Quantifying Recreation Impacts Along the Glacier Gorge Trail

Sponsored by the National Park Service and conducted by:

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Fort Collins, Colorado

Final Report

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Executive Summary

Protecting park resources and providing for a quality visitor experience are goals of the National Park Service mandated by the Organic Act of 1916 and the Wilderness Act of 1964. In order to manage natural resources in national parks, scientifically credible and standardized approaches are necessary for measuring and managing impacts to park resources. Developing a study that acknowledges and measures impacts to park resources can provide Rocky Mountain National Park managers with information that can be used to protect the quality of natural resources and visitor experiences.

Trails can be assessed by either sampling techniques or by complete census. Sampling techniques measure specified indicators at sample points in order to make statistical generalizations about the condition of a trail. Census techniques document the every occurrence of a predefined problem along a trail segment. Recently, work by Newman, Monz, Theobald, and Leung (in press) used Geographic Information Systems (GIS) to create spatially balanced probability based sampling plans to measure the proliferation of illegal campsites in Yosemite National Park. However, this technique has not been used to measure other types of recreation related impacts such as trail conditions, social trail proliferation, or litter. Therefore, the intent of this study was to create an efficient sampling plan to measure recreation related impacts along the Glacier Gorge trail.

This study specifically addressed the following objectives: 1) Estimate the number of visitors along the Glacier Gorge trail; 2) Identify what types, locations, and extents of recreation impacts occur in the Glacier Gorge area; 3) Estimate trail conditions and compare results of different data collection methods.

The results estimate that 474 visitors hiked to Alberta Falls per day, 157 visitors hiked to Mills Lake per day, and 46 visitors hiked to Black Lake per day. Social trail proliferation, litter, and vandalism were generally concentrated at lakes, Alberta Falls, and trail junctions. The average trail width for the entire trail, including the Fire Trail, was approximately 4.5 feet and the average maximum trail depth was approximately 2.75 inches. There was no statistically significant difference found between the results of the two data collection methods for trail width and depth.

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Introduction

As visitation to national parks continues to increase park managers are challenged with providing quality visitor experiences while protecting park resources as mandated by the Organic Act of 1916 and the Wilderness Act of 1964. Rocky Mountain National Park (RMNP) hosts approximately 3 million visitors per year. This high level of use is a concern to park managers because of the potential impacts to ecological resources and social conditions associated with recreation use.

Many visitors to RMNP use its trail system to access natural attractions in the backcountry. Attractive destinations within short distances of a trailhead tend to be heavily used by recreationists. This is especially true of parks that are close to large urban areas (Cole, Watson, Hall, & Spildie, 1997).

Methods to identify the types and extent of impacts that threaten the integrity of park resources and visitor experience are needed. However, because of limited budgets and time available to conduct impact monitoring, efficiency and precision are important factors to consider when creating a monitoring plan and protocol. The purpose of this research is to create an efficient monitoring program to quantify impacts caused by recreation use in backcountry areas.

Purpose and Research Questions

The overall purpose of this research in RMNP is to:

1) Estimate the number of visitors along the Glacier Gorge trail
2) Identify what types, the location, and the extent of recreation impacts that are occurring in the Glacier Gorge area
3) Estimate trail conditions and compare results of different data collection methods

The specific research questions addressed in this study are:

1) What is the distribution of visitation in the Glacier Gorge area?
2) What is the spatial distribution of recreation impacts in the Glacier Gorge area?
3) How does visitation affect trail conditions?
4) How do trail condition results of spatially balanced probability based sampling compare to interval based sampling methods?

Literature Review

All recreation use causes some impact. These impacts may be physical (e.g., trail erosion, creation of social trails, litter), or social (crowding or conflicting uses, wildlife disturbance, or reduced visitor satisfaction due to quality of the resource). Development of a monitoring program that measures recreation impacts can provide RMNP managers with information that can be used to protect park resources and visitor experience quality as well as inform elements of carrying capacity related frameworks such as Visitor Experience Resource Protection (VERP) or Limits of Acceptable Change (LAC) (NPS, 2002; Stankey, Cole, Lucas, Peterson, Frissel, & Washburne, 1976).

Recreation Impacts

Impacts caused by recreation have both ecological and social repercussions. Ecological impacts that can result from recreational use identified by research include: soil (soil compaction, loss of organic litter, loss of mineral soil), vegetation (reduced height and vigor, loss of ground vegetation cover, loss of fragile species, tree trunk damage, introduction of exotic species), wildlife (habitat alteration, loss of habitats, introduction of exotic species, wildlife harassment, modification of wildlife behavior, displacement of food, water, and shelter), and water (introduction of exotic species, increased turbidity, increased nutrient inputs, increased levels of pathogenic bacteria, altered water quality) (Leung & Marion, 2000).

Visitor satisfaction also can be affected by recreation impacts. Locally severe disturbances (including presence of social trails, damaged trees, litter, or inappropriate human waste disposal) detract from the quality of visitors' experiences (Cole, et al., 1997). These types of impacts have been identified as a greater concern of visitors to high use destination areas than the number of other people they encounter (Cole, et al., 1997).

Level of use has a curvilinear relationship with recreation impacts (Figure 1) (Cole, 1992). That is, low amounts of use have a disproportionately higher impact than progressively higher levels of use. Similarly, most trail impacts have been found to occur within the first half of a trail's length (Lucas, 1980).

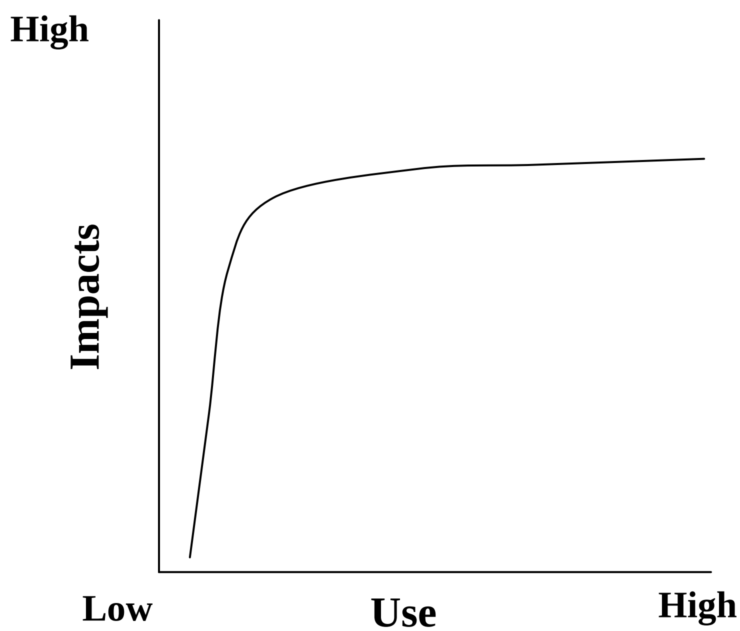

Figure 1. Hypothetical Use Impact Curve (Cole, 1992)

Cole and Landres (1996) proposed that the ecological extent of an impact in wilderness is a function of the intensity and areal extent of the impact in addition to the irreplaceability of the resource being affected. While the areal extent of most physical impacts is limited, visitors spend most of their time on localized sites that can be highly disrupted. Cole et al. (1997) found that 2/3 of visitors who noticed trail and campsite impacts reported that the impacts detracted from the quality of their experience.

User Types

In general, impact potential increases from human use to horse/mule use to motorized vehicles (Cole, 1989). It has been suggested that horse use causes more impact because the substantial body weight of a horse is supported on relatively small hooves which is less efficient at dispersing a horse's weight as compared to a human's weight and foot size (Cole, 1998; Marion, 1994). Horses tend to loosen surface soils and compact subsurface soils which increases erosion potential (Marion, 1994).

Dale and Weaver (1974) found that steeper slopes created more potential for user impact. Motorcycles were more destructive moving up a slope while horses and hikers were more destructive traveling down the same slope.

Summer (1980) found that erosion was more closely related to geomorphic processes on a landform interacting with climatic events rather than the result of use. She found that horse use exposed soil surfaces and encouraged soil movement. Soils compromised by horse use were then subject to erosion processes such as sheetwash, rilling, gullying and soil creep.

Visitor Behavior/Use

Visitors sometimes behave in ways that can affect the resource and visitor experience. These actions include walking off trail, walking around wet trail sections (creating wider trails), throwing debris, vandalism, disposing of litter, feeding wildlife, touching water, cutting trails, yelling, defecating, breaking tree branches, and developing unofficial sites (e.g. creating fire rings) (Brooks & Titre, 2001; Marion, 1994; Mortensen, 1987).

Brooks and Titre (2001) conducted a survey of user behaviors in Rocky Mountain National Park. Visitors walking off trail occurred more often than any other behavior (341 occurrences during 57.85 hours of observation). Walking off designated trails can cause social trails to develop.

Visitor Use Estimation

A survey of wilderness managers reported that 63% of managers relied on best guesses to estimate visitor use (McLaran & Cole, 1993). Lack of funding, logistic problems resulting from size of area, number of access points, lack of personnel time, and lack of knowledge and training about available methods to collect and analyze data have been identified as some reasons why wilderness use has not been examined adequately (Watson, Cole, Turner, & Reynolds, 2000).

Mechanical visitor counters allow managers to gather visitor counts with minimal to no disturbance to visitors. Mechanical monitors need to be calibrated to ensure accuracy (Watson, Cole, Turner, & Reynolds, 2000; Bates, Wallace, & Vaske, 2006). Infrared monitors were used in RMNP in previous studies and results needed to be inflated due to missed counts (Bates, Wallace, & Vaske, 2006).

Impacts to Trailside Vegetation

Trampling experiments show that vegetation is completely removed from a path with less than 1000 hiker passes (Cole, 1995; Quin, Morgan, & Smith, 1980; Bryan, 1979; Dale & Hartley, 1978). Some vegetation types, however, have more resistance and/or resilience to trampling than others. In general, graminoids (grasses) are more resistant to trampling and recover quicker and more efficiently than vegetation types with woody stems (Cole, 1995; Dale & Hartley, 1978).

Trail width has been found to be related to amount of use (Cole, 1991). Dale and Weaver (1974) found trail width increases linearly with the log of user numbers. In other words, a trail that is 100 cm wide with 1,000 annual visitors can be expected to increase to 200 cm wide with 10,000 annual visitors. With large amounts of users, trails in meadows tend to be a little wider than trails in forests. People tend to walk abreast in open meadow areas while trees, side slopes, and shrubs inhibit people from walking side by side in forests.

Species composition is affected by use and tends to be more diverse near a trail (Hall & Kuss, 1987; Cole, 1978; Dale & Weaver, 1974). This may be caused by a species' tolerance to trampling or because invading species are introduced by some other means (e.g. seeds in horse manure or from a user's clothes). Trail construction can promote increased sunlight in otherwise shaded areas and compacted soils may increase soil moisture (Hall & Kuss, 1987). At low levels of use this condition may increase vegetative production (Hall & Kuss, 1987).

Dale and Weaver (1974) found that plant species react in one of four different ways to the presence of a trail:

- Disappear (decreasers)
    - Tend to be forest cover species with woody or brittle stems
- Appear only at trail sides (increasers or invaders)
    - Meadow grasses tend to dominate trail side positions: increased light gradient may contribute to their presence
- Appear at some part of the gradient but not immediately next to the trail (increaser-decreasers)

    - Meadow species that require more light but cannot tolerate increased trampling
- Not affected by the presence of a trail (neutral)

Invasive species can be affected by elevation and are not well adapted to subalpine conditions. In a study of non-native plants in RMNP, Lee (2001) found that invasive species occurred more frequently at lower sites (<9,000 feet) than higher sites.

Monitoring Techniques

Trails can be assessed either through sampling techniques or by complete census (Marion & Leung, 1999; Cole, 1983). Sampling techniques involve measuring specified indicators at sample points while census methods document every occurrence of predefined problems.

Point sampling involves taking replicable measurements over small segments of a trail in order to make statistical generalizations about the condition of a trail. Permanent points may be established to monitor impacts over time. Point sampling can describe mean conditions for a trail but may miss conditions between sampling points. Marion and Leung (1998) examined the influence of sampling interval on trail impact assessments. A 10% loss in accuracy was found for sampling intervals of 100 m or less for lineal extent impact problems (e.g. trail width or tread incision). Longer intervals yielded progressively less accurate measures.

Problem assessment is a census method that yields more complete data on extent, frequencies and locations of impacts than sampling techniques (Marion & Leung, 1997). Problems are predefined and every occurrence is documented. Predefined problems might include excessive trail conditions (e.g. trail sections wider than 6 feet). This information is useful to managers and trail condition standards can be set and monitored using this technique. However, this method's precision is limited by the subjective nature of defining problems.

Geographic Information Systems (GIS) technology has been utilized to create a spatially balanced monitoring plan for campsite indicators in Yosemite National Park (Newman, Monz, Theobald, & Leung, in press). GIS was used to estimate locations of visitor campsites based on distances from trailhead, distances from water, distances from trail, and slope. Spatial algorithms were computed to establish sample points that were spatially balanced throughout Yosemite's Merced River corridor.

Spatial Distribution of Recreation Impacts

Spatial analyses examine how objects of interest are distributed throughout a landscape. Spatial analyses in natural resources have mostly been applied to biological populations (Davis & Reich, 2003; Diggle, 1983). Most biological populations are distributed in a non-random pattern. Plant ecologists have recognized three distinct spatial distributions of point patterns: random, clustered, and uniform (Davis & Reich, 2003).

Recreation use and associated impacts are also distributed in a non-random pattern and tend to be concentrated around recreation resources, facilities, and visitor distribution patterns (Leung & Marion, 1998; Cole, 1998; Manning, 1979). The proliferation of recreation impacts, such as illegal campsites and social trails, has been identified as a significant management problem to national park managers (Marion, Roggenbuck & Manning, 1993; Gamble, personal communication, September, 2004).

While the areal extent of an impact has been identified as an integral component of determining the severity of visitor impacts (Cole, 1994), methods for examining the spatial qualities of recreation impacts are undeveloped (Leung & Marion, 1998).

Computer Modeling of Recreation Use

Most computer simulation modeling has been applied in recreation use to study and predict visitor use flow. Recent models have used GIS to estimate access and to create efficient impact monitoring plans (Newman et al., in press).

The Wilderness Use Simulation Model was first developed in 1973 in a collaborative effort between International Business Machines (IBM) and the U.S. Forest Service (USFS) in order to replicate an area's travel network and simulate different groups moving along their routes (Cole, 2005). However, this model fell into disuse because of excessive costs. Interest in simulation models was renewed in the 1990's when Robert Manning and associates used a commercially developed general purpose simulation program called Extend (1996) (Cole, 2005). This application was similar to the Wilderness Use Simulation System but could be run on a personal computer. In 2002, the Recreation Behavior Simulator (RBSim) was developed by Gimblett and Itami to simulate recreation behavior specifically (Gimblett, 2002; Itami, Raulings, MacLaren, Hirst, Gimblett, Zanon, & Chladek, 2002).In addition to running probabilistic simulations like the Wilderness Use Simulator and Extend, RBsim also allows for rule based agent simulations.

GIS has also been used to estimate access to backcountry areas both on trail and off trail in RMNP (Theobald, 2005). Models were based on distance from trailhead, distance from trail, slope, and vegetation types. Outputs from the model were maps that estimated travel time to all locations considered.

Cole (2005) identified simulation modeling as a valuable tool for recreation planning and management that has potential to link models of recreation behavior to models of biophysical impacts. However, Cole also notes that one barrier to linking knowledge about the relationship between visitation and resulting impacts is lack of research on recreation impacts.

Summary

Impacts caused by recreation use have both ecological and social repercussions. These impacts have the potential to affect the integrity of natural resources and visitor experiences. Low levels of use cause a disproportionately higher amount of impact than progressively higher amounts of use. While the areal extent of these impacts is limited, visitors spend much of their time in these heavily impacted, localized areas. Many visitors who notice physical impacts say the quality of their experience is diminished by these impacts more than high encounter levels (Newman, Manning, Dennis, & Mckonly, 2005).

These findings suggest that the mitigation of physical impacts may permit large numbers of visitors and the resulting high levels of encounters to be acceptable (Cole, 1997). Visitor experience in wilderness has typically been measured as number of encounters or perceptions of crowding. While crowding measures deal with one intent of the Wilderness Act: to preserve opportunities for solitude, it does not address the intent to keep the human imprint on the land “substantially unnoticeable”.

Monitoring the physical conditions of recreation use areas is important because it creates baseline data which can be compared to future conditions. Endeavors to model physical impacts can aid park manager's efforts to protect the integrity of the resource and visitor experience in the face of increasing visitor use.

Methods

A. Study Area

The Mills Lake to Black Lake trail, originating at the Glacier Gorge trailhead, was selected as the study site because it is typical of a high use trail in the Bear Lake area (Figure 2). In addition, it was the only high use trail in the area that did not have major trail maintenance projects occurring that could affect visitor use or trail conditions.

The Mills to Black Lake trail offers three major attractions to visitors: Alberta Falls (approximately ¾ miles from the trailhead), Mills Lake (approximately 3 miles from trailhead), and Black Lake (approximately 5 mile from the trailhead). There is one major junction about 2.5 miles from the trailhead where visitors can access the Mills-Black Lakes drainage, the Loch-Sky Pond drainage, or Lake Haiyaha.

There are no facilities (restrooms or garbage cans) beyond the trailhead. While traveling in backcountry areas, visitors are expected to practice Leave No Trace techniques described in literature given to them when entering the Park. Although RMNP has not been designated as a wilderness area, RMNP administrators manage backcountry areas as wilderness.

B. Visitor Counters

Fifteen active infrared trail monitors were utilized to estimate visitor use along the Glacier Gorge trail (Figure 3). Monitors were placed at trail junctions, attractions, and along social trails to estimate use from August 7, 2005 to October 16, 2005. Results were uploaded from monitors regularly and downloaded to a personal computer (PC) using

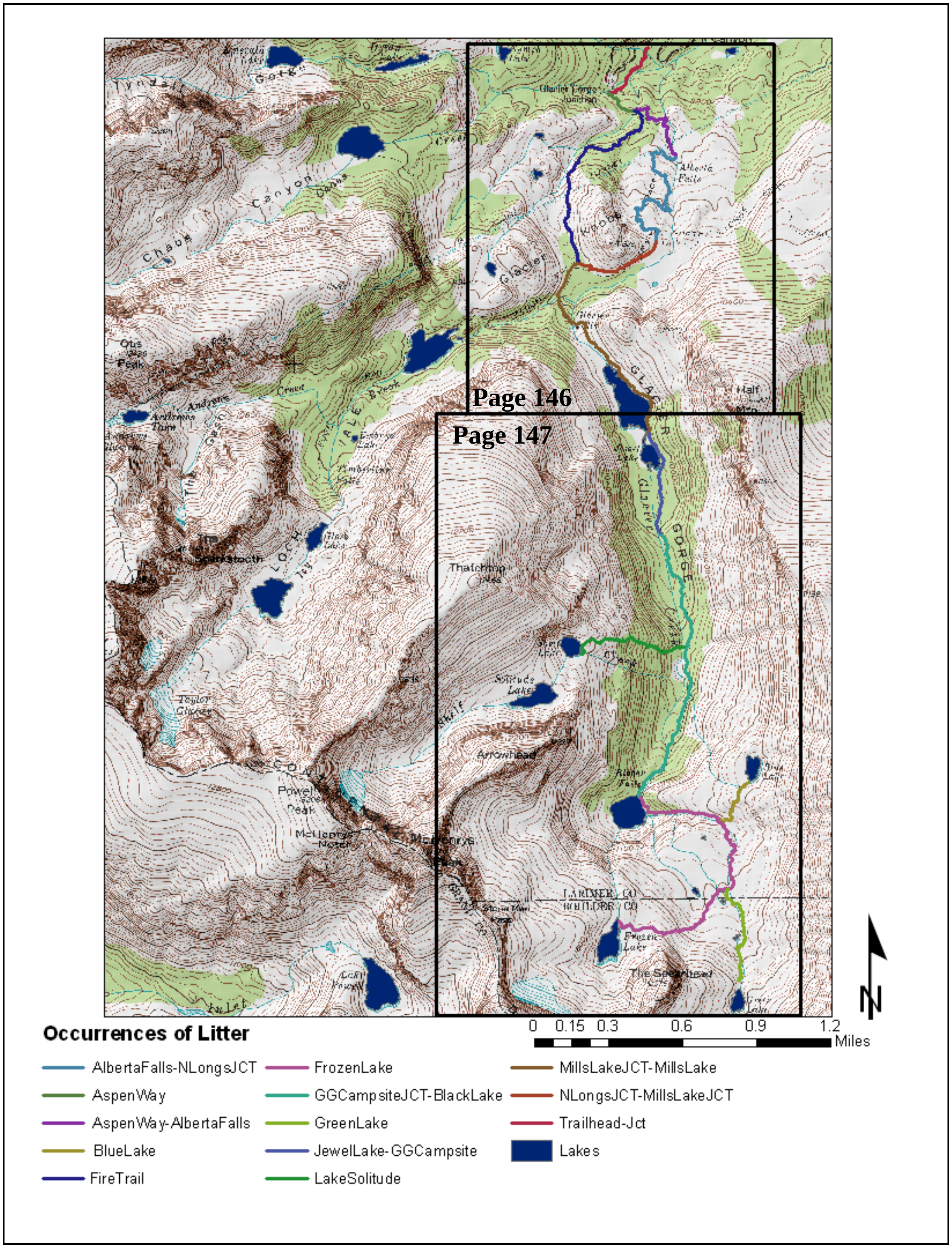

Figure 2. Trail locations along the Glacier Gorge trail

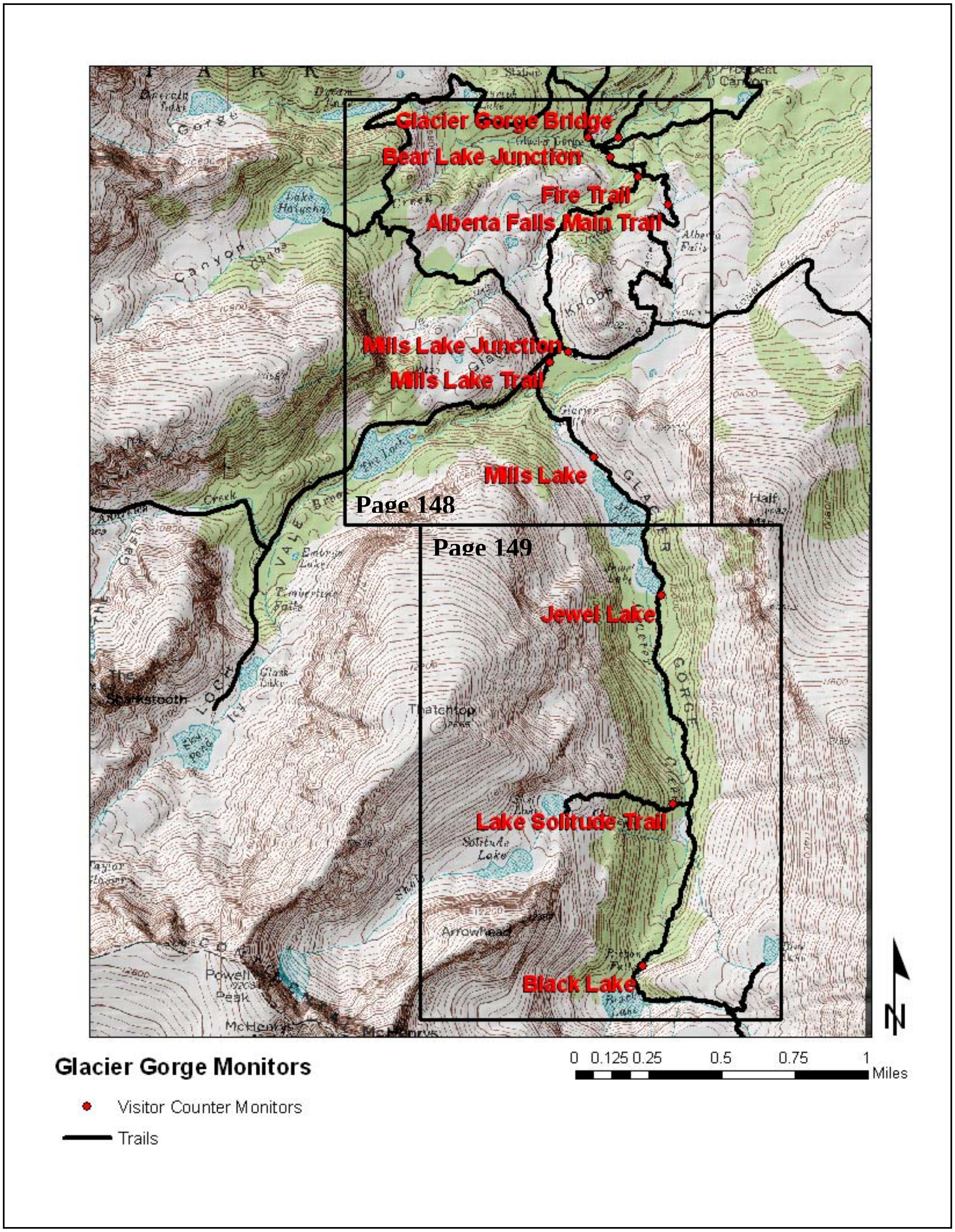

Figure 3. Visitor counter locations along the Glacier Gorge trail

Trail Master software. Visitor counter data was then imported into *Microsoft Excel* and then into *SPSSv14* for data analysis.

C. Sampling Plans

A spatially balanced sampling plan based on visitor accessibility was created (Theobald, 2005). *ArcGISv9.1* was utilized to create “accessibility probability” surfaces (Figure 4). Accessibility was defined as the time it would take a hiker to travel to a location within the study area both along the trail and off of the trail. Physical characteristics of the area considered were distance from trailhead, slope, and when considering off trail travel - vegetation type.

Typical walking velocity for a hiker is 5 km/hr on flat terrain. However, on steeper terrain hiking velocity diminishes. Hiking velocity on variable slopes can be computed by (vanWagtendonk & Bennett, 1980):

$$W=6*\exp(-3.5*\text{abs}(S + 0.05))$$

Where: W = walking velocity and S = slope = tan (theta).

Hiking off trail through vegetation also slows hiking time. Vegetation in off trail areas were weighted to reflect slowed hiking velocity (Table 1). Lakes were given an extremely high weighted value in order to make travel through these areas inaccessible.

Table 1. Weights for travel through different vegetation types

Weight	Vegetation Type
1.5	Grasslands
3	Forested Areas
5	Shrublands/Wetlands
1000	Water-Lakes

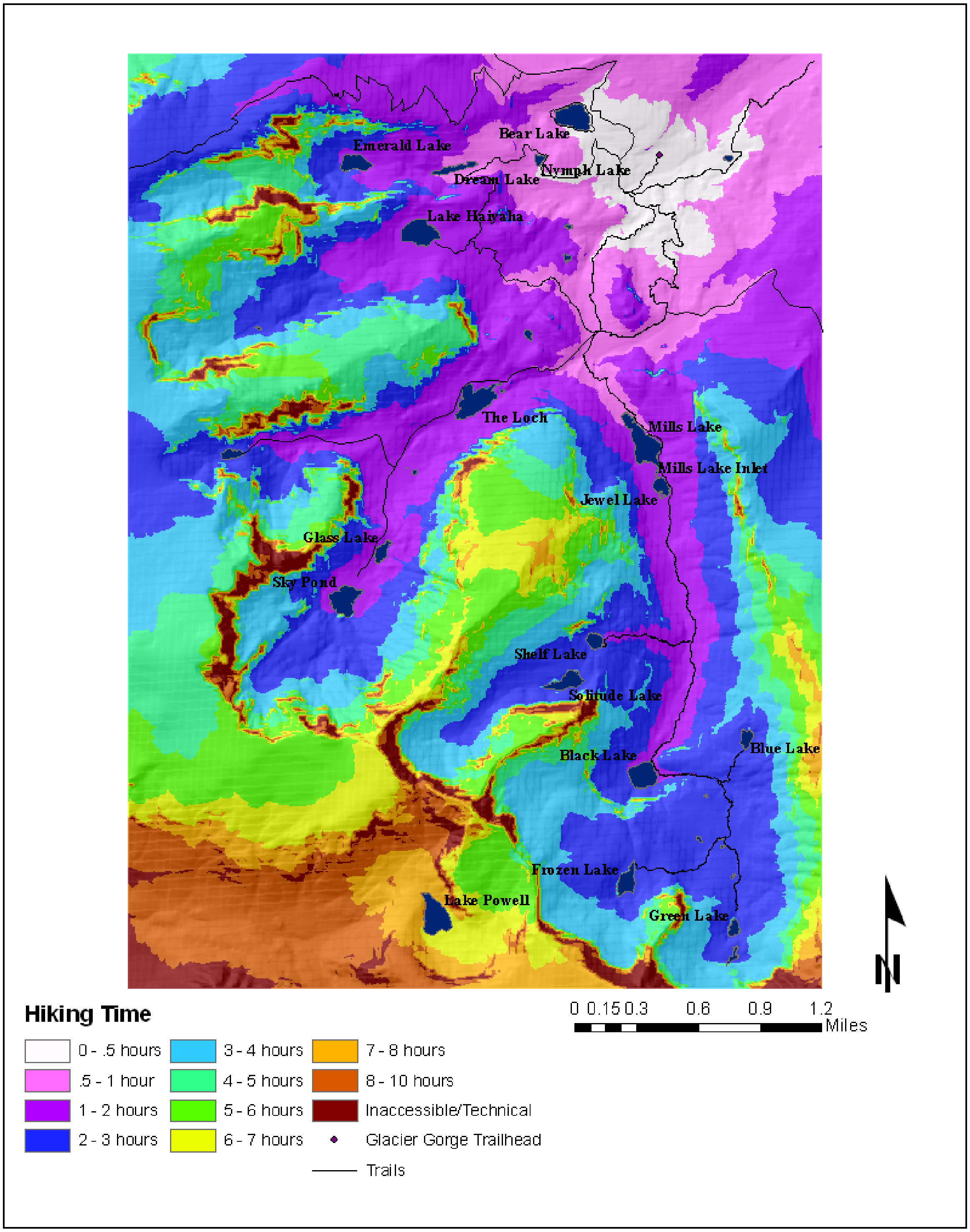

Figure 4. Accessibility Surface of Bear Lake Area

Spatially explicit maps were developed for each of these physical characteristics. Based on those maps, a function was generated that relates the probability of a hiker traveling to a location within the study area. These three factors were then combined by multiplying their probability (between 1 and 0) to find an overall model of probability of hiker visitation.

Using these parameters, an "accessibility probability" surface was created and sampling points were formulated and overlayed on the surface. Two sampling plans were created using the "accessibility probability" surface: a dataset of on-trail points and off-trail points.

On trail point probabilities were determined by a hiker's travel time along the trail corridor. All trail locations within one hour of the trailhead were given a probability of 1, locations within two hours of the trailhead were given a probability of 0.9, and locations beyond two hours of the trailhead were given a probability of 0.8. All locations beyond the trail corridor were given a probability of 0. Ninety-nine points were sampled in this dataset.

In order to examine the extent of recreation impacts beyond the trail corridor a set of off trail points were created. The off trail dataset considered all areas within the Glacier Gorge drainage. Point probabilities were determined by a hiker's travel time to all locations within the drainage (Table 2). Seventy-five points were sampled in this dataset.

During the field sampling of the off trail dataset it was noticed that most off trail recreational impacts occurred within a close proximity of the trail. This observation inspired the creation of a new dataset of off trail sample points within 150 meters of the

Table 2. Probability criteria for off trail dataset.

Probability	On/Off Tail	Hiking Time from Trailhead
1.00	On Trail	1 hour
0.90	On Trail	2 hours
0.80	On Trail	3 hours
0.50	Off Trail	0.5 hours
0.45	Off Trail	1 hour
0.40	Off Trail	1.5 hours
0.25	Off Trail	2 hours
0.15	Off Trail	3 hours
0.10	Off Trail	4 hours
0.05	Off Trail	> 4 hours

Glacier Gorge trail. Point probabilities for this dataset were based on distance from the maintained trail. Areas within 50 m of the trail were given a probability of 1, areas beyond 50 m but not more than 100 m of the trail were given a probability of 0.25, areas beyond 100 m but not more than 150 m of the trail were given a probability of 0.10, and areas beyond 150 m of the trail were given a probability of 0. One hundred points were sampled in this dataset.

In order to compare the efficiency of traditional sampling methods to the spatially balanced sampling plan, a dataset of on-trail points was sampled at 100 m intervals. A distance wheel was used to measure distances between sample points. Ninety-three points were sampled in this dataset.

For each point, Universal Transverse Mercator (UTM) coordinates were provided that allowed navigation to the sample point using a Global Positioning Unit (GPS). Data was collected using a Personal Dictation Accessory (PDA) running *ArcPad* and downloaded to a computer at the end of each day.

D. Sampling Protocol

Topographic features, physical features, and recreation related impacts were documented within a 5 m quadrat at each sample point.

Topographic variables included:

- Slope of the site area
    - Clinometer readings were taken from the center of the quadrat to the edge of the 5 m quadrat to the north, northeast, east, southeast, south, southwest, west, and northwest
- Trail aspect
    - Trail aspect was measured by compass from the center of the quadrat
    - Aspect was measured 0º-359º, both down trail and up trail aspects were documented
- Trail slope
    - Measured from the down trail edge of the quadrat to the center of the quadrat using a clinometer
- Trail position
    - Classified by the surveyor as: mid-slope, ridge line, valley bottom, or meadow; these classifications were visual observations
- Elevation measured by GPS
    - Measured in meters

Physical features of the site included:

- Dominant type of understory/tree types

    - Dominant type of understory and tree types were identified by the surveyor
    - The National Audubon Society Field Guide to the Rocky Mountains was consulted to identify vegetation types
- Canopy cover
    - Measured by spherical densiometer

Recreation impacts considered include both trail impacts and visitor related impacts.

Trail impacts included:

- Trail width (feet)/trail depth (inches)
    - Five locations were measured within the quadrat to estimate trail width and trail depth (Figure 5). Width and depth measurements were taken at the down trail edge of the quadrat, midway (2.5 meters) between the down trail edge and the center of the quadrat, the center of the quadrat, midway (2.5 meters) between the center and the up trail edge of the quadrat, and the up trail edge of the quadrat. Trail widths were measured in feet to the nearest half foot (6 inches) using a tape measure. Depths were measured in inches to the closest half inch. Depth was considered from the downhill side of the trail. A trekking pole was held horizontal from the downhill edge across the trail and leveled using a torpedo level. Measurements were taken at the deepest point in the trail to the bottom of the trekking pole using a tape measure.
    - Sections where trail width was indeterminable were not given a value (e.g. slick rock sections)

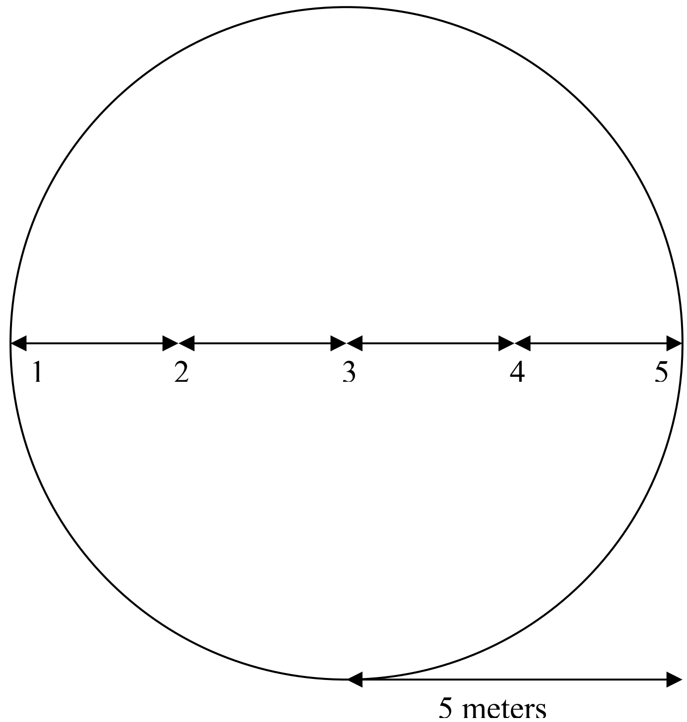

Figure 5. Diagram of trail and width measurement locations within quadrat

- Evidence of maintenance (presence of trail structures or imported trail tread)
    - Any trail structure or imported tread was considered evidence of maintenance
    - Trail structures types (retainer bars, water bars, retaining wall, and bridges) and quantities were documented
- Distance to nearest uphill water break
    - Measured from the center of the quadrat to the nearest water bar or natural water break (drainage dip or apex of hill)
    - Lineal distances were measured beyond the edge of the quadrat

- Root exposure
  - Measured as quantity of roots visible within the trail corridor; number of exposed roots was counted by the surveyor
- Braiding
  - Recorded as presence or absence
  - Trail braids were considered social trails, thus widths and depths were recorded as a social trail

Recreation related impacts included:

- Litter
  - Type and quantities of litter within the quadrat were documented
  - Occurrences of litter represent the number of pieces of litter found within a quadrat
- Social trails
  - Quantities and condition of all social trails within the quadrat were recorded using the same method as on-trail conditions. If social trails initiated from an existing trail, width and depth values were recorded at three positions within the quadrat: at the center, 2.5 meters from the center, and at the edge.
  - Vegetation loss caused by social trail development was estimated at each sample point. Social trail locations were drawn on a diagram of the five meter quadrat and vegetation cover was estimated at 13 points within the quadrat (Figure 6).

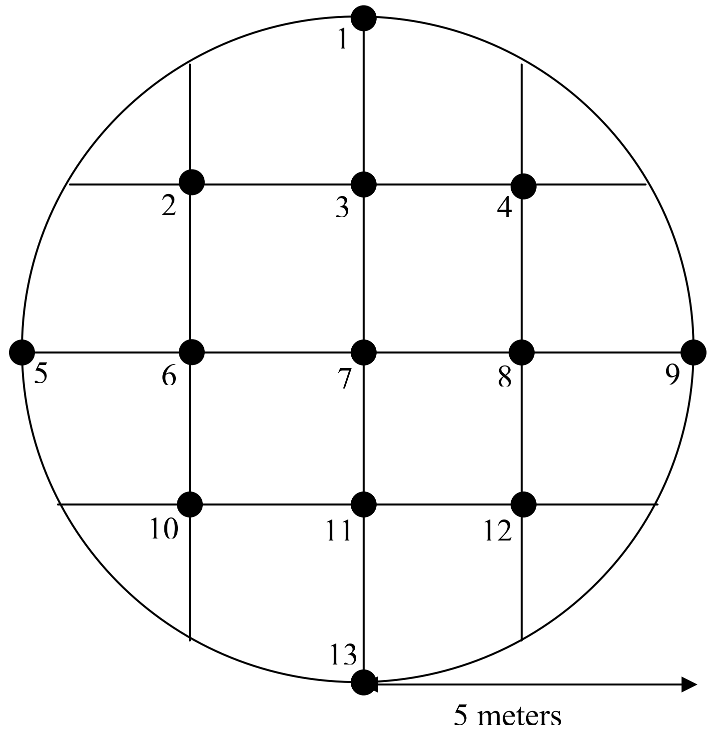

Figure 6. Diagram of the thirteen points where vegetation was estimated within quadrat

- Invasive species
    - Presence and type of any invasive species within the quadrat was documented
- Human waste
    - Presence or absence of any human waste within the quadrat was documented

Each site was photographically documented. Photos were taken to the north, south, east, and west from the center of the study area. Trails were photographed from the downtrail end of the study site.

Three hundred sixty-seven sample points were visited in this study. The totals for each dataset are reported in Table 3.

Table 3. Number of sample points in each dataset

Dataset	Number of Sample Points
On-trail (spatially balanced)	99
On-trail (100 meter interval)	93
Off-trail	75
Off-trail (150 meter buffer)	100
Total =	367

E. Spatial Distributions of Recreation Impacts

Multiple methods were used to analyze the spatial distribution of recreation impacts along the Glacier Gorge trail. Various *ArcGISv9.1* tools were used to analyze and create maps of recreation impacts. Basic spatial measures originally developed to identify spatial distributions of vegetation were applied to litter occurrences.

Getis-Ord Index Tool

The spatial distribution of social trails, litter, and vandalism were examined by using the Getis-Ord Gi* (G-Ord) index tool in *ArcGIS v9.1* to identify spatial clusters of statistically significant high or low impact values. This tool calculates the Getis–Ord Gi* statistic. The G-statistic describes whether high values or low values tend to cluster in an area. A high G-statistic value indicates that values higher than the mean tend to be found near each other and low G-statistic values indicate that values lower than the mean tend to be found near one another.

The output of the Getis-Ord function is a Z-score for each point. A Z-score is a statistical value that standardizes measurement units for comparison purposes. In this case, the Z-score represents the statistical significance of clustering for a specified distance. A Z-score of 1.96 would indicate positive spatial autocorrelation at the 95% confidence level. Spatial autocorrelation is based on the first law of geography: near things are more similar than things that are more distant (Tobler, 1970). Positive spatial autocorrelation is present when neighboring areas are similar or the same. Areas with positive spatial autocorrelation can be considered "hot spots" for impacts.

Recreation impact occurrence values were weighted for the probability-based datasets based on their point inclusion probability and applied in the Getis-Ord analysis. The distance from each point considered for this analysis was the distance with the strongest spatial autocorrelation. Spatial autocorrelation was identified using *ArcGIS v9.1* high/low clustering (Getis-Ord general) tool.

A map of G-statistic values was created using *ArcGISv9.1* Inverse Distance Weighting (IDW) tool. The twelve nearest sample points were identified for the IDW interpolation. The resulting maps display where positive spatial autocorrelation of recreation impacts occur.

Social Trails

Social trail development was quantified as vegetation loss. The proportion of vegetation loss caused by social trail development within each quadrat was calculated as:

$$\frac{\text{Number of estimated points of bare ground caused by social trails within a quadrat}}{\text{13 points}}$$

A continuous surface of vegetation loss was created from the results of this proportion using the IDW tool in *ArcGISv9.1.* The twelve nearest sample points were identified for the IDW interpolation.

Litter

Density has been used to measure the number of plants per unit area (Davis and Reich, 2003). This method was applied to estimate the density of litter occurrences using the following formula:

$$\text{Density} = \frac{1}{an} \sum_{i=1}^{n} yi$$

where:

yi = the number of litter occurrences present in the quadrat
a = area of quadrat
n = number of quadrats in sample

Three of the datasets collected were weighted samples. In order to account for the weights in the sample:

yi = weighted litter occurrence values
a = area of quadrat
n = ∑ weight for entire sample

Frequency is another measure of spatial distribution (Davis & Reich, 2003). This measure has been used to examine how many times a specie is encountered and can be applied to litter occurrence by:

$$\text{Frequency} = \frac{1}{n} \sum_{i=1}^{n} xi$$

Where:

xi = 0 or 1 representing the absence or presence of litter occurrence (weighted)

n = weighted quadrats

Frequency and density can be combined to measure abundance, the estimated number of litter occurrences per quadrat (David & Reich, 2003):

$$\text{Abundance (occurrences/quadrat)} = \frac{\sum_{i=1}^{n} yi}{\sum_{i=1}^{n} xi}$$

The relative randomness of litter occurrences can be measured by dividing abundance (A) by frequency (F) (Davis & Reich, 2003). A large R value indicates clustering (high density, low frequency) while a small value would indicate a uniform distribution (low density, high frequency).

$$R = \frac{A}{F}$$

The *ArcGISv9.1* Kernel Density tool was used to create a map of litter densities. The Kernel Density tool calculates the density of point features within a specified range of a point feature. Like the Getis-Ord analysis, the distance with the strongest spatial autocorrelation for each dataset was examined in this analysis.

Analysis and Results

Sample data was analyzed using *ArcGIS v9.1* and Statistical Packages for the Social Sciences *(SPSS v14)*. Visitor counter data was downloaded to *Microsoft Excel* and then into *SPSS v14* for data analysis.

A. Visitor Counter Results

Visitor monitor results were adjusted by 34% to account for visitors missed by trail counters (Bates, Wallace, & Vaske, 2006). Visitors may be missed by the counters by walking abreast or walking too close behind one another. Optimally, adjustment values would be determined by observation of each individual monitor. However, due to time constraints, this was not possible for this study. The adjustment value used was the average adjustment rate for a study by Bates, Wallace, and Vaske (2006) over a three year period which used the same visitor counters as this study. The result was then divided by two to account for visitors traveling both uphill and downhill. This final result is the estimate of the total number of visitors during the sampling period. Average daily visitation is reported in Figures 6-7.

