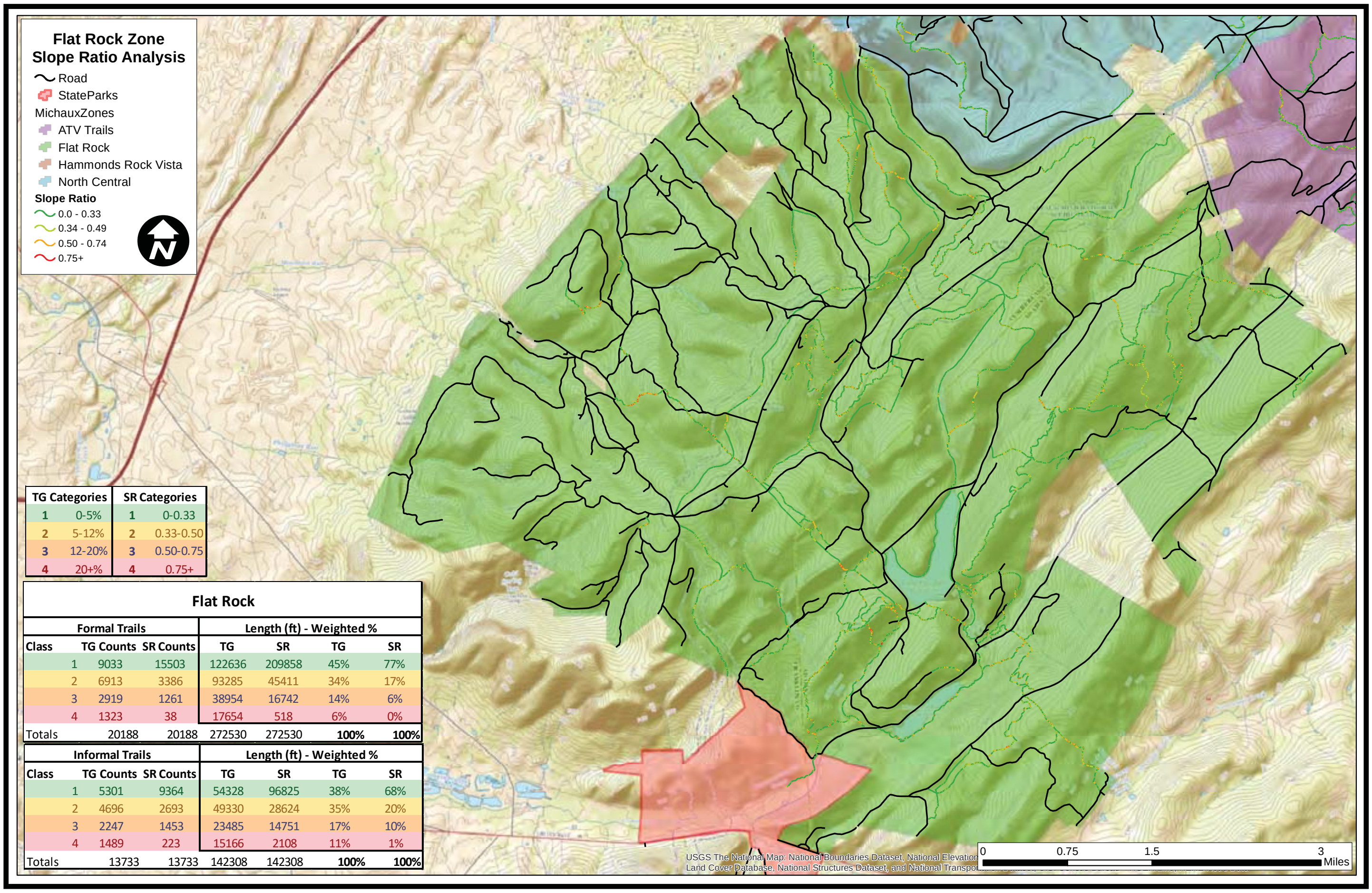
Formal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	9033	15503	122636	209858	45%	77%
2	6913	3386	93285	45411	34%	17%
3	2919	1261	38954	16742	14%	6%
4	1323	38	17654	518	6%	0%
Totals	20188	20188	272530	272530	100%	100%

Informal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	5301	9364	54328	96825	38%	68%
2	4696	2693	49330	28624	35%	20%
3	2247	1453	23485	14751	17%	10%
4	1489	223	15166	2108	11%	1%
Totals	13733	13733	142308	142308	100%	100%

Tread Grade Analysis

45% of the formal trail system and 38% of the informal trail system in the Flat Rock Zone have trail grades between 0 and 5%. 34% of the formal trail system and 35% of the informal trail system has trail grades between 5% and 12%. In the typical Michaux Forest soil conditions, especially in upslope areas, these trails can be generally considered to be durable. Trail segments with these sustainable grades are depicted in green (0-5%) and yellow (5-12%) in the map above.

14% of the formal trail system and 17% of the informal trail system have trail grades between 12% and 20%. These trails are depicted in orange on the map above. Trail grades in this range require significant water management to maintain a durable status that does not readily erode under recreational use. 6% of the formal trail system and 11% of the informal trail system have trail grades greater than 20%. These steep trail segments are depicted in red in the map above. Unless located on very rocky terrain, trails of this grade are rarely even maintainable.



TG Categories		SR Categories	
1	0-5%	1	0-0.33
2	5-12%	2	0.33-0.50
3	12-20%	3	0.50-0.75
4	20+%	4	0.75+

Flat Rock

Formal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	9033	15503	122636	209858	45%	77%
2	6913	3386	93285	45411	34%	17%
3	2919	1261	38954	16742	14%	6%
4	1323	38	17654	518	6%	0%
Totals	20188	20188	272530	272530	**100%**	**100%**

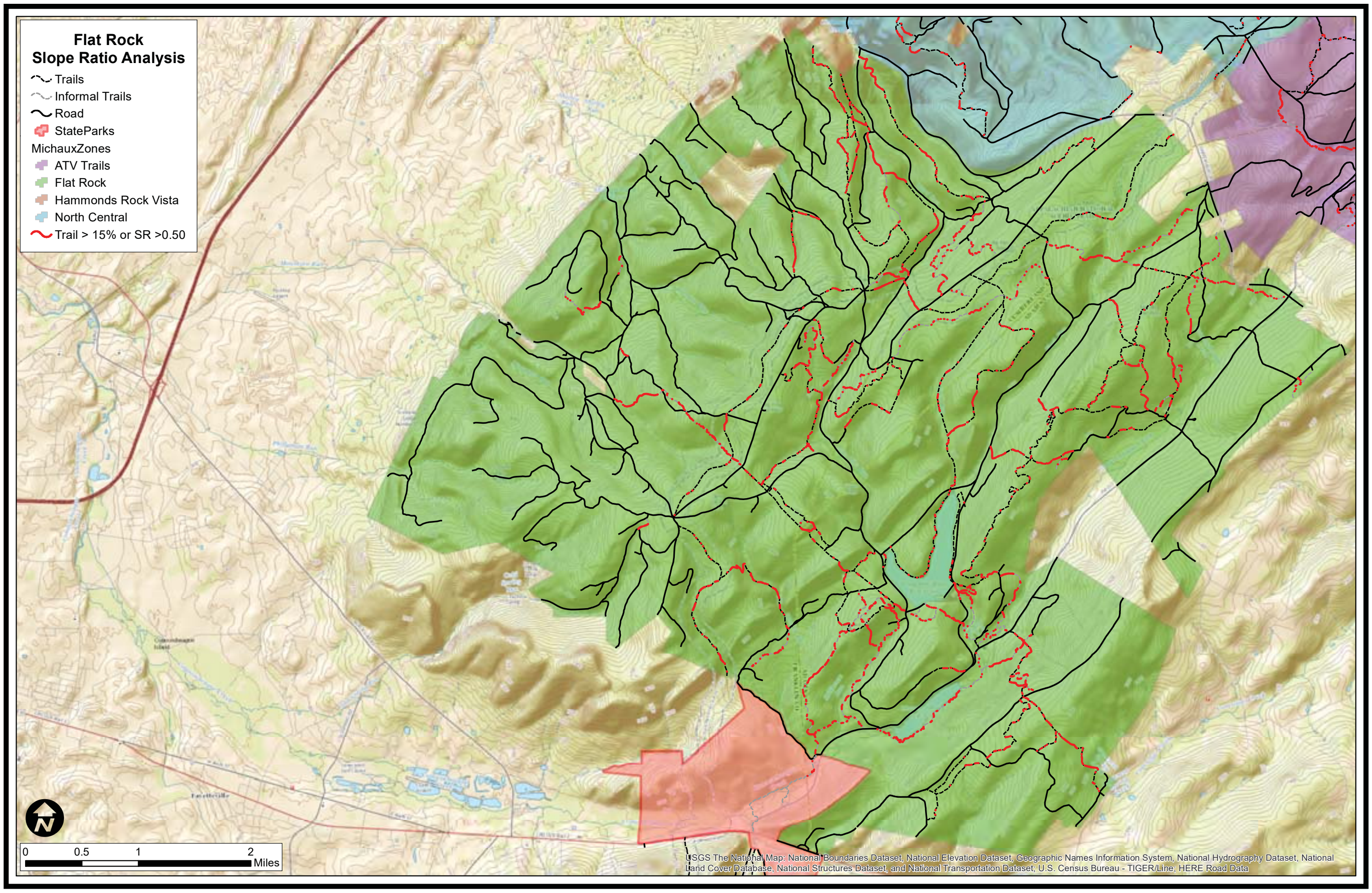
Informal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	5301	9364	54328	96825	38%	68%
2	4696	2693	49330	28624	35%	20%
3	2247	1453	23485	14751	17%	10%
4	1489	223	15166	2108	11%	1%
Totals	13733	13733	142308	142308	**100%**	**100%**

Slope Ratio Analysis

Durable trails are located across hillslopes with what is referred to as a contour alignment. Trails that readily erode are located, regardless of hillslope grade, at an angle that is closer to a fall line alignment. Trails with a steep alignment relative to the hillslope are very difficult to maintain effective water drainage. The “half rule” is a commonly accepted estimate of when a trail is located with a too steep a gradient in relation to the hillslope it is located. The maximum slope ratio for a trail that meets the “half rule” is 0.5.

77% of the formal trails and 68% of the informal trails in the Flat Rock Zone have slope ratios of 0 to 0.33. These areas are depicted in green on the map above. Trails falling in this zone typically do not provide water management challenges. 17% of the formal trail system and 20% of the informal trail system have slope ratios of 0.33 to 0.50. These segments are depicted in yellow on the map above. Water can be effectively managed on trails with this slope ratio range, but often maintenance in the form of diversions such as rolling grade dips or knicks are required.

6% of the formal trail system and 11% of the informal trail system have slope ratios greater than 0.50. These trail segments are represented in orange for trails with slope ratios of 0.50 to 0.75 and red for segments with slope ratios greater than 0.75. Water cannot be effectively managed in these locations without very significant inputs.



Sustainability Benchmarks

Combining locations that either have trail gradients greater than 15% or slope ratios greater than 0.50, a large portion of the Flat Rock Zone trail system requires attention. These trail segments are depicted in red on the map above. Relative to trail grade and an exhibited maximum sustainable grade of approximately 15% in the Michaux under the current allowed types and levels of use, 20% of the formal trail system (10.32 miles) and 28% of the informal trail system (7.56 miles) in the Flat Rock Zone have trail grades that currently or very likely in the future will require relatively tread hardening, drainage management or relocation.

With respect to the slope ratio or alignment of the trail on the hillslope, 6% (8.77 miles) of the formal trail system and 11% (5.4 miles) of the informal trail system will likely require new, additional, or effective water management maintenance. 3.09 miles of the formal trail system and 2.97 miles of the informal trail system would require relocation due to their alignment.

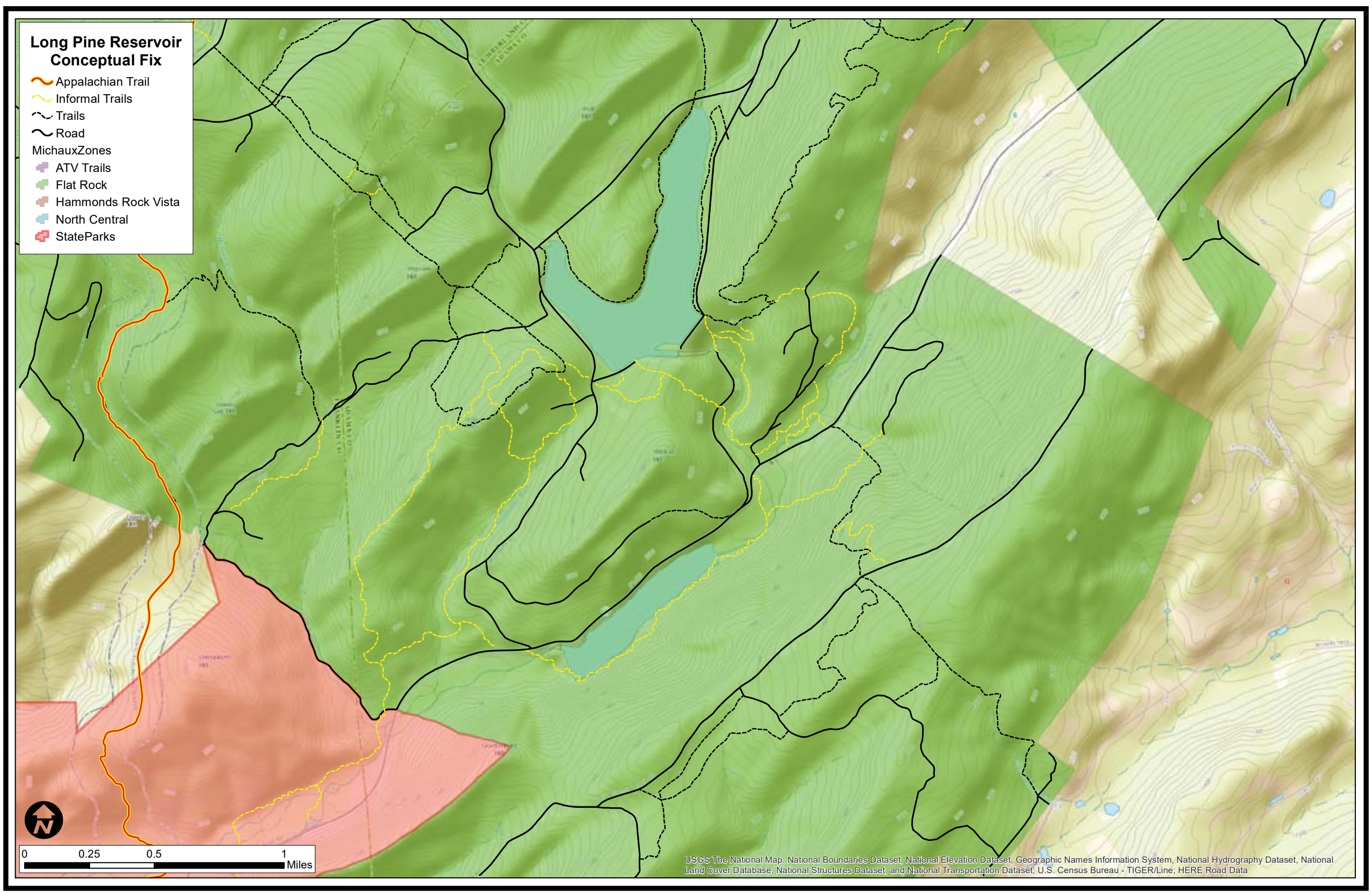
In some fall-line oriented trails on relatively steep slopes, both trail grade and slope ratio are problematic (meaning the percentages and mileages presented above are not additive), and thus become highest priority candidates for trail closure and relocation. Other high priority candidates for trail relocation are trails with high slope-ratio values and the potential for heavy use or proximity to water resources, such as many of the routes near the south end of Long Pine Run Reservoir.

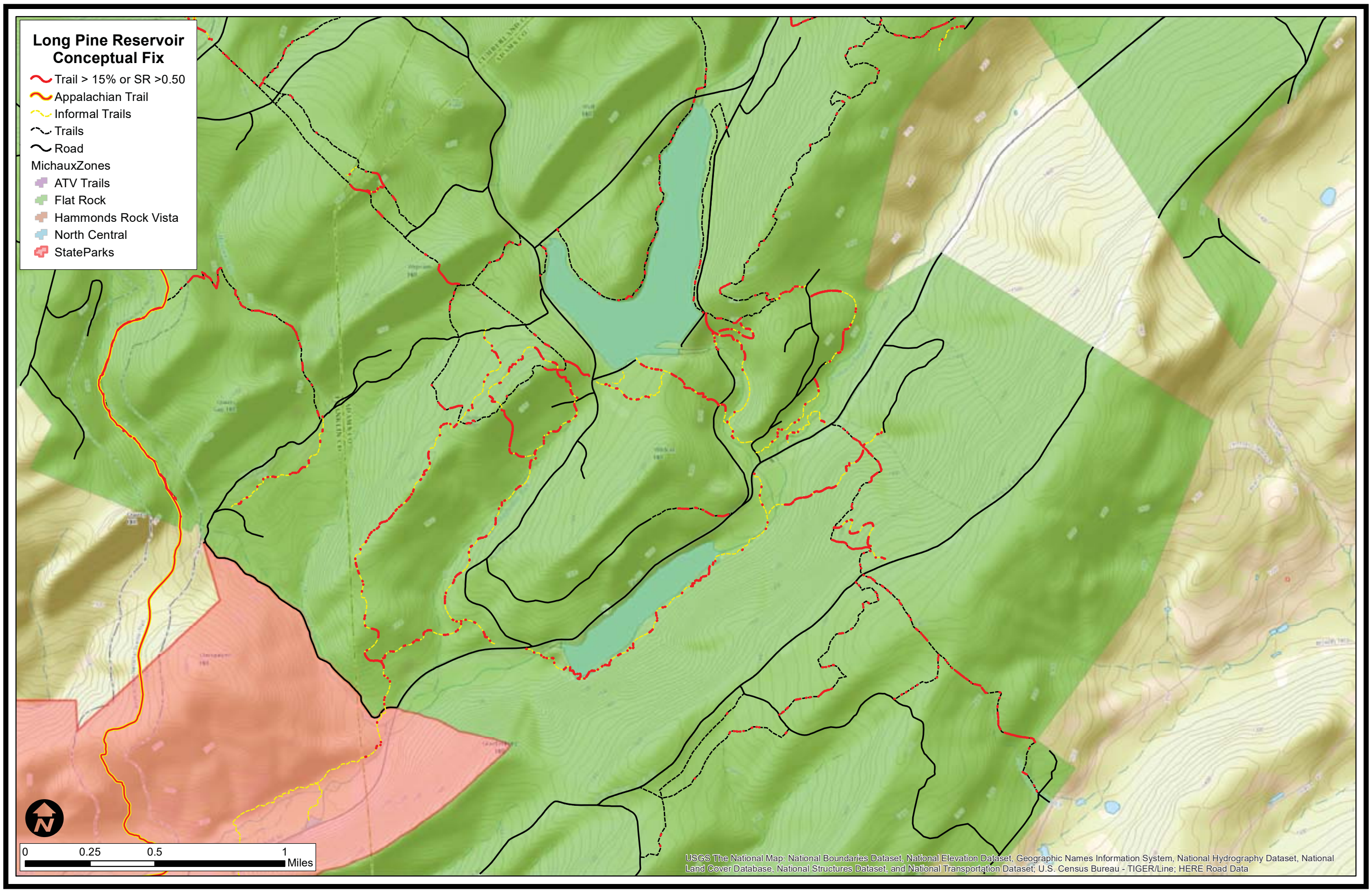
Long Pine Run Reservoir Conceptual Trail Redevelopment

The Long Pine Run Reservoir area in the Flat Rock Zone is a hub for recreational activity. It is easily accessed of HWY 30, has substantial parking next to the reservoir and along forest roads, and offers lake- and forest-based recreation. The area's trail system, utilizing old management corridors and informally developed routes up the area's hills, is rife with physical and social sustainability issues.

The trail system is challenging to navigate and does not provide well-developed options for the more casual forest visitor that frequents this type of area. Managerially, an improved trail system could function as an anchor for visitation and thus provide a location for targeted outreach for ranger and law enforcement staff. A higher density of use in this type of area should result in reduced density of use and higher quality experience in more backcountry locations.

The following is a narrative description of, and plan for recommended actions to redevelop the trail system near the Long Pine Reservoir to improve system function and improve social, managerial and physical conditions present on the trails.



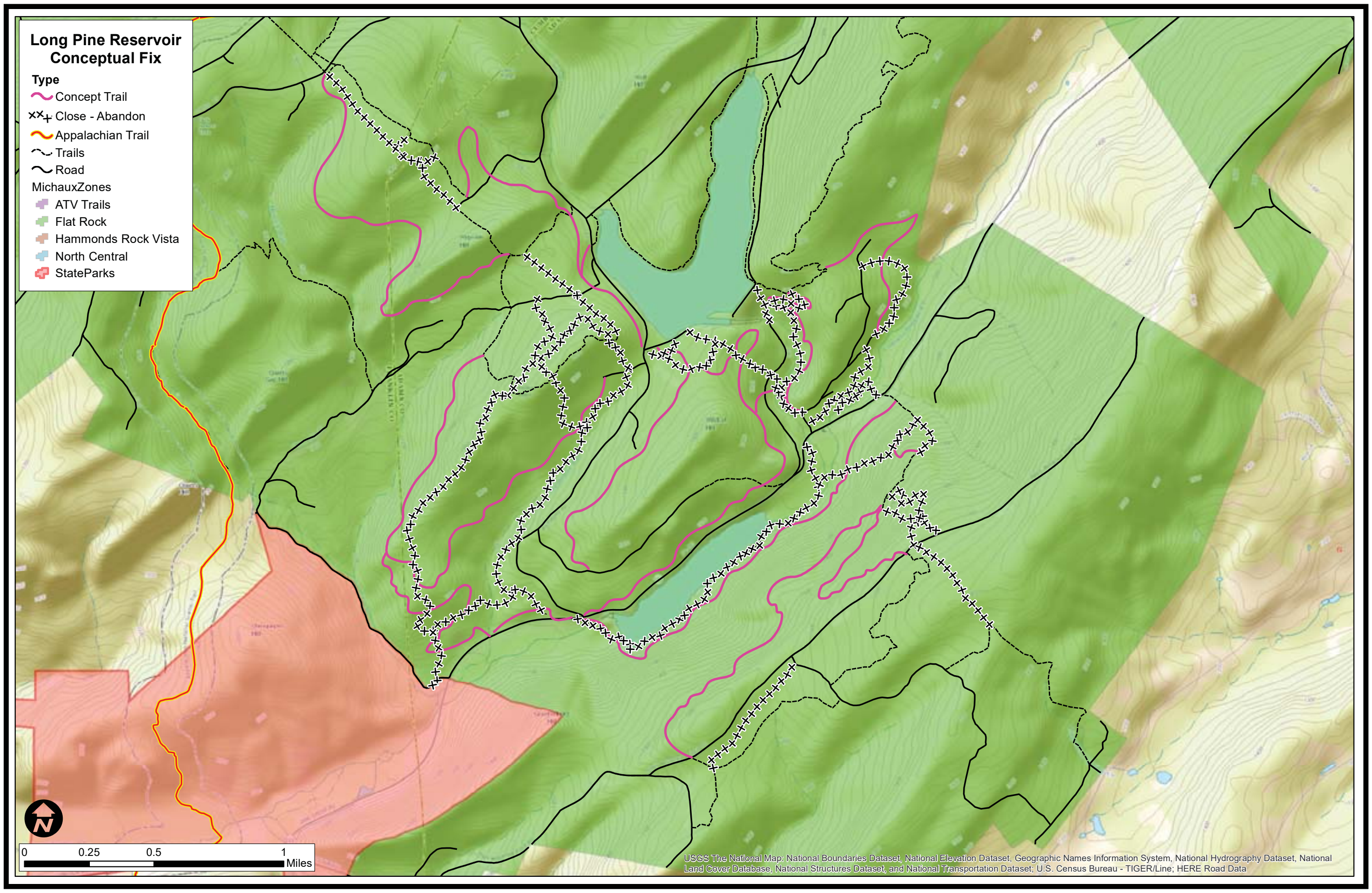


Long Pine Run Reservoir- Current Issues

The trail system in this area is comprised of nearly 50% (13.1 miles) of informally-developed trails. Several of these trails have been created as parallel but not unique experiences (i.e. Wigwam Trail and the parallel utility corridor trail), and are trending toward significant erosion impacts. However, the circuitry of the current trails point toward a need to provide additional trail routing options in the area.

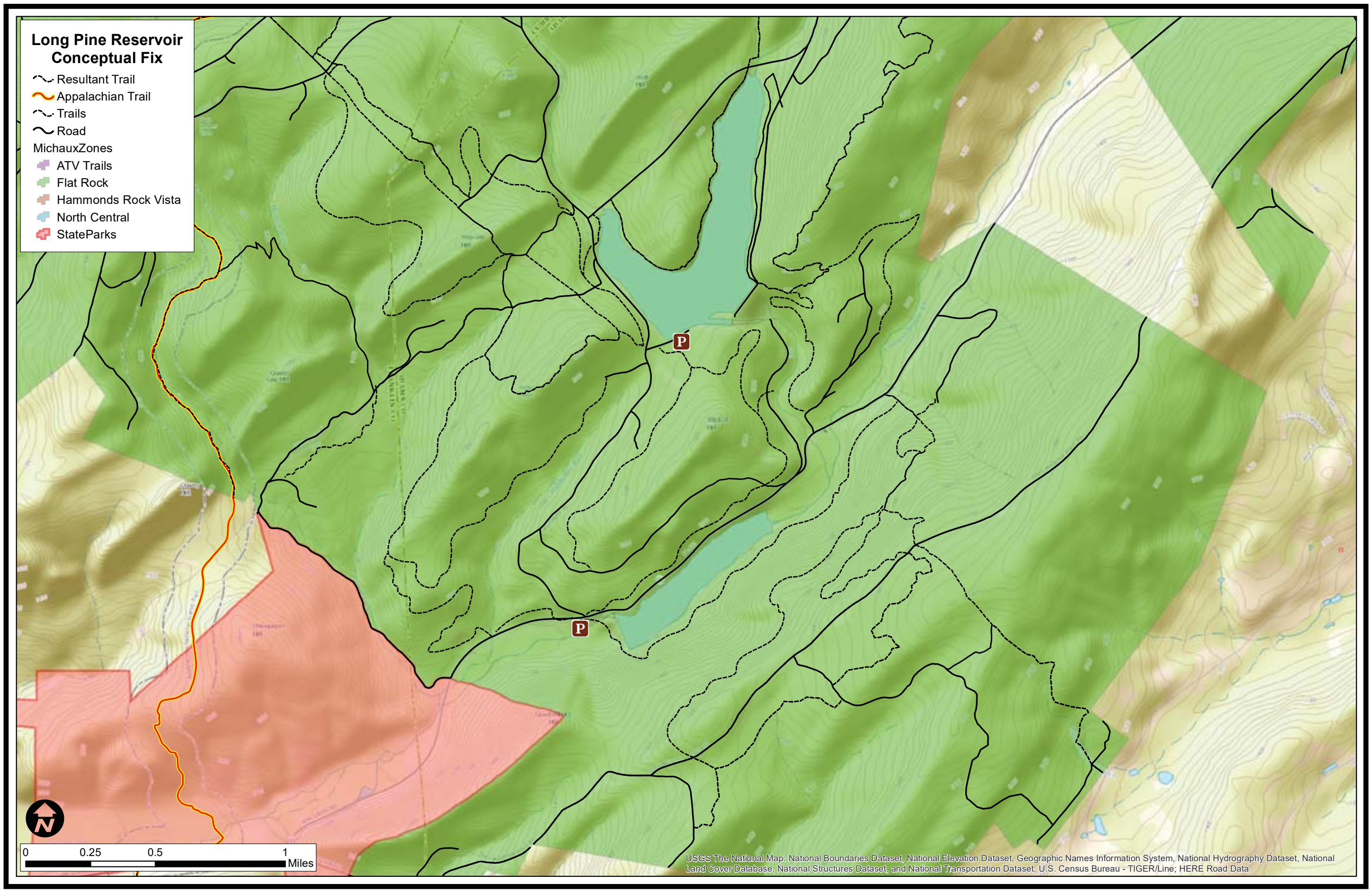
The hill-circumnavigating and shoreline trails of both the reservoir and southern wetland restoration area are sprinkled with trail segments that exceed a 15% trail grade or the “half rule” (slope ratio of 0.50). Removing these unsustainable, fall line-aligned and overly steep trails will provide long-term reductions in maintenance cost and natural resource damage and improve trail opportunities and experiences.

Removing these segments and replacing them with beginner-friendly, short to medium distance, looping trail options can vastly improve the social and managerial sustainability of the Flat Rock Zone. Visitors that can easily navigate a trail system, provided with intuitive mapping and signage, have much higher levels of satisfaction with their outdoor experience and generally a higher interest in returning or donating their volunteer time and resources.



Long Pine Run Reservoir- Conceptual Redevelopment
Providing solutions to an informally developed trail system often involves the removal of significant elements of the existing trail system. In order to redevelop the Long Pine Run Reservoir trails area, much of the trail will have to be replaced. However, the resulting mix of trails will provide resource damage-mitigating beginner and intermediate-level trail opportunities. Swapping out fall-line aligned trails in favor of lower maintenance, constructed sidehill trails on different levels of the regional topography that provide appropriately challenging and engaging trail-based recreation will satisfy forest visitors with a scope of opportunities.

