RESEARCH REPORT

FORMAL AND INFORMAL TRAIL MONITORING PROTOCOLS AND BASELINE CONDITIONS: GREAT FALLS PARK AND POTOMAC GORGE

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Virginia Tech, College of Natural Resources
Department of Forest Resources
& Environmental Conservation

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by: Jeremy Wimpey

Postdoctoral Research Associate
Virginia Tech/Department of Forest Resources
& Environmental Conservation
Virginia Tech/FREC (0324)
Blacksburg, VA 24061

Jeffrey L. Marion

Unit Leader/Adjunct Professor
Virginia Tech Field Unit
USGS Patuxent Wildlife Research Center
Virginia Tech/FREC (0324)
Blacksburg, VA 24061

Chesapeake & Ohio Canal National Historical Park
George Washington Memorial Parkway

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EXECUTIVE SUMMARY

This report presents the results of research on the conditions of formal and informal (visitor-created) trails conducted within the Great Falls Park (GFP) portion of George Washington Memorial Parkway (GWMP), Virginia, and the adjacent Maryland portions of the C&O Canal National Historical Park (CHOH). This research was prompted primarily by concerns about the impact of extensive informal trail networks within both parks on native vegetation and rare plant communities, rare flora and fauna, and historic and archaeological resources. Resource conditions on formal park trails were also assessed to provide information supporting the development of park planning and management decision-making.

The potential environmental impacts from recreational activities includes the trampling and loss of vegetation, including rare plants, alteration in vegetation composition, possible introduction and spread of non-native plants, compaction and loss of soil, and disturbance or displacement of wildlife. Deterioration of formal park trails and creation and proliferation of informal trails are significant management problems that can directly impact sensitive plant communities, rare or endangered flora and fauna, wildlife habitats, and historic/archaeological resources. Even limited trampling has the potential to significantly affect populations of plants that are small in size and number. Resource impacts from and on informal trails can be severe, partially because of the absence of professional design, construction, and maintenance practices. While some degree of visitor impact is unavoidable, excessive trampling impacts can threaten natural resource conditions and processes, visitor safety, and the quality of recreational experiences.

This program of research had the following objectives: 1) developing and refining assessment protocols for monitoring conditions along the park's formal and informal trail systems, 2) applying the protocols to collect and summarize baseline data on formal and informal trail resource conditions and impacts, and 3) providing recommendations on appropriate and effective trail and visitor management practices to avoid or reduce trail-related resource impacts.

This report contains a review of the relevant scientific literature describing trail impacts, criteria for selecting appropriate impact indicators, trail impact assessment methods, and a review of the study area and methods employed in this study. Study implications and recommendations for park planning, management, and monitoring are presented and discussed in the Discussion section of this report. This information is useful in selecting and implementing effective site or visitor management actions. If park staff implement procedures developed from this research as

part of a long-term monitoring program then comparisons to the baseline dataset provided by this study will allow the detection of trends and evaluation of the effectiveness of management interventions. Finally, these data support the selection of indicators and standards as part of Cliff and Trail Management Plans, or other carrying capacity planning based on the National Park Service Visitor Experience and Resource Protection (VERP) framework (described in this report).

All formal trails within both park study areas were assessed with point-sampling procedures to quantitatively characterize trail resource conditions. Field staff sought to apply a census-survey of all informal trails, which were mapped with accurate GPS units and assessed with descriptive condition class assessments. Salient findings include the following:

Great Falls Park

- 12.31 miles of formal trails were assessed; the majority is well-designed and in good condition.
- Less than 2% of the formal trail system have steep grades (>15%) but 60% have grades of 0-2%, which are susceptible to poor drainage, muddiness, and trail widening. A large portion (41%) are also aligned close to the fall line (landform grade), a less sustainable design that increases the difficulty of water drainage and tread susceptibility to tread muddiness, soil erosion, and widening.
- The most common assessed formal trail impacts include muddiness (948 ft) and the occurrence of secondary (parallel) treads (3,314 ft).
- Soil loss was assessed by maximum tread incision (mean = 1.69 inches) and cross sectional area soil loss (mean = 89.5 in^2). Extrapolations of soil loss to the entire formal trail system yielded an aggregate soil loss estimate of 40,379 ft^3.
- A census survey of informal trails located and mapped 8.37 miles, 68% of the formal trail mileage and 23% of the areal extent of trampling impact.
- By lineal extent, 91% of the informal trails were rated condition class 3-5, indicating a loss of vegetation and organic litter cover from trail treads, with evidence of soil erosion visible on 49%.
- A majority of the informal trails are concentrated along the Potomac River in forested areas adjacent to the cliff-tops and rocky areas. Most appear to be related to general exploration and visitors seeking cliff-top vistas.
- There is considerable duplication in the distribution of informal trails, i.e., two or more trails accessing common locations. This represents “avoidable” impact.
- Potential landscape and habitat fragmentation impacts are assessed by computation of several fragmentation indices.

C&O Canal National Historical Park

- 14.67 miles of formal trails were assessed; the majority is well-designed and in good condition.
- Approximately 10% of the formal trail system has steep grades (>15%) which are susceptible to erosion, and 37% have grades of 0-2%, which are susceptible to poor drainage, muddiness, and trail widening. A portion (23%) of formal trails are also aligned close to the fall line (landform grade), a less sustainable design that increases the

difficulty of water drainage and tread susceptibility to tread muddiness, soil erosion, and widening.

- Soil loss was assessed by maximum tread incision (mean = 1.61 inches) and cross sectional area soil loss (mean = 49.0 in^2). Extrapolations of soil loss to the entire trail system yielded an aggregate soil loss estimate of 26,368 ft^3.
- A census survey of informal trails located and mapped 19.29 miles, 130% of the formal trail mileage and 48% of the areal extent of trampling impact.
- By lineal extent, 69% of the informal trails were rated condition class 3-5, indicating a loss of vegetation and organic litter cover from trail treads, with evidence of soil erosion visible on 36%.
- A majority of the informal trails are concentrated along the Potomac River in forested areas adjacent to the cliff-tops and rocky areas. Most appear to be related to general exploration and visitors seeking cliff-top vistas.
- There is considerable duplication in the distribution of informal trails, i.e., two or more trails accessing common locations. This represents "avoidable" impact.
- Potential landscape and habitat fragmentation impacts are assessed by computation of several fragmentation indices.

The formal trail system mileage within both park study areas was quite limited, and trail conditions are generally good. Some areas exhibited erosion, muddiness, tread widening, and the development of secondary trails. The most effective long-term response to these problems is to relocate the worst sections to side-hill alignments that promote tread drainage and deter trail widening and secondary tread development. Graveling, when appropriate, can also be an effective maintenance practice. Other corrective practices, such as construction of grade reversals to drain water, and low impact educational practices are also described.

The most substantial and significant trail-related impacts in both parks are their extensive informal trail networks, particularly in the CHOH study area. Given the rare and fragile plant communities and substantial number of rare plant species in both parks, these extensive networks of informal trails pose a serious threat to the resource protection mandates of both parks. One product of these surveys are GIS informal trail data layers that will permit additional analyses to evaluate their proximity to rare species locations or sensitive historic/cultural sites (unavailable to our study). Readers are referred to a companion study by Hockett and others (2010) for more in-depth discussion and presentation of information regarding the causes of informal trail formation and possible site management and educational responses. Some of that material is also included in this report to make this document a more complete resource. Potential solutions include the improvement of visitor communication and low impact practices, improved trail maintenance and markings, formalizing some informal trails, and informal trail closures and restoration.

Resolving the substantial informal trail impacts documented by this study will be a significant and ongoing management challenge for both parks. A collaborative adaptive management process is recommended, with ongoing monitoring to evaluate resource conditions and management success over time. Additional research may also be needed. Some individuals, including those interested in nature study, photography, fishing, and climbing, "need" to engage in off-trail hiking to fulfill their trip objectives. Some degree off off-trail hiking and trailing is unavoidable, so management planning and decision-making should seek to incorporate carefully

selected indicators with quantitative standards representing “acceptable” limits of change, combined with periodic monitoring to compare conditions to standards. Report Appendices provide protocols that can be incorporated into formal and informal trail monitoring programs.

INTRODUCTION

The National Park Service (NPS) accommodates nearly 300 million visitors per year, visitation that presents managers with substantial challenges at some 392 park units across some 83.6 million acres of protected lands. An increasing number of visitors inevitably contribute negative effects to fragile natural and cultural resources. Such visitation-related resource impacts can degrade natural conditions and processes and the quality of recreation experiences. According to the NPS *Management Policies*: "The fundamental purpose of the national park system, established by the Organic Act and reaffirmed by the General Authorities Act, as amended, begins with a mandate to conserve park resources and values…The fundamental purpose of all parks also includes providing for the enjoyment of park resources and values by the people of the United States." (NPS 2006, Section 1.4.3). However, what might appear to be dual mandates, visitation and resource protection, are clarified to reveal the primacy of resource protection. The *Management Policies* acknowledge that some resource degradation is an inevitable consequence of visitation, but directs managers to "ensure that any adverse impacts are the minimum necessary, unavoidable, cannot be further mitigated, and do not constitute impairment or derogation of park resources and values" (NPS 2006).

The increasing popularity of the national park system presents substantial management challenges. Too many visitors may cause unacceptable impacts to fragile natural and cultural resources, and may also cause crowding and other social impacts which can also degrade the quality of visitor experiences. How many visitors can be accommodated and how much resource and social impact can be accepted in a park or related area? These and related questions are commonly referred to as carrying capacity (Manning 1999, Stankey & Manning 1986, Shelby & Heberlein 1986, Graefe *et al.* 1984). Research and management experience are increasingly revealing that carrying capacity is less about actual numbers of visitors; factors such as visitor behavior, site design and management practices, and environmental resistance/resilience are often as or more important.

Responding to these concerns, NPS managers at C&O Canal National Historical Park (CHOH) in Maryland and George Washington Memorial Parkway (GWMP) in Virginia supported this research investigating visitation-related impacts to formal and informal (visitor-created) trails in Great Falls Park, Virginia, and adjacent sections of CHOH. To better understand the extent and severity of these resource impacts and identify effective management techniques, this research develops monitoring protocols, collects baseline data, and identifies recommendations for management strategies. The study area, extending approximately five miles along the Potomac River from Great Falls to the downstream end of Carderock, is one of the most biologically significant natural areas in the eastern United States, supporting more than 400 occurrences of 200 rare species and communities. Located in a densely populated urban landscape, the Potomac Gorge is also recognized for its exceptional recreational and scenic features. More than four million people live within the Washington metro region and the Potomac Gorge is a noted tourist attraction in the area. This report includes only data from the formal and informal trail assessment portion of this program of research.

The potential environmental impacts from recreational activities includes the trampling and loss of vegetation, including rare plants and plant communities, alteration in vegetation composition, possible introduction and spread of non-native plants, compaction and loss of soil, and

disturbance or displacement of wildlife. Deterioration of formal park trails and creation and proliferation of informal trails are significant management problems that can directly impact sensitive plant communities, rare or endangered flora and fauna, and wildlife habitats (Leung *et al.* 2002, Wood *et al.* 2006). Even limited trampling has the potential to significantly affect populations of plants that are small in size and number. Resource impacts on informal trails can be severe, partially because of the absence of professional design, construction, and maintenance practices (Wimpey & Marion 2011). While some degree of visitor impact is unavoidable, excessive trampling impacts can threaten natural resource conditions and processes, visitor safety, and the quality of recreational experiences (Leung *et al.* 2002). These potential impacts are reviewed more fully in the Literature Review section of this report.

This program of research has the following specific objectives:

1) developing and refining assessment protocols for monitoring conditions along the park's formal and informal trail systems,
2) applying the protocols to collect and summarize baseline data on formal and informal trail resource conditions and impacts, and
3) providing recommendations on appropriate and effective trail and visitor management practices to avoid or reduce trail-related resource impacts.

This report contains a review of the relevant scientific literature describing trail impacts, criteria for selecting appropriate impact indicators, trail impact assessment methods, and a review of the study area and methods employed in this study. Study implications and recommendations for park planning, management, and monitoring are presented and discussed in the Discussion section of this report. This information is useful in selecting and implementing effective site or visitor management actions. If park staff implement procedures developed from this research as part of a long-term monitoring program then comparisons to the baseline dataset provided by this study will allow the detection of trends and evaluation of the effectiveness of management interventions. Finally, these data support the selection of indicators and standards as part of Cliff and Trail Management Plans, or other carrying capacity planning based on the NPS Visitor Experience and Resource Protection (VERP) framework (described in the following section).

JUSTIFICATION FOR MONITORING

Sustaining any type of long-term natural resource monitoring program over time can be exceptionally challenging for agencies due to changing personnel, management priorities, and budgets. This section reviews legislative mandates, management policies and guidelines, carrying capacity, visitor perceptions of recreation resource conditions, and monitoring program capabilities. The purpose of this review is to describe legislative and management intent regarding visitor impact monitoring and its role in balancing visitor use and resource protection objectives. This section is included to assist in justifying implementation of a trail monitoring program and to describe its utility to enlist organizational support for sustaining such a program over time.

Legislative mandates challenge managers to develop and implement management policies, strategies, and actions that permit recreation without compromising ecological and aesthetic integrity. Furthermore, managers are frequently forced to engage in this balancing act under the close scrutiny of the public, competing interest groups, and the courts. Managers can no longer afford a wait-and-see attitude or rely on subjective impressions of deterioration in resource conditions. Professional land management increasingly requires the collection and use of scientifically valid research and monitoring data. Such data should describe the nature and severity of visitor impacts and the relationships between controlling visitor use and biophysical factors. These relationships are complex and not always intuitive. A reliable information base is therefore essential to managers seeking to develop, implement, and gauge the success of visitor and resource management programs.

Although numerous reasons for implementing a visitor impact monitoring program are described in the following sections, the actual value of these programs is entirely dependent upon the park staff who manage them. Programs developed with little regard to data quality assurance or operated in isolation from resource protection decision-making will be short-lived. In contrast, programs that provide managers with relevant and reliable information necessary for developing and evaluating resource protection actions can be of significant value. Only through the development and implementation of professionally managed and scientifically defensible monitoring programs can we hope to provide legitimate answers to the question, "Are we loving our parks to death?"

Legislative Mandates

Current legislation and agency documents establish mandates for monitoring (Marion 1991). Recent legislative mandates allow managers more latitude to make proactive decisions that can be defended in court if necessary. Managers who make proactive decisions should be prepared to prove the viability of their strategies, or risk public disapproval or even legal action against the agency. Survey and monitoring programs provide the means for such demonstrations.

Agency Organic Act

The National Park Service Organic Act of 1916 (16 *United States Code* (USC) 1) established the Service, directing it to:

> "promote and regulate the use…[of parks]…to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

These provisions were supplemented and clarified by the Congress through enactment of the General Authorities Act in 1970, and through a 1978 amendment expanding Redwood National Park (16 USC 1a-1):

> "the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established…"

Congress intended park visitation to be contingent upon the National Park Service's ability to preserve park environments in an unimpaired condition. However, unimpaired does not mean unaltered or unchanged. Any recreational activity, no matter how infrequent, will cause changes or impacts lasting for some period of time. What constitutes an impaired resource is ultimately a management decision, a judgment. The Organic Act's mandate presents the agency with a management challenge since research demonstrates that resources are inevitably changed by recreational activities, even with infrequent recreation by conscientious visitors (Cole 1982 1995, Leung & Marion 2000). If interpreted overly strictly, the legal mandate of unimpaired preservation may not be achievable, yet it provides a useful goal for managers in balancing these two competing objectives.

More recently, the National Parks Omnibus Management Act of 1998 established a framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park System. The Act charges the Secretary of the Interior to:

> "develop a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources."

Congress reinforced the message of the National Parks Omnibus Management Act of 1998 in its text of the FY 2000 Appropriations bill:

> "A major part of protecting [park] resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."

Management Policies and Guidelines

Authority to implement congressional legislation is delegated to agencies, which identify and interpret all relevant laws and formulate administrative policies to guide their implementation. A document titled *Management Policies* (NPS 2006) describes these policies to provide more specific direction to management decision-making. For example, relative to the need for balancing visitor use and resource impacts, the NPS *Management Policies* state that:

> "The "fundamental purpose" of the national park system, established by the Organic Act and reaffirmed by the General Authorities Act, as amended, begins with a mandate to conserve park resources and values. This mandate is independent of the separate prohibition on impairment, and so applies all the time, with respect to all park resources and values, even when there is no risk that any park resources or values may be impaired. NPS managers must always seek ways to avoid, or to minimize to the greatest degree practicable, adverse impacts on park resources and values.
>
> Congress, recognizing that the enjoyment by future generations of the national parks can be ensured only if the superb quality of park resources and values is left unimpaired, has provided that when there is a conflict between conserving resources and values and providing for enjoyment of them, conservation is to be predominant. This is how courts have consistently interpreted the Organic Act, in decisions that variously describe it as making "resource protection the primary goal" or "resource protection the overarching concern"… (*Section 1.4.3*)
>
> The impairment that is prohibited by the Organic Act and the General Authorities Act is an impact that, in the professional judgment of the responsible NPS manager, would harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources or values. Whether an impact meets this definition depends on the particular resources and values that would be affected; the severity, duration, and timing of the impact; the direct and indirect effects of the impact; and the cumulative effects of the impact in question and other impacts. (*Section 1.4.5*)
>
> Impacts may affect park resources or values and still be within the limits of the discretionary authority conferred by the Organic Act. In these situations, the Service will ensure that the impacts are unavoidable and cannot be further mitigated. Even when they fall far short of impairment, unacceptable impacts can rapidly lead to impairment and must be avoided. When a use is mandated by law but causes unacceptable impacts on park resources or values, the Service will take appropriate management actions to avoid or mitigate the adverse effects." (*Section 8.1.1*)

Thus, relative to visitor use, park managers must evaluate the types and extents of resource impacts associated with recreational activities, and determine to what extent they are unacceptable and constitute impairment. Further, managers must seek to avoid or limit any form of resource impact, including those judged to fall short of impairment. Visitor impact monitoring programs can assist managers in making objective evaluations of impact acceptability and impairment and in selecting effective impact management practices by providing quantitative documentation of the types and extent of recreation-related impacts to natural resources. Monitoring programs are also explicitly authorized in Section 4.1 of the Management Policies:

> "Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions". (*Section 4.1*)
>
> "Further, The Service will:
>
> - Identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents.

- Define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources.
- Use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals.
- Analyze the resulting information to detect or predict changes, including interrelationships with visitor carrying capacities, that may require management intervention, and to provide reference points for comparison with other environments and time frames.
- Use the resulting information to maintain-and, where necessary, restore-the integrity of natural systems" (*Section 4.2.1*).

The National Park Service has implemented a strategy designed to institutionalize natural resource inventory and monitoring on a programmatic basis throughout the agency. A service-wide Inventory & Monitoring Program has been implemented to ensure that park units with significant natural resources possess the resource information needed for effective, science-based managerial decision-making and resource protection. A key component of this effort, known as the NPS Inventory & Monitoring Program, is the organization of park units into 32 ecoregional networks to conduct long-term monitoring for key indicators of change, or "vital signs." Vital signs are measurable, early warning signals that indicate changes that could impair the long-term health of natural systems. Early detection of potential problems allows park managers to take steps to restore ecological health of park resources before serious damage can happen.

Carrying Capacity Decision-Making

Decisions regarding impact acceptability and the selection of actions needed to prevent resource impairment frequently fall into the domain of carrying capacity decision-making. The 1978 National Parks and Recreation Act (P.L. 95-625) requires the NPS to determine carrying capacities for each park as part of the process of developing a general management plan. Specifically, amendments to Public Law 91-383 (84 Stat. 824, 1970) require general management plans developed for national park units to include "identification of and implementation commitments for visitor carrying capacities for all areas of the unit" and determination of whether park visitation patterns are consistent with social and ecological carrying capacities. Regulations implementing the National Forest Management Act of 1976 (P.L. 94-588) dictate that, in wilderness management planning, provision be made "for limiting and distributing visitor use of specific areas in accord with periodic estimates of the maximum levels of use that allow natural processes to operate freely and that do not impair the values for which wilderness areas were created."

The NPS employs the Visitor Experience and Resource Protection (VERP) planning and decision-making framework for formal evaluations of the acceptability of visitor impacts and for establishing carrying capacity limits on visitation (NPS 1997, NPS 2006) (Figure 1). Visitor impact monitoring programs provide an essential component of such efforts. VERP and other similar frameworks (e.g., Limits of Acceptable Change, LAC), evolved from, and have largely replaced, management approaches based on the more traditional carrying capacity model (Stankey *et al.* 1985). Under these newer frameworks, numerical standards are set for individual biophysical or social condition indicators. These limits define the critical boundary between acceptable and unacceptable change in resource or social conditions, and against which

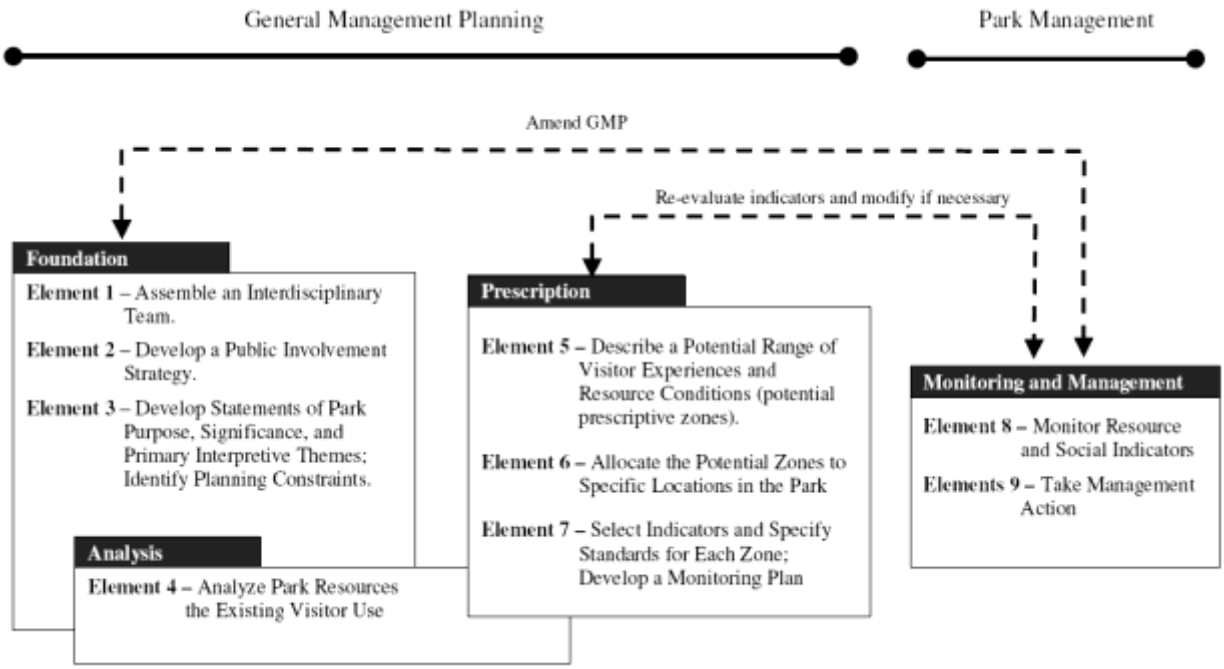

Figure 1. The NPS Visitor Experience and Resource Protection framework used to address carrying capacity decision making.

future conditions can be compared through periodic monitoring. VERP is an adaptive management process wherein periodic monitoring is conducted to compare actual conditions to quantitatively defined standards of quality. If standards are exceeded, an evaluation is conducted to identify those factors that managers can effectively manipulate to improve conditions for the indicators with sub-standard (unacceptable) conditions. For example, if a standard for the individual or aggregate size of recreation sites was exceeded, managers might consider implementing one or more site management or educational actions. If the next cycle of monitoring also found sub-standard conditions, more restrictive actions like fencing or area closures would be considered.

Additional guidance on visitor carrying capacity decision-making is provided in the NPS *Management Policies* (2006):

> "Visitor carrying capacity is the type and level of visitor use that can be accommodated while sustaining the desired resource and visitor experience conditions in the park. By identifying and staying within carrying capacities, superintendents can prevent park uses that may unacceptably impact the resources and values for which the parks were established. For all zones, districts, or other logical management divisions within a park, superintendents will identify visitor carrying capacities for managing public use. Superintendents will also identify ways to monitor for, and address, unacceptable impacts to park resources and visitor experiences.
>
> When making decisions about carrying capacity, superintendents must utilize the best available natural and social science and other information, and maintain a comprehensive administrative record relating to their decisions. The decision-making process should be based on desired resource conditions and visitor experiences for the area; quality indicators and standards that

> define the desired resource conditions and visitor experiences; and other factors that will lead to logical conclusions and the protection of park resources and values…
>
> The general management planning process will determine the desired resource and visitor experience conditions that are the foundation for carrying capacity analysis and decision-making. If a general management plan is not current or complete, or if more detailed decision-making is required, a carrying capacity planning process, such as the Visitor Experience and Resource Protection (VERP) framework, should be applied in an implementation plan or an amendment to an existing plan.
>
> As use changes over time, superintendents must continue to decide if management actions are needed to keep use at acceptable and sustainable levels. If indicators and standards have been prescribed for an impact, the acceptable level is the prescribed standard. If indicators and standards do not exist, the superintendent must determine how much impact can be tolerated before management intervention is required." (*Section 8.2.1*)

Visitor Perceptions of Resource Conditions

Visitors to wildland environments are aware of resource conditions along trails and at recreation sites, just as are managers (Lucas 1979, Marion & Lime 1986, Vaske *et al.* 1982), though their perceptions often differ markedly (Farrell *et al.* 2001). Legislative mandates set high standards when they direct managers to keep protected natural areas "unimpaired" and human impacts "substantially unnoticeable." Seeing trails and recreation sites, particularly those in degraded condition, reminds visitors that others have preceded them. In remote areas even the presence of trails and recreation sites reduce perceived naturalness and can diminish opportunities for solitude. In accessible and popular areas the proliferation and deterioration of trails and recreation sites present a "soiled" or "used" appearance, in contrast to the ideal of a pristine natural environment (Leung & Marion 2000).

Degraded resource conditions on trails and recreation sites can have significant utilitarian, safety, and experiential consequences for visitors (Leung & Marion 2000). Trails serve a vital transportation function in protected natural areas and their degradation greatly diminishes their utility for visitors and land managers. For example, excessive tread erosion or muddiness can render trails difficult and unpleasant to use. Such conditions can also threaten visitor or packstock safety and prevent or slow rescues, possibly increasing agency liability. Impacts associated with certain types of uses, such as linear rutting from bikes or vehicles or muddy hoof prints from horses, can also exacerbate conflicts between recreationists.

Visitors spend most of their time within protected natural areas on trails and recreation sites, so their perceptions of the area and its naturalness are strongly influenced by trail and site conditions. Visitors are sensitive to overt effects of other visitors (such as the occurrence of litter, horse manure, malicious damage to vegetation) and to visually obtrusive examples of impacts such as tree root exposure, tree felling, and soil erosion. A survey of visitors to four wilderness areas, three in southeastern states and another in Montana, found that littering and human damage to recreation site trees were among the most highly rated indicators affecting the quality of recreational experiences (Roggenbuck *et al.* 1993). Amount of vegetation loss and exposed soil around a recreation site were rated as more important than many social indicators, including number of people seen while hiking and encounters with other groups at recreation sites.

Hollenhorst and Gardner (1994) also found vegetation loss and bare ground on recreation sites to be important determinants of satisfaction by wilderness visitors.

Monitoring Program Capabilities

Visitor impact monitoring programs can be of significant value when providing managers with reliable information necessary for establishing and evaluating resource protection policies, strategies, and actions. When implemented properly and with periodic reassessments, these programs produce a database with significant benefits to protected area managers (Figure 2). Data from the first application of impact assessment methods developed for a long-term monitoring program can objectively document the types and extent of recreation-related resource impacts. Such work also provides information needed to select appropriate biophysical indicators and formulate realistic standards, as required in VERP or LAC planning and decision-making frameworks.

Reapplication of impact assessment protocols as part of a monitoring program provides an essential mechanism for periodically evaluating resource conditions in relation to standards. Visitor impact monitoring programs provide an objective record of impacts, even though individual managers come and go. A monitoring program can identify and evaluate trends when data are compared between present and past resource assessments. It may detect deteriorating conditions before severe or irreversible changes occur, allowing time to implement corrective actions. Analysis of monitoring data can reveal insights into relationships with causal or non-causal yet influential factors. For example, the trampling and loss of vegetation or soils may be greatly reduced by shifting trails to more resistant and resilient vegetation types or topographic alignments, instead of more contentious limitations on use. Following the implementation of corrective actions, monitoring programs can evaluate their efficacy.