Visitation was then broken down into weekend visitation and weekday visitation. These statistics were calculated for the total study duration and the individual months of August, September, and October (Tables 4-8). Mean visitation values are normalized by day and should be used to compare individual monitors. Each monitor may have a different amount of sampling days because of date of placement in the field or sampling days lost due to monitor memory filling up before data was downloaded.

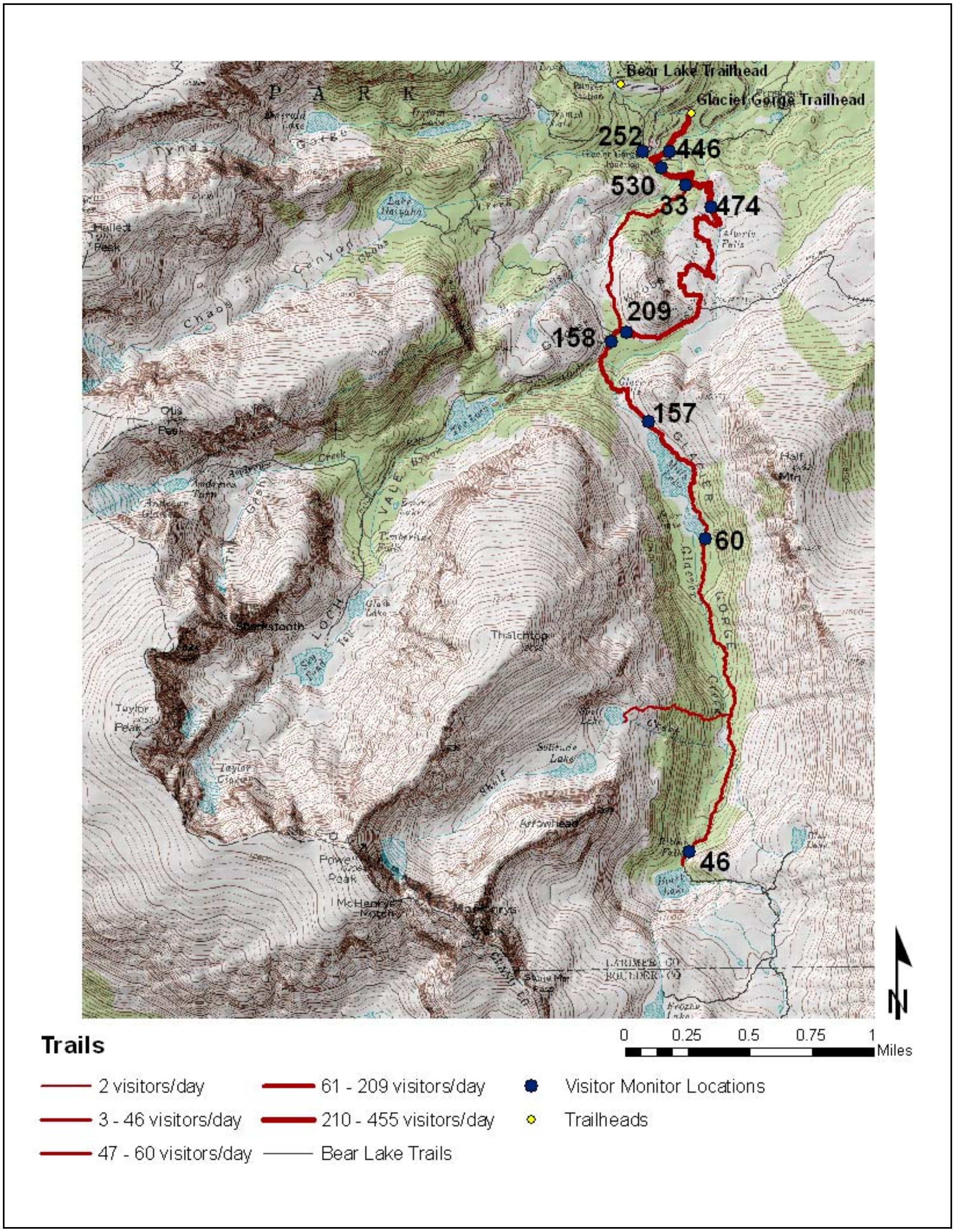

Figure 7. Mean daily visitations along Glacier Gorge trail

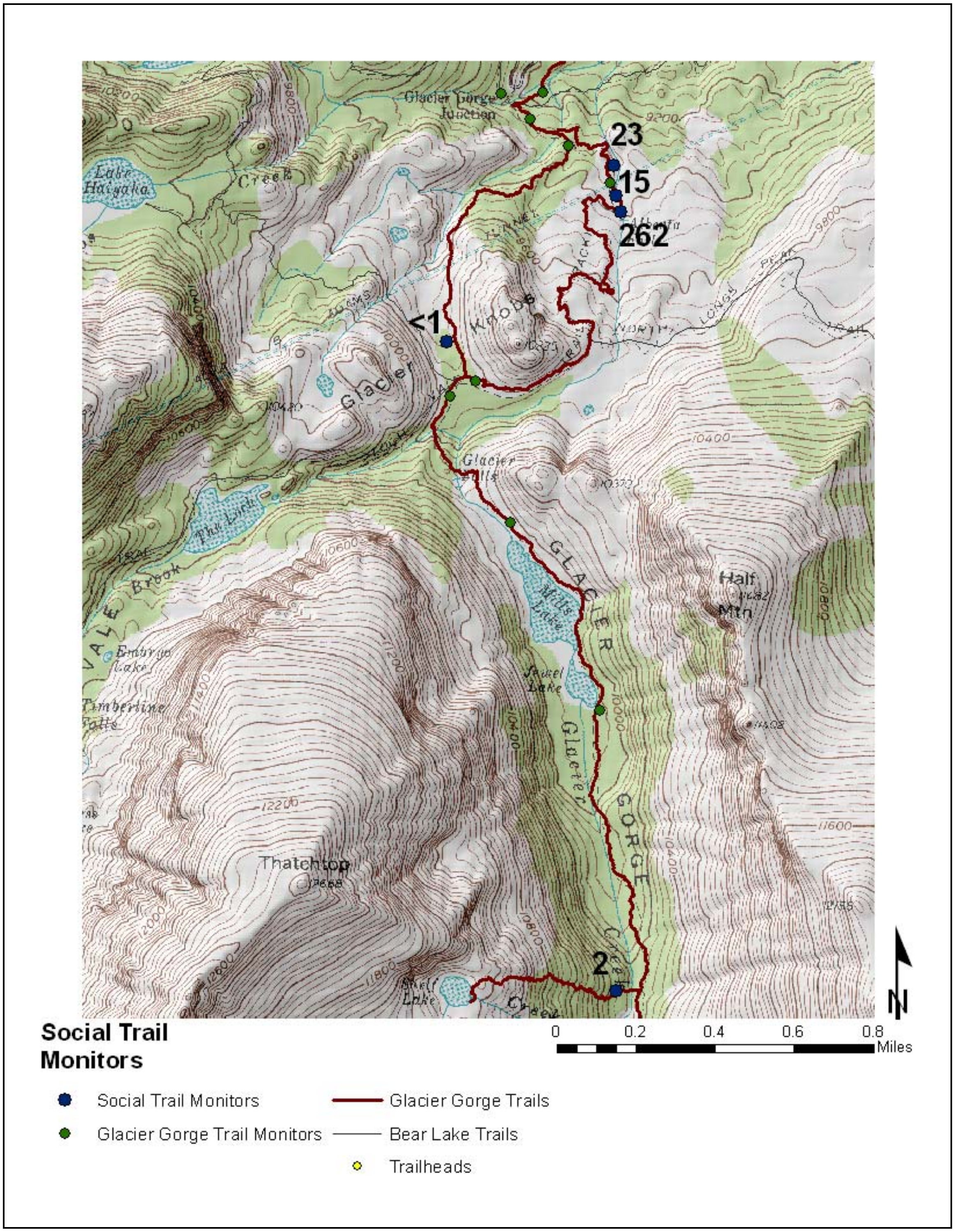

Figure 8. Mean daily visits for social trail monitors

Table 4. Locations of visitor monitors

Unit	Location
1	Fire trail
2	Social trail below fire trail
3	Lake Solitude trail
4	Social trail below Alberta Falls (1)
5	Social trail below Alberta Falls (2)
6	Social trail above Alberta Falls
7	Mills Lake/Loch Vale Junction
8	Mills Lake trail entrance
9	Mills Lake
10	Jewel Lake
11	Black Lake
12	Glacier Gorge Trailhead (located at bridge)
13	Glacier Gorge/Bear Lake trail junction (located in aspen grove)
14	Alberta Falls
15	Bear Lake trail junction

Table 5. Visitation rates for visitor monitors: entire study duration

Unit	Total	Mean Daily	Weekend Visitation	Mean Weekend	Weekday Visitation	Mean Weekday
1	2332	33	830	38	1502	31
2	63	<1	20	<1	43	<1
3	151	2	56	3	95	2
4	1550	23	667	32	883	19
5	965	15	345	16	621	14
6	1793	262	7770	370	1016	22
7	8342	209	3748	312	4594	164
8	10602	158	4282	204	6320	137
9	10549	157	4352	207	6197	135
10	4043	60	1843	88	2201	48
11	3045	46	1490	71	1556	35
12	26767	446	10571	587	16196	368
13	27562	530	12666	745	14896	426
14	27511	474	12591	700	14920	373
15	10817	252	5299	379	5518	190

Table 6. Visitation rates for visitor monitors: August, 2005

Unit	August Visitation (Total)	August Visitation (Mean)	August Weekend Visitation (Total)	August Weekend Visitation (Mean)	August Weekday Visitation (Total)	August Weekend Visitation (Mean)
1	1126	45	321	46	806	45
2	38	2	8	1	31	2
3	73	3	17	3	57	5
4	764	32	258	44	506	32
5	414	20	147	25	268	18
6	8171	371	2653	442	5518	345
7	n/a	n/a	n/a	n/a	n/a	n/a
8	4454	212	1353	225	3101	207
9	4439	211	1447	241	2992	200
10	1689	80	679	113	1010	67
11	1283	64	629	105	654	47
12	9573	598	1948	649	7624	587
13	10332	738	3579	894	6752	675
14	7098	591	2459	819	4639	515
15	n/a	n/a	n/a	n/a	n/a	n/a

Table 7. Visitation rates for visitor monitors: September, 2005

Unit	September Visitation (Total)	September Visitation (Mean)	September Weekday Visitation (Total)	September Weekend Visitation (Mean)	September Weekday Visitation (Total)	September Weekend Visitation (Mean)
1	903	30	356	39	547	26
2	20	<1	10	1	10	<1
3	69	2	36	4	34	2
4	578	19	281	32	296	14
5	456	15	124	14	332	16
6	6949	232	3572	397	3378	161
7	6073	253	2205	368	3868	215
8	4786	160	2073	230	2714	133
9	4767	159	2055	229	2712	98
10	1882	63	838	93	1044	49
11	1279	43	611	68	668	32
12	12456	445	6072	674	6384	336
13	11941	542	5720	817	6221	414
14	15525	518	7048	783	8478	404
15	8053	298	3382	423	4671	246

Table 8. Visitation rates for visitor monitors: October, 2005

Unit	October Visitation (Total)	October Visitation (Mean)	October Weekday Visitation (Total)	October Weekend Visitation (Mean)	October Weekday Visitation (Total)	October Weekend Visitation (Mean)
1	303	19	154	26	150	17
2	5	<1	3	<1	2	<1
3	9	<1	4	<1	6	<1
4	209	13	160	27	49	5
5	95	6	74	12	22	2
6	2807	175	1545	257	1262	126
7	2270	142	1543	258	726	73
8	1363	85	857	143	506	51
9	1344	84	850	142	494	50
10	473	30	327	55	147	15
11	484	30	249	42	235	24
12	4738	296	2551	426	2188	219
13	5289	331	3367	561	1922	192
14	4888	306	3085	514	1803	180
15	2763	173	1916	320	847	85

A surface of distance in meters and a surface of access time values along the Glacier Gorge trail were created in *ArcGIS v9.1*. Distance and access values for each visitor monitor were acquired by using *ArcGIS's* Extract Values to Points tool. Monitor point data was then imported into *SPSSv14* for analysis.

In general, mean daily visitation along the main Glacier Gorge trail decreases further from the trailhead (Figure 8). The one exception, monitor 15 (the Bear Lake trail junction), is not part of the Glacier Gorge trail route. This trail section accesses the Glacier Gorge trail from the Bear Lake parking lot and functions like a trailhead.

Regression analysis shows a strong relationship between mean daily visitation and distance from trailhead (Table 9).

Table 9. Regression results for mean daily visitation-distance from trailhead

R	R^2	Adjusted R	Standard Error
.835	.698	.655	106.49771

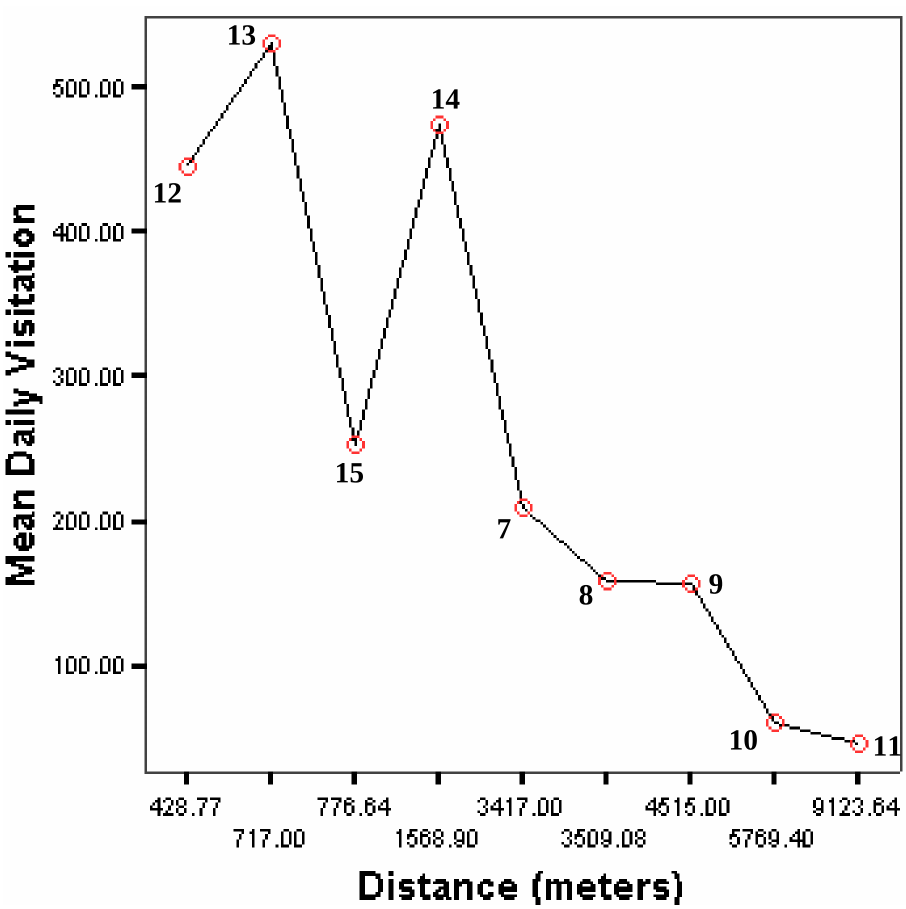

Figure 9. Graph of relationship between mean daily visitation and distance from trailhead. Number in graph represents trail monitor number.

Similarly, mean daily visitation decrease as access times increase (Figure 9). Again, monitor 15 is the one exception.

Regression analysis shows a strong relationship between mean daily visitation and access times from trailhead (Table 10).

Table 10. Regression results for mean daily visitation-access time (hours)

R	R^2	Adjusted R	Standard Error
.835	.698	.655	106.50061

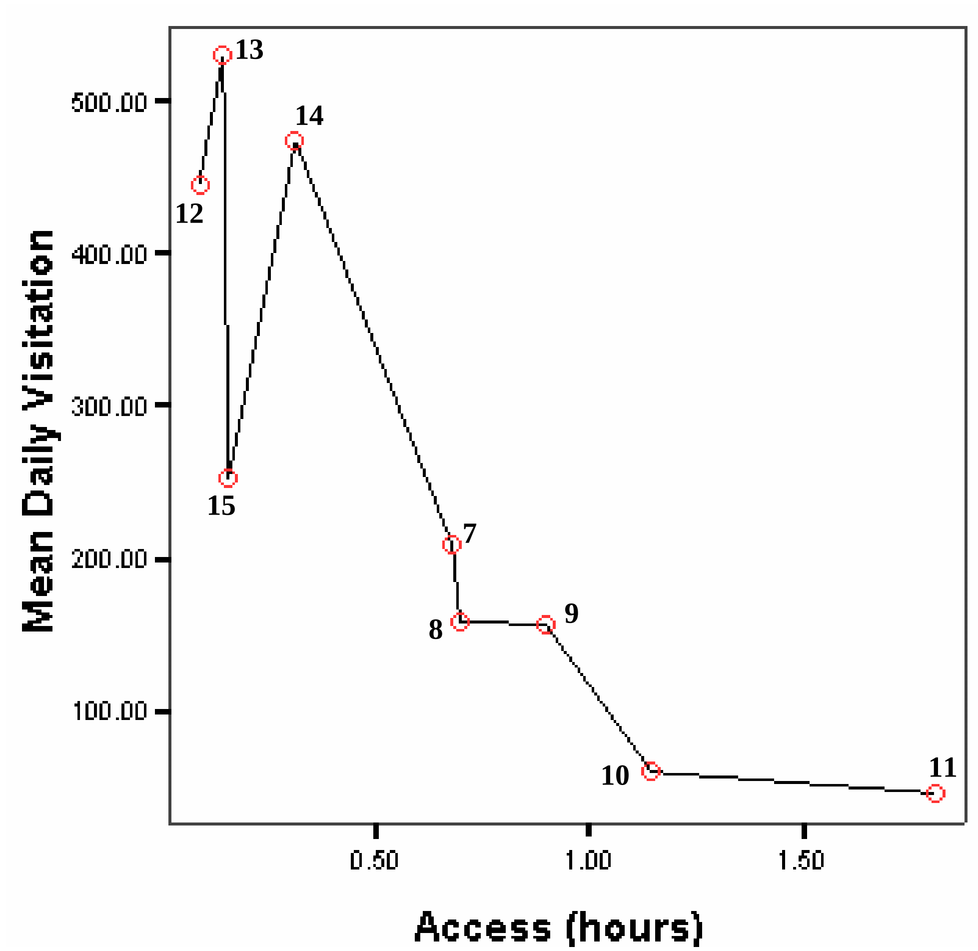

Figure 10. Graph of relationship between mean daily visitation and distance from trailhead. Number in graph represents trail monitor number.

The rate of decay along the Glacier Gorge trail was measured as:

$$\frac{\text{Mean daily visitation at monitor X}}{\text{Overall daily visitation to Glacier Gorge trail}}$$

The Glacier Gorge trail can be accessed from either the Glacier Gorge trailhead or the Bear Lake trailhead. Monitor 12 was placed near the Glacier Gorge trailhead but it became apparent that use along the Glacier Gorge trail was exceeding the visitation amounts collected at monitor 12. Monitor 15 was placed on the trail to Bear Lake early in September to estimate the amount of use on the Glacier Gorge trail originating at Bear Lake. Overall daily visitation to the Glacier Gorge trail was computed as the sum of mean daily visitation for monitors 12 and 15. Analysis of decay for the month of August used mean daily visitation at monitor 13 as the overall visitation value along the Glacier Gorge trail since monitor 15 had not been placed yet. Monitor 13 captured visitors who passed by monitors 12 and 15. Rate of decay is reported in Tables 11-14.

Table 11. Percentage of overall use along the Glacier Gorge trail

Location (Unit)	Mean Daily Visitation	Overall Daily Visitation	Percentage of Overall Visitation
Alberta Falls (12)	474	698	67.9%
Mills Lake/Loch Vale Jct (7)	209	698	29.9%
Mills Lake Trail (8)	158	698	22.6%
Mills Lake (9)	157	698	22.5%
Jewel Lake (10)	60	698	8.6%
Black Lake (11)	46	698	6.6%
Fire trail (1)	33	698	4.7%

Table 12. Percentage of overall use along the Glacier Gorge trail (August)

Location (Unit)	Mean Daily Visitation	Overall Daily Visitation	Percentage of Overall Visitation
Alberta Falls (12)	591	738	80.1%
Mills Lake/Loch Vale Jct (7)	n/a	n/a	n/a
Mills Lake Trail (8)	212	738	28.7%
Mills Lake (9)	211	738	28.6%
Jewel Lake (10)	80	738	10.8%
Black Lake (11)	64	738	8.7%
Fire trail (1)	45	738	6.1%

Table 13. Percentage of overall use along the Glacier Gorge trail (September)

Location (Unit)	Mean Daily Visitation	Overall Daily Visitation	Percentage of Overall Visitation
Alberta Falls (12)	518	743	69.7%
Mills Lake/Loch Vale Jct (7)	253	743	34.1%
Mills Lake Trail (8)	160	743	21.5%
Mills Lake (9)	159	743	21.4%
Jewel Lake (10)	63	743	8.5%
Black Lake (11)	43	743	5.8%
Fire trail (1)	30	743	4.0%

Table 14. Percentage of overall use along the Glacier Gorge trail (October)

Location (Unit)	Mean Daily Visitation	Overall Daily Visitation	Percentage of Overall Visitation
Alberta Falls (12)	306	469	65.2%
Mills Lake/Loch Vale Jct (7)	142	469	30.3%
Mills Lake Trail (8)	85	469	18.1%
Mills Lake (9)	84	469	17.9%
Jewel Lake (10)	30	469	6.4%
Black Lake (11)	30	469	6.4%
Fire trail (1)	19	469	4.1%

Visitation levels at each monitor were analyzed by hour to examine how daily visitation in the Glacier Gorge area flows. Visitation levels for each hour were computed at each monitor and divided by total visitation to that monitor. Table 15 reports the top five highest hours of visitation at each visitor monitor. Complete analysis of visitation by hour is reported in Table B16.

Table 15. Five highest visitation times (military time(% of total visitation))

Unit	1st	2nd	3rd	4th	5th	Total Percentage
1	14 (14.1%)	15 (10.4%)	8 (9.8%)	13 (9.1%)	16 (8.8%)	52.2%
2	14 (21.3%)	9 (18.1%)	6 (10.6%)	10 (11.1%)	16 (9.6%)	69.2%
3	14 (20.4%)	12 (14.7%)	13 (12.4%)	10 (11.1%)	9 (10.2%)	68.8%
4	12 (14.6%)	11 (13.1%)	13 (11.6%)	15 (11.1%)	14 (10.3%)	71.4%
5	12 (19.7%)	10 (14.0%)	10 (13.7%)	13 (10.6%)	16 (10.6%)	68.6%
6	12 (17.1%)	11 (14.8%)	13 (14.3%)	14 (12.4%)	15 (10.9%)	69.4%
7	13 (15.2%)	14 (14.1%)	12 (12.0%)	15 (12.4%)	11 (10.2%)	67.9%
8	13 (16.5%)	12 (15.8%)	11 (13.5%)	14 (12.8%)	15 (11.0%)	69.6%
9	13 (16.8%)	12 (16.8%)	14 (13.6%)	11 (13.2 %)	15 (11.0%)	71.3%
10	14 (13.9%)	13 (13.0%)	12 (12.7%)	11 (12.3%)	10 (11.9%)	63.8%
11	13 (20.8%)	12 (16.7%)	11 (13.6%)	14 (12.4%)	15 (10.0%)	73.5%
12	15 (12.0%)	14 (12.0%)	13 (11.4%)	16 (10.6%)	12 (10.0%)	56.0%
13	14 (12.8%)	13 (12.6%)	15 (11.9%)	12 (11.7%)	11 (10.4%)	59.4%
14	14 (13.7%)	13 (13.1%)	12 (13.1%)	15 (12.4%)	11 (11.8%)	64.1%
15	13 (14.7%)	14 (14.6%)	15 (12.7%)	12 (12.3%)	11 (11.5%)	65.8%

B. Social Trails

Percentage of vegetation loss caused by social trails was computed and compared between datasets (Table 16). The area of each dataset was computed in *ArcGIS v9.1* by creating a polygon of each dataset based on its individual parameters. The area of each polygon was then calculated in *ArcGIS v9.1*

Table 16. Percent of vegetation loss caused by social trails

Dataset	Percent Vegetation Loss	Area of dataset (acres)	Vegetation Loss (acres)
150 meter buffer off-trail	2.2%	582.55	12.816
Off trail	.24%	3433.83	8.241
Spatially balanced on-trail	4.6%	28.66	1.310
100 meter on-trail	3.4%	22.81	.775

Vegetation loss caused by social trails is not widespread throughout the Glacier Gorge drainage but is concentrated near the main trail. Percent of vegetation loss increased in areas close to the Glacier Gorge trail.

Spatially Balanced 150 Meter Buffer Off-Trail Dataset

Twenty four of 100 sample points contained social trails (Figure 10). The mean width of all social trails found was 2.08 feet and the mean depth of all social trails found was 1.50 inches. Widths and depths of social trails are displayed in Table 17 and 18, respectively.

Spatial autocorrelation was found to be strongest at 200 m for the spatially balanced 150 meter buffer off-trail dataset and was applied to the G-Ord analysis (Figure 11). Twelve nearest points were identified for the IDW of vegetation loss (Figure 12).

Table 17. Widths of social trails by vegetation loss along Glacier Gorge trail

Vegetation Loss Within Quadrat	Number of Occurrences	Mean Width (Weighted)	Minimum Width	Maximum Width
0-10%	5	1.94	1.50	2.30
10-20%	7	1.94	1.60	2.40
20-30%	8	2.18	1.50	3.33
30-40%	3	2.55	2.16	3.00
>40%	1	3.00	3.00	3.00

Table 18. Depths of social trails along by vegetation loss Glacier Gorge trail

Vegetation Loss Within Quadrat	Number of Occurrences	Mean Depths (Weighted)	Minimum Depths	Maximum Depths
0-10%	5	1.59	0	3.80
10-20%	7	.94	0	5.30
20-30%	8	1.58	0	14.40
30-40%	3	2.00	0	0.67
>40%	1	1.78	1.78	1.78

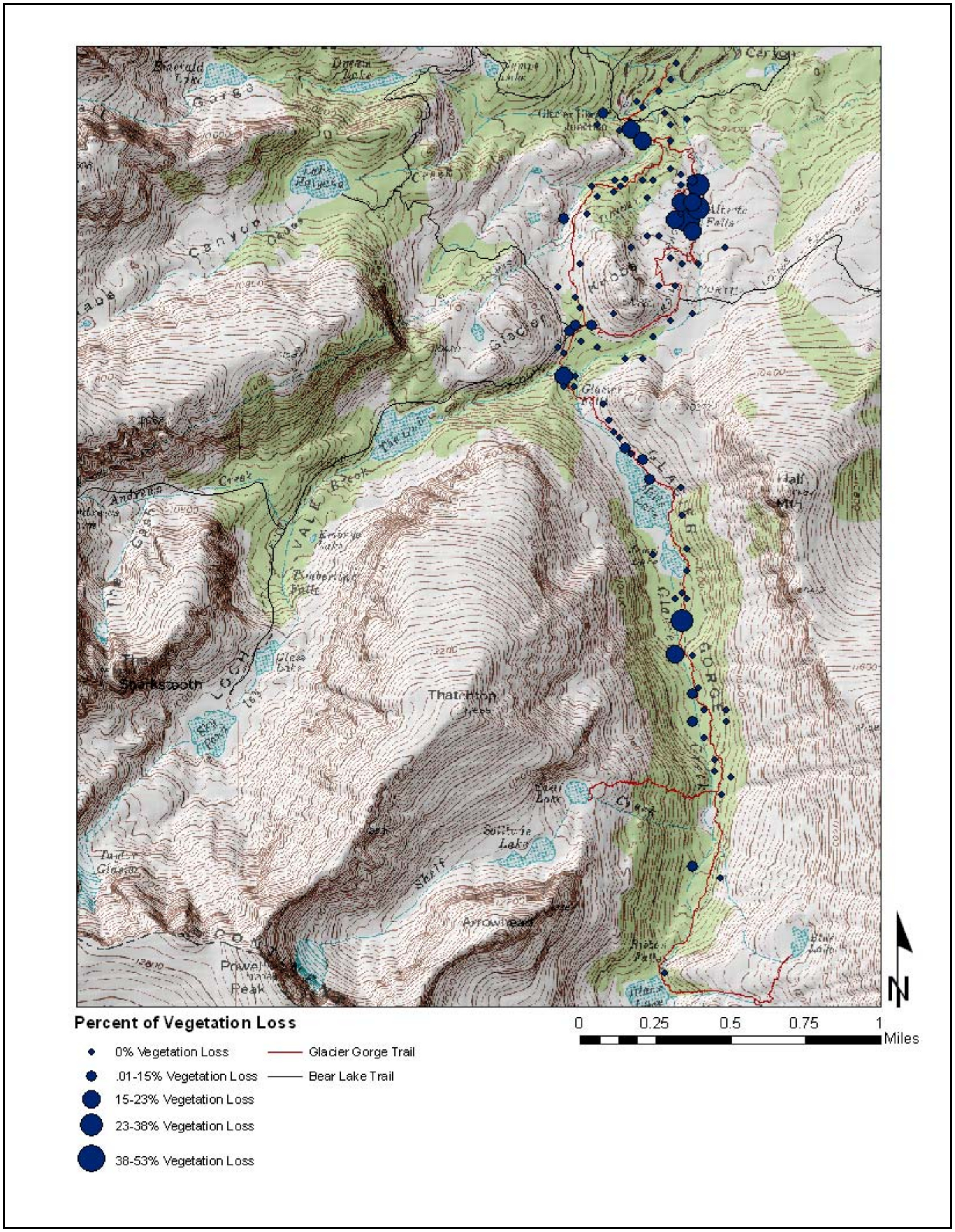

Figure 10. Percentage of vegetation loss caused by social trails (spatially balanced 150 meter off-trail buffer dataset)

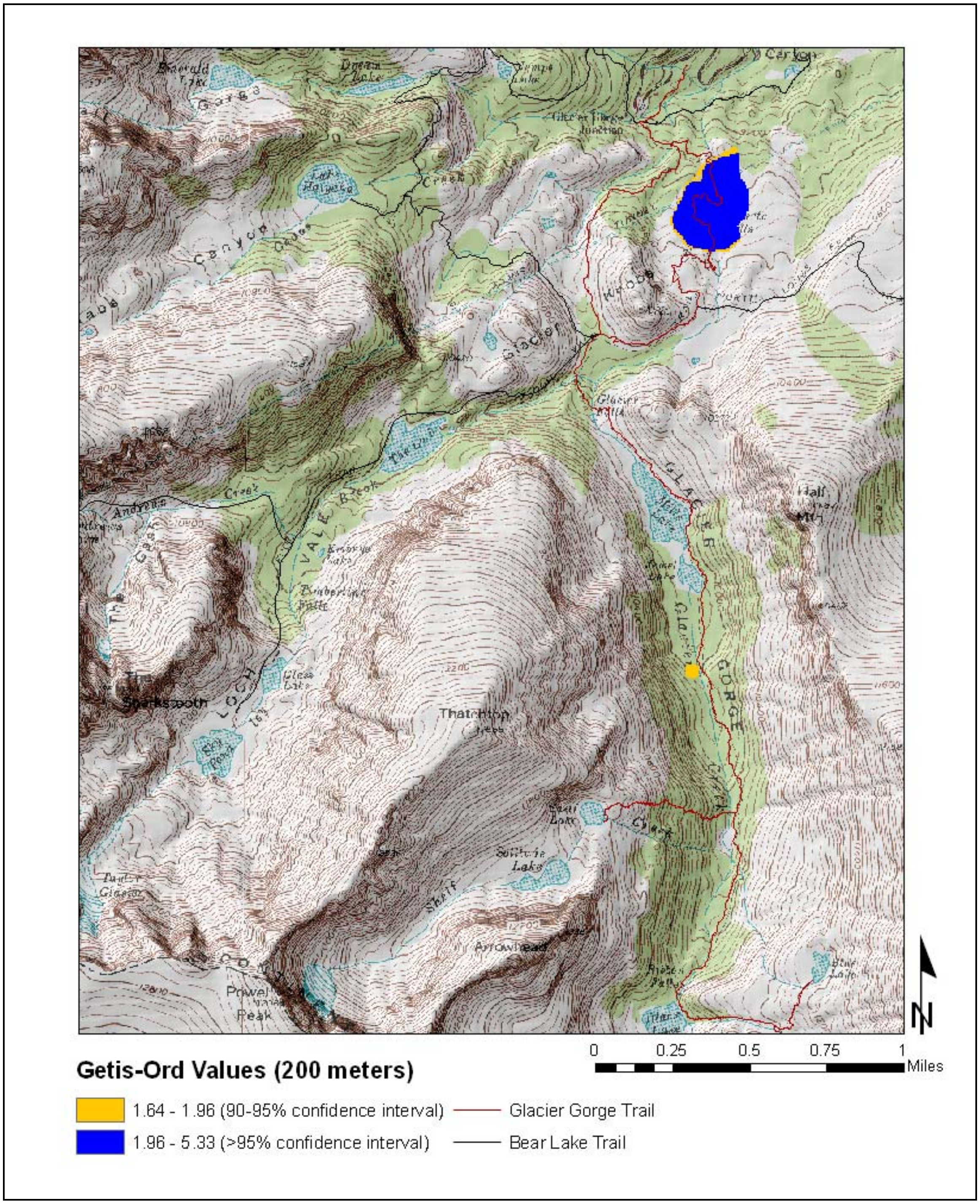

Figure 11. Getis-Ord Values for vegetation loss caused by social trails (spatially balanced 150 meter off-trail buffer dataset)

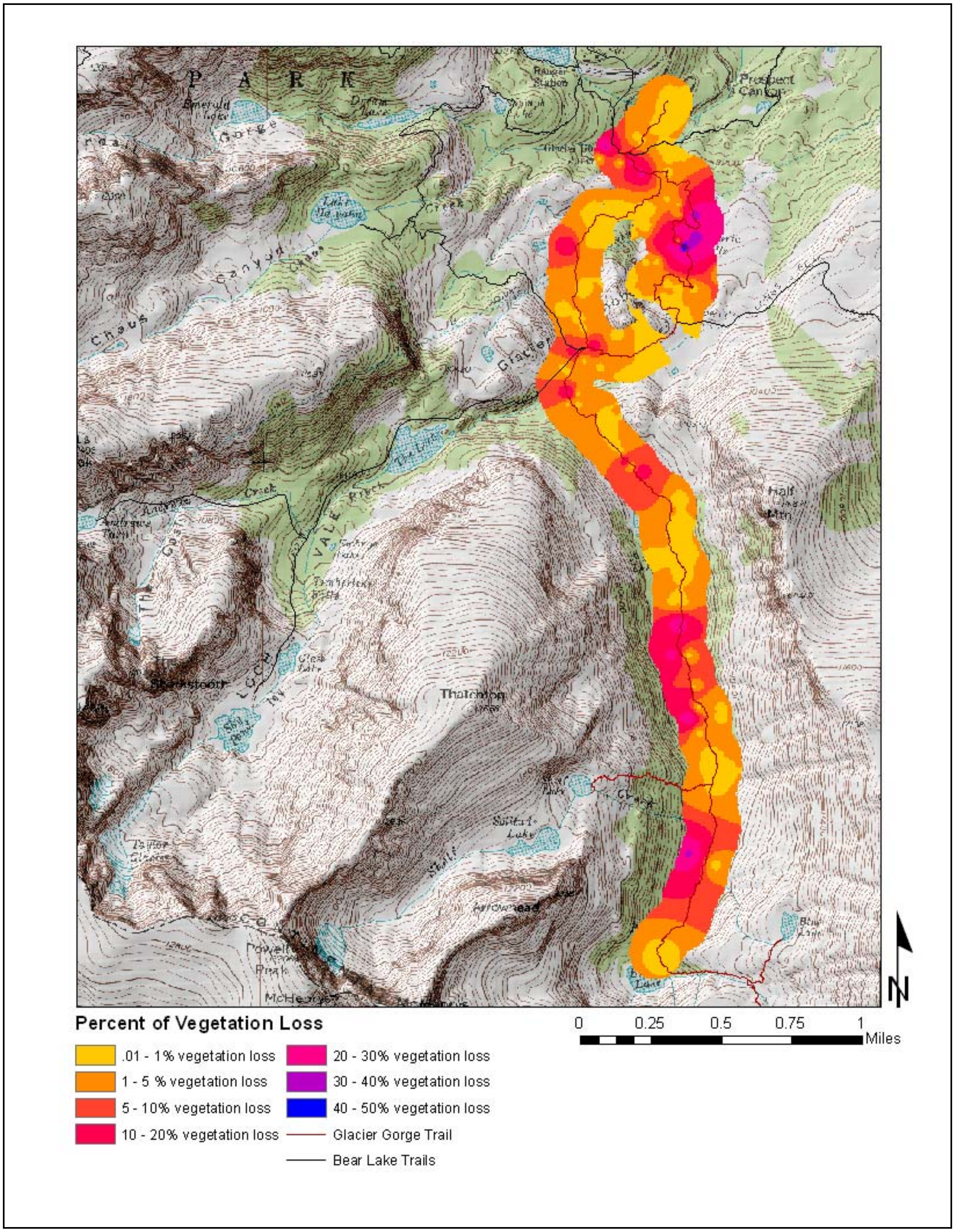

Figure 12 Vegetation loss density caused by social trails (spatially balanced 150 meter buffer off-trail dataset)

Spatially Balanced On-Trail Dataset

Thirty-six of 99 sample points contained social trails (Figure 13). Tables 19-20 summarize the quantities of social trails found. The mean width of all social trails was 2.31 feet and the mean depth of all social trails was 2.05 inches.

Table 19. Widths of social trails by vegetation loss along Glacier Gorge trail

Vegetation Loss Within Quadrat	Number of Occurrences	Mean Width (Weighted)	Minimum Width	Maximum Width
0-10%	18	1.95	1.00	4.00
10-20%	12	2.49	1.00	5.67
20-30%	6	3.05	1.92	4.33

Table 20. Depths of social trails by vegetation along Glacier Gorge trail

Vegetation Loss Within Quadrat	Number of Occurrences	Mean Depth (Weighted)	Minimum Depth	Maximum Depth
0-10%	18	3.09	0.00	8.00
10-20%	12	2.54	0.00	14.00
20-30%	6	4.18	1.67	7.17

Braided trail sections were found in thirteen quadrats. The mean width of a braided trail was 1.89 feet and the mean depth of a braided trail was 2.02 inches.

Spatial autocorrelation was found to be strongest at 500 m for the spatially balanced on-trail dataset and was applied in the G-Ord analysis (Figure 14). Twelve nearest points were identified for the IDW of vegetation loss (Figure 15).

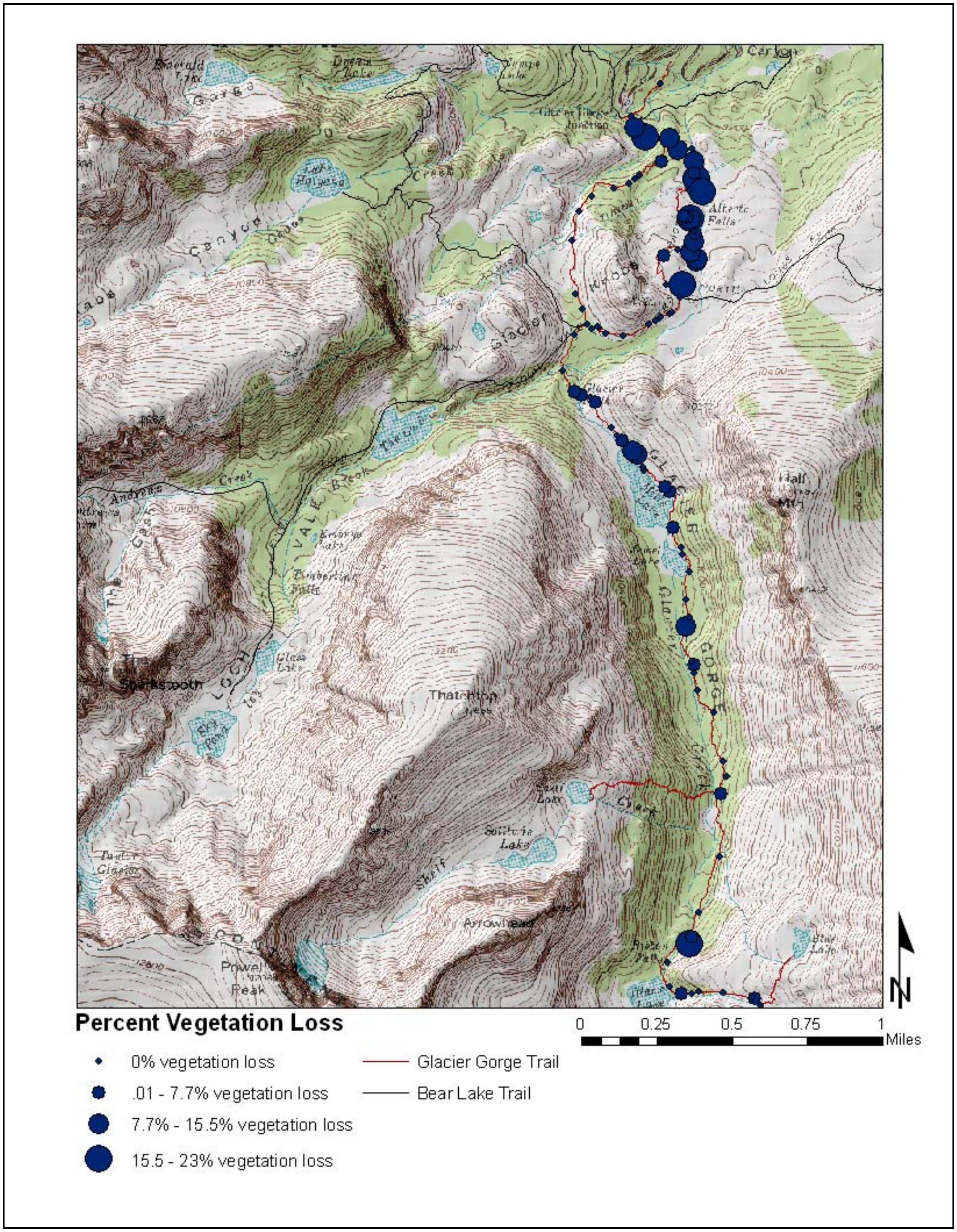

Figure 13. Percent of vegetation loss caused by social trail (spatially balanced on-trail dataset)

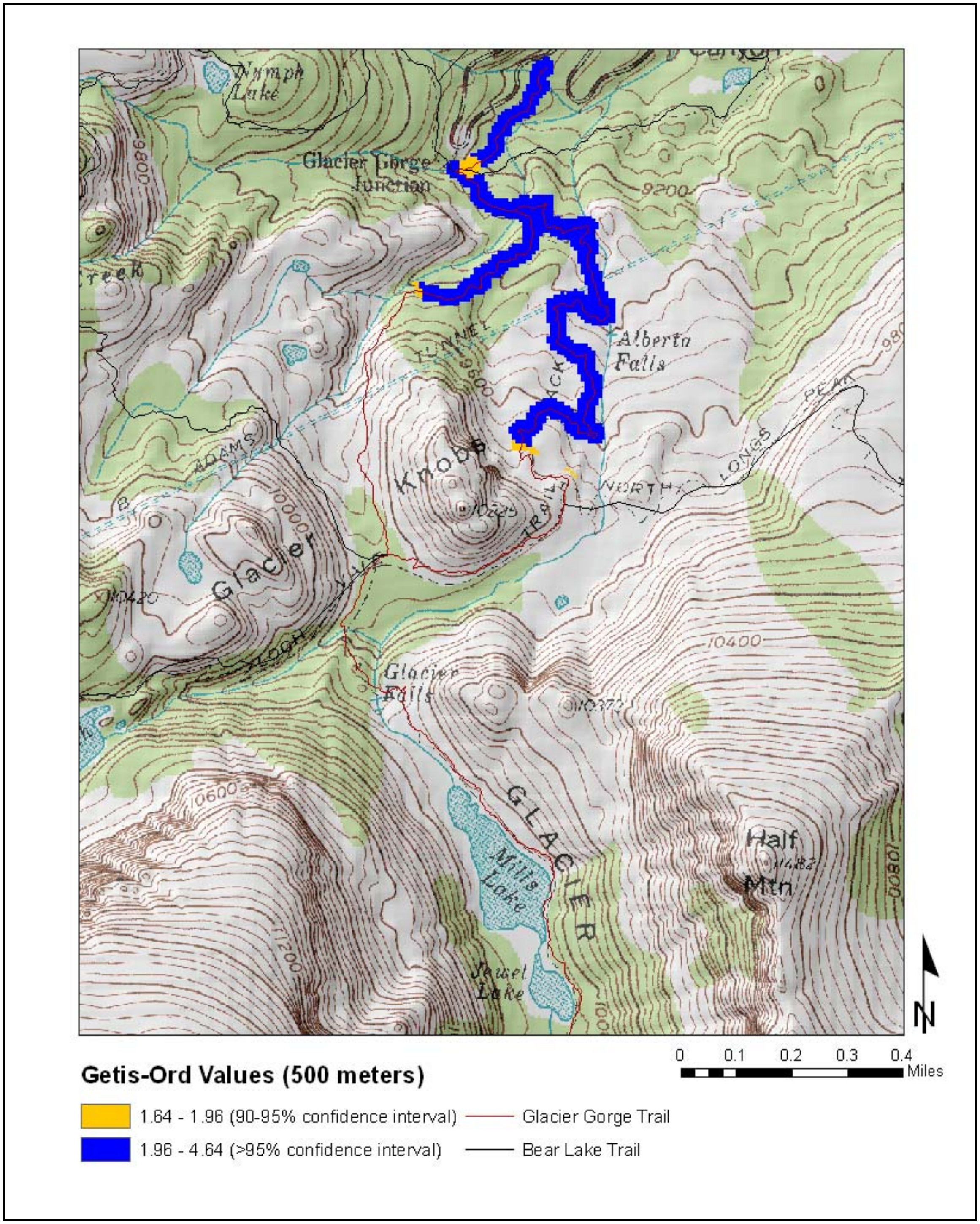

Figure 14. Getis-Ord values for vegetation loss caused by social trails (spatially balanced on-trail dataset)

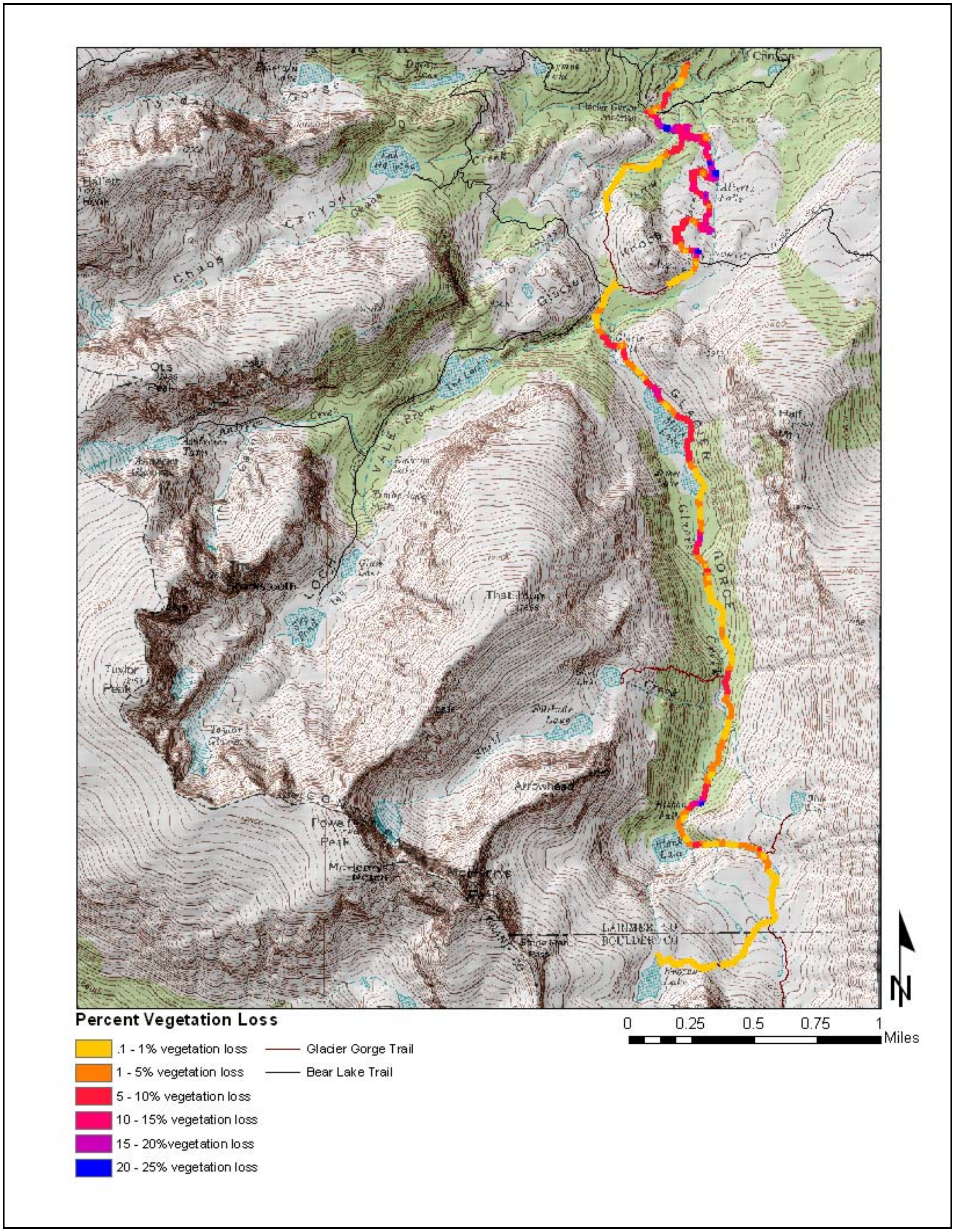

Figure 15. Vegetation loss density caused by social trails (spatially balanced on-trail dataset)

100 Meter Interval On-Trail Dataset

Twenty-six of 93 sample points contained social trails (Figure 16). The mean width of all social trails was 2.86 feet and the mean depth of all social trails was 1.92 inches. Widths and depths of social trails are displayed in Table 21 and 22, respectively.