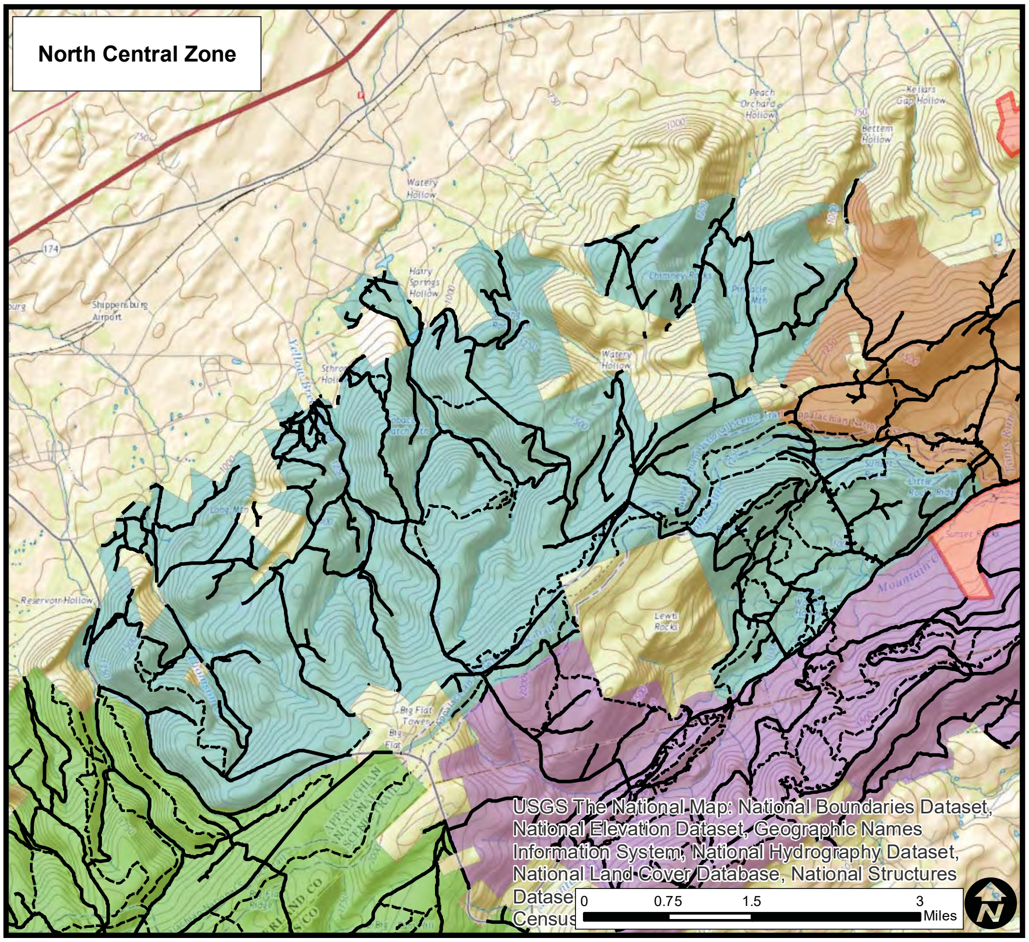
Per the above map, 13.2 miles of trail in this area would be closed and reclaimed to reduce long-term natural resource damage and maintenance needs, which will be replaced with 17.2 miles of trail that would require low-level ongoing maintenance to protect natural resources and minimize erosion/deposition impacts.



Long Pine Run Reservoir- Resulting Trail System

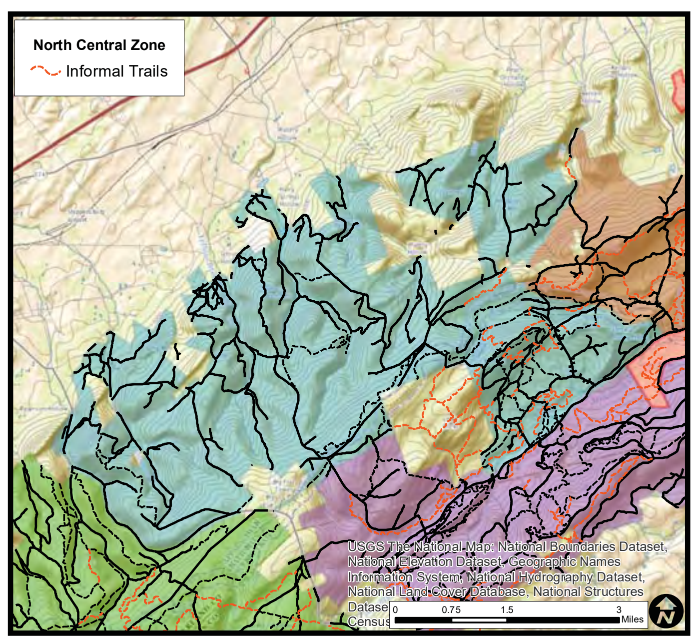
The conceptualized redesign of the trail system incorporates the natural features in the area that have been selected for exploration by visitors and the access points/trailheads that have been developed by the Forest. From it's current mileage of 28.2 miles, the trail system would increase to 30.7 miles. The system would provide this mileage in the form of easily navigable loops, augmented with signage placed at each intersection and other navigational aids (trailhead kiosks, maps, latitude/longitude, emergency management point, etc.), as needed.

North Central Zone



General Description

The North Central Zone of approximately 13,000 acres has the lowest density and total mileage of shared-use, non-motorized trails in the northern portion of the Forest due to the lack of parking/ access infrastructure, numerous inholdings, and a dense network of administrative and open forest roads.



22.3 miles of formal trail and 10.3 miles of informal trail were catalogued in the assessment. 68% of the trails in this zone are part of the formal trail system and 32% are informal trails. This equates to a trail density of 9.02 feet/acre of formal trail, 4.19 feet/

acre of informal trail, and 13.21 trail feet/acre of for the total trail network. This is much lower than the overall trail density of 21.73 feet/acre.

Along Ridge Road and on the eastern portion of this zone there is significant recreational pressure with proximity and access to the Appalachian National Scenic Trail, and a dense network of informal and formal trails and forest roads above the “mud flats” parking lot along Route 233 and the Tumbling Run Preserve. Dead Woman Hollow, Blueberry, 3-Mile trail and trails along Woodrow road are popular with more advanced users.

Trail Durability

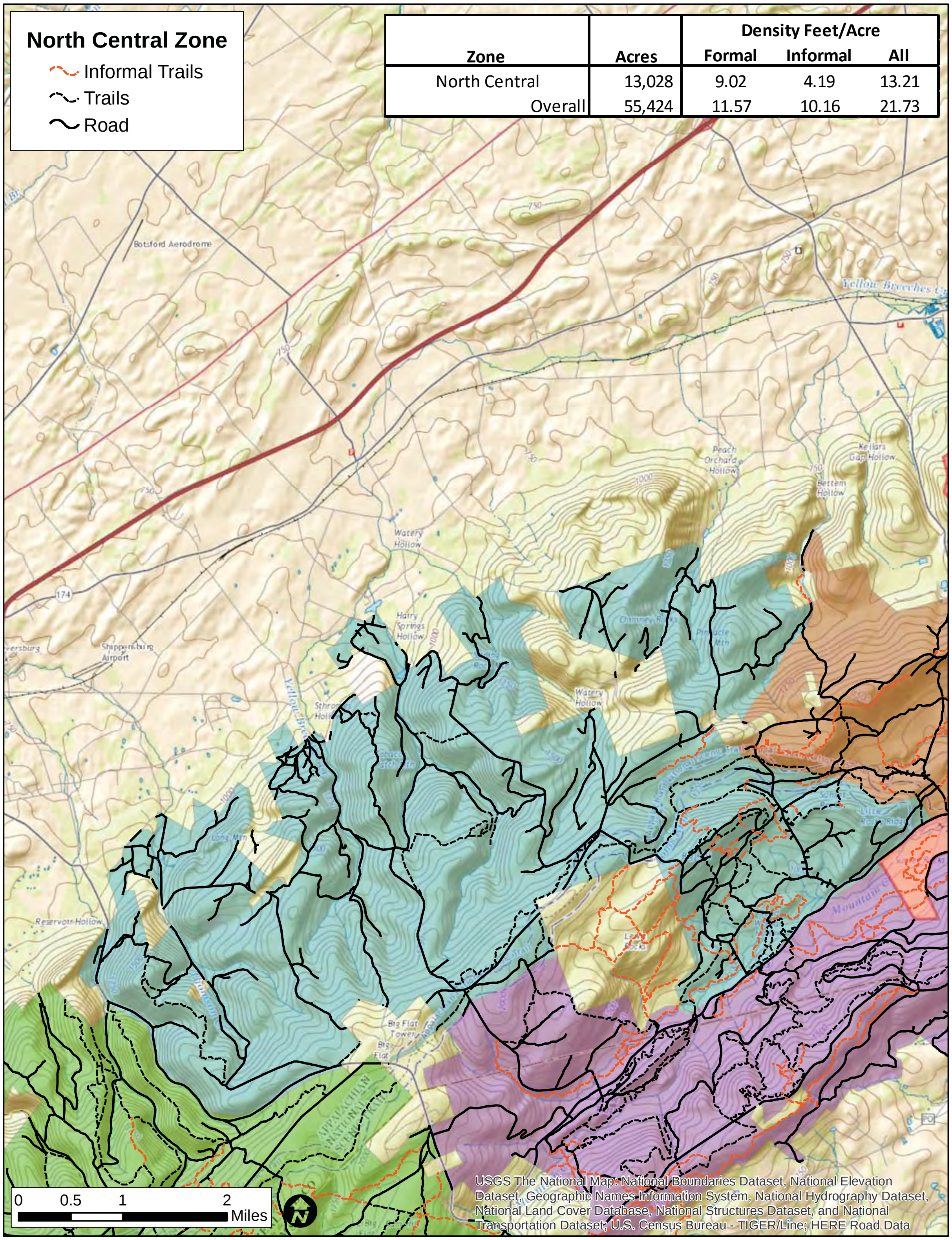
Soils on the southern facing aspects and low bottom areas are less rocky and will require deliberate design and management of users and water to ensure sustainability. It is recommended that trail grades be lower than 10% with constant reversals on these soils to ensure durability for a diverse set of uses.

Trail Conditions

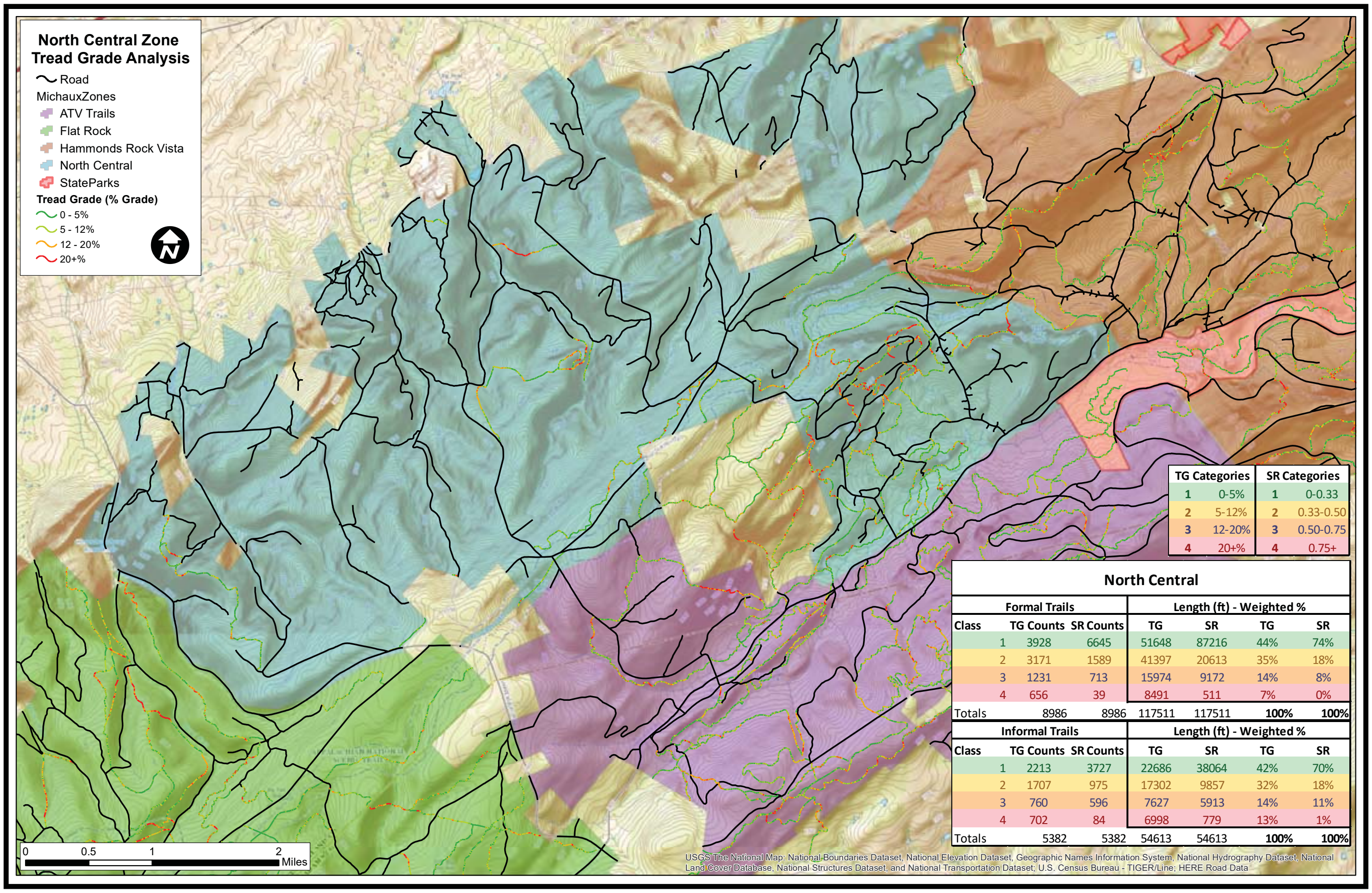
A very dense network of trail centered on the southern facing slopes and flat bottoms from Woodrow Road to Michaux Road is known as the “black hole”. Trails in this area often utilize old extraction routes (charcoal furnace era woods roads) and lack design and construction for the most part. Several trails include drops and features indicative of mountain bike use; “Happy Hour” and trails descending from Rattle Snake are good examples of such development.

Water Management Capacity

Significant work is needed in this zone to redevelop the trail system to better manage water and users and provide a diverse set of experiences for hikers, mountain bikers, trail runners and others. A lower density trail system that provides for these uses and connects in to the larger trail system to provide for special event and day-to-day recreation is possible but will take significant resource to plan and develop.



Zone	Acres	Density Feet/Acre Formal	Density Feet/Acre Informal	Density Feet/Acre All
North Central	13,028	9.02	4.19	13.21
Overall	55,424	11.57	10.16	21.73



TG Categories		SR Categories	
1	0-5%	1	0-0.33
2	5-12%	2	0.33-0.50
3	12-20%	3	0.50-0.75
4	20+%	4	0.75+

North Central

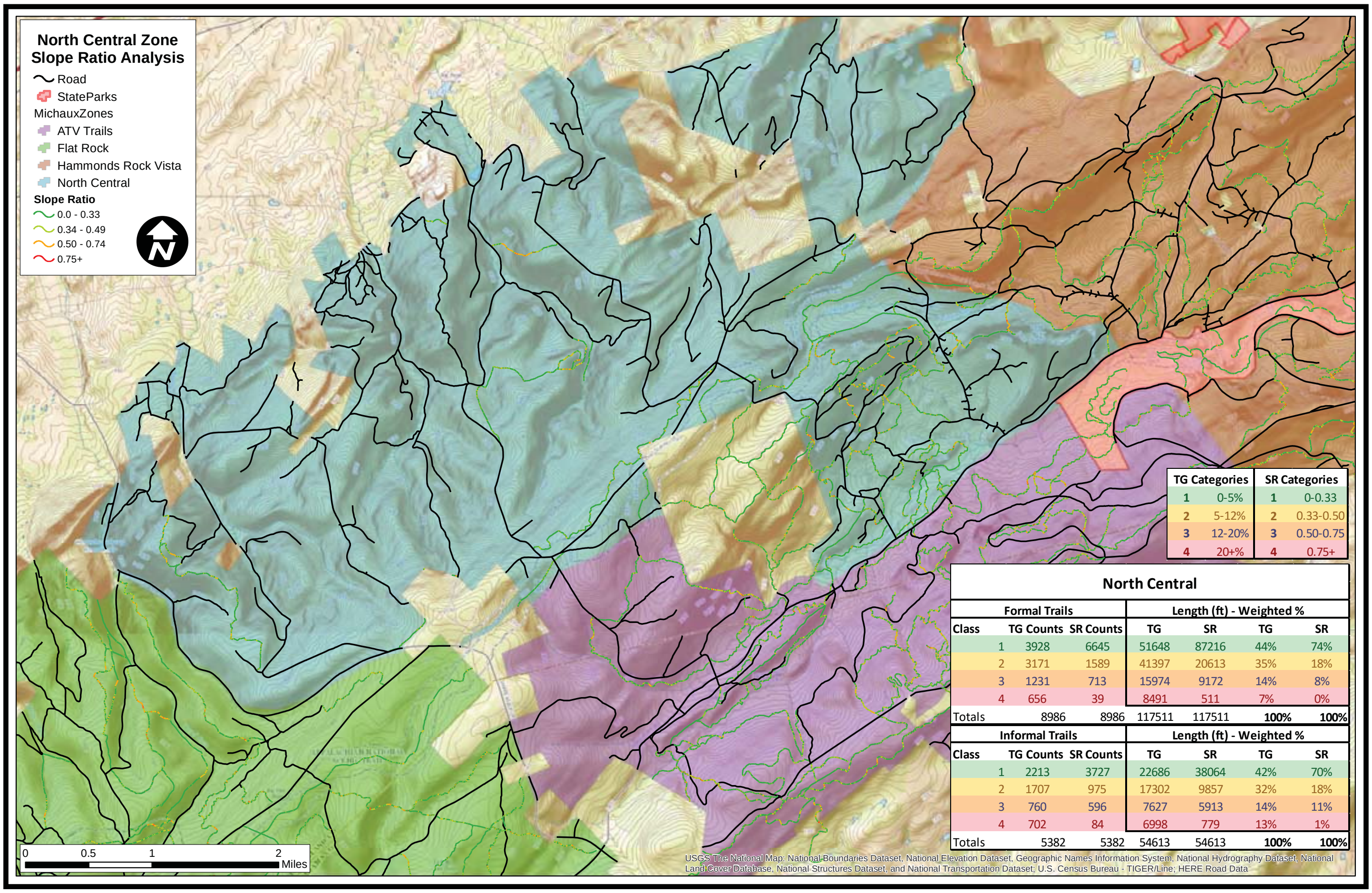
Formal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	3928	6645	51648	87216	44%	74%
2	3171	1589	41397	20613	35%	18%
3	1231	713	15974	9172	14%	8%
4	656	39	8491	511	7%	0%
Totals	8986	8986	117511	117511	**100%**	**100%**

Informal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	2213	3727	22686	38064	42%	70%
2	1707	975	17302	9857	32%	18%
3	760	596	7627	5913	14%	11%
4	702	84	6998	779	13%	1%
Totals	5382	5382	54613	54613	**100%**	**100%**

Trail Grade Analysis

44% of the formal trail system and 42% of the informal trail system in the North Central Zone have trail grades between 0 and 5%. 35% of the formal trail system and 32% of the informal trail system have trail grades between 5% and 12%. In the typical Michaux Forest soil conditions, especially in upslope areas, these trails can be generally considered to be durable. Trail segments with these sustainable grades are depicted in green (0-5%) and yellow (5-12%) in the map above.

14% of the formal trail system and 14% of the informal trail system have trail grades between 12% and 20%. These trails are depicted in orange on the map above. Trail grades in this range require significant water management to maintain a durable status that does not readily erode under recreational use. 7% of the formal trail system and 13% of the informal trail system have trail grades greater than 20%. These steep trail segments are depicted in red in the map above. Unless located on very rocky terrain, trails of this grade are rarely even maintainable.



TG Categories		SR Categories	
1	0-5%	1	0-0.33
2	5-12%	2	0.33-0.50
3	12-20%	3	0.50-0.75
4	20+%	4	0.75+

North Central

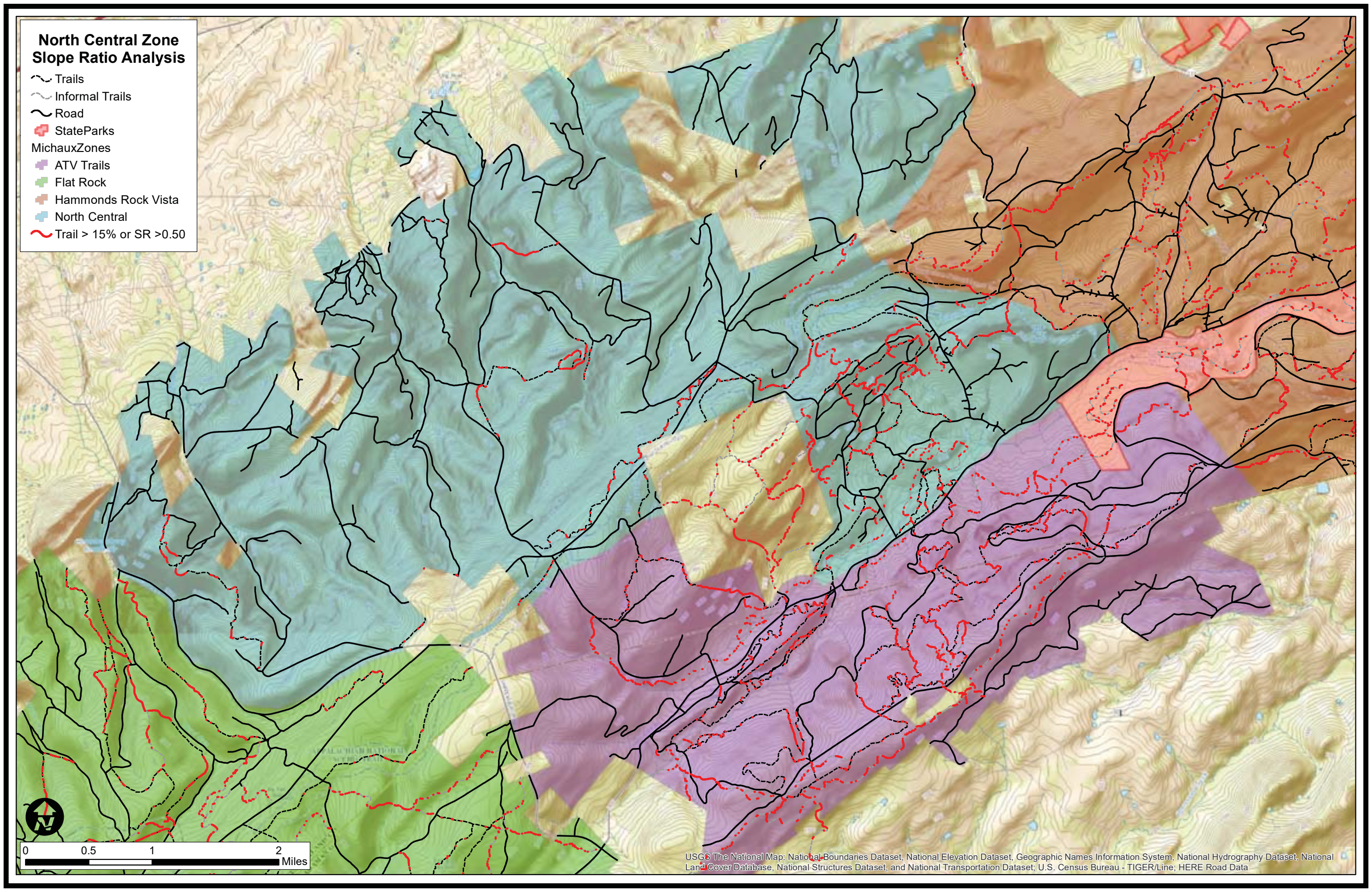
Formal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	3928	6645	51648	87216	44%	74%
2	3171	1589	41397	20613	35%	18%
3	1231	713	15974	9172	14%	8%
4	656	39	8491	511	7%	0%
Totals	8986	8986	117511	117511	**100%**	**100%**
Informal Trails			**Length (ft) - Weighted %**			
Class	**TG Counts**	**SR Counts**	**TG**	**SR**	**TG**	**SR**
1	2213	3727	22686	38064	42%	70%
2	1707	975	17302	9857	32%	18%
3	760	596	7627	5913	14%	11%
4	702	84	6998	779	13%	1%
Totals	5382	5382	54613	54613	**100%**	**100%**

Slope Ratio Analysis

Durable trails are located across hillslopes with what is referred to as a contour alignment. Trails that readily erode are located, regardless of hillslope grade, at an angle that is closer to a fall line alignment. Trails with a steep alignment relative to the hillslope are very difficult to maintain effective water drainage. The "half rule" is a commonly accepted estimate of when a trail is located with a too steep a gradient in relation to the hillslope it is located. The maximum slope ratio for a trail that meets the "half rule" is 0.5.

74% of the formal trails and 70% of the informal trails in the Flat Rock Zone have slope ratios of 0 to 0.33. These areas are depicted in green on the map above. Trails falling in this zone typically do not provide water management challenges. 18% of the formal trail system and 18% of the informal trail system have slope ratios of 0.33 to 0.50. These segments are depicted in yellow on the map above. Water can be effectively managed on trails with this slope ratio range, but often maintenance in the form of diversions such as rolling grade dips or knicks are required.

8% of the formal trail system and 12% of the informal trail system have slope ratios greater than 0.50. These trail segments are represented in orange for trails with slope ratios of 0.50 to 0.75 and red for segments with slope ratios greater than 0.75. Water cannot be effectively managed in these locations without very significant inputs.



Sustainability Benchmarks

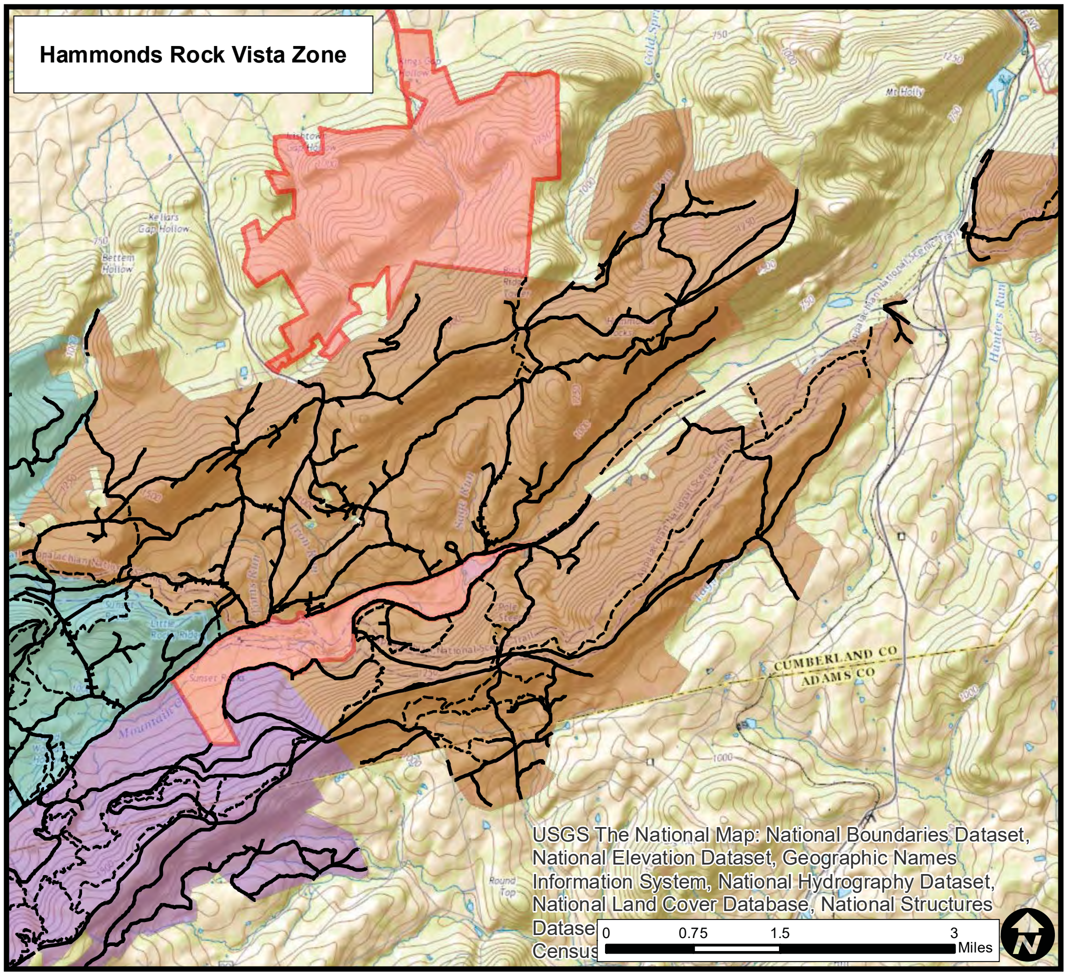
Combining locations that either have trail gradients greater than 15% or slope ratios greater than 0.50, a large portion of the North Central Zone trail system requires attention. These trail segments are depicted in red on the map above.

Relative to trail grade and an exhibited maximum sustainable grade of approximately 15% in the Michaux under the current allowed types and levels of use, 21% of the formal trail system (4.68 miles) and 27% of the informal trail system (2.78 miles) in the North Central Zone have trail grades that currently or very likely in the future will require tread hardening, drainage management or relocation.

With respect to the slope ratio or the alignment of the trail on the hillslope, 18% (4.01 miles) of the formal trail system and 18% (1.85 miles) of the informal trail system will likely require new, additional, or effective water management maintenance. No miles of the formal trail system and 1% (0.10 miles) of the informal trail system would require relocation due to their alignment to local topography.

In some fall-line oriented trails on relatively steep slopes, both trail grade and slope ratio are problematic (meaning the percentages and mileages presented above are not additive), and thus become highest priority candidates for trail closure and relocation. Other high priority candidates for trail relocation are trails with high slope-ratio values and the potential for heavy use or proximity to water resources, such the main shared-use non-motorized arterial trails such as Blueberry, and Sunset.

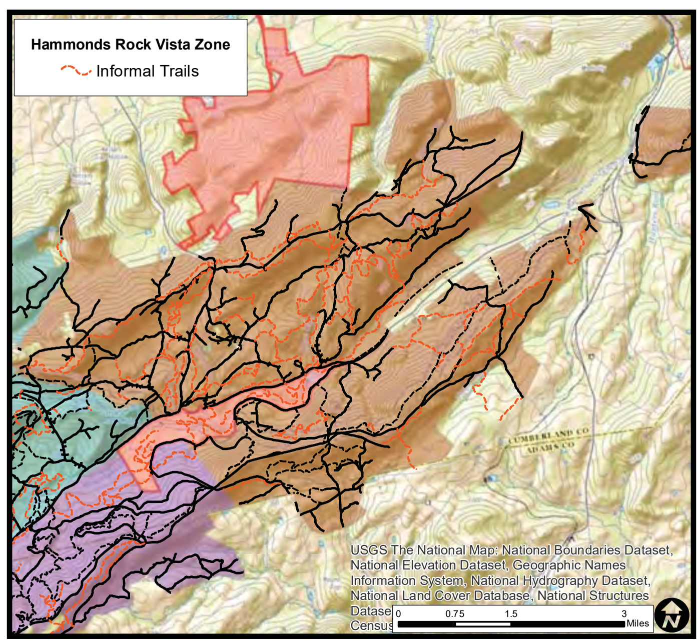
Hammonds Rock Vista Zone



General Description

The Hammonds Rock Vista Zone of approximately 13,750 acres has the largest total mileage of informal, non-motorized trails in the northern portion of the Forest. 20.5 miles of formal trail, consisting primarily of the foot traffic-only Appalachian and Buck Ridge Trails, and 50.5 miles of informal trail were catalogued in the assessment. 29% of the trails in this zone are part of the formal trail system and 71% are informal trails.