- Identify and quantify site-specific resource impacts.
- Summarize impacts by environmental or use-related factors to evaluate relationships.
- Aid in setting and monitoring resource conditions standards of quality.
- Evaluate deterioration to suggest potential causes and effective management actions.
- Evaluate the effectiveness of resource protection measures.
- Identify and assign priorities to maintenance needs.

Figure 2. Capabilities of visitor impact monitoring programs.

LITERATURE REVIEW

Two primary issues associated with the development of a visitor impact monitoring program are the selection of indicators that will be monitored and their assessment procedures. Criteria for selecting indicators of change related to trails are reviewed, and prospective indicators and measurement units are presented. Common trail impact assessment procedures are also reviewed.

Visitation-Related Resource Impacts

Visitors participating in a diverse array of recreation activities, including hiking, camping, wildlife viewing, biking, and boating, contribute to an equally diverse array of effects on the resources of protected natural areas, including vegetation, soils, water, and wildlife. The term *impact* is commonly used to denote any undesirable visitor-related change in these resources. This study was restricted to assessments of trampling-related impacts to vegetation and soil along trails.

Formal Trail Impacts

The NPS has applied a wide range of tools and techniques to manage visitor use, including the development of recreation infrastructures that include formal designated trail systems. Well-designed formal trail networks provide enjoyable recreation experiences for a wide variety of visitors and allow access to many points of interest within protected areas. Formal trails accommodate intensive visitor traffic by providing durable treads "hardened" to sustain substantial traffic. The provision of formal trails is consistent with a "containment" strategy that minimizes visitor impacts by concentrating traffic on durable tread surfaces that provide access to a variety of park locations (Hammitt & Cole 1998, Marion & Leung 2004). Confining trampling impacts to a limited network of formal trails avoids more widespread degradation that would be caused by less structured patterns of visitor activity and traffic.

Most formal trail systems are designed and maintained to sustain high traffic while minimizing associated environmental impacts. For example, well-designed trails avoid steep grades and "fall line" alignments parallel to the landform grade that are difficult to drain and intercept natural water flows (Marion & Leung 2004, Olive & Marion 2009). Unfortunately, many trails are not properly located, constructed or maintained to sustain their intended uses. Many formal trails were originally created by visitors or individuals who lacked trail design expertise, or were directed by objectives (e.g., fire fighting) that resulted in less sustainable designs (Marion & Leung 2004). Even well-designed and managed trails are susceptible to the many forms of degradation.

Resource impacts associated with trampling on trails include an array of direct and indirect effects (Table 1). Even light traffic can remove protective layers of vegetation cover and organic litter (Cole 2004, Leung & Marion 1996). Trampling disturbance can alter the appearance and composition of trailside vegetation by reducing vegetation height and favoring trampling resistant species. The loss of tree and shrub cover can increase sunlight exposure, which

promotes further changes in composition by favoring shade-intolerant plant species (Hammitt & Cole 1998, Leung & Marion 2000).

When a trail is constructed or created from visitor use, the surface vegetation and organic litter are lost, exposing underlying mineral soil that is shaped and compacted into a durable tread to support visitor traffic. However, exposure of soil on natural surfaced trails can lead to several resource impacts, including soil compaction, muddiness, erosion, and trail widening (Hammitt & Cole 1998, Leung & Marion 1996, Tyser & Worley 1992). The compaction of soils decreases soil pore space and water infiltration, which in turn increases muddiness, water runoff and soil erosion. The erosion of soils along trails exposes rocks and plant roots, creating a rutted, uneven tread surface. Eroded soils may smother vegetation or find their way into water bodies, increasing water turbidity and sedimentation impacts to aquatic organisms (Fritz 1993). Visitors seeking to circumvent muddy or badly eroded sections contribute to tread widening and creation of parallel secondary treads, which expand vegetation loss and the aggregate area of trampling disturbance (Marion 1994, Liddle & Greig-Smith 1975).

The creation and use of trails can also directly degrade and fragment wildlife habitats, and the presence of trail users may disrupt essential wildlife activities such as feeding, reproduction and the raising of young (Knight & Cole 1995). For example, Miller and others (1998) found decreased presence of nesting birds near trails in grassland ecosystems. Trails can alter hydrology by intercepting and channeling surface water (Sutherland *et al.* 2001), and fragment the landscape with potential barriers to flora and some small fauna (Leung *et al.* 2002). Finally, visitors and livestock can also introduce and transport non-native plant species along trails, some of which may out-compete undisturbed native vegetation and migrate away from trails (Benninger-Truax *et al.* 1992, Adkison & Jackson 1996, Bhuju & Ohsawa 1998, Potito & Beatty 2005, Hill & Pickering 2006)

Table 1. Direct and indirect effects of recreational trampling on soils and vegetation.

Effects	Vegetation	Soil
Direct	Reduced height/vigor Loss of ground vegetation, shrubs and trees Introduction of non-native vegetation	Loss of organic litter Soil exposure and compaction Soil erosion
Indirect	Altered composition – shift to trampling resistant or non-native species Altered microclimate	Reduced soil pore space and moisture, increased soil temperature Increased water runoff Reduced soil fauna

In summary, most trail-related resource impacts are limited to a linear corridor of disturbance, though impacts like altered surface water flow, invasive plants, and wildlife disturbance, can extend considerably further into natural landscapes (Kasworm & Monley 1990, Tyser & Worley 1992). However, even localized disturbance within trail corridors can harm rare or endangered species or damage sensitive plant communities, particularly in environments with slow recovery rates.

Informal Trail Impacts

When formal trail networks fail to provide visitors the access and experiences they desire, visitors frequently venture "off-trail" to reach locations not accessible by formal trails. Even relatively low levels of informal trail traffic can wear down vegetation and organic litter to create visible informal (visitor-created) trail networks (Weaver & Dale 1978, Thurston & Reader 2001). The establishment of informal trails is commonplace in national parks and other protected areas, especially heavily visited areas. Often referred to as *social* trails, their proliferation in number and expansion in length over time are perennial management concerns. Furthermore, because informal trails are not professionally designed, constructed or maintained they can contribute substantially greater impacts to protected area resources than formal trails (Wimpey & Marion 2011). Many of these impacts are related to their poor design, including alignments parallel to slopes or along shorelines, multiple trails accessing the same destinations, routes through fragile vegetation, soils, or sensitive wildlife habitats, and disturbance to rare flora, fauna, or archaeological sites. These design attributes also make informal trails far more susceptible to tread impacts, including expansion in width, soil erosion, and muddiness (Wimpey & Marion 2011).

Areas previously untrampled by human footprints can become severely degraded when repeated visitation results in the creation of informal trails. A study by Thurston and Reader (2001) found an 81% mean loss of vegetation density in the center zone of new informal trails, and a 71% decline in the species present. Mean soil exposure also increased by 23% in these areas. Understanding and minimizing the ecological disturbance caused by off-trail hiking is important to maintaining both the environmental and social aspects of the recreation experience. Research demonstrates that the quality of a visitor's experience is likely to decrease if degradation to a trail is present (Lynn & Brown 2003).

Informal trail proliferation is common in high visitation settings and in some parks is responsible for extensive areas of impact. A study in Mount Rainier National Park on the impacts of informal trail use identified 913 degraded sites and attributed 89% of them to the presence of informal trails (Rochefort & Gibbons 1992). Other studies show that certain landscapes and visitor motivations might make some areas more susceptible to informal trail proliferation. In areas such as open moorland in the UK, informal trails and consequent degradation of the landscape are widely visible (Pearce-Higgins & Yalden 1997). Other areas appear to be more prone to off-trail hiking because most visitors who wander off the official trail are taking a shorter route to a site of interest (Keirle & Stephens 2004). Conversely, informal trails are less common in areas that have more medium-sized trees, topographical elements, and fallen trees that impede the ease of human access (Lehvavirta 1999). Regardless of an area's susceptibility to off-trail hiking, this form of depreciative behavior causes hundreds of thousands of dollars in damage each year (Christensen & Clark 1983). In an effort to reduce the damage caused by informal trail use, educational and site management techniques can be evaluated and tested for their effectiveness in reducing off-trail travel.

Trail Management

Several studies show that proper trail design and construction principles minimize adverse impacts to natural resources and reduce the need for trail maintenance (Leung & Marion 1996, Marion & Leung 2004, Marion 2006, Olive & Marion 2009). The source of many forms of

degradation along formal trails can be related to poor design attributes such as steep grades, alignments close to the fall line (parallel to landform aspect), or to locations on perennially wet soils. Some formal trails were originally created by visitors or individuals who lacked trail design expertise or were directed by objectives in conflict with resource protection goals (Marion & Leung 2004). Well-designed trails require periodic maintenance, which can be challenging to sustain under conditions of declining agency budgets. Even well-designed and managed trails are susceptible to the several forms of degradation when subjected to high use or to high-impact behaviors or types of use (e.g., horse riding and motorized uses) (Aust *et al.* 2004).

Common knowledge assumes that informal trails are less "sustainable" than their formal trail counterparts, because of the lack of professional design and construction associated with their creation. Visual observation and research also suggests that visitors traveling off-trail often take the shortest path, cutting switchbacks or directly ascending slopes (Cole 1993), or the path of least resistance, avoiding dense vegetation or challenging terrain (Bayfield 1973). Finally, common knowledge assumes that off-trail hikers do not generally recognize or attempt to avoid sensitive resources (e.g., rare fauna/flora habitats), or select routes that reflect the principles of sustainable trail design (e.g., side-hill alignments) (Marion & Leung 2004).

The development, deterioration and proliferation of informal trails in protected areas can be a vexing management issue for land managers. Traveling off-trail is generally necessary to engage in activities such as nature study, photography, or exploration. Unfortunately, management experience reveals that informal trail systems are frequently poorly designed, including "shortest distance" routing with steep grades and fall-line alignments. Such routes are rarely sustainable under heavy traffic and subsequent resource degradation is often severe. Creation of multiple routes to common destinations is another frequent problem, resulting in "avoidable" impacts such as unnecessary vegetation/soil loss and fragmentation of flora/fauna habitats.

Once created, managers have found it difficult to deter their use and even when successful, their recovery requires long periods of time (Grabherr 1982, Cole 1990, Boucher *et al.* 1991, Roovers *et al.* 2005). Restoration work can hasten recovery but is expensive and generally requires archeological assessment and compliance work. Informal trails are particularly problematic because they become more visually obvious as they form, acting as a "releasor cue" that draws even more visitors off formal trails (Roggenbuck 1992, Brooks 2003). Informal trails are often indistinguishable from formal trails, except for the lack of formal trail blazes or markings.

Previous research has investigated the deterrence of off-trail hiking through educational messages (Johnson & Swearingen 1992) and site management (Matheny 1979, Johnson *et al.* 1987, Sutter *et al.* 1993, Park *et al.* 2008). Informal trail proliferation and resource impact is a problem across all types of protected natural areas as shown by research and monitoring studies conducted around the globe (Grabherr 1982, Cole 1990, Ferris *et al.* 1993, Marion & Cahill 2006, Manning *et al.* 2006, Marion & Hockett 2008a, Wood *et al.* 2006). However, few studies have extensively mapped or investigated the resource impacts of informal trail networks within protected natural areas (Cole *et al.* 1997, Leung *et al.* 2002, Marion & Hockett 2008b), although several have collected informal trail counts in conjunction with campsite, recreation site, or formal trail inventories (Marion 1994, Leung & Marion 1999c, Dixon *et al.* 2004, Marion & Cahill 2006, Wood *et al.* 2006).

Indicators and Selection Criteria

Indicators are measurable physical, ecological, or social variables used to track trends in conditions caused by human activity so that progress toward goals and desired conditions can be assessed. An indicator is any setting element that changes in response to a process or activity of interest (Merigliano 1990). An indicator's condition provides a gauge of how recreation has changed a setting. Comparison to management objectives or indicator standards reveals the acceptability of any resource changes. Indicators provide a means for restricting information collection and analysis to the most essential elements needed to answer management questions. Examples of questions related to trails include:

Are visitors experiencing an environment where the evidence of human activity is substantially unnoticeable?

Are trail numbers and conditions acceptable given each management zone's objectives and desired conditions?

Are visitor and trail management practices effective in minimizing the establishment of informal trails or degradation in formal and informal trails?

Before a monitoring program can be developed, appropriate resource indicators must be selected. A single, direct measurement of a trail's condition is inappropriate because the overall condition is an aggregate of many components. Typically, then, monitoring evaluates various soil, vegetation, or aesthetic elements of a trail that serve as indicators of that facility's condition. Cole (1989), Marion (1991) and Merigliano (1990) review criteria for the selection of indicators (Table 2), which are summarized here. Management information needs, reflected by the management questions such as the examples above, guide the initial selection of indicators.

Preferred indicators should reflect attributes that have ecological and/or aesthetic significance. Indicator measures should primarily reflect changes caused by the recreational activity of interest. For example, measures of soil loss related to trail construction would be inappropriate. Indicators should be measurable, preferably at an interval or ratio scale where the distances between numeric values are meaningful, i.e. a 36-inch wide trail is twice the width of an 18-inch wide trail. In comparison, a categorical ratings system based on subjective assessments rather than quantitative measures provides data at an ordinal scale. Distance between numeric values are not meaningful so computing an average or using them in statistical analyses or testing is not appropriate.

Table 2. Criteria for selecting indicators of resource condition.

Criteria	Rationale
Quantitative	Can the indicator be measured?
Relevant	Does the indicator change as a result of the process or activity of interest?
Efficient	Can the measurements be taken by available personnel within existing time and funding constraints?
Reliable	How precise are the measurements? Will different individuals obtain similar data of the same indicator?
Responsive	Will management actions affect the indicator?
Sensitive	Does the indicator act as an early warning, alerting you to deteriorating conditions before unacceptable change occurs?
Integrative	Does the indicator reflect only its condition or is its condition related to that of other, perhaps less feasibly measured, elements?
Significant	Does the indicator reveal relevant environmental or social conditions?
Accurate	Will the measurements be close to the indicator's true condition?
Understandable	Is the indicator understandable to non-professionals?
Low Impact	Can the indicator be measured with minimal impact to the resource or the visitor's experience?

Adapted from Cole (1989), Marion (1991), Merigliano (1990), O'Connor & Dewling (1986).

Potential indicators of resource condition are numerous and there is great variation in our ability to measure them with *accuracy*, *precision*, and *efficiency*. All assessments are approximations of an indicator's true value; a measurement method is *accurate* if it closely approximates the true value. *Efficiency* refers to the time, expertise, and equipment needed to measure the indicator's condition. Unfortunately, efficient methods often yield inconsistent results when applied by different individuals. A measurement method is *precise* if it consistently approximates a common value when applied independently by many individuals. Accurate measurements correctly describe how much change has occurred; precise measurements permit objective comparisons of change over time (Cole 1989, Marion 1991). Indicator assessment methods should also be considered when selecting indicators. When choosing a method managers must balance accuracy and precision, for each places constraints upon efficiency and cost-effectiveness. For example, recreation site condition assessments range from highly efficient but subjective evaluations (e.g. photographs or condition class ratings), to rapid assessments (ratings based on numeric categories of damaged trees), to time-consuming research-level measurements (quadrat-based vegetation loss assessments). Regardless of the method selected, comprehensive procedural manuals, staff training, and program supervision stressing quality control can improve both accuracy and precision. However, poorly managed monitoring efforts can result in measurement error that confounds data interpretation or even exceeds the magnitude of impact caused by recreational activities.

Some indicators are less appropriate than others. For example, indicators of depreciative behavior, such as tree damage, litter, and fire construction in areas where fires are banned, detract unacceptably from environmental or social conditions. Unfortunately, indicators that reflect depreciative behavior present difficulties for managers because the resource degradation is often attributable to a small number of visitors whose actions may be less responsive to traditional management actions. These, and other indicators that are temporally dynamic, are also difficult to monitor effectively. For example, the number of fire sites and extent of litter and improperly disposed human waste can vary considerably from one week or month to the next.

Preferred Indicators

From these indicator criteria and knowledge of how recreation affects soil, vegetation, and aesthetics, managers select preferred indicators of trail or recreation site conditions. Table 3 includes a listing of commonly employed indicators for assessing resource conditions on trails and recreation sites using measurement-based approaches. Generally a small number of indicators are selected for use in LAC or VERP frameworks. However, that does not preclude monitoring of additional resource condition indicators or from also assessing various inventory indicators. Travel time to the sampling locations is often the most substantial portion of the time budget so assessing a few additional indicators can be negligible. A final consideration is the measurement units employed for reporting results and/or setting standards. Measurement-based approaches permit the most flexibility in this respect.

For trails, the number, length, and density of informal trails, along with tread width, are the most commonly used indicators. Soil loss, the most ecologically significant trail impact, can be assessed at sample points by measuring maximum incision or cross sectional area. Similarly, tread muddiness can be assessed at sample points as a percentage of tread width.

Table 3. Potential indicators of trail conditions and measurement units.

Trail Indicators	Measurement Units
Informal Trails	Length/unit area, % of formal trail length, #/unit length on formal trails
Tread Width	Max. value, value/unit length, running avg./unit length
Maximum Incision	Max. value, value/unit length, running avg./unit length
Cross Sectional Area	Max. value, value/unit length, running avg./unit length
Muddiness	Max. % of tread width, avg. %/unit length, running avg. %/unit length

In summary, managers must consider and integrate a diverse array of issues and criteria in selecting indicators for monitoring impacts on trails. Indicators will rarely score high on all criteria requiring good judgment as well as area-specific field trials and direct experience. Indicators that score high on some criteria but low on others may be retained in some instances or omitted in others. Tradeoffs are also required, such as a necessary reduction in accuracy so that precision and efficiency may be increased.

Types of Trail Impact Assessment Systems

Formal trail surveys provide information for a number of important management needs. The location and lineal extent of formal and informal trails can be documented and monitored. The number, location and efficacy of trail maintenance features, such as water bars and drainage dips, can be assessed. Trail conditions may be assessed to identify the location, type and extent of trail resource impacts. Information on trail conditions can be used to inform the public about trail resources, justify staffing and funding, evaluate the acceptability of existing resource conditions, analyze relationships between trail impacts and contributing factors, identify and select appropriate management actions, and evaluate changes in trail conditions and the effectiveness of implemented actions.

A variety of efficient methods for evaluating trails and their resource conditions have been developed and described in the literature, as reviewed and compared by Coleman (1977), Cole (1983), and Leung and Marion (2000). At the most basic level, a trail inventory may be employed to locate and map trails and to document trail features such as type of use, segment lengths, hiking difficulty, and natural and cultural features. Trail location information can be accurately documented using a Global Positioning System (GPS) device, which can be input to a Geographic Information System (GIS) for display and analysis of trail attributes (Wolper *et al.* 1994, Wing & Shelby 1999).

Trail facility and maintenance assessments provide information on existing or needed trail maintenance features or work. These assessments may be used to develop databases on signs (e.g., location and text), existing facilities (e.g., bridges) and tread features (e.g., water bars, steps, bog bridging). Prescriptive trail maintenance work log assessments have also been developed to describe recommended solutions to existing tread deficiencies, such as installation of water bars and steps or trail rerouting (Birchard & Proudman 2000, Williams & Marion 1992). Data can be summarized to provide cost and staffing estimates and to direct work crews.

Trail condition assessments seek to describe resource conditions and impacts for the purpose of documenting trends in trail conditions, investigating relationships with influential factors, and evaluating standards or the efficacy of corrective management actions. Leung and Marion (2000) provide a classification of alternative trail impact assessment and monitoring methods. Sampling-based approaches employ either systematic point sampling, where tread assessments are conducted at a fixed interval along a trail (Cole 1983, 1991), or stratified point sampling, where sampling varies in accordance with various strata such as level of use or vegetation type (Hall & Kuss 1989). Alternately, census-based approaches employ either sectional evaluations, where tread assessments are made for entire trail sections (Bratton *et al.* 1979), or problem census evaluations, where continuous assessments record every occurrence of predefined impact problems (Cole 1983, Leung & Marion 1999a, Marion 1994). These two approaches of assessment have been combined in an integrative survey (Bayfield & Lloyd 1973). More elaborate and time-consuming methods for accurately characterizing soil loss (Leonard & Whitney 1977) and vegetation changes (Hall & Kuss 1989) have also been developed.

An evaluation by Marion and Leung (2001) concluded that the point sampling method provides more accurate and precise measures of trail characteristics that are continuous or frequent (e.g., tread width or exposed soil). The problem census method is a preferred approach for monitoring

trail characteristics that can be easily predefined or are infrequent (e.g., excessive width or secondary treads), particularly when information on the location of specific trail impact problems is needed.

Assessing Informal Trail Networks

A comprehensive review of the literature found very few reported examples of research or monitoring efforts focused on assessing informal trail networks (Marion *et al.* 2006, Wimpey & Marion 2011). While informal trails likely occur in nearly every protected area, managers have frequently ignored their presence, limiting monitoring efforts to formal trail systems. Furthermore, conventional trail condition assessment protocols are often difficult to apply to informal trails due to their unique spatial characteristics (Marion & Leung 2001). Informal trail segments are often comparatively numerous, short, and often braided in complex patterns (see Figure 3), creating sampling and assessment difficulties for point sampling or problem assessment methods (Leung & Marion 1999a, Wimpey & Marion 2011).

However, scientists and managers have recently been focusing greater attention to the impacts of informal trail networks and to developing methods for assessing and monitoring their impacts on protected area resources. Managers seeking to assess informal trails must first consider two categories of attributes: spatial and resource condition. Spatial attributes include the location, arrangement, and lineal extent of informal trails. Resource condition attributes include assessed degradation of vegetation, organic litter, and soils along informal trails.

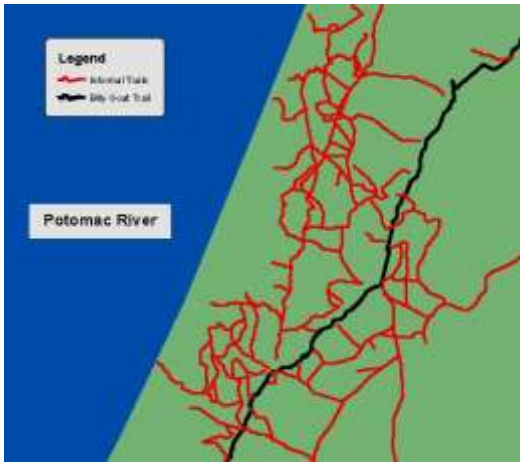

Figure 3. A “spaghetti” map showing the complex network of informal trails branching off the Potomac Gorge’s Billy Goat Trail, CHOH.

It is possible to assess most spatial attributes using scale-appropriate airborne remote sensing techniques if trails are not under concealing vegetation or when they are readily visible in leaf-off photography (Witztum & Stow 2004). Kaiser and others (2004) applied the best available techniques, including high spatial resolution (0.6m/pixel) digital multi-spectral imagery, digital image processing, and visual image analysis techniques, to detect and delineate new illegal immigrant trails in shrublands along the US-Mexico border. They found that an automated linear feature extraction routine (Feature Analyst in ArcView GIS), followed by manual interpretation, delineation, and editing using false color infrared imagery, yielded the most accurate results. However, this method only resulted in 56% of the GPS surveyed trail locations matching by length, in part due to shielding overhead vegetation.

Extending this work, Cao and others (2007) evaluated three trail monitoring approaches and two types of spectral transformation to aid in locating trails in imagery, procedures designed to evaluate temporal changes in US-Mexico cross-border trail networks. They found that a map-to-image differencing approach was the most sensitive and reliable in detecting new trails, though no ground-based GPS surveys were conducted for comparison. For disturbed areas where the

trail networks were extensive, Principal Component Analysis (PCA) of the image was more effective at enhancing new trails. For densely vegetated areas, a Normalized Difference Vegetation Index (NDVI) image yielded more interpreted trails. The authors stress that high quality, well registered, and radiometrically matched multi-temporal image datasets are needed for efficient and reliable trail map updating procedures. Imagery from different years must also be collected at the same phenological time and time of day to minimize errors due to vegetation seasonality and sun angles.

We conclude that these techniques are impractical for most protected area managers due to the substantial expense associated with image acquisition, technician expertise and time, and substantial inaccuracies associated with the methodologies used and concealing vegetation cover. Ground-based Global Positioning System (GPS) surveys are more accurate, use existing staffing and resources, and provide more immediate results. Point-based assessment methods include trailhead and transect surveys. A highly efficient method is to inventory informal trail junctions with protected area roads, trails, or recreation sites, documenting junction locations with a recreation or professional grade GPS, odometer, or measuring wheel (Bacon *et al.* 2006, Marion & Cahill 2006). Alternately, an approach applying transects at fixed intervals within travel zones was developed for Zion National Park to document the number and location of intersecting informal trails (Marion & Hockett 2008a).

Line feature assessment methods provide more comprehensive information on the spatial distribution and lineal extent of informal trail networks. This method requires a GPS set to collect line features (tracks) as field staff walk all informal trails within a management unit. Trail information from the GPS is then input to a Geographic Information System (GIS) for display and analysis of trail attributes (Wolper *et al.* 1994). This commonly applied protocol has been reported in several publications (Bacon *et al.* 2006, Cole *et al.* 1997, Leung *et al.* 2002, Leung & Louie 2008, Manning *et al.* 2006, Marion *et al.* 2006, Marion & Hockett 2008b). Advantages of census surveys include the ability to produce maps showing the location and spatial arrangements of informal trail networks, document the number of trail segments and aggregate lineal extent, perform GIS analyses to investigate proximity to rare flora or fauna or sensitive environments, evaluate landscape fragmentation, and perform other relational analyses.

Resource conditions along informal trails can also be assessed to document effects on vegetation and substrates. A common method is to assign a condition class rating, generally five categories describing increasing levels of trampling impact from a faint trace to a barren and eroded tread (see examples in Manning *et al.* 2006 and Marion *et al.* 2006). Informal trails are broken into separate segments whenever condition classes change categories. Other tread condition indicators such as width and depth, and inventory indicators such as trail grade and vegetation type, can also be assessed using ratings and input as attributes of these segments (Rochefort & Swinney 2000). Resource condition assessments recorded for trail segments generally employ “typical” or categorical range data representative of the entire segment, resulting in some inaccuracies because these assessments are generally not measured. Measurements that are more accurate can be taken using a point sampling approach, generally employing a fixed interval between points with a random start. This method was employed by Wood and others (2006) to characterize informal tread width, depth, cross sectional area soil loss, and estimated total area of disturbance.

STUDY AREA

The study area for this research extends along the Potomac River from Great Falls downstream approximately five miles, including all of Great Falls Park on the Virginia side, Mather Gorge, and Maryland side parklands down to and including the Carderock area. Park lands on the Virginia side are managed by the George Washington Memorial Parkway (GWMP) (Figure 4); park lands on the Maryland side are managed by the C&O Canal National Historical Park (CHOH) (Figure 5). This area is located along a gradient where erosion-resistant Piedmont bedrock gives way to the softer, sandy deposits of the Atlantic Coastal Plain. Its diverse habitats of scoured bedrock river terraces, cliffs, flood plain forests, and upland woods include four globally rare plant communities and many rare plants (Fleming *et al.* 2004). For example, 28 plant species found within GFP are on the State list of rare, threatened or endangered species, including the sticky goldenrod (*Solidago racemosa*), Nantucket shadbush (*Amelanchier nantucketensis*), sterile sedge, (*Carex straminea*), and western sunflower (*Helianthus occidentalis*) (Charlie Davis, personal communication, Steury *et al.* 2008). However, the area is also easily accessible by more than four million people in the Washington metro region and offers a wide range of recreational activities including hiking, cycling, horseback riding, kayaking, rock climbing, photography, fishing, and nature study. The majority of visitors (64%) come to the area to walk, jog, or hike (Meldrum *et al.* 2004). The National Park Service and Fairfax County protected natural areas recorded 2,809,968 visitors in 2007 (NPS, 2009), which reflects the popularity of the Potomac Gorge.