Table 21. Widths of social trails by vegetation loss along Glacier Gorge trail (100 Meter Interval Dataset)

Vegetation Loss Within Quadrat	Number of Occurrences	Mean Width (Weighted)	Minimum Width	Maximum Width
0-10%	16	2.56	1.00	6.00
10-15%	5	1.62	1.00	2.33
15-20%	5	3.43	1.67	6.33

Table 22. D*epths of social trails by vegetation loss along Glacier Gorge trail (100 Meter Interval Dataset)*

Vegetation Loss Within Quadrat	Number of Occurrences	Mean Depth (Weighted)	Minimum Depth	Maximum Depth
0-10%	16	1.75	0.00	5.33
10-15%	5	2.47	0.00	7.00
15-20%	5	1.29	0.00	2.58

Braided trail sections were documented in eight quadrats. The mean width of a braided trail was 2.31 feet and the mean depth of a braided trail was 1.375 inches.

Spatial autocorrelation was found to be strongest at 250 meters for the 100 meter on-trail dataset and applied to the G-Ord analysis (Figure 17). Twelve nearest points were identified for the IDW of vegetation loss (Figure 15).

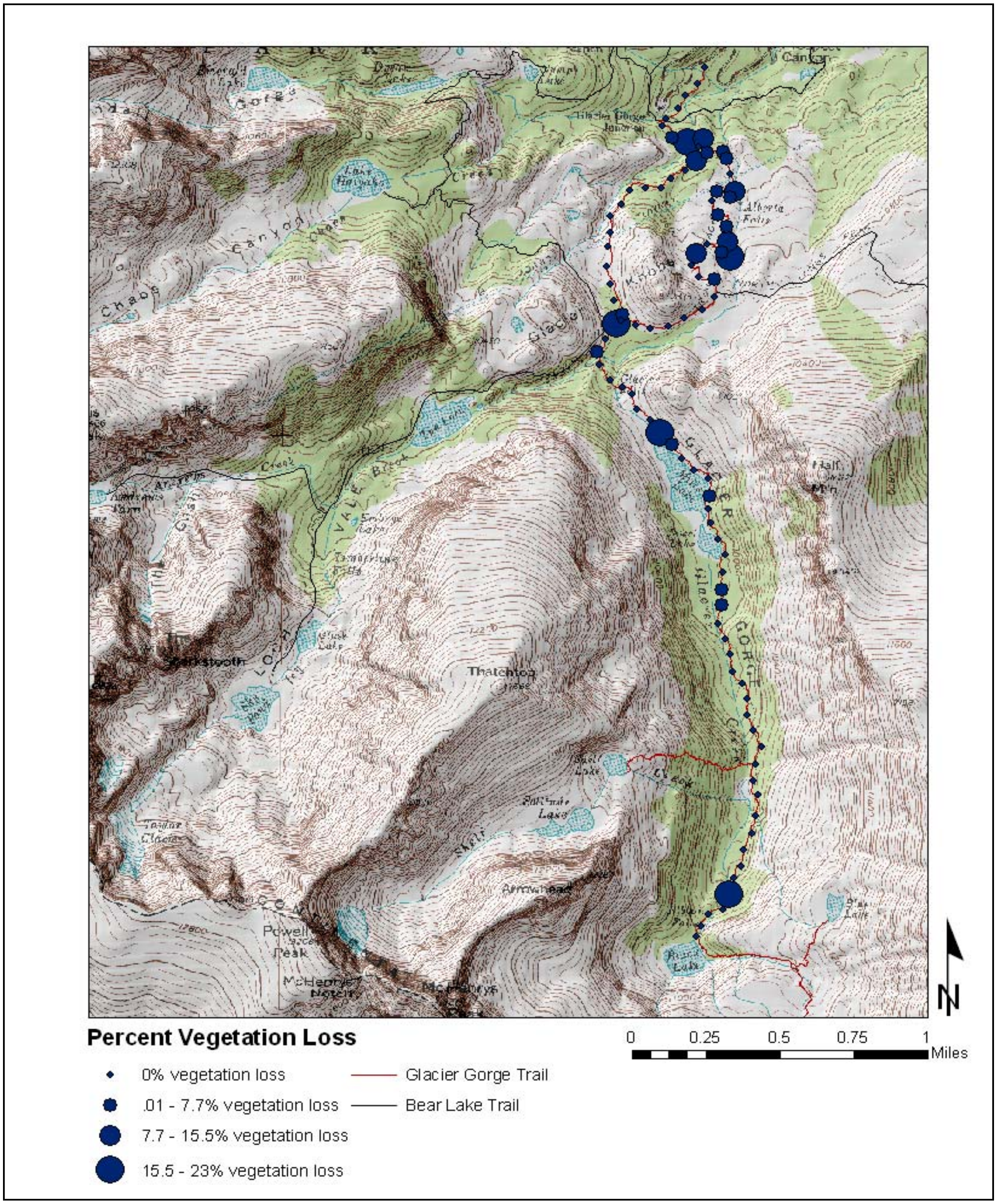

Figure 16. Percent of vegetation loss caused by social trails (100 meter interval on-trail dataset)

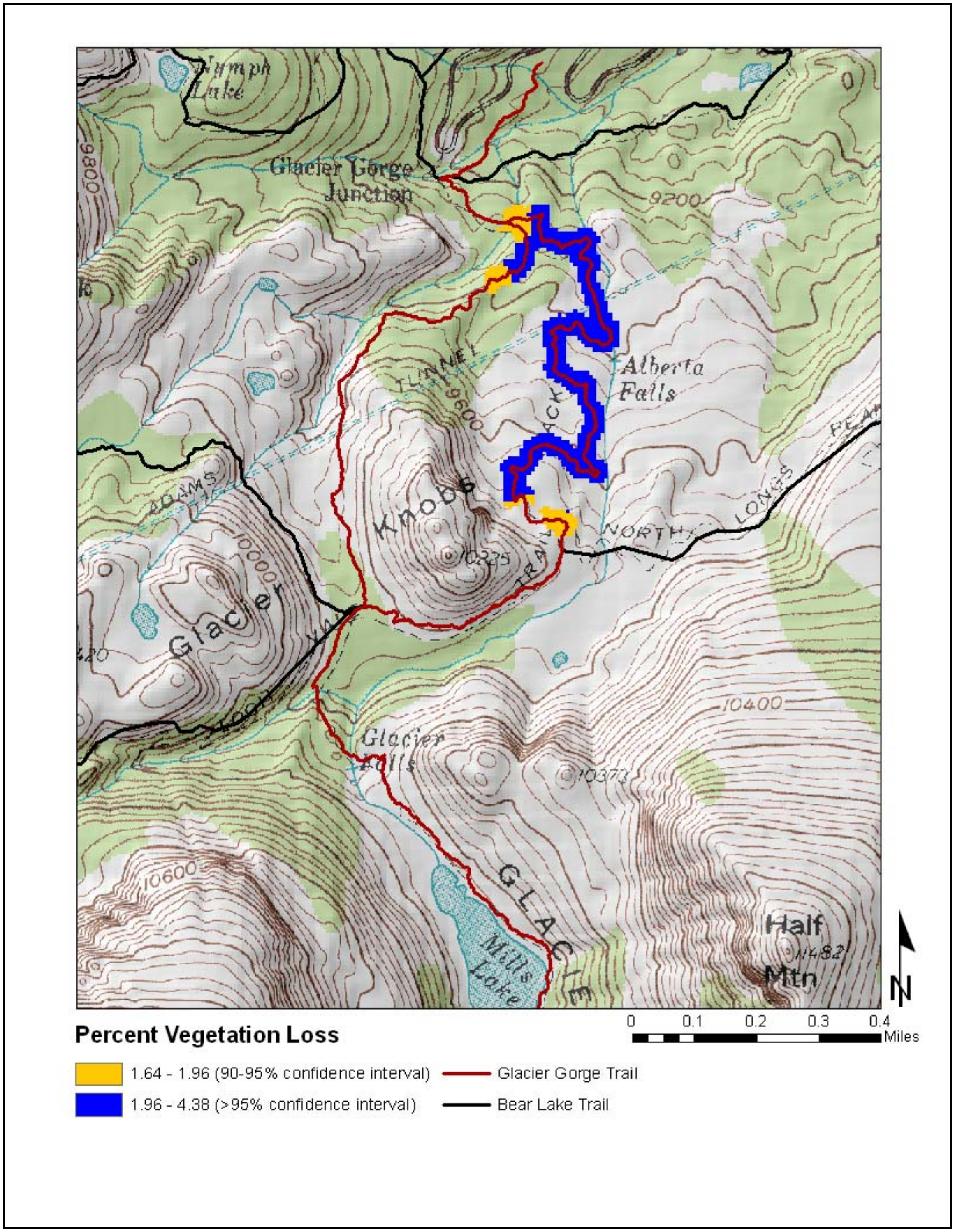

Figure 17. Getis-Ord values for vegetation loss caused by social trails (100 meter interval on-trail dataset)

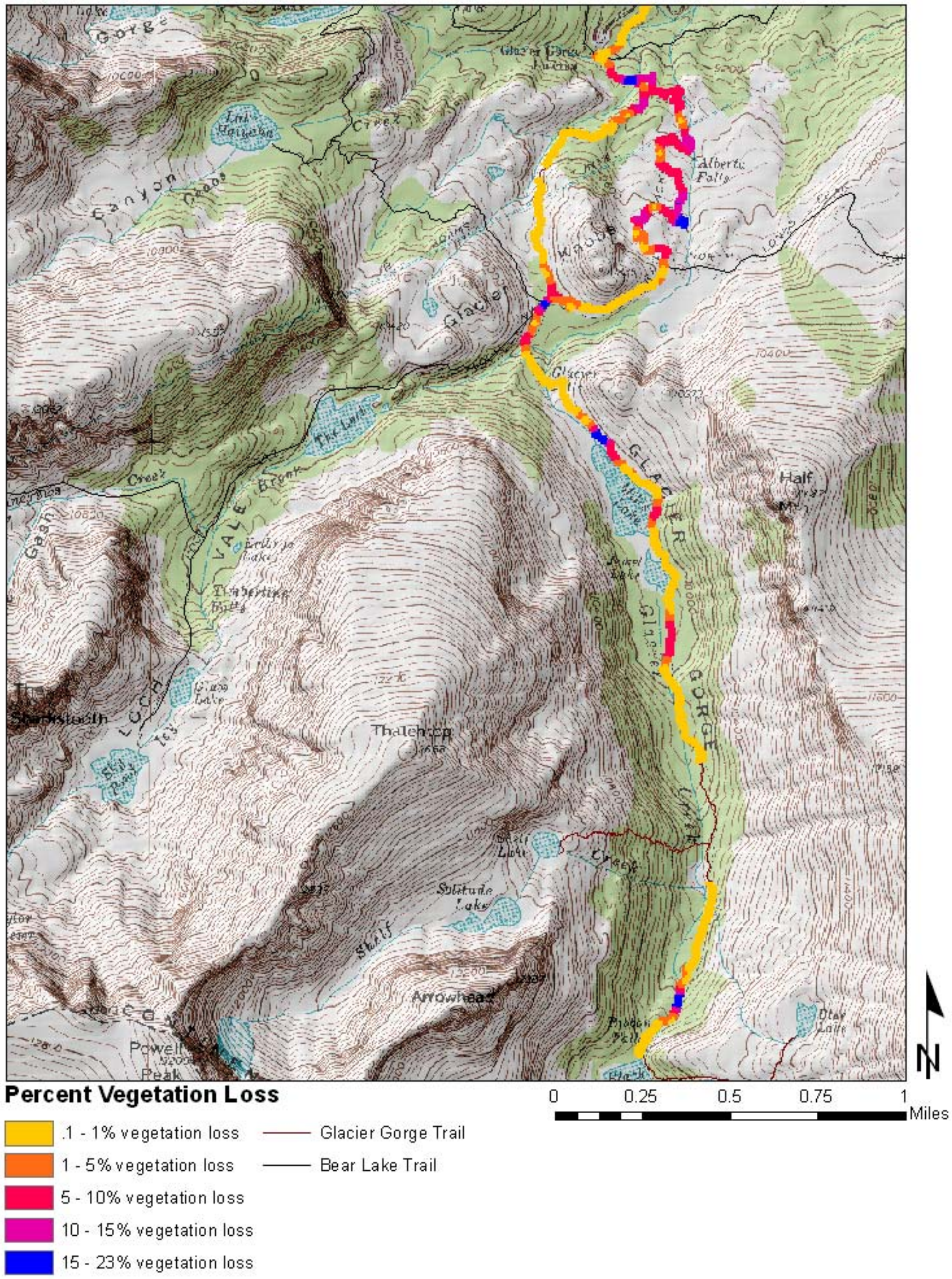

Figure 18. Vegetation loss density caused by social trails (100 meter interval on-trail dataset)

Spatially Balanced Off-Trail Dataset

Three of 75 sample points contained social trails (Figure 19). Only one social trail occurred in any quadrat. The mean width of all social trails was 1.57 feet and the mean depth of all social trails was 0.95 inches. Widths and depths of social trails are reported in Tables 23-24.

Table 23. Widths of social trails by vegetation loss along Glacier Gorge trail (Spatially balanced off-trail Dataset)

Vegetation Loss Within Quadrat	Number of Occurrences	Mean Width (Weighted)	Minimum Width	Maximum Width
0-10%	3	1.56	1.00	1.83

Table 24. Depths of social trails by vegetation loss along Glacier Gorge trail (Spatially balanced off-trail Dataset)

Vegetation Loss Within Quadrat	Number of Occurrences	Mean Width (Weighted)	Minimum Width	Maximum Width
0-10%	3	0.95	0.00	1.33

Spatial autocorrelation was found to be strongest at 350 m for the spatially balanced off-trail dataset and was applied to the G-Ord analysis (Figure 20). Twelve nearest points were identified for the IDW of vegetation loss (Figure 21).

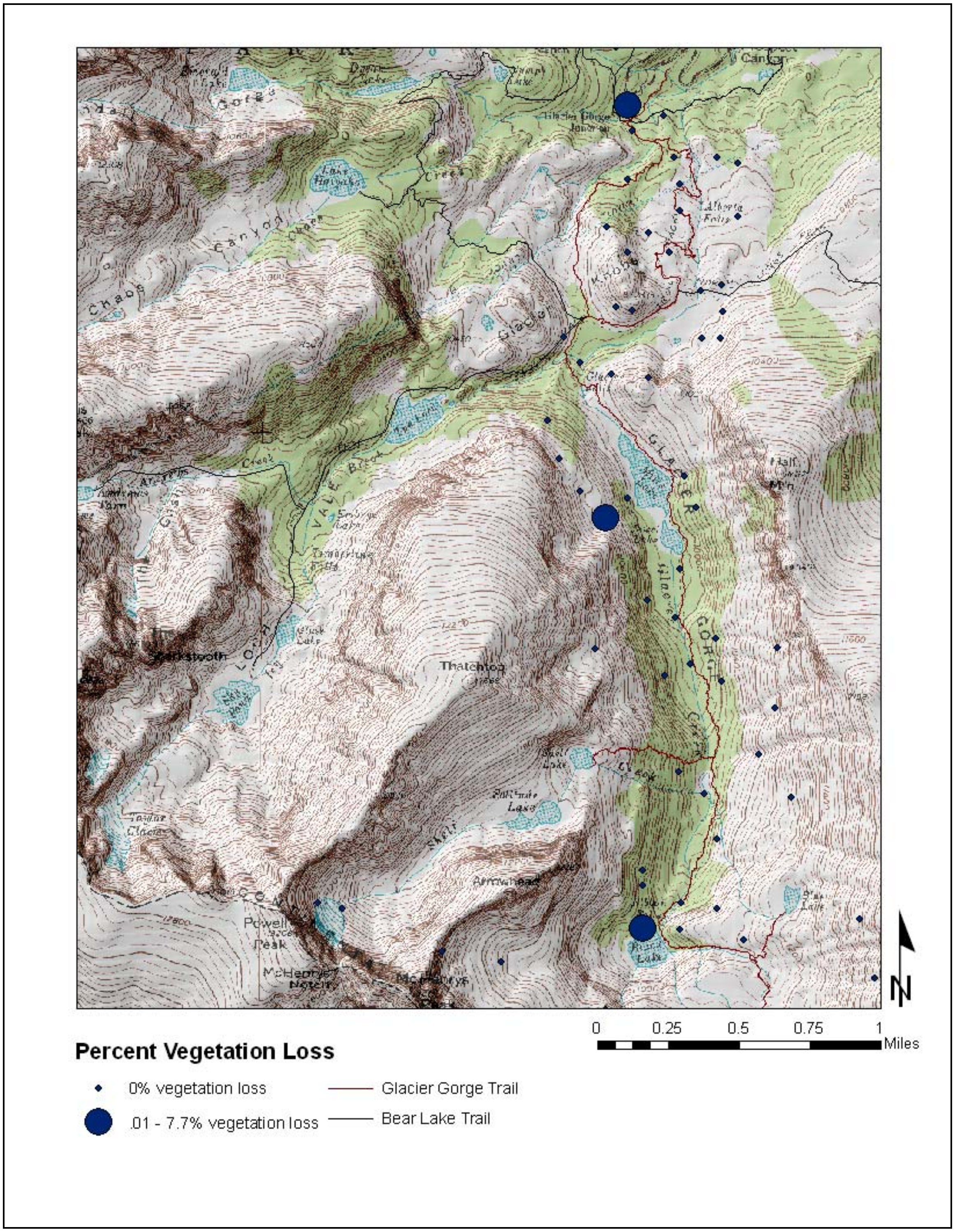

Figure 19. Percent of vegetation loss caused by social trails (off-trail dataset)

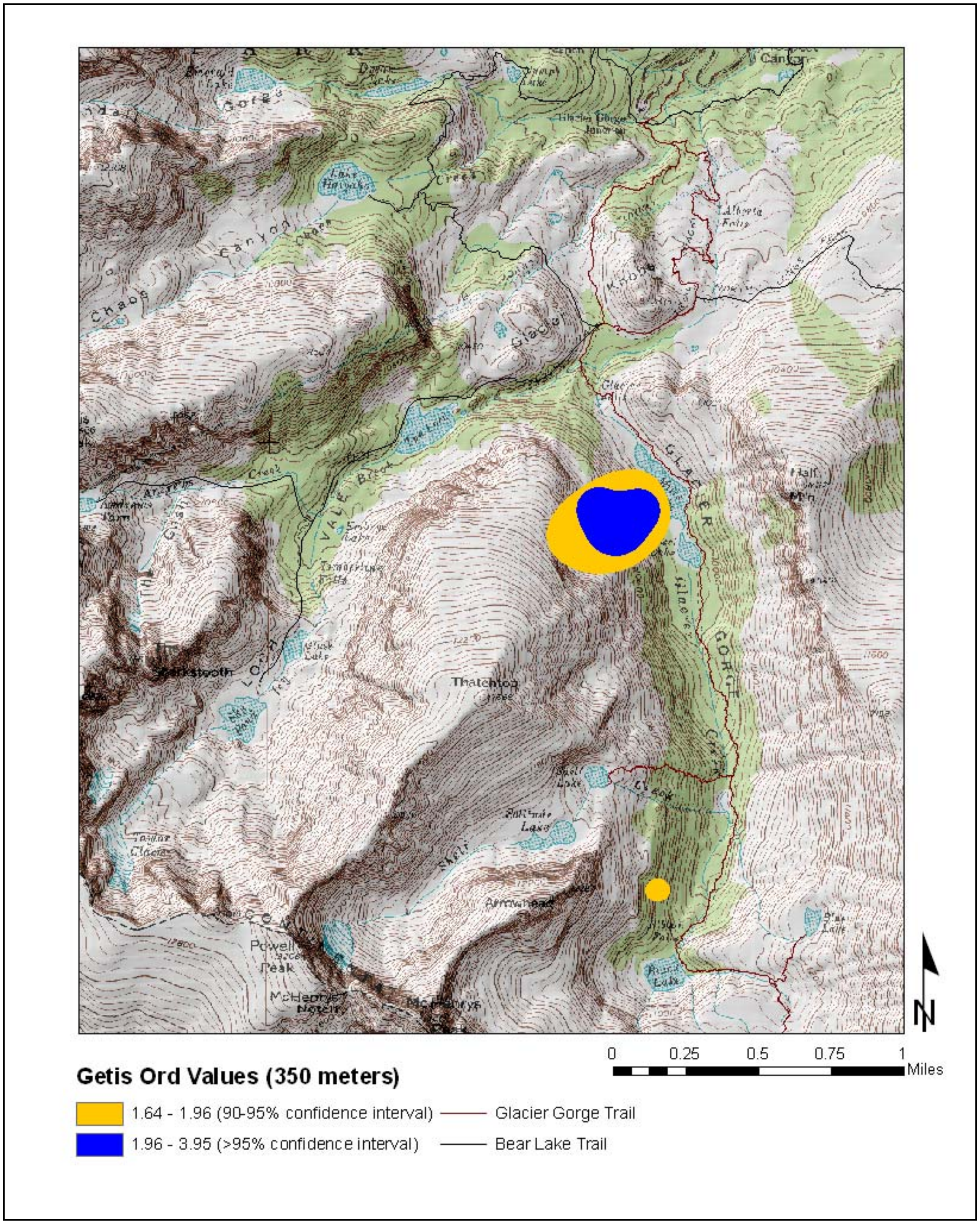

Figure 20. Getis-Ord values for social trails (off-trail dataset)

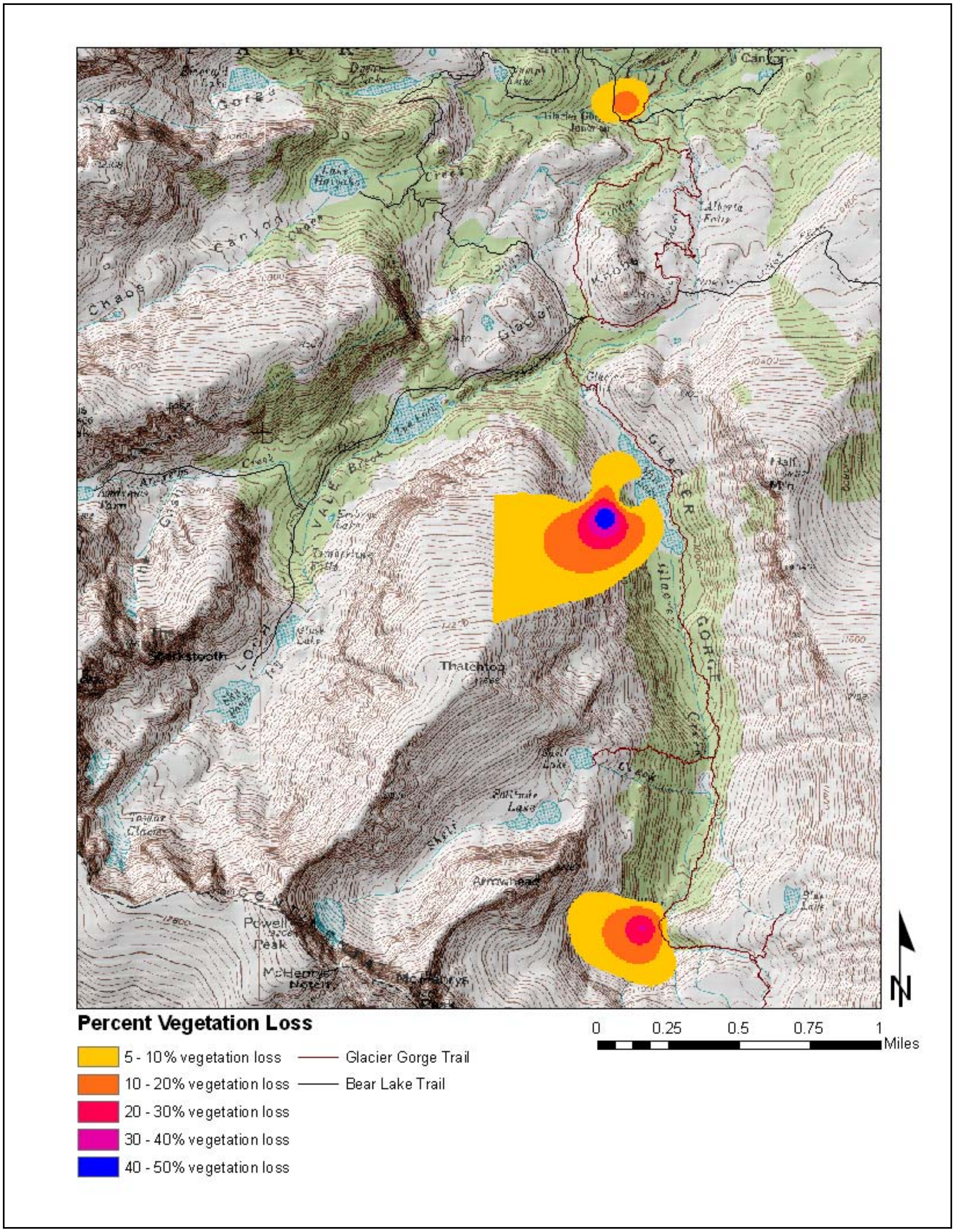

Figure 21. Social trail density (off-trail dataset)

C. Litter

The spatial distribution of litter was examined using basic spatial analysis measures and various *ArcGISv9.1* tools. Density, frequency, abundance, and overall randomness were computed for litter occurrences (Tables 25-26). The area of each polygon was then calculated in *ArcGISv9.1*

Table 25. Litter occurrences for each dataset

Dataset	Litter Occurrences/ acre	Area of Dataset (acres)	Litter Occurrences
150 meter buffer off-trail	7.93	582.55	4620
Off-trail	1.21	3433.83	4154
Spatially balanced on-trail	6.07	28.66	174
100 meter on-trail	6.48	22.81	148

Table 26. Spatial distribution measures for litter occurrences

Dataset	Litter Occurrences/ acre	Frequency	Abundance	Randomness	Spatial Pattern
150 meter buffer off-trail	7.93	0.119	1.30	10.92	Clustered
Off-trail	1.21	0.026	1.00	38.46	Clustered
Spatially balanced on-trail	6.07	0.121	1.00	8.26	Clustered
100 meter on-trail	6.48	0.130	1.00	7.69	Clustered

These results show that litter is not widespread throughout the Glacier Gorge drainage but is concentrated near the main Glacier Gorge trail. Litter also occurs more frequently along the Glacier Gorge trail than in off-trail areas. While litter occurs less frequently in off-trail areas it occurs in more abundance.

150 Meter Off-Trail Buffer Dataset

Twenty-two of 100 sample points contained litter (Figure 22). The types of litter found are listed in Table 27.

Spatial autocorrelation was found to be greatest at a distance of 200 m and was applied to the G-Ord (Figure 23) and Kernel Density analysis (Figure 24).

Table 27. Types and Occurrences of Litter along Glacier Gorge Trail

Type of Litter	Sample Point Occurrences	Occurrences of Litter
13 Old Tin Cans / 1 Beer Can	1	14
Bottle Cap	1	1
Candy Wrapper	2	1
Candy Wrapper / Knobs	1	2
Flagging	1	1
Jar / Wrapper	1	2
Old Tin Can	1	1
Orange / Food Wrapper	1	2
Plastic Bag	1	1
Toilet Paper	4	1
Toilet Paper/Diaper Wrapper / Bottle Lid	1	3
TP/ Tampon	1	2
TP/ Underwear	1	2
Tent Stakes	1	1
Ziploc Bag	2	1
Swim Suit	1	1
Cigarette Butt	1	1
Total	22	

Litter occurrence values from Table 27 were applied in the Getis-Ord analysis. However, the value of the sample point with 13 old tin cans and 1 beer can was reduced because the old tin cans appeared to be a historic can dump. An occurrence value of one was given to the sample point to reflect the one beer can found.

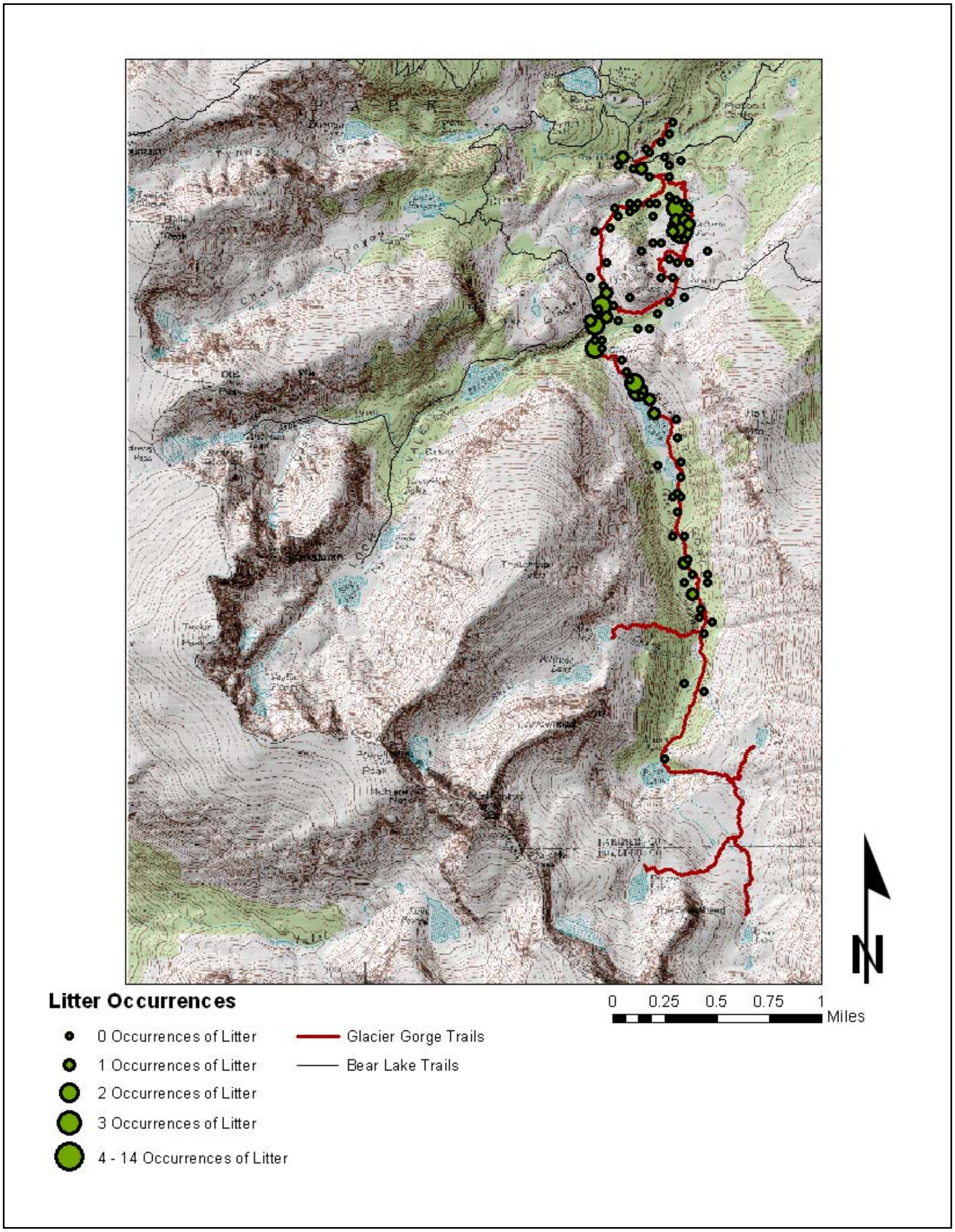

Figure 22. Occurrences of litter (150 meter off-trail buffer dataset)

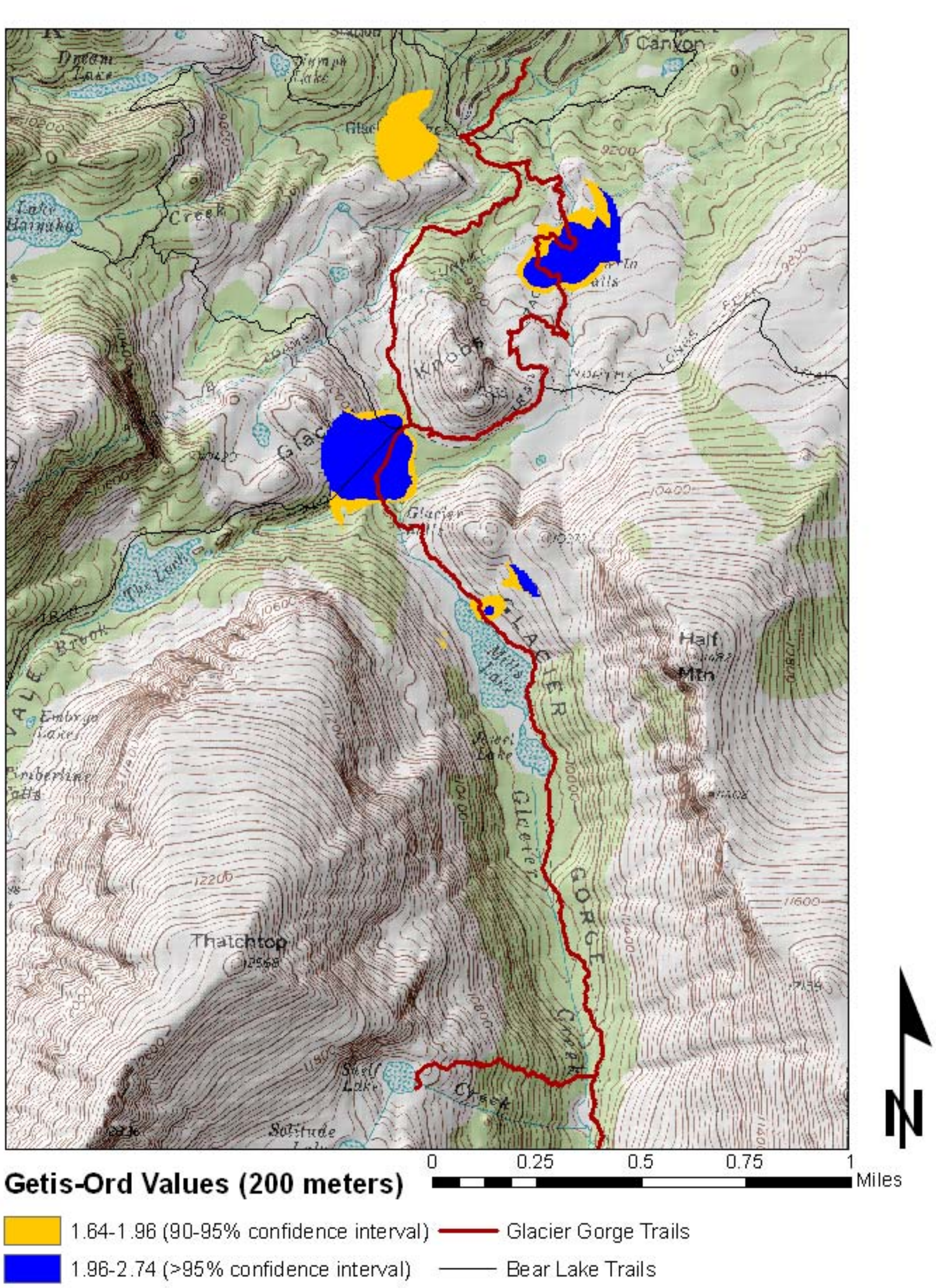

Figure 23. Getis-Ord values for litter (150 meter off-trail buffer dataset)

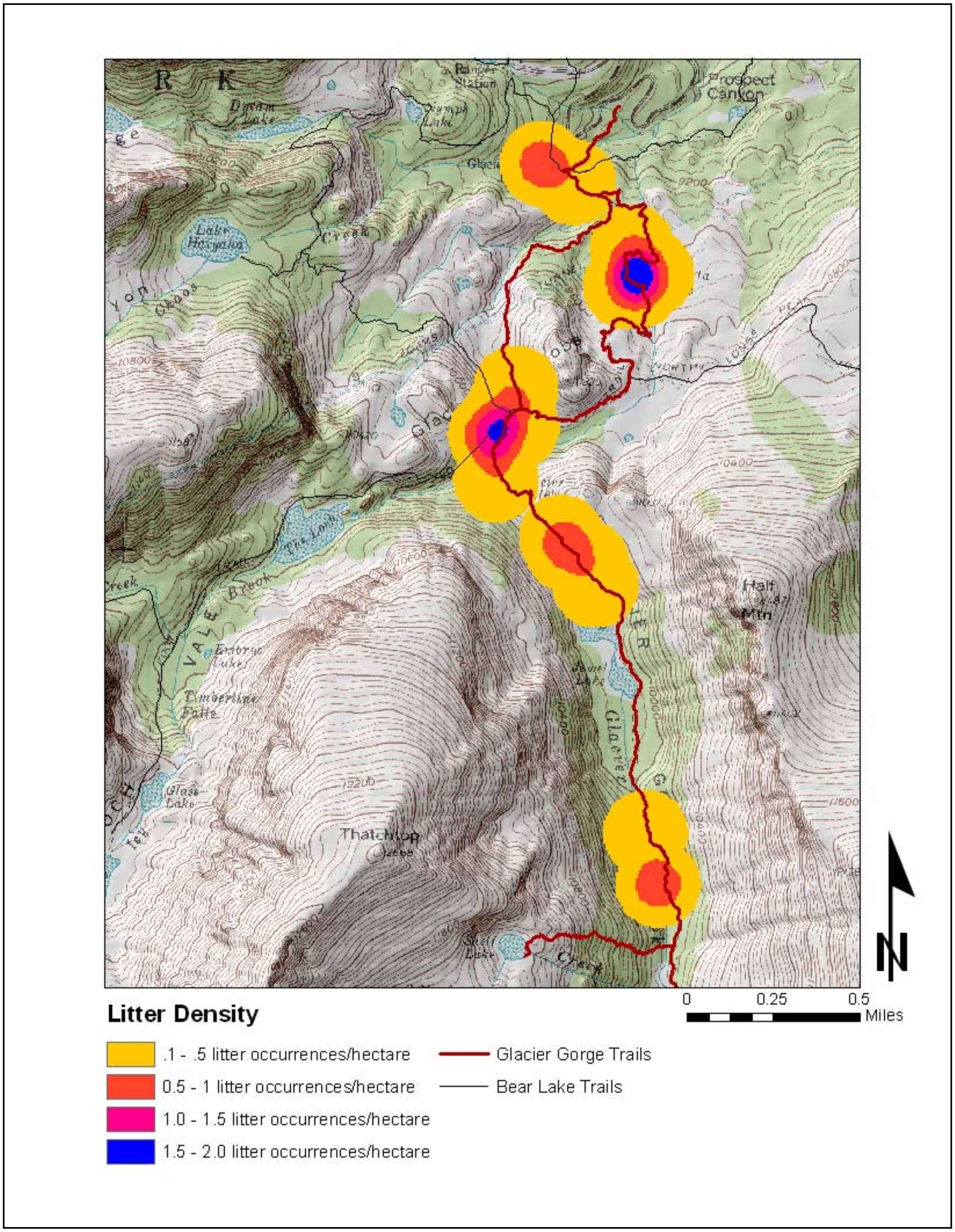

Figure 24. Litter density (150 meter off-trail buffer dataset)

Spatially Balanced On-Trail Dataset

Litter was found in 12 of 99 sample points (Figure 25).

