# Strategies for Monitoring Multiuse Trail Networks: Implications for Practice

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**ABSTRACT**

Many municipalities, park districts, and nonprofit organizations have begun monitoring non-motorized traffic on multiuse trails as the need for information about use of facilities has grown and relatively low-cost sensors for automated monitoring have become available. As they have gained experience, they have begun to move from site-specific monitoring on individual trails to more comprehensive monitoring of trail networks. This case study compares strategies developed by 10 organizations for monitoring traffic on multi-use trails, including local, multi-county, statewide and multi-state trail networks. We focus on approaches to design of monitoring networks, particularly the rationales or objectives for monitoring and the selection of monitoring sites. We show that jurisdictions are following principles of monitoring established by the Federal Highway Administration and that the design of monitoring networks is evolving to meet new challenges, including monitoring large-scale networks. We summarize relevant outcomes and implications for practice. We conclude FHWA guidelines can be adapted to many circumstances and can increase information for decision-making. Trail monitoring is informing decisions related to facility planning, investment, and safety.

## INTRODUCTION

Many municipalities, park districts, and nonprofit organizations have begun monitoring non-motorized traffic on multiuse trails as the need for information about use of facilities has grown and relatively low-cost sensors for automated monitoring have become available. As these organizations have gained experience, they have begun to move from site-specific monitoring on individual trails to more comprehensive monitoring of trail networks. This review summarizes strategies developed by 10 organizations for monitoring traffic on multi-use trails, including local, multi-county, statewide and multi-state trail networks. Each organization has collaborated with others in the development of monitoring plans. Some have initiated monitoring and published results, while others still are considering implementation. We focus on approaches to design of monitoring networks, rationales for monitoring, and the siting of permanent and short duration monitors. The majority of our cases are from the Midwest, though one case includes monitoring locations from across the United States:

- Indy Parks and Recreation, Greenways Division, Indiana (1, 2);
- Minneapolis Park and Recreation Board, Minneapolis Department of Public Works (3,4);
- Three Rivers Park District, Minnesota (5);
- Mid-Ohio Regional Planning Commission (4, 6);
- Arrowhead Regional Development Commission, Minnesota (7);
- Rails to Trails Conservancy Midwest Office (8);
- Parks and Trails Council of Minnesota (9);
- Minnesota Department of Natural Resources (10);
- Interact for Health, Ohio; and
- Rails to Trails Conservancy, Inc., Washington DC (11,12).

## BACKGROUND

During the past 15 to 20 years significant efforts have been devoted to developing technologies for monitoring non-motorized traffic and protocols for collection and analysis of traffic volume data. Different sensors, including passive and active infrared counters, inductive loops, and pneumatic tubes, have been deployed and validated in a variety of settings, and their capabilities are fairly well understood (14, 15, 16, 17, 18, 19, 20, 21, 22). For example, infrared monitors are reliable and produce consistent counts of mixed-mode traffic (i.e., undifferentiated bicyclists and pedestrians), but typically undercount because of the problem of occlusion (i.e., users passing sensors simultaneously; 14, 21). Higher rates of occlusion may be associated with higher traffic volumes or the configuration of facilities, so site-specific validation of counts is important.

As analysts have gained experience, they have published guidance for the design of non-motorized monitoring systems, selection of equipment, and analysis of bicyclist and pedestrian traffic data (e.g., 13-22). These guidelines build on established procedures for motorized traffic monitoring, but recognize important differences, including greater variation associated with seasonality and weather. Perhaps most importantly, the FHWA added Chapter 4 Traffic Monitoring for Non-motorized Traffic to its authoritative *Traffic Monitoring Guide* (TMG) (13). While recognizing that much remains to be learned, the TMG recommends a standard process of:

- Establishing monitoring objectives,
- Determining modes of traffic to be monitored,
- Selecting monitoring sites within the network, including permanent and short-duration stations,
- Determining the type(s) of devices to be deployed,
- Implementation of monitoring following recommended guidelines,
- Using ratios or factors derived from permanent monitoring stations for extrapolation of short duration counts to estimate annual average daily bicyclists (AADB) or pedestrians (AADP), and

- Following recommended analytic procedures to ensure statistically valid estimates of annual traffic flows.

The TMG notes the importance of identifying different traffic patterns such as commuting or recreational and establishing factor groups for extrapolating short-duration counts. The TMG also identifies needs for research, including monitoring site selection criteria and procedures for minimizing uncertainty and error when estimating AADB or AADP. Since revision of the TMG, the Transportation Research Board has published a circular that assess the state-of-the-art in monitoring (22), and researchers have published papers that advance practice. These papers propose methods that categorize hourly and day-of-week traffic patterns to establish factor groups (23) and illustrate how the accuracy of estimates of annual average daily traffic (AADT) varies with the duration of samples, the time-of-year samples were taken, and methods used to control for the effects of weather (24, 25, 26, 27). They also have shown manual and automated counts can be integrated to characterize the validity of estimates of bicycle volumes for an entire street network (28).