This equates to a trail density of 7.86 feet/acre of formal trail, 18.38 feet/acre of informal trail, and 27.24 trail feet/acre of for the total trail network.



This is much higher than the overall trail density of 21.73 feet/acre.

Development of this trail system focuses on intermediate to advanced mountain bike use made difficult by steep trail grades and by incorporating rock features into the tread. Trail development links camp/cabin access roads and the network of forest roads to provide a wide variety of options for recreational outing routes, lengths and opportunities. Navigation is extremely difficult even for seasoned users.

Trail Durability

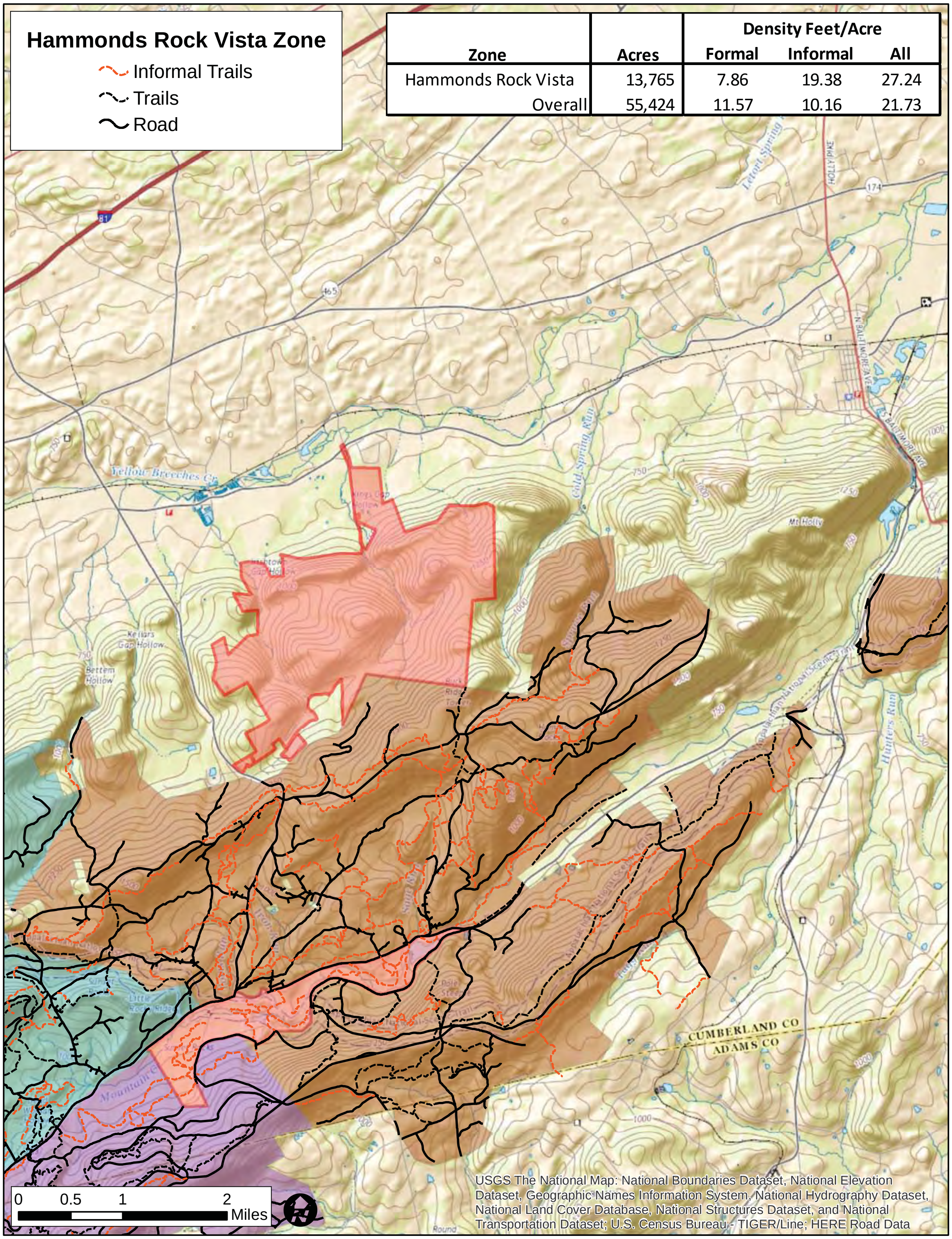
Much of the trail system in this zone is not designed in a traditional sense, rather it was created opportunistically, individually and sporadically in an ad-hoc fashion over the past few decades. As such trail grades and alignment to the topography are often outside of sustainable specifications. When trails begin to deteriorate, there is evidence that they fall out of favor, are abandoned, and replaced in the general area with a similarly designed route.

Trail Conditions

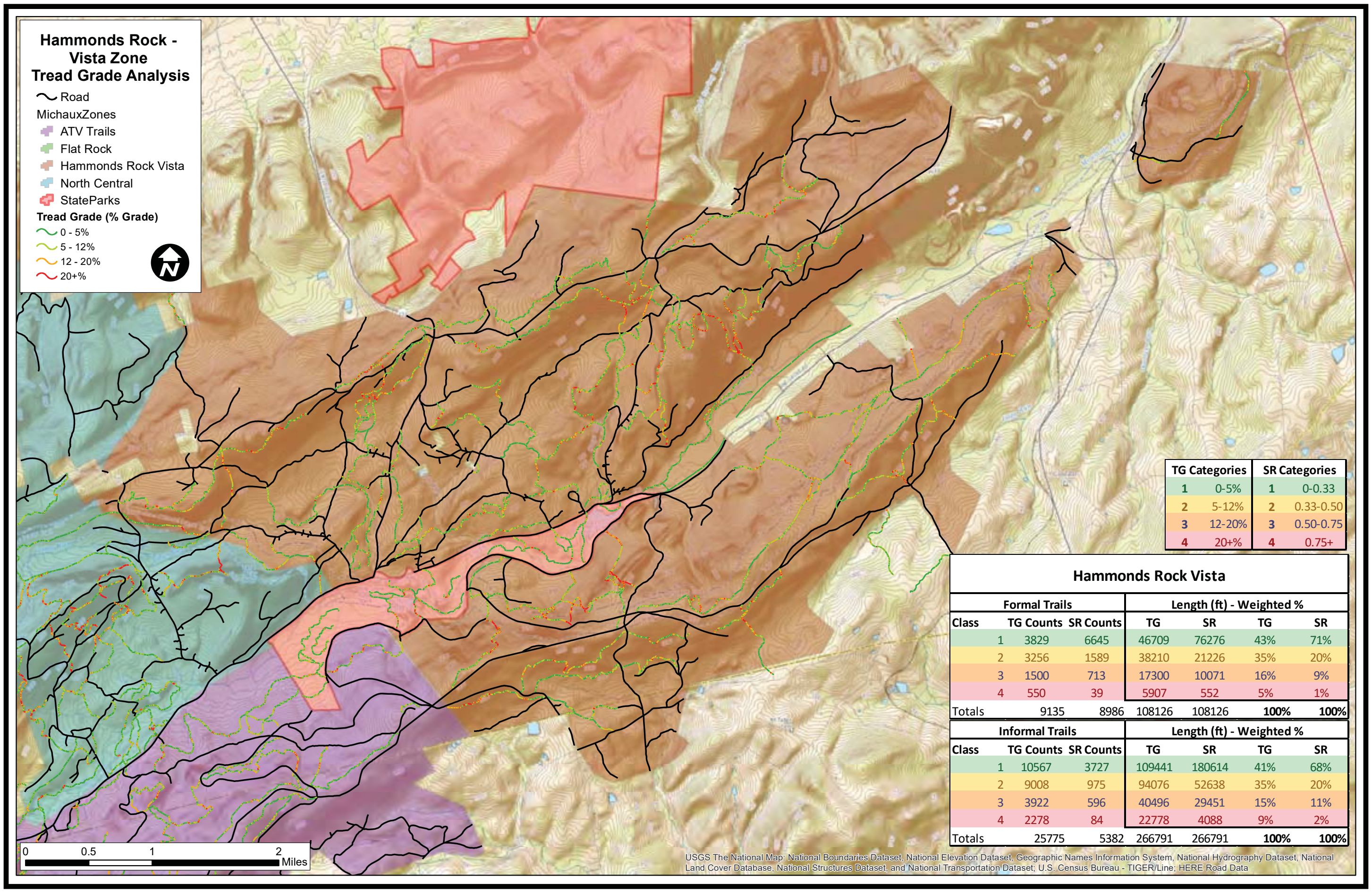
Trails have been developed at varying levels of quality; some are created by clearing corridor and “burning” the trail in with use, others show signs of trail tread development coupled with placement and removal of rocks and soil to provide a more lasting and defined trail tread.

Water Management Capacity

In higher elevation locations, the trails have more natural water management capacity due to rocky substrate and smaller watershed catchment areas. In cupland locations near the Pine Grove Furnace valley, soils are less rocky and terrain is flatter, allowing seasonally muddy conditions. There is little or no evidence of effective water management attempts in the Forest trail system. Instead, improperly constructed waterbars, installed as post-event mitigation, abound.



Zone	Acres	Density Feet/Acre Formal	Informal	All
Hammonds Rock Vista	13,765	7.86	19.38	27.24
Overall	55,424	11.57	10.16	21.73



TG Categories		SR Categories	
1	0-5%	1	0-0.33
2	5-12%	2	0.33-0.50
3	12-20%	3	0.50-0.75
4	20+%	4	0.75+

Hammonds Rock Vista

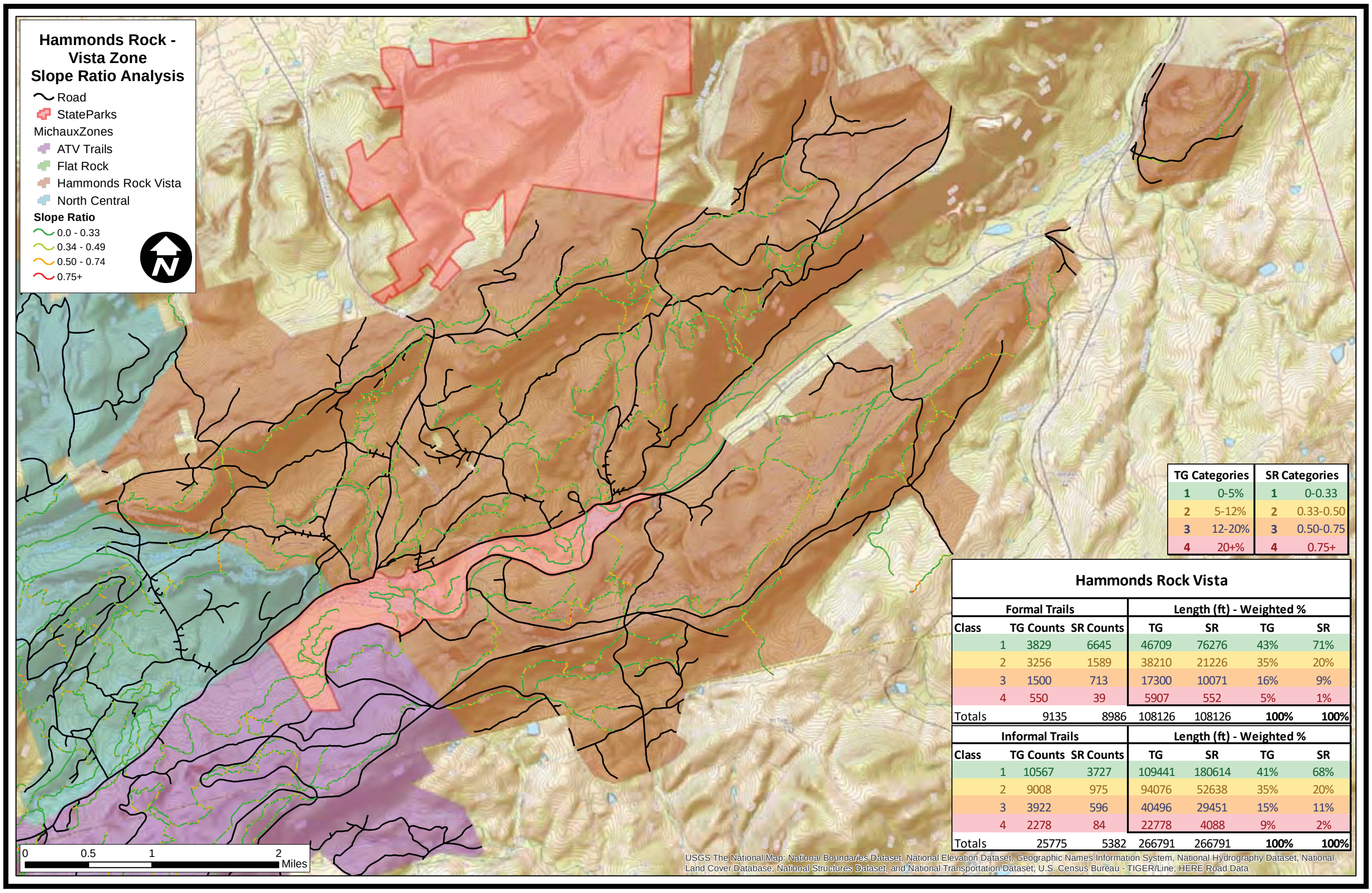
Formal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	3829	6645	46709	76276	43%	71%
2	3256	1589	38210	21226	35%	20%
3	1500	713	17300	10071	16%	9%
4	550	39	5907	552	5%	1%
Totals	9135	8986	108126	108126	**100%**	**100%**

Informal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	10567	3727	109441	180614	41%	68%
2	9008	975	94076	52638	35%	20%
3	3922	596	40496	29451	15%	11%
4	2278	84	22778	4088	9%	2%
Totals	25775	5382	266791	266791	**100%**	**100%**

Tread Grade Analysis

43% of the formal trail system and 41% of the informal trail system in the Hammonds Rock Vista Zone have trail grades between 0 and 5%. 35% of the formal trail system and 35% of the informal trail system have trail grades between 5% and 12%. In the typical Michaux Forest soil conditions, especially in capland areas, these trails can be generally considered to be durable. Trail segments with these sustainable grades are depicted in green (0-5%) and yellow (5-12%) in the map above.

16% of the formal trail system and 15% of the informal trail system have trail grades between 12% and 20%. These trails are depicted in orange on the map above. Trail grades in this range require significant water management to maintain a durable status that does not readily erode under recreational use. 5% of the formal trail system and 9% of the informal trail system have trail grades greater than 20%. These steep trail segments are depicted in red in the map above. Unless located on very rocky terrain, trails of this grade are rarely even maintainable.



TG Categories		SR Categories	
1	0-5%	1	0-0.33
2	5-12%	2	0.33-0.50
3	12-20%	3	0.50-0.75
4	20+%	4	0.75+

Hammonds Rock Vista

Formal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	3829	6645	46709	76276	43%	71%
2	3256	1589	38210	21226	35%	20%
3	1500	713	17300	10071	16%	9%
4	550	39	5907	552	5%	1%
Totals	9135	8986	108126	108126	**100%**	**100%**

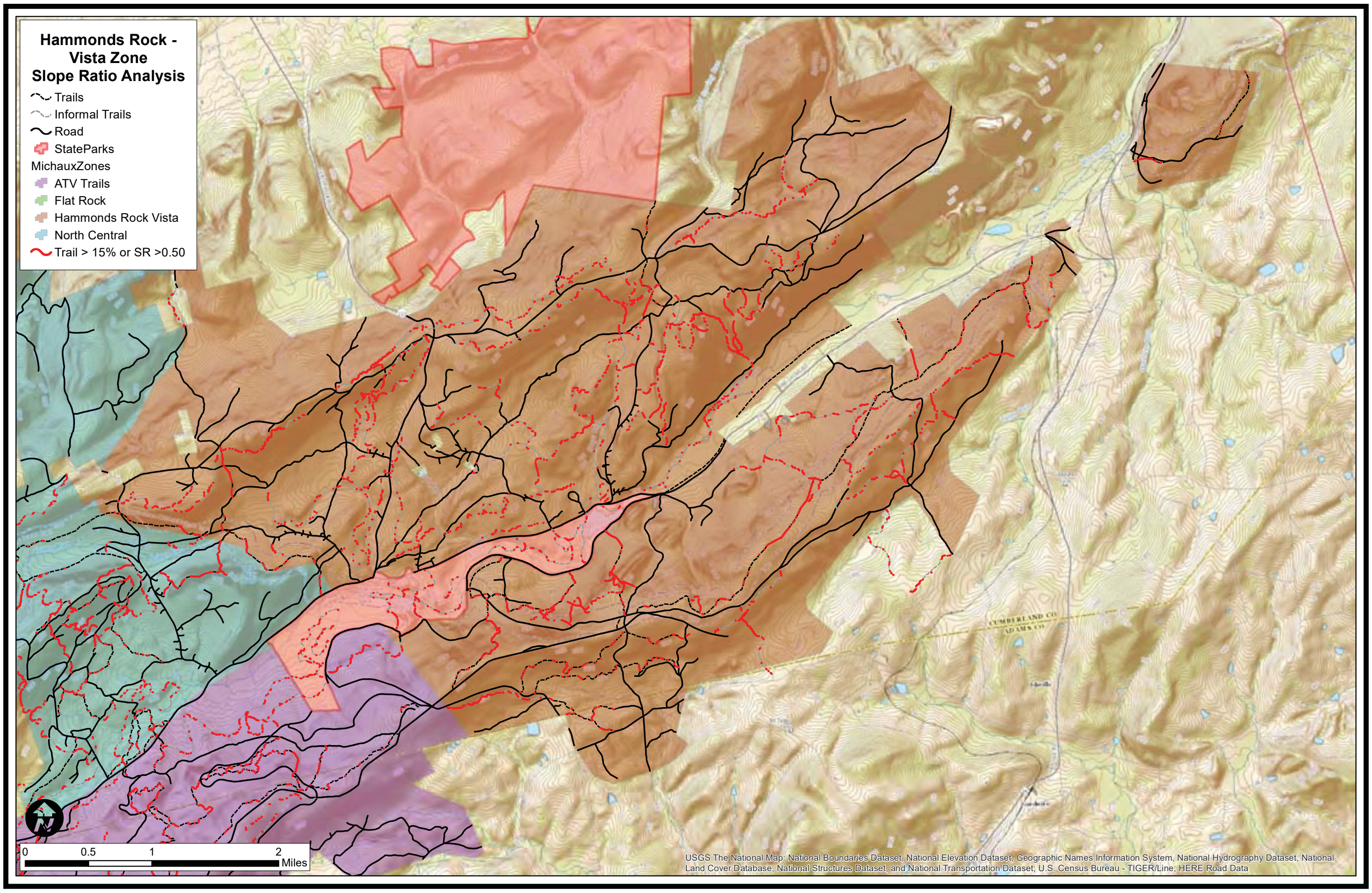
Informal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	10567	3727	109441	180614	41%	68%
2	9008	975	94076	52638	35%	20%
3	3922	596	40496	29451	15%	11%
4	2278	84	22778	4088	9%	2%
Totals	25775	5382	266791	266791	**100%**	**100%**

Slope Ratio Analysis

Durable trails are located across hillslopes with what is referred to as a contour alignment. Trails that readily erode have are located, regardless of hillslope grade, at an angle that is closer to a fall line alignment. Trails with a steep alignment relative to the hillslope are very difficult to maintain effective water drainage. The “half rule” is a commonly accepted estimate of when a trail is located with a too steep a gradient in relation to the hillslope it is located. The maximum slope ratio for a trail that meets the “half rule” is 0.5.

71% of the formal trails and 68% of the informal trails in the Hammonds Rock Vista Zone have slope ratios of 0 to 0.33. These areas are depicted in green on the map above. Trails falling in this zone typically do not provide water management challenges. 20% of the formal trail system and 20% of the informal trail system have slope ratios of 0.33 to 0.50. These segments are depicted in yellow on the map above. Water can be effectively managed on trails with this slope ratio range, but often maintenance in the form of diversions such as rolling grade dips or knicks are required.

10% of the formal trail system and 13% of the informal trail system have slope ratios greater than 0.50. These trail segments are represented in orange for trails with slope ratios of 0.50 to 0.75 and red for segments with slope ratios greater than 0.75. Water cannot be effectively managed in these locations without very significant inputs.



Sustainability Benchmarks

Combining locations that either have trail gradients greater than 15% or slope ratios greater than 0.50, a large portion of the Hammonds Rock Vista Zone trail system requires attention. These trail segments are depicted in red on the map above.

Relative to trail grade and an exhibited maximum sustainable grade of approximately 15% in the Michaux under the current allowed types and levels of use, 21% of the formal trail system (4.31 miles) and 24% of the informal trail system (12.12 miles) in the Hammonds Rock Vista Zone have trail grades that currently or very likely in the future will require tread hardening, drainage management or relocation.

With respect to the slope ratio or alignment of the trail on the hillslope, 9% (1.85 miles) of the formal trail system and 11% (5.56 miles) of the informal trail system will likely require new, additional, or effective water management maintenance. 1% (0.21miles) of the formal trail system and 2% (1.01 miles) of the informal trail system would require relocation due to their alignment to local topography.

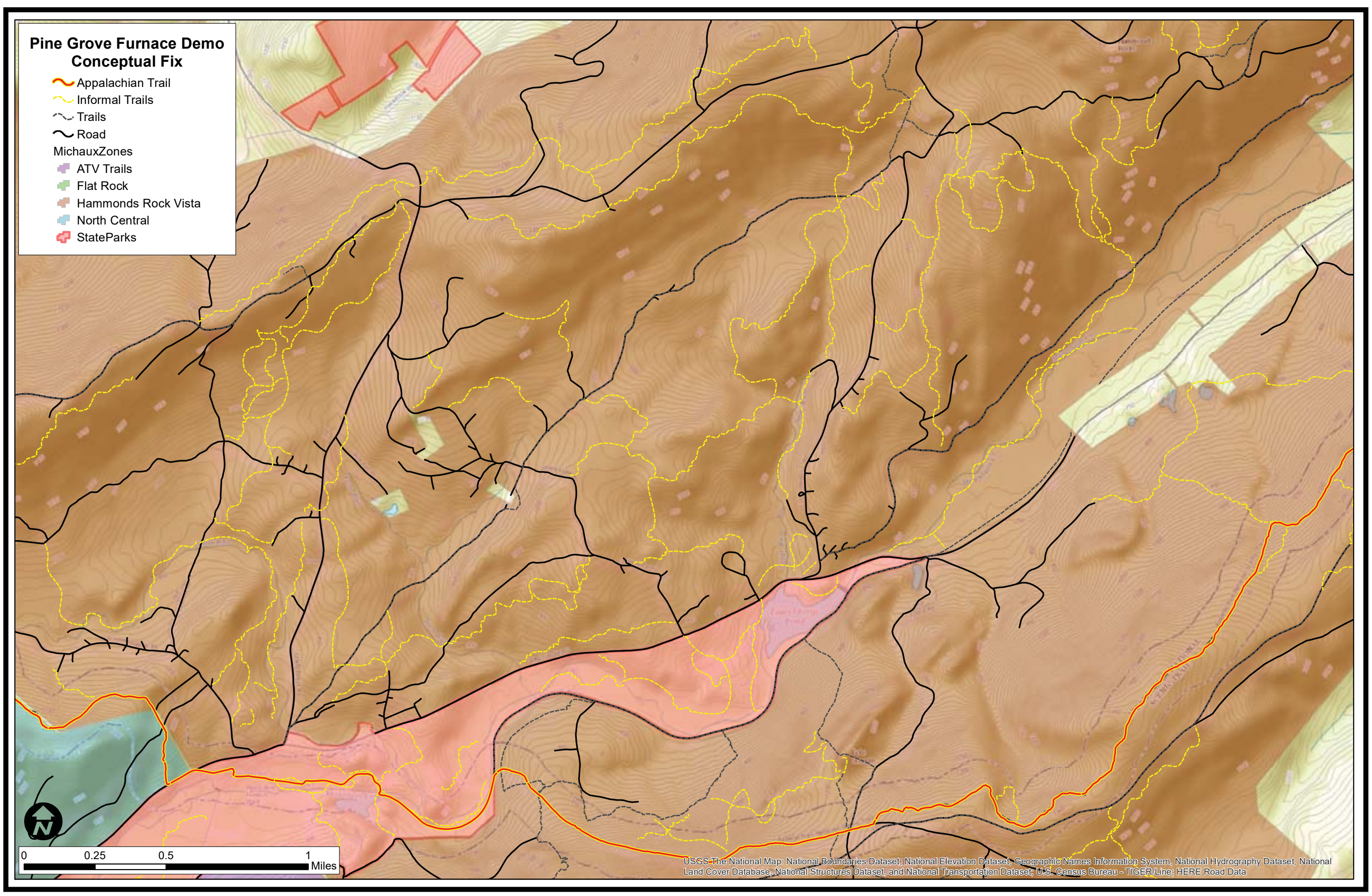
In some fall-line oriented trails on relatively steep slopes, both trail grade and slope ratio are problematic, and thus become highest priority candidates for trail closure and relocation. Other high priority candidates for trail relocation are trails with high slope-ratio values and the potential for heavy use or proximity to water resources, such the trails connecting the Forest to Pine Grove Furnace State Park (i.e informal trail to Bendersville lot, toward Pole Steeple/AT, and above Mountain Creek Haul Road .

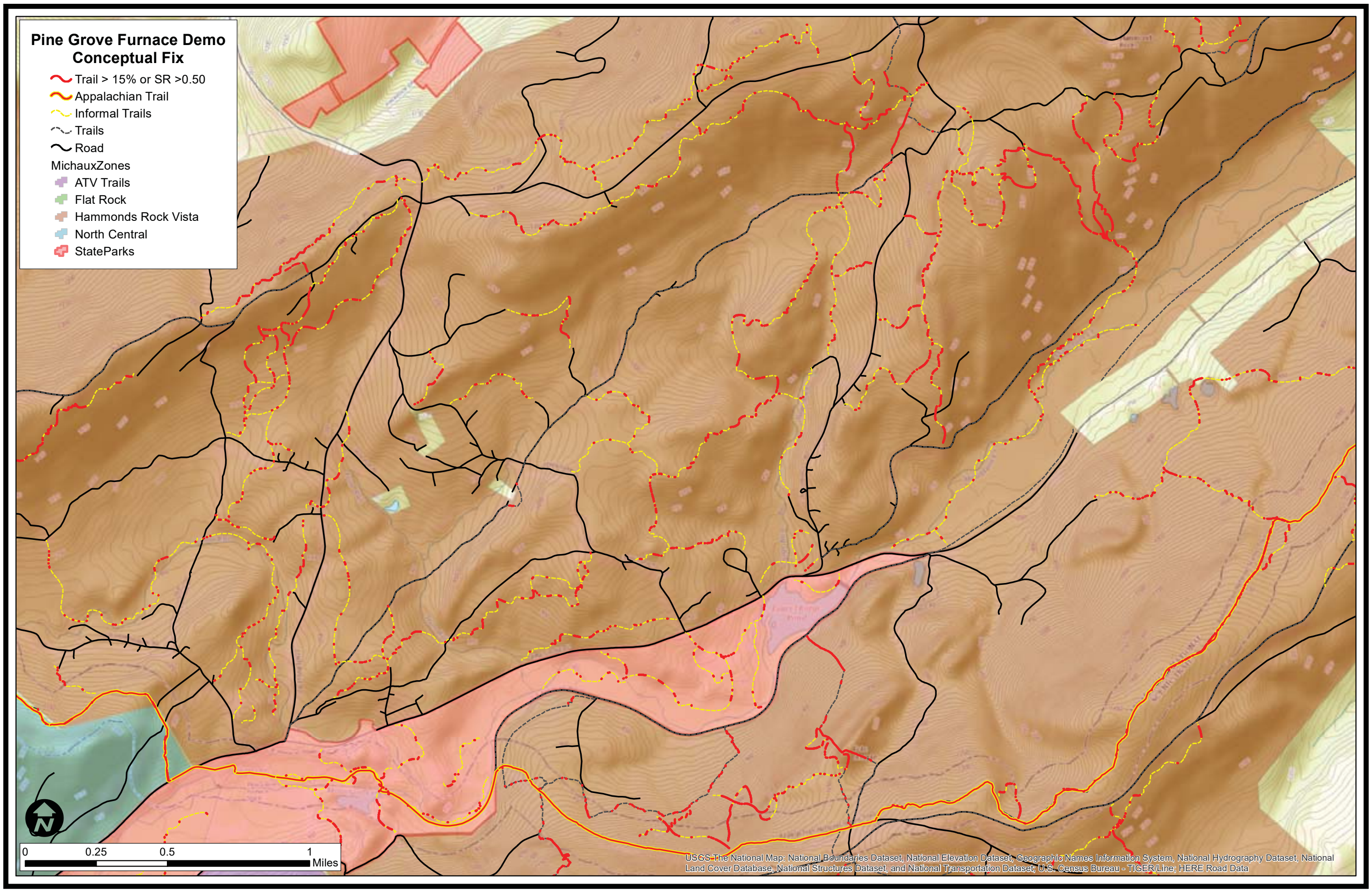
Pine Grove Furnace State Park Area Conceptual Trail Redevelopment

The Pine Grove Furnace area in the Hammonds Rock Vista Zone is a hub for recreational activity. It is easily accessed from the Harrisburg-Carlisle side of the Forest, has substantial day-use parking within the State Park, and offers Appalachian Trail- and Forest-based recreation. The area's trail system, utilizing old management corridors and informally developed routes up the area's hills, is rife with physical sustainability issues.

The trail system is challenging to navigate and does not provide well-developed options for the typical more casual forest visitor that frequents this type of area. Managerially, an improved trail system would function as an attractant for visitation and thus targeted outreach for ranger and law enforcement staff. A higher density of use in this type of area should result in reduced density of use and higher quality experience in more backcountry locations.