Table 28. Types and Occurrences of Litter along Glacier Gorge trail

Type of Litter	Sample Point Occurrences	Occurrences of Litter
Food Wrapper	3	1
Athletic Tape	1	1
Toilet Paper	2	1
Bubble Wrap	1	1
Ribbon	1	1
Pudding Cup	2	1
Masking Tape	1	1
Old Can	1	1
Total	12	

Spatial autocorrelation was found to strongest at a distance of 200 m and applied to the Getis-Ord analysis (Figure 26) and Kernel Density analysis (Figure 27).

100 Meter Interval On-Trail Dataset

Litter was found in 12 of 93 sample points (Figure 28).

Table 29. Types and Occurrences of Litter along Glacier Gorge trail

Type of Litter	Sample Point Occurrences	Occurrences of Litter
Bottle	1	1
Tin Can	1	1
Toilet Paper	3	1
Cigarette Butt	3	1
Food Wrapper	3	1
Flagging	1	1
Total	12	

Spatial autocorrelation was found to strongest at a distance of 250 m and applied to the Getis-Ord analysis (Figure 29) and Kernel Density analysis (Figure 30).

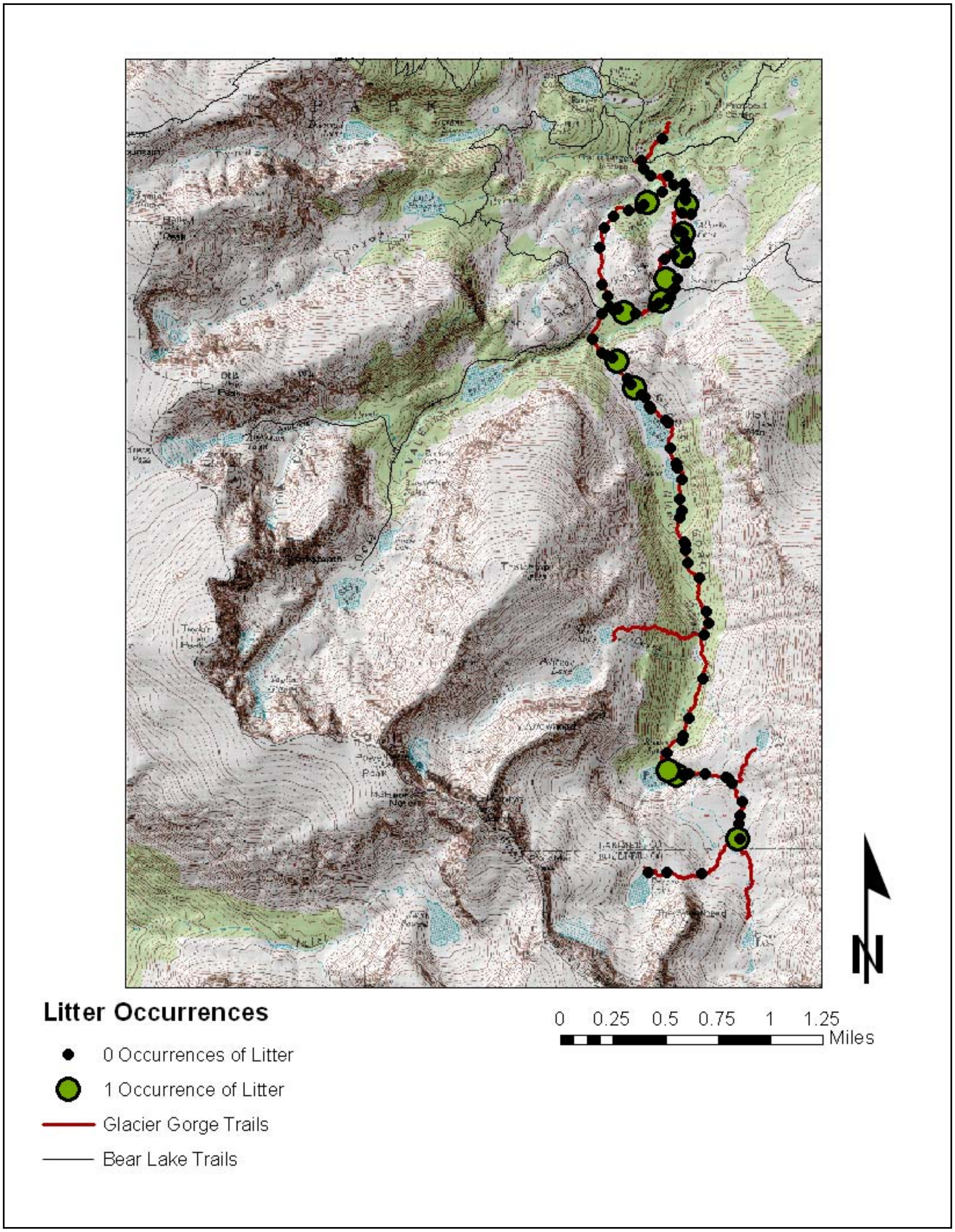

Figure 25. Occurrences of litter (spatially balanced on-trail dataset)

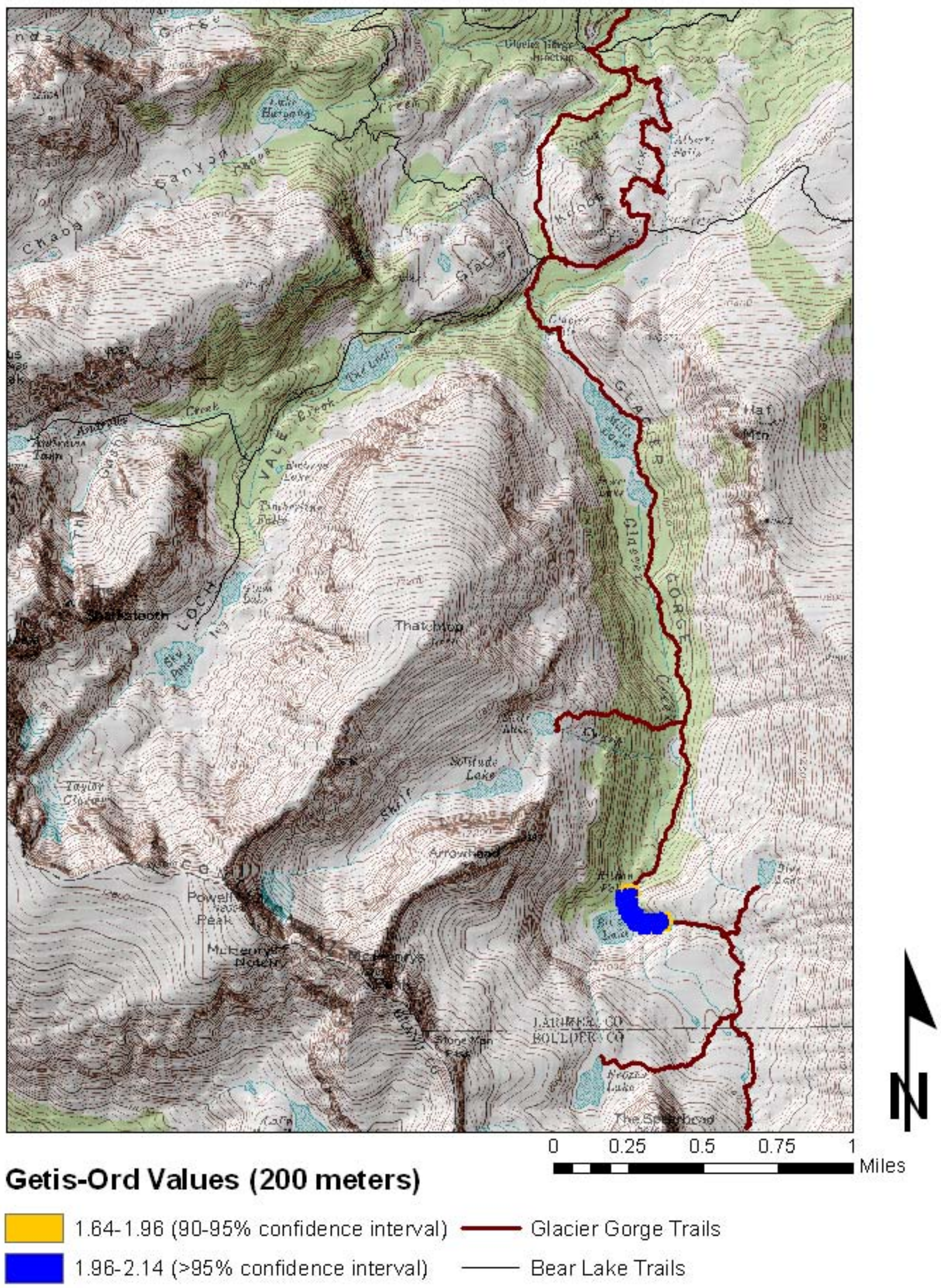

Figure 26. Getis-Ord values for litter (spatially balanced on-trail dataset)

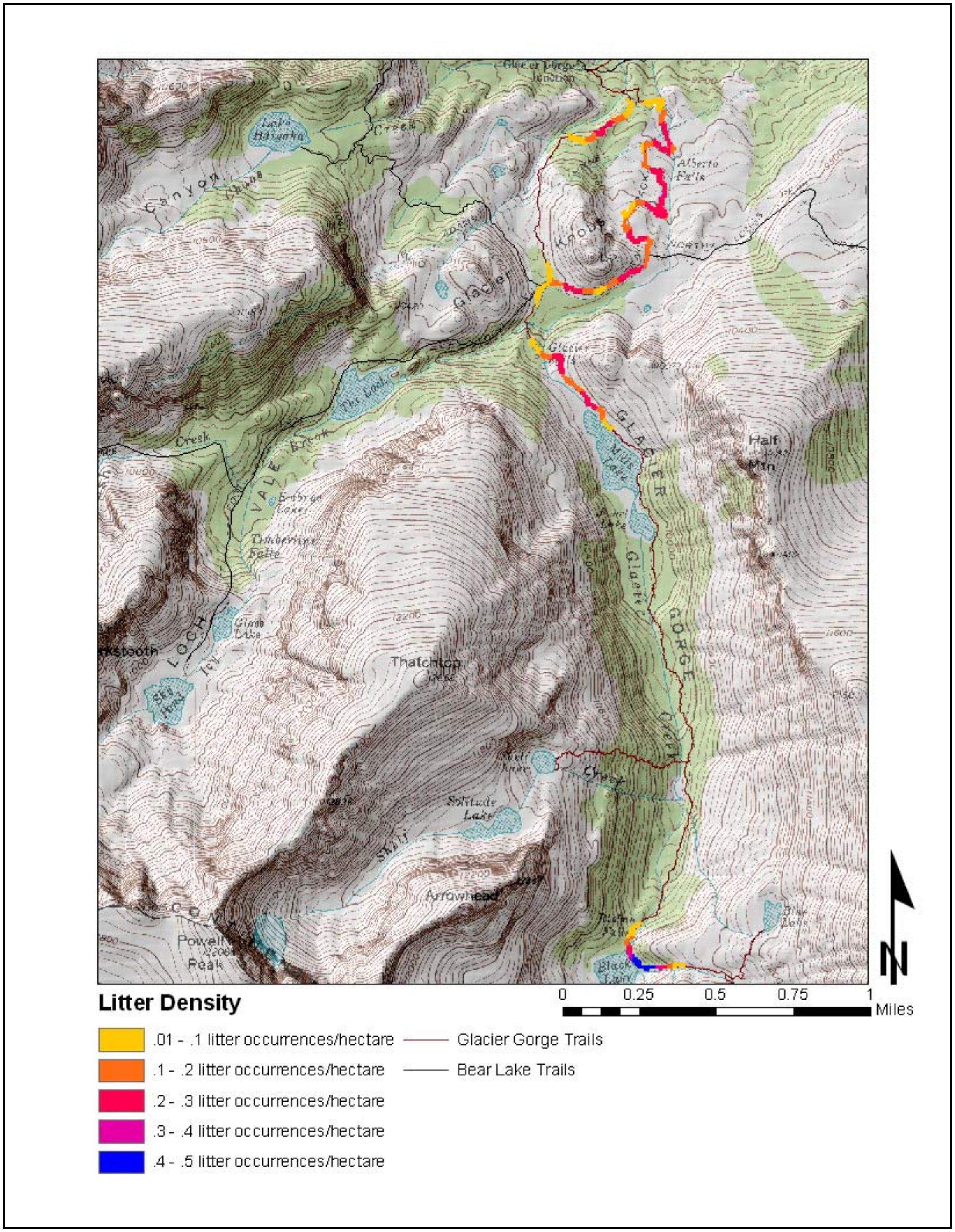

Figure 27. Litter density (spatially balanced on-trail dataset)

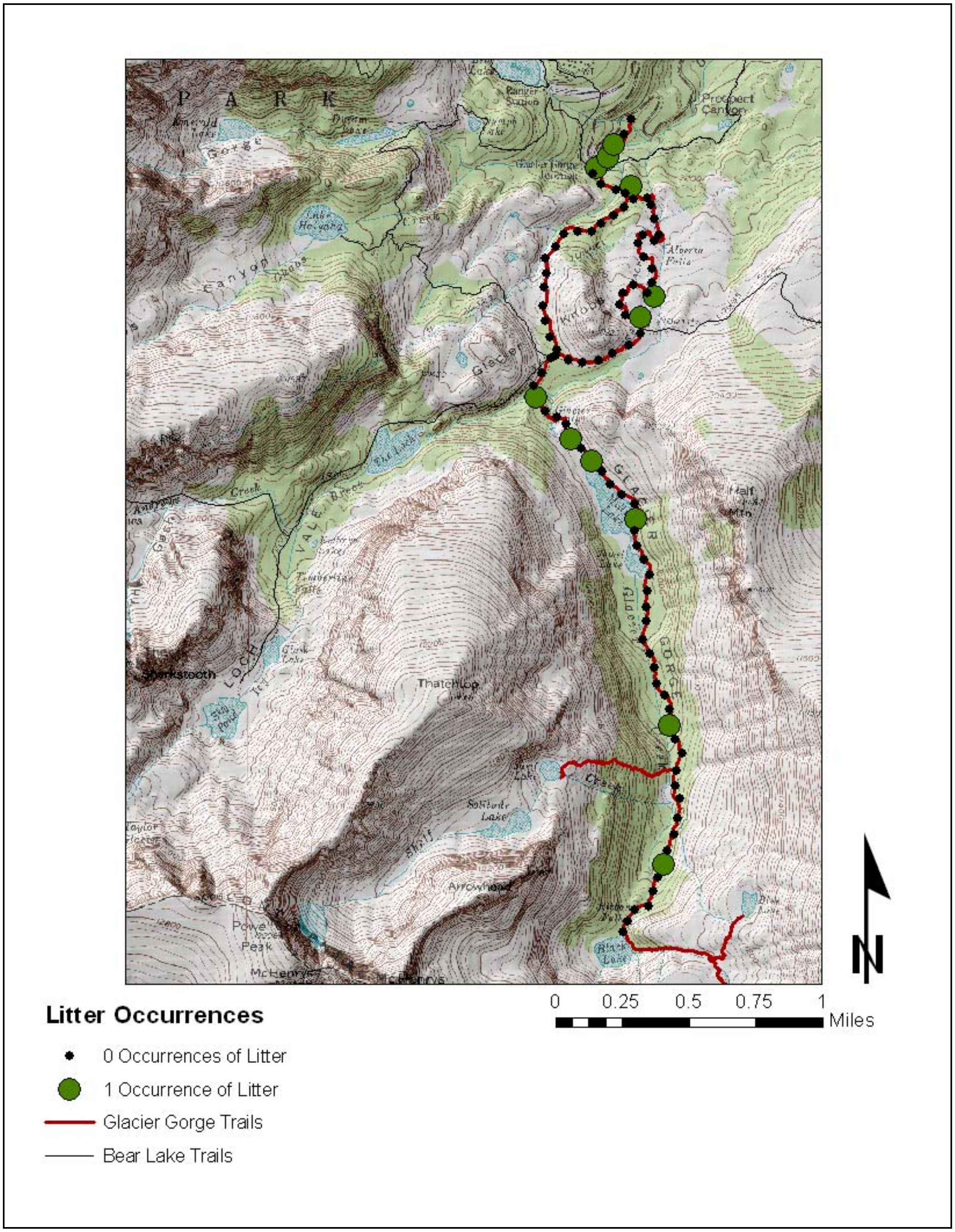

Figure 28. Occurrences of litter (100 meter interval on-trail dataset)

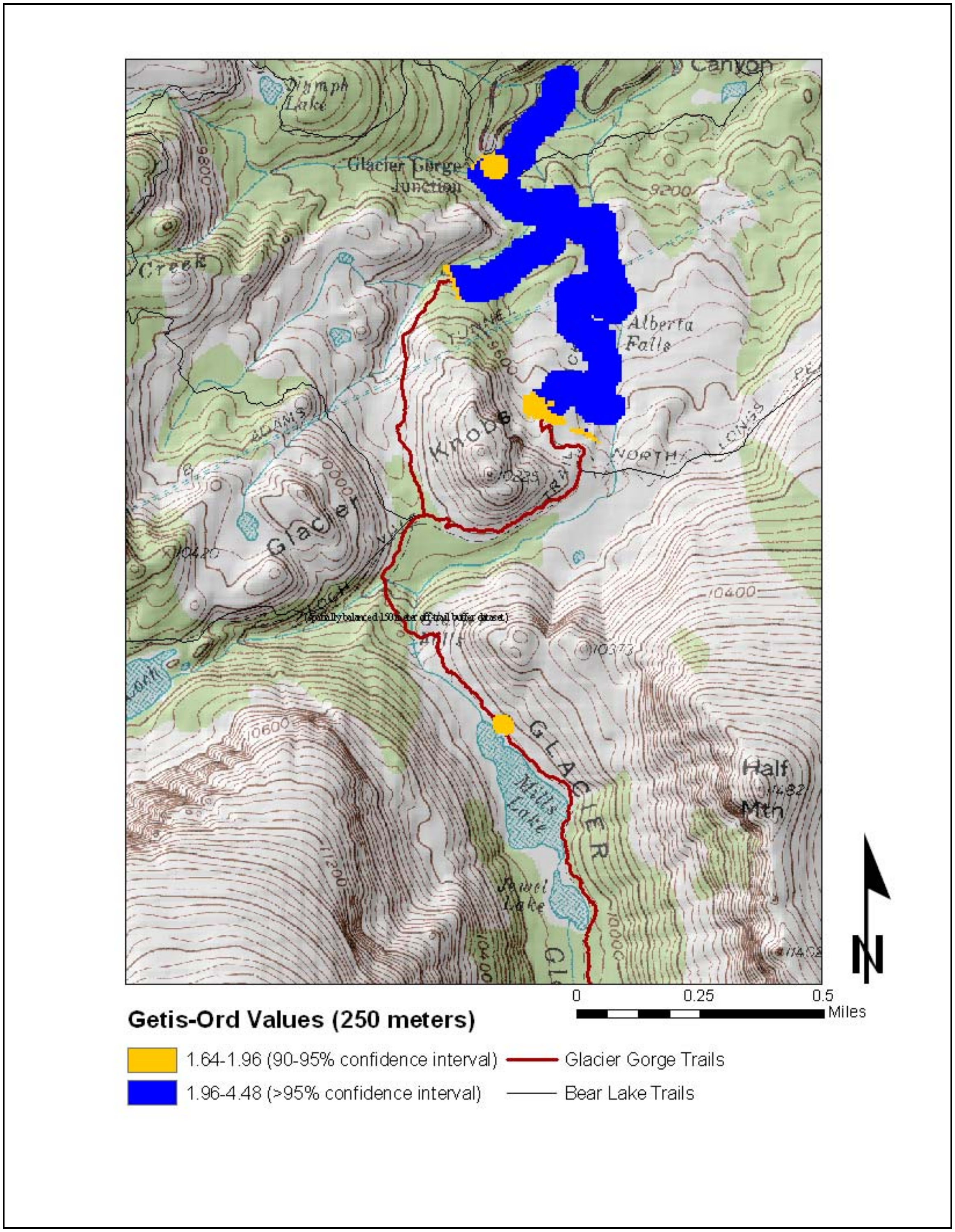

Figure 29. Getis-Ord values for litter (100 meter interval on-trail dataset)

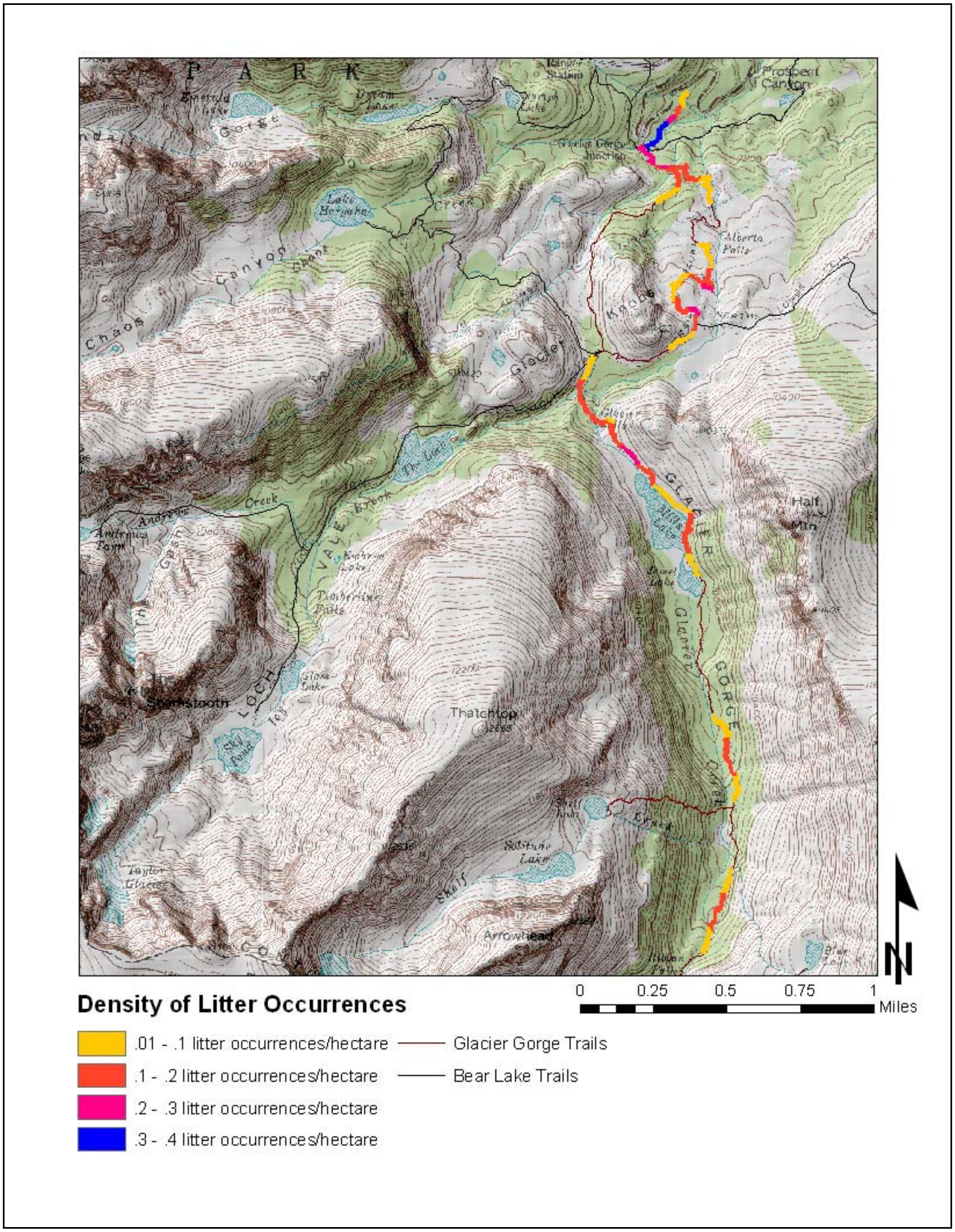

Figure 30. Litter density (100 meter interval on-trail dataset)

Spatially Balanced Off-Trail Dataset

Three of 75 sample points contained litter (Figure 31).

Table 30. Types and Occurrences of Litter along Glacier Gorge Trail

Type of Litter	Sample Point Occurrences	Occurrences of Litter
Multi Tool	1	1
Plastic Bag	1	1
Wrapper	1	1
Total	3	

Spatial autocorrelation was found to strongest at a distance of 350 m and applied to the G-Ord analysis (Figure 32). A 350 m radius was applied to the kernel density analysis (Figure 33).

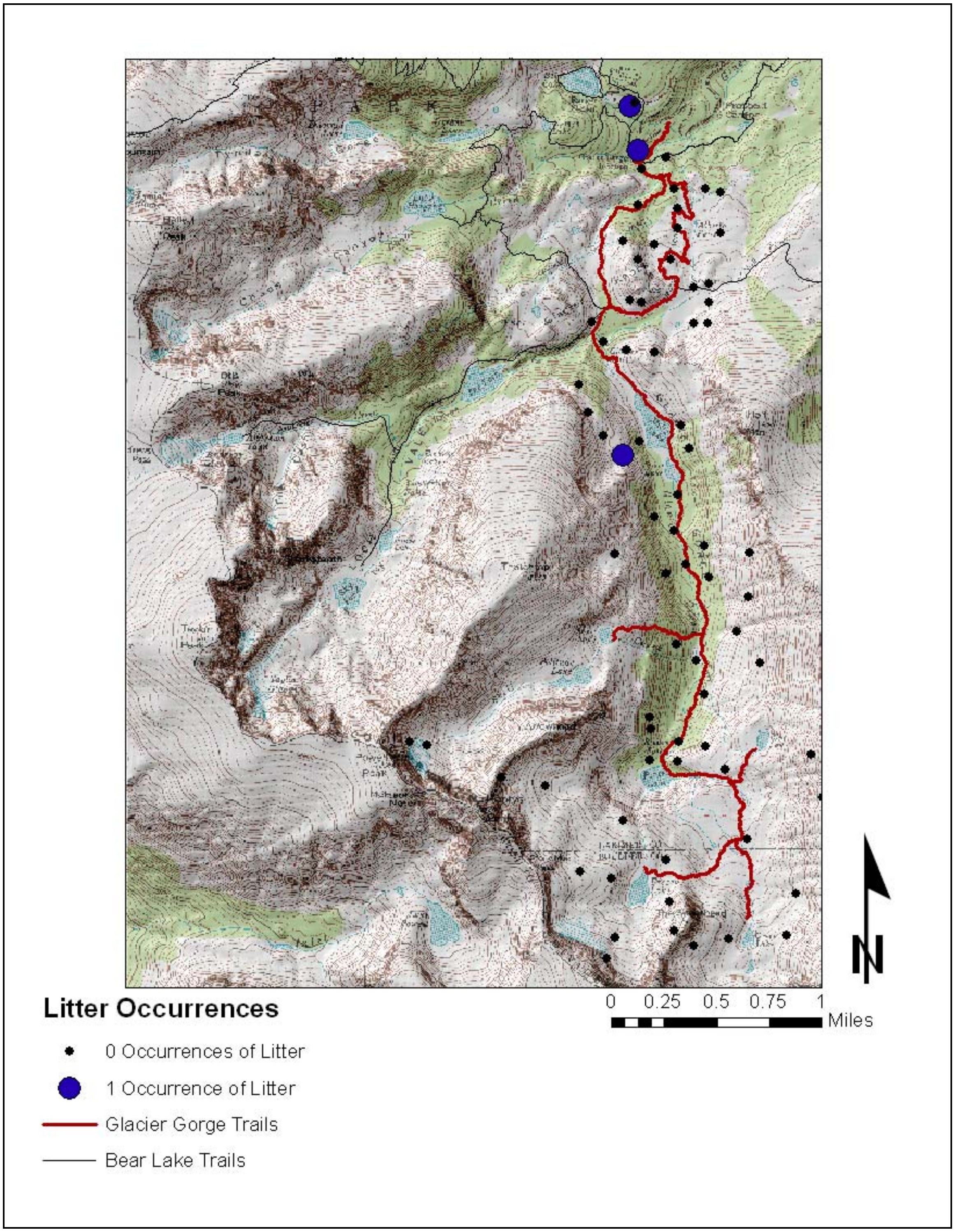

Figure 31. Litter occurrences (spatially balanced off-trail dataset)

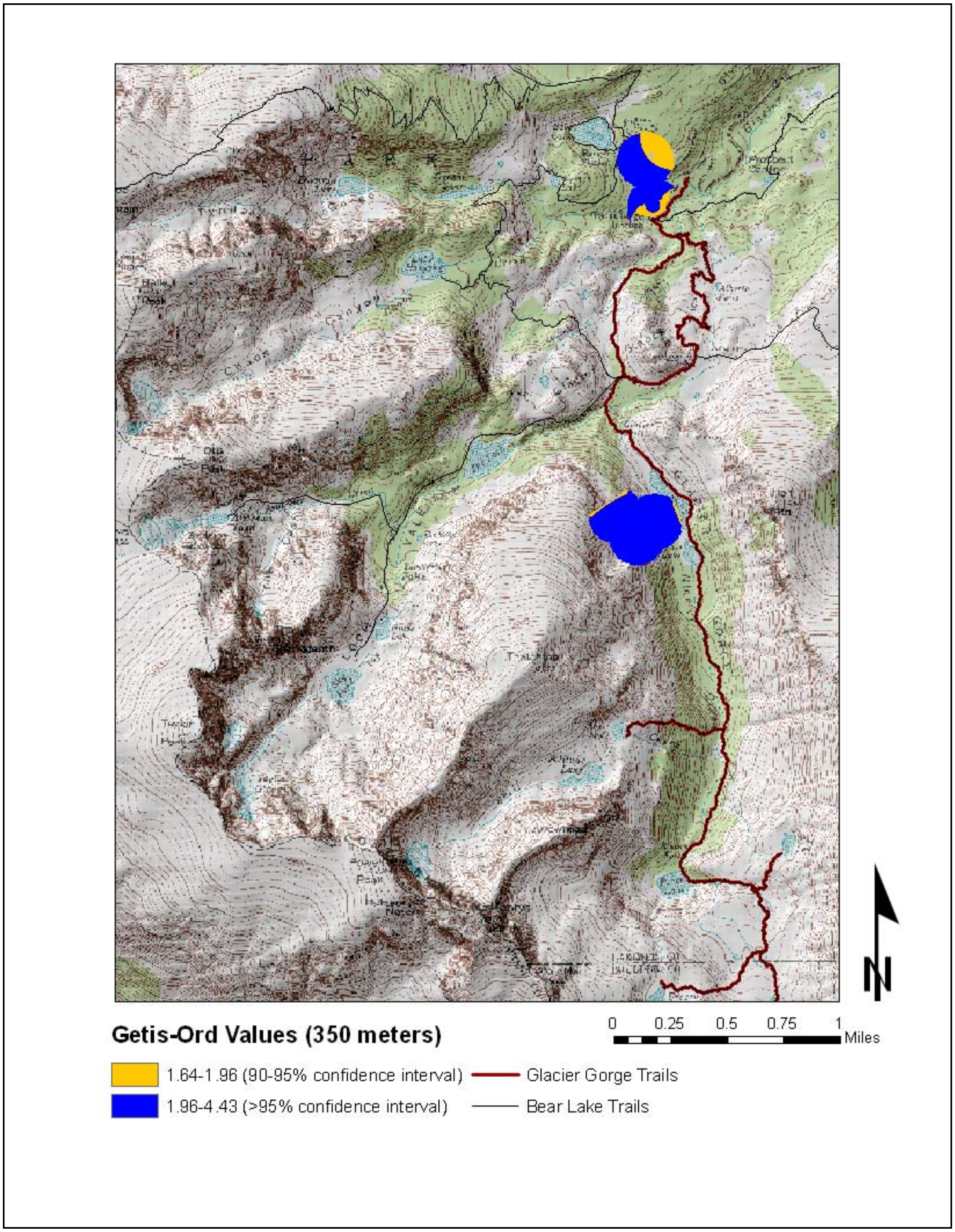

Figure 32. Getis-Ord values for litter (spatially balanced off-trail dataset)

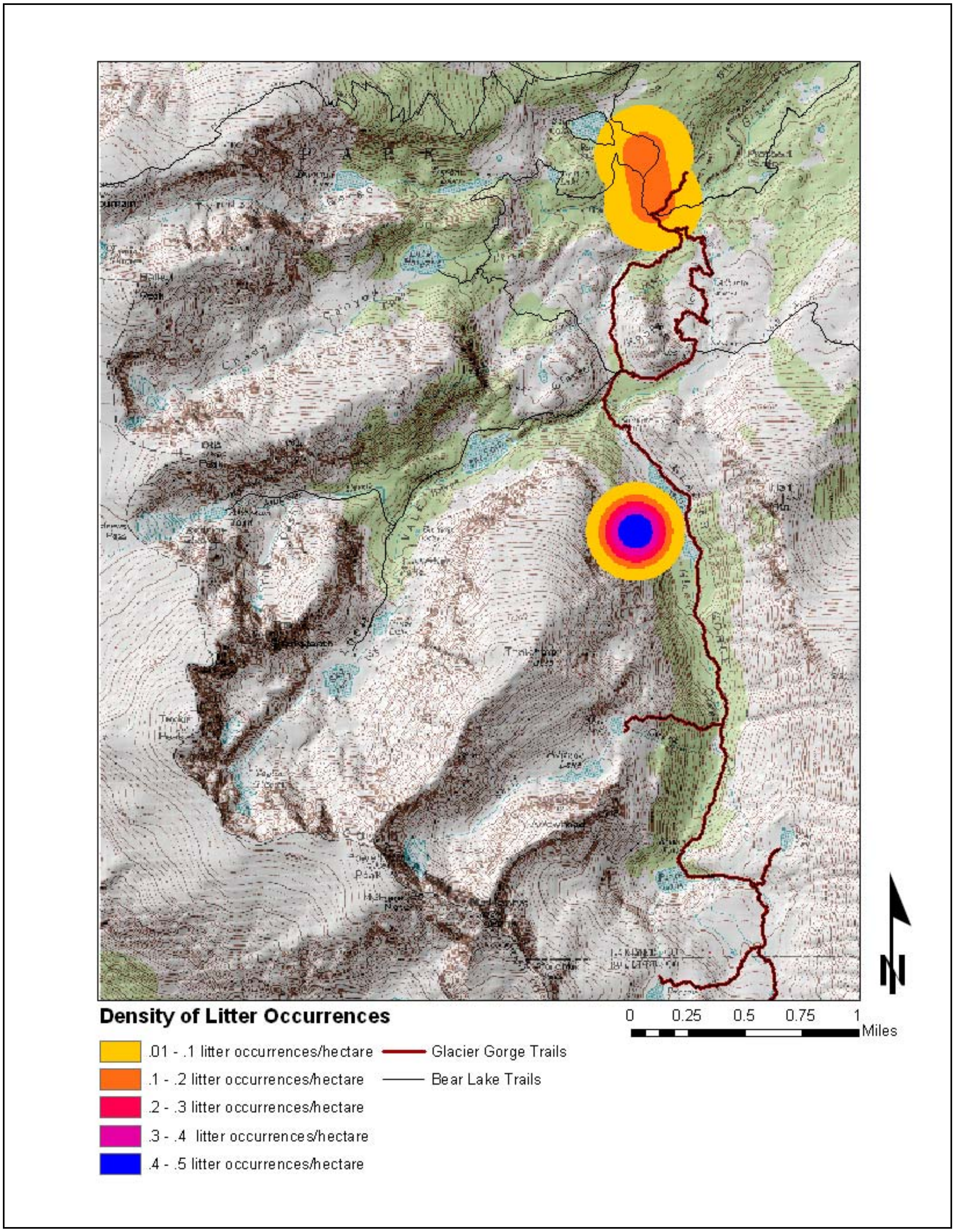

Figure 33. Litter density (spatially balanced off-trail dataset)

D. Vandalism

Spatially Balanced 150 Meter Buffer Off-Trail Dataset

Carvings into aspen trees were the only type of vandalism found in this study (Figure 34). Three of 100 sample points contained vandalism (Figure 35).

Figure 34. Photograph of tree carvings

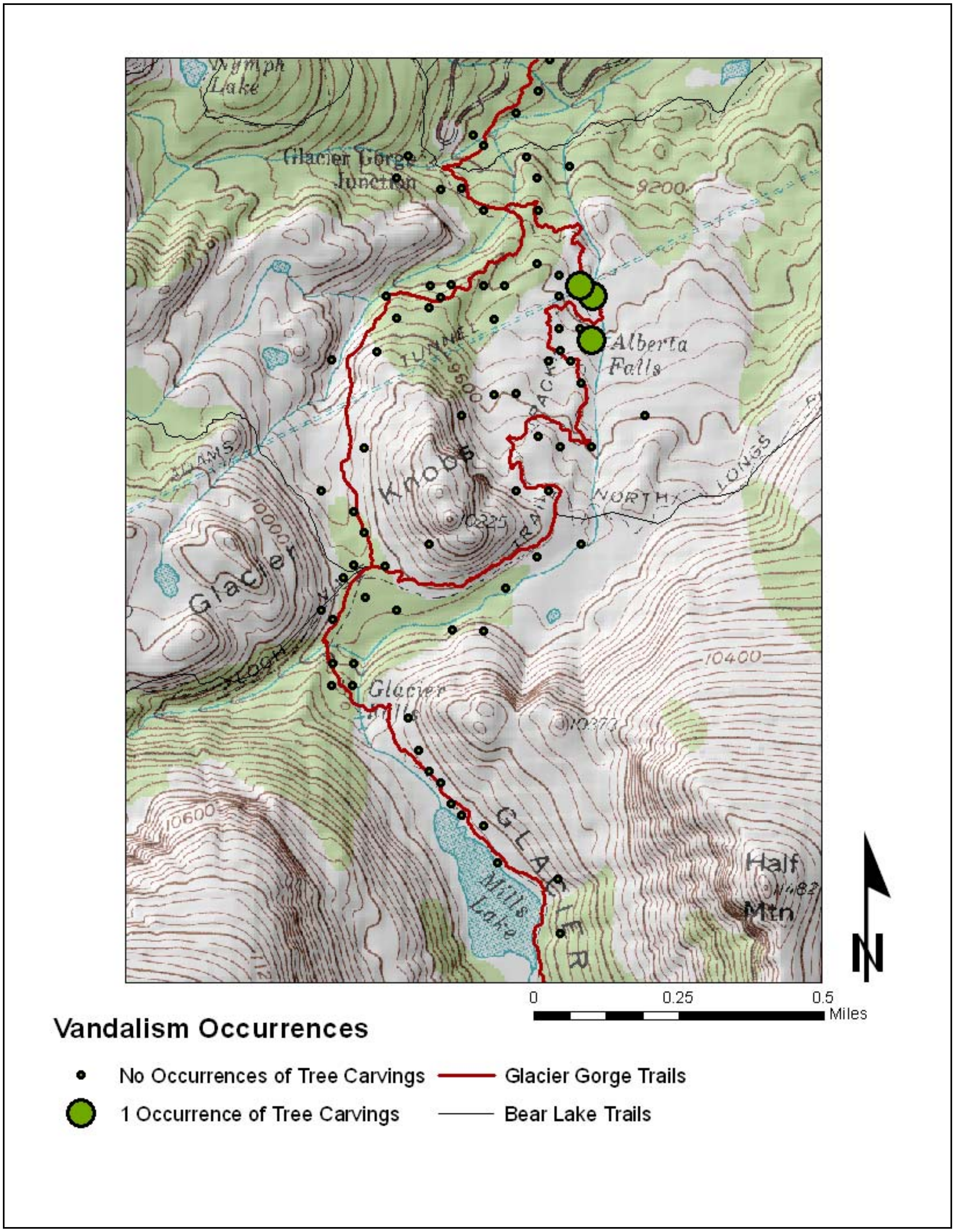

Figure 35. Vandalism Occurrences (spatially balanced 150 meter buffer dataset)

Spatial autocorrelation for the spatially balanced 150 meter buffer off-trail dataset was found to be greatest at a distance of 200 m and applied to the G-Ord analysis (Figure 36).

Vandalism occurrence values reflect the presence or absence of vandalism. Any occurrence of vandalism was given a value of one and absence of vandalism was given a value of zero.

Spatially Balanced On-Trail Dataset

Vandalism was found in 13 of 99 sample points (Figure 37). Spatial autocorrelation was found to strongest at a distance of 400 m and applied to the Getis-Ord analysis (Figure 38).

100 Meter Interval On-Trail Dataset

Litter was found in six of 93 sample points (Figure 39). Spatial autocorrelation was found to strongest at a distance of 400 m and was applied to the G-Ord analysis (Figure 40).