Many jurisdictions now have initiated monitoring, but most state and urban monitoring programs remain relatively ad-hoc compared to monitoring programs for motorized traffic. Several states are working to institutionalize trail monitoring (29, 30). A distinctive element of the North Carolina approach has been its systematic planning for selection of monitoring sites, including establishment of permanent monitors in locations representing different factor groups (30). For example, Jackson et al. (*30*) propose short and long-term monitoring stations in urban, rural, and near-university areas for locations believed to have commuting, recreation, and mixed traffic patterns. They stress the importance of site visits and test-monitoring prior to confirming permanent or short-duration monitoring locations.

Although few organizations have established monitoring programs that have produced standard performance measures such as AADT, many are moving from site-specific monitoring to more comprehensive monitoring systems. Multiuse trail networks are good candidates for experimentation with different monitoring approaches because of their importance for both transportation and recreation, their separation from vehicular traffic, their smaller geographic scale, and the relative ease of monitoring.

## APPROACH

We summarize here strategies for monitoring non-motorized traffic on trails developed by 10 public and nonprofit organizations in several Midwestern states and cities. The set of organizations is best characterized as a purposeful or convenience sample. One or more of the authors has collaborated with each organization in the design and, in some cases, implementation of the monitoring programs. Most information, with the exception of information related to trails in the Cincinnati-metropolitan area, comes from published papers, technical reports, or memoranda (1-12).

We use the guidelines in the *TMG* to frame our discussion, with the goal of illustrating how these principles can be adapted to meet local circumstances and monitoring objectives. We focus on technical elements of monitoring networks, including the rationale for selecting monitoring locations. We describe monitoring efforts that incorporate new techniques developed to address particular challenges or unique monitoring objectives, emphasizing those that have not been described previously in the peer-reviewed literature. We summarize monitoring results and present maps that illustrate how geographic factors related to land use or transportation affect monitoring design. We conclude with a discussion of implications of our insights for trail traffic monitoring in other places.

## MONITORING STRATEGY SUMMARIES

Table 1 summarizes basic information about each monitoring initiative; the columns correspond to the main elements of monitoring programs described in FHWA's TMG (13). The initiatives range from monitoring each mile of a 29-mile destination trail, to monitoring a 650-mile trail network across four states, to monitoring 32 locations in 14 urban areas in seven climatic regions in the United States. Although this review focuses on design on the monitoring system, monitoring results also are summarized.

Indy Parks and Recreation, Greenways Division. In an initiative that pre-dated the FHWA's (13) publication of the *TMG*, the Greenways Division of Indy Parks and Recreation established a monitoring network on five trails that included 30 active infrared monitors, nearly one per mile for 33 miles of trails then in existence (1). The principal purpose for monitoring was to produce evidence of trail use to support system expansion. The monitoring network was designed to obtain valid estimates of trail use for the entire system that reflected variation in use over segments of individual trails. Based on prior experience, researchers concluded that monitors located on each mile of the network would accomplish these objectives. The underlying assumption was that trail traffic would be consistent for mile-long segments. Trail managers and researchers collaborated to delineate trail segments using access points, street intersections, and adjacent land uses. Grant funding was obtained, infrared monitors were installed, and data were collected for a minimum of one year at each location. Because the monitoring was comprehensive, no attempts were made to predetermine traffic patterns or factor groups.

Since completion of this effort, the trail network has expanded but the number of monitoring locations has been reduced, primarily for financial reasons. Researchers subsequently used monitoring results to produce monthly factors for extrapolating counts, estimate trail demand models and to test hypotheses about land use and other characteristics that affect trail traffic volumes (1,2).

Minneapolis Park and Recreation Board, Minneapolis Department of Public Works. In 2013, the Minneapolis Park and Recreation Board (MPRB), the Minneapolis Department of Public Works (MDPW), and the University of Minnesota monitored each mile of the city's 80-mile shared-use network following procedures in the *TMG* (1,3,4). The monitoring network included six permanent, reference sites and 80 short-duration sites on trail segments that averaged about one mile in length. All reference sites were established prior to the monitoring campaign because of interest in traffic flows at particular locations. Short-duration monitoring segments were established based on access points, intersections, and other aspects of the built environment. Counts were collected with active infrared sensors. Following recommendations by Nordback et al. (24) and Hankey et al. (25), short-duration counts were taken for at least seven days between April and October, adjusted for occlusion. Short duration counts for each segment were extrapolated to annual average daily trail traffic (AADTT) using the day-of-year factoring method proposed by Hankey et al. (25). Analysts estimated trail users traveled 28,000,000 miles on the Minneapolis network in 2013 (4).