Great Falls Park (GFP), Virginia is an approximately 800-acre park area managed by GWMP that attracts both local visitors from the region and tourists from around the world. In 2007, the NPS estimated annual visitation at just more than one-half million visitors (NPS 2009). Cultural resources within the park include the historic ruins of George Washington's "Patowmack" Canal and the town of Matildaville (NPS 2007). The park has established four management zones: the Canal, Cultural & Natural, Developed, and Mather Gorge. There are eleven formal trails within the GFP, a 12.31 mile network that includes 5 miles open to multiple uses to accommodate mountain biking and horseback riding (Figure 4). The River trail follows the Potomac River from the falls overlooks downstream along the scenic Mather Gorge. The Patowmack Canal trail follows the ruins of this historic canal and the ruins of the canal town of Matildaville. The Old Carriage Road trail, the Ridge trail and Mine Run trail follow upland oak forests and the Swamp trail follows along a unique swamp habitat and lowland forest.

CHOH park lands include approximately 1211 acres, with 22 formal trails totaling 14.67 miles (Figure 5). The River and Ford Mine trails provide visitor access to the areas upstream of Great Falls. The Gold Mine tract includes a network of inland formal trails through upland wooded terrain. The well-known Billy Goat Trail has three sections: Section A traverses Bear Island bordering the Mather Gorge cliffs and includes challenging rock scrambles, Sections B and C pass through floodplain.

Heavy park visitation, primarily on weekends, can lead to crowding at facilities within the park, including the parking and picnic areas, scenic overlooks, and along trails (NPS 2007). Off-trail traffic by visitors exploring and accessing a variety of locations not reached by the formal trail system has led to the development of extensive informal trail networks. Informal trails are so

prevalent and established in portions of the park that many visitors likely believe them to be part of the park's formal trail system.

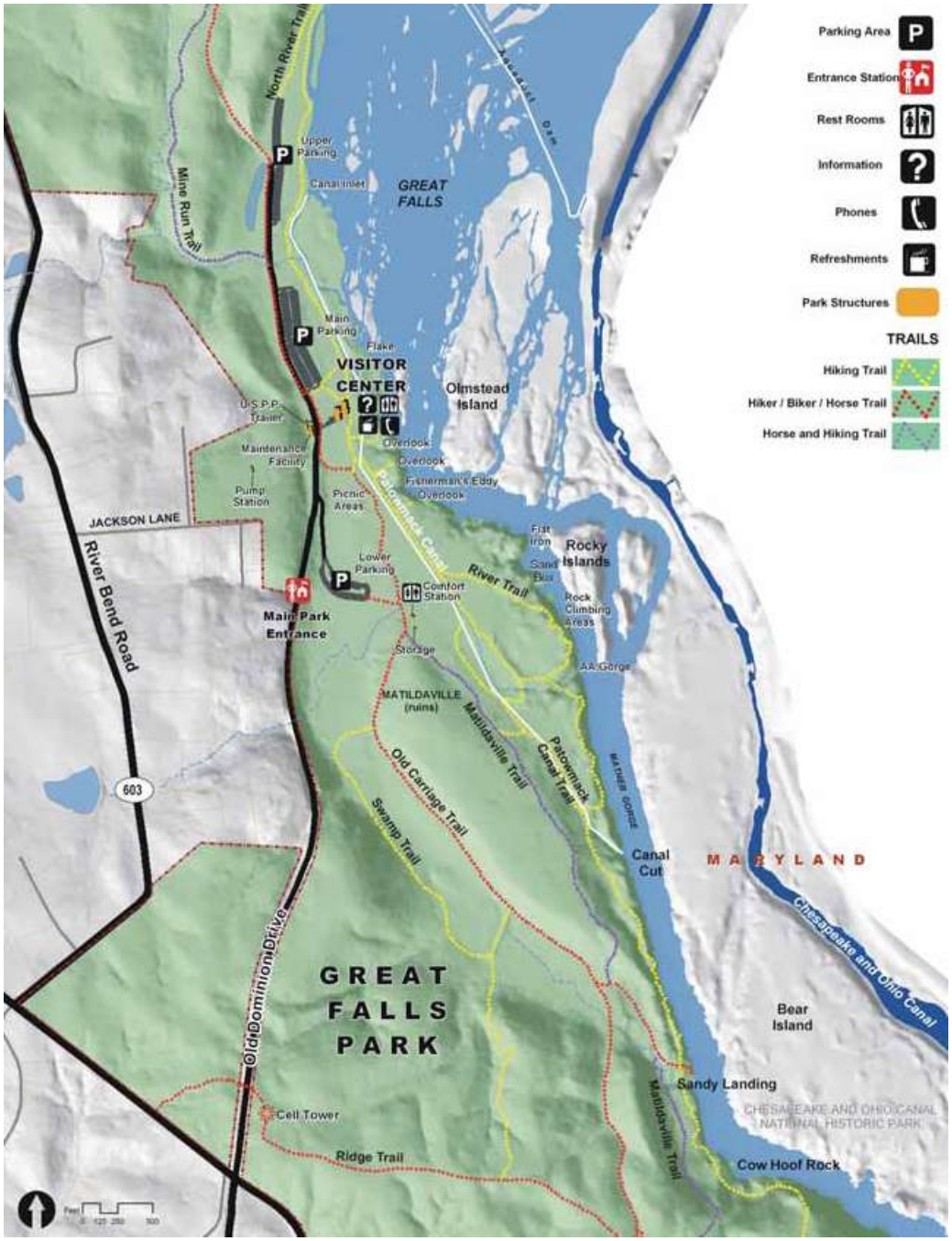

Figure 4. Great Falls Park of GWMP in northeastern Virginia with formal trail system depicted.

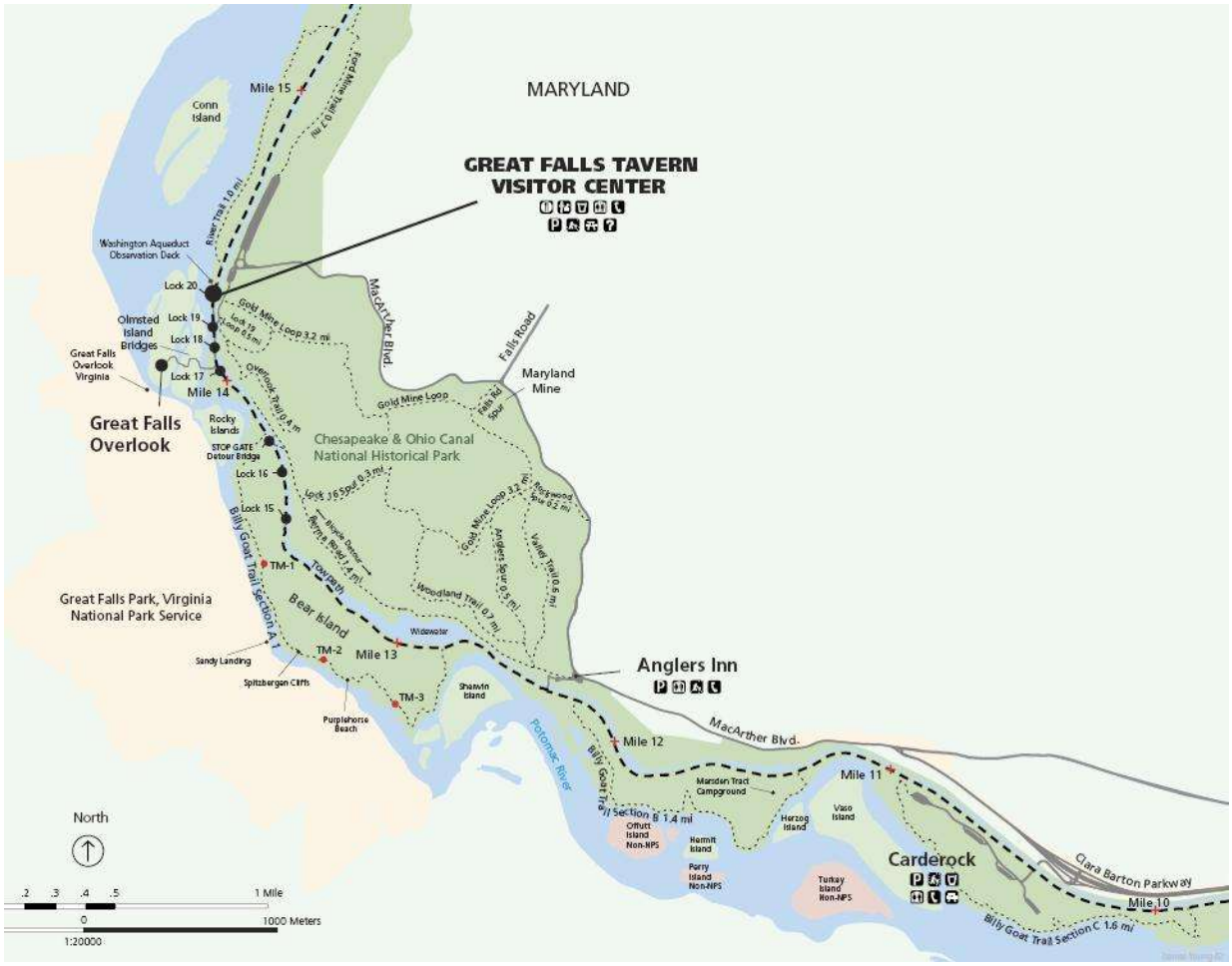

Figure 5. Upper Potomac Gorge and Carderock portions of CHOH in southeastern Maryland with formal trail system depicted.

METHODS

Given park objectives we emphasized measurement-based procedures in our selection and development of formal and informal trail monitoring procedures. To maximize flexibility in the future selection of appropriate trail condition indicators and comparisons to the baseline conditions documented by this study we developed and applied procedures for an array of potential indicators.

Impact assessment procedures were developed and applied to all unpaved formal trails, excluding the more intensively developed C&O Canal Towpath but including natural-surfaced and graveled woods roads that are included in the formal park trails systems. Separate procedures were developed and applied to all visitor-created informal trails that were located based on thorough searches by field staff. However, we note that field staff may have missed a small number of informal trails that were discontinuous (not connected) to the formal and informal trail networks, or were located within some cliff areas that would have been too dangerous to safely assess. Virginia Tech doctoral students Jeremy Wimpey and Logan Park conducted the majority of the fieldwork for this report during May and June of 2007 and 2008 with limited field assistance from Jeff Marion and William Armstrong. The following sections describe the sampling design, field methods, and analysis procedures applied to collect and analyze the impact assessment data.

Trail Assessment Procedures

Formal Trails

Research goals were to develop and apply accurate and precise trail condition monitoring protocols and provide baseline data for use in selecting environmental indicators and standards of quality. As concluded by Marion and Leung (2001), point sampling methods provide more useful and appropriate data for these purposes. Based on the findings of Leung and Marion (1999b) and the need for an efficient method that NPS staff can replicate as part of a long-term monitoring program, a 300 ft point-sampling interval was selected. This interval provided 184 sample points on the CHOH portion and 178 sample points on the GWMP portion of the park, permitting robust statistical analyses and the ability to characterize trail conditions across the trail networks. In addition, a problem assessment method was applied to document the number, location, and lineal extent of excessively eroded and muddy trail segments.

A measuring-wheel was pushed along each formal trail, beginning at a randomly selected location between 0 and 300 feet from the starting point, and stopping every 300 feet thereafter to establish a transect where indicator assessments were performed (Figure 6). A detailed description of the condition assessment procedures applied to formal trails is presented in Appendix 1 and summarized here. At each sample point, a transect was established perpendicular to the trail tread with endpoints defined by the most visually obvious outer boundary of trampling-related disturbance. These boundaries are defined by pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or when vegetation cover is reduced or absent, by disturbance to organic litter or lichen (intact vs. pulverized). Trail boundary definitions were illustrated with photographs and a consistent objective was to define the trail tread that receives the majority (>95%) of traffic. The distance between these

Figure 6. Trail assessment and paperless data recording using a GPS unit at a transect established on a sample point located by pushing a measuring wheel.

disturbance-associated boundaries was measured as trail width. Trail width was coded as "not applicable" in instances when sample points fell on barren non-vegetated bedrock (ledge). Averaged GPS locations, differentially corrected to increase point accuracy, were recorded at each transect to guide field staff in replicating procedures at approximately the same transect locations during future monitoring cycles.

At each transect, survey staff assessed the grade of the trail and the dominant fall-line (landform grade). Trail slope alignment angle (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 & Marion 1996). The TSA of a contour-aligned trail would equal 90° while a true "fall-line" trail (aligned congruent to the landform slope) would have a TSA of 0°. The landform position of the trail relative to the local topography was determined as side-hill or fall-line. Tread surface composition was assessed in the following categories: bare soil, vegetation, organic litter, roots, natural rock, stonework, and man-made materials (wood or gravel). For each category, the percent of trail width was recorded to the nearest 5%. A count of additional secondary trails that paralleled the survey trail at each sample point provided a measure of the extent of trail braiding.

The cross sectional area (CSA) of soil loss (in^2), from the taut string to the tread surface, was also measured using a fixed interval method (Cole 1983) (Figure 7, See Appendix 1 for detailed procedures). Soil loss as assessed by this method includes soil compaction, nearby displacement of soils (e.g. to trailsides), and soil loss from wind and water erosion. Temporary stakes were placed at positions that enabled a line to be stretched along what survey staff judged to represent

the original land surface for fall-line trails, or the post-construction tread surface for constructed side-hill trails. Vertical measurements from the line to the trail substrate surface were taken at a fixed interval of 0.3 ft for narrower trails and 1 ft for wider trails. CSA provides a more accurate measure of trail soil loss that can be extrapolated to provide an estimate of total soil loss from each trail (ft^3). CSA was calculated from the data collected at each sample point using spreadsheet formulas. CSA measurements were not able to be assessed when sample points fell on man-made materials (boardwalks, elevated treads, stonework) or on bare bedrock. As a consequence, CSA measures were completed for 163 of the 184 CHOH transects and 164 of the 178 GWMP transects in the sample population.

Trail condition measures were calculated for each trail and for all trails combined, including area of disturbance, CSA, and mean trail width and depth (Table 4). For example, "area of disturbance," an estimate of the land area intensively disturbed by trail traffic, was calculated by multiplying trail length by mean trail width. CSA volume, an estimate of aggregate soil loss (CSA ft^3), was calculated by multiplying mean CSA (converted to ft^2) by trail length.

Figure 7. Illustration of the fixed interval CSA method for assessing soil loss at each transect.

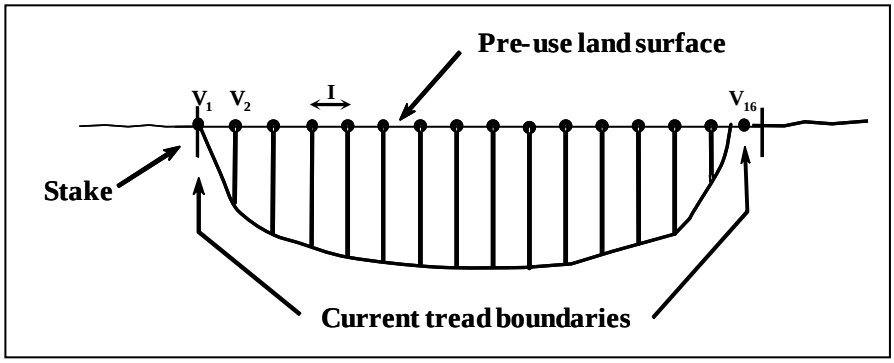

Table 4. Description of trail impact indicators and calculation methods.

Trail Length	Total length of the trail segment being assessed, summed to obtain an aggregate measure for each study area.
Trail Width	Width of trail that captures about 95% of all traffic, including trail-sides up to the pre-use land surface for fall-aligned trails or up to the estimated post-construction tread surface for side-hill trails. Assessed at sample points along each trail and averaged for each trail to obtain mean trail width.
Area of Disturbance	The mean trail width times the trail length.
CSA Soil Loss	An estimate of soil loss at each sample point from erosion, soil displacement, or compaction, assessed through vertical measurements at a fixed interval across the trail width from the pre-use or post-construction land surface to the current tread surface. Mean CSA is calculated as the average of CSA values measured at the sample points for each trail segment.
CSA Volume	The mean CSA for a trail times trail length – an estimate of the total volume of soil lost from a trail.
Mean Trail Depth	Calculated by dividing mean CSA by mean trail width.

Data were assembled in the attribute table of the transect data shapefile in ArcMap 9.3, and then exported to Microsoft Excel 2003 and SPSS 16.0 for analyses. The quotient of trail grade and landform grade was calculated as slope ratio. Trail design guidance recommends a slope ratio of less than 0.5 to facilitate water removal from trail treads (IMBA 2004). Use of trade, product, or firm names does not imply endorsement by the U.S. Government.

Informal Trails

Informal trails were mapped as lineal features using Trimble GeoXT and GeoXH GPS's with external Hurricane and Zephyr antenna; full procedures are provided in Appendix 2 and summarized here. All GPS data were post-processed using Trimble's Pathfinder Office 4.0 and base station data from nearby Continuously Operating Reference Stations (CORS). The GeoXH employs carrier-phase processing that uses base data from multiple CORS locations; the GeoXT data were often incomplete, requiring use of several nearby CORS stations. Informal trail conditions were assessed during field collection using a condition class (CC) system, as previously implemented in rapid assessment surveys of formal trails (Marion *et al.* 2006). Condition class ranged from 1-5 with an increase in value associated with greater departures from natural conditions, with regard to the condition or change in relative cover of vegetation, organic material, and mineral soil (Table 5**Error! Reference source not found.**). A new informal trail segment was designated and assessed when a change in condition class was noted in the field. Changes in condition class that were highly localized (< 10m) were not mapped. Point data were collected at formal and informal trail junctions and at endpoints to aid in the GIS editing process.

Post-processed GPS data were converted to ESRI ArcMAP 9.3 shapefiles for editing and analysis. Aerial imagery of the park was utilized during editing to improve editing accuracy and provide spatial context. Due to the nature of GPS data, the shapefiles required positional editing to create an accurate representation of the trail networks. The majority of this work involved snapping informal trail segment endpoints to the formal trail network and to other informal trail end points at junction points. Junction point data greatly improved the accuracy and efficiency of editing processes by providing anchor points for snapping trail segment endpoints.

Table 5. Condition Class rating descriptions applied to informal trails.

Class 1:	Trail distinguishable; slight loss of vegetation cover and /or minimal disturbance of organic litter.
Class 2:	Trail obvious; vegetation cover lost and/or organic litter pulverized in primary use areas.
Class 3:	Vegetation cover lost and/or organic litter pulverized within the center of the tread, some bare soil exposed.
Class 4:	Nearly complete or total loss of vegetation cover and organic litter within the tread, bare soil widespread.
Class 5:	Soil erosion obvious, as indicated by exposed roots and rocks and/or gullying.

Landscape fragmentation

To analyze landscape fragmentation by formal and informal trails we implemented methods similar to Leung and Louie's (2008) Yosemite National Park protocol. The park boundary polygon was used as a base layer, from which we removed the developed park infrastructure, including paved roads, parking lots, and buildings to create a "no roads" shapefile representing natural park land. This left us with a representation of the park's "natural areas" as a polygon. For fragmentation analyses we fractured this polygon with trails (including woods roads), and used the resultant polygons to calculate our fragmentation metrics. Removal of these features was accomplished by intersecting the features in ArcMAP 9.3 and manually selecting and deleting polygons that correspond to the infrastructure.

Next we created one-half trail width (TW) buffers on the formal and informal trail segments. The resultant buffers represent the areal impact associated with the trails within GFP. We used one-half trail width buffers because this results in the trail center-line being buffered to create a polygon representing the foot-print of the trail; one half of the trail width is projected to the right of the line, and one half projected to the left of the line. This results in a polygon that approximates the trail tread as measured in the field. The buffered trail segments were intersected with and removed from the "no roads" shapefile to create shapefiles representing the park's fragmentation by only formal trails and both formal and informal trails, respectively. These shapefiles were used to calculate the following landscape fragmentation metrics: Number of patches (N), Mean Patch Size (MPS), Largest Patch Index (LPI), Mean Perimeter: Area Ratio (MPAR). The NPS management zone layer was used to summarize and compare these fragmentation metrics across park sub-regions. LPI is a measure of the percentage of an area that is contained in the single largest patch. MPAR is the sum of all perimeters divided by the total area, essentially a measure of the amount of "edge" for a landscape.

RESULTS

George Washington Memorial Parkway, Great Falls Park

Formal Trails

The formal trail survey assessed conditions at 179 sample points selected to be representative of the 12.31-mile formal trail system within Great Falls Park (GFP). While trail condition assessment surveys are focused on achieving long-term monitoring objectives, they also provide an opportunity to collect useful data characterizing the current physical attributes of the trail system. Such data can also be used to evaluate the sustainability of the trails. Three such inventory indicators assessed in this survey are trail grade, trail slope alignment angle, and slope ratio. It is common knowledge among trail managers and reported in numerous studies that soil loss on trails is strongly influenced by trail grade. The speed of surface water runoff intercepted and carried downhill along trail treads increases exponentially with increasing trail grade (Dissmeyer & Foster 1984). In contrast, trails located in flatter terrain exacerbate the two other core trail impact problems, tread muddiness and excessive widening.

Trail Design Indicators

The distribution of trail grade values for GFP trails illustrates their susceptibility for all three core trail impact problems. Data reveal that trail grades rarely exceed 15% (Table 6). Trail manuals generally recommend keeping trail grades below 10% (Hooper 1988) or 12% (Hesselbarth & Vachowski, 2000) to limit soil erosion, with rockwork often needed to harden and reduce erosion on treads greater than 15%. However, the mean grade of GFP trails is 3.30% and less than 1% of the GFP system has trail grades exceeding 30%. Of greater concern are data revealing that approximately 60% of the trail system is located in flatter terrain (0-2% grade) where treads can be susceptible to widening and muddiness problems (Table 6). Formal trails within GFP are generally in good condition due to sustainable designs, and intensive maintenance (including graveling). The most common trail problems encountered during the survey was muddiness (24 occurrences totaling 948 linear feet) and secondary treads (22 occurrences totaling 3314 linear feet). Muddiness and secondary treads often occur at the same location, and are typical along flat natural surface trails that see high use and/or use during wet tread conditions. Muddiness results from water being held on the flat trail tread that is often difficult to drain due to a lack of grade; secondary treads develop as visitors seek and create alternate routes around muddy sections of trail. A section later in this report evaluates the informal (visitor created) trails that have developed in GFP.

A trail's slope alignment angle, as described in the methods section, is the angle between the prevailing landform slope and the trail's alignment extending downhill from the sample point. In contrast to trail grade, the influence and importance of this indicator is not widely known or investigated, though recent studies suggest it may be as influential as trail grade (Aust *et al.* 2005, Marion & Olive 2006). Incredibly, a large portion (41%) of GFP trails are aligned within 22° of the landform aspect or fall line (Table 6), the path naturally taken by water running down a mountain slope. Fall-aligned trails are particularly susceptible to soil erosion and tread widening. Figure 8 depicts a fall-line trail with substantial erosion, in comparison to the side-hill

trail in Figure 9 that has a slope alignment in the 69-90° range. While 78% of these fall line alignments are located on grades of less than 7%, 22% are located on grades steep enough to pose erosive problems (greater than 7%) (Table 6).

Table 6. Cross tabulation of trail grade and trail slope alignment inventory indicators, GFP.

Trail Grade	**Trail Slope Alignment Angle**				
	0-22°	23-45°	46-68°	69-90°	Totals
0-2%	41[1]	8	13	45	107, 60%
3-6%	16	6	10	13	45, 25%
7-10%	8	1	2	2	13, 7%
11-15%	6	3	0	2	11, 6%
16-20%	0	0	0	0	0, 0%
21-30%	1	0	0	0	1, <1%
31-100%	1	0	0	0	1, <1%
Missing	1	0	0	0	1, <1%
Totals:	73 41%	18 10%	25 14%	62 35%	178 100%

Trail Grade:	Mean = 3.3%	Median= 2.0%	Range= 0-36%
Trail Slope Alignment:	Mean = 40.07°	Median= 41.00°	Range= 0-89°

1 – Number of sample points. Divide by 178 to determine percentage of GFP trail system.

Once a fall-aligned trail becomes incised, water trapped on the tread is exceptionally difficult to direct off and can build in volume, substantially increasing its erosivity (Figure 8). As previously noted, erosivity also increases exponentially with trail grade, though natural rockiness and routine maintenance can limit erosion. In flatter terrain, such trail alignments are susceptible to muddiness and widening. Rerouting fall-aligned sections is generally preferred, though alternative routes may not be possible due to cliff-lines or land ownership. Park management may also feel compelled to retain such alignments on the basis of their historic values, including the protection of historic stonework associated with Matildaville and the Patowmack Canal.

Slope Ratio is an ancillary way to assess trail sustainability; IMBA (2004) suggests that keeping the ratio of trail grade to landform below 0.50 is recommended to ensure trail sustainability. This variable is similar to TSA in that it assesses how a trail is laid out relative to the prevailing landform slope; instead of using the difference of two compass bearings (azimuths), it uses the grade of the trail and the grade of the dominant landform. Over half of the trails within GFP have slope ratios that exceed 0.50 (Table 7). Similarly to fall-aligned trails, trails with excessive relative grade are prone to erosion problems as a result of the interception and channelization of surface water during periods of heavy runoff (spring melt and rain events).

Figure 8. Notice the greater soil loss associated with this fall-line trail alignment compared to the more minimal soil loss for the side-hill aligned trail in Figure 9.

Figure 9. A sidehill aligned trail sheds water rather than concentrating it and is less prone to erosion.

Trail Condition Indicators

Trail width ranged from 20 to 223 inches with a mean of 91.78 (Table 7). Over three-quarters of the trails exceed four feet in width. The total area of intensive trampling disturbance associated with the GFP trail system is estimated to be 11.4 acres, based on calculations extrapolating mean trail width to the 12.31-mile GFP trail system. This amounts to approximately 1.43% of the park acreage of GFP.

Assessed soil loss on trails is attributable to several causal factors, including erosion from water or wind, compaction from traffic, and soil displacement to the trail sides or downslope. Recognizing these differing causes, we refer to all as "soil loss" henceforth. At the locations where it was possible to apply this procedure (N=178), maximum incision ranged from 0 to 7.5 inches with a mean of 1.69 (Table 7).

Cross-sectional area soil loss measurements, while more time-consuming, provide a more accurate estimate of soil loss. CSA ranged from 0 to 573 in^2, with a mean of 89.46 in^2 (Table 7). A calculation extrapolating this measure by the trail system length yields an estimated aggregate soil loss of 40,379 ft^3 (1495 yd^3 or 150 ten cubic yard dump trucks). On a per-mile basis, soil loss is approximately 3,280 ft^3/mile (121.4 yd^3/mile).

Table 7. Number and percent of sample points by impact indicator category, GFP.

Indicator	Sample Points	Percent[1]
Trail Width (in)		
0-24	2	1.1
25-36	20	11.2
37-48	19	10.6
49-60	14	7.8
60+	122	68.2
Missing	2	1.1
Mean = 91.78	Median = 92.50	Range = 20-223
Maximum Incision (in)		
0	14	7.8
0.1-0.5	19	10.6
0.51-1.0	40	22.3
1.01-3.0	81	45.3
3.01-5.0	18	10.1
5.01+	6	3.4
Missing	1	0.6
Mean = 1.69	Median = 1.25	Range = 0-7.5
Cross Sectional Area Soil Loss (in^2)		
0	15	8.4
1-100	110	61.5
101-200	36	20.1
201-400	12	6.7
401+	5	2.8
Missing	1	0.6
Mean = 89.46	Median = 53.10	Range = 0-573
Slope Ratio		
0-0.09	18	10.1
0.1-0.35	35	19.6
0.36-0.50	21	11.7
0.51-0.75	16	8.9
0.76+	86	48
Missing	3	1.7
Mean = 0.65	Median = 0.75	Range = 0-1.0

1 – Percent of all sample points (including missing), i.e., percent of the GFP trail system.

Finally, field staff assessments of the tread substrate as a proportion of transect width are used to characterize the typical trail system substrates. The predominant tread substrate is gravel (55.0%), followed by soil (28.7%) and organic litter (8.17%) (Figure 10). The "other" category (0.9%) includes asphalt, concrete and other non-natural surfaces. The wood category (1.1%) represents constructed boardwalks and bridges. Naturally occurring rock surface contributes 3.5%, followed by roots (1.1%) and vegetation (1.1%). Field staff assessed mud (0.5%) and standing water (0.0%), however due to the time of year these were rarely encountered.