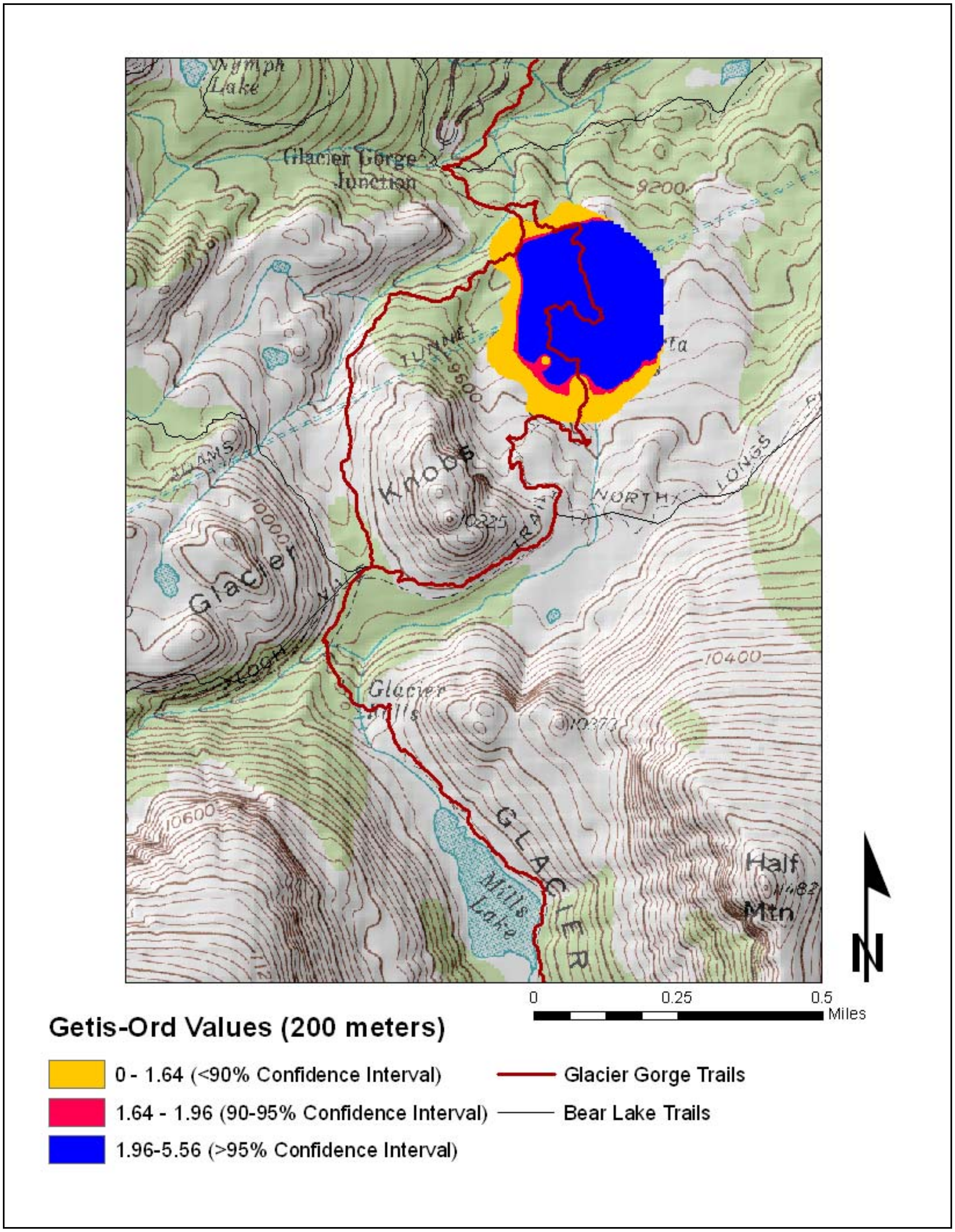

Figure 36. Getis-Ord Values for Vandalism (spatially balanced 150 meter buffer dataset)

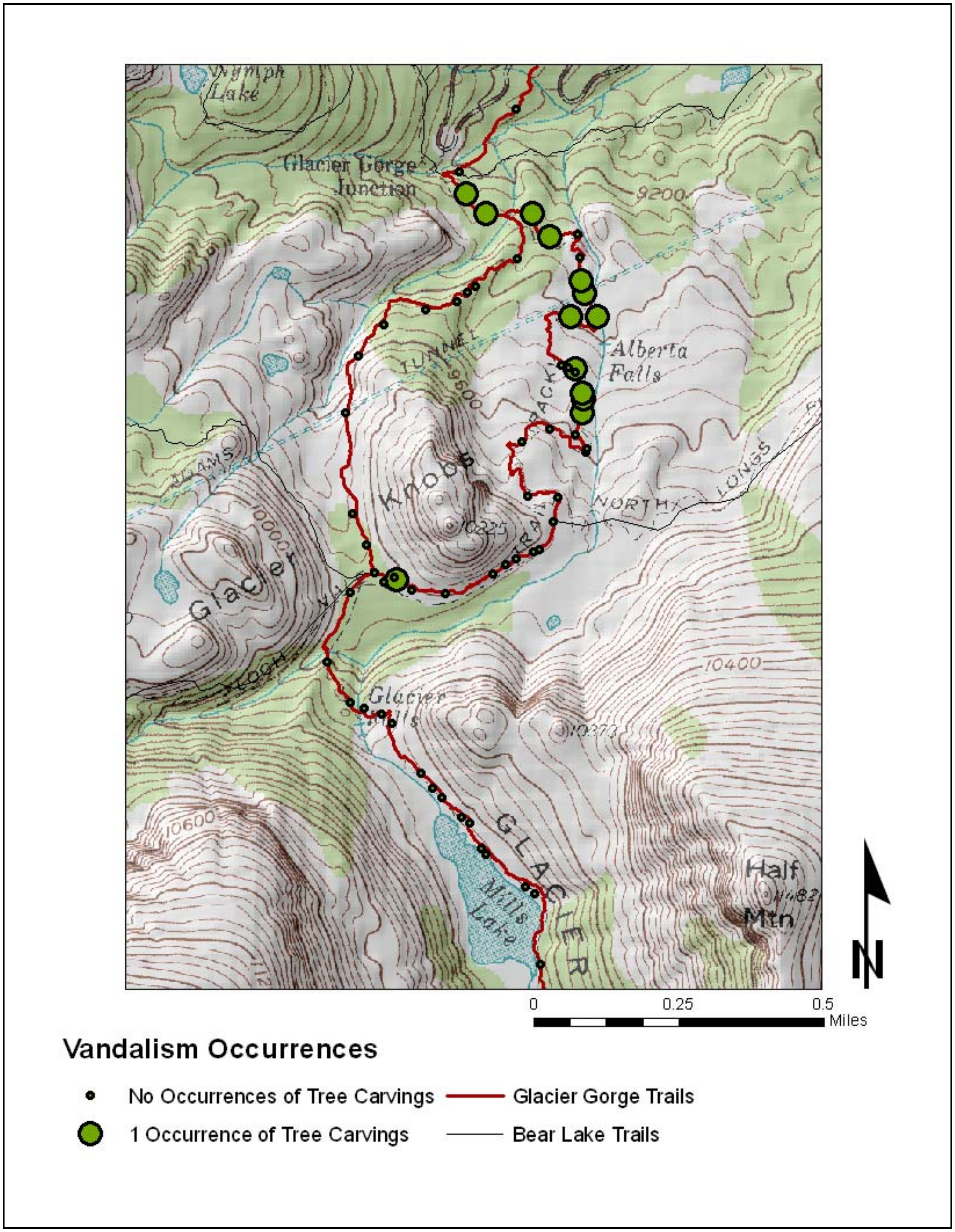

Figure 37. Vandalism Occurrences (spatially balanced on-trail dataset)

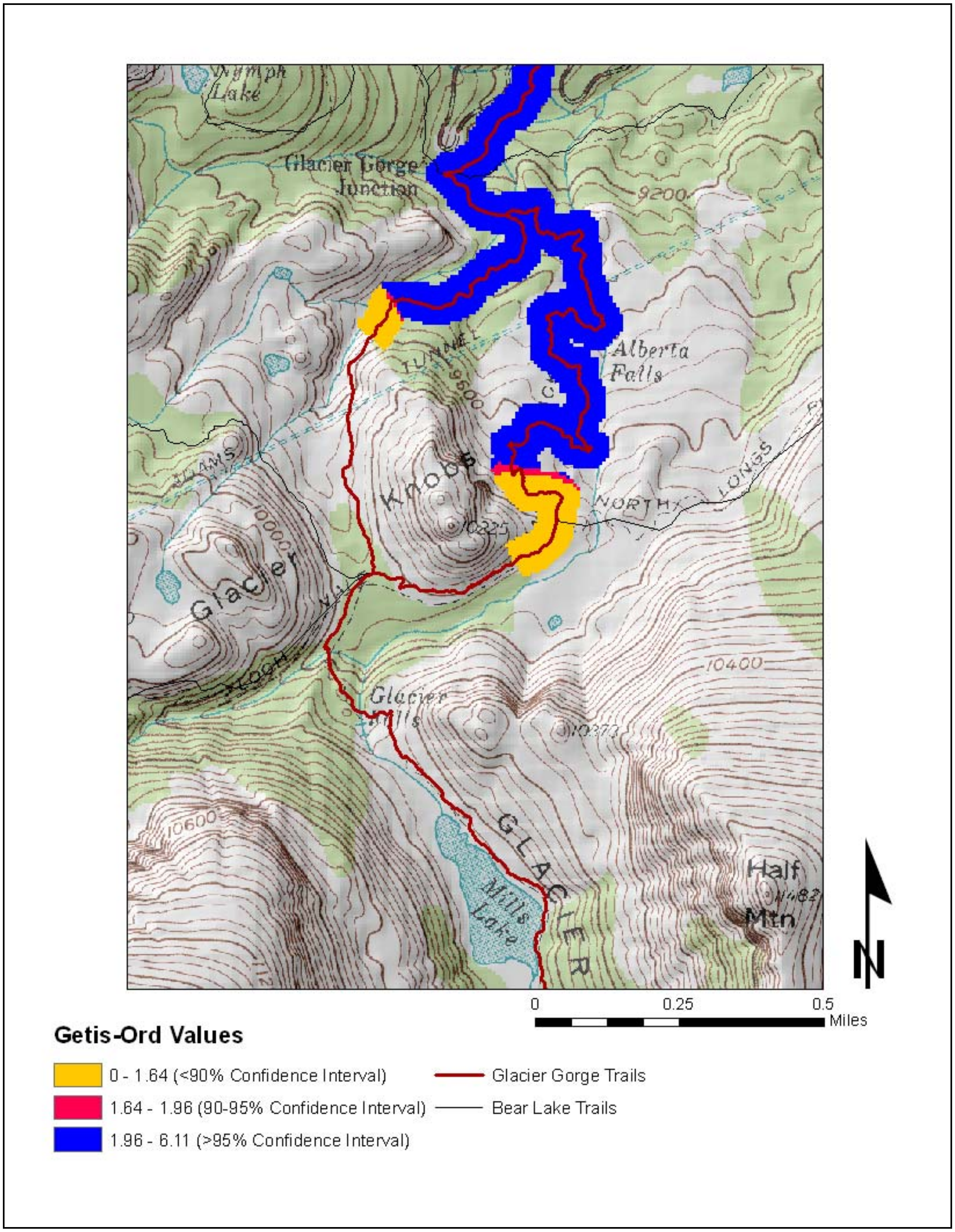

Figure 38. Getis-Ord Values (spatially balanced on-trail dataset)

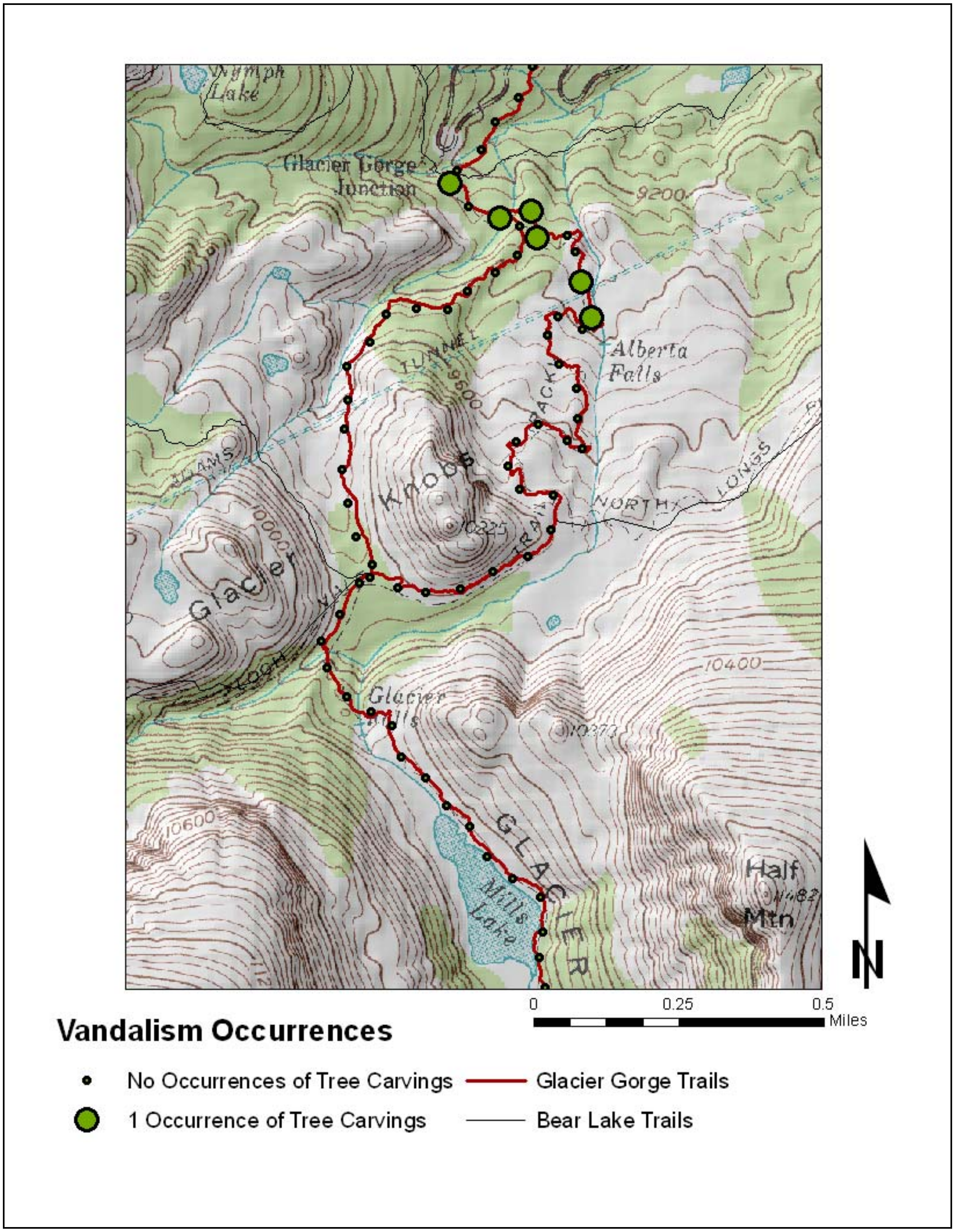

Figure 39. Vandalism occurrences (100 meter interval on-trail dataset)

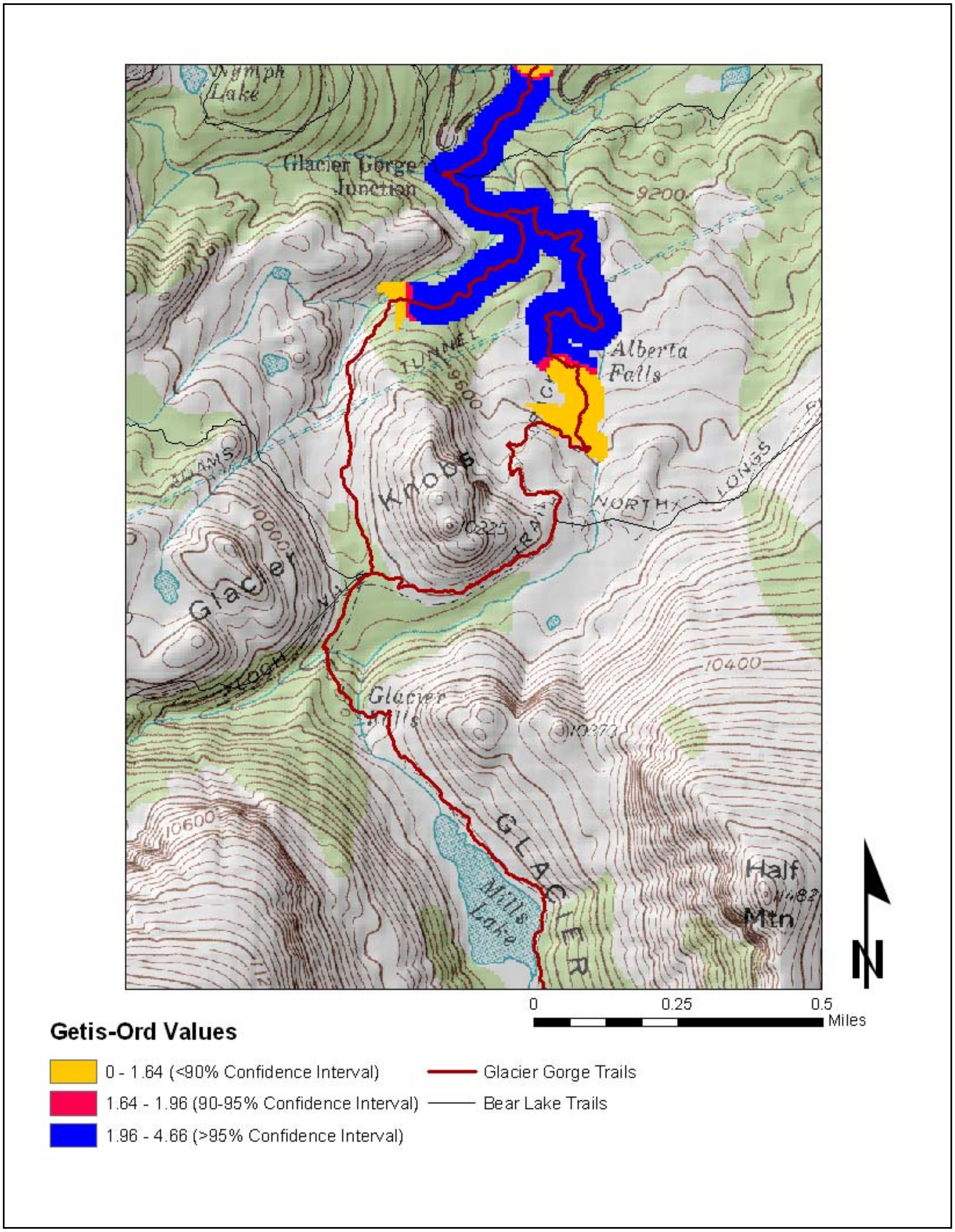

Figure 40. Getis-Ord Values (100 meter interval on-trail dataset)

E. Vegetation Affected by Social Trails

Vegetation within areas with positive Getis-Ord scores for social trail occurrence was examined. Getis-Ord values at the >95% confidence interval and the 90-95% confidence interval were identified. These areas were then converted from a raster surface to polygon features in *ArcGIS v9.1*.

A vegetation map of RMNP was then clipped based on these polygons and acreage was calculated for each vegetation type within the polygon. This process was repeated for all four datasets.

Spatially Balanced 150 Meter Buffer Off-Trail Dataset

Getis-Ord "hotspots" within 150 m of the trail were calculated. Generalizations are limited to the sampled areas (Figure 42).

Table 31. Vegetation within the Getis-Ord hotspot for social trails (95% confidence interval)

Vegetation Type	Acreage in Dataset	Acres in Hot Spot	Percentage
Lodgepole Pine - High Elevation > 9500 ft	25.48	13.55	53.2%
Lodgepole Pine - Low Elevation < 9500 ft	27.77	4.27	15.3%
Mixed Conifer with Aspen (Lodgepole Pine)	12.459	1.60	12.8%
Shrub Riparian Cross Zone < 9600 ft	67.00	4.07	6.1%
SubAlpine Limber Pine	12.46	0.45	3.6%
SubAlpine Mixed Conifer	8.77	3.35	38.2%
Upper Montane Aspen	18.88	2.50	13.2%

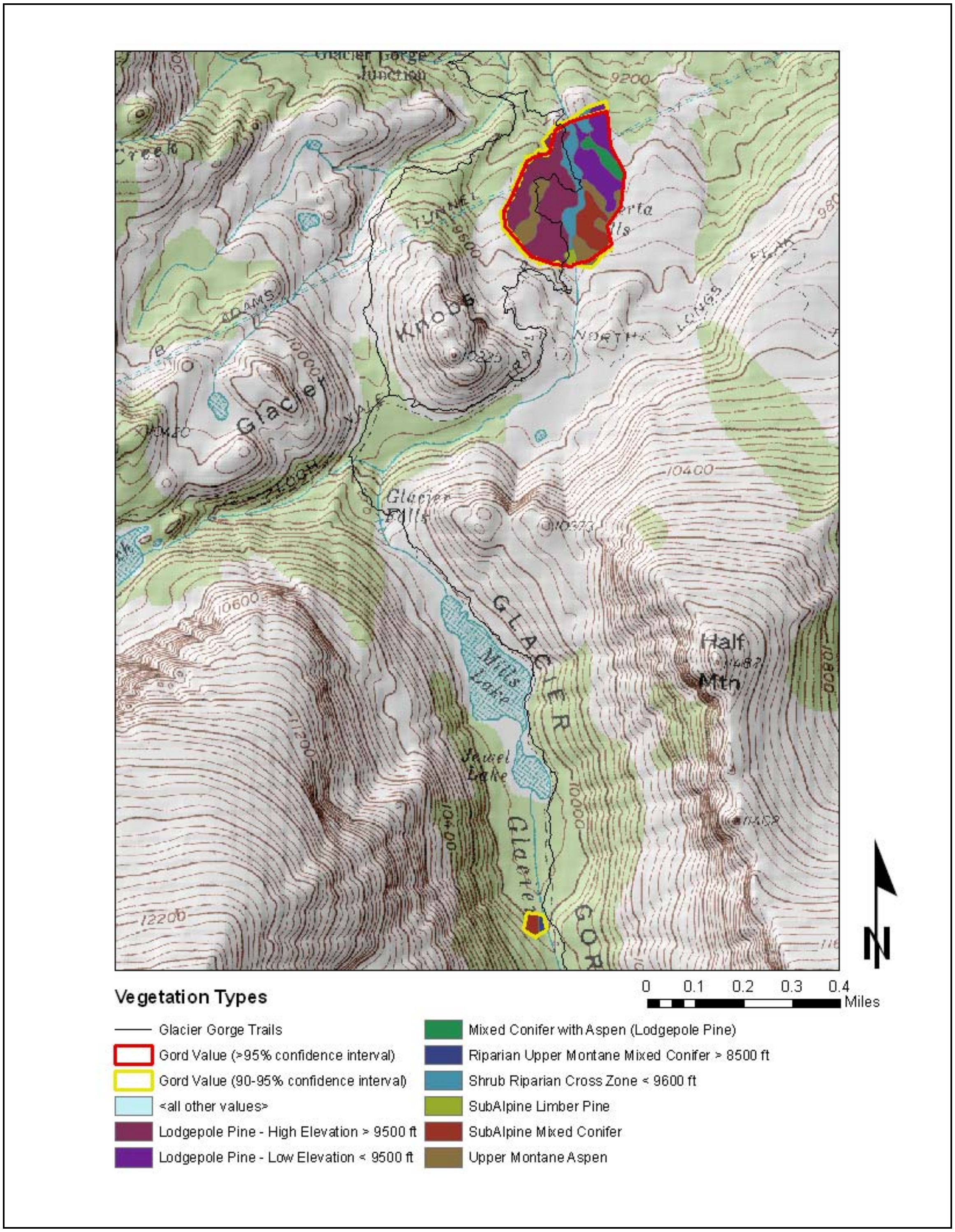

Figure 41. Vegetation within the Getis-Ord hotspot for social trails (spatially balanced 150 meter buffer off-trail dataset)

Table 32. Vegetation within the Getis-Ord hotspot for social trails (90-95% confidence interval)

Vegetation Type	Acreage in Dataset	Acres in Hot Spot	Percentage
Lodgepole Pine - High Elevation > 9500 ft	25.48	1.57	6.1%
Lodgepole Pine - Low Elevation < 9500 ft	27.77	0.41	1.4%
Riparian Upper Montane Mixed Conifer > 8500 ft	7.05	0.34	4.8%
Shrub Riparian Cross Zone < 9600 ft	67.00	0.38	0.6%
SubAlpine Limber Pine	12.46	0.002	<.1%
SubAlpine Mixed Conifer	8.77	0.79	9.0%
Upper Montane Aspen	18.88	0.31	1.6%

Spatially Balanced On-Trail Dataset

Getis-Ord “hotspots” were calculated within 10 m of the trail. Generalizations are limited because this dataset only sampled trail areas and data resolution is 10 m (Figure 42).

Table 33. Vegetation within Getis-Ord hotspots for social trails (>95% confidence interval)

Vegetation Type	Acreage in Dataset	Acres in Hot Spot	Percentage
Lodgepole Pine - High Elevation > 9500 ft	3.723	3.601	96.7%
Lodgepole Pine - Low Elevation < 9500 ft	3.493	3.074	88.0%
Lodgepole Pine - Rock	2.054	1.288	62.7%
Mixed Conifer with Aspen (Lodgepole Pine)	0.703	0.689	98.0%
Montane Douglas Fir	0.025	0.025	100%
Shrub Riparian Cross Zone < 9600 ft	1.875	1.875	100%
SubAlpine Limber Pine	1.276	0.394	30.9%
SubAlpine Mixed Conifer	2.176	0.114	4.0%
Upper Montane Aspen	0.624	0.624	100%

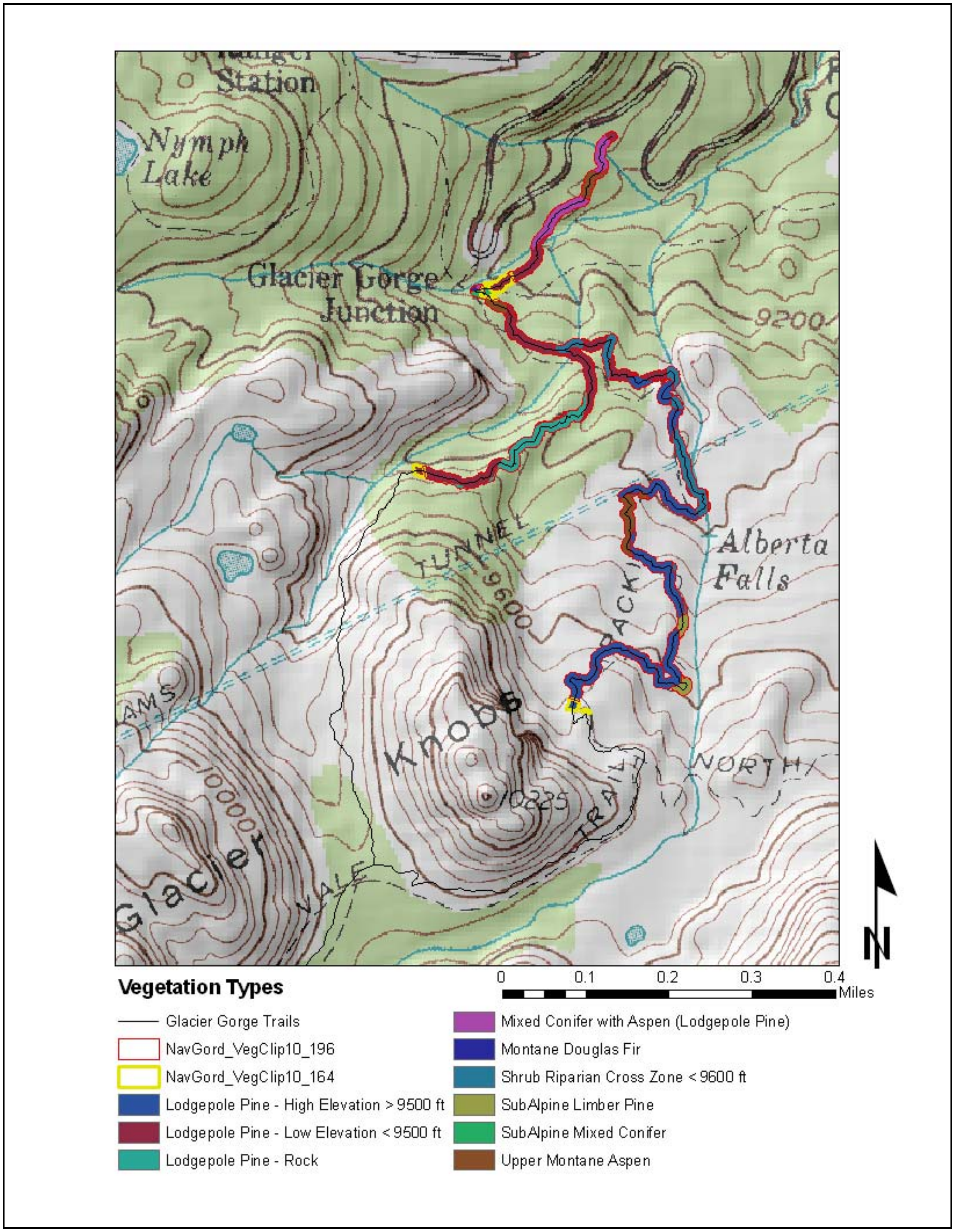

Figure 42. Vegetation within the Getis-Ord hotspot for social trails (spatially balanced on-trail dataset)

Table 34. Vegetation within Getis-Ord hotspots for social trails (90-95% confidence interval)

Vegetation Type	Acreage in Dataset	Acres in Hot Spot	Percentage
Lodgepole Pine - High Elevation > 9500 ft	3.723	0.122	3.3%
Lodgepole Pine - Low Elevation < 9500 ft	3.493	0.333	9.5%
Mixed Conifer with Aspen (Lodgepole Pine)	0.703	0.012	1.7%
SubAlpine Mixed Conifer	2.176	0.098	3.4%
Upper Montane Aspen	0.624	0.021	3.4%

100 Meter Interval Dataset

Like the spatially balanced on-trail dataset, only areas within 10 m of the trail were considered for this analysis (Figure 43).

Table 35. Vegetation within Getis-Ord hotspots for social trails (>95% confidence interval)

Vegetation Type	Acreage in Dataset	Acres in Hot Spot	Percentage
Lodgepole Pine - High Elevation > 9500 ft	3.723	3.572	96%
Lodgepole Pine - Low Elevation < 9500 ft	3.493	0.904	25.9%
Lodgepole Pine - Rock	2.055	0.250	12.2%
Shrub Riparian Cross Zone < 9600 ft	1.875	1.637	87.3%
SubAlpine Limber Pine	1.276	0.394	30.9%
Upper Montane Aspen	0.624	0.624	100%

Table 36. Vegetation within Getis-Ord hotspots for social trails (90-95% confidence interval)

Vegetation Type	Acreage in Dataset	Acres in Hot Spot	Percentage
Lodgepole Pine - High Elevation > 9500 ft	3.723	0.151	4.1%
Lodgepole Pine - Low Elevation < 9500 ft	3.493	0.508	14.5%
Lodgepole Pine - Rock	2.055	0.367	17.9%
Shrub Riparian Cross Zone < 9600 ft	1.875	0.206	11.0%
SubAlpine Limber Pine	1.276	0.110	5.6%
SubAlpine Mixed Conifer	2.176	0.423	19.4%

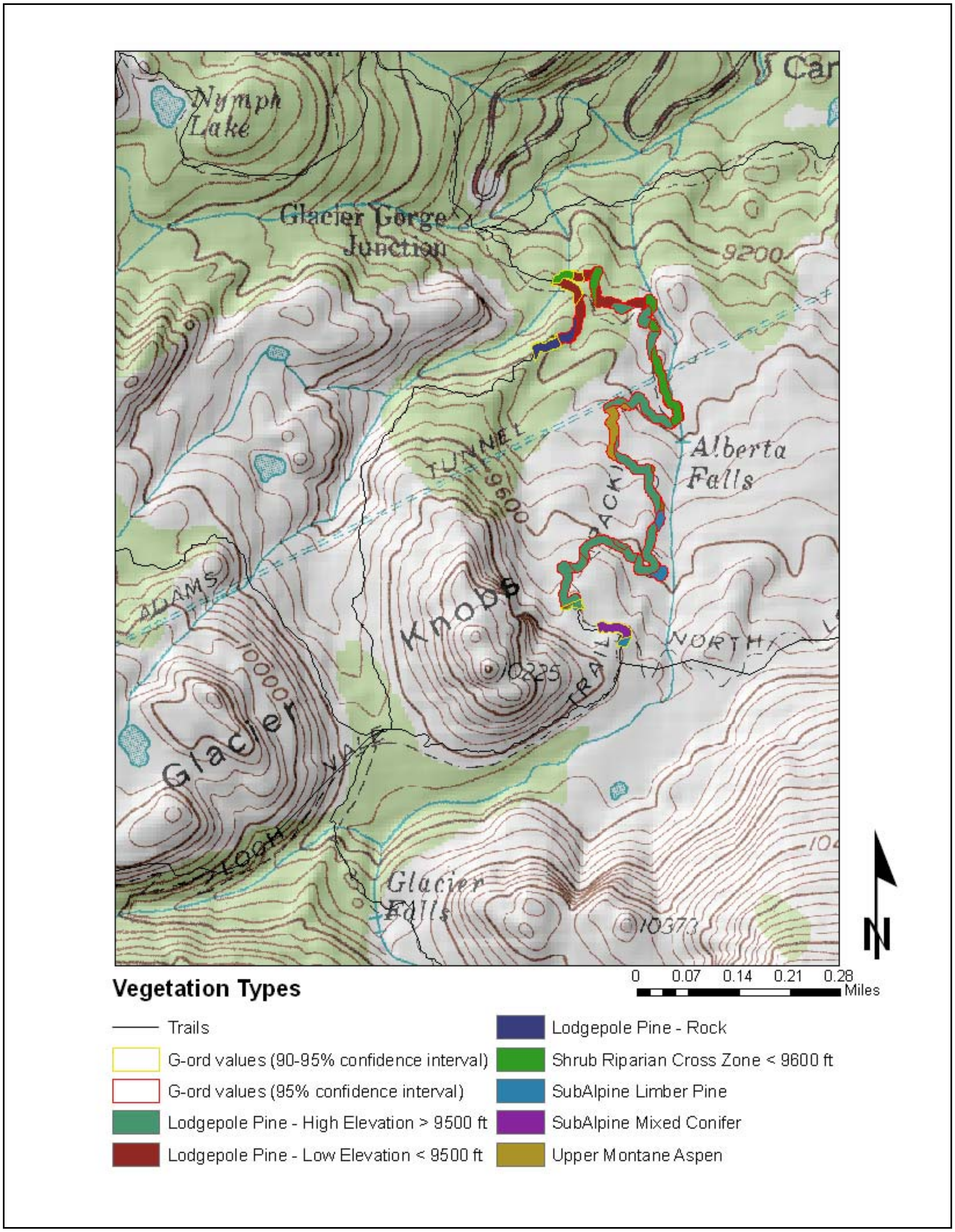

Figure 43. Vegetation within the Getis-Ord hotspot for social trails (100 meter on-trail dataset)

Spatially Balanced Off-Trail Dataset

Table 43. OT Vegetation within Getis-Ord hotspots for social trails (>95% confidence interval)

Vegetation Type	Acreage in Dataset	Acres in Hot Spot	Percentage
Cliff Face - Bare Soil / Rock	354.739	2.486	.7%
Herbaceous Upland Alpine Fellfield	320.683	2.073	.6%
Herbaceous Wetland SubAlpine / Alpine - Alpine Meadow	7.468	2.619	35.1%
Krummholz	24.179	1.803	7.5%
Natural Lakes - Ponds	17.965	2.754	15.3%
Riparian Upper Montane Mixed Conifer > 8500 ft	74.874	4.489	6.0%
Shrub Upland Alpine	37.032	1.243	3.4%
SubAlpine Mixed Conifer	48.997	15.149	31.0%
Talus	188.781	0.931	.5%

Table 44. OT Vegetation within Getis-Ord hotspots for social trails (90-95% confidence interval)

Vegetation Type	Acreage in Dataset	Acres in Hot Spot	Percentage
Cliff Face - Bare Soil / Rock	354.739	2.093	.6%
Herbaceous Upland Alpine Fellfield	320.683	1.563	.5%
Herbaceous Wetland SubAlpine / Alpine - Alpine Meadow	7.468	1.204	16.1%
Krummholz	24.179	1.857	7.7%
Natural Lakes - Ponds	17.965	1.663	9.3%
Riparian Upper Montane Mixed Conifer > 8500 ft	74.874	1.039	1.4%
SubAlpine Mixed Conifer	48.997	3.317	6.8%

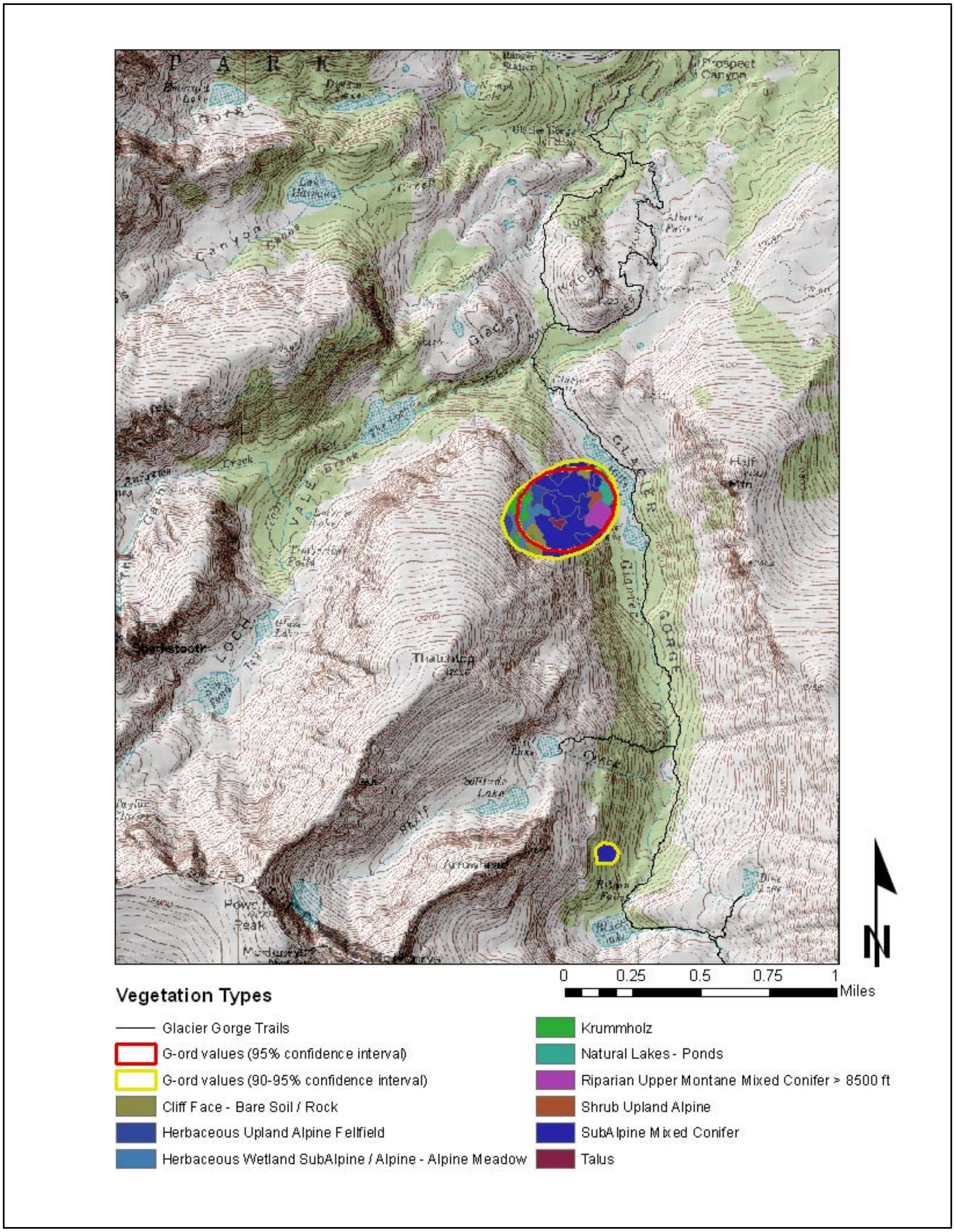

Figure 44. Vegetation within the Getis-Ord hotspot for social trails (spatially balanced off-trail dataset)

F. Proximity of Impact Occurrences to Trail and Destinations

Distances to destination areas where impacts occurred were examined. Destinations were defined as likely areas where hikers would stop hiking and spend time visiting, resting, or waiting for other hiking party members to rejoin the group. The hypothesis is that more impacts will occur closer to these areas than areas where hikers do not stop. The main destinations considered were lakes along the main Glacier Gorge trail (Mills Lake, Jewel Lake, and Black Lake), trail junctions (Glacier Gorge trail/Bear Lake junction, North Longs Peak junction, Mills Lake/Loch Vale junction, and Glacier Creek campsite junction), and Alberta Falls. A surface of distances to destinations was created in *ArcGIS v9.1* and values were extracted to points in the each dataset. Results are reported in Tables 45-47.

Table 45. Mean distances (meters) of social trail occurrences to destinations in Glacier Gorge Area

Dataset	Number of Social Trail Occurrences	Sample Points with Social Trail Occurrences	Sample Points without Social Trail Occurrences	Complete Dataset
Spatially Balanced Off-Trail 150 Meter Buffer	26	208.13	278.65	268.89
Spatially Balanced Off-Trail	3	124.71	625.03	609.35
On-Trail Spatially Balanced	34	181.30	259.93	232.80
On-Trail 100 meter Interval	25	152.16	276.23	242.88

Table 46. Mean distances (meters) of litter occurrences to destinations in Glacier Gorge Area

Dataset	Number of Litter Occurrences	Sample Points with Litter Occurrences	Sample Points without Litter Occurrences	Complete Dataset
Spatially Balanced Off-Trail 150 Meter Buffer	30	172.29	281.89	288.83
Spatially Balanced Off-Trail	3	195.48	620.57	609.35
On-Trail Spatially Balanced	12	202.56	236.95	232.80
On-Trail 100 meter Interval	12	202.49	248.86	242.88

Table 47. Mean distances (meters) of vandalism occurrences to destinations in Glacier Gorge Area

Dataset	Number of Vandalism Occurrences	Sample Points with Vandalism Occurrences	Sample Points without Vandalism Occurrences	Complete Dataset
Spatially Balanced Off-Trail 150 Meter Buffer	3	83.73	271.11	268.89
Spatially Balanced Off-Trail	0	n/a	n/a	n/a
On-Trail Spatially Balanced	13	158.78	243.45	232.80
On-Trail 100 meter Interval	6	160.23	248.58	242.88

Distances from the main Glacier Gorge trail to impact occurrences were examined for the off-trail datasets. The hypothesis for this examination is that sample points with impacts occur closer to the Glacier Gorge trail than sample points without impact occurrences. A surface of linear distances (meters) from the Glacier Gorge trail was created and values were extracted to the points in the spatially balanced 150 meter buffer off-trail dataset and the spatially balanced off-trail dataset. Access time values (minutes) were also examined. Results are reported in Tables 48-50.

Table 48. Mean distances (meters) and access time (minutes) of social trail occurrences to Glacier Gorge trail

Dataset	Number of Social Trail Occurrences	Distance to trail-Sample Points with Social Trail Occurrences	Distance to trail-Sample Points without Social Trail Occurrences	Distance to trail-Complete Dataset	Access Time to trail-Sample Points with Social Trail Occurrences	Access Time to trail-Sample Points without Social Trail Occurrences	Access Time to trail-Complete Dataset
Spatially Balanced Off-Trail 150 Meter Buffer	26	45.13	85.31	79.71	3.76	11.96	10.82
Spatially Balanced Off-Trail	3	232.57	500.35	491.96	49.71	87.34	86.16

Table 49. Mean distances (meters) and access time (minutes) of litter occurrences to Glacier Gorge trail

Dataset	Number of Litter Occurrences	Distance to trail-Sample Points with Litter Occurrences	Distance to trail-Sample Points without Litter Occurrences	Distance to trail-Complete Dataset	Access Time to trail-Sample Points with Litter Occurrences	Access Time to trail-Sample Points without Litter Occurrences	Access Time to trail-Complete Dataset
Spatially Balanced Off-Trail 150 Meter Buffer	21	33.86	85.88	45.06	3.59	11.80	10.82
Spatially Balanced Off-Trail	3	300.04	497.16	491.96	60.92	86.84	86.16

Table 50. Mean distances (meters) and access time (minutes) of vandalism occurrences to Glacier Gorge trail

Dataset	Number of Vandalism Occurrences	Distance to trail-Sample Points with Vandalism Occurrences	Distance to trail-Sample Points without Vandalism Occurrences	Distance to trail-Complete Dataset	Access Time to trail-Sample Points with Vandalism Occurrences	Access Time to trail-Sample Points without Vandalism Occurrences	Access Time to trail-Complete Dataset
Spatially Balanced Off-Trail 150 Meter Buffer	3	24.33	80.38	45.06	2.84	10.92	10.82
Spatially Balanced Off-Trail	0	n/a	n/a	n/a	n/a	n/a	n/a

.

Mann-Whitney nonparametric tests were used to examine if differences between impact occurrence distance and impact absence distance results were statistically significant (Tables 51-61). The Mann-Whitney nonparametric test is useful for determining whether or not the values of a particular variable differ between two groups when the assumptions of the *t*-test are not met.