The following is a narrative description of, and plan for recommended actions to redevelop the trail system near the Pine Grove Furnace State Park to improve system function and improve social, managerial and physical conditions present on the trails.

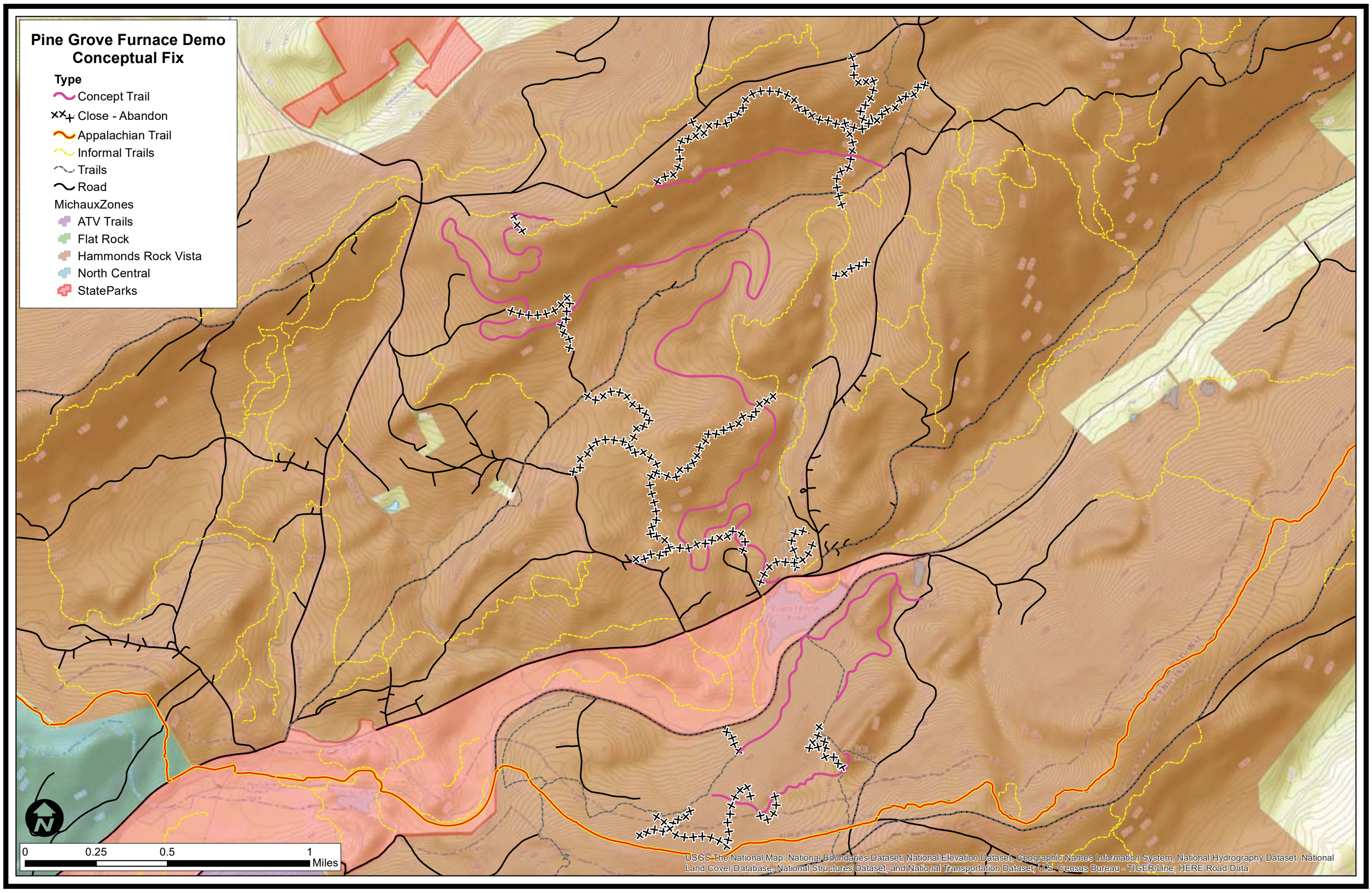




Pine Grove Furnace Area- Sustainability Issues

The trail system in this area is comprised of nearly 66% (11.3 miles) of informally-developed trails. Many of the trails north of Pine Grove Furnace State Park have developed as connectors between the ends of forest and camp roads or as relatively short directional routes from the ridge down toward the valley. Navigability of these trails is very challenging and a reliance on the forest roads for connectivity or travel back to the ridge impedes the quality of the recreational experiences. Many portions of these trails have slope alignment or trail grade issues that, with current levels of recreational use have not deteriorated to a great extent, but would be challenging to maintain with any increase in usage. Decommissioning many of these lightly traveled routes is simple at this stage of their informal development. Replacing these experiences with longer, purpose-designed routes that run from the highest points on the ridge to the lowest part of the valley and reduce the number of road junctions could create much higher quality mountain biking, trail running, and longer day hiking experiences.

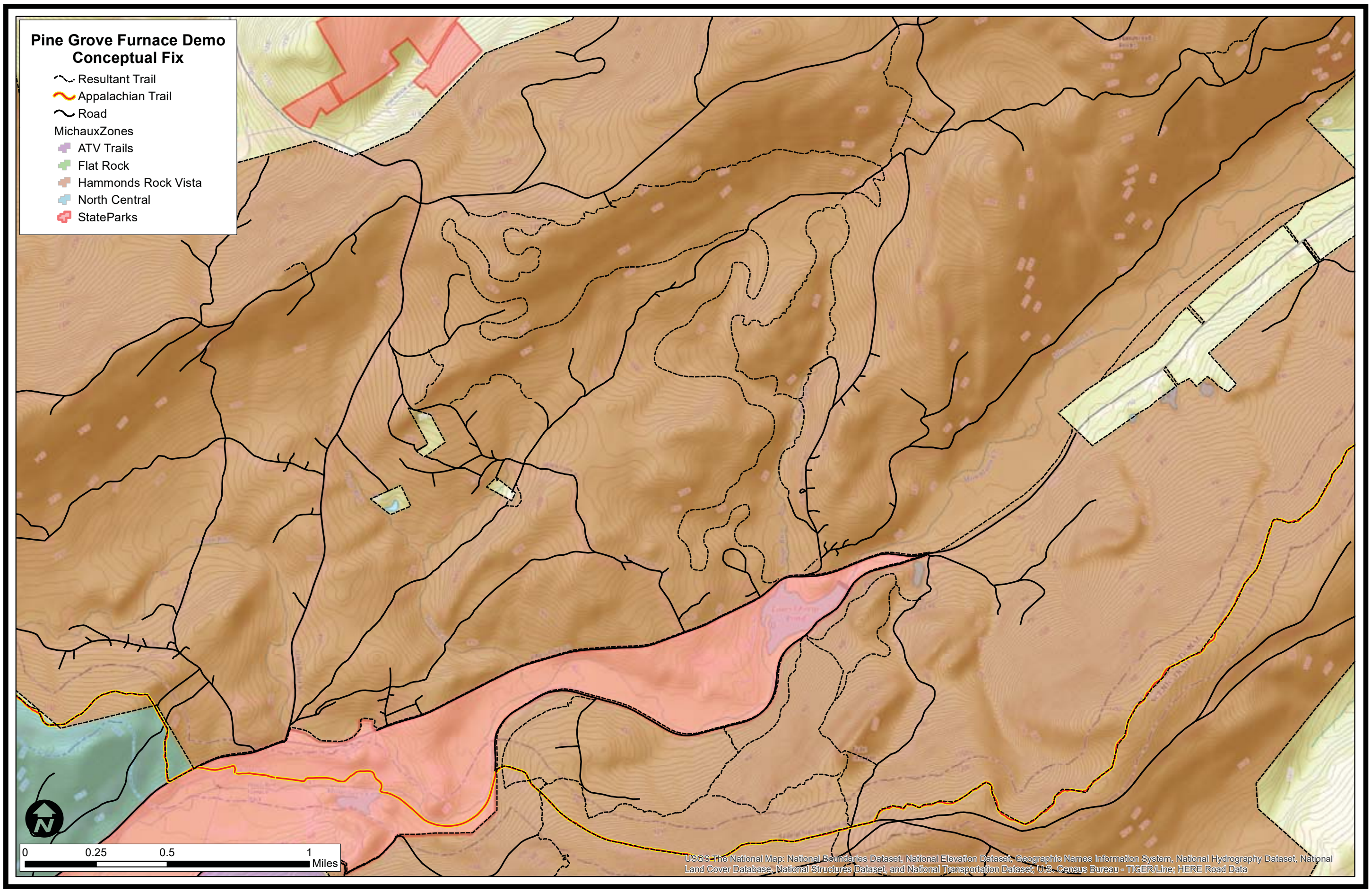
The trail segments south of the State Park in the vicinity and/or connecting to the Appalachian Trail have significant issues of redundancy, insignificant loop experiences, and as trail grade and slope alignment issues. Removing these segments and replacing them with family-friendly, shorter, looping trail options that connect the Park and the Appalachian Trail can vastly improve the trail durability and the quality of recreation experiences accessed from the State Park. Visitors that can easily navigate a trail system, provided with intuitive mapping and signage, have much higher levels of satisfaction with their outdoor experience and generally a higher interest in returning or donating their volunteer time and resources.



Pine Grove Furnace Area- Conceptual Redesign

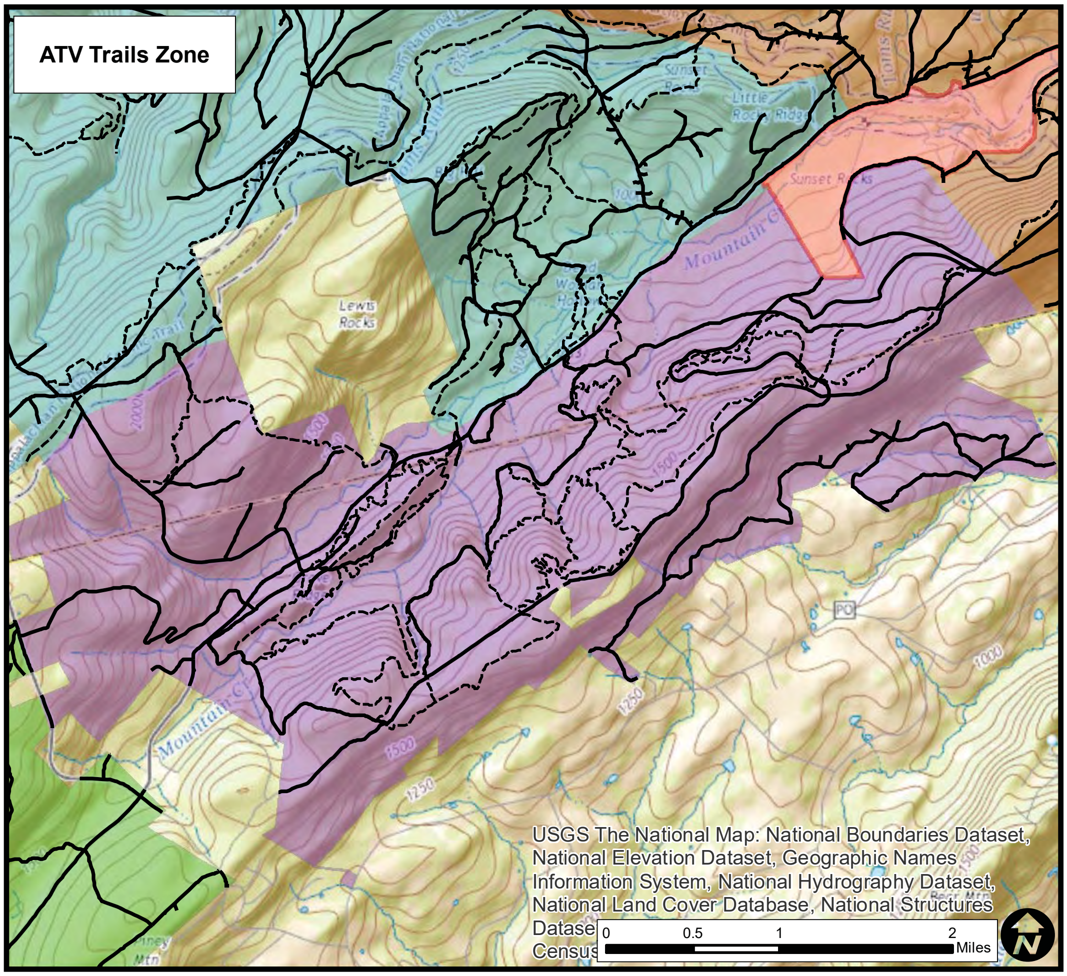
Providing solutions to an informally developed trail system often involves the removal of significant elements of the existing trail system. In order to redevelop the Michaux Forest trail system around Pine Grove State Park, a number of trails will have to be replaced. However, the resulting mix of trails will provide resource damage-mitigating beginner and intermediate-level trail opportunities that can be accessed south of the State Park. These shorter loop hiking experiences would allow visitors to more sustainably experience a portion of the Appalachian Trail. North of the Park, great opportunity exists to remove problematic trails and challenging navigation associated with the current spider web of routes and replace these short segments with a much longer ridgeline-valley-ridgeline loop with 12 fewer road contacts, a much continuous and improved backcountry type of experience for more advanced trail users.

With this type of conceptual redevelopment 7.8 miles of trail in this area would be closed and reclaimed to reduce long-term natural resource damage and replaced with 8.9 miles of trail that would require low-level ongoing maintenance to protect natural resources and minimize erosion/deposition impacts.



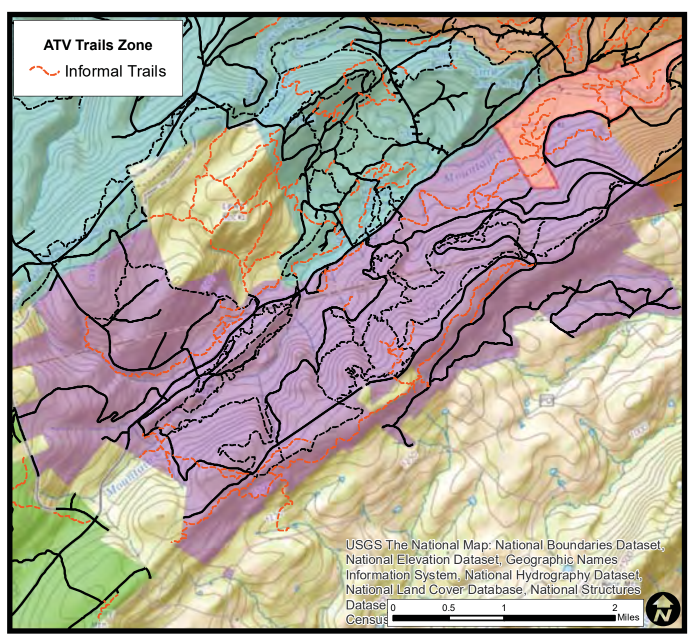
Pine Grove Furnace Area- Resulting Trail System
The conceptualized redesign of the trail system incorporates the natural features in the area that have been selected for exploration by visitors and the access points/trailheads that have been developed by the State Park. From it's current mileage of 17.3 miles, the trail system would increase to 18.2 miles. The system would provide this mileage in the form of easily navigable loops, with signage placed at each intersection and additional navigational aids (trailhead kiosks, maps, latitude/longitude, emergency management point, etc.), as needed.

ATV Zone



General Description

The ATV Zone of approximately 6,700 acres has the highest density of trails in the northern portion of the Forest. The zone straddles HWY 233 and includes ATV trail connecting Big Flat parking lot (along Shippensburg/Old Baltimore Rd) to the Bendersville Lot just South of Pine Grove Furnace State Park. Trails in this zone are managed for ATV use which currently doesn't include two-wheeled motorcycle use. Trails are wider to accommodate ATV and UTV/OHV traffic with larger radius turns required by this use type. Non-motorized users are accessing this zone, but as is indicated by a set of long visitor created trails along the southern flank of the zone area, these users are often minimizing their



use of the motorized trails during the open to ATV seasons.

45.9 total miles of trail, with 27.1 miles of formal trail and 18.8 miles of informal trail, were catalogued in the assessment. 59% of the trails in this zone are part of the formal trail system and 41% are informal trails. This equates to a trail density of 21.41 feet/acre of formal trail, 14.82 feet/acre of informal trail, and 36.23 trail feet/acre for the total trail network. This is much higher than the overall trail density of 21.73 feet/acre.

Trail Durability

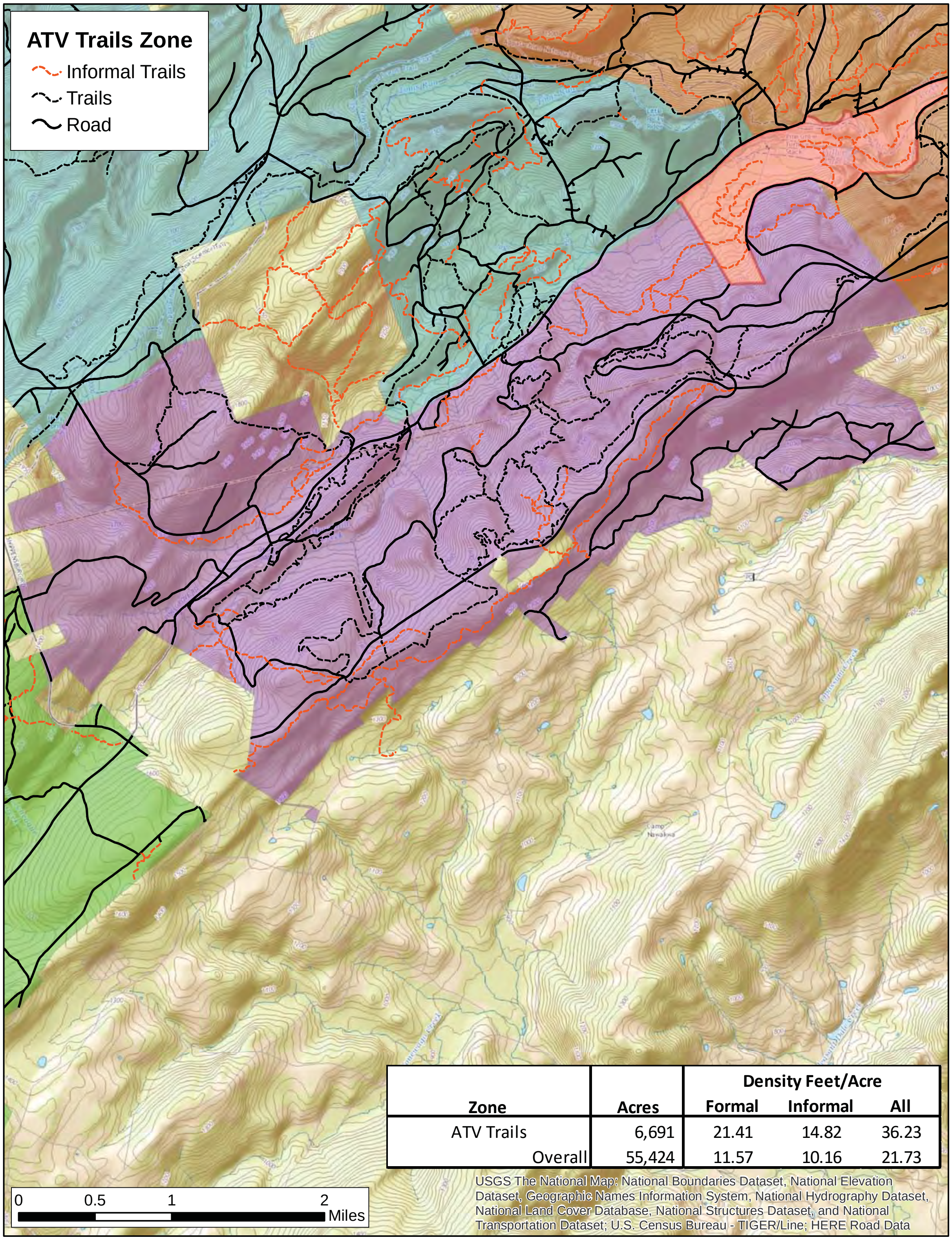
Rocky soils on the northern facing slopes in this zone allow for relatively steep grades for ATV use. Exposed rock punctuates the user experience limiting speeds, reducing throttle-induced soil loosening, and lengthening the typical user outing.

Trail Conditions

Much of the ATV system within this zone shows signs of active management in the form of trail surfacing, corridor and trail clearing, and recent forestry operations.

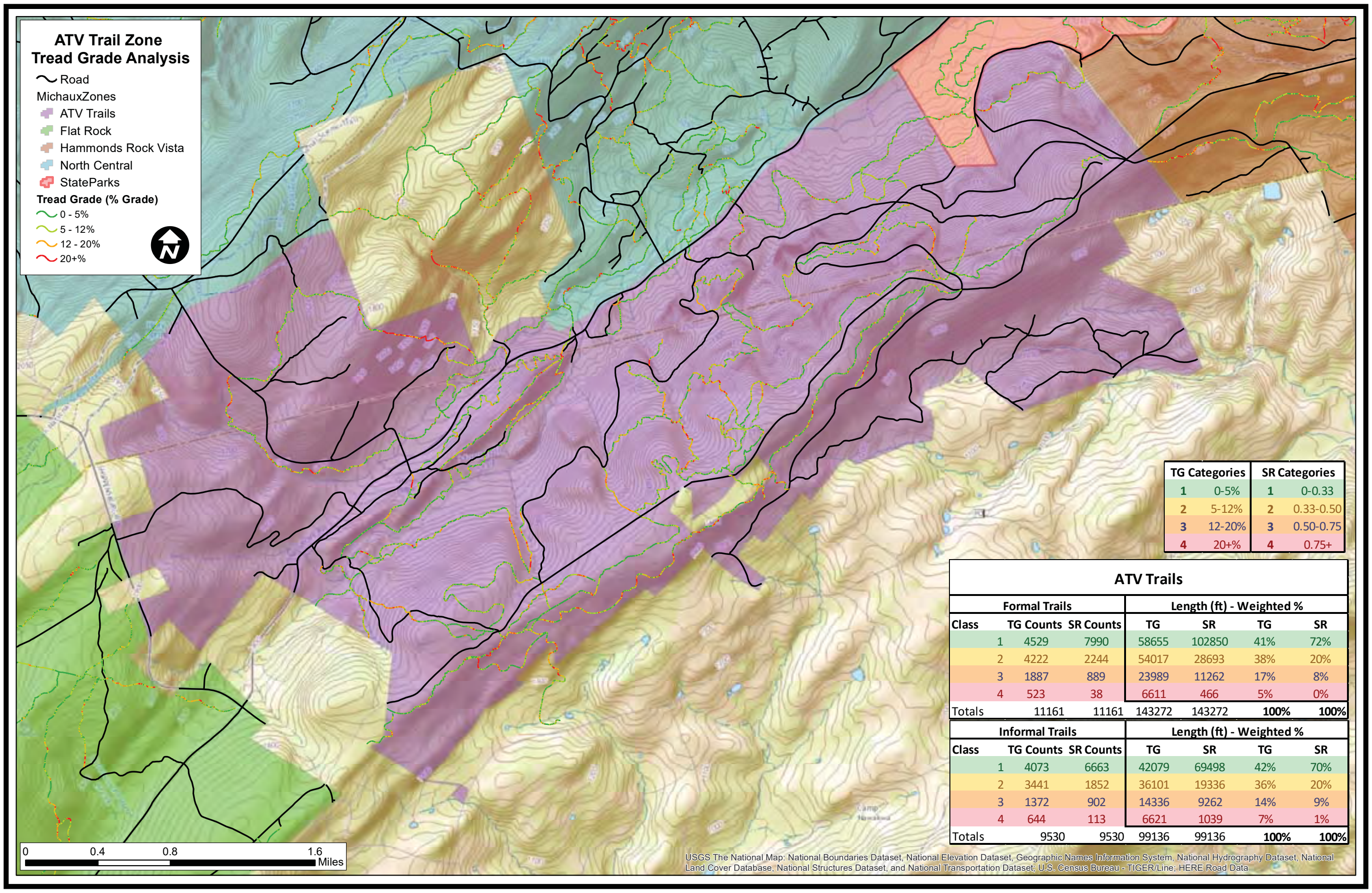
Water Management Capacity

Redevelopment of the fall aligned trails connecting ridge top to mid slope trails would reduce maintenance significantly (e.g. portions of Fuzzy, Piney Mtn Trail, Rocky Pass and Connector). Additional trail to consider redevelopment of is on the flat bottoms adjacent to grave’s ridge and route 233; these trails are low on the slope and have significant water and user management issues during wet times of the use season. Locating these trails slightly upslope will provide a more durable and easier to manage trail that still provides the connectivity and experience users currently enjoy.



Zone	Acres	Density Feet/Acre Formal	Informal	All
ATV Trails	6,691	21.41	14.82	36.23
Overall	55,424	11.57	10.16	21.73

USGS The National Map: National Boundaries Dataset, National Elevation Dataset, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; U.S. Census Bureau - TIGER/Line; HERE Road Data



TG Categories		SR Categories	
1	0-5%	1	0-0.33
2	5-12%	2	0.33-0.50
3	12-20%	3	0.50-0.75
4	20+%	4	0.75+

ATV Trails

Formal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	4529	7990	58655	102850	41%	72%
2	4222	2244	54017	28693	38%	20%
3	1887	889	23989	11262	17%	8%
4	523	38	6611	466	5%	0%
Totals	11161	11161	143272	143272	**100%**	**100%**

Informal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	4073	6663	42079	69498	42%	70%
2	3441	1852	36101	19336	36%	20%
3	1372	902	14336	9262	14%	9%
4	644	113	6621	1039	7%	1%
Totals	9530	9530	99136	99136	**100%**	**100%**

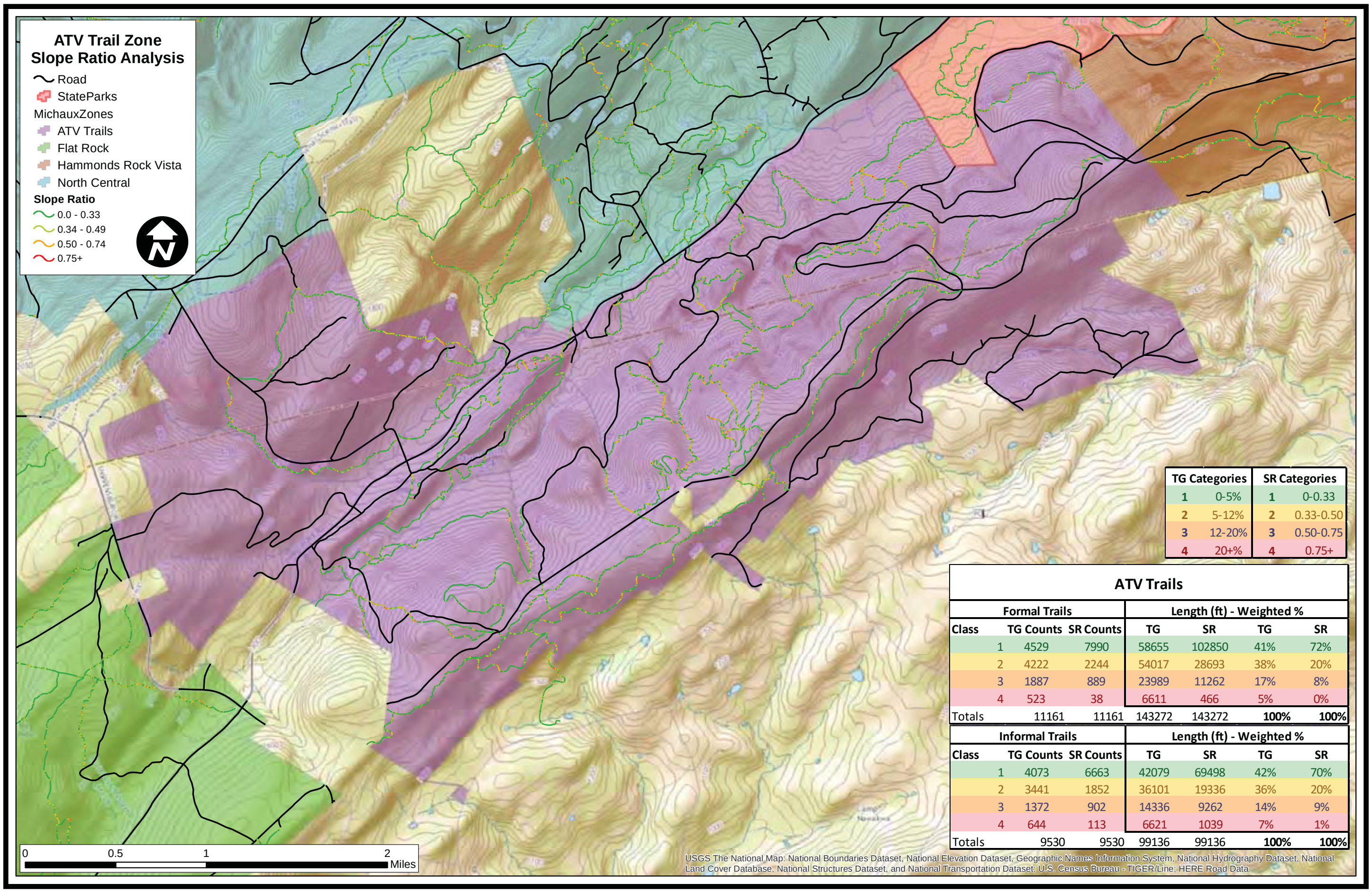
Trail Grade Analysis

41% of the formal trail system and 42% of the informal trail system in the ATV Zone have trail grades between 0 and 5%. These trail segments are depicted in green on the map above. While trails with low gradients do not typically require substantial maintenance, many of the ATV trails in this system have become entrenched to a level where drainage management will be challenging and mudhole formation is common.

38% of the formal trail system and 36% of the informal trail system have trail grades between 5% and 12%. Trail segments with these sustainable grades are depicted in yellow on the map above. With ATV use, these trail gradients can be maintained with a rigorous, annual work regime.

17% of the formal trail system and 14% of the informal trail system has trail grades between 12% and 20%. These trails are depicted in orange on the map above. Under ATV recreational use, these trail segments are very challenging to maintain and that maintenance is conditional upon the amount of natural rock and/or imported hardening materials.

5% of the formal trail system and 7% of the informal trail system have trail grades greater than 20%. These steep trail segments are depicted in red in the map above. Unless located on very rocky terrain, trails of this grade are not maintainable for the long term.