Analyses of traffic patterns showed that all reference sites exhibited mixed traffic patterns but that commuter and recreational traffic patterns characterize other trail segments (3). This outcome shows the need for additional permanent monitors for development of pattern-specific factors. In addition, analyses showed that traffic volumes on some adjoining segments were comparable, indicating that monitoring segment lengths could be increased, thereby reducing the number of short duration counters needed.

Monitoring results from Minneapolis have been used in a variety of ways in addition to informing MPRB and MDPW operations. The FHWA *TMG* (13) includes a factoring example based on this study's results, researchers have estimated demand models (4, 31), and segment traffic volumes have been used to apply Manual of Uniform Traffic Control Device (MUTCD) warrants for traffic signals and pedestrian hybrid beacons (32, 33).

**Table 1. Design characteristics and results of trail monitoring initiatives.***

| Agency / Geographic Scope | Monitoring Objectives | Modes Monitored & Type of Sensor | Trails | Miles in Network | Permanent Monitoring Sites | Short-Duration Sites | Factoring Approach / Factor Groups | Range of Estimated AADTTs (year) |
|---|---|---|---|---|---|---|---|---|
| Indy Parks and Recreation, Greenways Division, Indianapolis-Marion County, IN (1, 2) | • Support trail development | Mixed-Mode Active Infrared | 5 | 33 | 30 | 0 | Monthly factors / No factor groups. | 60 – 1,663 (2004-05) |
| Minneapolis Park and Recreation Board, Department of Public Works, Minneapolis, MN (3,4) | • Inform trail management<br>• O&M<br>• Assess crossing safety | Mixed-Mode Active Infrared | Many linked. | 80 | 6 | 80 | Day-of-year factoring / Ex-post factor groups | 39 – 3,754 (2013) |
| Three Rivers Park District, Hennepin County, MN (5) | • Support trail development<br>• Obtain regional funding<br>• O&M<br>• Assess safety | Mixed-Mode Passive Infrared<br><br>Manual | 16 | 133 (155 planned) | 7 | 109 (proposed) | Standard factoring / No factor groups | 379 – 1,084 (2014, automated)<br>424 – 1,239 (2014, manual ) |
| Mid-Ohio Regional Planning Commission, City of Columbus & Franklin & Delaware Counties, OH (4, 6) | • Support greenway development<br>• Inform trail management<br>• Link with bikeways | Mixed-Mode Active & Passive Infrared | 10 | 111 | 6 | 67 | Day-of-year factoring / Modeled factor groups | 13 – 1,403 (2014) |
| Arrowhead Regional Development Commission, Lake & Cook Counties, MN (7) | • Inform stakeholders and agencies<br>• Provide data for future monitoring | Mixed-Mode Active Infrared | 1 | 29 (86 planned) | 2 (control sites) | 21 | Day-of-summer factors / No factor groups | 36 – 201 (5/23/15 - 9/8/15) |
| Rails to Trails Conservancy, Inc. Midwest Office, 32 counties in Maryland, Ohio, Pennsylvania, West Virginia (8) | • Document trail use across network<br>• Support trail development | Mixed-Mode Passive Infrared | Many Linked | 1,056 (1,600 planned) | 30 (6 per trail type) | TBD | TBD | TBD |

**Table 1. Design characteristics and results of trail monitoring initiatives, continued.***

| Agency / Geographic Scope | Monitoring Objectives | Modes Monitored & Type of Sensor | Trails | Miles in Network | Permanent Monitoring Sites | Short-Duration Sites | Factoring Approach / Factor Groups | Range of Estimated AADTTs (year) |
|---|---|---|---|---|---|---|---|---|
| Parks and Trails Council of Minnesota, State of Minnesota (9) | • Estimate state trail use<br>• Engage local volunteers<br>• Show need for trail counts | Manual (Mixed-Mode at reference site) | 18 | 651 paved surface | (Minneapolis Monitors Used as Reference) | 25-35 | Standard factoring / No factor groups | 44 – 978 (April – October 2015) |
| Minnesota Department of Natural Resources, State of Minnesota (10) | • Document use of state trails<br>• Inform funding for system expansion<br>• Inform management and O&M | TBD | 25 | 680 | TBD | TBD | TBD | TBD |
| Interact for Health & Tri-State Trails, Cincinnati, OH & nine counties in OH, IN, and KY | • Document use of regional trails<br>• Build evidence for active living | Mixed-Mode Active & Passive Infrared TBD | Many linked | 313 | TBD | TBD | Day-of-year (planned) / Factor group TBD | TBD |
| Rails to Trails Conservancy, Inc., 7 U.S. Climatic Regions, 12 cities (11,12) | • Build trail planning tools<br>• Generate regional extrapolation factors<br>• Develop facility demand models | Mixed-Mode Passive Infrared & Inductive Loop | ± 28 | 14 urban areas 7 climatic regions | 32 | NA | Standard factoring / Ex-post factor groups | 159 – 3,542 (ADT) 39 – 2,299 (ADP) 30 – 1,243 (ADB) (2014-16) |