Table 51. Mann-Whitney test: distances to social trail occurrences (spatially balanced 150 meter buffer off-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Social Trail Occurrences	Distance to trail-Sample Points without Social Trail Occurrences	Number of Sample Points with Social Trail Occurrences (Weighted)	Number of Sample Points without Social Trail Occurrences (Weighted)	Z	Mann-Whitney	*p*
Destination Distance	208.13	278.65	35	218	-3.039	2594.0	.002
Distance From Trail	45.13	85.31	35	218	-4.926	1837.0	<.001
Access Time	3.76	11.96	35	218	-5.522	1596.5	<.001

Table 52. Mann-Whitney test: distances to litter occurrences (spatially balanced 150 meter buffer off-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Litter Occurrences	Distance to trail-Sample Points without Litter Occurrences	Number of Sample Points with Litter Occurrences (Weighted)	Number of Sample Points without Litter Occurrences (Weighted)	Z	Mann-Whitney	*p*
Destination Distance	172.29	281.89	30	223	-3.811	1911.5	<.001
Distance From Trail	40.00	85.91	30	223	-5.613	1234.5	<.001
Access Time	3.59	11.80	30	223	-5.196	1390.5	<.001

Table 53. Mann-Whitney test: distances to vandalism occurrences (spatially balanced 150 meter buffer off-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Vandalism Occurrences	Distance to trail-Sample Points without Vandalism Occurrences	Number of Sample Points with Vandalism Occurrences (Weighted)	Number of Sample Points without Vandalism Occurrences (Weighted)	Z	Mann-Whitney	*p*
Destination Distance	83.73	271.12	3	250	-2.263	90.0	.024
Distance From Trail	24.33	80.42	3	250	-2.061	115.5	.039
Access Time	2.84	10.83	3	250	-1.822	145.5	.068

Table 54. Mann-Whitney test: distances to social trail occurrences (spatially balanced off-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Social Trail Occurrences	Distance to trail-Sample Points without Social Trail Occurrences	Number of Sample Points with Social Trail Occurrences (Weighted)	Number of Sample Points without Social Trail Occurrences (Weighted)	Z	Mann-Whitney	*p*
Destination Distance	124.75	625.04	13	391	-5.094	442.0	<.001
Distance From Trail	49.71	87.34	13	391	-1.464	1975.0	.143
Access Time	232.57	500.35	13	391	-2.066	1721.0	.039

Table 55. Mann-Whitney test: distances to litter occurrences (spatially balanced off-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Litter Occurrences	Distance to trail-Sample Points without Litter Occurrences	Number of Sample Points with Litter Occurrences (Weighted)	Number of Sample Points without Litter Occurrences (Weighted)	Z	Mann-Whitney	*p*
Destination Distance	195.54	620.57	11	393	-3.927	676.0	<.001
Distance From Trail	60.95	86.84	11	393	-.458	2027.0	.647
Access Time	300.14	497.16	11	393	-.931	1843.0	.352

Table 56. Mann-Whitney test: distances to social trail occurrences (spatially balanced on-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Social Trail Occurrences	Distance to trail-Sample Points without Social Trail Occurrences	Number of Sample Points with Social Trail Occurrences (Weighted)	Number of Sample Points without Social Trail Occurrences (Weighted)	Z	Mann-Whitney	*p*
Destination Distance	181.30	259.93	36	68	-1.288	944.0	.198

Table 57. Mann-Whitney test: distances to litter occurrences (spatially balanced on-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Litter Occurrences	Distance to trail-Sample Points without Litter Occurrences	Number of Sample Points with Litter Occurrences (Weighted)	Number of Sample Points without Litter Occurrences (Weighted)	Z	Mann-Whitney	*p*
Destination Distance	202.56	236.95	12	91	-.558	470.0	.577

Table 58. Mann-Whitney test: distances to vandalism occurrences (spatially balanced on-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Vandalism Occurrences	Distance to trail-Sample Points without Vandalism Occurrences	Number of Sample Points with Vandalism Occurrences (Weighted)	Number of Sample Points without Vandalism Occurrences (Weighted)	Z	Mann-Whitney	*p*
Destination Distance	158.78	243.45	13	90	-.782	483.5	.434

Table 59. Mann-Whitney test: distances to social trail occurrences (100 meter interval on-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Social Trail Occurrences	Distance to trail-Sample Points without Social Trail Occurrences	Number of Sample Points with Social Trail Occurrences	Number of Sample Points without Social Trail Occurrences	Z	Mann-Whitney	*p*
Destination Distance	152.16	276.24	25	68	-2.370	576.5	.018

Table 60. Mann-Whitney test: distances to litter occurrences (100 meter interval on-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Litter Occurrences	Distance to trail-Sample Points without Litter Occurrences	Number of Sample Points with Litter Occurrences (Weighted)	Number of Sample Points without Litter Occurrences (Weighted)	Z	Mann-Whitney	*p*
Destination Distance	202.49	248.86	12	81	-.619	432.0	.536

Table 61. Mann-Whitney test: distances to vandalism occurrences (100 meter interval on-trail dataset)

Distance Variable	Mean Distance to trail-Sample Points with Vandalism Occurrences	Distance to trail-Sample Points without Vandalism Occurrences	Number of Sample Points with Vandalism Occurrences (Weighted)	Number of Sample Points without Vandalism Occurrences (Weighted)	Z	Mann-Whitney	*p*
Destination Distance	160.23	248.58	6	87	-.899	203.5	.369

G. Trail Conditions and Method Comparison

Average Trail Widths and Depths

Average width and depth of the Glacier Gorge trail was computed from 93 points surveyed in the interval based dataset and 99 points surveyed in the spatially balanced dataset (Table 62). Results for the average width of the Glacier Gorge trail were 4.33 feet for the interval based dataset and 4.50 feet for the spatially balanced dataset. Results for the average depth of the Glacier Gorge trail were 2.53 inches for the interval dataset and 2.54 inches for the spatially balanced dataset. However, due to time constraints, the interval dataset only surveyed the trail to Black Lake while the spatially balanced dataset considered points up to Frozen Lake. When the 16 points beyond Black Lake are removed from the spatially balanced dataset the average width of the trail is 4.70 feet and the average depth is 2.71 inches.

Table 62. Average, maximum, and minimum trail widths and depths along the Glacier Gorge trail

Data Set (# of sample points)	Average Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
100 m Interval Dataset (93 points)	4.33 ft	1.00 ft	9.83 ft	2.53 in	0 in	16.10 in
Spatially Balanced Dataset (99 points)	4.50	1.33	9.20	2.54	0	11.80
Spatially Balanced Dataset below Black Lake (83 points)	4.70	1.33	9.20	2.71	0	11.80

In order to examine the efficiency of the spatially balanced method, sample points were removed incrementally from the dataset and the resulting values compared to the results of the complete dataset. Sample points in the spatially balanced dataset are ordered. In other words, point 10 cannot be considered in the results until points one through nine are considered. Since the dataset contains 99 points, higher point values can be removed to create smaller subsets of the complete dataset. Subsets of 75, 50, 33, 25, 10, and five points were examined (Table 63).

Mann-Whitney nonparametric tests were used to examine the significance of the differences between the spatially balanced on-trail dataset and the 100 meter interval on-trail dataset. The results of the Mann-Whitney test show no significant differences between any of the subsets. Results are reported in Tables 64-69.

Table 63. Width and Depth Results for Spatially Balanced On Trail Points

Data Set (# of sample points)	Average Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
Spatially Balanced (99 points)	4.50 ft	1.33	9.20	2.54 in	0	11.80 in
Spatially Balanced (75 points)	4.35	1.33	8.80	2.74	0	11.80
Spatially Balanced (50 points)	4.46	1.33	8.80	2.67	0	11.80
Spatially Balanced (33 points)	4.49	1.33	8.80	2.70	0	8.80
Spatially Balanced (25 points)	4.49	1.33	8.80	2.69	0	8.80
Spatially Balanced (10 points)	4.45	2.70	8.80	2.54	0	5.00
Spatially Balanced (5 points)	5.08	2.90	8.80	2.58	0	5.00

Table 64. Complete Spatially Balanced Sample vs. 75 Spatially Balanced Points

Survey Item	Spatially Balanced Mean (99Points)	Spatially Balanced Mean (75Points)	n99 Points	n75 Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.50 ft	4.35	92	71	-.499	3117.0	.618
Mean Depth	2.54 in	2.74	99	75	-.639	3502.5	.523

Table 65. Complete Spatially Balanced Sample vs. 50 Spatially Balanced Points

Survey Item	Spatially Balanced Mean (99Points)	Spatially Balanced Mean (75Points)	n99 Points	n75 Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.50 ft	4.46	92	47	-.060	2148.5	.952
Mean Depth	2.54 in	2.67	99	50	-.616	2322.0	.538

Table 66. Complete Spatially Balanced Sample vs. 33 Spatially Balanced Points

Survey Item	Spatially Balanced Mean (99Points)	Spatially Balanced Mean (33Points)	n99 Points	n33 Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.50 ft	4.49	92	32	-.077	1458.5	.939
Mean Depth	2.54 in	2.70	99	33	-.794	1482.5	.427

Table 67. Complete Spatially Balanced Sample vs. 25 Spatially Balanced Points

Survey Item	Spatially Balanced Mean (99Points)	Spatially Balanced Mean (25Points)	n99 Points	n25 Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.50 ft	4.49	92	24	-.027	1100.0	.978
Mean Depth	2.54 in	2.69	99	25	-.754	1116.5	.451

Table 68. Complete Spatially Balanced Sample vs. 10 Spatially Balanced Points

Survey Item	Spatially Balanced Mean (99Points)	Spatially Balanced Mean (10Points)	n99 Points	n10 Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.50 ft	4.46	92	9	-.324	342.0	.746
Mean Depth	2.54 in	2.57	99	10	-518	399.0	.605

Table 69. Complete Spatially Balanced Sample vs. 5 Spatially Balanced Points

Survey Item	Spatially Balanced Mean (99Points)	Spatially Balanced Mean (5Points)	n99 Points	n5 Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.50 ft	5.08	92	5	-.441	203.0	.659
Mean Depth	2.54 in	2.58	99	5	-.251	231.0	.802

Odd and even points were removed from the interval dataset in order to examine 200 meter datasets. The odd numbered dataset (47 points) starts at the trailhead while the even numbered dataset (46 points) starts 100 meters beyond the trailhead. A 300 meter dataset (33 points) was created by removing every third sample point originating at the trailhead.

Mann-Whitney tests were performed to examine the significance of the differences between the subsets and the complete dataset. No statistically significant differences were found. Results are displayed in Tables 70-72.

Table 70. 100 Meter Sample vs. 200 Meter Sample (Starting at Trailhead)

Survey Item	100 Meter Interval Mean (93Points)	200 Meter Interval Mean (47Points)	n 100 Meter Points	n 200 Meter Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.33 ft	4.48	91	46	-.910	1893.0	.363
Mean Depth	2.54 in	2.63	93	47	-.119	2158.0	.905

Table 71. 100 Meter Sample vs. 200 Meter Sample (Starting 100 Meters from Trailhead)

Survey Item	100 Meter Interval Mean (93Points)	200 Meter Interval Mean (46Points)	n 100 Meter Points	n 200 Meter Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.33 ft	3.98	91	45	-.924	1848	.356
Mean Depth	2.54 in	2.43	93	46	-.121	2112	.903

Table 72. 100 Meter Sample vs. 300 Meter Sample (Starting at Trailhead)

Survey Item	100 Meter Interval Mean (93Points)	300 Meter Interval Mean (31Points)	n 100 Meter Points	n 300 Meter Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.33 ft	4.33	91	30	-.060	1355.0	.952
Mean Depth	2.54 in	2.52	93	31	-.434	1366.5	.664

Results from the subsets of the spatially balanced dataset were compared to the results of the complete 100 meter interval on-trail dataset. Mann-Whitney tests were performed to examine the significance of the differences between the datasets. No statistically significant differences were found. Results are reported in Tables 73-79.

Table 73. Complete 100 Meter Interval Dataset vs. Complete Spatially Balanced Dataset

Survey Item	100 Meter Interval Mean	Spatially Balanced Mean	n 100 Meter Interval Points	n Spatially Balanced Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.33 ft	4.70	91	83	-1.522	3270.5	.128
Mean Depth	2.54 in	2.71	93	83	-1.292	3424.0	.196

Table 74. Complete 100 Meter Interval Dataset vs. 75 Points Spatially Balanced Points

Survey Item	100 Meter Interval Mean	Spatially Balanced Mean	n 100 Meter Interval Points	n Spatially Balanced Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.33 ft	4.54	91	64	-.834	2682.5	.404
Mean Depth	2.54 in	2.86	93	64	-1.629	2520.5	.103

Table 75. Complete 100 Meter Interval Dataset vs.50 Spatially Balanced Points

Survey Item	100 Meter Interval Mean	Spatially Balanced Mean	n 100 Meter Interval Points	n Spatially Balanced Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.33 ft	4.59	91	44	-.885	1813.5	.376
Mean Depth	2.54 in	2.84	93	44	-1.602	1699.0	.109

Table 76. Complete 100 Meter Interval Dataset vs. 33 Spatially Balanced

Survey Item	100 Meter Interval Mean	Spatially Balanced Mean	n 100 Meter Interval Points	n Spatially Balanced Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.33 ft	4.61	91	30	-.721	1245.0	.471
Mean Depth	2.54 in	2.71	93	30	-1.266	1180.5	.206

Table 77. Complete 100 Meter Interval Dataset vs. 25 Spatially Balanced Points

Survey Item	100 Meter Interval Mean	Spatially Balanced Mean	n 100 Meter Interval Points	n Spatially Balanced Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.33 ft	4.57	91	23	-.562	967.0	.574
Mean Depth	2.54 in	2.77	93	23	-1.235	891.5	.217

Table 78. Complete 100 Meter Interval Dataset vs.10 Spatially Balanced Points

Survey Item	100 Meter Interval Mean	Spatially Balanced Mean	n 100 Meter Interval Points	n Spatially Balanced Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.33 ft	4.69	91	8	-.161	351.0	.872
Mean Depth	2.54 in	2.75	93	8	-.921	299.0	.357

Table 79. Complete 100 Meter Interval Dataset vs. 5 Spatially Balanced Points

Survey Item	100 Meter Interval Mean	Spatially Balanced Mean	n 100 Meter Interval Points	n Spatially Balanced Points	Mann Whitney Z	Mann Whitney	*p*
Mean Width	4.33 ft	5.08	91	5	-.380	204.5	.704
Mean Depth	2.54 in	2.58	93	5	-.405	207.5	.686

Trail conditions of individual trail segments were also examined (Table 80, Figures 45-46). Mann-Whitney nonparametric tests were used to examine the significance of the differences between the datasets. No statistically significant differences were found among trail depth results and only three trail width results were found to be significantly different: Fire Trail junction-Alberta Falls, Alberta Falls-North Longs Peak junction, and North Longs Peak junction-Mills Lake junction (Tables 81-88).

Table 80. Mean trail widths and visitation levels

Trail Segment	Mean Width-Spatially Balanced	Mean Depth-Spatially Balanced	Mean Width – 100 Meter Interval	Mean Depth – 100 Meter Interval	Mean Daily Visits
Trailhead-Bear Lake Jct	6.15	0.00	6.64	0.00	425
Bear LakeJCT-Fire Trail	6.35	2.62	5.40	1.33	447
Fire Trail-AlbertaFalls	7.46	2.99	5.50	2.76	455
AlbertaFalls-NorthLongsJCT	5.96	4.67	4.87	3.03	209
NorthLongsJCT-MillsLakeJCT	5.26	2.56	4.50	1.83	209
FireTrail-Mills Lake Jct	3.42	1.23	3.89	1.58	33
MillsLakeJCT-Jewel Lake	3.66	1.77	4.44	2.54	158
JewelLake-GGCampsite	3.59	2.48	3.64	1.86	60
GGCampsiteJCT-BlackLake	3.68	3.62	3.38	5.42	46
Black Lake-Frozen Lake	2.84	1.80	n/a	n/a	n/a

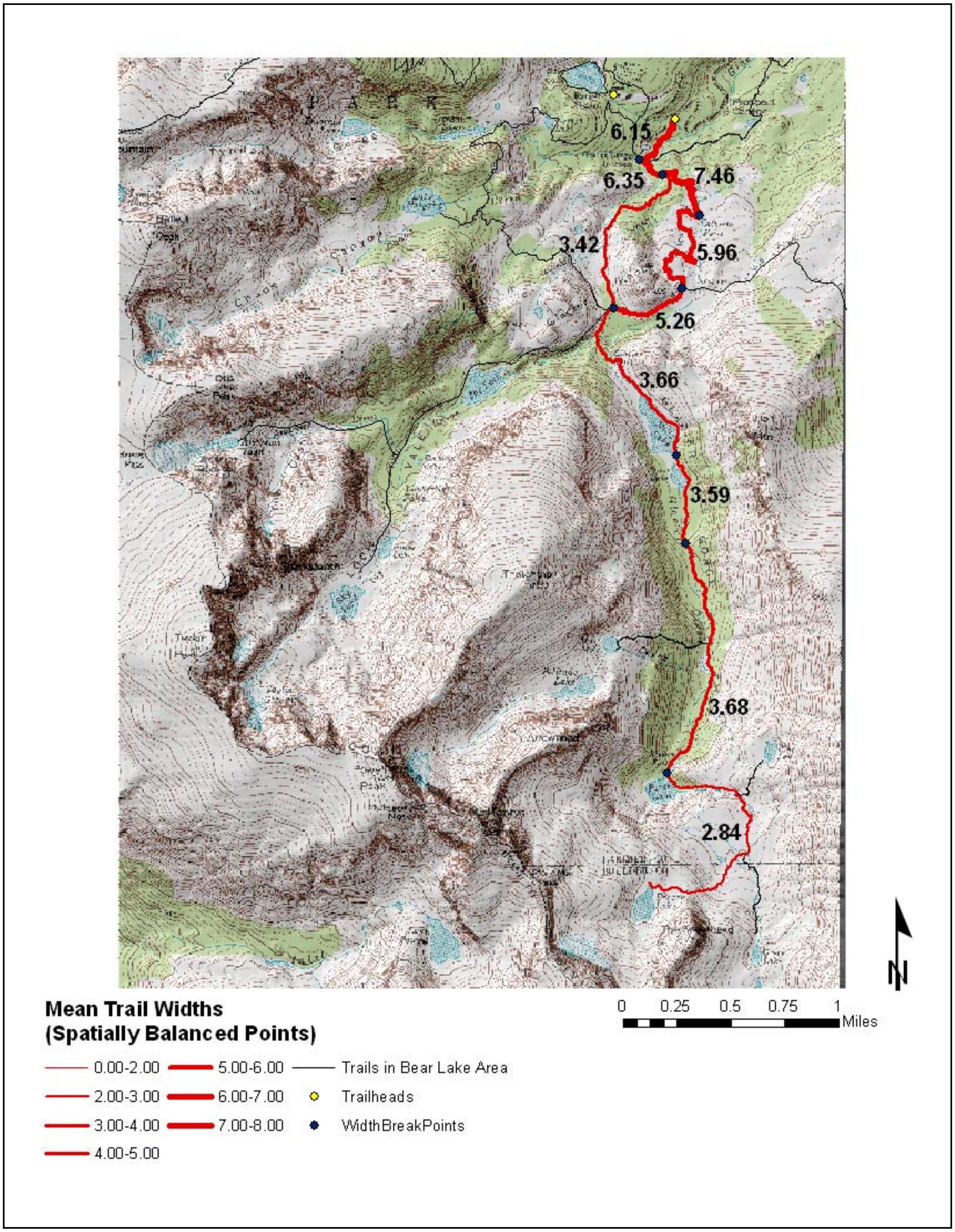

Figure 45. Mean trail widths for on-trail spatially balanced dataset

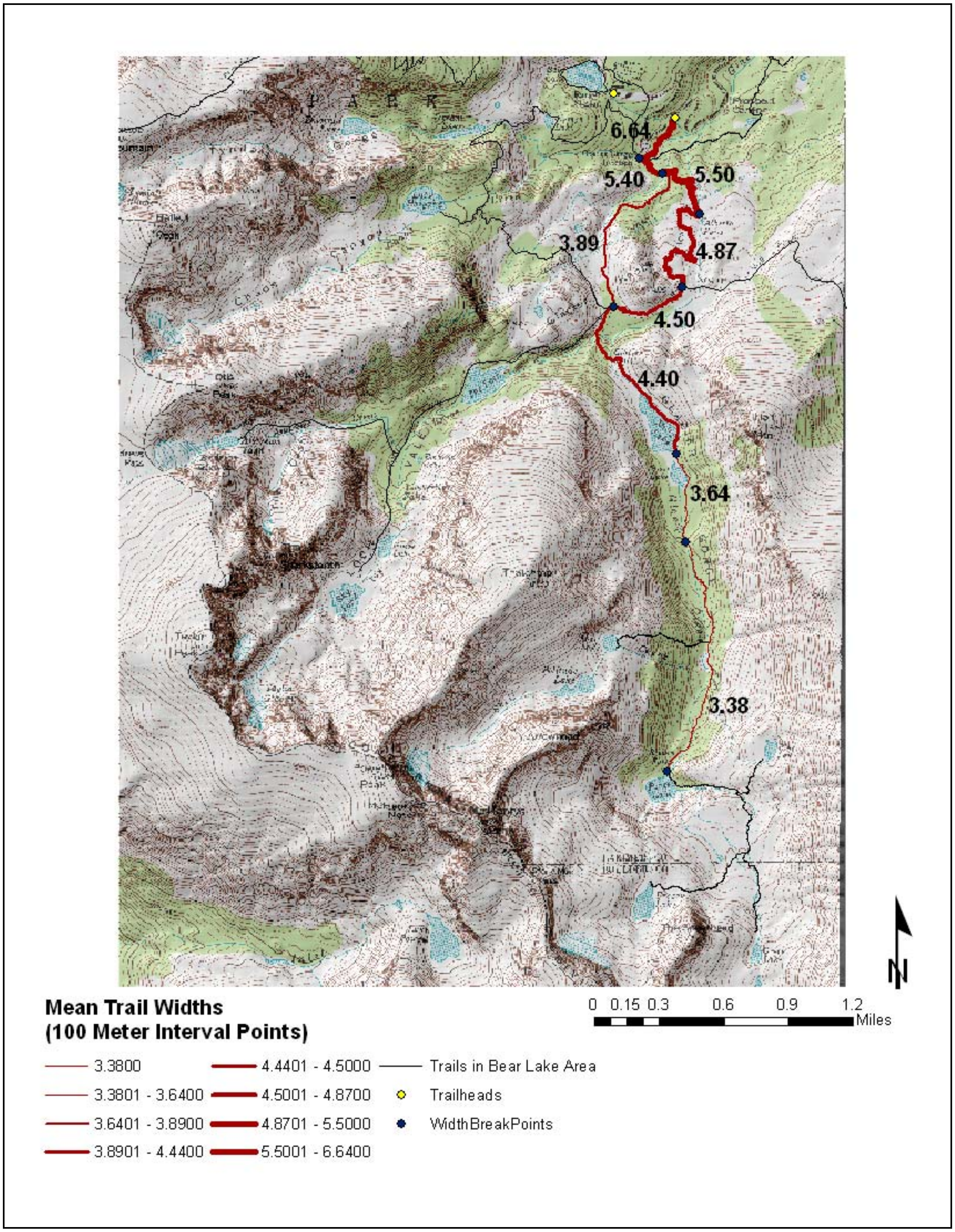

Figure 46. Mean trail widths for on-trail 100 meter dataset.

Table 81. Trailhead-Bear Lake junction trail width and depth comparison

Survey Item	Mean- Spatially Balanced	Mean- 100 Meter Interval	n points- Spatially Balanced	n points- 100 Meter Interval	Z	Mann Whitney	*p*
Mean Width	6.15	6.65	2	5	-.195	4.50	.857
Mean Depth	0.00	0.00	2	5	.000	5.00	1.00

Table 82. Bear Lake junction-Fire Trail junction trail width and depth comparison

Survey Item	Mean- Spatially Balanced	Mean- 100 Meter Interval	n points- Spatially Balanced	n points- 100 Meter Interval	Z	Mann Whitney	*p*
Mean Width	6.35	5.40	2	3	-1.155	1.00	.248
Mean Depth	2.60	1.33	2	3	-1.732	.000	.083

Table 83. Fire Trail junction-Alberta Falls trail width and depth comparison

Survey Item	Mean- Spatially Balanced	Mean- 100 Meter Interval	n points- Spatially Balanced	n points- 100 Meter Interval	Z	Mann Whitney	*p*
Mean Width	7.46	5.50	7	6	-2.477	4.00	.013
Mean Depth	2.99	2.76	7	6	-3.580	18.50	.720

Table 84. Alberta Falls-North Longs Peak junction trail width and depth comparison

Survey Item	Mean- Spatially Balanced	Mean- 100 Meter Interval	n points- Spatially Balanced	n points- 100 Meter Interval	Z	Mann Whitney	*p*
Mean Width	5.96	4.88	15	13	-3.232	27.50	.001
Mean Depth	4.67	3.03	15	13	-1.267	70.00	.205

Table 85. North Longs Peak junction-Mills Lake junction trail width and depth comparison

Survey Item	Mean- Spatially Balanced	Mean- 100 Meter Interval	n points- Spatially Balanced	n points- 100 Meter Interval	Z	Mann Whitney	*p*
Mean Width	5.26	4.36	12	7	-2.249	15.50	.025
Mean Depth	2.56	1.83	12	7	-1.138	26.50	.188

Table 86. Mills Lake junction-Jewel Lake trail width and depth comparison

Survey Item	Mean- Spatially Balanced	Mean- 100 Meter Interval	n points- Spatially Balanced	n points- 100 Meter Interval	Z	Mann Whitney	*p*
Mean Width	3.66	4.48	16	16	-1.707	71.00	.088
Mean Depth	1.23	1.58	16	16	-.114	125.00	.909

Table 87. Jewel Lake-Glacier Creek campsite trail width and depth comparison

Survey Item	Mean- Spatially Balanced	Mean- 100 Meter Interval	n points- Spatially Balanced	n points- 100 Meter Interval	Z	Mann Whitney	*p*
Mean Width	3.59	3.65	6	7	-.358	18.50	.721
Mean Depth	1.77	2.54	6	7	.000	21.00	1.00

Table 88. Glacier Creek campsite-Black Lake trail width and depth comparison

Survey Item	Mean- Spatially Balanced	Mean- 100 Meter Interval	n points- Spatially Balanced	n points- 100 Meter Interval	Z	Mann Whitney	*p*
Mean Width	3.42	3.89	10	15	-1.722	44.00	.085
Mean Depth	3.62	5.42	10	15	-.999	57.00	.318

Factors Contributing to Trail Width and Depth

Regression analyses were conducted to examine the influence of visitation on trail conditions. Visitation levels have been identified in the literature as a contributing factor that influences trail widths (Dale & Hartley, 1978; Cole, 1991). Visitation levels documented in this study (Appendix B) were used in linear regression analyses as the independent variable and trail width was used as the dependent variable (Table 89).

Table 89. Regression results of trail width at individual points–mean daily visitation

Dataset	R	R^2	Adjusted R^2
Spatially Balanced Dataset	.733	.537	.532
100 Meter Interval Dataset	.564	.319	.311

While visitation levels have been shown to have a relationship with trail width, trail erosion has been shown to be affected by physical processes. Length to the nearest uphill water break, trail slope, and trail alignment have been identified as potential factors that influence the amount of erosion (Leung, 2000; Cole, 1991).

Regression analyses were conducted to test the hypothesis that visitation levels are not a contributing factor of trail erosion (Table 90). Trail erosion was measured as trail depth in this study.

Table 90. Regression results of trail depth at individual points–mean daily visitation

Dataset	R	R^2	Adjusted R^2
Spatially Balanced Dataset	.015	.000	-.012
100 Meter Interval Dataset	.219	.048	.037

Regression analyses were also conducted to examine the influence of physical factors that may contribute to trail erosion. Length to nearest uphill water break in the 100 meter interval on-trail dataset resulted in the highest R^2 value (Table 91). Analyses of trail slope, number of water bars in quadrat, number of retainer bars in quadrat, and trail alignment all yielded R^2 results less than .050.

Table 91. Regression results of trail depth-length to nearest uphill water break

Dataset	R	R^2	Adjusted R^2
Spatially Balanced Dataset	.664	.441	.435
100 Meter Interval Dataset	.275	.075	.066

Extreme Trail Widths and Depths

Trail widths ranged from a minimum of 1 ft to 9.20 feet in the spatially balanced on-trail dataset and ranged from a minimum of 1 ft to 9.83 feet in the 100 meter on-trail dataset. Widths 5 feet or wider are displayed in Figures 47-48.

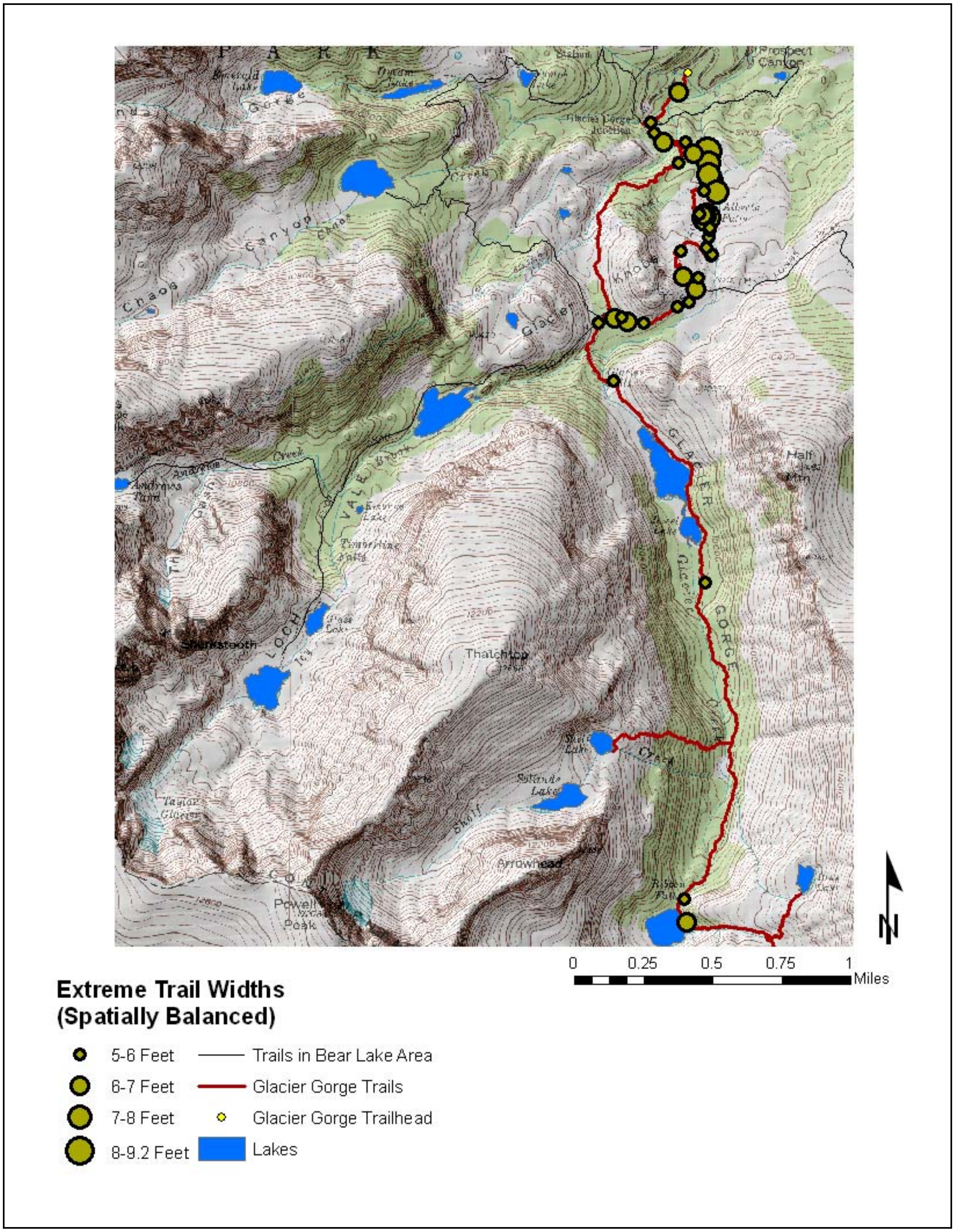

Figure 47. Sample points with trail widths >5 feet (Spatially balanced on-trail dataset)

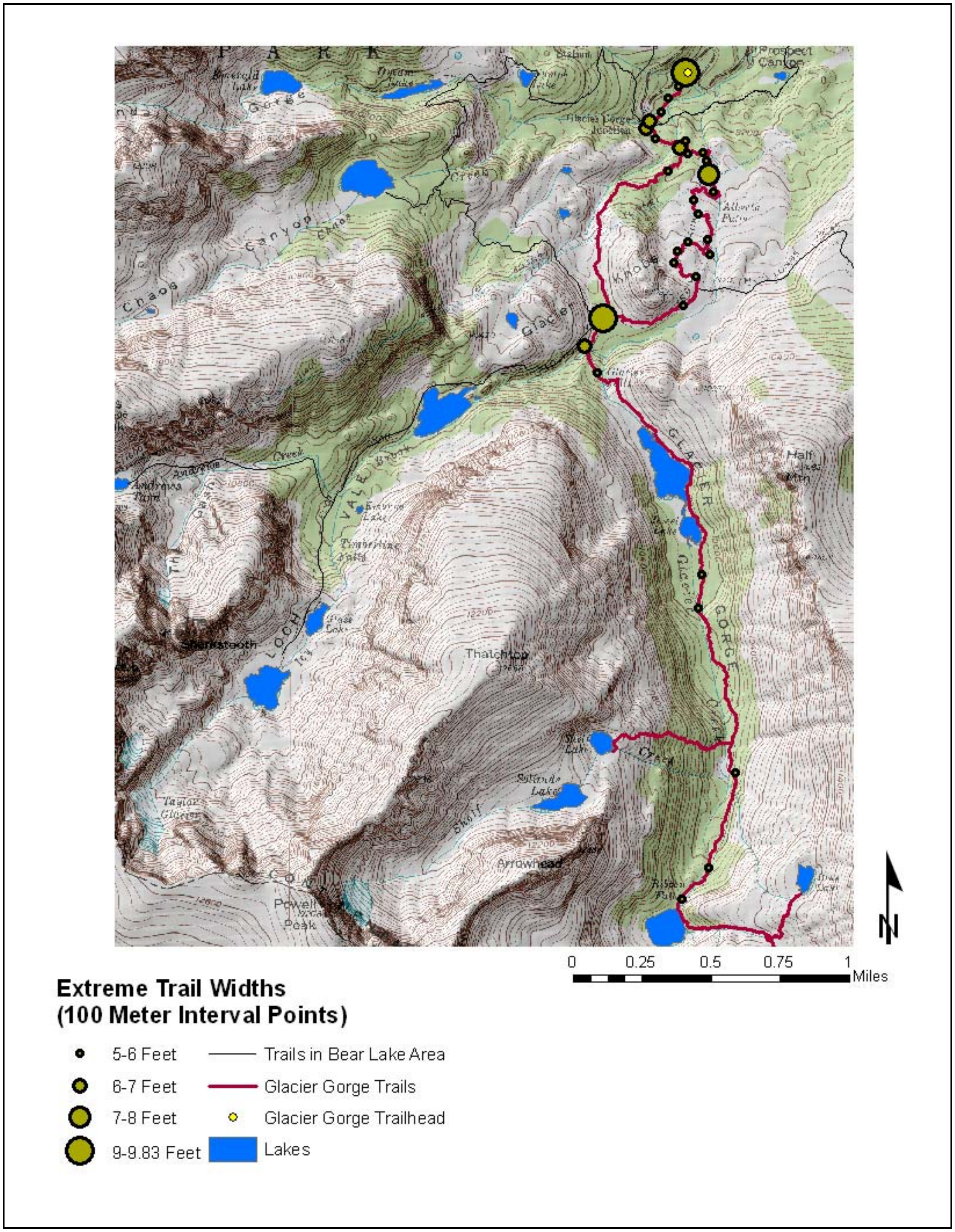

Figure 48. Sample points with trail widths >5 feet (100 meter interval on-trail dataset)

Trail depths ranged from 0-11.8 inches in the spatially balanced on-trail dataset. Depths greater than four inches are displayed in Figure 49.

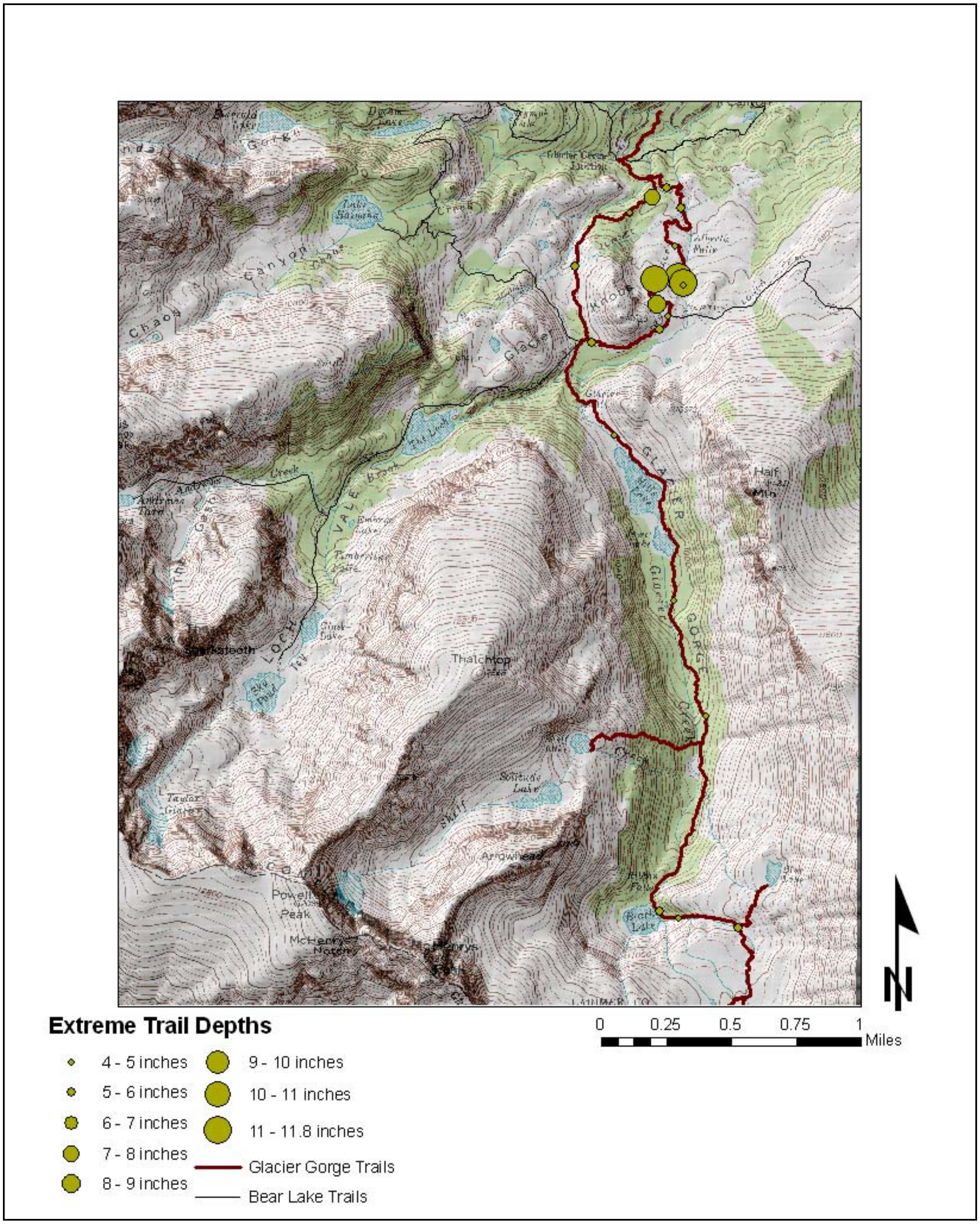

Figure 49. Locations of extreme trail depths (spatially balanced on-trail dataset)

Trail depths ranged from 0-16.1 inches in the 100 meter interval on-trail dataset. Depths greater than four inches are displayed in Figure 50.

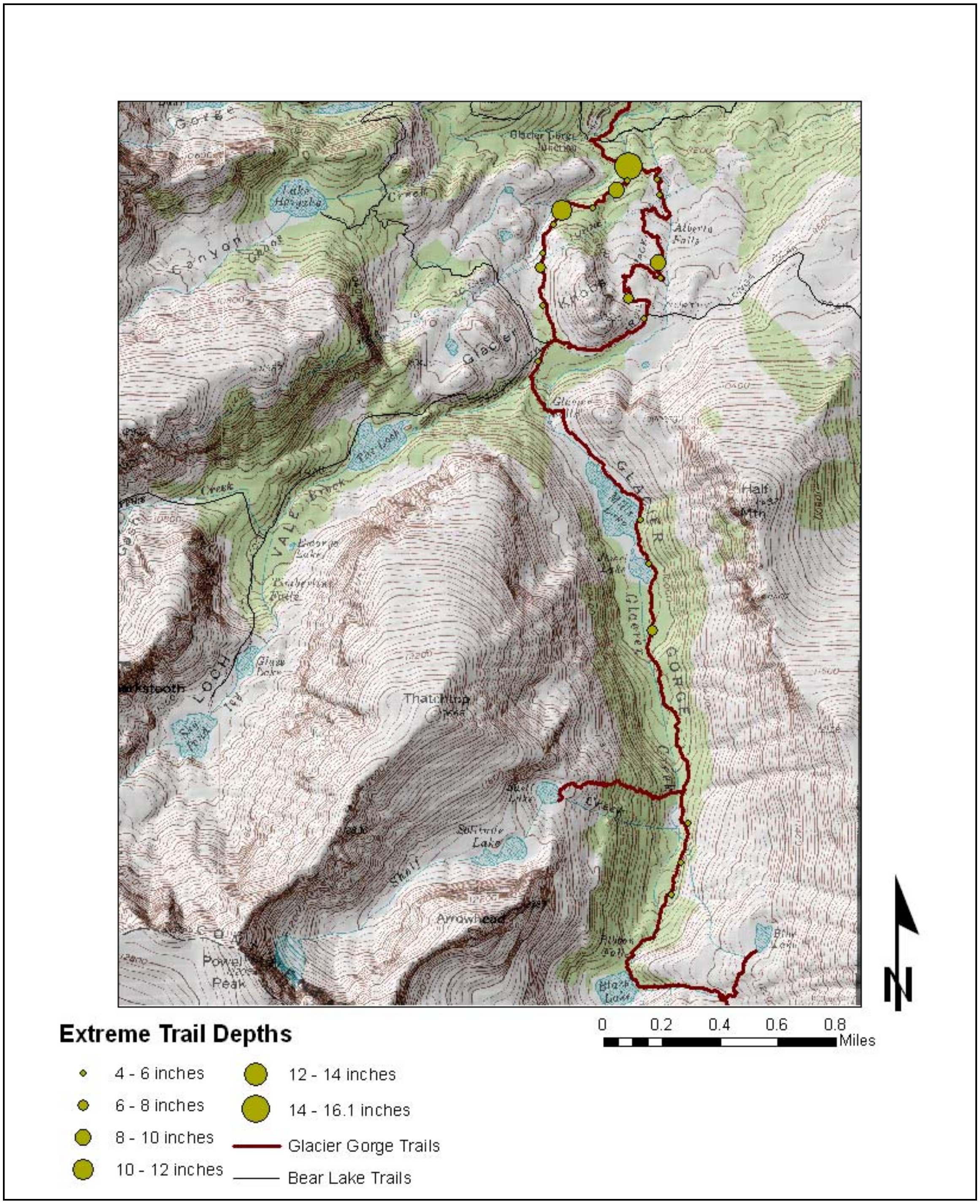

Figure 50. Locations of extreme trail depths (100 meter interval on-trail dataset)

Discussion

The proliferation of recreation related impacts in parks and protected areas is a growing concern to land managers. However, few studies have examined the spatial qualities of impacts caused by recreation use. This study examined four sampling methods to estimate the extent of recreation impacts within the Glacier Gorge drainage. The sampling methods used in this study identified areas where recreation use impacts occurred. These areas were considered "hot spots" and defined as areas where statistically significant clusters of impacts occurred.

Increased monitoring efforts should now be focused in areas that have been identified as "hot spots" for recreation related impact occurrences. Census methods can be used to obtain the most accurate estimation of impact occurrence and proliferation. Data collected in a census method can then be applied to a management by objectives framework in order to create indicators and standards of quality.

This discussion section contains: an evaluation of the methods used in this project, a discussion of the results found in this study, and recommendations for RMNP managers.

A. Sampling Plans

The off-trail 150 meter buffer spatially balanced sampling plan, on-trail spatially balanced sampling plan, and 100 meter interval on-trail sampling plan were effective methods to identify where impacts occurred along the Glacier Gorge trail. Results of these three datasets revealed similar locations for social trail, litter, and vandalism occurrences. The on-trail datasets also yielded similar results for the condition of the

Glacier Gorge trail. The spatially balanced off-trail sampling plan, however, was less effective.

The intent of the spatially balanced off-trail sampling plan was to estimate the extent of recreation impacts within the entire Glacier Gorge drainage. However, it became apparent early in the data collection process that the majority of recreation related impacts occurred within 150 m of the maintained trail. Social trails and areas littered with toilet paper were encountered on the way to remote sample points in the spatially balanced off-trail sampling plan. The only remote impacts identified by this sampling plan were a lightly worn social trail and one occurrence of litter (a multi tool) above Mills Lake. The multi tool was considered litter in the litter analysis but is not necessarily the type of object associated with litter or trash. All other impacts identified by the spatially balanced off-trail sampling plan were near the main trail at Black Lake and near the Bear Lake parking lot. The lack of recreation impacts found in the spatially balanced off-trail dataset suggests that recreation impacts are not widespread throughout the entire Glacier Gorge drainage but are concentrated in areas near the main trail.

The results of the spatially balanced off-trail dataset initiated the creation of the spatially balanced 150 meter buffer off-trail sampling plan. This illustrates the flexibility of the spatially balanced sampling method. Areas of concern can be targeted by this sampling method and conditions evaluated without having to sample areas of less concern. Unlike the 100 meter interval on-trail sampling method, the number of sample points collected in a dataset can be chosen. This can be beneficial if data collection time is limited or a quick estimate of conditions is desired. The drawback to limiting a study area is that generalizations can only be made about the area sampled.

B. Data Collection

Each point in the spatially balanced sampling plans was navigated to using a Dell Axiom PDA with a Pharos wireless bluetooth GPS unit. *ArcPad* was used to collect data at each sample point. This was a reliable, efficient method to collect data and eliminated the need for data entry. The advantage of using *ArcPad* was the ability to create GIS shapefiles in the field. At the end of each day data was downloaded from the PDA to a personal computer and could be viewed immediately in *ArcGIS*.

In order to operate *ArcPad,* some training and basic GIS/GPS knowledge is required. Basic knowledge about map projections, datums, shapefile types, feature attributes, and GPS navigation techniques are necessary to operate *ArcPad* effectively.

C. Sampling Protocol

In early discussions with RMNP managers about this project, both trail conditions and recreation related impacts were identified as concerns. The goal of this project was to explore methods to identify and quantify these types of impacts. Topographic features, physical features, and recreation related impacts were collected in this study in order to identify relevant data.

Topographic Features

Topographic features measured in this study did not yield any significant results in any analyses. Trail aspect, trail position, and elevation were quick and easy variables to measure and could be useful references for sample points. Trail aspect and trail position are recommended variables to be collected in future studies. It is not necessary to collect elevation values from the GPS because digital elevation models (DEM) can easily identify elevations during GIS analysis.