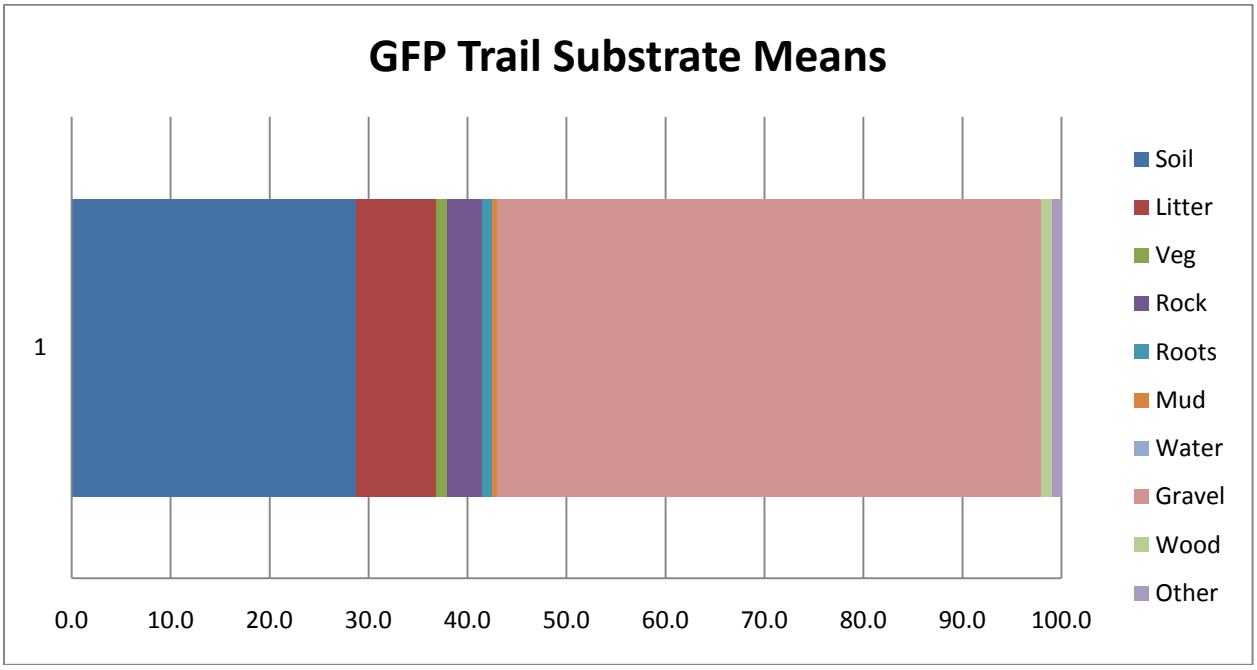

Figure 10. Mean trail substrate cover as a proportion of transect (tread) width, GFP.

Data have also been summarized by trail name (Table 8); this format may be of more use to park managers who are familiar with trails and would like to see how the average design and impact indicators associated with a particular trail relate to their perception of the trail(s). The "worst" values for each indicator are in bold, while the "best" are underlined. Old Carriage Road is the widest trail (mean of 154in) and represents 11.8% of the linear extent of the trail system within GFP. Ridge Trail has the highest mean CSA at 195in^2, note that it also has poor values for mean TSA (33°) and a high mean slope ratio (0.7). Sandy landing has the worst values for mean TSA (0°) and Slope Ratio (1.0); however it is a relatively short trail with only 3 sample points which represent 1.7% of GFP's trail system. Swamp-Ridge Connector Trail has the highest mean maximum incision (3.4in) and has a poor value for mean Slope Ratio (0.6).

Table 8. Trail impact and design indicators summarized by trail name, GFP[1].

Trail Name[2]	Trail Width (in)			CSA (in2)	Max. Incision (in)	Trail Slope Alignment (°)	Slope Ratio
	Mean	Count	Trail System (%)	Mean	Mean	Mean	Mean
Matildaville Trail (North)	81	10	5.6%	46	1.2	67	0.4
Matildaville Trail (South)	49	7	3.9%	36	1.5	60	0.8
Mine Run	38	7	3.9%	33	1.6	45	0.6
North River Trail	111	5	2.8%	25	0.4	33	0.8
Old Carriage Road	**154**	21	11.8%	110	1.7	53	0.5
Patowmack Canal Trail	132	11	6.2%	88	1.1	22	0.8
Patowmack Canal Trail (North)	97	12	6.7%	73	1.3	54	0.6
Potomac Canal Connectors	116	13	7.3%	106	1.5	25	0.7
Ridge Trail	111	27	15.2%	**195**	2.5	33	0.7
Ridge Trail Extension	55	3	1.7%	89	2.9	47	0.8
River Trail (North)	61	12	6.7%	54	1.1	36	0.7
River Trail (South)	47	14	7.9%	62	2.0	41	0.6
River Trail Detour	59	3	1.7%	34	0.9	60	0.2
Riverbend Connector	129	6	3.4%	39	0.8	26	**1.0**
Riverbend Road Trail	39	8	4.5%	40	1.8	37	0.6
Sandy Landing	122	3	1.7%	189	2.2	**0**	**1.0**
Swamp Trail	40	10	5.6%	32	1.8	41	0.5
Swamp-Ridge Connector Trail	65	6	3.4%	123	**3.4**	37	0.6

1 – The "worst" values for each indicator are in bold, the "best" values are underlined.
2 – See trail map, Figure 4.

C&O Canal National Historical Park

Formal Trails

The formal trail survey assessed conditions at 184 sample points selected to be representative of the 14.67-mile formal trail system within CHOH. While trail condition assessment surveys are focused on achieving long-term monitoring objectives, they also provide an opportunity to collect useful data characterizing the current physical attributes of the trail system. Such data can also be used to evaluate the sustainability of the trails. Three such inventory indicators assessed in this survey are trail grade, trail slope alignment angle and slope ratio. It is common knowledge among trail managers and reported in numerous studies that soil loss on trails is strongly influenced by trail grade. The speed of surface water runoff intercepted and carried downhill along trail treads increases exponentially with increasing trail grade (Dissmeyer & Foster 1984). In contrast, trails located in flatter terrain exacerbate the two other core trail impact problems, tread muddiness and excessive widening.

Trail Design Indicators

The distribution of trail grade values for CHOH trails illustrates their susceptibility for all three core trail impact problems. Data reveal that trail grades seldom (10%) exceed 15% (Table 9). Trail manuals generally recommend keeping trail grades below 10% (Hooper 1988) or 12% (Hesselbarth & Vachowski, 2000) to limit soil erosion, with rockwork often needed to harden and reduce erosion on treads greater than 15%. However, the mean grade of CHOH trails is 6.51% and with 3% of the CHOH system has trail grades exceeding 30%. Data also reveal that approximately 37% of the trail system has very low grades (0-2% grade); alignments that are susceptible to widening and muddiness problems when located in flatter terrain (Table 9). Formal trails within CHOH are generally in good condition due to sustainable designs, and intensive maintenance (including gravelling). The most common trail problems encountered during the survey were informal trails, secondary treads and excessive width. A section later in this report evaluates the informal (visitor created) trails that have developed in CHOH.

A trail's slope alignment angle, as described in the methods section, is the angle between the prevailing landform slope and the trail's alignment extending downhill from the sample point. In contrast to trail grade, the influence and importance of this indicator is not widely known or investigated, though recent studies suggest it may be as influential as trail grade (Aust *et al.* 2005, Marion & Olive 2006). A significant portion (23%) of CHOH trails are aligned within 22° of the landform aspect or fall line (Table 9), the path naturally taken by water running down a mountain slope. Figure 8 depicts a fall-line trail with substantial erosion, in comparison to the side-hill trail in Figure 9 that has a slope alignment in the $69\text{-}90^{o}$ range. While 52% of these fall line alignments are located on grades of less than 7%, 48% are located on grades steep enough to pose erosive problems (greater than 7%) (Table 9).

Once a fall-aligned trail becomes incised, water trapped on the tread is exceptionally difficult to direct off and can build in volume, substantially increasing its erosivity (Figure 8). As previously noted, erosivity also increases exponentially with trail grade, though natural rockiness intensive routine maintenance can limit erosion. In flatter terrain, such trail alignments are susceptible to muddiness and widening. Rerouting fall-aligned sections is generally preferred, though

alternative routes may not be possible due to cliff-lines or land ownership. In addition, park management may feel compelled to retain most of these alignments on the basis of their historic values, including the protection of historic stonework associated with ruins in the Gold Mine Tract and along the C&O Canal.

Table 9. Cross tabulation of trail grade and trail slope alignment inventory indicators, CHOH.

Trail Grade	**Trail Slope Alignment Angle**				
	0-22°	23-45°	46-68°	69-90°	Totals
0-2%	11	5	17	35	68, 37%
3-6%	14	5	19	22	60, 33%
7-10%	3	10	7	3	23, 13%
11-15%	4	3	6	1	14, 8%
16-20%	3	2	2	1	8, 4%
21-30%	3	0	0	2	5, 3%
31-100%	4	0	2	0	6, 3%
Totals	42	25	53	64	184
	23%	14%	29%	34%	100%
Trail Grade:	Mean = 6.51%		Median= 4.00%		Range= 0-58%
Trail Slope Alignment:	Mean = 48.71°		Median= 59.00°		Range= 0-90°

1 – Number of sample points. 2- Percentage of CHOH trail system determined using weighted averages to adjust for differing sample interval.

Slope Ratio is an ancillary way to assess trail sustainability; IMBA (2004) suggests that keeping the ratio of trail grade to landform below 0.50 is recommended to ensure trail sustainability. This variable is similar to TSA in that it assesses how a trail is laid out relative to the prevailing landform slope; instead of using the difference of two compass bearings (azimuths), it uses the grade of the trail and the grade of the dominant landform. A large portion (40.7%) of the trails within CHOH has slope ratios that exceed 0.50 (Table 10). Similarly to fall-aligned trails, trails with excessive relative grade are prone to erosion problems as a result of the interception and channelization of surface water during periods of heavy runoff (spring melt and rain events).

Trail Condition Indicators

Trail width ranged from 10 to 192 inches with a median of 42 (Table 10). Over one-third (37%) of the trails exceed four feet in width. The total area of intensive trampling disturbance associated with the CHOH trail system is estimated to be 7.0 acres, based on calculations extrapolating mean trail width to the 14.67-mile CHOH trail system. This amounts to slightly less than 0.005% of total CHOH acreage.

Assessed soil loss on trails is attributable to several causal factors, including erosion from water or wind, compaction from traffic, and soil displacement to the trail sides or downslope.

Recognizing these differing causes, we refer to all as "soil loss" henceforth. At the locations where it was possible to apply this procedure (N=183), maximum incision ranged from 0 to 7.0 inches with a mean of 1.61 (Table 10).

Table 10. Number and percent of sample points by impact indicator category, CHOH.

Indicator	Sample Points[1]	Percent[2]
Trail Width (in)		
0-24	13	7.1
25-36	55	29.9
37-48	48	26.1
49-60	32	17.4
60+	36	19.6
Missing	0	0
Mean = 47.29 Median = 42.00 Range = 10-192		
Maximum Incision (in)		
0	25	13.6
0.1-0.5	15	8.2
0.51-1.0	32	17.4
1.01-3.0	97	52.7
3.01-5.0	11	6
5.01+	3	1.6
Missing	1	0.5
Mean = 1.61 Median = 1.50 Range = 0-7.0		
Cross Sectional Area Soil Loss (in^2)		
0	25	13.6
1-100	134	72.8
101-200	22	12
201-400	2	1.1
401+	0	0
Missing	1	0.5
Mean = 49.02 Median = 37.35 Range = 0-339		
Slope Ratio		
0-0.09	32	17.4
0.1-0.35	50	27.2
0.36-0.50	27	14.7
0.51-0.75	24	13
0.76+	51	27.7
Missing	0	0
Mean = 0.49 Median = 0.42 Range = 0-1.0		

1 – Number of sample points. 2- Percentage of CHOH trail system determined using weighted averages to adjust for differing sample interval.

Cross-sectional area soil loss measurements, while more time-consuming, provide a more accurate estimate of soil loss. CSA ranged from 0 to 339 in^2, with a mean of 49.02 in^2 (Table 10). A calculation extrapolating this measure by the trail system length yields an estimated aggregate soil loss of 26,368 ft^3 (977 yd^3 or 98 ten cubic yard dump trucks). On a per-mile basis, soil loss is approximately 1,797 ft^3/mile (66.6 yd^3/mile).

Finally, field staff assessments of the tread substrate as a proportion of transect width are used to characterize the typical trail system substrates depicted in Figure 11. The predominant tread substrate is bare soil (44.5%), followed by organic litter (36.1%) and rock (14.2%). The man made category (1.33%) includes asphalt, concrete and other non-natural surfaces such as wooden boardwalks and bridges. Roots (2.2%) and vegetation (2.2%) account for very little of the tread substrate by width.

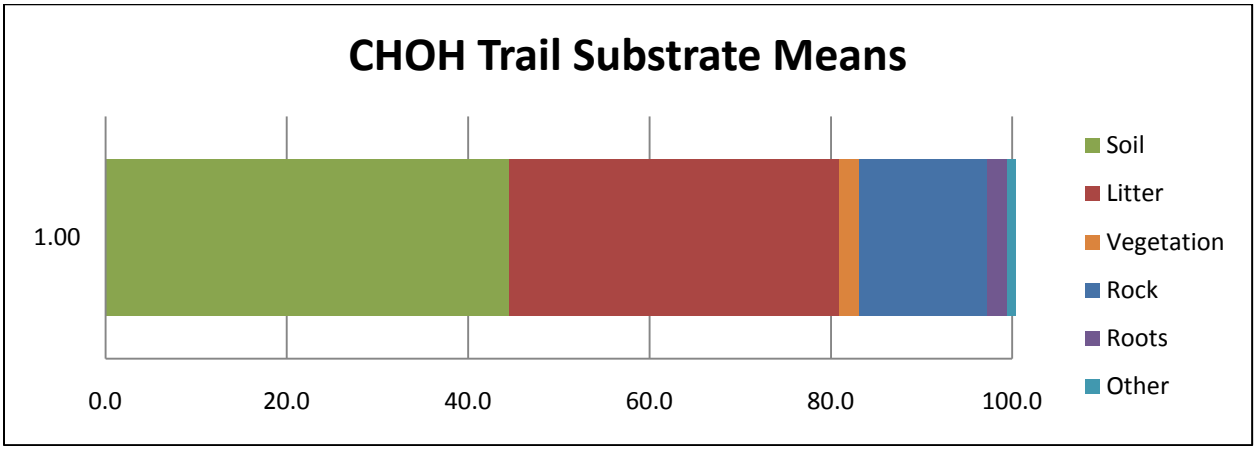

Figure 11. Mean trail substrate cover as a proportion of transect (tread) width, CHOH.

Data have also been summarized by trail name (Table 11); this format may be of more use to park managers who are familiar with trails and would like to see how the average design and impact indicators associated with a particular trail relate to their perception of the trail(s). The "worst" values for each indicator are in bold, while the "best" are underlined. Billy Goat A is the widest trail (mean of 73in) and represents 17.9% of the linear extent of the trail system within CHOH. Billy Goat A Emergency Access has the highest mean CSA at 74.5in^2, note that it also has poor values for mean TSA (28°) and a high mean slope ratio (0.67). Falls Spur Road has the worst values for mean TSA (0°) and Slope Ratio (1.0); however it is a relatively short trail with only 1 sample point which represent 0.5% of CHOH's trail system. Overlook Trail has the highest mean maximum incision (2.3 in) yet has acceptable values for slope ratio (0.386) and TSA (52°).

Table 11. Trail impact and design indicators summarized by trail name, CHOH[1].

Trail Name[2]	**Trail Width (in)**			**CSA (in^2)**	**Max. Incision (in)**	**Trail Slope Alignment (^{o})**	**Slope Ratio**
	Mean	N	Trail System %	Mean	Mean	Mean	Mean
Anglers Inn Spur	51	5	2.7%	48.24	1.50	41	0.572
Berma Road	72	1	0.5%	40.50	1.00	85	0.000
BGA Emergency Access Trail	61	3	1.6%	**74.55**	1.67	28	0.670
Billy Goat A	**73**	33	17.9%	71.59	2.02	41	0.539
Billy Goat B	37	25	13.6%	50.42	1.94	56	0.488
Billy Goat C	44	28	15.2%	52.81	1.74	51	0.476
Falls Road Spur	72	1	0.5%	0.00	0.00	**0**	**1.000**
Ford Mine Trail	38	15	8.2%	22.75	0.88	63	0.345
Ford Mine Spur	68	2	1.1%	0.00	0.00	84	0.200
Gold Mine Loop	53	25	13.6%	60.55	1.61	43	0.539
Lock 16 Spur	34	4	2.2%	29.93	1.31	45	0.460
Lock 19 Loop	26	3	1.6%	25.65	1.25	44	0.350
Overlook Trail	36	5	2.7%	40.77	**2.30**	52	0.386
River Trail	36	17	9.2%	17.90	0.84	68	0.324
Rockwood Spur	24	3	1.6%	8.40	0.50	60	0.277
Valley Trail	38	7	3.8%	57.47	2.04	36	0.740
Woodland Trail	40	7	3.8%	62.29	2.29	43	0.583

1 – The "worst" values for each indicator are in bold, the "best" values are underlined. Note that mean values based for short trails are based on few transects and may be strongly influenced by a single value.
2 – See trail map, Figure 5.

George Washington Memorial Parkway, Great Falls Park

Informal Trails

A GPS census inventory of the informal trails within GFP produced spatial datasets that can be summarized in a variety of ways; we have selected three types of summaries that lend themselves to understanding the informal trails within GFP: A quantitative summary of the extent of informal trails, a description of the spatial distribution of informal trails, and a summary of park fragmentation by informal trails. In each of these three summaries we make comparisons to the formal trails within the GFP, in an effort to provide context and an understanding of the relative level of impacts associated with informal trails.

Quantitative Summary of Informal Trails: GFP

Field staff surveyed 8.37 miles of informal trail within GFP, which is equal to over two-thirds (68%) of the formal trails within the park by length (Table 12). Informal trails within GFP tend to be much narrower than their formal trail counterparts; when we examine the areal extent of informal trails we find that they represent less than one-quarter (23%) of the areal extent of the formal trail system. Further examination of the extent of informal trails by condition class show that most (95% by areal extent 91% by lineal extent) of the informal trail system is CC3 or higher indicating a loss of vegetation and organic litter from the trail (Table 13). Of greater concern is the fact that much of these informal trails fall into CC4 and CC5 (60% by areal extent and 49% by lineal extent), condition classes that indicate erosion has or is actively occurring within the tread.

Table 12 also reveals the distribution of informal trails by park management zones (Figure 12). These zones are defined and described in the 2007 General Management Plan (GMP). This permits comparison of the management objectives for each zone to the quantity and distribution of informal trails within each zone to evaluate where conditions may be in congruence or contrary to desired conditions.

The Mather Gorge Zone contains the largest proportion of informal trails (41% by length, 44% by area) out of the four management zones outlined in the 2007 GMP (Table 14). The Canal Zone ranks second with 35% of the informal trails by length (32% by area). Within each of the management zones we can look at the distribution of informal trails by condition class; these data show that the majority of the informal trails are CC3 or higher, indicating severe reduction of vegetation and organic litter cover from the tread (Table 14).

Table 12. Formal and informal trail extents within GFP.

Impact Indicators	GFP Park Zones				Overall
	Developed	**Canal**	**Mather Gorge**	**Cultural/ Natural**	
	29.86 acres	74.48 acres	40.04 acres	581.53 acres	725.91 acres
	High	← *Recreation Infrastructure* →		*Low*	*N/A*
Aggregate Length (ft)					
Formal Trails	4,951	12,503	6,050	33,753	65,092
Informal Trails	1,453	14,888	18,150	19,072	53,563
Disturbance Area (ft^2)					
Formal Trails	41,764	117,994	36,048	268,775	497,820
Informal Trails	2,809	42,647	46,662	60,784	152,901
Lineal Extent (ft/acre)					
Formal Trail Length	166	168	151	58	90
Informal Trail Length	49	200	453	33	74
Disturbance Density (ft^2/acre)					
Formal Trails	1,399	1,584	900	462	686
Informal Trails	94	573	1,165	105	211

Table 13. Formal and informal trails of GFP summarized by Condition Class.

Trail Type	Linear Extent (mi)	Areal Extent (yd^2)
Formal	12.31	55,313
Informal (all)	8.37	12,765
CC1	0.05	25
CC2	0.69	526
CC3	3.65	4,601
CC4	2.16	3,693
CC5	1.82	3,920

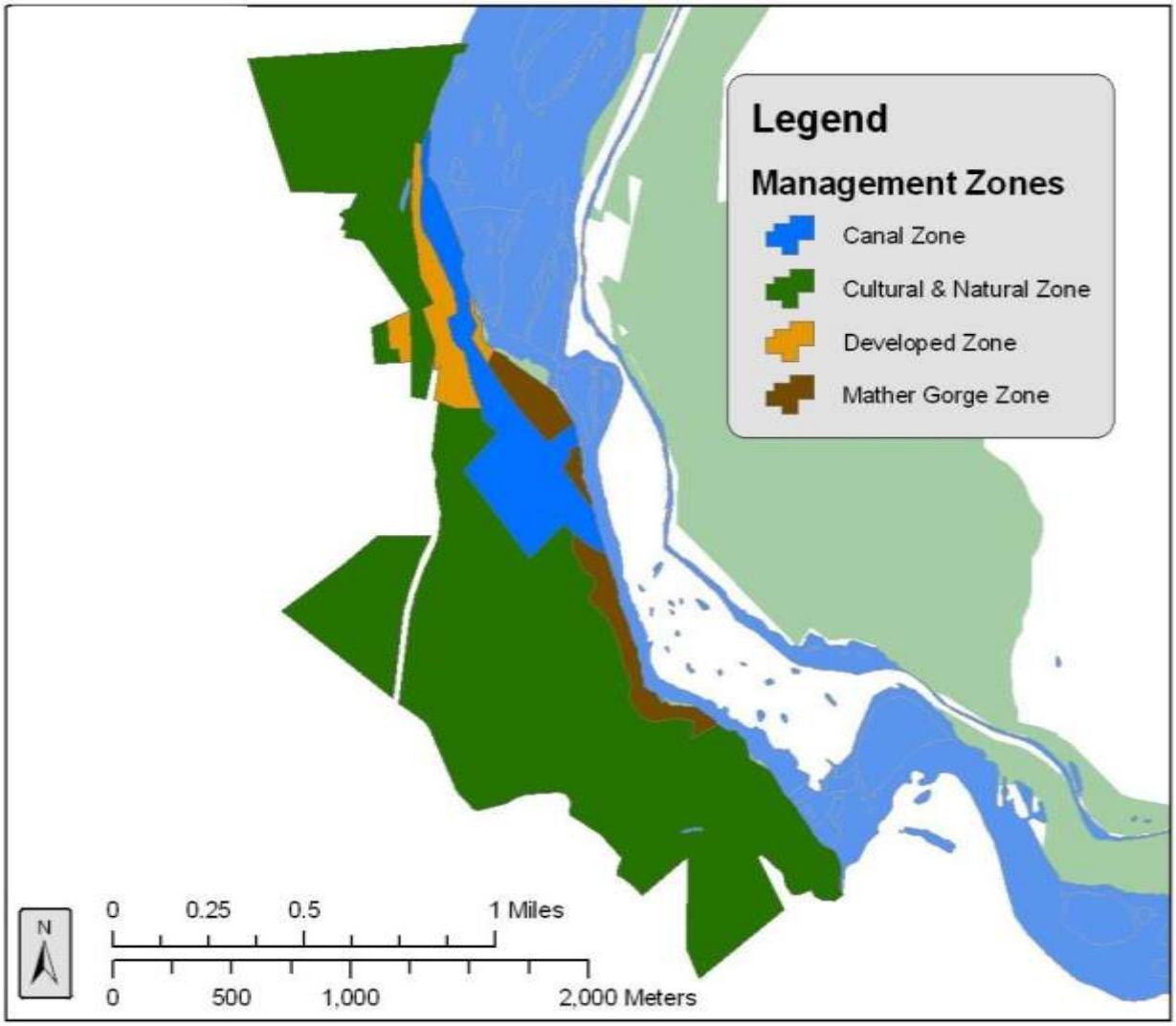

Figure 12. Management zones of GFP.

Table 14. Summary of informal trails by management zone and Condition Class, GFP.

Zone	Condition Class	Lineal Extent (ft)	Areal Extent (ft^2)	% by Length*	% by Area*
Developed	**CC1**	0	0	0%	0%
	CC2	52	75	4%	2%
	CC3	935	2002	71%	68%
	CC4	331	883	25%	30%
	CC5	0	0	0%	0%
	IT Total	1316	2960	3%**	3%**
Canal	**CC1**	105	97	1%	0%
	CC2	2,159	2,540	14%	7%
	CC3	7,300	15,425	48%	42%
	CC4	3,556	10,064	23%	28%
	CC5	2,198	8,288	14%	23%
	IT Total	15,322	36,425	35%**	32%**
Mather Gorge	**CC1**	151	108	1%	0%
	CC2	1,114	1,442	6%	3%
	CC3	6,467	14,876	36%	29%
	CC4	5,322	15,812	30%	31%
	CC5	4,902	18,718	27%	37%
	IT Total	17,955	50,956	41%**	44%**
Cultural/Natural	**CC1**	13	11	0%	0%
	CC2	308	678	3%	3%
	CC3	4,590	9,106	48%	37%
	CC4	2,182	6,469	23%	26%
	CC5	2,510	8,267	26%	34%
	IT Total	9,603	24542	22%**	21%**
Overall	**CC1**	269	226	1%	0%
	CC2	3,632	4,736	8%	4%
	CC3	19,291	41,409	44%	36%
	CC4	11391	33,239	26%	29%
	CC5	9,610	35,284	22%	31%
	Overall Total	44,196	114,883	100%**	100%**

* % IT Total for Zone ** % of Overall Total

Spatial Distribution of Informal Trails: GFP

The majority of informal trails within GFP are concentrated along the Potomac River and the area atop the adjacent cliffs. A secondary area where networks of informal trails occur is along Difficult Run at the south end of GFP's property. Additional informal trails have formed along the formal trail network within inland areas of the park; these trails tend to parallel formal trails, shortcut junctions and access the park from adjoining properties (Figure 13).

The pattern of the informal trails adjacent to the Potomac River and Mather Gorge, are consistent with visitors exploring and accessing the overlooks and cliffs. The trails tend to leave the formal trail and head towards the river especially in the area near Great Falls proper. These trails seem to be formed and used by a wide variety of trail users including anglers, climbers, day hikers, swimmers, families and river users (commercial rafting groups and private rafters, canoeists and kayakers) The majority of these trails have formed because the formal trail network does not provide the access and/or experience that visitors are seeking; this may be a problem related to location of the formal trails as well as the carrying capacity of the trails. Along the River Trail the informal trail network is indicative of shortcutting, exploration and access.

The informal trailing along Difficult Run is primarily access and exploration based; these routes appear to be used by anglers, kayakers and more dispersed uses such as exploration and nature study. Trail erosion can be quite a problem along these trails as they descend steep slopes in some areas to access Difficult Run. Runoff from these trails raises concern over secondary impacts to water quality from sedimentation.

Informal trails within the inland portion of the park have developed along the formal trail network for a variety of reasons: parallel trails tend to form when visitors seek to avoid an undesirable trail condition (e.g. muddiness, crowding), whereas spur trails tend to develop as shortcuts or to provide access. Several trails around the western perimeter of the park appear to exist to provide access to the park from adjacent communities and roads. Three distinct access/shortcut routes cut through the park from Georgetown Pike (Rte. 193) and Difficult Run Trail (gated road) in the southwest reaches of the park. One informal route leaves the gravel parking lot on Georgetown pike and ascends the hollow to access the formal trail on the ridge. A second informal route leaves Difficult Run Trail and ascends steeply around (both sides) of a quarry and ultimately accesses formal trails atop the ridge.

Safety around the quarry area is a concern as informal trails brings visitors very close to the edge of the quarry walls, where a slip and fall could prove deadly. The third informal route is a shortcut from the Ridge Trail to Difficult Run Trail that cuts off about three-quarter of a mile when compared to walking around the formal trail. All three of these routes have poor alignments and steep grades. Should use level increase on these trails we expect that erosion and gullying of the trails will occur. We note that the informal route from the gravel lot on Georgetown Pike to the Ridge Trail appears to receive the most use, and also has a shallower grade; this informal route also appears to provide access to many visitors to the park because they seek to avoid the muddy and eroded trail that leads from the gravel parking lot to Difficult Run Trail, and hiking along Route 193 appears to be unsafe. With some effort from park managers this informal route could be rerouted and improved to provide access without incurring additional impacts to the natural resources.