TG Categories		SR Categories	
1	0-5%	1	0-0.33
2	5-12%	2	0.33-0.50
3	12-20%	3	0.50-0.75
4	20+%	4	0.75+

ATV Trails

Formal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	4529	7990	58655	102850	41%	72%
2	4222	2244	54017	28693	38%	20%
3	1887	889	23989	11262	17%	8%
4	523	38	6611	466	5%	0%
Totals	11161	11161	143272	143272	**100%**	**100%**

Informal Trails			Length (ft) - Weighted %			
Class	TG Counts	SR Counts	TG	SR	TG	SR
1	4073	6663	42079	69498	42%	70%
2	3441	1852	36101	19336	36%	20%
3	1372	902	14336	9262	14%	9%
4	644	113	6621	1039	7%	1%
Totals	9530	9530	99136	99136	**100%**	**100%**

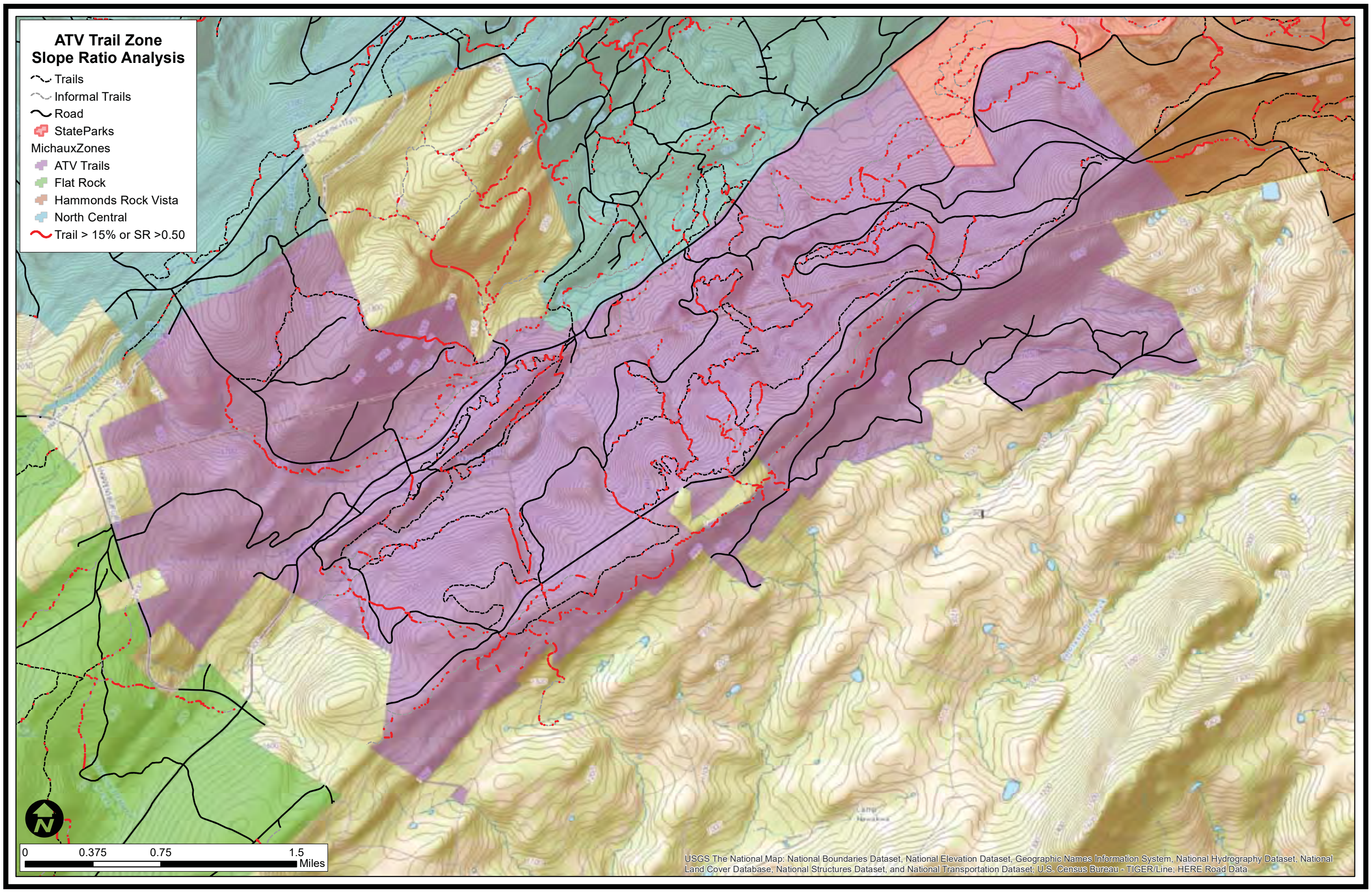
Slope Ratio Analysis

Durable trails are located across hillslopes with what is referred to as a contour alignment. Trails that readily erode have are located, regardless of hillslope grade, at an angle that is closer to a fall line alignment. Trails with a steep alignment relative to the hillslope are very difficult to maintain effective water drainage. The “half rule” is a commonly accepted estimate of when a trail is located with a too steep a gradient in relation to the hillslope it is located. The maximum slope ratio for a trail that meets the “half rule” is 0.5.

41% of the formal trails and 42% of the informal trails in the ATV Zone have slope ratios of 0 to 0.33. These areas are depicted in green on the map above. Trails falling in this zone typically do not provide water management challenges. However, many of the ATV trails are significantly entrenched and lack functional water management.

38% of the formal trail system and 36% of the informal trail system have slope ratios of 0.33 to 0.50. These segments are depicted in yellow on the map above. Water can be effectively managed on ATV trails with this slope ratio range with the development and ongoing maintenance of many rolling grade dips.

22% of the formal trail system and 21% of the informal trail system have slope ratios greater than 0.50. These trail segments are represented in orange for trails with slope ratios of 0.50 to 0.75 and red for segments with slope ratios greater than 0.75. Water cannot be effectively managed in these locations without very significant inputs.



Sustainability Benchmarks

Combining locations that either have trail gradients greater than 15% or slope ratios greater than 0.50, a large portion of the ATV Zone trail system requires attention. These trail segments are depicted in red on the map above.

Relative to trail grade and an exhibited maximum sustainable grade of approximately 15% in the Michaux under the current allowed types and levels of use, 22% of the formal trail system (5.96 miles) and 21% of the informal trail system (3.95 miles) in the ATV Zone have trail grades that currently or very likely in the future will require additional tread hardening, drainage management or relocation.

Relative to the alignment of the trail on the hillslope and the current ATV use, 8% (2.17 miles) of the formal trail system will require relocation due to their alignment on the hillslope. 9% (1.70 miles) of the informal trail system would require significantly improved water management, tread hardening, or relocation.

In some fall-line oriented trails on relatively steep slopes, both trail grade and slope ratio are problematic (meaning the percentages and mileages presented above are not additive), and thus become highest priority candidates for trail closure and relocation. Other high priority candidates for trail relocation are trails with high slope-ratio values, high use, and close proximity to water resources.

Social Sustainability Assessment

The social sustainability assessment was conducted in the winter of 2015/2016 and spring of 2016. With assistance from Michaux State Forest staff regarding organized, forest-recreating groups in the area, introductory meetings were held to explain the reasons for the trail assessment, anticipated process and timeline, and desired feedback from the stakeholding groups. Meetings were held with:

- South Mountain Rangers (Equestrian group)
- Appalachian Trail Conservancy
- Mountain Bikers of Michaux (Mountain bike club)
- Friends of Pine Grove Furnace State Park
- South Penn Enduro Riders (Off-road motorcycle club)
- Michaux Off-Road Enthusiasts (Multi-use group)
- Keystone Trails Association (Statewide hiking club's regional representative)
- PA State Snowmobile Association (regional representative)
- ATV (Denny Mann, local representative)

Following the initial discussions, each group was provided with an open-ended survey document to be developed by the group's broader membership. The groups were then invited to a public meeting held at the Forest office on the evening of February 11, 2016. The public meeting included a one-hour presentation and a one-hour open discussion. The presentation provided greater detail on the assessment process, the scope of assessment findings, and utility of the assessment by the Forest and volunteers in developing and implementing a long-term vision for the Michaux State Forest's trail system.

Specifically, outreach to the stakeholder groups attempted to gauge recreational forest users' opinions regarding the:

- Quality of trail experiences available
- Access to forest places of interest
- Quantity of trails and density of use
- Navigability of the trail system
- Typical use patterns- days of use, recreational residence time, seasonality of use
- Potential for conflicts between different use groups or visitors with different recreational motivations
- Needs for improvement in the trail system to provide better recreational experiences.

On April 9, 2016 an additional public meeting was held. All previously contacted stakeholder groups were invited to attend a morning-long sustainable trail development best practices presentation and an afternoon trail issues and opportunities planning session where stakeholders provided comments on trails, access, and issues around the forest on large-scale maps. The four trail zones outlined in the physical sustainability assessment were separated with one zone per table and groups were shuffled to each table/zone throughout the exercise. Numbered sticky notes were placed on locations where issues or opportunities were noted and a comment sheets were provided so that ideas could be sufficiently described.

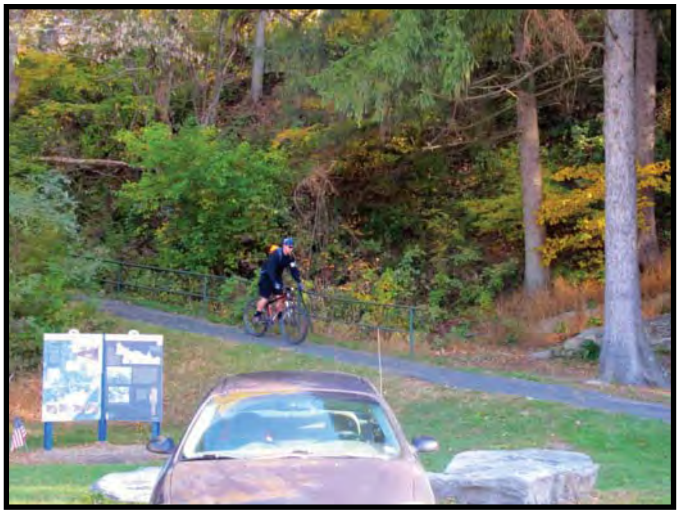
Qualitative Outreach Results

Several themes developed from the open-ended survey completed by the stakeholder groups, including 1) trail access, marking, and mapping, 2) trail sustainability, 3) trail types and allowed uses, and 4) trail connectivity, and 5) trail management. Below are representative comments from stakeholder groups as well as general commentary regarding the social sustainability of the trail system.

Trail Access, Marking, and Mapping

Representative stakeholder group comments included:

> *"There is a good variety of trails between Pine Grove and Caledonia, although many should be better marked."*
>
> *General comment from several people: "Lack of trail signage throughout the forest."*
>
> *"Need: small, unpaved parking areas at various trailheads that are adjacent to forest roads. Some exist, but many more would be appreciated."*
>
> *"Better maps that reflect reality 'on the ground' and include some way of indicating which specific gate or trailhead is being marked."*
>
> *"It would be nice to have additional signage and mileage info..."*
>
> *"[Trail system] is extensive enough that it does not suffer from overuse or ever get boring. It is use at your own risk, just like all other uses; hunting, bouldering, hiking, etc"*
>
> *"I like to describe them as a series of deer trails connected. I like how the trails are very challenging. You can ride anywhere from Carlisle to South Mountain. Trails are too hard to find. Impossible to find on your own."*



Roadside signage directing visitors is adequate for the highly developed ATV/Snowmobile trailheads, but nonexistent for other less developed parking locations. The less developed parking locations are also quite small and in some cases, quickly overflow during popular visitation times. These less developed locations, without trailhead kiosks, regulatory, etiquette, and leave no trace information, or maps do not provide visitors with any information regarding opportunities that may or may not be available in proximity to those locations. These issues are particularly problematic at the parking location on HWY 233 near the private inholding Tumbling Run Game Preserve and the numerous resource-damaging social routes that have developed in the area.

Trail marking is improving, according to all stakeholder groups surveyed, but remains inadequate for navigation in most locations. The Flat Rock area, with recently installed wooden posts at the trail junctions of formal trails, was noted as an improvement. However, this is complicated by the prevalent informal trails that are regularly utilized to form loops through this area during general recreation and special events.

Similar to trail marking issues, mapping and navigation throughout the forest is very problematic for visitors. Every stakeholder group provided multiple anecdotes of finding lost trail users of various use types and experience levels, and guiding them out of the forest. While long-time forest users are not deterred by this situation, many of those same people intimately know and navigate only within a relatively small portion of the forest. With limited cellular service and only a forest-wide recreation map that lacks many highly utilized, unmarked routes, this navigation limitation is a serious impediment to a quality experience generally and can become very serious in a single search and rescue operation.

Trail Sustainability

Representative stakeholder group comments included:

> *"I see many opportunities to mitigate erosion and impact."*
>
> *"However, with so many undesignated trails, the stability of the system is constantly affected by other activities, such as logging. Further, without designation, there is no perceived ownership and so improper modifications are sometimes put in place by random users. As for the designated trail systems, such as the Flat Rock system, it historically has been largely a network of segments that are not attractive to uses such as mountain biking or hiking/running. Forest roads do not equal multi-use trails."*
>
> *"…most of the most interesting/challenging/beautiful trails in Michaux are undesignated, built without permission and maintained by a small community. This happened because historically, the designated multi-use trails were in poor condition (usually unsustainable legacy trails) or too many segments were fire road."*
>
> *"Utilization of the fall line trails lacking proper design increases maintenance activities which could be better focused on further improving other more stable trail segments thereby increasing sustainability"*
>
> *"I would love to see the Flat Rock trail system reworked to remove as much road as possible, replaced with sustainable trails that are enjoyable to use. I would like to see two more multi-use trail systems designated, one south of Rt. 30 and one north of Shippensburg Road. I would like to see connector trails/routes linking these three systems together. A third official multi-use trailhead in the northern part of the forest would be part of this"*

For most trail users, a quality experience in the forest is closely tied to the level of intimacy with the natural resource. Whether that entails taking in the panoramic views of a scenic vista, the sounds of a running stream, or traversing a hillside, a higher level of naturalness is almost universally preferred over an engineered or overly developed experience. These are the reasons why forest roads and even historic, wide management-created corridors hold less appeal for recreationists than do narrow trails. The roads may be necessary, in some cases, to provide connectivity between trails, but an experience on a road does not equate to an experience in nature.

It was abundantly clear through the stakeholder engagement process that a lack of these high quality experiences and a perceived lack of interest by management in providing those experiences led passionate stakeholders to attempt to provide these experiences for themselves. Enthusiasts informally developing new routes through the forest, either by patterns of off-trail travel or by attempting to design a desired experience, are creating the high quality recreation experiences espoused by the Bureau. With many formal routes consisting of eroding wide corridors that don't provide an intimate setting for recreation, the stakeholders feel that a more sustainable, more authentic experience is needed.

The physical sustainability assessment provides quantitative data that suggests there are limited differences in the level of sustainable trail design between the formal and informal trail systems. However, stakeholders feel very strongly that the wide, eroding, historic corridors that, along with open roads, make up much of the formal trail system visibly cause a much higher level of erosion, sedimentation, and natural resource impacts than do the very narrow, informally created trails. Those perceptions are likely accurate on a number of fronts, as wider trails prove more difficult in managing water, encourage higher levels of speed and displacement, and often provide a full break in the forest canopy- all issues that are mitigated with narrower trails between one and four feet in width.

Trail Types and Allowed Uses
Representative stakeholder comments included:

"User groups need to cooperate and coexist respectfully. Making additional single-use trails does not address this need or an efficient use of space and resources."

"One of the greatest benefits of the existing trail "system" is that it provides so many choices, if you have the initiative and skills to navigate without blazes on trees. The existing trails provide a wide range of choices in difficulty, though most would say there are few easy trails in Michaux."

"I do not feel the forest requires any more single-use trails, specifically hiking. The AT bisecting the forest is already a major impediment to multi-use trail design and layout, as is the Buck Ridge Trail and Rocky Knob Trail."

"Need hiking-only trails and loops of various lengths from 2-20 miles and of varying difficulty from smooth and level to rough and steep."

"Any newly designated trails should be, at a minimum, hiking + biking multi-use. Horse access should be considered on a trail-by-trail basis to ensure the trails in question can withstand the impact."

"[Support] having motorcycle reclassified as an ATV. This would open the ATV trails in Michaux to motorcycle usage."

"ATV trails should not be considered when speaking of multi-use trail mileage, other than equestrian use. Again, most non-motorized users avoid them because, honestly, the trails are not much fun for non-motorized use and the user experience is subpar"

"Nearly all of the trails in Michaux are very technical and difficult. It would be nice to develop

a trail loop of 10 miles that is specifically designed for mountain biking. In the mountain biking parlance, this would be smooth and flowy single track. This would also be appealing to hikers and runners."

"Trails 4+ miles long, rocky technical singletrack, stacked loop trail systems. Trails that navigate through the forest/ mountains. Not just straight up or down the mountain. A couple of easier trails would also be really beneficial for more casual users."

"there is an existing recreational resource mapped, signed, blazed, and managed for cross-country skiing, a small degree of attention and investment could multiply the usefulness and enjoyment of the facility."

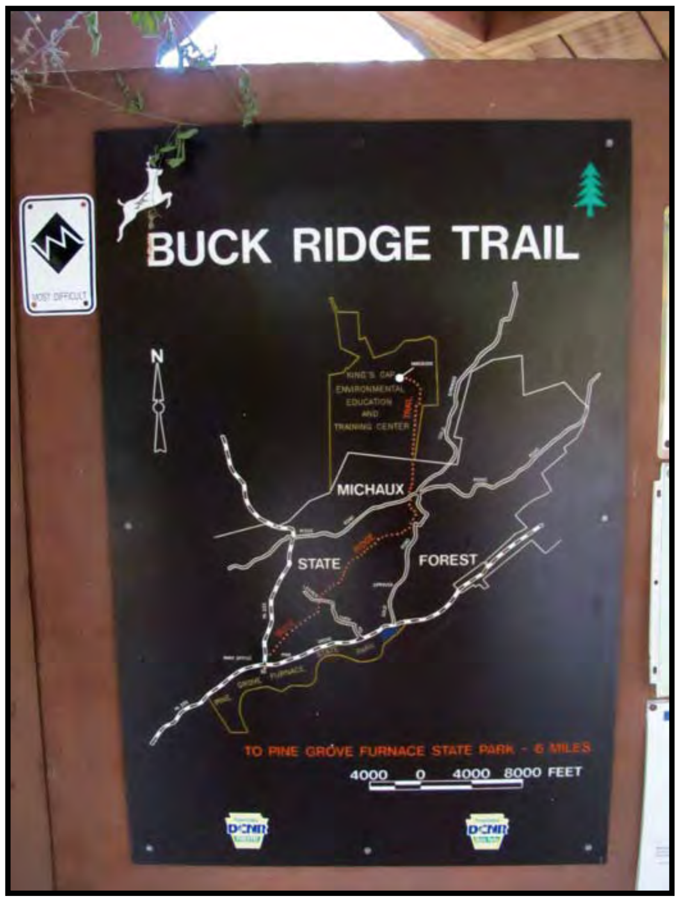
The stakeholder feedback related to trail types, allowed uses, and conflicts was the most unyielding positive feedback that was received. Recreationists of all types feel that other user groups did not hinder a quality experience. While there were numerous constructive comments regarding how management of existing trails could be different (i.e. not including ATV/Snowmobile trails or open roads as trail mileage or not running motorcycle enduro events on non-motorized, shared-use singletrack), very few disparaging comments were made regarding the impacts, prevalence, or attitudes of any one use group over another.

Universally, stakeholder groups have the opinion that the Michaux trails are physically challenging, especially for those visitors coming from nearby piedmont or coastal plain ecoregions where rocky trails and significant elevation are not available. Many avid users very clearly expressed that they do not wish to see this situation change, as they prefer the challenging experiences provided by the Michaux trails. Universally the stakeholders agreed that the trails do not, at this time, form natural "systems" where multiple experiences tailored to types of use or recreation residence time are provided. That stated, as part of the systemization of these trails, the stakeholder groups felt there is a distinct need for beginner-friendly, more developed trails that provide the experience that many out-of-area and new visitors want and need for a quality visit.

Trail Connectivity

Representative stakeholder comments included:

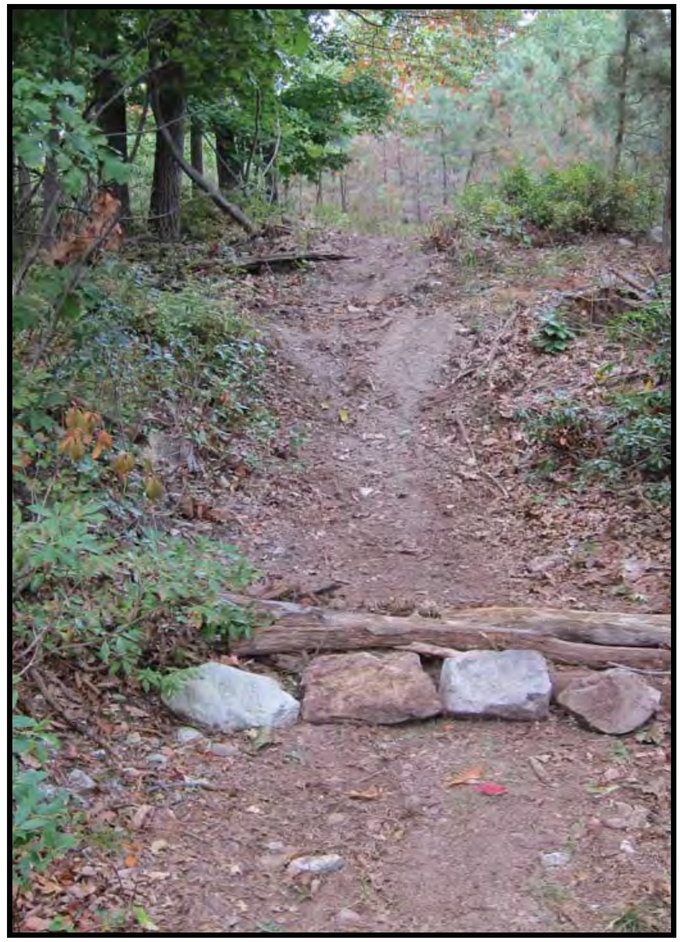
> *"Dislike – no trail, other than the Appalachian Trail, connects with trails in Pine Grove Furnace State Park."*
>
> *"…would also like to see cooperation between the Parks and Forestry, specifically Pine Grove Furnace and Forestry, to address and open up a viable multi-use trail link from State Parks into the State Forest. A prime example of this at Pine Grove Furnace is the trail known as Community Service."*
>
> *"more trails overall. Anyone who wants to 'go long' only need hop on the AT for a couple of thousand miles, obviously, but I think the locally intertwined 1-mile to 10-mile trails are the most useful on a daily basis and attract the greatest range of hikers. There are a bunch of those around but more could be created, or existing social trails marked"*
>
> *"The concept of stacked loops should be worked into any newly proposed systems to allow a range of user abilities and trail lengths."*
>
> *"The major thing that is lacking are loop trails. Most trails are out and back varieties. Loops can be made, but this often involves roadways with vehicles. Specifically, it would be good to have loop trails that can be short as a mile and up to at least 10 miles."*

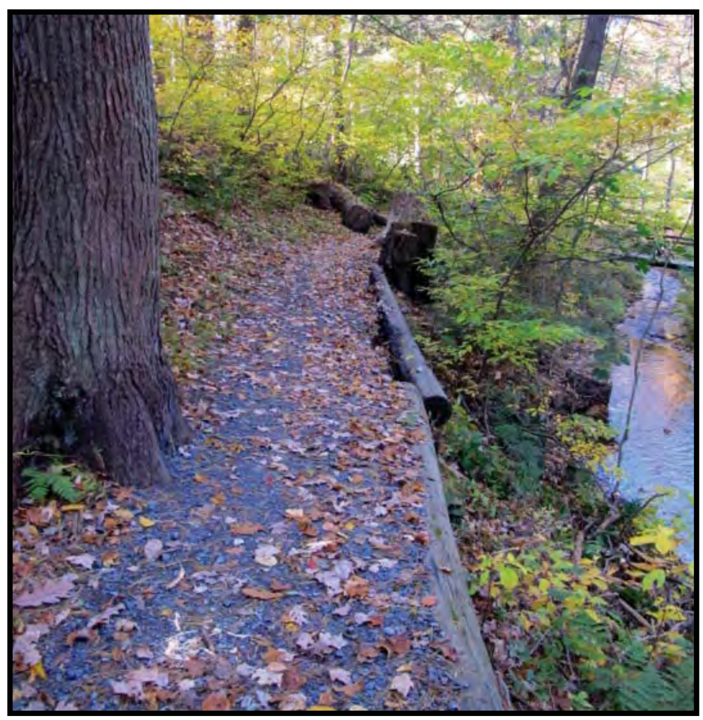


An extension of many other comments, the stakeholding groups felt quite strongly that the assemblage of trails and roads throughout the Michaux does not form a trail system that provides a diversity of high quality recreation experiences nor that connectivity and collaboration between the area's largest State Park "trailheads" is working to the advantage of forest visitors. Many comments were received regarding looped trail opportunities of varying lengths. Concentrated trail areas with stacked loop systems, connected by longer distance trails were seen as the ideal way to systemize the Forest's trails.

Trail Management
Representative stakeholder comments included:

> *"There should/could be many more trails between Rt. 233 and Piney Ridge and between Pine Grove and Kings Gap. For example, the "new" 1000 acres of King Gap between Pine Road and Pinebrook Drive could easily provide 3 or 4 new trails in addition to the new Irish Gap trail that was added recently. Buck Ridge is a great trail and constitutes a good start but needs (1) branching trails to either side (limited by private property), (2) better treatment of wet areas, and (3) less destruction by logging in the future."*
>
> *"Forestry did not focus much, if any, time or effort on managing the trail systems."*
>
> *"Logging lease -- boundaries, and internal to the leases area -- should recognize existing trails (even if not marked on "official" maps") and make an effort to avoid closing such trails with large amounts of slash or downed junk trees."*
>
> *"The trails are fantastic, albeit poorly to not managed at all."*
>
> *"I don't want to see any more development or new facilities in the forest."*
>
> *"Another thing I like about the Bureau of Forestry people in Michaux and all the people who work in the PA State Forests is the cooperation they exhibit with all forest users."*





Universally, the stakeholding groups felt that recreation has been a very low management priority for the Forest. Many expressed confusion regarding the process of working with Michaux officials to develop or maintain trails, how decisions are made regarding trail use in special events, and whether internal politics of the Forest would make any discussions regarding trails into non-starters. For instance, stakeholders of all use groups provided anecdotes regarding the destruction of quality trails during timber management operations. While most comprehended that informal trails could not “planned around” during the timber management, they expressed confusion in the Forest taking issue with users re-establishing trails and connectivity that was lost during the timber management operations.

Opinions were expressed very strongly by some groups regarding the strict regulation of their authorized use of the Forest and/or the illegality of creating trails that would provide a quality recreation experience for many user types. In general, stakeholder groups felt that the Forest had not managed recreation and fulfilling that need was incumbent on the public.

Managerial Sustainability Assessment

The managerial sustainability assessment was conducted through multiple meetings with Michaux State Forest staff from Fall, 2015 through Spring, 2016. The goals of the discussions were to develop a better knowledge base regarding past and present operations and the capacity of Forest staff and stewards, in terms of skills, knowledge, tools, hours/numbers, budget, fundraising, to manage the trail system, and potential management conflicts related to ecosystem management and facility capacity.

History

There is a clear history of very informal recreation management in the Michaux. Previous District Rangers provided relative carte-blanche to forest users in developing their own experiences, but clearly prioritized revenue-producing operations such as timber harvests in terms of management attention. These activities altered the recreation landscape that was being developed informally and conflict between the Forest and its recreation stakeholders began to develop.

As ecosystem and natural resource management has become a sharper focus for the Bureau Of Forestry at the state level, new issues with recreational trails have been identified. At the landscape level, trails have been classified as facilities that cause breaks in wildlife and plant habitats. At the forest level, informal trails in the Michaux have been shown to traverse through sensitive habitats.

Recreation Foresters and Law Enforcement Rangers have been in place and responsible, in part, for management of recreation, Campsite leases (Camps), and special events on the Forest. Much of the recreation staff's time was spent managing the Camp improvement and inspections, as well as integrating with fire and timber management and planning.

Present

The Michaux State Forest is reported to have the highest density of trails in any Pennsylvania State Forest and receives more requests for special events than any other District in the State. The density of recreation, including one of a handful of ATV trail systems and one of very few Forests to allow motorcycle special events, has necessitated a larger Law Enforcement Ranger staff (4) than is present in other Forests. Staff is responsible for managing special activity events and assuring post-event clean up and impact mitigation.

Leased Forest Campsite ($200/yr lease cost) building density is very high (455 Camps of 4,017 in Forests statewide), growing in number and level of development, and require inspection every three years. The management of these campsites falls into the job duties of the Recreation Forester, requiring roughly 150 inspections each year, as well as granting approvals for any alterations to the Campsite building or grounds. Cost recovery on the Campsites is approximately $91,000/year.

Michaux State Forest does not have an organized "Friends" group. A number of activity-specific organizations exist in the area and are often special activity permit holders in the Forest. These groups have been marginally more active in volunteering in the Forest in recent years. Members of the public, not necessarily affiliated with these groups, have been very active in developing the informal trails throughout Michaux for a number of decades. More than 105 miles of informal trail were catalogued in this assessment, nearly the 121-mile amount reflected in the formal trail system that are not co-located on open roads.

Other than staff, there is not a budget allocation for trail maintenance and management, outside of state funds earmarked for continued operations and maintenance of the ATV trail system.

Future

Given the staff duties and resource allocation above and the limited stewardship resources currently present in the user communities and DCNR staff, it is not surprising that trail conditions suffer as a result. The long history of hands-off management of trails, trail users, and special events utilizing the trails on the Michaux has resulted in a vast network of relatively unsustainable trails and significant internal and external inertia that limits progress towards a sustainable system of trails and trail management.