Clinometer readings for trail slope were taken in every quadrat for all trails. While this variable did not yield any significant results in our analyses it was an easy variable to measure and has been identified in the literature as a potential factor contributing to trail erosion. It is recommended to collect this variable in future studies.

Clinometer readings for the slope of the site area were taken in every quadrat. The steepest aspect was considered the fall line and was used to identify trail alignment. Trail alignment was identified as a percentage:

$$\frac{\text{Trail Slope}}{\text{Fall Line Slope}}$$

A trail alignment of 100% would follow the fall line while a lower percentage would represent a trail alignment more perpendicular with the fall line. Slope of the site area was the most time consuming variable to collect. Areas choked with brush or on steep slopes made collection difficult. Additionally, this variable yielded no significant results in any analyses. It is not recommended to collect this variable in future studies primarily because of the amount of time needed for collection.

Physical Features

Dominant types of understory and tree types for each quadrat were collected in this study but were not used in any analysis because a highly accurate vegetation map of RMNP was available. A surveyor knowledgeable about vegetation types in RMNP would be able to collect this data quickly and easily. This variable is not recommended for collection in future studies because of the availability of high quality electronic vegetation data.

Canopy cover was an easily collected variable but was not found to be significant in any analyses. This variable is recommended for collection if a spherical densiometer is available to the surveyor.

Recreation Impacts

Recreation related impacts collected in this study included on-trail and off-trail impacts. On-trail impacts measured trail condition and off-trail impacts examined the proliferation of visitor caused impacts such as social trail development, litter, and vandalism. All recreation impact variables documented in this study are recommended for collection in future studies.

Trail depths and widths were integral variables in this study that were quickly and easily collected. These variables helped describe the condition of the Glacier Gorge trail and statistically significant analyses of these variables were found.

Maximum trail depth was selected for this study instead of the more detailed cross sectional area loss (CSAL) technique developed by Cole (1989). While the CSAL method details how much soil is lost at a trail location this technique takes more time to collect. Measuring maximum trail depth does not quantify the amount of soil loss but quickly identifies trail sections where erosion is occurring. Recommended actions or continued monitoring can be identified by park managers for trail sections with extreme trail depths.

This study considered any trail depth lower than the downhill edge of the trail. Some of these areas included reconstructed sections with retainer bars put in below grade (Figure 51). Sometimes trail sections are reconstructed below the natural grade of an area in order to create a consistent trail slope. These reconstructed areas may not reflect

Figure 51. Example of retainer bars constructed below the natural grade

natural erosion patterns. Future studies should consider measuring trail depth below existing retainer bars instead of below the downhill edge of the trail.

Quantities and types of trail maintenance structures were documented in this study. This is useful information that can identify the effectiveness of trail maintenance efforts. Although this data did not yield any statistically significant results in analyses, trail structures are obvious factors that influence the rate of trail erosion.

Distance from the nearest uphill water break was collected in this study. Results from trail depth analyses were mixed when distance to nearest water break was considered. However, insufficient data about trail maintenance structures may have affected results. Future studies should consider documenting the quantities and types of trail structures found below the nearest water break in addition to those found within the quadrat. This data may prove useful in future analyses of trail erosion.

Root exposure was measured as the number of visibly exposed roots. However, measuring linear distance of root exposure may be a more effective way of analyzing root exposure. Root frequency does not describe how much of a root is exposed. A single, large root exposed for 15 feet may be a greater concern than 15 roots exposed less than six inches. Analysis of this variable yielded no statistically significant results. If collected in future monitoring efforts, root exposure should be measured as linear distance instead of frequency.

Litter was measured as the number of pieces of trash found within a quadrat. This measurement worked well for litter since it is a discrete variable.

Trail widths and depths were measured for each trail braid. These measurements were documented under the social trail depth and width columns but were identified as a braid in a separate column. This method required extra analysis time to identify social trail width and depth values from braided trail width and depth values. Future studies should consider unique trail width and depth columns specifically for braids to simplify the analysis process.

Social trails were diagramed and the amount of vegetation lost caused by social trails was estimated. This data yielded a map of vegetation loss due to social trail development. Future studies should consider using a denser grid on the quadrat diagram to estimate vegetation loss. A denser grid would yield a more accurate estimation of vegetation loss and provide more variation between quadrats. The linear distance of social trails within a quadrat should also be measured.

The presence or absence of any vandalism occurrence within a quadrat was documented. This was an exploratory variable that could measure any condition considered vandalism. However, the only occurrences of vandalism in this study were carvings into aspen trees. Trees carvings should become a new variable in future studies that documents the number of trees with carvings within a quadrat.

No fire rings were found in this study. However, we recommend that this variable be collected in future studies.

Very few invasive species were found in this study. Canadian thistle and dandelion were found near the Glacier Gorge/Bear Lake trail junction early in August but had been eradicated by the end of the study. Even though high elevation areas in RMNP are generally devoid of invasive species we recommend this variable be collected in future monitoring efforts.

The presence or absence of human waste was documented. However, this variable should be integrated into the litter variable. In this study, human waste was found as used toilet paper and was not visible without the presence of toilet paper. It would be more effective to document where used toilet paper occurred and infer that human waste was present within the quadrat.

Recommendations for the sampling protocol are summarized in Table 92.

Table 92. Recommendations for sampling protocol

Variable	Recommendation
Trail aspect	Yes
Trail position	Yes
Elevation	No
Trail slope	Yes
Slope of site area	No
Dominant understory	No
Dominant tree types	No
Canopy cover	Yes
Trail depth	Yes
Trail width	Yes
Trail structures	Yes
Distance to nearest water break	Yes
Litter occurrence	Yes
Trail braids	Yes
Social trails	Yes
Vandalism	Yes
Fire rings	Yes
Tree carvings (new)	Yes
Invasive species	Yes
Human waste	No

D. Visitor Use Monitors

The first goal of this project was to estimate the amount of use at different points along the Glacier Gorge trail in order to examine how visitor use decayed as a function of distance from the trailhead. While the use of automated visitor monitors was an effective method to capture visitor use levels it should be noted that some training and experience is required to fully learn how to operate the *Trail Master* monitors (Figures 52-53) and accompanying software.

Placement is the most crucial component affecting visitor monitor performance. In this study, monitors were placed at trail junctions and destination areas. In general, these are areas where visitors hike to and decide to stop or continue on from. Monitors were placed a little below these areas along the main Glacier Gorge trail in order to avoid capturing visitors milling about. When possible, narrow sections of trail with dense trees

Figure 52. *Trail Master* visitor monitor 1

Figure 53. Monitor 1 attached to tree

or shrubs on each side were chosen so that visitors would be most likely to be single file. Trees with an 8-16 inch diameter at breast height (dbh) were found to be optimal for attaching monitors.

Frequent data collection is important since each *Trail Master* monitor can capture only 8,000 events. In high use areas monitors should be checked every other day at the beginning of a study to estimate how many daily events are being captured. If data is not downloaded before 8,000 events, the unit will stop capturing data. During summer months monitors may fill up in a matter of days. Units that are placed further in the backcountry can be left for longer periods of time. However, data should be collected regularly in order to check the effectiveness of monitor placement and that no abnormal events are affecting the unit (e.g. visitor tampering).

The *Trail Master* monitor system comes with software to download data to a personal computer. Unfortunately, there are compatibility problems with the software package when using *Microsoft Windows XP*. While data can be downloaded using *Trail Master Stat Pack* it cannot be viewed. The downloaded data can be accessed from a temporary file in the Stat Pack program file, but this method is not advised. It is recommended that RMNP purchase an updated version of the *Trail Master Stat Pack.*

Results

Visitor use was highest in areas close to the trailhead and diminished at further distances from the trailhead. Alberta Falls (67.9% of visitation to the Glacier Gorge trail) receives far more use than Mills Lake (28.6% of visitation to the Glacier Gorge trail) or Black Lake (8.7% of visitation to the Glacier Gorge trail).

Distance from the trailhead explained 69.8% of the variation in visitor use levels. Access times along the Glacier Gorge trail also explained 69.8% of the variation in visitor use. While these results are encouraging towards the creation of predictive models of visitation use based on trailhead quotas, more research is needed to validate these findings.

Visitor use is temporally clustered. Visitation levels are highest during the mid-day and early afternoon hours. The highest visitation rates for all monitors occurred between 12 pm and 3 pm. *Furthermore, over 50% of the visitation in this study occurred between 11 am and 3 pm.*

Implications

These results show that most visitors use the Glacier Gorge trail for short trips to Alberta Falls. This implies that Alberta Falls is a high use destination area. While Mills

Lake and Black Lake receive fewer visitors than Alberta Falls, the rate of decay analysis indicates that visitation to these backcountry locations may increase if overall visitation to the Glacier Gorge trail increases. Once again, more research is needed to verify if these rates of decay are consistent with overall trail use.

E. Social Trails

Results from the social trail analysis imply that social trails are not widespread occurrences throughout the Glacier Gorge drainage but are clustered in areas near the Glacier Gorge trail. Sample points with social trails occurred closer to the main trail than sample points without social trails in both off-trail datasets. Mann-Whitney tests found that distance to the Glacier Gorge trail was statistically significant in the spatially balanced 150 meter buffer off-trail dataset but not in the spatially balanced off-trail dataset. However, since only three social trails were found in the off-trail dataset these results can be expected.

Vegetation loss greater than 5% is mostly concentrated in areas around trail junctions, Alberta Falls, and lake areas. The analysis of distances from destination areas revealed that sample points with social trails occur closer to lakes, trail junctions, and Alberta Falls than sample points without social trail occurrences. Destination distance to social trails was found to be statistically significant in all of the datasets except for the spatially balanced on-trail dataset.

The Getis-Ord analysis identified areas where statistically significant clusters of vegetation loss caused by social trails occurred. Areas where statistically significant clusters of social trails occur can be considered “hotspots” for social trail proliferation.

All datasets except the spatially balanced off-trail dataset identified “hotspots” near Alberta Falls.

Vegetation types within social trail “hot spots” were identified. Locations of vegetation types were displayed in maps and vegetation quantities summarized in Tables 31-44. This information will help RMNP managers focus monitoring efforts in areas where sensitive vegetation types may be affected by visitor use.

Social Trail Condition Description

Areas around Alberta Falls had the most vegetation loss caused by social trails (Figure 54) and were the most statistically significant areas found in the Getis-Ord analysis. Multiple social trails accessing Glacier Creek exist below the Alberta Falls viewing area. After the main trail passes Alberta Falls it travels away from Glacier Creek and then loops back towards the creek only a couple of hundred meters upstream from Alberta Falls. Hikers travel a long distance along the main trail to gain a relatively short amount of stream distance. Trails with sinuous tendencies are prone to short cutting. This situation coupled with its proximity to Alberta Falls and Glacier Creek makes this an attractive area for visitors to hike off trail.

Shortcuts between trails were found at the Mills Lake/Loch Vale junction (Figure 55) in the 100 meter interval on trail dataset. This is a typical problem at trail junctions and is difficult to prevent in flat, open areas such as this. While short cuts at trail junctions are undesirable, these short cuts are a minor concern when considering overall recreation impacts of the area and can be mitigated with basic trail maintenance.

Most social trails at Mills Lake were located on the north end of the lake. This is the busiest section of Mills Lake and offers spectacular views of Longs Peak, the

Figure 54. Social trails below Alberta Falls viewing area

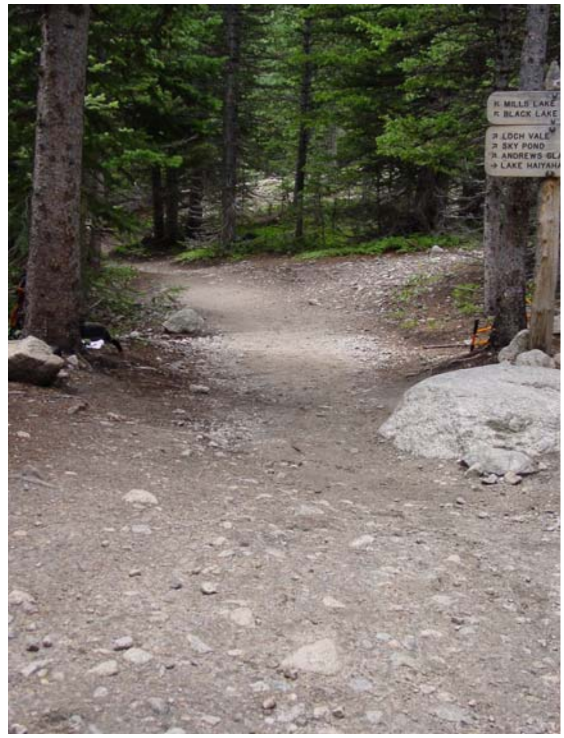

Figure 55. Mills Lake/Loch Vale junction

Spearhead, and the Continental Divide. Social trails in this area are, in general, short and provide access to the lake from the main trail. There are two large, bare areas caused by trampling near the outlet of the lake that visitors frequent. Social trails begin at these bare areas and follow the edge of the lake between these two impacted areas.

Social trails are less frequent beyond Mills and Jewel Lakes. The social trails beyond Mills and Jewel Lakes access Mills Creek and may be "fisherman trails". While many social trails in this area are short spurs that provide access to Mills Creek, there is a trail that parallels Mills Creek on its west side. This trail is continuous for long stretches and some evidence of maintenance was found. A cut branch was found along this trail, likely the result of a frequent visitor to this area (Figure 56). In past conversations, some

Figure 56. Cut branch on west side of Glacier Creek (spatially balanced 150 meter off-trail dataset sample point 22)

visitors have mentioned that they carry a small limbing saw in case they encounter obstacles in the trail. These visitors stress that they only cut branches protruding into maintained trails and not in off-trail situations. Overall, though, this seems to be an uncommon practice.

Socials trails have developed on both sides of the Black Lake outlet. Trails on the west side of the lake extend south around the lake and end at the talus fields on the extreme south side of the lake. Multiple trails cross the meadow area on the northeast side of the lake. The northeast side of Black Lake is a popular area for hikers to take breaks.

The main trail beyond Black Lake is unmaintained by RMNP but well established to tree line. Beyond tree line two main routes emerge, a high trail and a low trail. Both of these trails mostly cross slick rock terrain and rock cairns are used for navigation. These trails provide access to Frozen Lake, Green Lake, and the Spearhead. Since these trails mostly cross slick rock, spurious social trails have not developed in this area.

Social Trails leading to Remote Lakes

Trails that access remote lakes (Shelf, Solitude, Blue, Green, and Frozen Lakes) were identified as a concern by RMNP managers. While these trails can be considered "social trails" they need to be measured as continuous trail sections since they tend to be longer than the social trails mentioned in the previous section. Because the locations of these trails are easier to identify than spurious social trails, they can be targeted for trail condition monitoring.

The trail to Frozen Lake was surveyed as part of the spatially balanced on-trail dataset in this study. Locations of trails to Shelf, Blue, and Green Lakes were recorded with a GPS unit and are displayed in various maps in this report. While the conditions of these trails were not surveyed in this project, a brief condition description based on visual observations of each of these trails is given.

It is recommended that the condition of these trails be monitored using the methods established in this study. A sampling plan can be developed based on the GPS data acquired in this project.

Shelf Lake

The trail to Shelf Lake leaves the Glacier Gorge trail approximately one mile past Jewel Lake. The path from the main trail is not well worn and is only obvious to someone who is familiar with this trail. To access this trail, hikers must cross Glacier Creek. Once across the creek, the Shelf Lake trail becomes apparent. The trail quickly becomes steep and crosses many small creeks. Trail alignment is very poor and has been badly braided due to running water on the trail most of the summer. The alignment follows a steep fall line, is badly rutted, and is not well delineated. While the trail improves after it breaks out of the trees it becomes difficult to follow across rock fields. The trail becomes better defined as it crests the small ridge just before Shelf Lake. After crossing through some tall shrubs, the trail terminates at the outlet of Shelf Lake. No trails have developed beyond this point.

While the Shelf Lake trail is in poor condition, it is not a highly used trail (two hikers/day). RMNP maintenance crews may consider inspecting this trail at the beginning of each season and remove any major obstacles that would cause hikers to further braid this trail. Level of use should also be monitored to identify increasing use of the Shelf Lake trail.

Blue Lake

The trail to Blue Lake trail begins above tree line about 0.3 miles past Black Lake. A lightly worn path leaves the trail and winds uphill towards Blue Lake (Figure 57). However, this trail disappears less than 100 meters from the main trail and becomes a scramble across tundra that follows small cairns. While no established path has developed yet, Blue Lake is a short hike from the main trail and visitors familiar with this area can easily find it.

Currently, the trail to Blue Lake is not a concern; no path has become established and few visitors hike this far into the backcountry. It is advised that RMNP staff monitor

Figure 57. Trail to Blue Lake leaving main trail

the condition of this area to identify any trail development.

Green Lake

The trail to Green Lake is similar to Blue Lake. Most of the path to Green Lake is not established but a few sections show light development. Green Lake is more remote than Blue Lake and a much longer hike. Few visitors hike this far into the backcountry but it is still recommended that use in this area be monitored.

Implications

Intensive monitoring should be focused in areas where social trail "hot spots" have been identified. The extent of these areas can be defined and a census method used to identify all social trails within these areas. A census method will yield the most complete data about social trails and is more sensitive to change than sampling methods.

Furthermore, data from a census method can be used to inform management planning frameworks.

Future monitoring efforts should include social trails to remote lakes and use an on-trail sampling method to identify problem areas. Visitor use on these trails should also be monitored to detect any changes in visitor use patterns.

Social trails are most prevalent around the Alberta Falls area. RMNP may consider developing trails and infrastructure around Alberta Falls to manage use and mitigate widespread impacts. Developing this type of infrastructure will be a substantial investment but could mitigate current impacts and minimize future impacts. The Adams Falls area on the west side of RMNP, which had similar types of impacts, has been reconstructed recently. While part of the motivation at Adams Falls was visitor safety, the development of a maintained loop trail near the falls has helped reduce recreational impacts.

F. Litter

Litter is not widespread throughout the Glacier Gorge area but occurs most frequently on trails. While litter frequency is higher on-trail than off-trail, on-trail litter is found in less abundance than litter that is found off-trail. Litter occurred much less frequently in remote locations.

The mean distance of litter from the trail in the spatially balanced 150 meter buffer off-trail dataset was 40 m and was found to be statistically significant. Litter distance to trail was not found to be significant in the spatially balanced off-trail dataset. Once again, this can be expected due to the few occurrences of litter found in the off-trail dataset.

Litter distance to destinations was found to be significant in both off-trail datasets but not significant in either of the on-trail datasets. This may imply that visitors dispose of trash away from the main trail at destination areas while trash that occurs on-trail may be incidental. On-trail trash may be the result of carelessness: e.g. litter falling out of someone's backpack unknowingly while hiking.

Results from the Getis-Ord and Kernel Density analysis were mixed between the datasets. Getis-Ord analyses identified different "hot spots" for litter occurrences. Clusters of litter occurrences significant at the 95% confidence interval were identified:

- south of Alberta Falls and just south of the Mills Lake/Loch Vale junction in the spatially balanced 150 meter buffer off-trail dataset
- at Black Lake in the spatially balanced on-trail dataset
- along all trail areas from the trailhead to ½ mile beyond Alberta Falls on the Glacier Gorge trail and 1/3 of a mile up the fire trail in the 100 meter interval on-trail dataset
- west of Mills Lake and along the Bear Lake spur trail to Glacier Gorge in the off-trail dataset

The Getis-Ord analysis shows that litter in the spatially balanced 150 meter off-trail dataset occurred in a few, dense clusters while litter occurrences were more dispersed and less dense in both on-trail datasets. These results seem to support the frequency and abundance analyses of litter: litter occurs less abundantly but more frequently on a trail and more abundantly but less frequently away from a trail.

Litter density results were much higher in the spatially balanced 150 meter buffer off-trail dataset but similar for all other datasets. The highest density value in the spatially balanced off-trail dataset was two litter occurrences/hectare while the highest density in the other datasets was 0.5 litter occurrences/hectare.

Most litter occurrences were simple trash: toilet paper, food, or wrappers. However, there were a few litter occurrences worth noting. Sample point 54 in the spatially balanced 150 meter buffer off-trail dataset found what appeared to be a historic tin can dump (Figure 58). This sample point was located approximately 100 m west of the Glacier Gorge trailhead/Bear Lake trail junction. A lightly worn trail follows Chaos Creek past a stream flow gauge and up to a clearing. The can dump is located under a large overhanging boulder approximately 20 m north of the creek. This area does not appear to be used by visitors and the undisturbed tree litter suggests that these cans have been here for a while.

Figure 58. Can dump near Glacier Gorge trail/Bear Lake trail junction

Two tent stakes were found off trail in spatially balanced 150 meter buffer off-trail sample point 79 near the Mills Lake/Loch Vale junction. While no evidence of a campsite was found, visitors may have camped illegally here.

Although not captured by any sampling plan, there were two areas of note discovered during the course of this project. First, a tent was discovered in a meadow south of Jewel Lake. The tent was badly weathered, some of its poles were broken, had water inside, and had obviously been abandoned. This was not a designated backcountry campsite and there was no loss of vegetation. The tent was removed and disposed of. Second, there is an area on the northeast side of Mills Lake where large quantities of toilet paper and human waste were found. This area is located approximately 5 minutes beyond the Mills Lake outlet where large stepping stones cross through a seasonally wet area. As the stepping stones turn towards the lake, an obvious social trail initiates off the corner of the main trail. This social trail leads back into an opening in the vegetation where toilet paper is abundant.

Implications

Litter is a preventable impact resulting from visitor carelessness. Visitor education in the form of signage and literature is an indirect method to influence visitor behavior. Positioning park staff at busy areas, like Alberta Falls or Mills Lake, is a direct approach to influence visitor behavior. The mere presence of park staff can deter undesirable visitor behavior and staff can educate visitors on Leave No Trace practices.

Toilet paper was found in multiple places along the Glacier Gorge trail but most notably around the Mills Lake area. Mills Lake is approximately one hour from the trailhead which makes it accessible to many visitors but inconvenient to maintain facilities. RMNP may consider installing a composting toilet near the Mills Lake/Loch Vale junction. There are some south facing aspects on the hillside to the northeast of the trail junction that may provide enough sunlight to make a composting toilet feasible. While facilities in the backcountry provide their own set of maintenance issues for parks, a toilet in this area may limit the amount of human waste and toilet paper in backcountry areas.

G. Vandalism

The vandalism variable was an exploratory category intended to investigate potential types of visitor caused vandalism. Examples of vandalism might include: broken trail signs, carvings into trees, or graffiti. However, the only occurrences of vandalism found in this study were carvings into aspen trees.

Vandalism was recorded as a binary variable: one for presence of vandalism or zero for absence of vandalism within a quadrat. Getis-Ord analysis was conducted to identify where "hot spots" of vandalism were present but no density analysis was conducted.

Both on-trail datasets identified areas of statistical significance at the 95% confidence interval along all trail areas from the trailhead to areas just beyond Alberta Falls. The spatially balanced on-trail dataset identified areas up to ½ mile beyond Alberta Falls while the 100 meter on-trail dataset only identified areas up to ¼ mile beyond Alberta Falls. The spatially balanced 150 meter buffer off-trail dataset identified statistically significant areas at the 95% confidence interval around the Alberta Falls area. No occurrences of vandalism were found in the spatially balanced off-trail dataset.

Implications

Tree carving frequency was low and clustered around limited areas. Most quadrats where tree carving occurrences existed contained multiple occurrences of this impact. Unfortunately, tree carvings cannot be removed without removing the entire tree. In areas with many affected trees, tree removal would be a greater impact than leaving impacted trees. Educational signs could be placed to inform visitors that tree carving is prohibited. Some visitors may partake in this type of activity because its prevalence suggests that it is allowed.

H. Trail Conditions

Trail widths and depths were measured to examine the condition of the Glacier Gorge trail. This data can identify trail sections that are in poor condition and be statistically analyzed against other physical variables that may contribute to trail conditions.

The mean overall width and depth of the Glacier Gorge trail to Frozen Lake, including the Fire Trail, was 4.50 feet and 2.54 inches, respectively, as measured in the spatially balanced on-trail dataset. The mean overall width and depth of the Glacier Gorge trail below Black Lake was found to be 4.70 feet and 2.53 inches in the spatially balanced on-trail dataset and 4.33 feet and 2.71 inches in the 100 meter interval on-trail dataset. All Mann-Whitney comparisons between the datasets were found to statistically insignificant.

Extreme trail widths (five feet or wider) and depths (four inches or deeper) were identified in this study. These values were picked arbitrarily for descriptive purposes. Most extreme trail conditions occurred below the Mills Lake/Loch Vale junction. The widest trail section measured (9.83 feet) was the Glacier Gorge trailhead at the Glacier Gorge parking lot. The deepest trail section (16.1 inches) was found on the lower part of the Fire Trail.

The probability based spatially balanced sampling method had not been applied to trail condition sampling and was examined for efficiency. Data points were removed incrementally to examine how the results from fewer points would compare to the results from all 99 points in the dataset. Once again, no statistically significant difference was found.

The 100 meter interval on-trail dataset was also tested for efficiency by examining two 200 meter interval subsets and a 300 meter interval subset. No statistically significant difference was found in these analyses.

These results suggest that trail width and depth can be accurately measured using fewer sample points than were taken in this study. However, some considerations should be addressed before accepting these results. First, the Glacier Gorge trail from Mills Lake to Black Lake has been reconstructed in recent years. This high level of maintenance may have created uniform conditions that would not be encountered on less maintained trails. Second, mean trail width and depth of a five mile section of trail may not be the most useful information for park managers. Visitor use varies greatly along the Glacier Gorge trail and information about conditions of specific trail sections may be more useful for planning.

Statistically significant differences were found for three trail sections between the two on-trail datasets: the Fire Trail junction to Alberta Falls, Alberta Falls to the North Longs Peak junction, and the North Longs Peak junction to the Mills Lake/Loch Vale junction. These results may be expected because of the few sample points in this subset of the data.

In order to better represent conditions of short trail sections, denser sampling plans could be created. Specific trail sections could be identified in a probability based spatially balanced sampling plan and more sample points could be allocated. Similarly, a shorter interval based sampling plan could be used. Finally, a census method could be used for specific trail sections.

Regression analyses of trail conditions found statistically significant relationships between levels of use to trail width. These results support the findings of Dale and Hartley (1978) and Cole (1991) that trail width is influenced by level of use. Trail depth was not found to be related to level of use but was found to be related to water break distance in the 100 meter interval on-trail dataset. These results, however, were not replicated in the spatially balanced on-trail dataset.

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Appendicies

Appendix A -Maps

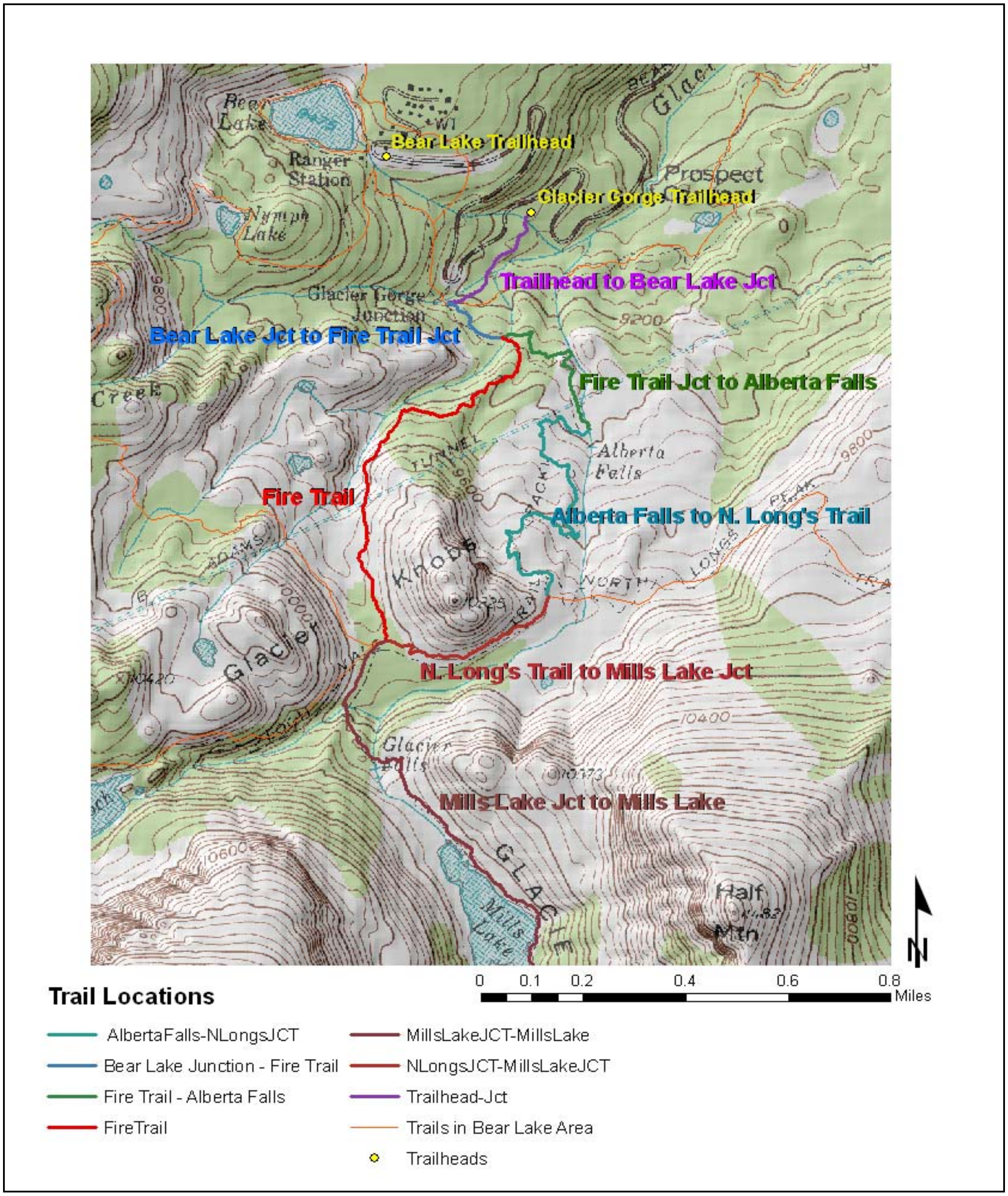


Figure A1. Trail locations along the Glacier Gorge trail (North)

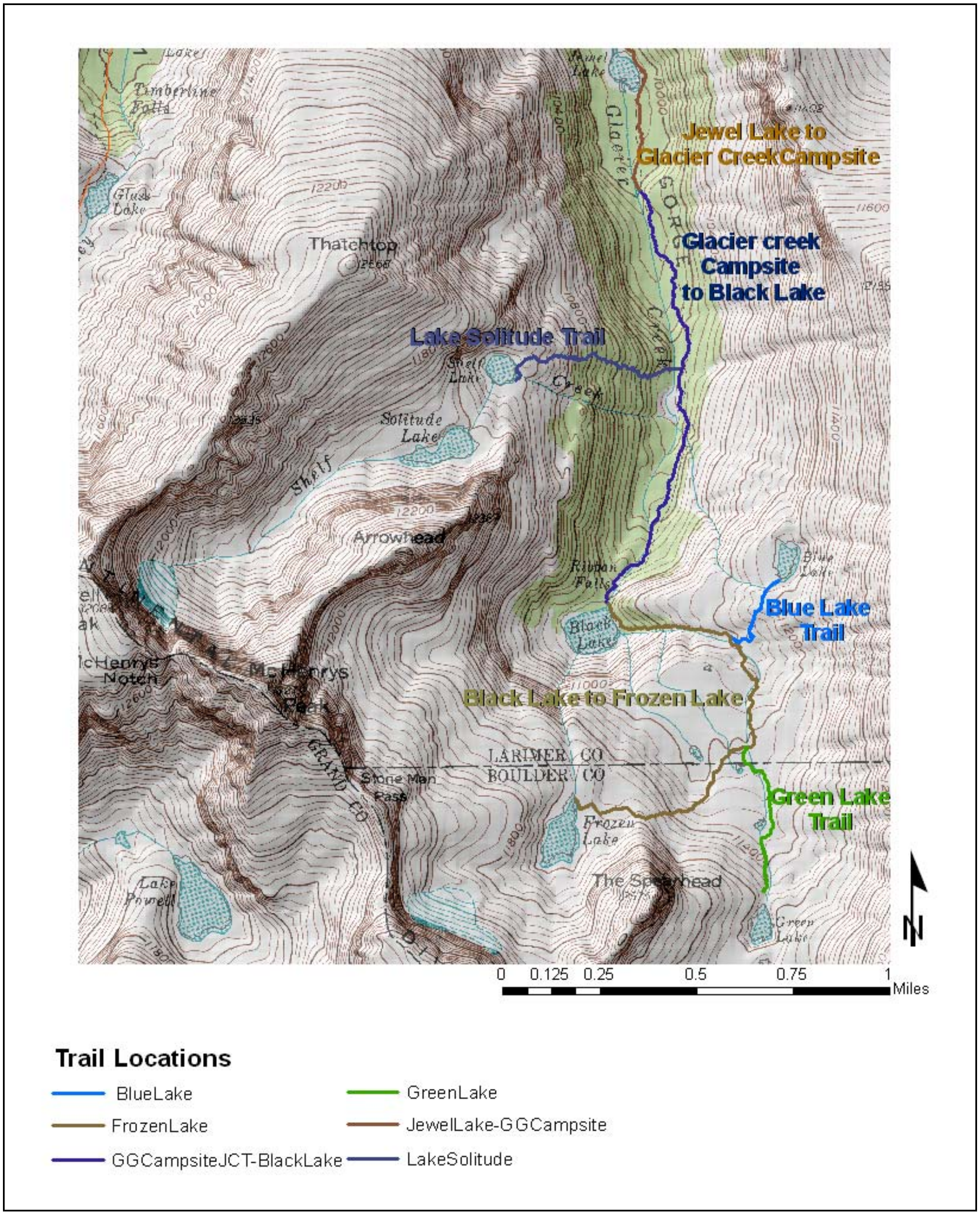


Figure A2. Trail locations along the Glacier Gorge trail (South)

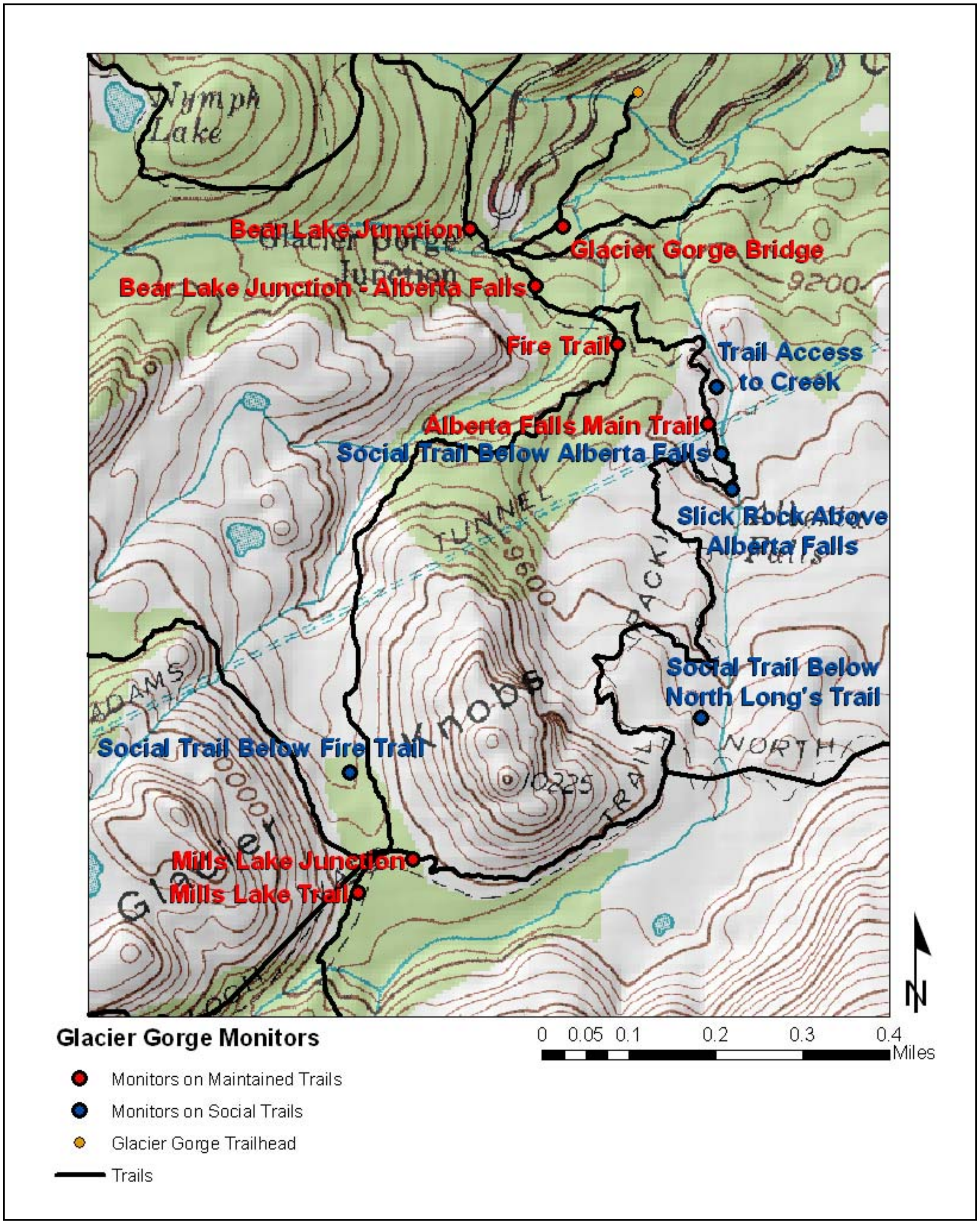


Figure A3. Visitor counter locations along Glacier Gorge trail (North)

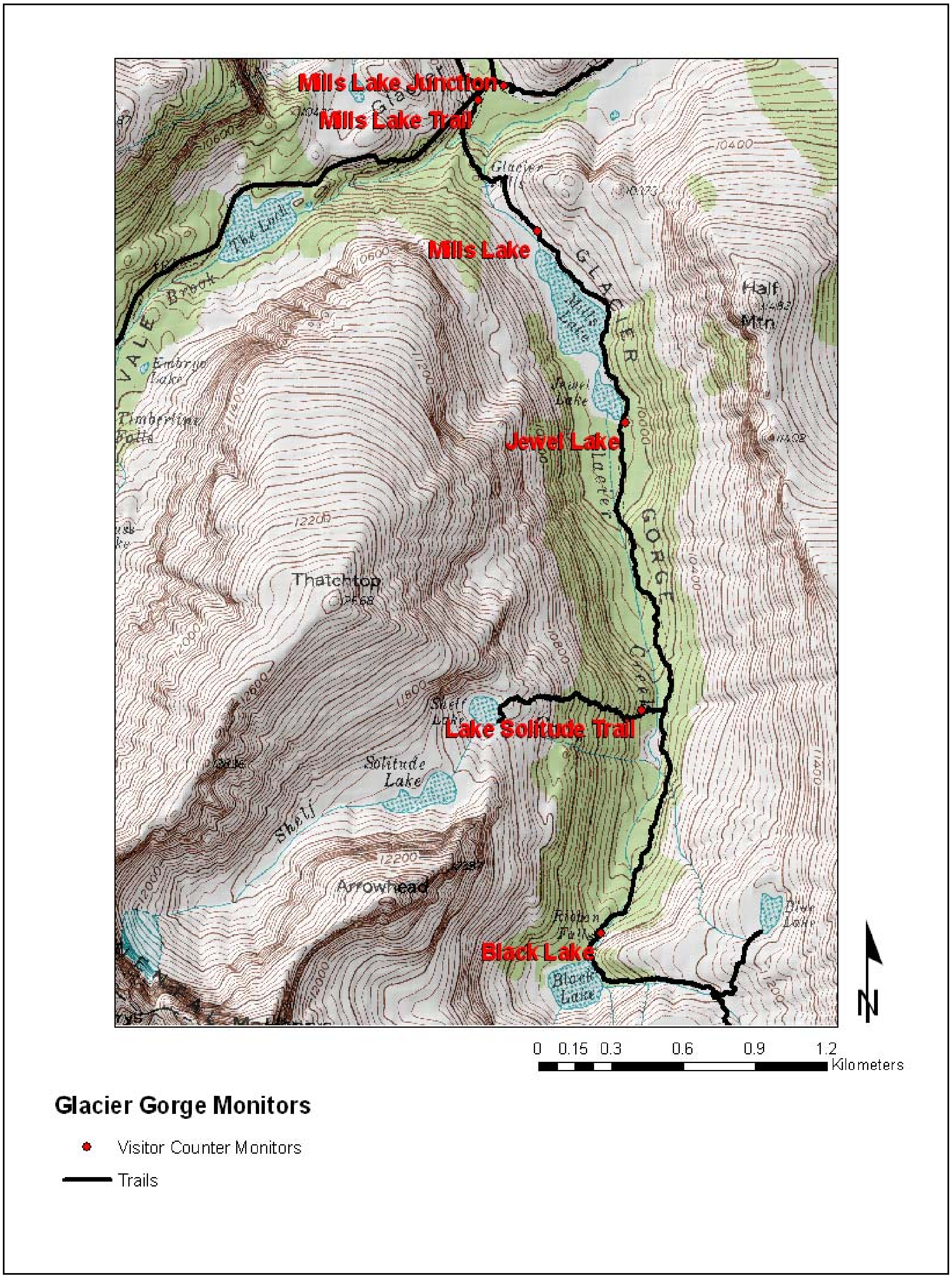


Figure A4. Visitor counter locations along Glacier Gorge trail (South)

Appendix B – Visitor Counter Results

Table B1. Visitor Counter Results for Unit 1 (Fire Trail)

Unit 1	Totals	Inflated (*1.34)	Divided by 2
Single Event	3480	4663	2332
# Days in Field	71	n/a	n/a
Avg. Daily	49	66	33
Weekend Events	1239	1660	830
Weekday Events	2241	3003	1502
Aug. Events	1681	2253	1126
Sep. Events	1347	1805	903
Oct. Events	452	606	303
# Aug. Days	25	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	479	641	321
Sep. Weekend Events	531	712	356
Oct. Weekend Events	229	307	154
Aug. Weekdays	1202	1611	806
Sep. Weekdays	816	1093	547
Oct. Weekdays	223	299	150
# Aug. Weekend Days	7/25	n/a	n/a
# Sep. Weekend Days	9/30	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	18/25	n/a	n/a
# Sep. Weekday Days	21/30	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	68	91	46
Avg. Sep. Weekend	59	79	39
Avg Oct Weekend	38	51	26
Avg Aug Weekday	67	90	45
Avg Sep. Weekday	39	52	26
Avg Oct Weekday	25	34	17

Table B2. Visitor Counter Results Unit 2 (Social Trail Below Fire Trail)

Unit 2	Totals	Inflated (*1.34)	Divided by 2
Single Event	94	126	63
# Days in Field	71	n/a	n/a
Avg. Daily	1	1	<1
Weekend Events	30	40	20
Weekday Events	64	86	43
Aug. Events	57	76	38
Sep. Events	30	40	20
Oct. Events	7	9	5
# Aug. Days	25	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	11	15	8
Sep. Weekend Events	15	20	10
Oct. Weekend Events	4	5	3
Aug. Weekdays	46	62	31
Sep. Weekdays	15	20	10
Oct. Weekdays	3	4	2
# Aug. Weekends	7/25	n/a	n/a
# Sep. Weekends	9/30	n/a	n/a
# Oct. Weekends	6/16	n/a	n/a
# Aug. Weekdays	18/25	n/a	n/a
# Sep. Weekdays	21/30	n/a	n/a
# Oct. Weekdays	10/16	n/a	n/a
Avg Aug. Weekend (Day)	2	3	2
Avg. Sep. Weekend	2	3	2
Avg Oct Weekend	1	1	<1
Avg Aug Weekday	3	4	2
Avg Sep. Weekday	2	3	2
Avg Oct Weekday	1	1	<1

Table B3. Visitor Counter Results Unit 3 (Lake Solitude Trail)

Unit 3	Totals	Inflated (*1.34)	Divided by 2
Single Event	225	302	151
# Days in Field	71	n/a	n/a
Avg. Daily	3	4	2
Weekend Events	83	111	56
Weekday Events	142	190	95
Aug. Events	109	146	73
Sep. Events	103	138	69
Oct. Events	13	17	9
# Aug. Days	25	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	25	34	17
Sep. Weekend Events	53	71	36
Oct. Weekend Events	5	7	4
Aug. Weekday Events	84	113	57
Sep. Weekday Events	50	67	34
Oct. Weekday Events	8	11	6
# Aug. Weekend Days	7/25	n/a	n/a
# Sep. Weekend Days	9/30	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	18/25	n/a	n/a
# Sep. Weekday Days	21/30	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	4	5	3
Avg. Sep. Weekend	6	8	4
Avg Oct Weekend	1	1	<1
Avg Aug Weekday	5	7	4
Avg Sep. Weekday	2	3	2
Avg Oct Weekday	1	1	<1