The greatest concerns with regards to informal trails are their duplicative nature (Figure 14) and their proximity to sensitive communities of rare vegetation. Informal trails are hiked in by users seeking to fulfill their own individual goals; these goals do not include protection of sensitive vegetation, or creating a route that can sustain high levels of use. Figure 13 clearly illustrates the issue of duplicative routes associated with informal trails; multiple spurs (12+ in less than one-tenth of a mile) to the rocky outcrop leave the formal trail and grass area of the park.

While we were unable to source spatial data showing the locations of sensitive and/or rare plant communities within the park, we suggest that park management should examine the proximity of the informal trails (shapefiles provided to NPS with this report) to these features. Informal trails with a condition class of 3 or higher represent trails that have removed the majority of the natural vegetation from within their tread boundary.

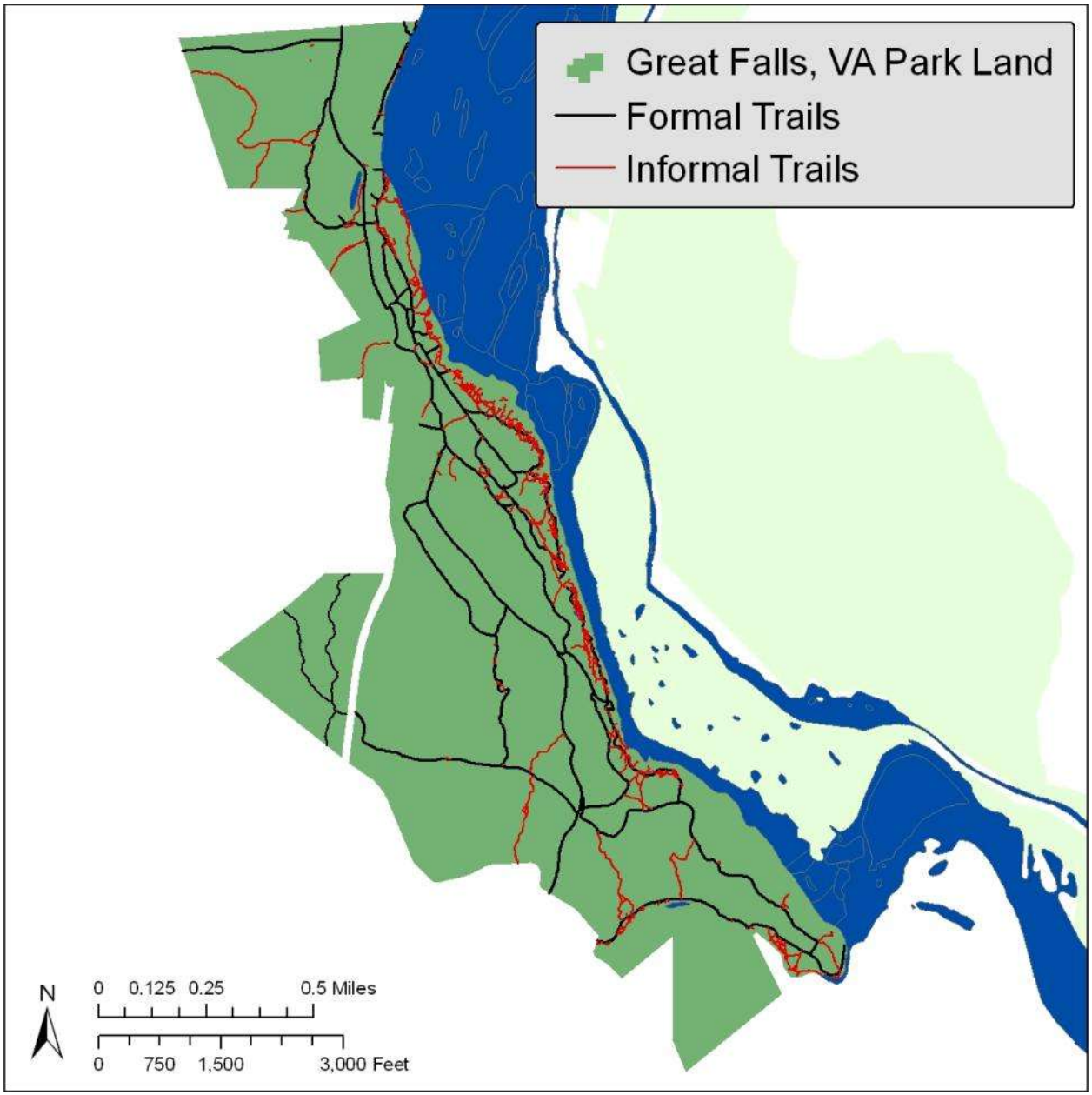

Figure 13. Location of informal trails within GFP.

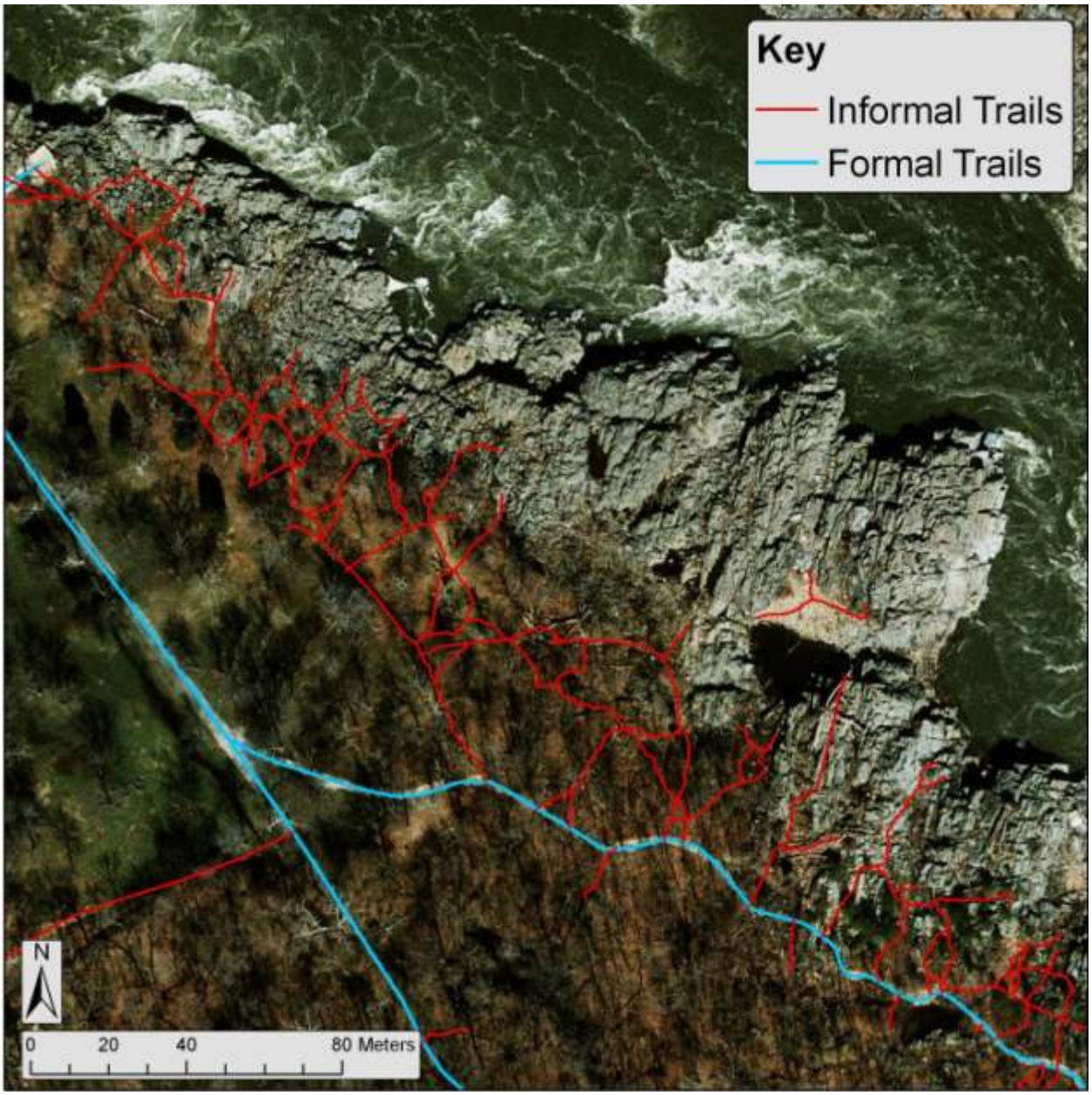

Figure 14. Duplicative routing of informal trails within GFP.

Fragmentation by Informal Trails: GFP

As described in the methods we analyzed GFP land fragmentation using protocols developed by Leung and Louie (2008). The output of these analyses are shown in Figure 15, and summarized quantitatively by zone in Table 15. Fragmentation summaries by management zone, GFP. Fragmentation statistics are typically used to describe landscape-scale impacts to a habitat of concern; we have generated fragmentation statistics for GFP in two iterations: one using just the formal trail network, and a second using all trails (formal and informal). Comparing the

landscape fragmentation indices generated by these two iterations allows us to quantify the park-wide impacts associated with informal trails.

We see that the Mather Gorge Zone has the largest increase in the number of parcels (+1900%) and the biggest decrease in Mean Patch Size (MPS) (-95%) (Table 15). This parcel also sees the largest changes in both Largest Patch Index (LPI) (-26%) and Mean Perimeter: Area Ratio (MPAR) (+1211%). At 40.04 acres, this zone represents just 5.5% of the GFP's park area, but contains over 40% of the informal trails within the park.

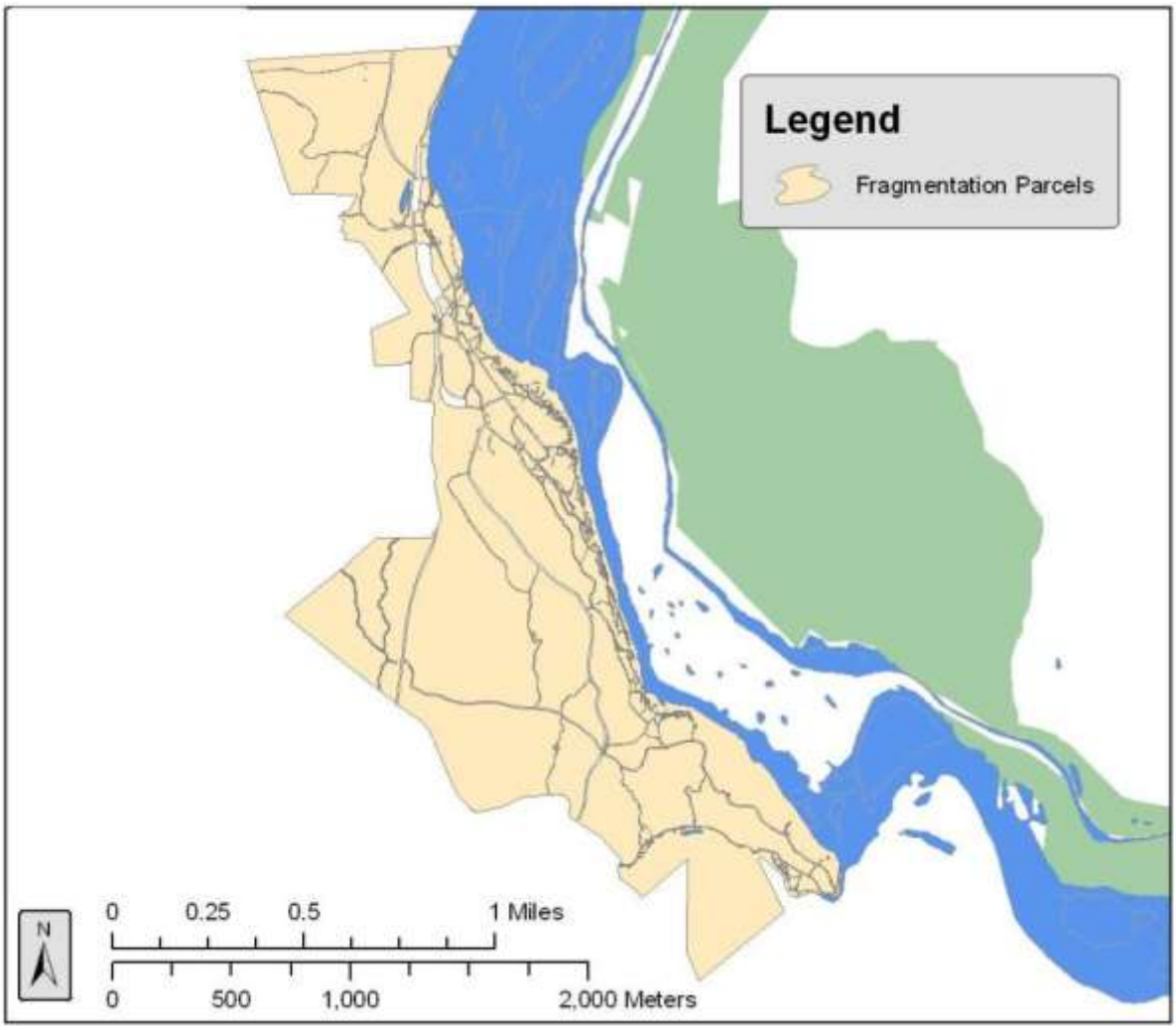

Figure 15. Fragmentation parcels within GFP.

Table 15. Fragmentation summaries by management zone, GFP.

Fragmentation Indices	Park Zones				Overall
	Developed 29.86 acres	**Canal** 74.48 acres	**Mather G.** 40.04 acres	**Cultural/Natural** 581.53 acres	725.91 acres
	High	← *Recreation Infrastructure* →		*Low*	*N/A*
Number of Patches (N)					
Formal Trails	15	25	8	22	70
All Trails (% change)	30 (+100%)	157 (+528%)	160 (+1900%)	96 (+336%)	443 (+533%)
Mean Patch Size (MPS) (ft^2)					
Formal Trails	56,123	119,426	209,121	1,128,112	433,129
All Trails (% change)	27,771 (-51%)	18,471 (-85%)	9,914 (-95%)	256,170 (-77%)	67,522 (-84%)
Largest Patch Index (LPI)					
Formal Trails	0.35	0.35	0.27	0.16	0.13
All Trails (% change)	0.30 (-14%)	0.36 (+3%)	0.20 (-26%)	0.17 (+6%)	0.14 (+8%)
Mean Perimeter: Area Ratio (MPAR) (ft/ft^2)					
Formal Trails	0.17	0.22	0.09	0.15	0.17
All Trails (% change)	0.44 (+159%)	1.16 (+427%)	1.18 (+1211%)	0.89 (+493%)	1.06 (+524%)

Cliff-Associated Trails: GFP

A Virginia Tech companion study has been investigating recreation impacts to the Potomac Gorge cliffs and rocky areas, particularly within GFP. To assist in that effort, this section examines and summarizes data from cliff-associated informal trails. Surveying informal trails requires the ability to detect and GPS map the trails based on vegetation and soil disturbance, the visible signs of which become intermittent or impossible to discern as substrates become rocky. This is clearly evident in the aerial photograph and mapped informal trails depicted in Figure 14, revealing that most informal trails terminate when they reach the cliffs and rocky areas that parallel the Potomac River. Trampling and impacts to plants do occur in these rocky environments, but informal trail assessment protocols are often unable to assess and characterize them.

GIS software was used to identify a subset of cliff-associated informal trails. A first step marked the boundary between the cliff-top wooded and rocky areas. From this boundary, buffers of 50, 75, 100, 150, 200 and 250 ft were investigated and a 100 ft buffer was selected for further analyses. This region, shown in blue in Figure 16, was modified to remove two developed areas where park staff maintain mowed grass cover.

Informal trail lineal and areal extent values are presented by condition class in Table 16. Summary of cliff-associated and inland trails by Condition Class, GFP.**Error! Reference source not found.** Within the cliff-associated areas there are 6,841 feet of formal trails, but nearly three times that amount of informal trails (19,980 ft, Table 16). Furthermore, nearly one-third of the informal trails by lineal extent were rated in condition classes 3, 4 and 5, well-established trails that have predominantly lost their vegetation and organic litter cover. Total area of trampling disturbance associated with the informal trails is 57,201 ft^2 (Table 16). In contrast, survey data reveal the more inland informal trails to be somewhat more extensive (24,216 ft), but with a similar area of disturbance (57,675 ft^2) and better resource conditions (76% rated as condition class 3 or 4) (Table 16).

The high density of informal trails in the cliff-associated zone substantially increases landscape fragmentation, from 5 separate patches created by formal trails to 182 patches when informal trails are added (Table 17). Mean patch size in the cliff-associated zone is reduced from 24,652 ft^2 with formal trails to 626 ft^2 when informal trails are added, a 97% reduction. In contrast, the mean patch size for all inland area trails is 12,367 ft^2, reflecting the higher density of informal trailing in the cliff areas (Table 17).

Table 16. Summary of cliff-associated and inland trails by Condition Class, GFP.

Zone	Condition Class	Lineal Extent (ft)	Areal Extent (ft^2)	% by Length*	% by Area*
Cliff-Associated	CC1	131	97	1%	0%
	CC2	1,184	1,518	6%	3%
	CC3	6,161	12,949	31%	23%
	CC4	6,129	18,611	31%	33%
	CC5	6,375	24,026	32%	42%
	IT Total	19,980	57,201	74%**	62%**
	Formal Total	6,841	35,081	26%**	38%**
	Overall Total	26,821	92,282	100%	100%
Inland	CC1	135	129	1%	0%
	CC2	2,448	3,219	10%	6%
	CC3	13,130	28,461	54%	49%
	CC4	5,262	14,618	22%	25%
	CC5	3,238	11,259	13%	20%
	IT Total	24,216	57,675	29%**	11%**
	Formal Total	58,251	480,840	71%**	89%**
	Overall Total	82,467	538,515	100%	100%

* % of IT Total for Zone ** % of Overall Zone Total

Table 17. Fragmentation summaries for cliff-associated and inland informal trails, GFP.

Fragmentation Indices	**Park Zones**		
	Cliff-Associated (31.92 acres)	**Inland** (688.93 acres)	**Overall** (720.85 acres)
Patches (#)			
Formal Trails	5	34	39
All Trails (% change)	182 (3540%)	218 (541%)	400 (926%)
Mean Patch Size (MPS) (ft^2)			
Formal Trails	24652	79838	72763
All Trails (% change)	626 (-97%)	12367 (-85%)	7025 (-90%)
Largest Patch Index (LPI)			
Formal Trails	0.857	0.244	0.230
All Trails (% change)	0.593 (-31%)	0.227 (-7%)	0.217 (-6%)
Mean Perimeter: Area Ratio (MPAR) (ft/ft^2)			
Formal Trails	0.108	0.033	0.043
All Trails (% change)	0.395 (265%)	0.348 (958%)	0.370 (766%)

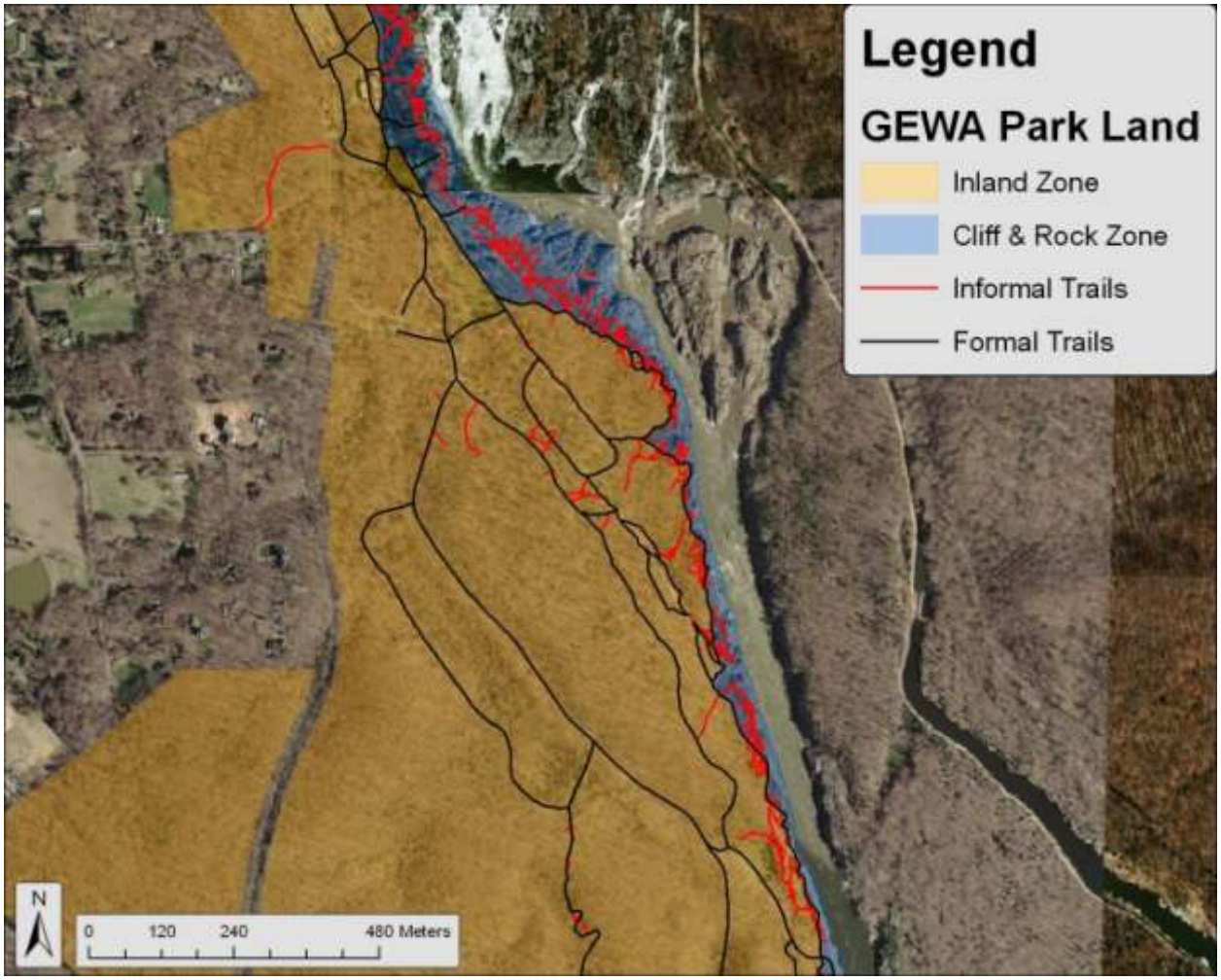

Figure 16. A portion of GFP showing the distribution of informal trails (red) within the inland and cliff /rocky area zones.

C&O Canal National Historical Park

Informal Trails

A GPS census inventory of the informal trails within CHOH produced spatial datasets that can be summarized in a variety of ways; we have selected three types of summaries that lend themselves to understanding the informal trails within CHOH: A quantitative summary of the extent of informal trails, a description of the spatial distribution of informal trails, and a summary of park fragmentation by informal trails. In each of these three summaries we make comparisons to the formal trails within the CHOH, in an effort to provide context and an understanding of the relative level of impacts associated with informal trails.

Quantitative Summary of Informal Trails: CHOH

Field staff surveyed 19.29 miles of informal trail within CHOH, which is greater (130%) than the amount of formal trail (excluding the C&O Canal Towpath) found within CHOH by length (Tables 18 & 19). Informal trails within CHOH tend to be narrower than their formal trail counterparts; when we examine the areal extent of informal trails we find that they represent less than one-half (48%) of the areal extent of the formal trail system. Further examination of the extent of informal trails by condition class show that most (80% by areal extent 69% by lineal extent) of the informal trail system is CC3 or higher indicating a loss of vegetation and organic litter from the trail (Table 19). Of greater concern is the fact that much of the informal trails fall into CC4 and CC5 (49% by areal extent and 36% by lineal extent), condition classes that indicate erosion has or is actively occurring within the tread.

Table 18 also provides data on the distribution of informal trails within CHOH by park management zone (Figure 17). These zones were defined with help from park management. The park is primarily divided into two non-overlapping zones: Gold Mine Tract/Inland and River Side zones; the BGA zone is a sub region of the River Side zone. Park management can compare management objectives for each zone to the quantity and distribution of trails within the zone and infer where conditions may be in congruence or contrary to desired conditions.

Table 18. Formal and informal trail extents within CHOH.

Impact Indicators	CHOH Park Zones			Overall
	BGA[1]	Gold Mine Tract/Inland	River Side	
	133 acres	706 acres	386 acres	1,225 acres
Aggregate Length (ft)				
Formal Trails	10,791	41,421	33,658	75,079
Informal Trails	52,244	14,606	83,835	98,442
Disturbance Area (ft^2)				
Formal Trails	64,433	216,086	150,932	367,017
Informal Trails	91,752	17,384	161,631	179,015
Lineal Extent (ft/acre)				
Formal Trail Length	81	59	87	61
Informal Trail Length	393	21	217	80
Disturbance Density (ft^2/acre)				
Formal Trails	484	306	391	300
Informal Trails	690	25	419	146

1- The BGA is a sub-region of the River Side zone.

Table 19. Formal and informal trail extents by Condition Class within CHOH.

Trail Type	Linear Extent (mi)	Areal Extent (yd^2)
Formal	14.78	41,614
Informal (all)	19.29	20,076
CC1	1.55	787
CC2	4.28	3,181
CC3	6.47	6,192
CC4	3.56	4,404
CC5	3.44	5,512

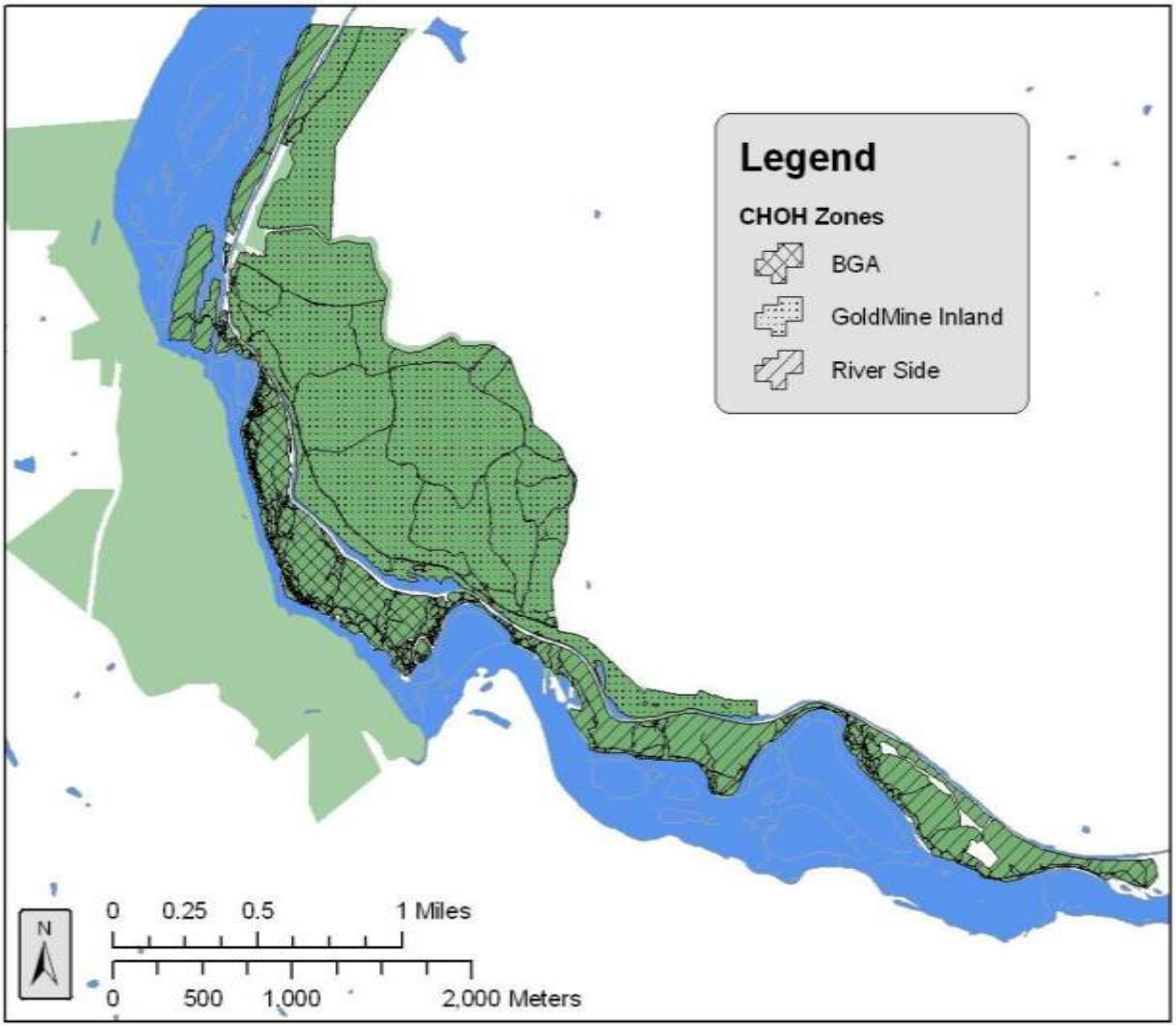

Figure 17. Management zones, CHOH.