The current staff has begun to engage and manage uses, users, and events on the Forest. Internally, progress is slowed by significant shortages of capacity in terms of staff time, equipment and knowledge related to sustainable trails and user engagement. Externally, user communities' and individuals' resistance to change, lack of trail design and construction fundamentals, and limited organizational engagement restrict the efficacy and direction of their efforts to improve trails on the Forest. Priorities for improving the managerial sustainability on the Michaux State Forest are:

- **Increased resource development**
  Internal to DCNR, budgets and staffing levels need to shift/rise to focus and prioritize management of trails, user community engagement, and management of special events and activities utilizing recreational resources on the Forest. As is common across most public lands in the United States, land managers will need to develop skills and relationships to successfully engage volunteer stewards to protect, preserve and manage recreational resources. DCNR staff will need to spend significant time fostering and improving their working relationships with user communities.

- **Increased trail specific skills, knowledge and tools**
  DCNR staff need the tools and skills to succeed. Training opportunities exist within the state and region to develop skills related to common trail design, maintenance and construction tasks. Mastering these skills and helping to coordinate and develop parallel skills within dedicated users and volunteer stewards is paramount to success.

- **Partnership enhancement**
  Working with dedicated stewards and users to pursue state and federal grants and other funding opportunities to implement trail trainings, design, constriction and maintenance is needed. These opportunities help solidify working relationships and allow for users and DCNR to understand each others' priorities, perspectives and processes.

Benchmarks

This section is still in progress, pending the results of the SAA/CAA portion of the project. Benchmarks will be related to the statewide Recreation Management Principle Goals and Objectives

Appendix A:

Trail Sustainability Primer

(Delivered April 9, 2016 to 25 stakeholders)

Trail Management 2.0

A multi-faceted approach to developing lasting and valued trails and trail systems.

PA DCNR, Michaux State Forest: April 9, 2016

Introductions

- Dr. Jeremy Wimpey- Applied Trails Research
- Scott Linnenburger- Kay-Linn Enterprises

Overview

- Introductions & Workshop Overview (15 minutes)
- Classifying Trail Sustainability (10 Minutes)
- Trail Design Parameters and Specifications (10 minutes)
  - Understanding slopes
  - Trail tread watershed
  - Rolling contour trails
  - Width, rugosity, and exposure
  - Trail features (turns, water crossings, structures)

Why is this important?

- Many new trails are being built, often without good planning/design process or effective user input
- Many older trails & systems are being retro-fitted to bring them to a more sustainable condition, sometimes at the dissatisfaction of users
- Trail users are ever changing and diversifying
- Desired trail experiences are often left out of sustainable trail development process

Classifying Trail Sustainability

- Primary focus in popular literature has been on:
- Physical Sustainability
- Maintenance and Construction Tools/ Techniques
- Lacks important social and managerial contexts

What is a sustainable trail?

- Ecological Sustainability
- Physically Sustainability
- Managerial Sustainability
- Social Sustainability
  - •Trail sustainability is not a yes or no scenario but instead a sliding scale measurement
  - •If one of the legs of the stool is weak or missing, another strong leg can compensate

Ecological Sustainability

- •Trail types that fit into surrounding landscapes
- •Right type of trail and users for given area
- •Level of impact during development stage appropriate for sensitivity of area
- •Level of long term impact of trail commensurate with landscape

This trail is having a large impact on water resources.

Physical Sustainability

- Physical robustness of the trail
- Ability of the trail to shed water thus preventing water based erosion
- Ability of the trail tread to withstand the impacts of permitted users
- Alignment is most important aspect
- Challenged alignments can be mitigated with various techniques: hardening or armoring

Social Sustainability

- Trail system generally meets the needs/desires of users
- Good variety of trails with a range different difficulties
- Good relationship between users and managing agency
- Design helps to mitigate user conflicts
- If enough and right type of trails are not provided, users will create their own
- Trail systems that "make sense"
- Ease of navigability

Managerial Sustainability

- Ability of the land managing agency and its partners to actively manage and maintain the trail
- Where management budgets lack in maintenance money, volunteers can make up deficit with trained volunteer labor
- Regular inspections and assessments of conditions
- Trail decisions (including wet weather closures) based on real time information
- Risk Management strategy

Trail Design Parameters and Specifications

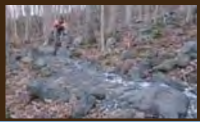
- Develop specifications to be as detailed as possible using many different metrics
- Recognize that most trails will get more textured over time
- Design/Build specs vs. managed to conditions
- Develop many different types of trails and difficulty levels
- Share information on trail types and rating with trail users at trailheads and on the trail

Trail Design Parameters and Specifications

- Trail Type Name: Name of trail for trail inventory to be included in management plan
- Difficulty Rating: Information to be shared with users on how difficult the trail experience will be
- Difficulty Symbol: Symbol of trail difficulty as shown on maps, kiosk, website and any other method of information conveyance
- Typical Tread Width: Typical range (narrowest to widest) of trail tread width for this type of trail
- Typical Corridor Width: General description of width between trees and other vegetative matter close to the trail

---

- Tread Rugosity: Smoothness or roughness of trail tread including roots or rocks protruding above main tread surface: Protrusions and Obstacles. The frequency and size of protrusions and obstacles combine to add an overall tread rugosity and affect the trail tread difficulty.
- Protrusions: Smaller irregularities in the trail surface in the form of smaller rocks and roots from vegetation (trees). Though these add texture to the trail tread, they are generally avoidable and/or small enough to not create significant issues of trail difficulty (unless there are long sections of a number of protrusions).
- Mandatory Obstacles: Larger (taller) irregularities in tread surface including rocks, roots, and drop offs that are mandatory and not avoidable.

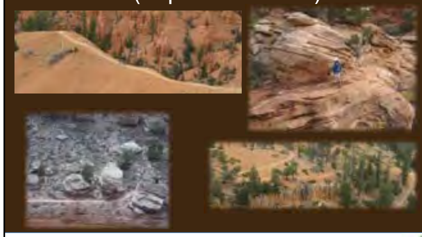


- Average Gradient: How steep is the average grade of the trail as measured in percent (vertical distance vs. linear distance)
- Maximum Sustained Grade: Steepest grade on trail for a sustained distance (50+ feet)
- Maximum Grade: Steepest overall section of trail (short distance)
- Typical Tread Materials: What does the tread surface of the trail consist of?
- Steepness of Side-slope (exposure factor): How steep is the prevailing side-slope of the landscape the trail is running through (how serious would a fall be off trail)? This relates to the penalty of failure for a fall off trail tread.
- Turn Radius: Tightness of turns and switchbacks found on the trail and general flow or rhythm of trail experience (open and flowing vs. tight and twisty)

- Formality of Trail and Structures: Trail rating helps to determine how formal the trail experience will be
- Typical Drainage and Waterway Crossings: Typical way the trail tread would interact and/or cross waterways (streams, creeks, drainages)
- Duty of Care: Sliding scale, refers to potential liability exposure of trail and structures
- User Profile: General description of experience level, fitness level, motivations, etc. of a typical user on any given trail type

---

Steepness of sideslope (Exposure factor)



Hike/Bike Singletrack 1

- Trail Type Name: H/B ST1 Hike/Bike Single track
- Difficulty Rating: Easy
- Difficulty Symbol: Green Circle
- Typical Tread Width: 36-48"
- Typical Corridor Width: 48-72"
- Tread Rugosity: Moderate, some irregularity, generally less than 6" in height and avoidable
- Average Gradient: 7% or less
- Maximum Sustained Grade: 10%
- Maximum Grade: 15% for short distances
- Typical Tread Materials: Natural surface, amended with rock where needed for stable condition.
- Steepness of Sideslope: Moderate, up to 50%
- Turn Radius: Mostly climbing turns with larger radius
- Formality of Trail and Structures: Welll-defined and somewhat formal
- Typical Drainage and Waterway Crossings: Developed bridges
- Duty of Care: Moderate
- User Profile: This trail type is for the broadest subset of hikers and bikers, with moderate levels of stamina, skills, and preparedness

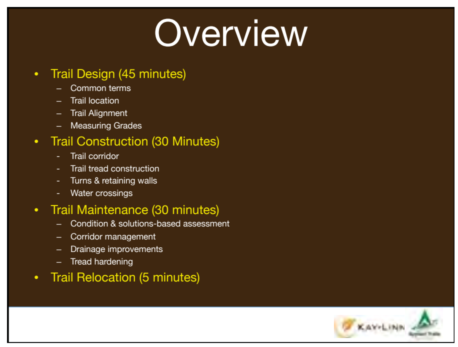
3

6/30/16

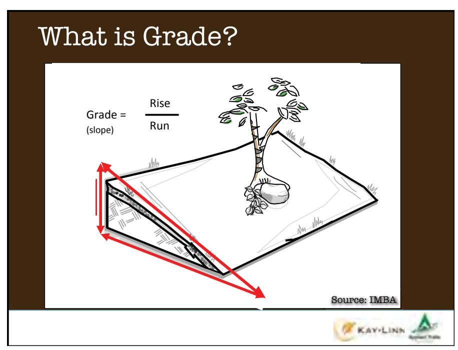

Hike/Bike Singletrack 2
Trail Type Name: H/B ST-2- Hike/Bike Natural Surface Single Track
Difficulty Rating: Moderate
Difficulty Symbol: Blue Square
Typical Tread Width: 24-40”
Typical Corridor Width: 36”-48” but open in some places
Tread Rugosity: Uneven, with regular rock and root protrusions above trail tread
Average Gradient: 10% or less
Maximum Sustained Grade: 15%
Maximum Grade: 20% for short distances
Typical Tread Materials: Mostly natural surface (native soils) with some rock armoring and light surfacing where needed
Steepness of Sideslope: Ranges from flat to steep sideslopes (>50%)
Turn Radius: Tight turns with possible switchbacks
Formality of Trail and Structures: Low formality
Typical Drainage and Waterway Crossings: Hardened or armored crossings where possible, bridges would be less formal with low level engineering.
Duty of Care: Low
User Profile: Experienced trail enthusiasts seeking a more rustic trail in remote and natural landscapes with some technical terrain features on the tread.


Hike/Bike Singletrack 3
Trail Type Name: H/B ST-4 Hike/Bike Natural Surface Single Track
Difficulty Rating: Most Difficult
Difficulty Symbol: Black Diamond
Typical Tread Width: 12”-30”
Typical Corridor Width: 36”
Tread Rugosity: Very rough and en-even, sometimes loose
Average Gradient: <15%
Maximum Sustained Grade: 20%
Maximum Grade: 25% for short distances
Typical Tread Materials: Natural surface, native soils sometimes loose
Steepness of Sideslope: Moderate to high sideslopes (40-100%)
Turn Radius: Tight
Formality of Trail and Structures: Only primitive structures such as a single log bridge or other structures using on site materials
Typical Drainage and Waterway Crossings: Wet feet is to be expected
Duty of Care: Very low
User Profile: A very difficult trail for expert trail users only


How trail specifications effect all 4 areas of sustainability


Overview
Trail Design (45 minutes)
Common terms
Trail location
Trail Alignment
Measuring Grades
Trail Construction (30 Minutes)
Trail corridor
Trail tread construction
Turns & retaining walls
Water crossings
Trail Maintenance (30 minutes)
Condition & solutions-based assessment
Corridor management
Drainage improvements
Tread hardening
Trail Relocation (5 minutes)


Sustainable Trail Design
Cuyuna, MN


What is Grade?
Grade = Rise / Run
(slope)
Source: IMBA

4

6/30/16

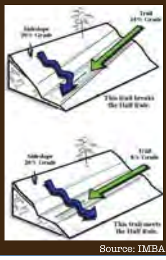
Trail Design Guidelines

- #1 Half Rule
- #2 User-Based Erosion
- #3 Average Grade
- #4 Outslope
- #5 Grade Reversals

Curt Gowdy State Park, WY

1 The Half Rule

- The trail tread grade should be less than half of the grade of the side slope.
- The keeps water from diverting down the tread.



Source: IMBA

1. Measure the side slope (fall line)

Las Vegas, NV

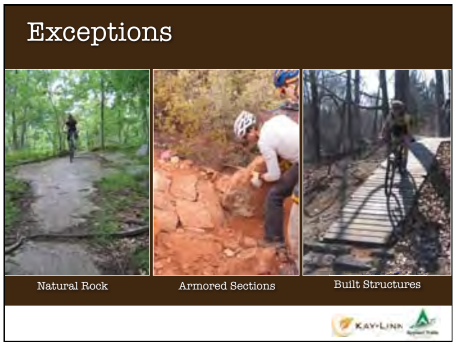
2. This determines the maximum trail tread grade

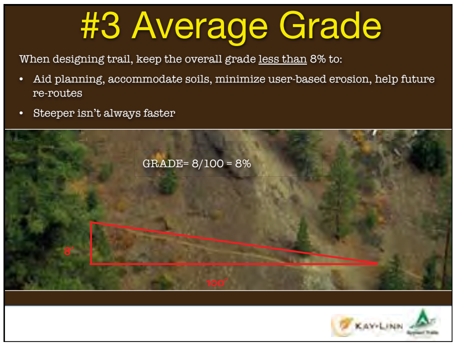
Problem?

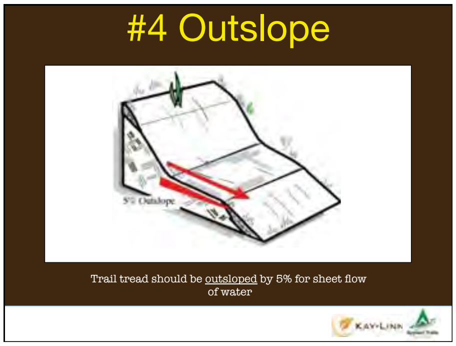
- What is our Grade?

5


#2 User-Based Erosion
On typical soil surfaces, the maximum trail tread grade should not exceed:
15% Hike and Bike
8% Equestrian and Motorized
The maximum trail tread varies depending on soil type.
Fort Myers, FL

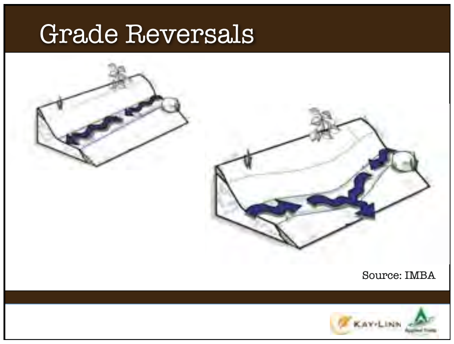

Exceptions
Natural Rock
Armored Sections
Built Structures


#3 Average Grade
When designing trail, keep the overall grade less than 8% to:
• Aid planning, accommodate soils, minimize user-based erosion, help future re-routes
• Steeper isn't always faster
GRADE= 8/100 = 8%

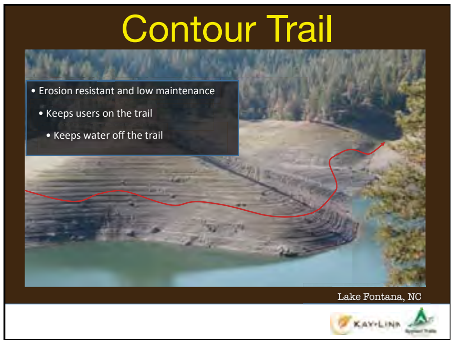

#4 Outslope
5% Outslope
Trail tread should be outsloped by 5% for sheet flow of water


Sheet Flow


#5 Grade Reversals
Creating microwatersheds along the trail


Grade Reversals
Source: IMBA


Fall-Line vs. Sidehill


Contour Trail
• Erosion resistant and low maintenance
• Keeps users on the trail
• Keeps water off the trail
Lake Fontana, NC

6/30/16


Science and Practice Agree
• Keys to sustainable trails are managing:
– Water
– Users


Trail Construction


Trail Construction
• Extremely satisfying- creation of a facility that will outlast every other human-built structure in the park
• Responsibility- a bad trail is a scar that could last equally long as the artisanal product of a great trail
• Perspective- dependent on a knowledgeable crew that understands all the aspects of good design and construction


Tools
• The Mind- high quality trails are built by crew members that understand how the trail will interact with the surrounding landscape
• The Body- trail construction is an athletic endeavor and can make or break a body
• The Tools- like the body and mind, tools need to be specific to the job at-hand and must be properly maintained for efficiency in production


Hand Tools- Trail Corridor
• Sharp, ergonomic, packable
1: hand saws, remove only what is necessary to meet specifications
2: long-handled, strong loppers for branches impeding the trail corridor
3: pole saws for removing impeding higher limbs
4: chain saws, only when larger trees need to be removed
5: pulaskis for grubbing stumps


Hand Tools- Initial Tread
• Sharp, largest blade possible, varying lengths
1: Hoes to move tread and backslope material efficiently
2: Pick mattocks for removing rocks
3: Flat shovels to disperse excavated materials
4: Round shovels to add rock or other fill materials
5: Bow rakes to initially smooth tread and spoils

8

Hand Tools- Final Tread

- Light, long, and flat
  - 1: McLeods for defining the tread, backslope, and critical edges
  - 2: leaf rakes for smoothing edges and spoil stabilization/ seed bank reintroduction
  - 3: hand clippers to remove finger roots in tread and backslope

Mechanized Tools

- Used like very strong hands
  - Diggers
  - Pushers
  - Carriers
- Smallest, strongest tool for the job
  - Width makes a huge difference in impact prism and experiential quality
- Safety is #1 priority
  - Majority of machines are not meant for work off of level surfaces or with numerous lateral and overhead obstructions
  - Damage to body or resources are exponential

Mechanized Tools

- Additional Needs
  - Mechanical knowledge
  - Extra fuel, fluids, grease, fuses, hoses
  - Fire extinguishers
  - Spill kits
  - Specific PPE
  - Specific tools
- More machines
  - Often needed to clean up behind lead machine
- Hand crews
  - Very difficult to get around not needing hand labor

Diggers

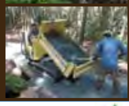
- Mini and micro excavators
  - Zero swing rear end
  - Adjustable tracks
  - Toothed bucket to get under roots and rocks
  - Small buckets to minimize swing loads
  - Grading buckets/blades (micros)
  - Thumbs for grabbing logs and rocks
- Smaller crews, slower speeds
- Higher level training needs

Pushers

- Stand-on
  - Ditchwitch, Vermeer, Bobcat, Toro
  - Multiple attachments for various park management tasks
  - Used like a vacuum or lawn mower
  - Lighter impact when off-trail
  - Lower level needs for training and competent operation
- Sit-in
  - Sutter, Sweco, ASV, Bobcat
  - More power and low center of gravity
  - More damage potential

Carriers

- Walk behind
  - Low cost
  - Truck bed-ready
  - Volunteer operable
  - Generally slow
  - Limited load capacity
- Stand on
  - More expensive
  - Fits on trailer with another small machine
  - Walking speeds
  - Best for park crews with some machine training
- Sit in
  - Fill entire trailer
  - Fast, with large load capacity
  - Trained machine operators



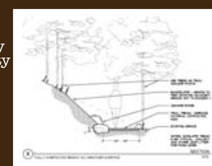
6/30/16

Trail Construction

- Trail corridor brushing and clearing
- Trail tread excavation
- Trail tread shaping
- Spoils management and stabilization
- Feature development

Trail Corridor

- Developed based on corridor flagging
- Transitions and/or alterations will gentle curves
- Balance between efficiency of construction with quality of trail experience (i.e. blowdowns, large rocks, dense understory
- Generally a couple feet wider than trail tread and estimated backslope
- 8' high for hikers, bikers and 12' high for equestrians



Trail Corridor

- Non-native species removal opportunity
- Cut stems at waist height for ease in root ball removal
- Buck cut material
- Rake organic matter uphill of tread/backslope prism
- Remove lateral branches at base of stem, notching larger stems from bottom to avoid bark peel
- Excavate stumps prior to hand construction
- Hazard tree decisions

Trail Corridor

Trail Corridor

Tread Excavation

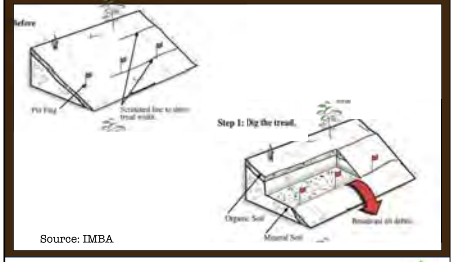
- Dictated by staking/flagging, even with experienced crews
- Rolling contour with grade reversals are essential and developed at this phase
- Full bench construction on mineral soils
- Move excavated tread and backslope material downslope of critical edge for dispersal
- Smooth tread and backslope and add material to off-trail spoil piles

10

Full Bench Construction

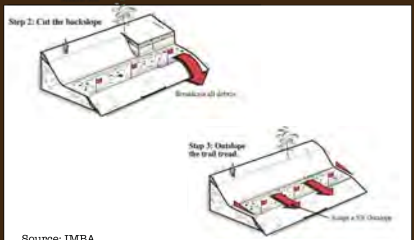
- Dictated by staking/ flagging, even with experienced crews
- Rolling contour with grade reversals are essential and developed at this phase
- Full bench construction on mineral soils
- Move excavated tread and backslope material downslope of critical edge for dispersal
- Smooth tread and backslope and add material to off-trail spoil piles

Full Bench Construction - Step 1



Source: IMBA

Step 2 & 3



Source: IMBA

Tread Excavation

Tread Excavation

Tread Excavation

Tread Excavation

Tread Excavation

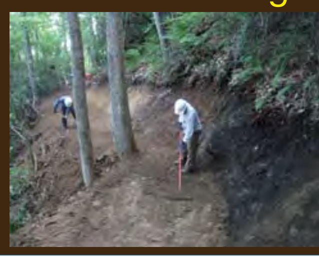
Tread Excavation

Tread Finishing

- Establish positive outslope to maintain sheet flow drainage
- Smooth tread/backslope to facilitate relatively uniform compaction
- Define downslope critical edge and upslope hinge point
- Remove finger roots to aid in compaction
- Compact tread, leave backslope

Tread Finishing

Tread Finishing



6/30/16


Spoils Stabilization
• Rake down spoils to a layer thin enough to allow existing vegetation to grow
• Disperse bucked corridor vegetation so that no wind row is present
• Rake down stockpiled leaf and organic material onto backslope and across tread to spoils location


Spoils Stabilization


Spoils Stabilization


Finished Product


Finished Product


Trail Maintenance
Managing Water, Managing People

13

6/30/16

Trail Maintenance

- All maintenance activities need to begin with a trail- or system-wide maintenance needs assessment
- Prioritization based upon safety/hazard management, followed by resource management concerns, and finally user experience issues
- Optimization based on number of issues that can be addressed in the shortest period, lowest cost, efficiency of effort

Annual Maintenance

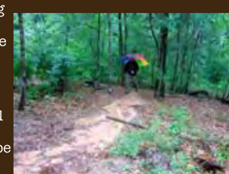
- Post-winter hazard tree assessment
- Trail corridor bucking of fallen trees
- Reestablishment of trail corridor specifications for lateral and vertical clearance
- Structure inspection
- While completing these tasks, it is the optimal time to assess and document the overall maintenance needs across the trail system

Managing Water

- Water creates the vast majority of trail issues
- 5% or less of events cause 95% of the damage
- Two potential issues: volume and velocity
- Treat the problem, not the symptom- water issues need to be addressed as close to source as possible with additional measures implemented as often as necessary
- Water needs to be "invited" off the trail rather than forced

Rolling Grade Dips

- A structure than mimics highly sustainable rolling contour trail
- Begin placement near the top of the hill or water source
- Locate dips where water continues to move in a straight line and the trail curves away
- Adjacent slope needs to be steeper than the trail tread or the maximum steepness present

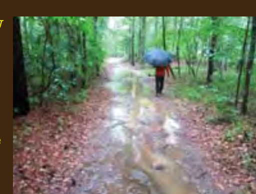


Rolling Grade Dips

Source: IMBA

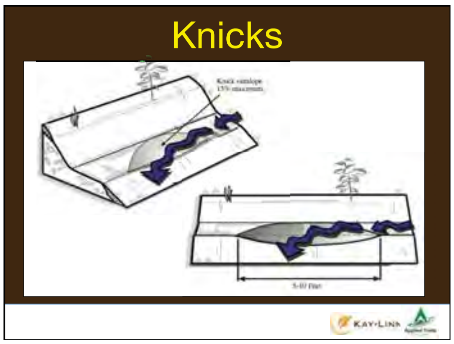
Knicks

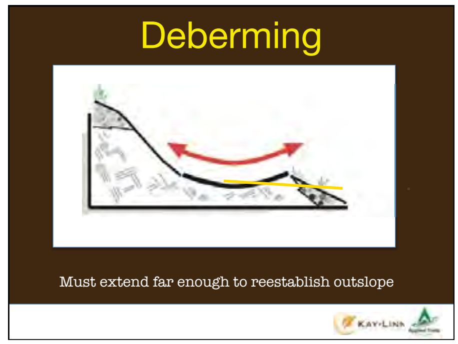
- A structure constructed at a low point in the trail where water is ponding
- Must have positive drainage relative to the trail tread gradients that are feeding water to the area
- Optimized locations for deberming, especially with equestrian trails

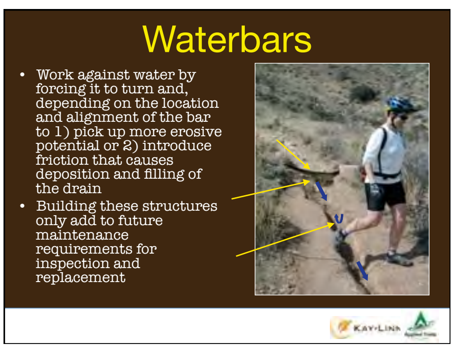


14

6/30/16


Knicks


Deberming
Must extend far enough to reestablish outslope


Waterbars
• Work against water by forcing it to turn and, depending on the location and alignment of the bar to 1) pick up more erosive potential or 2) introduce friction that causes deposition and filling of the drain
• Building these structures only add to future maintenance requirements for inspection and replacement


Waterbars


Maintenance 2.0
• When standard water management is not working…
1: Armoring the trail
2: Raising the trail
3: Relocating the trail
4: Abandoning the trail
5: Restoration of existing impacts


Armoring The Trail
• Relatively large labor commitment per linear foot of trail
• Non-engineered "structure" doesn't require the same level of inspection
• Technique of choice when natural rock is present
• Ideal for low or limited flow situations
• Best accomplished when conditions are moderately dry and tread is moderately firm rather than when trail conditions are wet or unconsolidated

15

Armoring The Trail: Basics

- Efficiency in sourcing rock is the primary factor in decision on rock technique
- Periodic "dead man" placement on ends and throughout armoring section
- Avoid aligning "joints" between rocks to reduce weak areas
- Rocks need 3 points of contact for stability
- The more rock underground, the more resilient the tread
- Trail users often need "guide structures" when rocks are uneven or large

Stone Pitching

- Ancient road building technique with many existing examples that are 100's of years old and have seen almost no maintenance
- Uses small, irregular rocks-easy to source
- Does not require significant masonry skills
- Dig trench, place anchor stone, stack the rocks like books in a shelf
- Fill and compact pore spaces with highest mineral content soil available

Stone Pitching

Source: IMBA

Stone Paving

- Larger rocks needed
- Aesthetically pleasing product
- Requires higher level training, experience, and more tools (bars, hammers, picks) and experience to "fit" rocks.
- Shaping rocks that don't fit is time consuming
- Largest rocks are placed first
- Smaller rocks wedged into pore spaces only, not on edges

Stone Paving

Boulder Causeway

- Largest rocks, typically only effective if they are larger than "one-person" rocks
- Most aesthetically impressive of tread hardening techniques
- Require additional training, coordination for safety and tools (haulers, straps, grip hoists)
- Can often be used to add a more challenging feature adjacent to the trail with only one or two rocks moved

6/30/16

Retaining Walls

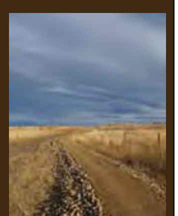
- Only for switchback deck development on slopes greater than 30% or degrading tread on sideslopes greater than 70%
- Not for cut-and-fill of partial bench construction unless needed for safety or resource protection reasons
- Very time consuming and requires significant experience to build properly

Retaining Walls

- Build up a rock cache-gather or transport approximately 30% more rock than necessary- fit issues
- Rock delivery in downhill direction
- The bigger the rock, the better the wall, but more safety issues in construction
- Base course almost entirely subsurface
- Batter (leaning into hill) needed to reduce lateral stress
- Constant compaction of fill

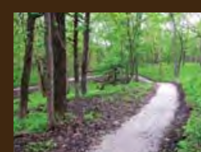
Raising The Trail

- Relatively large labor commitment per linear foot
- Engineered "structure" with wood and fasteners require additional level of inspection and maintenance
- Technique of choice when amounts of natural rock are not present
- Ideal for higher or consistent flow situations
- Best accomplished when conditions are moderately dry and tread is moderately firm rather than when trail conditions are wet or unconsolidated



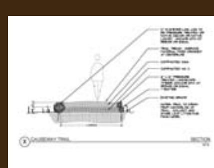
Raising The Trail: Basics

- Establish the lateral extent of raised trail needed during a very wet period
- Then, add 25% or more more distance to each end to account for saturated soils
- Establish the vertical clearance needed to never impede flow
- Ground contact-ready materials and fasteners or rock abutments
- Multiple drainage options throughout course



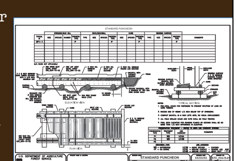
Rock/Log Turnpike

- Most efficient technique when rock and appropriate fill is available
- Appropriate technique for flat terrain that is periodically saturated
- Large rock needed
- Create "tub" for fill material with armored open or closed drains
- Fill and compact with mineral soil and any additional rock available
- Crown for drainage of precipitation



Puncheon

- Most efficient and effective technique when rock and/or appropriate fill is not available
- Essentially a low bridge resting on mud sills-materials must be chosen for a wet environment-engineering may be needed
- Rough cut materials provide best traction
- Mud sill placement at localized "high" spots
- Curves add naturalness or avoid obstacles along the course



17

Corduroy

- Logs laid side by side to create a harder trail surface on wet ground
- A temporary solution ONLY
- Does not solve drainage issue and likely makes situation worse
- Wood rots quickly in wet environment
- Not secured to ground and may provide safety issues

Culverts

- Engineered structures that require annual or more frequent inspection
- Improper alignment often results in hydraulic "jump" that obstructs upstream aquatic movement
- Woody material often blocks downstream water movement
- Solutions include employing oversized half-culverts for aquatic substrate maintenance

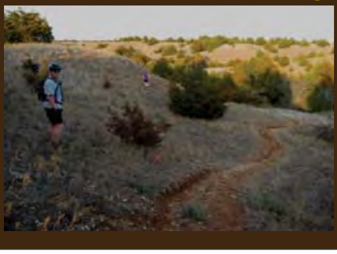
Trail Relocation

- Additional construction impacts must be weighed against long-term maintenance needs
- Often requires broader assessment of trail experiences and system navigation/connectivity- can solve multiple issues with one relocation
- Trail closure and restoration are as important as the new trail construction
- Public education is often necessary early in the process

Trail Relocation Design

- Begin relocation at a natural location and prior to the largest problem areas
- Specifications and trail experience should be retained with new trail
- New destinations should be sought, especially if strong features are being abandoned

Trail Relocation Design



Trail Relocation Design

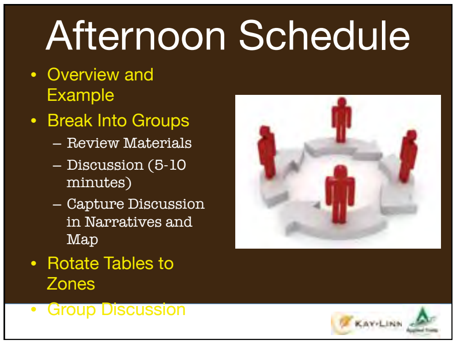

Trail Relocation Design


Trail Relocation Design

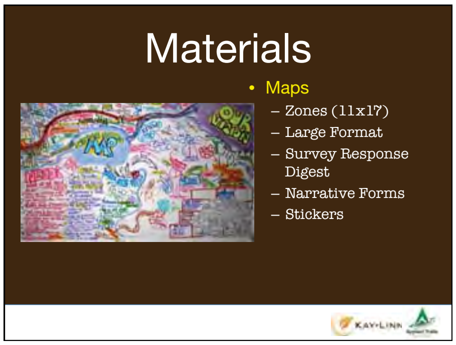

Maintenance 3.0
• Turns
• Mechanized Construction
• Road To Trail Conversion
• Advanced Feature Development

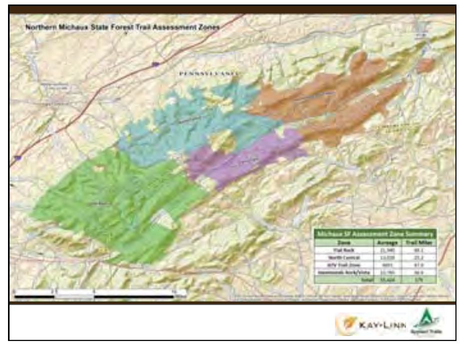

Thank You


Planning Workshop


Afternoon Schedule
• Overview and Example
• Break Into Groups
– Review Materials
– Discussion (5-10 minutes)
– Capture Discussion in Narratives and Map
• Rotate Tables to Zones
• Group Discussion

6/30/16

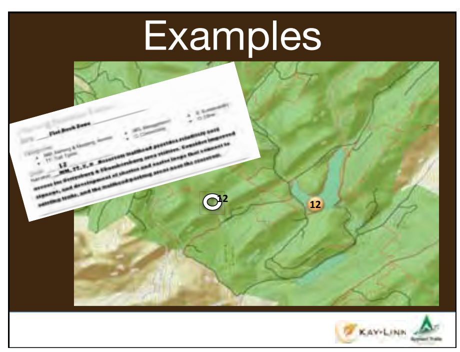

Materials
Maps
Zones (11x17)
Large Format
Survey Response Digest
Narrative Forms
Stickers
KAY-LINN


Northern Michaux State Forest Trail Assessment Zones
KAY-LINN


KAY-LINN


Survey Response Digest
Quotes distilled from Survey Responses
Categories
Marking, Mapping
Management
Sustainability
Connectivity
Trail Types
KAY-LINN


Narrative Forms
Categories
Marking, Mapping
Management
Sustainability
Connectivity
Trail Types
Other
KAY-LINN


Examples
12
KAY-LINN

20

Appendix B:

ASSESSING THE INFLUENCE OF SUSTAINABLE TRAIL DESIGN AND MAINTENANCE ON SOIL LOSS

ASSESSING THE INFLUENCE OF SUSTAINABLE TRAIL DESIGN AND MAINTENANCE ON SOIL LOSS

Jeffrey L. Marion[1] and Jeremy Wimpey[2]

[1] U.S. Geological Survey, Virginia Tech, 310 W. Campus Dr., 304f Cheatham, Blacksburg, VA 24061, USA.
[2] Jeremy Wimpey, Applied Trails Research, P.O. Box 424, State College, PA 16804, USA.