Table B4. Visitor Counter Results Unit 4 (Social Trail Below Alberta Falls (1))

Unit 4	Totals	Inflated (*1.34)	Divided by 2
Single Event	2313	3099	1550
# Days in Field	68	n/a	n/a
Avg. Daily	34	46	23
Weekend Events	996	1335	667
Weekday Events	1317	1765	883
Aug. Events	1140	1528	764
Sep. Events	862	1155	578
Oct. Events	311	417	209
# Aug. Days	22	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	385	516	258
Sep. Weekend Events	420	563	281
Oct. Weekend Events	238	319	160
Aug. Weekday Events	755	1012	506
Sep. Weekday Events	442	592	296
Oct. Weekday Events	73	98	49
# Aug. Weekend Days	6/22	n/a	n/a
# Sep. Weekend Days	9/30	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	16/22	n/a	n/a
# Sep. Weekday Days	21/30	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	65	87	44
Avg. Sep. Weekend	47	63	32
Avg Oct Weekend	40	54	27
Avg Aug Weekday	47	63	32
Avg Sep. Weekday	21	28	14
Avg Oct Weekday	7	9	5

Table B5. Visitor Counter Results Unit 5 (Social Trail Below Alberta Falls (2))

Unit 5	Totals	Inflated (*1.34)	Divided by 2
Single Event	1440	1930	965
# Days in Field	66	n/a	n/a
Avg. Daily	22	29	15
Weekend Events	514	689	345
Weekday Events	926	1241	621
Aug. Events	618	828	414
Sep. Events	680	911	456
Oct. Events	142	190	95
# Aug. Days	21	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	219	293	147
Sep. Weekend Events	185	248	124
Oct. Weekend Events	110	147	74
Aug. Weekday Events	399	535	268
Sep. Weekday Events	495	663	332
Oct. Weekday Events	32	43	22
# Aug. Weekend Days	6/21	n/a	n/a
# Sep. Weekend Days	9/30	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	15/21	n/a	n/a
# Sep. Weekday Days	21/30	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	37	50	25
Avg. Sep. Weekend	21	28	14
Avg Oct Weekend	18	24	12
Avg Aug Weekday	27	36	18
Avg Sep. Weekday	24	32	16
Avg Oct Weekday	3	4	2

Table B6. Visitor Counter Results Unit 6 (Social Trail Above Alberta Falls)

Unit 6	Totals	Inflated (*1.34)	Divided by 2
Single Event	26756	3585	1793
# Days in Field	68	n/a	n/a
Avg. Daily	391	524	262
Weekend Events	11596	15539	7770
Weekday Events	15160	2031	1016
Aug. Events	12195	16341	8171
Sep. Events	10372	13898	6949
Oct. Events	4189	5613	2807
# Aug. Days	22	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	3959	5305	2653
Sep. Weekend Events	5331	7144	3572
Oct. Weekend Events	2306	3090	1545
Aug. Weekday Events	8236	11036	5518
Sep. Weekday Events	5041	6755	3378
Oct. Weekday Events	1883	2523	1262
# Aug. Weekend Days	6/22	n/a	n/a
# Sep. Weekend Days	9/30	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	16/22	n/a	n/a
# Sep. Weekday Days	21/30	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	660	884	442
Avg. Sep. Weekend	592	793	397
Avg Oct Weekend	384	515	257
Avg Aug Weekday	515	690	345
Avg Sep. Weekday	240	322	161
Avg Oct Weekday	188	252	126

Table B7. Visitor Counter Results Unit 7 (Mills Lake Junction)

Unit 7	Totals	Inflated (*1.34)	Divided by 2
Single Event	12451	16684	8342
# Days in Field	40	n/a	n/a
Avg. Daily	311	417	209
Weekend Events	5594	7496	3748
Weekday Events	6857	9188	4594
Aug. Events	n/a	n/a	n/a
Sep. Events	9064	12146	6073
Oct. Events	3387	4539	2270
# Aug. Days	n/a	n/a	n/a
# Sep. Days	24	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	n/a	n/a	n/a
Sep. Weekend Events	3291	4410	2205
Oct. Weekend Events	2303	3086	1543
Aug. Weekday Events	n/a	n/a	n/a
Sep. Weekday Events	5773	7736	3868
Oct. Weekday Events	1084	1453	726
# Aug. Weekend Days	n/a	n/a	n/a
# Sep. Weekend Days	6/24	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	n/a	n/a	n/a
# Sep. Weekday Days	18/24	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	n/a	n/a	n/a
Avg. Sep. Weekend	549	736	368
Avg Oct Weekend	384	515	258
Avg Aug Weekday	n/a	n/a	n/a
Avg Sep. Weekday	321	430	215
Avg Oct Weekday	108	145	73

Table B8. Visitor Counter Results Unit 8 (Mills Lake Trail Entrance)

Unit 8	Totals	Inflated (*1.34)	Divided by 2
Single Event	15824	21204	10602
# Days in Field	67	n/a	n/a
Avg. Daily	236	316	158
Weekend Events	6391	8563	4282
Weekday Events	9433	12640	6320
Aug. Events	6647	8907	4454
Sep. Events	7143	9572	4786
Oct. Events	2034	2726	1363
# Aug. Days	21	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	2019	2705	1353
Sep. Weekend Events	3093	4145	2073
Oct. Weekend Events	1279	1714	857
Aug. Weekday Events	4628	6202	3101
Sep. Weekday Events	4050	5427	2714
Oct. Weekday Events	755	1012	506
# Aug. Weekend Days	6/21	n/a	n/a
# Sep. Weekend Days	9/30	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	15/21	n/a	n/a
# Sep. Weekday Days	22/30	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	336	450	225
Avg. Sep. Weekend	343	460	230
Avg Oct Weekend	213	285	143
Avg Aug Weekday	308	413	207
Avg Sep. Weekday	199	267	133
Avg Oct Weekday	76	102	51

Table B9. Visitor Counter Results Unit 9 (Mills Lake)

Unit 9	Totals	Inflated (*1.34)	Divided by 2
Single Event	15744	21097	10549
# Days in Field	67	n/a	n/a
Avg. Daily	235	3149	158
Weekend Events	6495	8703	4352
Weekday Events	9249	12394	6197
Aug. Events	6625	8878	4439
Sep. Events	7114	9533	4767
Oct. Events	2005	2687	1344
# Aug. Days	21	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	2160	2894	1447
Sep. Weekend Events	3067	4110	2055
Oct. Weekend Events	1268	1699	850
Aug. Weekday Events	4465	5983	2992
Sep. Weekday Events	4047	5423	2712
Oct. Weekday Events	737	988	494
# Aug. Weekend Days	6/21	n/a	n/a
# Sep. Weekend Days	9/30	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	15/21	n/a	n/a
# Sep. Weekday Days	21/30	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	360	482	241
Avg. Sep. Weekend	341	457	229
Avg Oct Weekend	211	283	142
Avg Aug Weekday	298	399	200
Avg Sep. Weekday	146	196	98
Avg Oct Weekday	74	99	50

Table B10. Visitor Counter Results Unit 10 (Jewel Lake)

Unit 10	Totals	Inflated (*1.34)	Divided by 2
Single Event	6035	8087	4043
# Days in Field	67	n/a	n/a
Avg. Daily	90	121	60
Weekend Events	2751	3686	1843
Weekday Events	3284	4401	2201
Aug. Events	2521	3378	1689
Sep. Events	2808	3763	1882
Oct. Events	706	946	473
# Aug. Days	21	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	1014	1359	679
Sep. Weekend Events	1250	1675	838
Oct. Weekend Events	487	653	327
Aug. Weekdays	1507	2019	1010
Sep. Weekdays	1558	2088	1044
Oct. Weekdays	219	293	147
# Aug. Weekend Days	6/21	n/a	n/a
# Sep. Weekend Days	9/30	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	15/21	n/a	n/a
# Sep. Weekday Days	21/30	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	169	226	113
Avg. Sep. Weekend	139	186	93
Avg Oct Weekend	81	109	55
Avg Aug Weekday	100	134	67
Avg Sep. Weekday	74	99	49
Avg Oct Weekday	22	29	15

Table B11. Visitor Counter Results Unit 11 (Black Lake)

Unit 11	Totals	Inflated (*1.34)	Divided by 2
Single Event	4545	6090	3045
# Days in Field	66	n/a	n/a
Avg. Daily	69	92	46
Weekend Events	2223	2979	1490
Weekday Events	2322	3111	1556
Aug. Events	1914	2565	1283
Sep. Events	1909	2558	1279
Oct. Events	722	967	484
# Aug. Days	20	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	939	1258	629
Sep. Weekend Events	912	1222	611
Oct. Weekend Events	372	498	249
Aug. Weekday Events	975	1307	654
Sep. Weekday Events	997	1336	668
Oct. Weekday Events	350	469	235
# Aug. Weekend Days	6/20	n/a	n/a
# Sep. Weekend Days	9/30	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	14/20	n/a	n/a
# Sep. Weekday Days	21/30	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	157	210	105
Avg. Sep. Weekend	101	135	68
Avg Oct Weekend	62	83	42
Avg Aug Weekday	70	94	47
Avg Sep. Weekday	47	63	32
Avg Oct Weekday	35	47	24

Table B12. Visitor Counter Results Unit 12 (Glacier Gorge Trailhead Bridge)

Unit 12	Totals	Inflated (*1.34)	Divided by 2
Single Event	39951	53534	26767
# Days in Field	60	n/a	n/a
Avg. Daily	666	892	446
Weekend Events	15778	21143	10571
Weekday Events	24173	32392	16196
Aug. Events	14288	19146	9573
Sep. Events	18591	24912	12456
Oct. Events	7072	9476	4738
# Aug. Days	17	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	2908	3897	1948
Sep. Weekend Events	9063	12144	6072
Oct. Weekend Events	3807	5101	2551
Aug. Weekday Events	11380	15249	7624
Sep. Weekday Events	9528	12768	6384
Oct. Weekday Events	3265	4375	2188
# Aug. Weekend Days	3/16	n/a	n/a
# Sep. Weekend Days	9/28	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	13/17	n/a	n/a
# Sep. Weekday Days	19/28	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	740	992	649
Avg. Sep. Weekend	1007	1349	674
Avg Oct Weekend	635	851	426
Avg Aug Weekday	875	1173	587
Avg Sep. Weekday	454	608	336
Avg Oct Weekday	327	438	219

Table B13. Visitor Counter Results Unit 13 (Glacier Gorge/Bear Lake Trails Jct)

Unit 13	Totals	Inflated (*1.34)	Divided by 2
Single Event	41137	55124	27562
# Days in Field	52	n/a	n/a
Avg. Daily	791	1060	530
Weekend Events	18904	25331	12666
Weekday Events	22385	29996	14998
Aug. Events	15421	20664	10332
Sep. Events	17822	23881	11941
Oct. Events	7894	10578	5289
# Aug. Days	16	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	5342	7158	3579
Sep. Weekend Events	8537	11440	5720
Oct. Weekend Events	5025	6734	3367
Aug. Weekday Events	10079	13506	6752
Sep. Weekday Events	9285	12442	6221
Oct. Weekday Events	2869	3844	1922
# Aug. Weekend Days	4/14	n/a	n/a
# Sep. Weekend Days	7/22	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	10/14	n/a	n/a
# Sep. Weekday Days	15/22	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	922	1235	894
Avg. Sep. Weekend	1121	1502	817
Avg Oct Weekend	837	1122	561
Avg Aug Weekday	981	1315	675
Avg Sep. Weekday	369	494	414
Avg Oct Weekday	287	385	192

Table B14. Visitor Counter Results Unit 14 (Alberta Falls Trail)

Unit 14	Totals	Inflated (*1.34)	Divided by 2
Single Event	41061	55022	27511
# Days in Field	58	n/a	n/a
Avg. Daily	708	949	474
Weekend Events	18793	25182	12591
Weekday Events	22268	29839	14920
Aug. Events	10594	14196	7098
Sep. Events	23172	31050	15525
Oct. Events	7295	9775	4888
# Aug. Days	12	n/a	n/a
# Sep. Days	30	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	3670	4918	2459
Sep. Weekend Events	10519	14095	7048
Oct. Weekend Events	4604	6169	3085
Aug. Weekday Events	6924	9278	4639
Sep. Weekday Events	12653	16955	8478
Oct. Weekday Events	2691	3606	1803
# Aug. Weekend Days	3/12	n/a	n/a
# Sep. Weekend Days	9/30	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	9/12	n/a	n/a
# Sep. Weekday Days	21/30	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	977	1309	655
Avg. Sep. Weekend	1169	1566	783
Avg Oct Weekend	767	1028	514
Avg Aug Weekday	769	1030	515
Avg Sep. Weekday	603	808	404
Avg Oct Weekday	269	360	180

Table B15. Visitor Counter Results Unit 15 (Bear Lake Trail Junction)

Unit 15	Totals	Inflated (*1.34)	Divided by 2
Single Event	16144	21633	10817
# Days in Field	43	n/a	n/a
Avg. Daily	375	503	252
Weekend Events	7908	10597	5299
Weekday Events	8236	11036	5518
Aug. Events	n/a	n/a	n/a
Sep. Events	12020	16107	8053
Oct. Events	4124	5526	2763
# Aug. Days	n/a	n/a	n/a
# Sep. Days	27	n/a	n/a
# Oct. Days	16	n/a	n/a
Aug. Weekend Events	n/a	n/a	n/a
Sep. Weekend Events	5048	6764	3382
Oct. Weekend Events	2860	3832	1916
Aug. Weekday Events	n/a	n/a	n/a
Sep. Weekday Events	6972	9342	4671
Oct. Weekday Events	1264	1694	847
# Aug. Weekend Days	n/a	n/a	n/a
# Sep. Weekend Days	8/27	n/a	n/a
# Oct. Weekend Days	6/16	n/a	n/a
# Aug. Weekday Days	n/a	n/a	n/a
# Sep. Weekday Days	19/27	n/a	n/a
# Oct. Weekday Days	10/16	n/a	n/a
Avg Aug. Weekend (Day)	n/a	n/a	n/a
Avg. Sep. Weekend	631	846	423
Avg Oct Weekend	477	639	320
Avg Aug Weekday	n/a	n/a	n/a
Avg Sep. Weekday	367	492	246
Avg Oct Weekday	126	169	85

Table B16. Visitation levels by hour in percentages (highest visitation levels in red)

Hour	Unit #														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	0	0	0	0	0	0	<1	<1	<1	0	<1	<1	<1	<1
1	<1	0	<1	0	0	0	0	0	<1	<1	0	<1	<1	<1	<1
2	0	0	0	<1	0	0	0	<1	<1	<1	<1	<1	<1	<1	<1
3	<1	0	1	0	<1	0	0	<1	<1	<1	<1	<1	<1	<1	<1
4	1.7	0	1.8	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
5	1.7	0	1	<1	0	<1	<1	<1	<1	1	<1	<1	<1	<1	<1
6	1.7	10.6	0	<1	<1	<1	<1	<1	<1	1.2	1.0	<1	<1	<1	<1
7	3.7	0	0	<1	<1	<1	<1	<1	1.1	1.6	2.0	2.2	1.8	<1	<1
8	9.8	2.1	3.6	1	2.7	1.1	1.9	2.2	2.0	1.5	2.4	4.4	3.9	2.7	1.4
9	7.5	18.1	10.2	6.7	4.2	3.7	5.6	4.9	4.5	2.2	4.0	4.9	5.8	5.7	5.5
10	5.1	9.6	11.1	6.1	13.7	6.8	10.2	9.7	8.9	11.9	7.5	8.5	8.7	8.7	9.3
11	5.0	5.3	8	13.1	14.0	14.8	12.2	13.5	13.2	12.3	13.6	9.8	10.4	11.8	11.5
12	6.3	3.2	14.7	14.6	19.7	17.1	14.0	15.8	16.8	12.7	16.7	10.0	11.7	13.1	12.3
13	9.1	5.3	12.4	11.6	10.6	14.3	15.2	16.5	16.8	13.0	20.8	11.4	12.6	13.1	14.7
14	14.1	21.3	20.4	10.3	9.1	12.3	14.1	12.8	13.6	13.9	12.4	12.0	12.8	13.7	14.6
15	10.4	2.2	5.3	11.1	8.5	10.9	12.4	11.0	10.9	8.5	10.0	12.0	11.9	12.4	12.7
16	8.8	9.6	8.8	10.7	10.6	9.3	8.0	6.8	6.4	6.0	4.0	10.6	8.9	9.4	9.9
17	7.1	2.2	1.8	9.2	4.7	5.3	3.6	3.1	2.7	3.4	2.8	7.3	6.1	5.7	5.1
18	4.3	9.6	<1	3.0	1.2	1.8	1.1	1.4	1.2	2.1	1.0	3.9	3.2	2.3	2.0
19	2.5	0	0	<1	<1	<1	<1	<1	<1	<1	<1	1.2	<1	<1	<1
20	<1	0	0	0	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
21	<1	0	0	<1	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
22	<1	0	0	0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
23	0	1	0	<1	0	<1	<1	0	0	<1	<1	<1	<1	<1	<1

Appendix C – Trail Width and Depths Data

Table C1. Mean width and probability values for spatially balanced trail points (feet)

Sample Point	Mean Trail Width (Xi)	Probability (π)	Weight (Wi = 1 / π)	Weighted Mean Trail Width (XiWi)
1	6.30	1.00	1.00	6.30
2	2.90	1.00	1.00	2.90
3	8.80	1.00	1.00	8.80
4	3.40	1.00	1.00	3.40
5	4.00	1.00	1.00	4.00
6	2.70	0.90	1.11	3.00
7	5.10	1.00	1.00	5.10
8	0.00	0.80	1.25	0.00
9	2.90	0.90	1.11	3.22
10	4.30	1.00	1.00	4.30
11	6.70	1.00	1.00	6.70
12	6.00	1.00	1.00	6.00
13	3.80	1.00	1.00	3.80
14	6.50	1.00	1.00	6.50
15	5.40	1.00	1.00	5.40
16	3.70	1.00	1.00	3.70
17	3.50	1.00	1.00	3.50
18	3.80	1.00	1.00	3.80
19	4.40	0.90	1.11	4.89
20	1.33	0.90	1.11	1.48
21	5.50	1.00	1.00	5.50
22	2.90	1.00	1.00	2.90
23	4.80	0.90	1.11	5.33
24	2.90	0.90	1.11	3.22
25	7.00	1.00	1.00	7.00
26	5.92	1.00	1.00	5.92
27	3.70	1.00	1.00	3.70
28	7.20	1.00	1.00	7.20
29	3.60	1.00	1.00	3.60
30	3.00	0.90	1.11	3.33
31	4.20	0.90	1.11	4.66
32	4.60	1.00	1.00	4.60
33	3.80	1.00	1.00	3.80
34	3.20	0.90	1.11	3.56
35	7.40	1.00	1.00	7.40
36	6.10	1.00	1.00	6.10
37	4.10	0.90	1.11	4.56
38	5.80	1.00	1.00	5.80
39	0.00	0.80	1.25	0.00
40	4.80	1.00	1.00	4.80
41	2.50	1.00	1.00	2.50
42	5.30	1.00	1.00	5.30
43	0.00	0.80	1.25	0.00
44	5.38	0.90	1.11	5.97
45	2.90	1.00	1.00	2.90
46	3.30	0.90	1.11	3.67
47	5.90	1.00	1.00	5.90
48	4.90	1.00	1.00	4.90

49	2.60	0.90	1.11	2.89
50	2.50	0.90	1.11	2.78
51	5.10	1.00	1.00	5.10
52	2.50	1.00	1.00	2.50
53	1.70	0.90	1.11	1.89
54	2.40	1.00	1.00	2.40
55	1.50	0.90	1.11	1.67
56	7.40	1.00	1.00	7.40
57	4.10	0.90	1.11	4.56
58	5.90	1.00	1.00	5.90
59	3.30	1.00	1.00	3.30
60	2.40	0.90	1.11	2.67
61	3.10	1.00	1.00	3.10
62	6.50	1.00	1.00	6.50
63	4.80	1.00	1.00	4.80
64	0.00	0.90	1.11	0.00
65	5.30	1.00	1.00	5.30
66	2.60	1.00	1.00	2.60
67	6.20	0.90	1.11	6.89
68	2.75	0.90	1.11	3.06
69	5.80	1.00	1.00	5.80
70	6.10	1.00	1.00	6.10
71	2.90	0.90	1.11	3.22
72	5.90	1.00	1.00	5.90
73	2.70	1.00	1.00	2.70
74	5.20	0.90	1.11	5.78
75	4.10	1.00	1.00	4.10
76	5.60	1.00	1.00	5.60
77	4.60	1.00	1.00	4.60
78	6.00	1.00	1.00	6.00
79	2.70	1.00	1.00	2.70
80	5.80	1.00	1.00	5.80
81	3.20	0.90	1.11	3.56
82	0.00	0.90	1.11	0.00
83	3.00	1.00	1.00	3.00
84	4.00	0.90	1.11	4.44
85	8.00	1.00	1.00	8.00
86	5.40	1.00	1.00	5.40
87	5.80	1.00	1.00	5.80
88	5.70	1.00	1.00	5.70
89	5.40	1.00	1.00	5.40
90	9.20	1.00	1.00	9.20
91	6.80	1.00	1.00	6.80
92	4.90	1.00	1.00	4.90
93	3.40	1.00	1.00	3.40
94	7.00	1.00	1.00	7.00
95	0.00	0.80	1.25	0.00
96	0.00	0.80	1.25	0.00
97	1.60	0.90	1.11	1.78
98	3.50	0.90	1.11	3.89
99	3.90	1.00	1.00	3.90

Table C2. Mean depth and probability values for spatially balanced trail points (inches)

Sample Point	Mean Trail Depth (Xi)	Probability (π)	Weight (Wi = 1 / π)	Weighted Mean Trail Depth(XiWi)
1	3.90	1.00	1.00	4.30
2	4.30	1.00	1.00	5.00
3	2.20	1.00	1.00	1.30
4	1.70	1.00	1.00	2.30
5	2.30	1.00	1.00	0.00
6	3.40	0.90	1.11	4.33
7	0.00	1.00	1.00	3.40
8	0.00	0.80	1.25	0.00
9	0.00	0.90	1.11	3.78
10	0.00	1.00	1.00	2.20
11	0.20	1.00	1.00	8.80
12	5.70	1.00	1.00	2.70
13	3.60	1.00	1.00	1.60
14	2.00	1.00	1.00	0.00
15	0.60	1.00	1.00	2.50
16	2.00	1.00	1.00	4.00
17	5.40	1.00	1.00	1.90
18	3.10	1.00	1.00	0.80
19	0.90	0.90	1.11	1.00
20	0.00	0.90	1.11	0.44
21	0.00	1.00	1.00	4.70
22	2.00	1.00	1.00	2.00
23	4.60	0.90	1.11	3.78
24	2.40	0.90	1.11	3.55
25	3.20	1.00	1.00	5.20
26	1.60	1.00	1.00	1.80
27	1.20	1.00	1.00	1.00
28	3.40	1.00	1.00	1.20
29	4.80	1.00	1.00	1.40
30	0.70	0.90	1.11	4.77
31	0.40	0.90	1.11	5.33
32	0.60	1.00	1.00	1.20
33	1.00	1.00	1.00	5.90
34	3.20	0.90	1.11	2.56
35	0.40	1.00	1.00	6.00
36	0.40	1.00	1.00	1.50
37	0.20	0.90	1.11	1.89
38	1.20	1.00	1.00	2.10
39	2.00	0.80	1.25	0.00
40	1.60	1.00	1.00	6.00
41	1.40	1.00	1.00	0.40
42	0.00	1.00	1.00	11.80
43	4.00	0.80	1.25	0.00
44	0.80	0.90	1.11	2.44
45	1.80	1.00	1.00	1.20
46	0.20	0.90	1.11	2.67
47	0.00	1.00	1.00	3.20
48	2.20	1.00	1.00	2.70
49	0.00	0.90	1.11	0.67
50	3.40	0.90	1.11	2.22
51	6.00	1.00	1.00	1.40

52	1.80	1.00	1.00	1.80
53	2.70	0.90	1.11	6.33
54	1.50	1.00	1.00	0.20
55	1.00	0.90	1.11	0.67
56	1.20	1.00	1.00	1.50
57	1.20	0.90	1.11	3.44
58	1.40	1.00	1.00	3.40
59	6.00	1.00	1.00	1.30
60	2.70	0.90	1.11	2.22
61	4.30	1.00	1.00	1.10
62	2.70	1.00	1.00	4.30
63	8.80	1.00	1.00	0.00
64	11.20	0.90	1.11	0.22
65	0.90	1.00	1.00	11.10
66	4.70	1.00	1.00	3.80
67	11.10	0.90	1.11	6.00
68	11.80	0.90	1.11	1.78
69	3.40	1.00	1.00	0.00
70	2.10	1.00	1.00	6.00
71	2.50	0.90	1.11	5.11
72	1.30	1.00	1.00	7.40
73	0.90	1.00	1.00	3.70
74	4.30	0.90	1.11	0.78
75	1.50	1.00	1.00	1.20
76	2.90	1.00	1.00	0.20
77	1.50	1.00	1.00	3.20
78	6.00	1.00	1.00	2.40
79	3.20	1.00	1.00	0.40
80	1.40	1.00	1.00	1.00
81	1.20	0.90	1.11	2.22
82	5.20	0.90	1.11	0.00
83	2.40	1.00	1.00	3.80
84	2.00	0.90	1.11	4.00
85	3.20	1.00	1.00	3.20
86	0.00	1.00	1.00	11.20
87	0.00	1.00	1.00	2.70
88	7.40	1.00	1.00	2.90
89	3.80	1.00	1.00	1.50
90	5.00	1.00	1.00	1.40
91	1.90	1.00	1.00	2.00
92	3.70	1.00	1.00	0.90
93	3.80	1.00	1.00	0.90
94	1.10	1.00	1.00	0.90
95	5.90	0.80	1.25	0.00
96	1.30	0.80	1.25	0.00
97	2.30	0.90	1.11	2.56
98	0.90	0.90	1.11	1.33
99	2.30	1.00	1.00	0.00

Table C3. Mean depth and width values for 100 meter interval dataset

Sample Point	Mean Width	Mean Depth
1	9.83	0.00
2	5.80	0.00
3	5.50	0.00
4	5.90	0.00
5	6.20	0.00
6	6.20	1.40
7	5.40	1.80
8	4.60	0.80
9	5.60	1.00
10	5.00	2.00
11	5.00	1.00
12	5.00	4.00
13	7.40	6.00
14	5.00	2.60
15	3.60	3.80
16	4.00	3.20
17	5.80	2.00
18	5.60	3.80
19	4.20	1.60
20	5.00	8.40
21	5.00	4.40
22	4.60	0.80
23	5.20	0.60
24	5.00	0.60
25	5.60	1.20
26	4.80	7.80
27	5.00	1.20
28	4.60	5.00
29	5.00	1.20
30	4.10	1.20
31	4.00	3.60
32	4.00	0.00
33	4.80	0.80
34	4.00	1.00
35	8.20	2.90
36	4.80	5.00
37	6.20	1.40
38	3.90	0.00
39	5.00	0.00
40	4.70	0.00
41	3.90	1.00
42	0.00	0.00
43	0.00	0.00
44	4.50	0.50
45	3.20	3.70
46	3.50	1.10
47	2.70	1.20
48	4.00	0.80
49	4.80	5.00
50	3.30	2.60
51	2.50	0.50
52	4.80	5.70

53	1.00	0.00
54	1.50	0.00
55	5.30	1.40
56	4.60	7.90
57	5.83	2.30
58	3.40	1.10
59	4.50	0.30
60	2.70	0.00
61	4.30	2.90
62	2.20	1.70
63	3.60	2.00
64	2.50	0.30
65	2.00	1.80
66	3.00	3.40
67	2.30	2.40
68	5.30	4.70
69	3.50	0.80
70	3.10	5.90
71	3.10	2.30
72	3.70	4.60
73	2.90	0.80
74	6.00	1.30
75	3.40	1.40
76	2.80	0.00
77	5.30	1.40
78	1.50	0.00
79	6.40	16.10
80	3.40	5.80
81	5.20	10.00
82	3.00	2.50
83	4.00	4.60
84	3.10	2.60
85	3.20	10.80
86	3.70	4.30
87	4.20	1.20
88	2.90	4.40
89	3.50	7.20
90	3.67	1.20
91	3.30	5.10
92	4.50	2.20
93	4.30	3.30

Table C4. Width and Depth Results for On Trail Points below Black Lake.

Data Set (# of sample points)	Avegrage Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
100 m interval (93 points)	4.33	1.00	9.83	2.53	0	16.10
Spatially Balanced (83 points)	4.72	1.33	9.20	2.72	0	11.80
Spatially Balanced (75 points)	4.63	1.33	8.80	2.89	0	11.80
Spatially Balanced (50 points)	4.61	1.33	8.80	2.74	0	11.80
Spatially Balanced (33 points)	4.72	1.33	8.80	2.76	0	8.80
Spatially Balanced (25 points)	4.62	1.33	8.80	2.67	0	8.80
Spatially Balanced (10 points)	5.04	2.70	8.80	3.34	0	8.80
Spatially Balanced (5 points)	5.08	2.90	8.80	2.58	1.30	5.00
200m interval (47 points)	4.58	1.00	9.83	2.64	0	16.10
200m interval (46 points)	4.07	1.50	6.20	2.44	0	8.40
300m interval (31 points)	4.47	2.30	9.83	2.53	0	7.2

Table C5. Width and Depth Results for On Trail Points (Trailhead to Bear Lake Jct)

Data Set (# of sample points)	Avegrage Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
Spatially Balanced (99) 2 points	6.15 ft	5.80 ft	6.50 ft	0 in	0 in	0 in
100 m interval (93) 5 points	6.64	5.50	9.83	0	0	0
Spatially Balanced (75) 2 points	6.15	5.80	6.50	0	0	0
Spatially Balanced (50) 1 point	6.50	6.50	6.50	0	0	0
Spatially Balanced (33) 1 point	6.50	6.50	6.50	0	0	0
Spatially Balanced (25) 1 point	6.50	6.50	6.50	0	0	0
Spatially Balanced (10) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
Spatially Balanced (5) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
200m interval (47) 3 points	7.18	5.50	9.83	0	0	0
200 m interval (46) 2 points	5.85	5.80	5.90	0	0	0
300m interval (31) 2 points	7.87	5.90	9.83	0	0	0

Table C6. Width and Depth Results for On Trail Points (Bear Lake Junction to Fire Trail)

Data Set (# of sample points)	Avegrage Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
Spatially Balanced (99) 2 points	6.35 ft	5.90 ft	6.80 ft	2.60 in	2.00 in	3.20 in
100 m interval (93) 3 points	5.40	4.60	6.20	1.33	.80	1.80
Spatially Balanced (75) 1 point	5.90	5.90	5.90	3.20	3.20	3.20
Spatially Balanced (50) 1 point	5.90	5.90	5.90	3.20	3.20	3.20
Spatially Balanced (33) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
Spatially Balanced (25) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
Spatially Balanced (10) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
Spatially Balanced (5) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
200m interval (47) 1 point	5.40	5.40	5.40	1.80	1.80	1.80
200m interval (46) 2 points	5.40	4.60	6.20	1.10	.80	1.40
300m interval (31) 1 point	5.40	5.40	5.40	1.80	1.80	1.80

Table C7. Width and Depth Results for On Trail Points (Fire Trail – Alberta Falls)

Data Set (# of sample points)	Avegrage Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
Spatially Balanced (99) 7 points	7.46 ft	6.00 ft	9.20 ft	2.99 in	1.20 in	6.00 in
100 m interval (93) 6 points	5.50	5.00	7.40	2.77	1.00	6.00
Spatially Balanced (75) 4 points	7.25	7.00	7.40	3.48	1.20	6.00
Spatially Balanced (50) 3 points	7.20	7.00	7.40	4.13	1.20	6.00
Spatially Balanced (33) 2 points	7.10	7.00	7.20	3.20	1.20	5.20
Spatially Balanced (25) 1 point	7.00	7.00	7.00	5.20	5.20	5.20
Spatially Balanced (10) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
Spatially Balanced (5) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
200m interval (47) 3 points	6.00	5.00	7.40	2.67	1.00	6.00
200m interval (46) 3 points	5.00	5.00	5.00	2.87	2.00	4.00
300m interval (31) 2 points	6.20	5.00	7.40	4.00	2.00	6.00

Table C8. Width and Depth Results for On Trail Points (Alberta Falls – N. Long's Jct)

Data Set (# of sample points)	Avegrage Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
Spatially Balanced (99) 14 points	5.95 ft	4.90 ft	8.80 ft	4.81 in	.90 in	11.80 in
100 m interval (93) 12 points	4.87	3.60	5.80	3.18	.60	8.40
Spatially Balanced (75) 9 points	6.11	5.30	8.80	5.55	1.30	11.80
Spatially Balanced (50) 7 points	6.25	5.30	8.80	5.07	1.30	11.80
Spatially Balanced (33) 5 points	6.54	5.40	8.80	4.32	1.30	8.80
Spatially Balanced (25) 5 points	6.54	5.40	8.80	4.32	1.30	8.80
Spatially Balanced (10) 2 points	7.55	6.30	8.80	2.80	1.30	4.30
Spatially Balanced (5) 2 points	7.55	6.30	8.80	2.80	1.30	4.30
200m interval (47) 6 points	4.90	3.60	5.80	2.26	.60	4.40
200m interval (46) 6 points	4.83	4.00	5.60	4.10	.60	8.40
300m interval (31) 4 points	4.60	4.00	5.60	1.70	.80	3.20

Table C9. Width and Depth Results for On Trail Points (N. Long's Jct – Mills Jct)

Data Set (# of sample points)	Avegrage Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
Spatially Balanced (99) 13 points	5.31 ft	3.40 ft	6.50 ft	2.56 in	.90 in	6.00 in
100 m interval (93) 8 points	4.50	4.00	5.00	1.86	0	5.00
Spatially Balanced (75) 10 points	5.41	4.10	6.50	2.88	1.20	6.00
Spatially Balanced (50) 6 points	5.38	4.60	6.10	2.65	1.20	6.00
Spatially Balanced (33) 3 points	5.51	4.60	6.00	1.90	1.20	2.70
Spatially Balanced (25) 1 point	6.00	6.00	6.00	2.70	2.70	2.70
Spatially Balanced (10) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
Spatially Balanced (5) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
200m interval (47) 4 points	4.70	4.00	5.00	1.70	.80	3.60
200m interval (46) 4 points	4.18	4.00	4.60	1.80	0	5.00
300m interval (31) 3 points	4.20	4.00	4.60	3.20	1.00	5.00

Table C10. Width and Depth Results for On Trail Points (Mills Lake Jct – Jewel Lake)

Data Set (# of sample points)	Avegrage Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
Spatially Balanced (99) 16 points	3.65 ft	2.40 ft	5.60 ft	1.22 in	0 in	4.00 in
100 m interval (93) 16 points	4.44	2.70	8.20	1.74	0	5.00
Spatially Balanced (75) 13 points	3.56	2.40	5.10	1.46	0	4.00
Spatially Balanced (50) 10 points	3.66	2.50	5.10	1.46	0	4.00
Spatially Balanced (33) 8 points	3.90	2.90	5.10	1.93	0	4.00
Spatially Balanced (25) 7 points	3.74	2.90	5.10	2.00	0	4.00
Spatially Balanced (10) 3 points	4.46	4.00	5.10	1.86	0	3.40
Spatially Balanced (5) 1 point	4.00	4.00	4.00	0.00	0	0
200m interval (47) 8 points	4.83	2.70	8.20	2.53	1.00	5.00
200m interval (46) 8 points	4.08	3.30	4.80	1.38	0	5.00
300m interval (31) 4 points	4.80	3.50	6.20	1.88	0	5.00

Table C11. Width and Depth Results for On Trail Points (Jewel Lake – Black Lake)

Data Set (# of sample points)	Avegrage Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
Spatially Balanced (99) 19 points	3.63 ft	1.30 ft	5.38 ft	2.25 in	.40 in	4.80 in
100 m interval (93) 28 points	3.45	1.00	6.00	2.03	0	7.90
Spatially Balanced (75) 16 points	3.61	1.33	5.38	2.26	.40	4.80
Spatially Balanced (50) 9 points	3.56	1.33	5.38	2.19	.40	4.80
Spatially Balanced (33) 7 points	3.46	1.33	4.80	2.44	.40	4.80
Spatially Balanced (25) 5 points	3.26	1.33	4.80	2.26	.40	3.40
Spatially Balanced (10) 1 point	2.90	2.90	2.90	3.40	3.40	3.40
Spatially Balanced (5) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
200m interval (47) 14 points	3.36	1.00	6.00	2.61	0	7.90
200m interval (46) 14 points	3.53	1.00	5.83	1.45	0	2.90
300m interval (31) 9 points	3.48	2.30	5.30	2.28	0	5.90

Table C12. Width and Depth Results for On Trail Points (Black Lake – Frozen Lake)

Data Set (# of sample points)	Avegrage Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
Spatially Balanced (99) 16 points	2.84 ft	1.50 ft	6.20 ft	1.88 in	0 in	5.70 in
100 m interval (93)	n/a	n/a	n/a	n/a	n/a	n/a
Spatially Balanced (75) 11 points	2.85	1.50	6.20	2.19	0	5.70
Spatially Balanced (50) 6 points	2.73	2.50	3.00	1.70	0	4.30
Spatially Balanced (33) 3 points	2.85	2.70	3.00	2.73	0	4.30
Spatially Balanced (25) 2 points	2.70	2.70	2.70	1.95	0	3.90
Spatially Balanced (10) 2 points	2.70	2.70	2.70	3.90	3.90	3.90
Spatially Balanced (5) 0 points	n/a	n/a	n/a	n/a	n/a	n/a
200m interval (47)	n/a	n/a	n/a	n/a	n/a	n/a
200m interval (46)	n/a	n/a	n/a	n/a	n/a	n/a
300m interval (31)	n/a	n/a	n/a	n/a	n/a	n/a

Table C13. Width and Depth Results for On Trail Points (Fire Trail)

Data Set (# of sample points)	Avegrage Width	Minimum Width	Maximum Width	Average Depth	Minimum Depth	Maximum Depth
Spatially Balanced (99) 10 points	3.42 ft	2.60 ft	5.90 ft	3.62 in	1.10 in	7.40 in
100 m interval (93)	3.89	2.90	6.40	5.42	1.20	16.10
Spatially Balanced (75) 9 points	3.47	2.60	5.90	3.60	1.10	7.40
Spatially Balanced (50) 4 points	3.40	2.90	3.80	3.78	1.90	5.90
Spatially Balanced (33) 4 points	3.40	2.90	3.80	3.78	1.90	5.90
Spatially Balanced (25) 3 points	3.27	2.90	3.50	3.07	1.90	5.00
Spatially Balanced (10) 2 points	3.15	2.90	3.40	3.65	2.30	5.00
Spatially Balanced (5) 2 points	3.15	2.90	3.40	3.65	2.30	5.00
200m interval (47) 8 points	4.26	3.20	6.40	7.29	1.20	16.10
200m interval (46) 7 points	3.47	2.90	4.50	3.29	1.20	5.80
300m interval (31) 5 points	3.76	2.90	6.40	7.78	2.50	16.10

Appendix D – Data Collection Sheet

Topography of Sample Area:

N __________

NE __________

E __________

SE __________

S __________

SW __________

W __________

NW __________

Elevation: ___________________

Soil: _________________________

Evidence of Visitors: (Y / N)

Type of User: ________________________

Invasive Species: (Y / N) ____________

Social Trails: (Y / N)

Presence of:

Litter: (Y / N)

Human Waste: (Y / N)

Vandalism: (Y / N)

Fire Rings: (Y / N)

Other: (Y / N) ________________

Trees Types > 4 inches dbh:

____

____

____

Dominant Understory:

____

Canopy Density:

N________E________S________W_________

Does a Trail Exist?: (Y / N)

How many: __________________________

Aspect: up trail _____________

down trail _____________

Slope: up trail _____________

down trail _____________

Trail Position: _____________

Length of uphill trail: __________________

Condition:

Evidence of Maintenance: (Y / N)

drains ____________________

water bars _____________________

steps _________________________

wall __________________________

Imported tread (Y/N/) ___________

Evidence of Erosion: (Y / N)

Max Width_____ _____ _____ _____ _____

Max Depth_____ _____ _____ _____ _____

Muddiness (linear)______________________

Root Exposure (frequency) ______________

Braiding (Y / N)

Other __________________________________

Date:

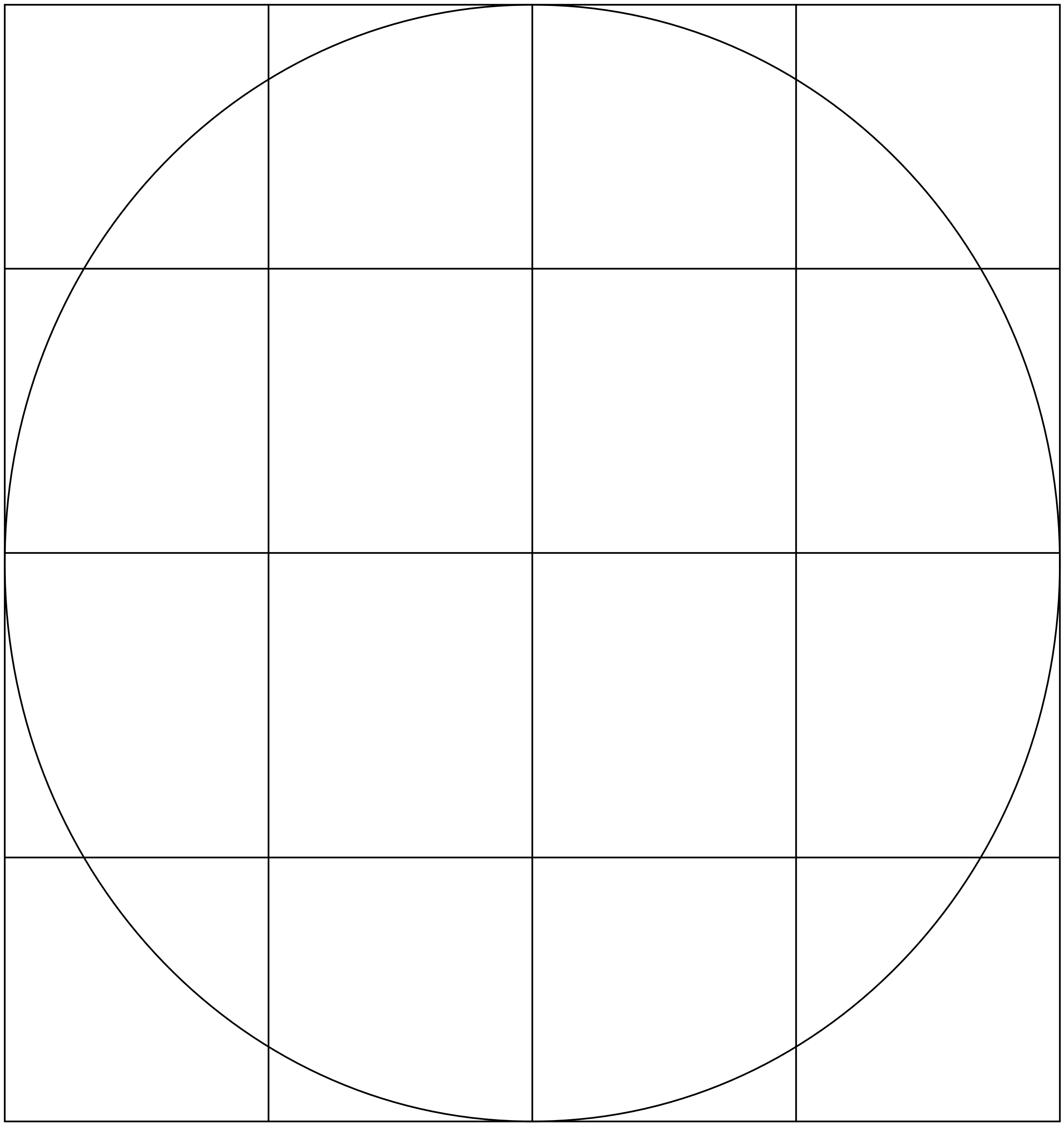
Data Set:

Sample Plot #:

Time:

Sample Time:

Coordinates:



T= Tree

G = Grasses

S = Shrubs

R = Rock

L= Log

E= Bare Earth