The River Side zone contains the largest proportion of informal trails (85% by length, 90% by area) out of the three management zones (Table 20, Table 18). The BGA zone ranks second with 54% of the informal trails by length (22% by area), keep in mind that this is a subset of the River Side zone. Within each of the management zones we can examine the distribution of informal trails by condition class; these data show that the majority of the informal trails are CC3 or higher, indicating severe reduction of vegetation and organic litter cover from the tread (Table 20).

Table 20. Summary of informal trails by management zone and Condition Class, CHOH.

Informal Trail Summary for CHOH					
Zone	**Condition Class**	**Lineal Extent (ft)**	**Areal Extent (ft^2)**	**% by Length***	**% by Area***
BGA	CC1	5181	5950	10%	6%
	CC2	13567	17106	26%	18%
	CC3	15263	24757	29%	27%
	CC4	8541	17443	16%	19%
	CC5	10180	27503	19%	30%
	Total	52733	92763	54%**	52%**
Gold Mine Tract	CC1	2425	1830	17%	11%
	CC2	2936	3201	20%	18%
	CC3	5209	6490	36%	37%
	CC4	1886	2623	13%	15%
	CC5	2153	3244	15%	19%
	Total	14610	17384	15%**	10%**
River Side	CC1	5595	6520	7%	4%
	CC2	19276	26311	23%	16%
	CC3	27255	46985	33%	29%
	CC4	16439	36840	20%	23%
	CC5	15268	44980	18%	28%
	Total	83832	161631	85%**	90%**
Overall	CC1	8020	8350	8%	5%
	CC2	22212	29512	23%	16%
	CC3	32464	53475	33%	30%
	CC4	18325	39462	19%	22%
	CC5	17421	48224	18%	27%
	Overall Total	98442	179025	100%**	100%**

*% of Zone Total **% of Overall Total

Spatial Distribution of Informal Trails: CHOH

The majority of informal trails within CHOH are concentrated along the Potomac River and the area atop the adjacent cliffs and shoreline. Additional informal trails have formed along the formal trail network within inland areas of the park; these trails tend to parallel formal trails, shortcut junctions and access the park from adjoining properties (Figure 18).

The pattern of the informal trails adjacent to the Potomac River, are consistent with visitors exploring and accessing the overlooks and cliffs. The trails tend to leave the formal trail and head towards the river especially along the Billy Goat Trails and in the area of Angler's Inn. These trails seem to be formed and used by a wide variety of trail users including anglers, climbers, day hikers, swimmers, families and river users (commercial rafting groups and private

rafters, canoeists and kayakers). The majority of these trails have formed because the formal trail network does not provide the access and or experience that visitors are seeking; this may be a problem related to location of the formal trails as well as the carrying capacity of the trails. The trails can be fit into two primary categories: shortcut/avoidance routes and access/exploration routes. Access and exploration routes tend to be spurs off of the formal trails to unique features within the park. These trails are common where access to the river and overlooks is desired. Shortcut and avoidance routes are often parallel to existing formal trail often leaving and returning to the same trail. These routes are used to avoid undesirable trail conditions (mud, sun, insects, other visitors, rocky or difficult terrain) or to shortcut a route. The trails inland of the traverse section of Billy Goat A trail are clearly developed by visitors looking to avoid the traverse. They may be seeking to avoid the difficult terrain posed by the traverse, or the delay associated with crowds on that section of trail.

Informal trails within the inland portion of the park have occurred along the formal trail network for a variety of reasons: parallel trails tend to form when visitors seek to avoid an undesirable trail condition (e.g. muddiness), whereas spur trails tend to develop as shortcuts or to provide access. The informal trailing along the eastern perimeter of CHOH is primarily created by users seeking access to the river or the trail system from adjacent properties and trails. Many of these trails terminate along River Road across from housing developments, or on secondary roads in the developments. One lengthy informal trail exists in the Gold Mine Tract; it leaves the Gold Mine Loop Trail and descends through a hollow to the north end of Berma Road Trail. This trail seems to receive heavy use and is situated in the bottom of a swale for much of its path. The poor design coupled with concentration of run-off surface water will lead to increasing amounts of erosion and tread damage.

The greatest concerns with regards to informal trails are their duplicative nature (Figure 18) and their proximity sensitive communities of rare vegetation. Informal trails are hiked in by users seeking to fulfill their own individual goals; these goals do not include protection of sensitive vegetation, or creating a route that can sustain high levels of use. Figure 19 clearly illustrates the issue of duplicative routes associated with informal trails; multiple spurs (14+ in less than one-tenth of a mile) to the rocky outcrops leave the formal Billy Goat A Trail.

While we were unable to source spatial data showing the locations of sensitive and/or rare plant communities within the park, we suggest that park management should examine the proximity of the informal trails (shapefiles provided to NPS with this report) to these features. Informal trails with a condition class of 3 or higher represent trails that have removed the majority of the natural vegetation from within their tread boundary.

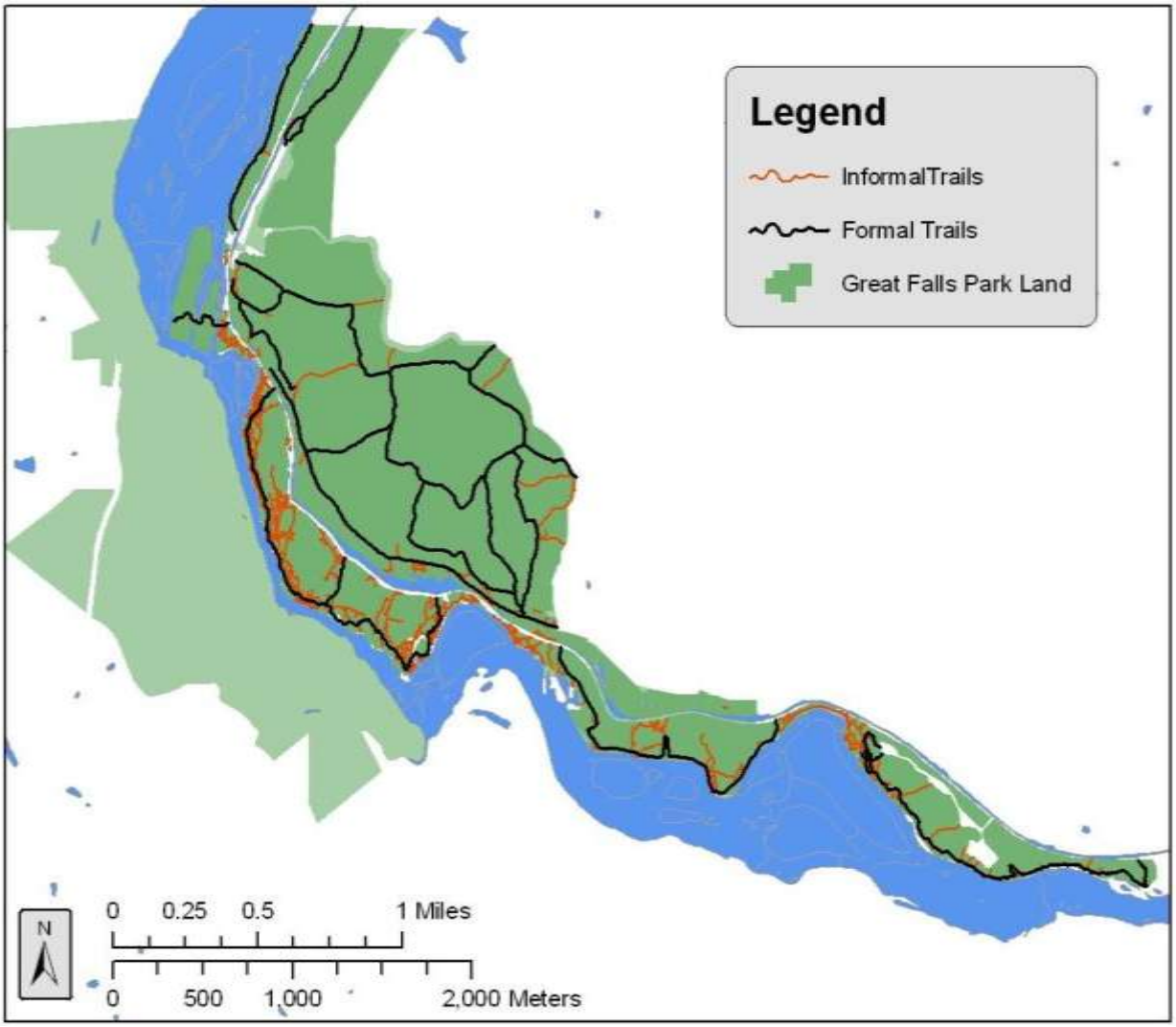

Figure 18. Location of informal trails within CHOH.

Figure 19. Duplicative routing of informal trails within CHOH.

Fragmentation by Informal Trails: CHOH

As described in the methods we analyzed CHOH land fragmentation using protocols developed by Leung and Louie (2008). The output of these analyses are shown in Figure 20, and summarized quantitatively by zone in Table 21. Fragmentation statistics are typically used to describe landscape-scale impacts to a habitat of concern; we have generated fragmentation statistics for CHOH in two iterations: one using just the formal trail network and a second using all trails (formal and informal). Comparing the landscape fragmentation indices generated by these two iterations allows us to quantify the park-wide impacts associated with informal trails.

We see that the Billy Goat A Zone has the largest increase in the number of parcels (+2367%) and the biggest decrease in Mean Patch Size (MPS) (-96%) (Table 21). This parcel also sees the largest changes in both Largest Patch Index (LPI) (-38%) and Mean Perimeter:Area Ratio (MPAR) (+38,359%). At 133 acres, this zone represents just 10.8% of the CHOH's park area, but contains over 53% of the informal trails within the park.

When we examine the River Side and Gold Mine Tract Zones, we find that the vast majority of informal trails exist on the Potomac River side of the C&O Canal: 85% by length and 90% by area (Table 21).

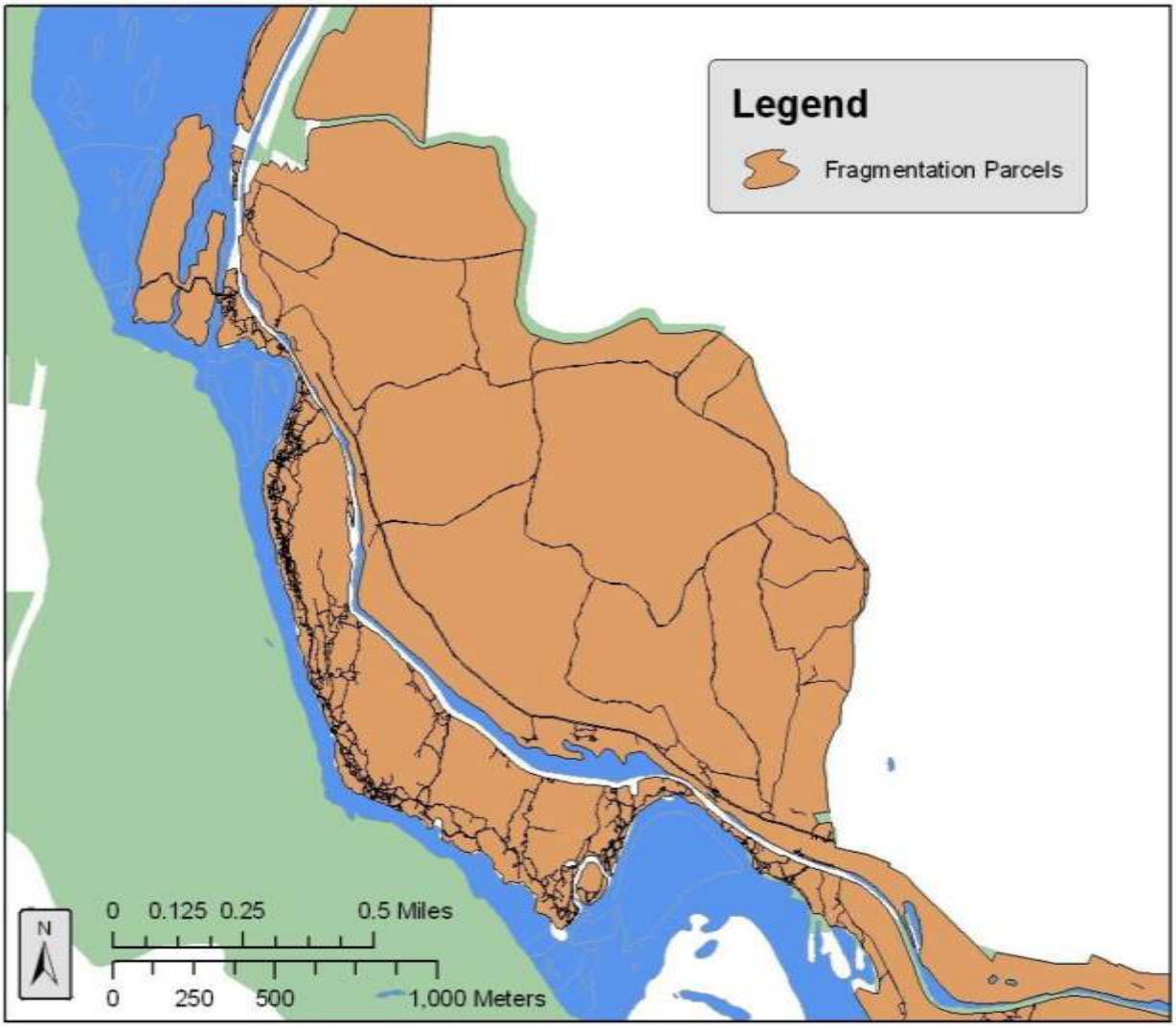

Figure 20. Fragmentation parcels within CHOH.

Table 21. Fragmentation summaries by management zone, CHOH.

Fragmentation Indices	CHOH Park Zones			
	BGA (133 acres)	**Gold Mine Tract/Inland** (706 acres)	**River Side** (386 acres)	**Overall** (1225 acres)
Number of Patches (N)				
Formal Trails	6	11	19	30
All Trails (% change)	148 (+2367%)	20 (82%)	163 (+758%)	183 (+510%)
Mean Patch Size (MPS) (ft^2)				
Formal Trails	953833	2777627	877323	1574103
All Trails (% change)	3593 (-96%)	141849 (-45%)	9412 (-88%)	23886 (-98%)
Largest Patch Index (LPI)				
Formal Trails	0.50077	0.28142	0.17193	0.18208
All Trails (% change)	0.31078 (-38%)	0.28122 (0%)	0.17171 (0%)	0.18252 (0%)
Mean Perimeter: Area Ratio (MPAR) (ft/ft^2)				
Formal Trails	0.0467	0.0196	0.0585	0.04427
All Trails (% change)	17.9137 (+38359%)	0.4215 (+2051%)	19.825 (+33789%)	17.7044 (+39892%)

DISCUSSION AND MANAGEMENT IMPLICATIONS

This section of the report reviews and summarizes the study findings and discusses some implications for management actions that can help avoid or reduce the impacts of visitation on the park's formal trail system and informal trails. Discussion dialogue is combined for both parks as both share similar visitor impact problems and solutions.

Review and Summary of Findings

Park managers operate under legislative mandates to provide appropriate recreational opportunities while protecting and preserving park resources and natural processes. While a variety of recreational uses, including trail-related activities, are clearly appropriate, park managers must also ensure that they avoid significant impairment of natural and cultural resources. As described in the Introduction section, park managers are charged with applying their professional judgment in evaluating the type and extent of recreation-related impacts when judging what constitutes impairment. This report provides useful information for rendering such determinations and provides a basis for decisions to enhance management of visitors and resources to avoid or minimize recreation impacts.

This research developed and applied state-of-the-art trail condition assessment and monitoring procedures and applied them to the park's formal and informal (visitor-created) trails. A variety of trail condition indicators were identified in consultation with park staff for potential use in future park management or VERP carrying capacity planning and decision-making. Protocols were developed, field-tested and applied with results fully summarized to provide baseline data to inform managers regarding the current condition of their formal trails, guide potential selection of indicators and standards, and allow comparison to future condition assessments to evaluate trends over time. These protocols are included in report appendices for adaptation and use by park staff.

Management Recommendations

Formal Trails: Both parks have fairly small formal trail systems (GFP: 12.31 mi; CHOH: 14.67 mi) that are in relatively good condition, despite some common design-related problems. For example, 60% of GFP formal trails are located in flatter terrain where muddiness, trail widening, and the formation of secondary trails can become common problems, and 41% are aligned within 22° of the fall line. Fall-aligned trails are particularly susceptible to soil loss and tread widening. At CHOH, 31% of the formal trails are located in flatter terrain, and 23% are aligned within 22° of the fall line. Trail widening was difficult to assess because some trails are woods roads and data was unavailable on the design and/or maintenance widths of the various trails. Both formal trail systems are affected somewhat by muddiness and formation of secondary treads. Soil loss is greater at GFP than at CHOH (mean CSA soil loss of 89.5 in^2 for GFP vs. 49.0 in^2 for CHOH). This is of particular interest given that trails at GFP are commonly surfaced with gravel (55%), which effectively deters substrate loss, while none of the CHOH trails are graveled (the C&O Canal tow path was excluded from our study). The GFP Ridge Trail accounts for much of the

soil loss, largely due to poor trail design. At CHOH, the Bear Island Billy Goat A and Emergency Access Trails stand out with respect to excessive width and soil loss.

Trail widening appears to be the most common problem affecting formal trails within Potomac Gorge. Wimpey and Marion (2010) identify six general behaviors that contribute to trail widening: 1) passing other trail users, 2) side-by-side travel, 3) avoidance of tread problems (e.g., muddiness, erosion, roughness), 4) inability to remain on the intended tread due to poorly marked trails or ambiguous tread borders, 5) roaming associated with picking the easiest route when traversing steep grades, and 6) attraction and avoidance behaviors (e.g., gaining a view or staying away from a drop-off).

Trail widening behaviors can be substantially modified by a number of environmental and managerial factors (Wimpey & Marion 2010). Trails in flatter terrain are particularly prone to widening, unless prevented by dense woody vegetation. Relocation to side-hill alignments is the most effective permanent solution but is often impractical, so establishing trail borders with rocks, logs, or fencing can be considered when this form of impact becomes excessive. Managers can also contain the lateral spread of traffic along trails by adequately addressing tread problems, such as muddiness, erosion, and excessive rockiness, which visitors will seek to circumvent. Managers can provide physically challenging trails, but keeping visitors on them requires design and maintenance practices that ensure the provision of a tread that is more inviting to traffic than the adjacent trailside terrain. A tread that always appears to the trail user as the most direct or easiest route will likely be used consistently with minimal lateral dispersal of traffic.

To address tread widening in problem areas trail maintainers can strategically place large rocks or cut ends of fallen trees placed perpendicular to the tread to force visitors to the center of widened treads. Low impact education encouraging visitors to walk single file and stay to the center of the trail can also assist. Wimpey and Marion (2010) provide additional research and guidance on this topic.

Excessive soil loss is also generally best addressed through sidehill trail relocations that avoid steep fall line alignments. Trail grades of less than 10-12% and alignments greater than 22° from the fall line are recommended (Olive & Marion 2009). Alternate actions include hardening treads through the application of gravel or rockwork, or installing wooden or rock steps when grades are steep. Effective trail maintenance solutions include the incorporation of periodic grade reversals (rolling grade dips) within steeper treads that are carrying water (IMBA 2004). A combination of water bars and outsloped treads are additional alternatives which reduce soil loss from trails (Birchard & Proudman 2000, Marion & Leung 2004). Properly designed grade reversals require no subsequent maintenance but water bars and outsloped treads need to be maintained once or twice each year or they will fail and allow water to run down treads with increasing erosive force.

Informal Trails: Protocols for assessing the spatial patterns, lineal extent, and condition of informal (visitor-created) trail networks were also developed and applied. The creation and proliferation of informal trails has been a substantial, and common long-term management problem at both parks, particularly for CHOH. Census surveys of informal trails revealed 8.37 mi of informal trails at GFP and 19.29 mi at CHOH. Given the rare and fragile plant communities and substantial number of rare plant species in both parks, these extensive networks of informal trails pose a serious threat to the resource protection mandates of both parks. At GFP,

91% by lineal extent of these informal trails are rated Condition Class 3 or higher, indicating a more complete loss of tread vegetation and organic litter cover (69% at CHOH). Additional concerns include the potential dispersal of non-native and invasive plants along informal trails, habitat fragmentation, and access to sensitive historic or cultural resources.

In the past, very few parks have surveyed or monitored their informal trail networks, though such surveys are becoming more common recently (Leung & Louie 2008, Marion *et al.* 2006). The number, density, and spatial extent of informal trails at these study parks generally exceeds that of other parks where they have been investigated, though they are comparable to some valley floor meadows within Yosemite National Park.

Informal trail data from both parks is presented in a variety of formats to document their spatial extent and distribution, condition, and land fragmentation. Data were presented by park management zone to facilitate discussion of the appropriateness and acceptability of informal trail networks relative to differing management zone objectives. GIS informal trail data layers were also provided to each park to support planning and decision-making. These permit additional analyses through examination of proximity between the informal trail network and rare species locations or sensitive historic/cultural sites. Readers are referred to Hockett and others (2010) for more in-depth discussion and presentation of information regarding the causes of informal trail formation and possible site management and educational responses. Some of that material is also included in this report to make this document a more complete resource. In particular, refer to Appendix 3 for guidance on deterring off-trail hiking and managing informal trail impacts.

Informal trails may be considered appropriate under some circumstances to provide visitor access to various park locations not accessed by formal trails. Indeed, many informal trails appear to have been created because the formal trail networks do not provide access to attraction features of interest to visitors. Unfortunately, visitors generally lack trail design knowledge, and often create unsustainable trails that are highly duplicative, creating impacts that could be avoided by improved trail design and management. Informal trails that pass through areas with rare or sensitive flora or fauna, or sensitive cultural/archaeological resources, are inappropriate and unacceptable. Informal trails that directly ascend steep slopes and/or will easily erode are less acceptable than trails with a side-hill design. Informal trails prone to muddiness and widening are also less acceptable, as are trails that may contribute eroded soils to water resources. These and other factors must be evaluated by park managers before selecting and applying corrective actions. Comprehensive guidance for managing informal trail networks is provided in Appendix 3.

Readers are referred to results from a companion study at CHOH's Bear Island that sought to reduce off-trail hiking rates (Hockett *et al.* 2010). This study experimentally applied combinations of site management and educational practices and reduced self-reported off-trail hiking from 70% of surveyed visitors to 43% along the 1.7 mile Billy Goat Trail A. Observations at two specific formal trail locations reported a reduction in off-trail hiking from 30% to 0%. Study treatments were applied in an additive fashion, and included educational signs placed at formal trailheads, educational messages delivered through personal contact at trailheads, symbolic prompter signs placed at all formal/informal trail intersections, log barriers and symbolic fencing, light brushing to hide informal trails, and restoration work and signing. Visitor surveys also documented off-trail hiking motivations and preferences for alternative management

actions. The most common motivations for hiking off-trail were to get to a scenic vista or take a photo (50.7%), to avoid or pass others (45.4%), or because of poor or challenging trail conditions (43.0%). Hikers with a greater knowledge of off-trail hiking impacts were less likely to hike off-trail than those who had less knowledge.

The Bear Island study was designed to inform managers at both parks of effective practices for reducing off-trail hiking impacts, particularly within sensitive rare plant communities. We urge readers to consider the results of that study (Hockett *et al.* 2010), and include its key management recommendations here to highlight effective practices for decreasing off-trail travel:

- Improve Communication with Visitors: Many visitors do not know about the special and rare plant and animal communities that live within the Potomac Gorge. Trail stewards are more effective in communicating educational messages than the trailhead signs, in part because they are able to contact a greater percentage of visitors. Most visitors simply do not read signs.
- Improve Maintenance and Trail Markings: Some hikers hike off-trail accidentally because formal trails may be poorly marked or indistinguishable from informal trails. Managers must ensure that formal trails are maintained to be a better and preferred route than alternate trail-side terrain or informal trails. During wet periods managers should identify muddy sections and apply corrective actions so that visitors can remain on them.
- Consider Formalizing Some Informal Trails: Some informal trails were created as by-passes around difficult or crowded trail sections. Others were created to access scenic vistas or favorite places. Managers should consider if those trails are acceptable. If they are, they should be formalized, or closed and replaced by formal trails designed by a trail professional with more sustainable alignments.
- Close and Restore Unacceptable Trails: The closure and recovery of all remaining informal trails will be a formidable management challenge. Trampling impacts and trail creation occur with limited or low levels of traffic, while unassisted natural recovery requires little to no use over years for vegetation to return. We recommend use of both informative trailhead signs and symbolic prompter signs at formal/informal trail intersections. Brushing the visible portion of all informal trails can further reduce off-trail travel by removing the "releasor cue" of a path that others have obviously taken.

An array of educational and site management actions is necessary to reach visitors who are hiking off-trail for different reasons. Trail stewards and educational signs can convey information about off-trail hiking impacts to reduce the number of visitors who hike off-trail because they do not know it is harmful. Small symbolic prompter signs can more clearly communicate where not to hike and provide reminders of appropriate behavior at decision points. These reminders at the decision points have been shown to be more effective at reducing off-trail hiking than trailhead signs alone (Park *et al.* 2008, Bradford & MacIntyre 2007). Brushing the beginning of an informal trail removes the evidence that many others have taken that path. Fencing and restoration signs provide additional cues that the park is really concerned about an area and have been shown to be very effective in this and other studies in keeping visitors from using informal trails. However, there is a risk that if a fence is applied to a very popular place, where there is a strong motivation for leaving the trail, visitors might create additional trails to access the area so such an occurrence must be carefully monitored (Johnson *et al.* 1987).

An important note of caution: Some individuals, including those interested in nature study, photography, fishing, and climbing, "need" to engage in off-trail hiking to fulfill their trip objectives. What will they be told given that their motivations for visiting the trail are in direct conflict with NPS management objectives? The experiential quality for these individuals is negatively impacted by management guidance asking visitors to remain on formal trails. The history of visitors exploring off-trail areas, including off-trail visits to favorite places, fishing spots, or climbing areas, will make it very challenging to achieve high compliance rates. Local visitors may also have strong place attachment, which could make them resistant to management changes.

For visitors or NPS and volunteer staff who must hike off-trail, there are a number of preferred low impact practices that could be conveyed:

1) remain on formal trails as long as possible and minimize off-trail travel,
2) when hiking off formal trails use well-established informal trails whenever possible; minimize use of lightly-impacted informal trails to allow their recovery,
3) when hiking off formal and informal trails, travel on rock, non-vegetated substrates, and grasses; minimize and disperse traffic in all other vegetated areas.

One concern is how such information might be communicated to visitors. If posted on signs or in printed material it could send potentially confusing mixed messages, or that off-trail hiking is really "OK." To address those concerns it may be preferable to communicate these practices only orally, such as when trail stewards or park staff see visitors going off-trail or when stewards or park staff are explicitly asked by visitors about off-trail hiking.

If the NPS is able to effectively implement most of the actions suggested above we can expect conditions to slowly improve on many miles of informal trail and for those most lightly impacted informal trails to disappear. A long-term monitoring program could prove valuable to document and evaluate progress. We recommend continuation of the informal trail monitoring protocols included in this management report. This would provide quantitative data to track management success and that could also allow managers to set and evaluate standards of quality (see discussions of VERP and LAC in Appendix 3). Informal trail management requires an ongoing adaptive management program, where actions are implemented, evaluated periodically, and findings used to support the selection of additional actions as needed to achieve management objectives.

Finally, we recommend that a workshop with NPS and various representatives of the public be convened to discuss these or other general strategies and actions in a collaborative process. Regardless of what actions are adopted, we recommend that an adaptive management decision-making process be implemented to evaluate management success and alter actions over time as needed to best accomplish management objectives.