Corresponding Author: Jeff Marion, jmarion@vt.edu, ph: 540-231-6603, fax: 540-231-3698

Abstract

Natural-surfaced trail systems are an important infrastructure component providing a means for accessing remote protected natural area destinations. The condition and usability of trails is a critical concern of land managers charged with providing recreational access while preserving natural conditions, and to visitors seeking high quality recreational opportunities and experiences. While an adequate number of trail management publications provide prescriptive guidance for designing, constructing, and maintaining natural-surfaced trails, surprisingly little research has been directed at providing a scientific basis for this guidance. Results from a review of the literature and three scientific studies are presented to model and clarify the influence of factors that substantially influence trail soil loss and that can be manipulated by trail professionals to sustain high traffic while minimizing soil loss over time. Key factors include trail grade, slope alignment angle, tread drainage features, and the amount of rock in tread substrates. A new Trail Sustainability Rating is developed and offered as a tool for evaluating the sustainability of existing trail systems or improving the sustainability of newly designed trails.

Keywords: Recreation impact, trail impact, trail erosion, sustainable trail design, trail maintenance.

1.0 INTRODUCTION

Achieving conservation objectives in protected natural areas requires the ability to sustain visitation while avoiding or minimizing adverse environmental impacts. While roads provide visitor access to protected natural areas, trails are often the predominant means of access within protected areas. Some trails, such as the Appalachian National Scenic Trail in the U.S., the Via Alpina and Grand Randonnée 20 trails in Europe, and the Overland Track in Australia, are themselves a primary attraction feature that draws visitation to protected natural areas. Trails are an essential infrastructure component that can minimize resource impacts by concentrating traffic on hardened treads sustainably designed and maintained to limit the areal extent and severity of resource impact. In this paper we define a sustainably designed trail as one that limits both trail degradation and annual maintenance while accommodating its intended amount and type of use.

Concentrated traffic from hikers, backpackers, mountain bikers, and horse riders on natural surfaced trails removes or prevents vegetative and organic litter cover on treads, compacts substrates, and increases water runoff and the erosion of soil (Hammitt and Cole, 1998; Marion et al., 2016; Whinam and Chilcott, 2003; Wilson and Seney, 1994). Trails in flat terrain can also suffer from trail widening, braiding, and muddiness (Leung and Marion, 1996; Wimpey and Marion, 2010). From a conservation perspective, the loss of soil is perhaps the most significant form of environmental impact because it is long-term or irreversible without substantial management action, and eroded soil can enter waterways, causing secondary impacts to aquatic environments (Marion et al., 2016; Olive and Marion, 2009). The rutting, exposed roots and rocks, and tread roughness caused by soil loss also: 1) increases the difficulty of hiking or riding, 2) diminishes aesthetic qualities, 3) impedes maintenance efforts to remove water from incised treads, and 4) contributes to trail widening, expanding the total area of disturbance associated with trail networks, (Marion et al., 2016). While some of these environmental impacts are unavoidable, excessive impacts threaten resource protection values, visitor safety, and the quality of recreational experiences.

Trail degradation, particularly soil loss, is a complex process. Soil scientists have developed a number of soil erosion models for agricultural settings, beginning with the universal soil loss equation (USLE) and later improved as the RUSLE (Renard et al. 1997). The models predict average annual soil loss based on six factors, including soil erodibility, rainfall erosivity, topography (slope length and steepness), cover management, and support practice. These models and others (e.g., the Water Erosion Prediction Project for forest roads, WEPP_Road) have been adapted and applied to forest roads (Croke and Nethery 2006, Rhee et al. 2004, Wade et al. 2012), and even to unsurfaced trails (Aust et al. 2004, Kidd et al. 2014).

Recreation ecology studies have also investigated numerous factors that influence trail soil loss, including use-related factors such as the amount, type, and behavior of trail users, environmental factors such as soil and vegetation abundance and type, and managerial factors such as trail design, construction, maintenance, and visitor use regulation and education programs (Leung and Marion, 1996, 2000; Newsome et al., 2001; Olive and Marion, 2009; Ramos-Scharrón et al., 2014). Much of the existing research has focused predominantly on use-related and environmental factors (Farrell and Marion, 2002). Few studies have investigated the influence of managerial actions, though they have considerable potential for modifying the roles of use-related and environmental factors (Leung and Marion, 1996; Marion and Leung, 2004; Marion, 2016). Among managerial factors, research attention has focused on design attributes, primarily trail grade, and less frequently on trail slope alignment, tread drainage, and tread surfacing (Olive and Marion, 2009). For example, we found only two studies that evaluated the effectiveness of alternative tread drainage actions on soil loss (Marion, 1994; Grab and Kalibbala 2008).

Sustainable trails are designed, constructed, and managed to accommodate their intended types, amounts, and seasons of use to provide high quality visitor experiences while protecting the trail infrastructure and adjacent natural resources. Existing research suggests that trail design, a trail's siting and alignment relative to topography and soils, is the most important factor influencing long-term sustainability (Marion, 2016; Marion et al., 2011; Olive and Marion, 2009; Ramos-Scharrón et al., 2014). Poorly designed trails deteriorate quickly under traffic, unnecessarily degrade the local environment, and are more difficult to use and manage, requiring substantially greater maintenance effort (Marion and Leung, 2004). Such trails are unsustainable unless extensively hardened, or tread degradation is likely to be severe and unacceptable.

This paper investigates the influence of selected managerial factors on trail soil loss through regression modeling and analyses of trail datasets from research conducted at the Hoosier National Forest (Indiana), Big South Fork National River and Recreational Area (Tennessee), and Acadia National Park (Maine). Data from these protected natural areas are used to evaluate similarities and differences in findings and to gain improved insights from different environmental settings and trail design and management practices.

2.0 LITERATURE REVIEW

This review focuses on several managerial factors pertaining to the design and maintenance of sustainable trails, including trail grade, trail slope alignment angle, trail drainage, and trail substrates.

2.1 Trail Grade and Slope Alignment

The slope or grade of a trail and its alignment relative to local topography are determined when it is laid out or created by visitor use, hence our inclusion of these attributes as managerial factors. Numerous studies have examined the influence of trail grade on tread soil loss and found a strong positive relationship (Farrell and Marion, 2002; Helgath, 1975; Olive and Marion, 2009). The authors note that statistical modeling by Dissmeyer and Foster (1984) reveal that soil erosion rates become exponentially greater with increasing trail grades, particularly above 10%. These findings can be explained by the greater velocity and erosivity of running water on steep slopes as shown in soil erosion models (Renard et al. 1997), and by increased slippage or gouging of feet, wheels, and hooves that displace soil down-hill (IMBA, 2007; Leung and Marion, 1996).

Numerous trail maintenance books offer guidance regarding maximum trail grades to minimize soil loss on trails, though none appear to be based on empirical data from scientific studies. Some recommended maximum trail grades are 10% (Hooper 1988), 12% (Agate, 1996; Hesselbarth et al., 2007, National Park Service, 2007), and for horse trails 9% (Vogel, 1982), 10% (Wood, 2007), and 5-12% (Hancock et al., 2007). These values are generally applicable for medium-textured soil substrates; many authors suggest steeper grades are acceptable over short distances, particularly if they have sufficient native or applied rock to deter tread displacement and erosion. Regression modeling by Olive and Marion (2009) found trail grade to significantly influence soil loss, with substantially greater soil loss at grades above 11%.

Parker (2004) provides guidance on maximum permissible tread lengths between trail dips and crests based on trail grade and substrate texture, though empirical data are not cited as a basis. The IMBA (2007) suggests a maximum sustainable grade as low as 5% for sandy/fragile soils, 10% for loamy/mixed textures, and 15% for rocky or durable soils. Again, no empirical data are cited as a basis for this guidance. This reference and the widely cited Trail Solutions book (IMBA, 2004) highlight the need to consider an array of variables in determining maximum sustainable grades, including trail alignment relative to the landform slope (discussed below), frequency of grade reversals, soil and vegetation type, and type or number of trail users and trail difficulty.

IMBA (2004, 2007) promotes the "10% Average Guideline," which suggest that trails with an average or overall grade of 10% or less will generally be sustainable. The average grade is calculated by summing elevation gain for sections of the trail that are consistently climbing, dividing by trail length, and multiplying by 100. This guidance can be difficult and/or inaccurate to apply when a trail alternately ascends and descends or when exceptionally steep trail grades are offset by large portions with low grades. Such guidance is most easily applied when comparing alternative trail alignments on topographic maps or with Geographic Information System (GIS) software; application in the field with clinometers, tape measures, and flagging tape presents greater difficulty.

A trail design factor that receives considerably less attention by trail professionals and scientists is what Leung and Marion (1996) term trail slope alignment angle (TSA). This indicator is assessed as the smallest difference in compass bearing between the prevailing landform slope (aspect) and the trail's alignment. The TSA of a contour-aligned trail would equal 90^{o}, while a "fall-line" trail (aligned congruent to the landform slope or aspect) would have a TSA of 0^{o}. Trail alignments with low TSA's more directly ascend slopes and their adjacent side-slopes are relatively flat in reference to the plane of the trail tread (Figure 1). Such alignments are highly susceptible to degradation because initial traffic displaces or compacts soil, incising the tread, which then transports water that contributes to erosion in sloping terrain and muddiness in flat terrain (Basch et al., 2007; Olive and Marion, 2009; Wimpey and Marion, 2010). Tread water drainage features are difficult or impossible to install and are often ineffective in removing intercepted water from treads with low slope alignments (TSA of 0-22^{o}) because both side-slopes are higher in elevation (Figure 1) (Leung and Marion, 2004; Wimpey and Marion, 2010). Additionally, the side-slopes of fall-aligned trails also offer no resistance to lateral visitor traffic, so trail widening is a common problem.

In contrast, trails that more closely follow the contour of the surrounding topography, termed "side-hill" trails, always have one lower side-slope to drain water from out-sloped treads or drainage features (Figure 1). While side-hill trails have larger uphill watersheds and will intercept more water than fall-aligned trails, it's substantially easier to shed water from side-hill treads. Side-hill trails also rarely become muddy as maintainers can generally excavate through trailside berms to drain tread water to the lower side-slope. The adjacent sloping side-hill areas also naturally act to concentrate traffic on the tread, which effectively limits trail widening.

Regression modeling by Olive and Marion (2009) determined that TSA has "a major and robust influence" on trail soil loss. TSA's influence on soil loss was more significant than trail grade, with regression modeling revealing a diminished but still significant "trail grade" influence after TSA was added to the regression model. Results from statistical modeling of soil loss supported earlier speculation by Leung and Marion (1996) that: "the importance of slope alignment angle increases in its significance as trail grade increases." The authors also found that horse and ATV use caused significantly greater trail damage by erosion on trails closely aligned to the fall-line than either hiking or mountain biking, with a suggestion to keep horse and ATV trail alignments greater than 48^{o}. In summary, we conclude that increasing TSA values contribute to increasing trail sustainability, minimizing soil loss, muddiness, and tread widening. Furthermore, the positive influence of higher TSA values increases with increasing landform grade (less muddiness, trail widening, and soil loss), while the negative influence of lower TSA values increases with increasing trail grade (steeper fall-aligned trails erode more quickly) (Figure 2).

While many trail guidance publications recommend side-hill trail alignments and include warnings to avoid routing close to the fall-line, most give this topic scant treatment relative to their substantially greater focus on trail grade. The IMBA publications (2004, 2007) highlight the traditional trail grade recommendations but also developed the “Half Rule” guidance, which recommends trail grades should not exceed half the grade of the landform being traversed. This guidance is widely applied for all types of trails but no research is cited in support of the selection of 50% versus some other value. Computed by dividing trail grade by landform grade, Half Rule slope-ratio values should not exceed 0.5. A trail on a landform or “side-slope” grade of 20% should have a grade of ≤10%, which has the primary effect of preventing trails from being aligned close to the fall-line. Other organizations recommend more conservative slope-ratio guidance, suggesting a limit of 0.33 (Minnesota DNR, 2007). Slope ratios can be easily calculated in the field when flagging new trails, or assessed through point sampling surveys of existing trails to evaluate their sustainability. For example, our survey of trails in Great Falls Park, VA, found that half of all sample points had a slope ratio ≥0.75, indicating a large proportion of this trail network is aligned too close to fall lines (Wimpey and Marion, 2011).

The Half Rule is similar to TSA in that it assesses how a trail is aligned relative to the landform slope, employing the quotient between trail and landform grades instead of the smallest difference between their compass bearings (azimuths) (Wimpey and Marion, 2011). IMBA (2007) notes the need for exceptions to the Half Rule on particularly steep landforms, for example a landform with 50% grade would allow an unsustainable 25% grade trail. They advocate applying a maximum trail grade in such instances, recommending that most trail grades should “never exceed 15%, even if a steeper trail would meet the Half Rule” (IMBA, 2007).

2.2 Trail Drainage

One objective of sustainable trail design and management is a goal to create trails that are hydrologically invisible, with a goal of minimizing the diversion and concentration of surface water runoff. Tread drainage features have been a traditional method for removing water from trails, generally constructed by excavating tread substrates to create an angled drainage ditch (Birchard and Proudman, 2000; Birkby, 2005; Demrow and Salisbury, 1998). These include drainage dips constructed with a ditch backed by a mound of soil, water bars backed and armored with wood or stonework to extend their life (Figure 3a), and less commonly, flexible rubber “wheel friendly” water bars (Minnesota DNR, 2007). These features are installed during construction or subsequent maintenance to intercept and drain surface runoff from treads, with the number and spacing of features matched to trail grade and substrate erosivity (Parker, 2004; Forest Service, 1991).

Minimal research has been applied to evaluate the efficacy of tread drainage features. A survey of 528 km of hiking and horseback trails in Great Smoky Mountains National Park rated the perceived efficacy of drainage dips (unarmored) and water bars (armored with rock or wood, Figure 3a) in removing water from treads (Marion 1994). A total of 4,137 drainage dips and 3,804 water bars were assessed (mean=10.6/km and 6.6/km, respectively), with a larger percentage of water bars judged to be very effective (44%) compared to drainage dips (20%). While factors such as rating subjectivity and the relative ages, quality of installation, and annual maintenance confound such evaluations, the extremely large number of features evaluated and considerable diversity in soil types, elevations, trail grades and expertise of installers and maintainers lends veracity to this finding. Mende and Newsome (2006) assessed the condition and effectiveness of tread drainage features on 32.7 km of trails in Stirling Range National Park, Western Australia. While 87% of the water bars were judged to be in good condition, only 13% were judged to be very effective in removing water from treads, suggesting improper and unskilled installation. When tread drainage features fill up and fail the slope-length increases, thus increasing soil erosion during rain events. Dixon and Hawes (2015) noted that water bars had prevented erosion along some segments, while active erosion occurred within segments that lacked such features.

Water can also be drained from side-hill trails by shaping the tread (out-sloping, in-sloping, or crowning) (Birchard and Proudman, 2000; IMBA, 2004; Parker 2004) (Figure 2b). Authors most commonly recommend out-sloping treads to the downhill side 2-3% for hiking trails and 5% for mountain biking trails to promote tread drainage (Minnesota DNR, 2007). However, all tread shapes constructed to shed water rarely maintain their constructed profiles over time: tread compaction, soil displacement from traffic, soil erosion, and the development of a berm along the lower trail edge soon act to keep water on the trail (Parker, 2004).

Side-hill trails that roll up and down along the contour, or that have substantial grade reversals designed and built into the tread (Figure 3b), are the most permanent, effective, and sustainable practice for draining water from trails (Hesselbarth et al., 2007; IMBA, 2007; Parker 2004). Known variously as terrain dips, rolling grade dips, or simply grade reversals, these features temporarily reverse the trail grade to shunt all water from treads and require little maintenance (IMBA, 2007; Hesselbarth et al., 2007).

2.3 Trail Substrates

Soil texture is another core factor that substantially influences the sustainability of a trail to accommodate traffic without degradation. A wide range of soil particle sizes comprise trail treads, ranging from fine-grained clay, to silt, sand, and rock (gravel, stone, bedrock). Differing proportions of these constituents have widely varied properties relating to how easily trail substrates compact, are displaced by traffic, or are eroded by water or wind. Fine-textured substrates compact and resist displacement when dry but can retain and puddle water and promote muddiness when wet. Coarse-textured substrates are well-drained but more easily displaced by traffic (Parker 2004), unless rock components are angular and/or large in size. The best tread substrates include a wide range of particle sizes, including angular rocks and gravel to support heavy traffic and resist displacement and erosion, sand to promote drainage, and silts and clay to act as binders promoting cohesion.

When trail design is constrained or insufficient to create a sustainable trail, managers can apply trail construction and maintenance practices, including application of stonework or gravel to harden trail treads (Figure 4). Research has shown that trail substrates with a high rock or gravel content are less susceptible to soil erosion and better able to sustain heavy traffic, particularly by horses (Bryan, 1977; Weaver and Dale, 1978). A four-year study of primitive forest roads used for logging and recreation found that non-graveled roads lost 112 metric tons/ha/year of substrates while graveled roads lost only 13.5 metric tons/ha/year (Kochenderfer and Helvey, 1987). Tread substrates with substantial rock and gravel content are also less easily displaced by recreational traffic, and these materials can act as filters, retaining and binding finer soil particles (Aust et al. 2004).

Crushed gravel is a commonly used amendment on frontcountry trails but is considered less appropriate in backcountry areas, and generally inappropriate in wilderness unless locally-sourced. For example, hikers on a popular, highly accessible trail in Acadia National Park found the use of gravel and dimensional plank boardwalks to be acceptable, while hikers visiting a remote backcountry area disapproved of such treatments

(Cahill et al., 2008). Managers on the Hoosier National Forest experienced substantial public opposition to the use of gravel to harden backcountry multi-use trails (Wadzinski, 2000). Aust et al. (2004) suggest that mixing gravel with native soil prior to application can be an effective practice for hardening trail treads while alleviating aesthetic objections.

Crushed gravel is an effective amendment on horse trails (Wood, 2007). When applied with the fines from the crushing process it forms a highly resistant tread substrate, particularly when dry. The material is more easily displaced when wet by the heavy weight of horse and rider. It's efficacy in limiting erosion on steeper trail grades has not been sufficiently investigated, though some guidance suggests it can be applied to slopes up to 16% when stone anchors and sufficient drainage are also incorporated (The Footpath Trust, 1999). Additional means to increase efficacy include integrating the aggregate with geotextiles, using angular crushed stone with crusher fines retained, and shifting to coarser materials on steeper slopes (Meyer, 2002; The Footpath Trust, 1999). However, coarser materials (>4 cm) can be harmful to horses and have lower trafficability to most trail users.

Various types of well-anchored rockwork, including stone pitching, tread armoring, and rock steps, are common tread hardening techniques used to deter erosion on steeper trail grades (Demrow and Salisbury, 1998; The Footpath Trust, 1999) (Figure 4a). This practice replaces erodible substrates with rockwork on wet or steeply graded trail segments particularly prone to erosion. No studies evaluating the long-term efficacy of employing rockwork to limit trail erosion could be found.

3.0 METHODS

3.1 Study Sites

Data presented in this paper are from three study areas:

Hoosier National Forest (HNF) in south-central Indiana with 81,014 ha and 352 km of trails open to mixed uses. HNF visitation data from 2004 show that these trails received approximately 100,918 hikers, 32,625 horseback riders, and 3,227 mountain bikers (Forest Service, 2005; Strout, 2005). The terrain is characterized by hardwood forests on rounded hills underlain by limestone, with loess soils that have silt loam textures.

Big South Fork National River and Recreational Area (BSF) in north-central Tennessee and south-central Kentucky with 50,990 ha and over 365 km of single and multi-use trails. BSF receives approximately 700,000 visitors annually (Marion and Olive, 2006), most of which use some portion of the trails to hike, horseback ride, mountain bike, or ride ATV's. Predominantly hardwood forests cover a tableland underlain by resistant sandstone, shale, and dry sandy soils, carved by erosion into impressive cliffs, arches and chimneys and steep-walled gorges.

Acadia National Park (ANP), in the central coast of Maine, has 13,300 ha and 183 km of hiking trails, most of which were crafted 90-130 years ago. ANP received approximately 2.2 million visitors in 2007 (Marion et al., 2011). The glacially shaped terrain is highly varied; beaches and cliffs along the rocky coastline give way to steep ridges of exposed granite bedrock and thin, coarse soils, interlaced with woodlands and open shrub communities.

3.2 Trail Selection

In HNF, a systematic sample of horse trails was conducted, with representative stratifications of tread substrate (graveled and non-graveled) and three levels of use (low, moderate, and heavy). The resulting sample included 58 km (18%) of the forest's horse trails. In BSF, a use-type stratified random sample yielded 126 km of the park's trails and primitive recreational roads (24% of the total network), selected using the park GIS database and the SPSS Random Sample procedure. At ANP all trails (183 km) within the Mount Desert Island portion of the park were surveyed.

3.3 Field Procedures

For the sampled trails within each study area a point-sampling method using a systematic interval following a randomized start was used to locate transects along each trail where trail conditions were assessed (Marion and Olive, 2006). An interval of 152 m was used following guidance provided by Leung and Marion (1999). At each sample point, a transect was established perpendicular to the trail tread with endpoints defined by visually pronounced changes in non-woody vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is minimal or absent, by disturbance to organic litter. The objective was to define the trail tread that receives the majority (>95%) of traffic, selecting the most visually obvious boundaries that can be most consistently identified. Temporary stakes were placed at these boundaries and the distance between was measured as tread width. At BSF, the percentage of this width with visible human-placed gravel was estimated to the nearest 5%. At HNF, the depth of human-placed gravel was measured at the center of each transect. At ANP, trail substrate class was assessed as natural, graveled, stonework, or bridge/boardwalk.

Soil loss at each transect was measured using a Cross-Sectional Area (CSA) method (Olive and Marion, 2009). A taut nylon line was stretched between the trail boundary stakes from their base at the ground surface. CSA was assessed by taking vertical measurements along the horizontal transect line at points directly above tread surface locations where changes in tread micro-topography occurred. Spreadsheet formulas were developed to calculate CSA based on these data. The total number of CSA soil loss measurements at each study area are: ANP (489), HNF (619), and BSF (827) for a total of 1935 measures.

Trail grade was assessed at sample points with a clinometer and TSA was assessed as the difference in compass bearing between the prevailing landform slope (aspect) and the trail's alignment at the sample point (Leung and Marion, 1996). The TSA of a contour-aligned trail would equal 90^{o} while a "fall-line" trail (aligned congruent to the landform slope) would have a TSA of 0^{o}. At HNF and BSF, tread drainage was assessed as the distance, in 7.6 m increments up to 30.5 m, to any tread drainage feature located in an upslope trail direction from the sample point. For more complete descriptions of sampling and field research methods, see the respective final research reports (HNF: Aust et al., 2005; BSF: Marion and Olive, 2006, and ANP (Marion, et al., 2011).

3.4 Data Analysis

Data were input into spreadsheets and imported into the SPSS statistical package for analyses. Multiple regression analyses were used to evaluate the influence of trail grade, slope alignment angle, tread drainage, and gravel (independent variables) on trail soil loss (CSA, dependent variable). Analyses were run separately for each study area. A stepwise method was used with the probability of F-to-enter of 0.05 (PIN) and the probability of F-to-remove of 0.10 (POUT). Two iterations of the equations were run, removing outliers whose standardized residuals exceed an absolute value of three. One-way analysis of variance (ANOVA) testing was used to evaluate the veracity of a trail Sustainability Rating developed to indicate the potential for soil loss on trails. This analysis employed the Least Significant Difference (LSD) post-hoc comparison test for mean values (alpha < .05). Two-way ANOVA tests were used to evaluate the influence of tread drainage features and gravel application on soil loss. Use of trade, product, or firm names does not imply endorsement by the U.S. Government.

4.0 RESULTS

4.1 Evaluating Trail Design and Maintenance

Trail surveys can efficiently provide a variety of information characterizing the sustainability of trails to accommodate use while minimizing degradation (Marion et al., 2012). As revealed in the Literature Review, research and the trail design literature commonly cite trail grade as a principal trail design attribute, and recent research is indicating the importance of TSA. Survey data from the study areas examined in this paper show substantial variation in both attributes for these three trail systems. Mean trail grade ranges from 4.3% for HNF, to 8.0% for BSF and 13.2% for ANP, and mean TSA values range from 32.4^{o} for ANP, 54.5^{o} for BSF, and 61^{o} for HNF. Table 1 presents the distribution of trail grade values in a cross-tabulation with TSA values, showing the percentage of the surveyed trail systems within each of 12 trail grade/slope alignment categories.

To summarize the implications of these trail design attributes and values, we developed a *Trail Sustainability Rating* index and assigned it to the matrix of trail grade and TSA values (Table 1). Applying guidance derived from published research, trail design and maintenance books, and our professional judgment, we suggest that optimal or “Good” trail alignments are those with grades of 3-10% and TSA values greater than 30^{o}. Trails with extremely low grades (0-2%) are potentially more susceptible to muddiness and trail widening so these were given a lower “Neutral” trail sustainability rating. A “Poor” sustainability rating was assigned to trails with optimal grades (3-10%) but the poorest TSA alignments (0-30^{o}), and to trails with alignments over 30^{o} but grades of 11-20%. Finally, trails with exceptionally steep grades (>20%), or with moderately steep grades (11-20%) but low TSA alignments (0-30^{o}), received a “Very Poor” trail sustainability rating (Table 1).

The Trail Sustainability Ratings reveal that 83% of the HNF horse trails have good or neutral designs with respect to grade and TSA, with only 3.7% rated as very poor (Table 1). At BSF, 68.4% of the trail system has sustainability ratings of good or neutral, with 6.9% rated very poor. Largely due to higher percentages of trails in the lowest TSA category, the ANP trail system has substantially lower sustainability ratings, including less than half (48.1%) with good or neutral ratings and 18.3% with very poor sustainability ratings.

The veracity of the Trail Sustainability Ratings in reflecting the soil loss potential of alternative trail alignments was tested with ANOVA for CSA soil loss. The tests for all three study areas were statistically significant (p<.001), with post hoc testing of mean values revealing significant increases in soil loss for trail alignments with Sustainability ratings progressing from neutral to poor, and from poor to very poor (Table 1).

Differences in CSA mean values for the good and neutral Sustainability Ratings were mixed, as expected, given that the neutral rating was applied to alignments with potential to suffer from trail widening or muddiness, rather than soil loss.

Trail survey data also provided information to characterize trail maintenance actions, including the spacing of tread drainage features and application of gravel. No tread drainage features were located within 30m of 75% of the sample points at HNF and within 92% of the sample points at BSF (drainage features were not assessed at ANP). U.S. Forest Service guidance on recommended drainage feature spacing by trail grade class for medium-textured soils was applied to the survey data for sample points on native soils on grades above 7% (Forest Service, 1991). Guidelines for grades below 7% could not be applied because the spacing exceeded 30 m, our maximum assessment distance for drainage features. This guidance recommends spacing tread drainage features 23 m apart on trails with grades between 7.1–9%. For HNF trails, 97 of 133 sample points (72%) exceeded the Forest Service tread drainage spacing guidance; for BSF trails, 332 of 346 sample points (96%) exceeded the recommended spacing.

Gravel was found on trails previously or currently used as primitive roads, and on trails where it was applied to harden substrates, improving their ability to sustain higher levels of traffic or the greater weight and ground pressure of equestrian traffic. At HNF, graveled trails were intentionally selected as one-half of the sample population, all of which were equestrian trails. Mean gravel depth for these trails was 7.5 cm. Two-way ANOVA testing revealed a significant relationship between increasing distance to tread drainage features and increased soil loss ($F=3.0$, $p=.050$, $df=2$), but the effect of gravel application was not significant ($F=2.2$, $p=.133$, $df=1$), nor was the interaction term. The relationship between these variables is shown in Figure 5, which shows the greater influence of drainage features on trails with native soils than for graveled trails.

At BSF, 55% of the sample points were located on native substrates, 28% had some gravel cover, and 17% were predominantly graveled. Equestrian trails were most frequently graveled, with some gravel found on mixed use trails and more rarely on hiking trails. ANOVA testing at BSF yielded similar results to HNF, with a significant relationship between tread drainage feature spacing and soil loss ($F=3.3$, $p=.046$, $df=2$), not significant for gravel application ($F=0.09$, $p=.768$, $df=1$), and a non-significant interaction term.

The efficacy of gravel application to limit erosion on steeper trail grades was also investigated. Two-way ANOVA testing of HNF data revealed significant relationships between soil loss and gravel application ($F=9.4$, $p=.002$, $df=1$) and trail grade ($F=14.3$, $p<.001$, $df=2$), with a significant interaction ($F=3.1$, $p=.044$, $df=2$). As depicted in Figure 6, soil loss increases significantly with trail grade on native soils. However, this relationship is weak on graveled trails, appearing to suggest that gravel is effective in reducing soil loss on trail grades over 15%. However, discussions with managers revealed that gravel placed on steep trail grades commonly suffered downhill displacement problems in areas of heavy horse traffic. Such locations are visited more frequently by maintenance staff to regrade these problem segments, often shifting gravel back upslope and/or adding more gravel. We conclude that the CSA soil loss for graveled trails at 16-50% grades would likely be much higher than depicted in Figure 6 in the absence of such maintenance work.

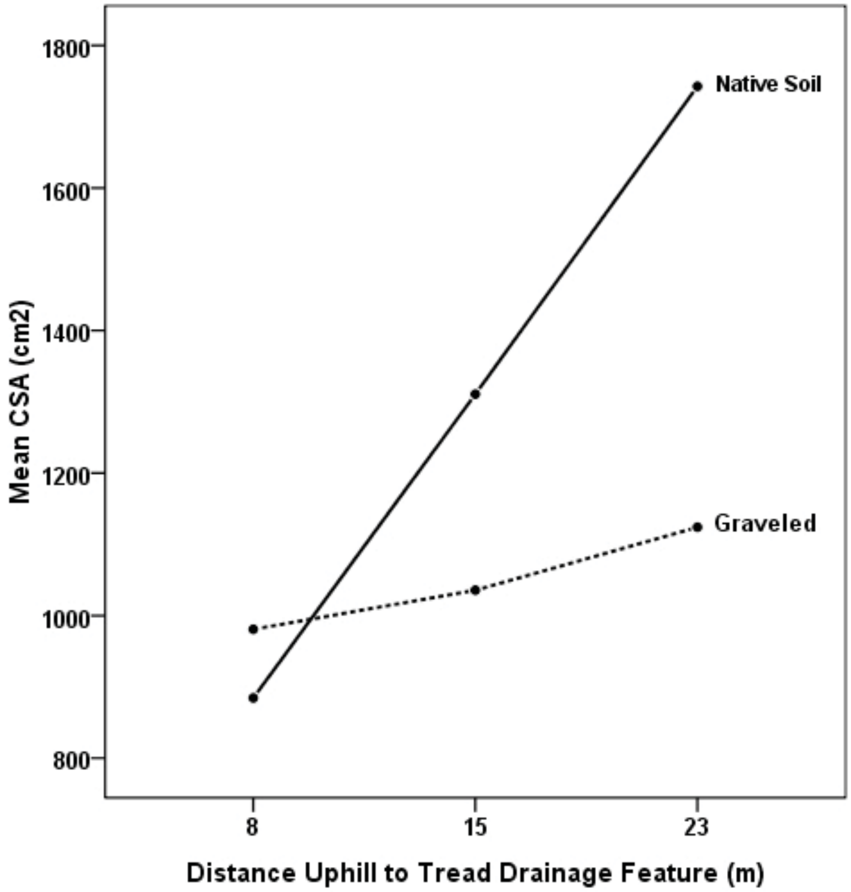


Figure 5. Soil loss on HNF trails as influenced by graveling and proximity to tread drainage features.

4.2 Understanding Trail Degradation

The relative influence of trail grade, TSA, gravel application, and tread drainage feature spacing on CSA trail soil loss was evaluated through multiple regression analyses. These attributes are under managerial control through trail design and maintenance. Table 2 presents multiple regression results. For ANP, trail grade and TSA were retained and are highly significant predictors of CSA soil loss. For HNF and BSF, trail grade and TSA were also the most significant predictors of soil loss, though distance to tread drainage features remained in the final models (Table 2). Note that gravel application was not included in the final equations, indicating the higher influence of the three included factors.

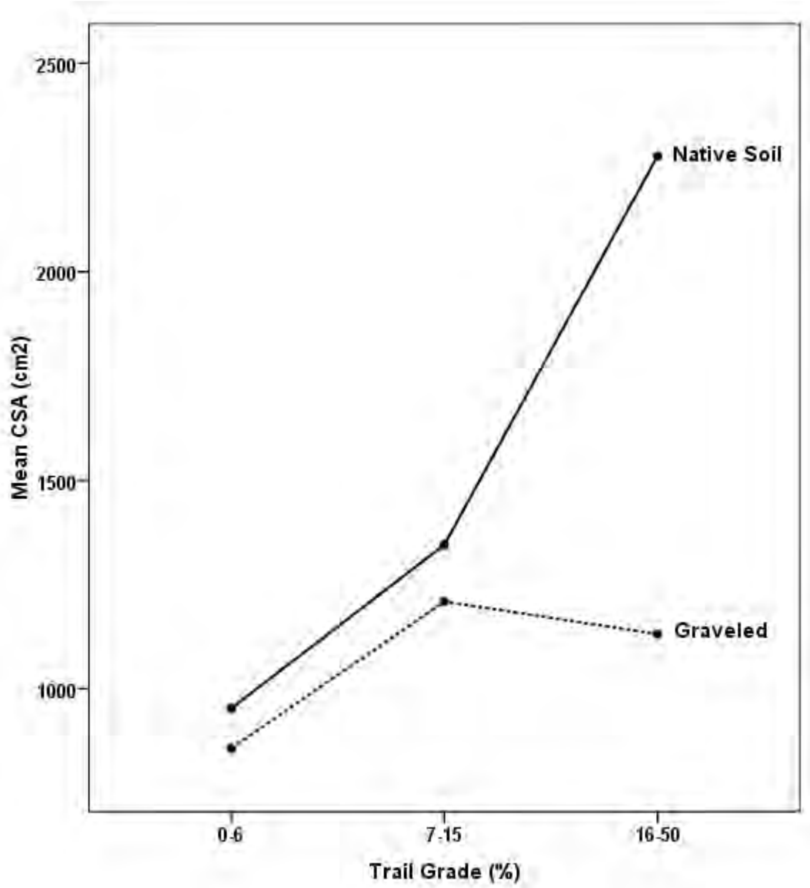


Figure 6. Soil loss on HNF trails as influenced by trail grade and application of gravel.

Table 2. Multiple regression results evaluating the influence of trail grade, trail slope alignment (TSA), and tread drainage feature spacing on soil loss assessed on recreational trails.

Variables	Protected Natural Area		
	HNF	BSF	ANP
Trail Grade (%)	45.4[1] (.000)	17.2 (.000)	5.9 (.006)
TSA (deg)	-2.1 (.039)	-9.9 (.000)	-1.6 (.004)
Tread Drainage (m)	6.1 (.074)	14.8 (.022)	N.A.
Constant	722.9	524.7	482.1
Adjusted R^2	0.09	0.11	0.05

1 – Unstandardized CSA coefficients, cm^2.

A graph illustrating the relationships of the two most significant factors that influence CSA soil loss, trail grade and TSA, is shown in Figure 7 using BSF data. On fall-line trails (TSA <23°) there is a substantial difference between the amount of soil loss across all trail grades compared to those with alignment angles over 23° (Figure 7). Soil loss is particularly pronounced on fall-line trails with trail grades above 16%. Coincidentally, the influence of trail grade on soil loss appears to be less substantial on trails with TSA values exceeding 22 degrees.

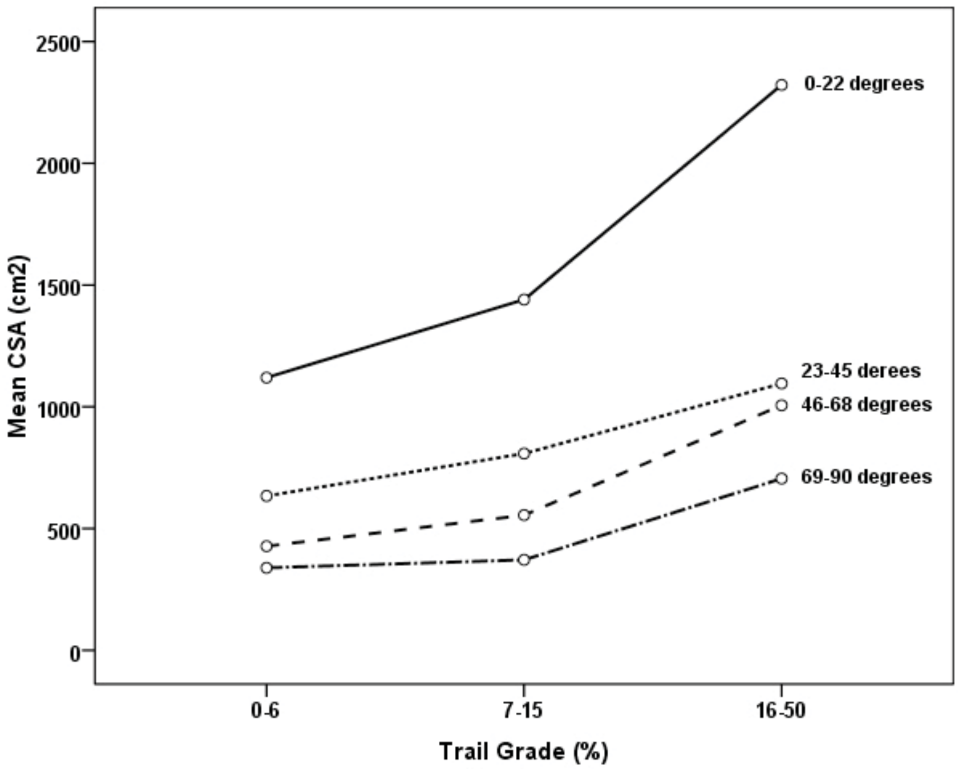


Figure 7. Soil loss on Big South Fork NRR trails as influenced by trail grade and trail slope alignment angle.

5.0 DISCUSSION

The management guidance for subjects like fisheries, wildlife, and recreation management are generally “science-based,” with Best Management Practices derived from research findings published in the peer-reviewed literature. Unfortunately this is not the situation for most of the existing trail design and maintenance literature. Exceedingly few of the current publications mention linkages between the guidance presented and research studies, or include citations referencing scientific literature. As an example, the widely disseminated and applied IMBA “Half Rule” (IMBA, 2007) was not derived from research, nor has it been evaluated by an empirical study. Such guidance is being widely applied in the U.S. and internationally; should it not be based on or evaluated by trail science research?

This study and others in the recreation ecology field examine the environmental impacts of visitation to protected natural areas to provide a scientific basis for managing visitor use sustainably – avoiding impacts when possible and minimizing those that are unavoidable. While recreation ecology studies with findings relevant to sustainable trail design and management have been conducted, funding has been limited and some critical topics have not been fully evaluated (Marion et al., 2011; Marion, 2016). Nevertheless, there is a growing body of applicable literature available that can assist the trail community in designing and managing trails that will better accommodate a diverse array of trail activities while resisting degradation, including the perennial problems of trail soil loss, muddiness, and widening (Farrell and Marion, 2002; Nepal, 2003; Olive and Marion, 2009; Pickering et al. 2010; Wimpey and Marion, 2010).

Results from this study included trail measurements characterizing trail design, construction, maintenance, and conditions from National Park Service and U.S. Forest Service areas. A surprisingly large percentage of the trail systems in these areas would be described as “unsustainable” by the existing management and scientific literature. For example, the percentages of the sampled trail systems for these protected areas that exceed a 10% grade range from 9.6 to 29% (Table 1). Similarly, the percentage of trail miles located in flat terrain (0-2%) that are highly susceptible to muddiness and trail widening range from 22 to 57%. Finally, as noted in the Literature Review, trail alignments close to the fall-line are extremely difficult to drain water from, contributing to excessive soil loss, muddiness, and widening. The percentages of the sampled trail systems with TSA values $<30^{o}$ range from 19 to 48%.

Based on this study we propose a set of Trail Sustainability Ratings to guide and evaluate proposed and existing trail alignments and designs:

Trail Sustainability Rating	Trail Grade and Trail Slope Alignment Criteria
Good:	Trail grade of 3-10% and TSA $>30^{o}$
Neutral:	Trail grade of 0-2%
Poor:	Trail grade of 3-10% and TSA of 0-30^{o}, trail grade of 11-20% and TSA $>30^{o}$
Very Poor:	Trail grade of 11-20% and TSA of 0-30^{o}, and trail grade of >20%

With respect to soil loss on trails, these proposed Trail Sustainability Ratings are supported by the findings of several studies and the trail management literature and statistical testing shown in Table 1. For example, substantially and significantly greater amounts of soil were lost from the treads of each study area between trail segments rated Good or Neutral (combined) and Poor, and between Poor and Very Poor. We emphasize that this study did not evaluate or validate these proposed ratings with respect to two other important forms of trail degradation: trail muddiness and widening. We suggest that further research and evaluations for additional forms of trail degradation are needed to validate these ratings.

Multiple regression analyses found trail grade to be a highly significant predictor of soil loss in all three study areas (Table 2). Higher trail grades showed substantially increased soil loss (Figure 7), particularly as grades exceeded 15%. ANP findings were similar, except that segments with low grades (0-4%) had similar low levels of soil loss. At HNF, as trail grade increased from 0-6% to 7-15% soil loss also increased (Figure 6). Soil loss continued to increase substantially, with grades greater than 15% on native substrate trail segments. The guidance found in the existing trail design and management literature are supported by these findings.

Regression analyses also found TSA to be a highly significant predictor of soil loss in all three study areas (Table 2), even when including and accounting for the strong influence of trail grade. This can be seen in Figure 7 with the substantially greater erosion depicted by the 0-22^{o} TSA line for each trail grade category, with similar results from ANP except for low trail grades. At both protected areas the influence of TSA increased with increasing trail grade, i.e., soil loss on trails is particularly pronounced on steep fall-line trails. Coincidentally, soil loss is quite low on trails that are aligned close to contour lines (Figure 7). In summary, this regression modeling indicates that TSA is similar to trail grade in its influence on soil loss; we recommend additional studies to validate this finding. Our examination of the current management literature on trail design and sustainability guidance reveals a substantially greater emphasis on trail grade. Some books and guidance advise trail designers to avoid the fall line or apply the Half Rule (which prevents fall-line alignments), but others barely mention this topic. Based on this study, current trail design guidance underestimates the relative influence and importance of TSA as compared to trail grade.

Study findings also point to the strong influence of tread drainage features and gravel application in reducing soil loss on trails. Our findings indicate these attributes are important, but less influential than trail grade and TSA. However, we emphasize that trail segments with sub-optimal grades or TSA values are more sustainable if they have excellent drainage characteristics and rocky or gravel substrates. For example, a very steep side-hill trail with an out-sloped tread or closely spaced drainage features, or a steep fall-line trail entirely on rock can be highly sustainable. These options are available to trail managers seeking to provide challenging trail experiences while also protecting natural resources.

In this study, trail measurements revealed substandard tread drainage feature densities at HNF and BSF (not assessed at ANP). Other studies have also reported this finding, which we attribute to insufficient maintenance related to funding and staffing limitations. Even when drainage dips or wood and stone water bars are present in sufficient densities they are ineffective unless properly installed and frequently maintained. Some disadvantages of these features are that they: 1) can be an obstacle contributing to trail widening and bicycle accidents, 2) are degraded over time by traffic and filled in by sediment deposition, 3) can focus larger volumes of runoff and sediments into water bodies, and 4) are frequently incorrectly installed (too short or low, improper angle, poorly anchored rocks or logs) (Hesselbarth et al., 2007).

We conclude that these “traditional” drainage features are less effective and desirable than full-tread grade reversals, which are extremely effective and require little to no recurring maintenance. Other methods of tread drainage, including elevated/crowned, and in- and out-sloped tread shaping, are also only effective when initially constructed and regularly maintained (Parker 2004). Over time, soil loss and displacement and development of a higher trailside berm will reduce or negate their efficacy. However, we are unaware of any studies that have empirically evaluated the efficacy of these options; research is needed.

In summary, trail grade and slope alignment angle appear to have the most influence on soil loss from trails. A Trail Sustainability Rating System is offered to trail designers and managers to more clearly guide the development and evaluation of trail sustainability and to show the tradeoffs between these influential factors. Poorly designed trails will continue to have substantial soil loss until sustainable reroutes are constructed. If reroutes are not an option, rockwork, graveling and installing additional drainage features can be effective actions to decrease trail soil loss. While grade reversals are a preferred tread drainage option, measures like out-sloped treads, drainage dips, and water bars can also be effective, though only when frequently maintained. We note that trail segments supporting higher impact uses, such as horses and motorized traffic, require greater adherence to sustainability guidelines, and in particular, can benefit from larger amounts of substrate rock or gravel application.

This research suggests that sustainably designed and well-maintained trails can substantially avoid or minimize tread soil loss, enhancing physical and managerial sustainability. The full application of these management actions should, in most instances, accommodate recreational traffic within acceptable levels of resource degradation, alleviating the need for use reduction and enhancing social sustainability.

Acknowledgements: The authors would like to thank the National Park Service and the U.S. Forest Service for sponsoring the research reported in this paper. We also acknowledge the assistance our several additional colleagues involved in these studies, including Mike Aust, Kevin Kyle, Nate Olive, and Logan Park.

6.0 REFERENCES

Agate, E., 1996. Footpaths: A Practical Handbook. British Trust for Conservation Volunteers. The Eastern Press Ltd., London, UK.

Aust, M.W., Marion, J.L., Kyle, K., 2004. Research for the Development of Best Management Practices for Minimizing Horse Trail Impacts on the Hoosier National Forest. Final Research Rpt. USDA, U.S. Forest Service, Bedford, IN.

Basch, D., Duffy, H., Giordanengo, J., Seabloom, G., 2007. Guide to Sustainable Mountain Trails: Trail Assessment, Planning and Design Sketchbook. USDI National Park Service, Denver Service Center. NPS D-1811A. Denver, CO.

Birchard, W., Proudman, R.D., 2000. Appalachian Trail Design, Construction, and Maintenance. 2nd ed. Appalachian Trail Conference, Harpers Ferry, WV.

Birkby, R.C., 2005. Lightly on the Land: The SCA Trail-Building and Maintenance Manual. 2nd Edit., Student Conservation Association, Inc. The Mountaineers, Seattle, WA.

Bryan, R.B., 1977. The influence of soil properties on degradation of mountain hiking trails at Grovelsjon. Geografiska Annaler 59A, 49-65.

Cahill, K., Marion, J.L., Lawson, S., 2008. Exploring visitor acceptability for hardening trails to sustain visitation and minimize impacts. Journal of Sustainable Tourism 16, 232-245.

Croke, J. Nethery, M. 2006. Modelling runoff and soil erosion in logged forests: Scope and application of some existing models. Catena 67, 35-49.

Demrow, C., Salisbury, D., 1998. The Complete Guide to Trail Building and Maintenance. 3rd Edition. The Appalachian Mountain Club, Boston, MA.

Dissmeyer, G.E., Foster, G.R., 1984. A Guide for Predicting Sheet and Rill Erosion on Forest Land. USDA Forest Service Technical Publication R8 TP 6. 40 p.

Dixon, G., Hawes, M., 2015. A longitudinal multi-method study of recreational impacts in the Arthur Ranges, Tasmania, Australia. Journal Outdoor Recreation & Tourism 9, 64-76.

Farrell, T,A., Marion, J.L., 2002. Trail impacts and trail impact management related to ecotourism visitation at Torres del Paine National Park, Chile. Leisure/Loisir: Journal of the Canadian Association for Leisure Studies 26, 31-59.

Footpath Trust, 1999. Upland Pathwork: Construction Standards for Scotland: The Footpath Trust for the Path Industry Skills Group. Scottish Natural Heritage, Battleby, Redgorton, Perth.

Forest Service, 1991. Trails Management Handbook. USDA Forest Service, Washington, DC.

Forest Service, 2005. National Visitor Use Monitoring Results. USDA Forest Service, Natural Resource Manager Program. Washington, D.C.

Grab, S., Kalibbala, F., 2008. Anti-erosion logs across paths in the southern uKhahlamba-Drakensberg Transfrontier Park, South Africa: Cure or Curse? Catena 73, 134-145.

Hammitt, W.E., Cole, D.N., 1998. Wildland Recreation: Ecology and Management. 2nd ed. John Wiley and Sons, New York, NY.

Hancock, J., Vander Hoek, K.J., Bradshaw, S., Coffman, J.D., Engelmann, J., 2007. Equestrian Design Guidebook for Trails, Trailheads, and Campgrounds. Tech. Rpt. 0723-2816-MTDC. USDA Forest Service, Missoula Technology and Development Center, Missoula, MT.

Helgath, S.F., 1975. Trail Deterioration in the Selway-Bitterroot Wilderness. USDA Forest Service, Intermountain Res. Stn., Res. Note INT- 193, Ogden, UT.

Hesselbarth, W., Vachowski, B., Davies, M.A., 2007. Trail Construction and Maintenance Notebook. Publication 0723-2806-MTDC. USDA Forest Service, Technology and Development Center, Missoula, MT.

Hooper, L., 1988. National Park Service Trails Management Handbook. USDI National Park Service, Denver Service Center, Denver, CO.

IMBA, 2004. Trail Solutions: IMBA's Guide to Building Sweet Singletrack. The International Mountain Bike Association, Boulder, CO.

IMBA, 2007. Managing Mountain Biking: IMBA's Guide to Providing Great Riding. Webber, P. (editor). The International Mountain Bike Association, Boulder, CO.

Kidd, K.R., Aust, W.M., Copenheaver, C.A., 2014. Recreational stream crossing effects on sediment delivery and macroinvertebrates in southwestern Virginia, USA. Environmental Management 54, 505-516.

Kirkby, M.J., 1980. Modelling water erosion processes, in Soil Erosion, edited by M. J. Kirkby and R. P. C. Morgan, pp. 183-216, John Wiley & Sons, Chichester.

Kochenderfer, J.N., Helvey, J.D., 1987. Using gravel to reduce soil losses from minimum-standard forest roads. Journal of Soil and Water Conservation 42, 46-50.

Leung, Y.F., Marion, J.L., 1996. Trail degradation as influenced by environmental factors: A state-of-the-knowledge review. Journal of Soil and Water Conservation 51, 130-136.

Leung, Y.F., Marion, J.L., 1999. The influence of sampling interval on the accuracy of trail impact assessment. Landscape and Urban Planning 43, 167-179.

Leung Y.F., Marion J.L., 2000. Recreation impacts and management in wilderness: A state-of knowledge review. In: Cole, D.N., McCool, S.F., Borrie, W.T., O'Loughlin, J. (comps) Wilderness science in a time of change conference, Vol 5. pp 23–48. Wilderness ecosystems, threats and management. Proceedings RMRS-P-15-Vol-5. USDA Forest Rocky Mountain Research Station.

Marion, Jeffrey L. 2016. A Review and synthesis of recreation ecology research supporting carrying capacity and visitor use management decision-making. Journal of Forestry 114, 339-351.

Marion, J.L., 1994. An Assessment of Trail Conditions in Great Smoky Mountains National Park. Research/ Resources Management Report. USDI National Park Service, Southeast Region. Atlanta, GA.

Marion, J.L., Leung, Y-F., 2004. Environmentally sustainable trail management. In: Buckley, R. (Ed.), pp. 229-244, Environmental Impact of Tourism. CABI Publishing, Cambridge, MA.

Marion, J.L., Leung, Y-F., Eagleston, H. & Burroughs, K., 2016. A review and synthesis of recreation ecology research findings on visitor impacts to wilderness and protected natural areas. Journal of Forestry 114, 352-362.

Marion, J.L., Olive, N., 2006. Assessing and Understanding Trail Degradation: Results from Big South Fork National River and Recreational Area. USDI, U.S. Geological Survey, Final Research Rpt., Virginia Tech Field Station, Blacksburg, VA.

Marion, J.L., Wimpey, J.F., Park, L.O., 2011. Informal and Formal Trail Monitoring Protocols and Baseline Conditions: Acadia National Park. U.S. Geological Survey, Final Research Rpt., Virginia Tech College of Natural Resources and Environment, Blacksburg, VA.

Marion, J.L., Wimpey, J.F., Park, L.O., 2012. The science of trail surveys: Recreation ecology provides new tools for managing wilderness trails. Park Science 28, 60-65.

Mende, P., Newsome, D., 2006. The assessment, monitoring and management of hiking trails: A case study from the Stirling Range National Park, Western Australia. Conservation Science W. Australia 5, 285-295.

Meyer, K.G., 2002. Managing Degraded Off-highway Vehicle Trails in Wet, Unstable, and Sensitive Environments. Publication 0223-2821-MTDC. USDA Forest Service, Tech. and Development Program, Missoula, MT.

Minnesota DNR, 2007. Trail Planning, Design, and Development Guidelines. Minnesota Department of Natural Resources, Trails and Waterways Division. St. Paul, MN.

National Park Service, 2007. Guide to Sustainable Mountain Trails: Trail Assessment, Planning, and Design Sketchbook. USDI National Park Service, Denver Service Center, Denver, CO.

Nepal, S.K., 2003. Trail impacts in Sagarmatha (Mt. Everest) National Park, Nepal: A logistic regression analysis. Environmental Management 32, 312–321.

Newsome, D., Moore, S.A., Dowling, R.K., 2001. Natural Area Tourism: Ecology, Impacts, and Management. Channel View Books, Clevedon, UK.

Olive, N.D., Marion, J.L., 2009. The Influence of use-related, environmental and managerial factors on soil loss from recreational trails. Journal of Environmental Management 90, 1483- 93.

Parker, T.S., 2004. Natural Surface Trails by Design. Natureshape, Boulder, CO.

Pickering, C. M., Hill, W., Newsome, D., Leung, Y.-F., 2010. Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America. Journal of Environmental Management 91, 551-562.

Ramos-Scharrón, C.E., Reale-Munroe, K., Atkinson, S.C., 2014. Quantification and modeling of foot trail surface erosion in a dry sub-tropical setting. Earth Surface Processes and Landforms 39, 1764-1777.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA, Agriculture Handbook No. 703, 404pp.

Rhee, H., Fridley, J.L., Foltz, R.B., 2004. Modeling erosion from unpaved forest roads at various levels of geometric detail using the WEPP model. Trans. ASAE. 47, 961–968.

Scottish Natural Heritage, 2000. A Technical Guide to the Design and Construction of Lowland Recreation Routes. Scottish Natural Heritage, Battleby Redgorton, Perth.

Strout, D., 2005. Estimation of horse and bike trail use for CY 2004. Memorandum to Forest Supervisor dated January 11, 2005 (file code 2350-1). USDA Hoosier National Forest, Bedford, IN.

Vogel, C., 1982. Trails Manual, 2nd ed. Equestrian Trails, Sylmar, CA.

Wade, C.R., Bolding, M.C., Aust, W.M., Lakel III, W.A., Schilling, E.B., 2012. Comparing sediment trap data with the USLE-Forest, RUSLE2, and WEPP-Road erosion models for evaluation of bladed skid trail BMPs. Transactions of the ASABE 55, 403-414.

Wadzinski, L., 2000. Mud, manure, and money: Fixing the trails in Indiana. 15th National Trails Symposium. American Trails. Sept. 21-24, 2000. Redding, CA

Weaver, T., Dale, D., 1978. Trampling effects of hikers, motorcycles and horses in meadows and forests. Journal of Applied Ecology 15, 451-457.

Wimpey, J., Marion, J.L., 2010. The influence of use, environmental and managerial factors on the width of recreational trails. Journal of Environmental Management 91, 2028-2037.

Wimpey, J., Marion, J.L., 2011. Formal and informal trail monitoring protocols and baseline conditions: Great Falls Park and Potomac Gorge. Final Research Report. U.S. Geological Survey, Distributed by the Virginia Tech College of Natural Resources and Environment, Blacksburg, VA.

Whinam, J., Chilcott, N.M., 2003. Impacts after four years of experimental trampling on alpine/sub-alpine environments in western Tasmania. Journal of Environmental Management 67, 339–351

Wilson, J.P., Seney, J.P., 1994. Erosional impact of hikers, horses, motorcycles, and off-road bicycles on mountain trails in Montana. Mountain Research and Development 14, 77-88.

Wood, G.W., 2007. Recreational Horse Trails in Rural and Wildland Areas: Design, Construction, and Maintenance. Clemson University, Dept. of Forestry and Natural Resources, Clemson, SC.