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APPENDIX 1: FORMAL TRAIL MONITORING MANUAL

Formal Trail Condition Monitoring Manual
Great Falls Parks[1]
(*version 4/25/07*)

This manual describes standardized procedures for conducting an assessment of resource conditions on formal (designated) recreation trails within Great Falls and C&O Parks. The principal objective of these procedures is to document and monitor changes in trail conditions following construction. Their design relies on a sampling approach to characterize trail conditions from measurements taken at transects located every 300 feet along randomly selected trail segments. Distances are measured with a measuring wheel. Measurements are conducted at sample points to document the trail's width, depth, substrate, slope, alignment and other characteristics. These procedures take approximately three minutes to apply at each sample point. Data is summarized through statistical analyses to characterize resource conditions for each trail segment and for the entire trail system. During future assessments it is not necessary to relocate the same sample points for repeat measures. Survey work should be conducted during the middle or end of the primary use season. Subsequent surveys should be conducted at approximately the same time of year.

Materials
(Check before leaving for the field)

- ☐ This manual on waterproof paper
- ☐ Field forms - some on waterproof paper
- ☐ Topographic and driving maps
- ☐ Clipboard w/compartment for forms
- ☐ Pencils
- ☐ Tape measure in inches (6 ft)
- ☐ Metal binder clips (2) to attach tape to stakes
- ☐ Line level
- ☐ Measuring wheel
- ☐ Compass
- ☐ Tape measure in tenths of feet (20 ft)
- ☐ Tent stakes (3)
- ☐ Clinometer

Point Sampling Procedures

Trail Segments: During the description of amount and type of use (indicators 5 & 6 below) be sure that the use characteristics are relatively uniform over the entire trail segment. Sampled trails may have substantial changes in the type or amount of use over their length. For example, one portion of a trail may allow horse use or a trail may join the study trail, significantly altering use levels. In these instances where substantial changes in the type and/or amount of use occur, the trail should be split in two or more segments and assigned separate names and forms, upon which the differences in use can be described. This practice will facilitate the subsequent characterization of trail use and statistical analyses.

Also collect and record any other information that is known about the trail's history, such as original construction, past uses, type and amount of maintenance, history of use, etc.

1 - Developed by Dr. Jeff Marion, USDI, U.S. Geological Survey, Patuxent Wildlife Research Center, Virginia Tech Field Station, Dept. of Forestry (0324), Blacksburg, VA 24061 (540/231-6603) Email: jmarion@vt.edu

General Trail Information

1) **Trail Segment Code:** Record a unique trail segment code (can be added later).

2) **Trail Name:** Record the trail segment name(s) and describe the segment begin and end points.

3) **Surveyors:** Record initials for the names of the rail survey crew.

4) **Date:** Record the date (mm/dd/yr) the trail was surveyed.

5) **Use Level (UL):** Record an estimate of the amount of use the trail receives (high, med., low), relative to other forest trails, from the most knowledgeable staff member. Work with them to quantify use levels on an annual basis (e.g., low use: about 100 users/wk for the 12 wk use season, about 30 users/wk for the 20 wk shoulder season, about 10 users/wk for the 20 wk off-season = about 2000 users/yr).

6) **Use Type (UT):** Record estimates for the types of use the trail receives (including any illegal uses) using percentages that sum to 100%. These should be provided by the most knowledgeable forest staff member. Categories include: Hiking, Horseback, Biking, Other (specify).

Starting/Ending Point: Record a brief description of the starting and ending point of the trail survey. Try to choose identifiable locations like intersections with other trails, roads, or permanent trailhead signs.

Measuring Wheel Procedures: At the trail segment starting point, use a random number table to select a random number from 0 to 300. Record this number on the first row of the form. This will be the first sample point, from which all subsequent sample points will be located in 300 foot intervals. This procedure ensures that all points along the trail segment have an equal opportunity of being selected. Once you get to the first sample point, reset the wheel counter and use it to stop at 300 foot intervals thereafter.

Push the measuring wheel along the middle of the tread so that it does not bounce or skip in rough terrain. Lift the wheel over logs and larger rocks, adding distance manually where necessary to account for horizontal distances. Your objective is to accurately measure the distance of the primary (most heavily used) trail tread. Monitor the wheel counter closely and stop every 300 feet to conduct the sampling point measures. If you go over this distance, you can back the wheel up to the correct distance. If the wheel doesn't allow you to take distance off the counter then stop immediately and conduct your sampling at that point, recording the actual distance from the wheel, not the "missed" distance.

If an indicator cannot be assessed, e.g., is "Not Applicable" code the data as -9, code missing data as -1.

Rejection of a sample point: Given the survey's objective there will be rare occasions when you may need to reject a sampling point due to the presence of: 1) bedrock or cobble stone areas that lack defined trail boundaries, and 2) uncharacteristic settings, like tree fall obstructions, trail intersections, road-crossings, stream-crossings, bridges and other odd uncommon situations. The data collected at sample points should be "representative" of the 250 foot sections of trail on either side of the sample point. Do not relocate a point to avoid longer or common sections of bog bridging, turnpiking, or other trail tread improvements. Use your judgment but be conservative when deciding to relocate a sample point. The point should be relocated by moving forward along the trail an additional 30 feet, this removes the bias of subjectively selecting a point. If the new point is still problematic then add another 30 feet, and so on. Record the actual distance of the substituted sample point and then push the wheel to the next sample point using the original 300 foot intervals.

7) **Distance:** In the first column record the measuring wheel distance in feet from the beginning of the trail segment to the sample point.

8) **Trail Type (TT):** Record whether the tread at the sample point was assessed as a direct ascent or side-hill constructed trail (see definitions in #11). Record the letter code in the TT column.
DA – Direct ascent (fall-line), **SH** – Side-hill trail

9) **Erosion Type (ET):** Record whether soil erosion at the sample point, if present, appears to be recent or historic (see definitions in #11). Record the letter code in the ET column.
RE – Recent erosion, **HE** – Historic erosion

10) **Trail Grade (TG):** The two field staff should position themselves on the trail 5 ft either side of the transect. A clinometer is used to determine the grade (% slope) by sighting and aligning the horizontal line inside the clinometer with a spot on the opposite person at the same height as the first person's eyes. Note the percent grade (right-side scale in clinometer viewfinder) and record (indicate units used). Note: if conducted by one person then place clinometer on a clipboard with the window facing you. Orient the clipboard to be parallel to the trail grade and record degrees off the visible scale in the window. After data entry convert to percent slope = [tan (degrees)] x 100.

11 **Landform Grade (LG):** Assess an approximate measure of the prevailing landform slope in the vicinity of the sample point. Follow the one-person procedure described in #7.

12) **Trail Slope Alignment Angle (TSA):** Assess the trail's alignment angle to the prevailing land-form in the vicinity of the sample point. Position yourself about 5 ft downhill along the trail from the transect and sight a compass along the trail to a point about 5ft past the transect; record the compass azimuth (0-360, not corrected for declination) on the left side of the column. Next face directly upslope, take and record another compass azimuth - this is the aspect of the local landform. The trail's slope alignment angle ($<90^0$) is computed by subtracting the smaller from the larger azimuth (done after data entry).

13) **Secondary Treads (ST):** Count the number of trails, regardless of their length, that closely parallel the main tread at the sample point. *Do not count the main tread.*

14) **Tread Width (TW):** From the sample point, extend a line transect in both directions perpendicular to the trail tread. Identify the endpoints of this trail tread transect as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced trampling-related changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, changes in organic litter (intact vs. pulverized) (see photo illustrations in Figure 1). The objective is to define the trail tread that receives the majority (>95%) of traffic, selecting the most visually obvious outer boundary that can be most consistently identified by you and future trail surveyors. Include any secondary parallel treads within the transect only when they are not differentiated from the main tread by strips of less disturbed (taller) vegetation or organic litter.

Also pay close attention to selecting boundary points that reflect the extent of soil loss representative for this location along the trail. Soil loss measures will be taken from a line stretched between the endpoints you select so the line should be unobstructed. Organic litter or small rocks that obstructs the line can be removed but large rock or root obstructions will necessitate moving the line forward along the trail in one foot increments until you reach a location where the line is unobstructed. Temporarily place tent stakes at the boundary points and then step back to verify their horizontal and vertical placement as projected along the trail in the vicinity of the sample point. Measure and record the length of the transect (tread width) to the nearest inch (don't record feet and inches).

15) **Maximum Incision, Current Tread (MIC):** Stretch the fiberglass tape tightly between the two tent stake pins that define the tread boundaries - any bowing in the middle will bias your measurements. This transect line should reflect your estimate of the post-construction, pre-use land surface, serving as a datum to measure tread incision caused by soil erosion, displacement and/or compaction. Measure the maximum incision (nearest 1/4 inch: record .25, .5, .75) from the string to the deepest portion of the trail tread. Measure to the surface of the tread's substrate, not the tops of rocks or the surface of mud puddles. Your objective is to record a measure that reflects the maximum amount of soil loss along the transect within the tread boundaries. See Figure 2, noting differences in MIC measures for side-hill vs. non-side-hill trails.

16) **Modal Incision, Current Tread (MOD):** Record what you judge to be the "most typical" or "modal" incision measure for the entire transect. This measure will be used to compare against "actual" modal incision measures from # 16 to evaluate the accuracy of such judgments for use in new rapid assessment tread erosion procedures currently under development.

17) **Cross-Sectional Area (CSA):** The objective of the CSA measure is to estimate soil loss from the tread at the sample point following trail creation. Soil loss may be due to erosion by water or wind, soil displacement from trail users, or compaction. Accurate and precise CSA measures require different procedures based on the type of trail and erosion, some definitions:

Direct-ascent vs. side-hill trails: Trails, regardless of their grade, that more or less directly ascend the slope of the landform are direct-ascent or "fall-line" trails. Direct-ascent trails involve little or no tread construction work at their creation – generally consisting of removal of organic litter and/or soils. Trails that angle up a slope *and* require a noticeable amount of cut-and-fill digging in mineral soil (generally on landform slopes of greater than about 10%) are termed side-hill trails. The movement of soil is required to create a gently out-sloped bench to serve as a tread. Separate procedures are needed for side-hill trails to avoid including construction-related soil movement in measures of soil loss following construction.

Recent vs. historic erosion: Recreation-related soil loss that is relatively recent is of greater importance to protected land managers and monitoring objectives. Severe erosion from historic, often pre-recreational use activities, is both less important and more difficult to reliably measure. Historic erosion is defined as erosion that occurred more than 10-15 years ago and is most readily judged by the presence of trees and shrubs growing from severely eroded side-slopes.

Measurement Procedure: On the CSA data form, label a new row with the measuring wheel distance for the transect (e.g., D=600 ft). Place the transect stakes as described under the appropriate situation (a-d below). Starting on the left side record a 0 for the 1st mark on the line (V_1, at 0 ft), followed by the measurement for the 2nd mark (V_2 at 0.3 ft). The standard interval for these measures is 0.3 ft (3 5/8 in) but for wide trails alternative intervals can be used (e.g., 0.5 ft or 1.0 ft) – if alternative intervals are used *note the interval value* on the CSA form. Take all vertical measures *perpendicular* to the transect line down to the ground surface recording values to the nearest 1/4 in (e.g., .25, .5, .75). Record the values on the data sheet next to their labeled numbers (e.g., V_1, $V_2 \ldots V_n$). Continue measuring each vertical until you reach the far side of the trail and obtain a measure of 0 when the original (non-eroded) ground is reached. ***Note:*** The transect line is not likely to be "level" so be cautious in measuring vertical transects that are *perpendicular* to the horizontal transect line. Contact Jeff Marion for a spreadsheet that calculates CSA for this data.

a) Direct-ascent trails, recent erosion: Refer to Figure 2a and follow these procedures. Place two stakes and the transect line to characterize what you judge to be the pre-trail or original land surface. Place the left-hand stake so that the "0" mark on the transect tape will fall on what you believe was the "original" ground surface but at the edge of any tread incision, if present (see Figure 2a). The tape has been sewn to allow two stake placement options to accomplish this. The transect incision value you record for the 1st

mark (V_1) must be 0. Stretch the transect tape tightly between the two stakes - any bowing in the middle will bias your measurements. Insert the other stake just beyond the first transect line mark on the other side of the trail that is on the original ground surface and will be measured as a 0. The transect line should reflect your estimate of the pre-trail land surface, serving as a datum to measure tread incision caused by soil erosion and/or compaction.

Note: For this and all other options (b-d), if the line cannot be configured properly at the sample point due to rocks or obstructing materials that cannot be moved, then move the line forward along the trail in one-foot increments until you reach a location where the line can be properly configured.

b) Direct-ascent trails w/historic erosion: Refer to Figure 2b – if you judge that some of the erosion is historic then follow these procedures. Generally you will find an eroded tread within a larger erosional feature. Place two stakes and stretch the transect line to reflect and allow measurements of the more recent recreation-related erosion (if present) – see guidance in 16a above. If there is no obvious recent-erosion tread incision then position the stakes the same as for your tread width measurement and assess incision between tread boundaries (option not depicted in Figure 2b). The 1st left-side measure (V_1) must be 0. At the right boundary you must also record a transect with a measure of 0.

c) Side-hill trail: Refer to Figure 2c. The objective of this option is to place the transect stakes and line to simulate the post-construction tread surface, thereby focusing monitoring measuresments on post-construction soil loss and/or compaction. When side-hill trails are constructed, soil on the upslope side of the trail is removed and deposited downslope to create a gently out-sloped bench (most agency guidance specify a 5% outslope) for the tread surface (see Figure 3). Outsloped treads drain water across their surface, preventing the buildup of larger quantities of water that become erosive. However, constructed treads often become incised over time due to soil erosion and/or compaction. The extent of this incision are what these procedures are designed to estimate.

Carefully study the area in the vicinity of the sample point to judge what you believe to be the post-construction tread surface. Pay close attention to the tree roots, rocks or more stable portions of the tread to help you judge the post-construction tread surface. Look in adjacent undisturbed areas to see if roots are exposed naturally or the approximate depth of their burial. Configure the stakes and transect line to approximate what you judge to be the post-construction tread surface. Note that sometimes a berm of soil, organic material and vegetation will form on the downslope side of the trail that is raised slightly above the post-construction tread surface (generally less than 6 inches in height). If present, place the stake and line below the height of the berm as shown in Figure 2c so that it does not influence your measurements. If erosion is severe and/or if the line placement is subjective, use a line level with marks on the bubble glass that allow you to level and then configure the tape as a 3% outslope (a 1 in. drop over 33 in. – see table at right of offset values from level) to standardize the line placement. A 3% outslope is used because actual tread construction may have been somewhat less than 5%, and 3% provides a more conservative estimate of soil loss. It is generally easier and more accurate to place the downslope stake first and configure the line to a 3% outslope to reveal where the uphill stake should be placed. Measure the left-hand stake as transect 1 with a 0 measure and also record a final transect beyond the right-hand stake with a measure of 0.

Trail Width	3% outslope offset
20	0.6”
30	0.9”
40	1.2”
50	1.5”
60	1.8”
70	2.1”
80	2.4”
90	2.7”
100	3.0”
110	3.3”
120	3.6”
130	3.9”
140	4.2”
150	4.5”

d) Side-hill trail with historic erosion: Refer to Figure 2d - if you judge that the erosion is historic then follow these procedures. Generally you will find an eroded tread within a larger erosional feature. Place two stakes and stretch the transect line to reflect and allow measurements of the more recent recreation-related erosion (if present). If there is no obvious recent-erosion tread incision then position the stakes the same as for your tread width measurement and assess

incision between tread boundaries (option not depicted in Figure 2d). The left-hand stake can serve as vertical transect 1, record a 0 for this. At the right boundary you must also record a vertical transect with a measure of 0.

Note: If the line cannot be configured properly at the sample point due to rocks or obstructing materials that cannot be moved, then move the line forward along the trail in one-foot increments until you reach a location where the line can be properly configured.

18-27) **Tread Condition Characteristics:** Along the trail tread width transect, estimate to the nearest 10% (5% where necessary) the aggregate lineal length occupied by any of the mutually exclusive tread surface categories listed below. **Be sure that your estimates sum to 100%**.

S-Soil:	All soil types including sand and organic soils, excluding organic litter unless it is highly pulverized and occurs in a thin layer or smaller patches over bare soil.
L-Litter:	Surface organic matter including intact or partially pulverized leaves, needles, or twigs that mostly or entirely cover the tread substrate.
V-Vegetation:	Live vegetative cover including herbs, grasses, mosses rooted within the tread boundaries. Ignore vegetation hanging in from the sides.
R-Rock:	Naturally-occurring rock (bedrock, boulders, rocks, cobble, or natural gravel). If rock or native gravel is embedded in the tread soil estimate the percentage of each and record separately.
M-Mud:	Seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints from previous or current use (omit temporary mud created by a very recent rain). The objective is to include only transect segments that are frequently muddy enough to divert trail users around problem.
G-Gravel:	Human-placed (imported) gravel.
RT-Roots:	Exposed tree or shrub roots.
W-Water:	Portions of mud-holes with water or water from intercepted seeps or springs.
WO-Wood:	Human-placed wood (water bars, bog bridging, cribbing).
O-Other:	Specify.

Collect all equipment and move on to the next sample point. **Be sure to assess and record information on the Problem Assessment indicators as you proceed to the next sample point.** These indicators are assessed continuously as pre-defined trail tread problems and when found, surveyors record begin and end distances (from the start of the survey) on the Problem Assessment Form. **Note: after data entry and before analysis the data for these indicators need to be corrected to add in the 1st randomly selected interval distance so that location data are accurate. In particular, examine any indicators that may begin before and end after the first sample point.**

Problem Assessment Procedures

28) **Informal Trails (IT):** Record the trail distance form the measuring wheel for each informal (visitor-created) trail that intersects the survey trail segment. This indicator is intended to provide an approximation of the extensiveness of unofficial, visitor-created trails associated with survey trail. Do not count formal trails, roads of any type, extremely faint trails with untrampled vegetation in their treads, trails <10 ft long, or trails that have been effectively blocked off by managers. Informal trails are trails that visitors have created to access features such as streams, scenic attraction sites1, cliffs, vistas, cultural sites, or to cut switchbacks, avoid mud-holes, rutted treads, steep obstacles, or downed trees, or that simply parallel the main trail. Count both ends of any informal trails ≥10 feet long that loop out and return to or parallel the survey trail. Include any distinct animal or game trails as these are generally indistinguishable from human trails and their true origin is likely unknown.

29) **Muddy Soil (MS):** Sections of tread (≥10 ft) with seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints (≥½ inch). Omit temporary muddiness created by a recent rain. This should generally include any longer mud-holes or treads with running water. The objective is to include only tread segments that are frequently wet or muddy enough to divert trail users around the problem, often leading to an expansion of trail width.

30) **Soil Erosion (SE):** Sections of tread (≥10 ft) with soil erosion exceeding 5 inches in depth within current tread boundaries. Record SE1 for soil loss 5-10 in., SE2 for 10.1-15 in. and SE3 for 15.1-20 in.

Figure 1. Photographs illustrating different types of boundary determinations. Trail tread boundaries are defined as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, as pronounced changes in organic litter (intact vs. pulverized). The objective is to define the trail tread that receives the majority (>80%) of traffic, selecting the most visually obvious boundary that can be most consistently identified by you and future trail surveyors.

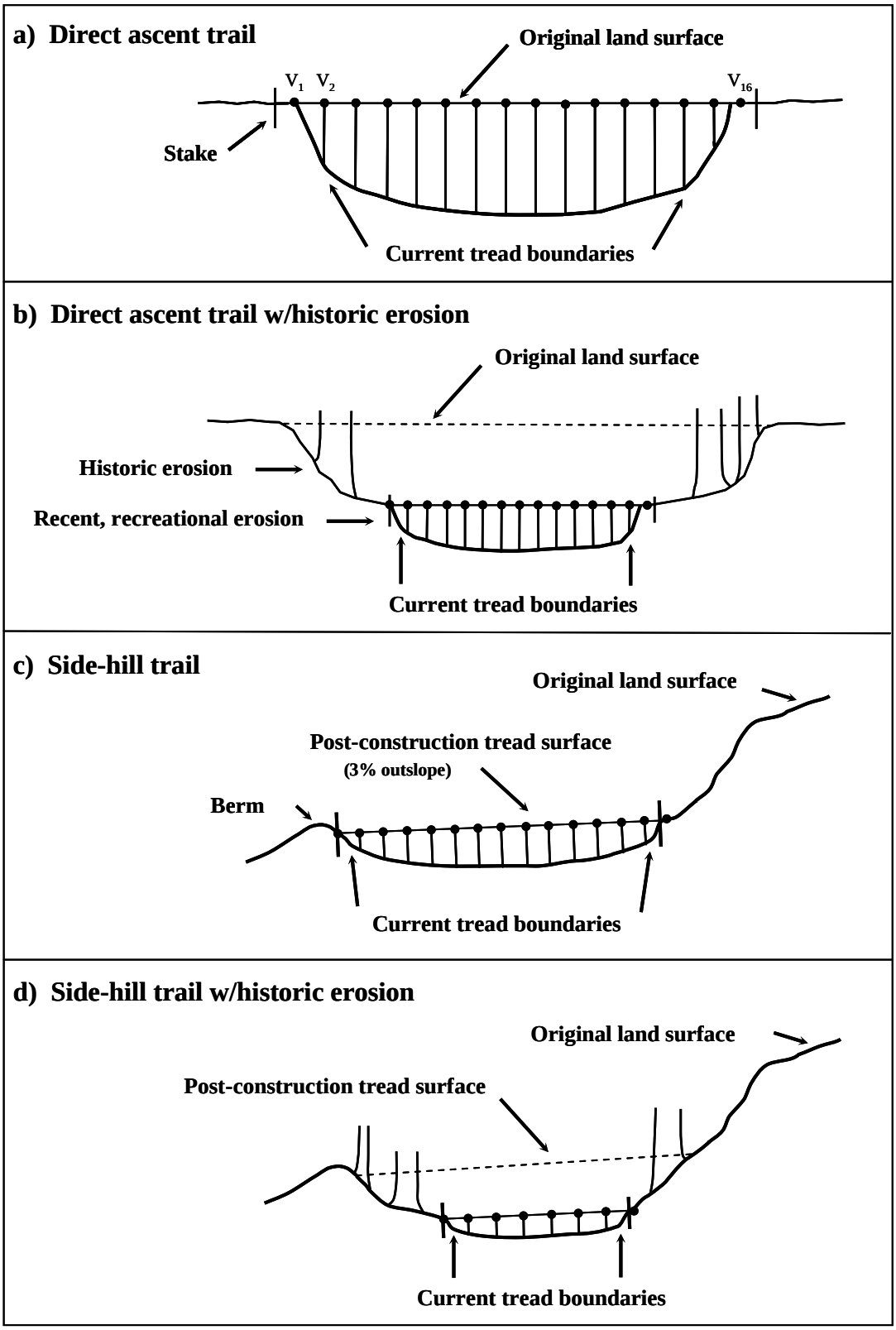

Figure 2. Cross sectional area (CSA) diagrams illustrating alternative measurement procedures for direct ascent trail alignments (a & b) vs. side-hill trail alignments (c & d) and for relatively recent erosion (a & c) vs. historic erosion (b & d).

Cross Sectional Area Form

Trail Segment Code _____ **Trail Name** _____

CSA		**CSA**		**CSA**	
Transect (in)	**Area**	**Transect (in)**	**Area**	**Transect (in)**	**Area**
D=					
V_1=					

Point Sampling Form

Trail Segment Code _____ **Trail Name** _____ **Surveyors** _____
Date _____ **Use Level** _____ **Use Type(s):** Hiker %, Horse %, Bike %, Other %
Starting Point: **UTM:**_____

Ending Point: **UTM:**_____

Dist	TT	ET	TG	LG	TSA	ST	TW	Tread Substrate Characteristics	MIC	MOD	CSA
					/			| . | . | . | . | . | . | . | . | . | . |			
					/			| . | . | . | . | . | . | . | . | . | . |			
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								0 10 20 30 40 50 60 70 80 90			

Dist = Wheel Distance
TT = Trail Type (DA, SH)
ET = Erosion Type (RE, HE)form)
TG = Trail Grade
LG = Landform Grade

TSA = Alignment (Trail^{o} / Landform^{o})
ST = Secondary Treads
TW = Tread Width
MIC = Max. Incision
CSA (calculated from data)

S = Soil G = Gravel
L = Litter RT = Roots
V = Vegetation W = Water
R = Rock WO = Wood, human-placed
M = Mud O = Other (Specify)

Problem Assessment Form

Cross Sectional Area Form

Trail Segment Code _____ **Trail Name** _____

Informal Trails	Muddy Soil		Soil Erosion		CSA		CSA		CSA	
Distances	Begin Dist	End Dist	Begin Dist	End Dist	Transect (in)	Area	Transect (in)	Area	Transect (in)	Area
					D=					
					V_1=					

APPENDIX 2: INFORMAL TRAIL MONITORING MANUAL

Informal Trail Monitoring Manual

Developed by Jeremy Wimpey, Jeff Marion, and Logan Park
Virginia Tech/Dept. of Forestry, Blacksburg, VA
Contact: jmarion@vt.edu, 540-231-6603

Introduction

The creation and proliferation of informal (visitor-created) trails can directly impact sensitive plant communities, rare or endangered flora and fauna, and wildlife habitats. For example, a small patch or population of rare plants may be eliminated by trampling, habitat changes caused by visitor use, or through competition from non-native species introduced by park visitors. Recreationists seeking to access scenic overlooks, water resources, or merely to explore, often trample vegetation sufficiently to create extensive informal trail networks. Such unplanned trail networks generally receive no environmental reviews and resource degradation is often severe due to their lack of professional design, construction, and maintenance. While some degree of visitor impact is unavoidable, excessive trail impacts threaten natural resource values, visitor safety, and the quality of recreational experiences.

Objectives

These protocols are designed to document the number, lineal extent, spatial distribution, area of trampling disturbance, and resource condition of all informal trails within a specified study area. Assessment procedures are efficiently applied through walking surveys that employ sub-meter accuracy Global Positioning System (GPS) units providing field staff a paperless method for collecting trail inventory and resource condition data. When periodically collected over time, these data assist with the monitoring of onsite resource conditions and provide long-term documentation of the existence, location, and condition of informal trails. The data also provide supporting information for management decisions, such as to evaluate which informal trails should be closed or left open, and later to evaluate the success of management efforts to close selected trails, prevent the creation of new trails, or prevent further deterioration of existing trails.

Guidance

This collection protocol should be performed at the end of peak season visitation, i.e., mid-August, when evidence of visitor use is most pronounced and to minimize seasonal variations in trail conditions. Collection should be done at multi-annual intervals (e.g., every three to five years). This schedule assists in locating trails that may emerge or change conditions later in the season. It is important to perform the collection consistently in time across each year to provide management with comparable data.

Materials

- Trimble GeoXT GPS[1]
    - Loaded with: 1) Informal Trail (IT) Data Dictionary, and 2) formal trail layer
        - Contact Dr. Jeffrey Marion, Virginia Tech, Department of Forestry, jmarion@vt.edu for replacement layers and data dictionaries
    - Stylus
    - Hurricane antenna and connecting lead
    - Trimble backpack and spare external battery
- Tape measure (6ft auto-retracting)
- Paper maps showing formal trail system
- Pens and notebook

1 – Use the most accurate equipment available. Greater accuracy in data collection translates to more accurate, objective, and efficient GIS editing work.

Methods

Survey staff should be familiar with study area and its visitor use patterns, particularly where visitors are most likely to depart formal trails and potential off-trail destinations. Scheduling field surveys during times of optimal satellite constellations may be necessary for some areas. Begin work by selecting an area (sub region of the study area) on the paper map to search. Use features such as trails, roads, and streams, along with prior survey data and personal knowledge, to divide the area into manageable units. Prior data should be used as a guide but not as an authoritative catalog of where informal trails will be found and mapped. To ensure that all informal trails are located, walk all formal trails and search the areas adjacent to each trail for informal trails.

Where possible, do not assess trails created and/or used predominantly by wildlife (e.g., deer). Such trails are generally narrow and go under low-hanging branches that would obstruct human traffic. Be spatially aware and thoroughly search along/near formal trails and features for areas that are likely to draw visitors off the formal trail network (e.g., vistas, water bodies, geographic features of interest, historic structures). In particular, beware of informal trails that depart a formal trail on resistance surfaces (e.g., rock, gravel, bare soil, grass) that may hide the beginning of in informal trail. Some random searching and walking transects across off-trail areas, particularly near any features of interest, are necessary to locate and map all informal trails.

When an informal trail is located, begin an informal trail segment using the IT data dictionary. Use the Condition Class descriptors below to determine and record the appropriate condition class. Do not begin walking the trail segment until the GPS has successfully recorded its first position fix. Walk the trail while collecting the feature until it reaches a junction or changes condition class. Assess and record the segment's average trail width (see below) and then close the segment in the GPS.

Trail width is defined as the most visually obvious outer boundary of trampling-related disturbance that receives the majority (>95%) of traffic. These boundaries are defined by pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition,

or, when vegetation cover is reduced or absent, by disturbance to organic litter (intact vs. pulverized) or lichen. Include any secondary parallel treads within this assessment only when they are not differentiated from the main tread by strips of less disturbed vegetation or organic matter. See Figure 1 for photographs illustrating these trail boundary definitions.

When in areas or times with poor GPS accuracy, stop at trail junctions to record an averaged IT trail junction point. These points will improve the accuracy of GIS data editing.

After thoroughly collecting all informal trails within your sub region, make a notation on you paper map to indicate it has been collected and move on to another sub region.

Decision rules for Collecting Informal Trail segments

A condition class change that occurs for less than 2 meters (approximately 6 feet) can be ignored (i.e. collect it as one segment and assign the dominant condition class to the segment). Be careful to try to avoid collecting animal trails. These trails will be narrow and have low hanging branches/vegetation. Use your judgment and look for signs of human and animal use (footprints, litter, deer browse, etc.).

Condition Classes

Class 1:	Trail distinguishable; slight loss of vegetation cover and /or minimal disturbance of organic litter.
Class 2:	Trail obvious; vegetation cover lost and/or organic litter pulverized in primary use areas.
Class 3:	Vegetation cover lost and/or organic litter pulverized within the center of the tread, some bare soil exposed.
Class 4:	Nearly complete or total loss of vegetation cover and organic litter within the tread, bare soil widespread.
Class 5:	Soil erosion obvious, as indicated by exposed roots and rocks and/or gullying.

Condition Class rating descriptions applied to informal trails.

Surveying Tips

- Use the pause and resume (log) capabilities of the GPS to prevent collecting extraneous points at the beginning and end of a segment. Pause the logger when not moving; restart it as you resume movement.

- Working in pairs or using flagging tape and or pin flags will help when the IT network is very dense. Flag sub regions on the ground and work through them individually.
    - When working a dense network work small sub areas and utilize flags and landmarks to delineate them; when collection has been completed within one flagged sub area, establish an adjacent sub area and collect it (e.g., 50-100 m long on one side of a formal trail).

- Collect IT anchor points when needed to aid in tying trail junctions to a specific location. Use Trimble's nest feature option.

- Use the formal trail layer and paper maps as a reference.

Data Download and Backup

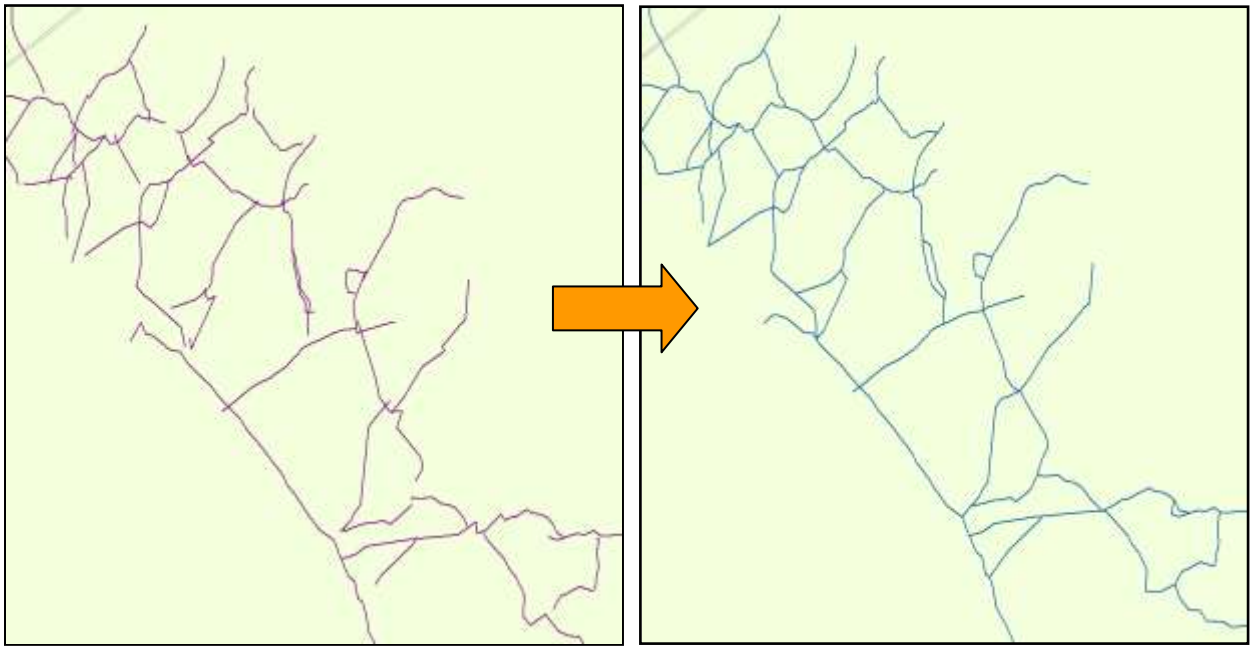
- When finished collecting for the day, close the rover file on the Trimble GPS.
- Connect the GPS to a computer with Pathfinder Office software (work within the preexisting project directory for the current collection).
- Transfer the rover files to the computer.
- If an internet connection is available, download the differential correction files that correspond to all new rover files and differentially correct them.
    - Designate the source base station as the closest available geographically.
    - Review the correction report as well as the corrected files for any errors or processing problems. Open the files in GIS to visually inspect them each day.
    - Ensure that the data were not removed during the correction procedure (e.g., due to missing base station data, high PDOP, etc).
    - Correction files that are not immediately available are generally made available within a week or two.
- Backup all data on a separate HDD and document all necessary metadata.
- Recharge the GPS and external battery.
- Keep a written field notebook record of all fieldwork, including field staff names, search areas, dates/times, and computer filenames.

Editing Data

Data should be post-processed (differentially corrected and converted to GIS appropriate format) using GPS software (e.g., Trimble's Pathfinder Office with conversion to ArcMAP Shapefiles). Merge output files into a single file representing the Informal trail network.

Informal trail data requires editing due to the nature of GPS data collection. GIS staff should edit the data to clean up and improve the accuracy of the informal trail network. Tips for doing this work:

- Use imagery and ancillary GIS datasets to help visualize the local environment.
- Move trail segment endpoints (minimally) to establish connectivity to other informal segments, recreation sites, and formal trails.
    - Use the anchor points layer for establishing junction locations.
- Use snapping and zoom tools to assist.
- Once the network is close, a "clean" or "build" procedure can be used (adjust fuzzy tolerance and dangle length as needed).



Before Editing After Editing

Figure 1. Trail width is defined as the most visually obvious outer boundary of trampling-related disturbance that receives the majority (>95%) of traffic. These boundaries are defined by pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, by disturbance to organic litter (intact vs. pulverized) or lichen.

Data Dictionary

Informal Trail:

LineFeature

Label1=Average Width

Condition Class: Menu; Normal, Normal

1 2 3 4 5 Other

Average Width=Numeric, Decimal Places=0

Minimum=1,Maximum=144,DefaultValue=8 Normal, Normal

Segment#:

Numeric, Decimal Places=0

Minimum=0, Maximum=500, Default Value=1, StepValue=1 Normal, Normal

Comment:

Text, Maximum Length=30 Normal, Normal

IT Anchor Point:

Feature

Label1=Number

Label2=Comment

Number=Numeric Decimal Places=0

Minimum=0,Maximum=500, DefaultValue=1, StepValue=1 Normal, Normal

Comment:

Text, Maximum Length=30 Normal, Normal

APPENDIX 3: GUIDANCE FOR MANAGING INFORMAL TRAILS

Guidance for Managing Informal Trails

Jeff Marion, USGS Research Scientist
(jmarion@vt.edu, 540-231-6603)

The development, deterioration and proliferation of visitor-created informal trails in protected areas can be a vexing management issue for land managers. Formal trail systems never provide access to all locations required by visitors seeking to engage in a variety of appropriate recreational activities. Traveling off-trail is necessary to engage in activities such as nature study, fishing, or camping. Unfortunately management experience reveals that informal trail systems are frequently poorly designed, including "shortest distance" routing with steep grades and alignments parallel to the slope. Such routes are rarely sustainable under heavy traffic and subsequent resource degradation is often severe. Vegetation impacts include trampling damage leading to changes in species composition, potential introduction and dispersal of non-native plants, and the loss of vegetation cover. Soil impacts include the pulverization and loss of organic litter, and exposure, compaction, and erosion of soil. Soil deposition in streams, disturbance to wildlife, and damage to historic resources are also possible. Creation of multiple routes to common destinations is another frequent problem, resulting in "avoidable" impacts such as unnecessary vegetation/soil loss and fragmentation of flora/fauna habitats.

This guidance is provided to assist land managers and volunteer trail maintainer organizations in evaluating informal trail impacts and in selecting the most appropriate and effective management responses.

Adopt a Decision-Making Process

The management of informal trail networks can benefit from application of a planning and decision-making process or framework that includes public dialogue and input. Decisions regarding impact acceptability and the selection of actions needed to prevent recreation-related resource impacts fall into the domain of carrying capacity decision-making. The NPS defines carrying capacity as "the type and level of visitor use that can be accommodated while sustaining the desired resource and visitor experience conditions in the park" (NPS 2006). The NPS applies the Visitor Experience and Resource Protection (VERP) decision-making framework (NPS 1997), while the U.S. Forest Service applies the Limits of Acceptable Change (LAC) framework (Stankey *et al.* 1985).

These formal frameworks direct managers to prescribe objectives for biophysical and social conditions they intend to achieve for specific park zones. Numerical standards of quality are established for each indicator and zone to define the critical boundary line between acceptable and unacceptable conditions, establishing a measurable reference point against which future conditions can be compared through periodic monitoring. These frameworks incorporate an adaptive management decision process, whereby managers can apply actions, evaluate their success, and when needed, apply alternative actions as a follow-up until management objectives are achieved. A simplified framework known as Protected Area Visitor Impact Management (PAVIM) employs an expert panel and problem analysis process (Figure 1) that requires less data (Farrell & Marion 2002). The problem analysis process, which is particularly applicable and useful in informal trail management decision-making, is described below.

Problem Analysis Process

Assemble a team of knowledgeable and experienced individuals with expertise in recreation resources management, visitor management, social science, site and trail management, natural resource management, and interpretation. Visit the site where the impacts or problems are occurring and apply this problem analysis process to guide discussions.

Identify and Evaluate the Problem

The problem analysis begins by developing the group's collective knowledge of the area, amounts and types of recreational uses, and the resource and social problems currently present. Group members most knowledgeable about these topics are asked to share their knowledge with the group. The sharing of differing perspectives, land management agency, trail club, recreation representatives, is encouraged. The significance of the problems and degree to which current conditions are unacceptable are considered when deciding whether management actions are needed. Next, participants with the longest experience in the area are asked to relate the history of the problems or impacts. Previous management actions are described and their effectiveness discussed and evaluated, including why implemented actions were or were not effective.

The core of a good problem analysis is a thorough evaluation of a problem's underlying causes and identification of factors that influence impact severity. For example, substantial off-trail traffic may be the cause for excessive vegetation loss but fragile ground vegetation and poorly marked or maintained formal trails may significantly contribute to the creation of unacceptably extensive or impacted informal trails. The relative influence of three groupings of factors: use-related, environmental, and managerial, should be examined. An improved understanding of these causes and factors are essential to evaluating alternative actions and selecting effective actions.

Identify and Evaluate Strategies and Actions

Step two involves brainstorming by team members to list and then evaluate a diverse array of management strategies and actions. Following list development, study team discussions should focus on careful evaluations of the advantages and disadvantages of each action. A number of important attributes should be considered, including potential effectiveness, management feasibility, costs to visitor freedom and satisfaction, expected visitor compliance, and others as appropriate.

The final step is selecting one or more preferred actions recommended for implementation. Careful consideration of the history of impacts and their management, the desired resource and social conditions for the area, and factors which either cause or influence impacts can help guide more objective and effective decision-making. Management objectives or desired condition statements will suggest the appropriateness of alternative actions relative to the natural, social, and managerial settings of the zone the area is situated within.

Generally, initial actions are feasible, have a low "cost" to visitors, and are judged to have a good chance at effecting the desired change in conditions. For example, indirect actions such as education or site maintenance should be considered before regulatory or site development actions as they are less obtrusive and do not compromise visitor freedom. More restrictive, expensive, and/or obtrusive actions are generally deferred until justified by the failure of one or more

preceding actions. However, severe or unacceptable impacts may warrant bypassing such light-handed efforts in favor of actions necessary to achieve more effective or immediate results. Alternative actions should be identified for potential implementation in the event that initial actions are ineffective.

For each action, identify likely individuals or organizations responsible for implementing the action and describe the necessary resources they will require. An implementation schedule should also be developed and efforts to obtain funding and staff initiated. At this time it is also useful to consider how a planned action should be monitored for evaluating effectiveness. For example, an accurate GPS survey of informal trail networks with condition class assessments provides a baseline for future comparison and should be conducted prior to implementing corrective actions.

Table 1. Problem analysis for managing resource and social impacts related to visitation.

I. Identify and Evaluate the Problem

- ***Describe area and use(s)*** - provide background information about the area, facilities, and visitor use.
- ***Describe problem(s)*** - briefly describe the facility, resource and social impact problems that are occurring.
- ***Problem significance*** - consider if and why the impacts are significant or unacceptable to land managers and protected area visitors
- ***Previous management actions*** - describe the history of the problems and previous actions; discuss the effectiveness of these actions and why they did or didn't work.
- ***Causes and influential factors*** - discuss the underlying causes for the impacts and the role of non-causal but influential factors that may intensify impacts. Consider use-related factors (type and amount of visitor use, visitor behavior and motives, use density), environmental factors (soil and vegetation type, environmental sensitivity, topography), and managerial factors (siting, design, construction, and maintenance of facilities, visitor management).

II. Identify and Evaluate Strategies and Actions

- ***List potential strategies and actions*** - create a comprehensive list of appropriate and potentially effective management strategies and actions. Strategies are broad approaches (e.g., modify visitor behavior, manage sites and facilities) and actions are the specific means used to implement a strategy (e.g., educate visitors, relocate campsites).
- ***Evaluate strategies and actions*** - discuss and evaluate the following attributes for each strategy and action: potential effectiveness, management feasibility (cost, staffing, long-term maintenance), advantages/disadvantages (e.g., costs to visitor freedom), expected visitor compliance, etc.
- ***Formulate recommendations*** - through group discussion, develop and write recommendations that reflect the group's consensus views. Describe the recommended action or group of actions to implement first and what might be tried next if these are ineffective.

Problem Definition: For informal trail management decision-making, an inventory of the informal trail network within an area of management concern is particularly useful. If GPS devices and expertise is available, a simple inventory technique is to conduct a walking GPS survey, provided the terrain and forest canopy permit accurate GPS use. GIS software can input, map and analyze the data, providing a visual display of the informal trail network relative to designated trails, roads and other resource features. Computation of the lineal extent of the informal trail network is also possible. If GPS devices cannot be used then an inventory can be made by hand-sketching informal trails onto large-scale maps with lengths assessed by pacing or a measuring wheel.

Where possible, managers may also wish to consider various options for assessing the condition of the informal trails. Many options, ranging from simple condition class evaluations, to trail width and depth measurements, or detailed assessments of soil and vegetation loss are possible. Guidance for assessing trail conditions may be found in the scientific literature (Cole 1983, Leung & Marion 2000, Marion & Leung 2001). Some rapid assessment "condition class" options are included at the end of this document or contact the author for examples of alternative monitoring protocols and manuals. An objective assessment of informal trail conditions can produce quantitative data for indicator variables that can be summarized to characterize current trail conditions, or when replicated, to monitor changes in trail conditions over time. Such data can be used in the previously described formal or informal adaptive management decision-making frameworks.

Evaluate Impact Acceptability: The acceptability of informal trail impacts should be evaluated according to park or management zone objectives. Informal trails located in pristine areas where preservation values are paramount are less acceptable than when located in areas that are intensively developed and managed for recreation use. Trails in areas with sensitive cultural and archaeological resources are particularly unacceptable if they threaten such irreplaceable resources.

Environmental factors: Informal trails located in sensitive or fragile plant/soil types, near rare plants and animals, or in critical wildlife habitats are less acceptable than when located in areas that are resistant to trampling damage and lack rare species. Informal trails that directly ascend steep slopes and/or will easily erode are less acceptable than trails with a side-hill design. Informal trails prone to muddiness and widening are less acceptable, as are trails that may contribute soils to water resources.

Use-related factors: Why is a trail in a particular location and what are the visitors trying to access? Which recreation activities are most responsible for creating informal trails? What are the motives responsible for off-trail hiking? Are some impacts avoidable? For example, informal trail impacts related to a poorly marked formal trail or that result from visitors trying to circumvent muddiness or severe erosion are more easily avoided and should be targeted first. It is not uncommon to find several "duplicative" informal trails in close proximity to each other accessing a common destination. Impacts caused by visitors seeking to shortcut a longer, more resistant route are unacceptable, as are impacts caused by visitors who could alternately access their intended destination by staying on resistant durable surfaces (e.g., rocks or gravel) (www.LNT.org). Informal trails resulting from illegal or inappropriate types of uses are less acceptable than if they are caused by permitted uses.

A careful consideration of these and other relevant factors (e.g., visitor safety) can assist managers in making value-laden decisions regarding the acceptability of informal trail impacts. The acceptability of these impacts, in turn, guides decisions about which trails should be left open, rerouted, or closed, and selection of appropriate and effective management interventions.

Selection of Management Strategies: The problem analysis process can assist managers in considering and evaluating a diverse array of potential management strategies and actions. Note that some degree of degradation to natural resources is an inevitable consequence of recreation use, requiring managers to balance recreation provision and resource protection mandates. Roads and formal trails can never provide complete access to the locations visitors wish to see, hence, some degree of informal trail development is inevitable and must be tolerated. The challenge for managers is to evaluate the impacts in light of recreation provision and resource protection objectives, and apply professional judgment to determine which impacts are unacceptable and require management action.

The following section describes four general strategies for managing informal trail impacts: 1) Improve management of formal trails, 2) Ignore or formalize informal trails, 3) Maintain informal trails, and 4) Close and restore unacceptable trails.

Improve Management of Formal Trails

If formal trail problems are contributing to the development of informal trails, then addressing such problems is generally one of the more effective and efficient options available to managers. Four problems are common. Make sure that formal trails are well-marked in some distinctive fashion so that visitors can clearly distinguish between formal and informal trails – this is often very confusing to most visitors. In rocky areas, paint blazes may be needed on rocks rather than trees because the terrain demands constant attention to the immediate trail tread. “Overblazing” or clearly defined trail borders (e.g., spaced rocks, logs, or low rock walls) may be necessary in some tricky areas. Boardwalks, low symbolic fencing, or higher rustic fencing are more effective but more visually obtrusive and costly. The treads of formal trails should be the most attractive location for walking, maintained to be free of muddiness or deeply eroded ruts with exposed roots and rocks. When braided or multiple parallel treads occur managers should define a single intended tread throughout.

Ignore or Formalize Informal Trails

Some informal trails may have reasonably sustainable design attributes and access locations, such as vistas or campsites (hikers), water resources (fishermen), or cliffs (climbers) that are acceptable to land managers. When visitor access to these locations is appropriate, such trails should generally be left open as informal trails or even designated and managed as formal trails. They serve an important resource protection function by concentrating visitor traffic on a narrow tread and protecting adjacent vegetation from trampling damage. Recreation ecology studies have consistently found a curvilinear relationship between the amount of traffic and trampling impacts (Leung and Marion 2000). The majority of trampling impact occurs with relatively low levels of trampling; once a trail is established, further trampling impact is greatly minimized by a “concentration” strategy that focuses all further traffic to its barren tread. An alternate “dispersal” strategy is only effective under conditions of very low use and/or when traffic can be confined to durable substrates (e.g., rock, gravel) or vegetation (grasses/sedges).

Sometimes a portion of such informal trails may require a reroute to improve the sustainability of an alignment, such as a very steep section aligned with the fall-line (parallel to the landform slope). An experienced trails professional should conduct a review and provide recommendations for informal trails left open to use. Generally trail alignments should favor side-hill over fall-line alignments, avoid grades over 15%, and favor rocky substrates and non-vegetated or grassy groundcover. As with formal trails, leaving an informal trail with a poor "impact susceptible" alignment is rarely a preferred long-term solution. Site development actions, such as graveling or installation of water bars and rock steps, could be applied but these are generally less appropriate on informal trails and would be unnecessary on a well-designed alignment. In most instances, relocation to an improved alignment will be a more cost-effective and sustainable long-term solution, even though pristine terrain is affected.

Due to the relatively poor trail design skills of visitors, it may even be necessary to replace several non-sustainable informal trails with a new well-designed informal or formal trail (with appropriate environmental reviews). An objective evaluation of the aggregate or cumulative impacts, including the total area of trampling disturbance and soil loss, will generally support such a decision. However, this option should only be attempted when managers are relatively certain of their ability to effectively close the pre-existing informal trails.

Maintain Informal Trails

Historically, most park managers have not maintained informal trail networks. However, extending maintenance work to those trails with reasonably sustainable designs left open to use can substantially reduce impacts. For example, managers can piece together a single sustainable route in an area with numerous braided trails and trim obstructing vegetation, subtly enhance tread drainage, or install natural-appearing rockwork on steep slopes. These actions will effectively encourage use and reduce impacts on the sustainable route while reducing use and encouraging natural recovery on alternate informal trail segments. Additional actions, discussed in the following section, can be applied to discourage their continued use.

Close and Restore Unacceptable Trails

Informal trails with poor, non-sustainable design attributes, trails that threaten sensitive resources, or unnecessary trails with duplicative routings should generally be closed and rehabilitated. Managers should recognize that successful trail closures and restoration are rare and require substantial and sustained management effort. The principal reason for low success rates is that while trampling impacts occur rapidly with low levels of use, vegetative and soil recovery occurs very slowly and complete recovery is prevented unless nearly all traffic is removed from treads for several consecutive years. A substantial restoration program involving the addition of soil and plantings of native species, with watering as needed to ensure survival, can hasten natural recovery. However, care must be taken to apply such intensive work only when managers are reasonably certain that effective measures are in place to prevent further trampling of the restoration work.

Selection of Management Actions: An adaptive management program involving education and site management actions is recommended when implementing strategies. Management experience and research have demonstrated that integrating site management and educational actions consistently achieve the highest rates of success. Site management actions are needed to mark and keep visitors on formal trails or to block or hide informal trails; educational actions are

needed to inform visitors of the impacts associated with off-trail traffic and what managers would like them to do to protect natural and cultural resources. Visitors frequently misunderstand site management actions that lack signs placed to convey information about impacts of concern and management intent. In the absence of site management actions, visitors may choose to disregard a prompter sign if a well-used informal trail branches off to what looks like an appealing vista.

Educational Actions

An educational component is often critical to communicate a clear rationale for an action – for example, that significant resource impacts can occur in some areas if visitors travel off designated trails. A message with a rationale should be followed by a plea for visitors to remain on formal trails, which need to be clearly designated through site management actions (e.g., blazing, symbolic markers, cairns) to distinguish them from informal trails. Social science research and theory has found that signs with a compelling rationale and clear behavioral plea are more effective than simple "do" and "do not" messages (e.g., "Please Stay on Designated Trails to Preserve Sensitive Vegetation") (Cialdini 1996, Cialdini *et al.* 2006, Johnson & Swearingen 1992, Marion & Reid 2007, Vande Kamp *et al.* 1994, Winter 2006). Such literature should be consulted to improve the efficacy of educational messaging.

Some principal goals that educational efforts seek to communicate include: 1) trampling impacts represent a significant threat to resource protection in some areas, 2) that off-trail traffic has created informal trails that managers would like to close and restore, 3) remaining on formal trails avoids these impacts, 3) formal trails can be distinguished from informal (visitor-created) trails by distinctive markings, and 4) even small amounts of continued traffic prevents the recovery of informal trails that managers are seeking to close and restore. Unfortunately, as you might expect, this is a lengthy and complex educational message that is challenging to communicate effectively. Research suggests that more complex messages are more effectively communicated personally, rather than on signed or in brochures. Regardless, examples of signs that seek to accomplish these objectives and that have received NPS approval for use are depicted in Figure 1. Note the inclusion of the "no-step" icons that communicate the message with just a glance and are understandable by children and non-English speaking visitors. Generally the larger informative signs are placed in conspicuous locations near trailheads and the more numerous "prompter" signs are placed just beyond junctions with informal trails.

Site Management Actions

A variety of site management actions are available for closing informal trails. Close lightly used trails by actions that naturalize and hide their tread disturbance, particularly along initial visible sections where visitors make the decision to venture down them. Effective actions include raking organic debris such as leaves onto the tread, along with randomly placed local rocks, gravel, and woody debris designed to naturalize and hide the tread. These actions also lessen soil erosion and speed natural recovery. On trails that have been effectively closed, transplanting plugs of vegetation at the beginning of wet seasons can hasten natural recovery. Revegetation work conducted before successful closure is achieved can be a frustrating waste of time and materials if visitors continue use of the trail and trample the transplanted vegetation.

Figure 1. Examples of informative trailhead sign (left) and trailside prompter signs that can assist management efforts in closing informal trails.

For well-used trails, such work generally cannot fully disguise the disturbed substrates and vegetation so additional measures are necessary for effective closures. Construct a visually obvious border along the main trail, such as a row of rocks or a log, to communicate an implied blockage for those seeking to access the closed trail. Alternately, embed large rocks or place large woody materials or fencing to obstruct access at the entrance to closed trails to fully clarify management intent. Even temporary 2 ft tall post and cord symbolic fences can communicate the importance of closures and effectively deter traffic (Figure 2) (Park *et al.* 2006). Taller plastic fencing (preferably in green or brown) is also easy to transport and install to discourage traffic on trails that prove more difficult to close. However, fencing is generally perceived as visually obtrusive and inappropriate in more primitive settings.

Placing rocks or woody debris that physically obstructs traffic beyond the beginning of closed trails may be ineffective if visitors are able to circumvent these by walking around them. This can result in new trampling and trails parallel to the "closed" trail – a significant problem in areas with sensitive or rare vegetation. In such areas it is better for hikers who ignore closures to remain on the "closed" tread than to create new treads on each side (Johnson *et al.* 1987). If the trail is in sloping terrain its closure may require the addition of soil to fill ruts and reestablish the original surface contour, and organic litter and vegetation to keep the soil from eroding. Finally, integrating site management work with temporary educational signs may be necessary to obtain a level of compliance that allows vegetative recovery. Also, consider signs to communicate the location of a preferred alternate route when visitors are seeking to reach a particular destination and their only visible access trail is closed.

Conclusions: Informal trail management actions should be implemented as part of an ongoing adaptive management program Experimentation will be necessary to refine site management

procedures that are appropriate in each management zone or location. Some form of periodic monitoring is critical to program success. A 5-year interval could be sufficient for monitoring with quantitative procedures, but annual informal evaluations are needed to effectively guide the application of management actions.

Objective monitoring will be needed if any potentially controversial management actions may be needed (e.g., use restrictions or high fencing). In exceptionally high use areas with sensitive resources there is a good probability that such actions will be necessary. For example, a combination of signs and restoration work may be able to keep 95% of visitors on a designated trail but 5% of 2000 visitors/day is 100 visitors/day, a level of trampling that is sufficient to both create and maintain informal trails. Tall fencing or a regulatory sign that prohibits use of the closed trail and threatens fines may be necessary on trails that are particularly difficult to close. Such situations also indicate a need for further dialogue with trail users to discover their motives and a review of whether the formal trail system should be extended or modified.

Figure 2. Low symbolic post and rope fencing (left) and high fencing designed to physically obstruct access (right).

Regardless, periodic monitoring provides feedback for gauging the success of management interventions in keeping conditions within acceptable limits. A documented failure of one intervention can be used to justify the use of a more obtrusive or expensive intervention.

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