*Columns represent key steps in non-motorized traffic monitoring outlined by the FHWA in the *Traffic Monitoring Guide* (13). The FHWA recommendation for quality assurance/quality control is not addressed in Table 1. All jurisdictions use some combination of on-site validation of sensors when installed and visual inspections of data to identify potential problems. Decisions for identify and controlling data believed to be incorrect generally remain ad hoc.

Three Rivers Park District (TRPD). The TRPD in suburban Hennepin County (excluding Minneapolis) maintains 16 regional trails totaling 133 miles (5). The TRPD, like other park districts in the Twin Cities Metropolitan Area (TCMA) that participate in a regional funding program, manually counts trail visitors at access points following protocols established by the Metropolitan Council. The protocols involve a combination of randomized and systematic sampling at low, medium, and high volume times. The TRPD also has maintained seven permanent passive infrared monitors to obtain more detailed traffic data.

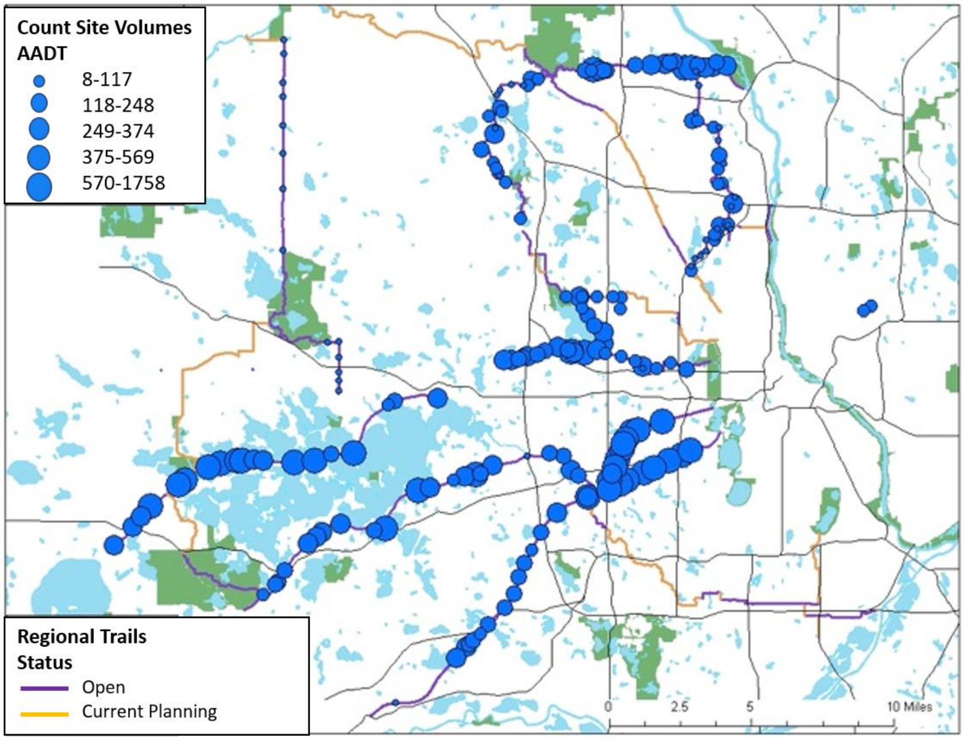
In 2014, an intern developed a plan for automated trail monitoring for the existing and planned TRPD regional trail network using both manual and automated counts to identify potential network segments and monitoring locations. The monitoring design involved mapping access points used for manual counts, establishing preliminary segments based on access points, using factors from the permanent monitoring sites to extrapolate manual counts to AADTT, and, based on differences in estimated AADTT, combining similar adjoining segments into longer units for short-duration automated monitoring (5). Across network, trail length averaged eight miles, with an average of 17 access points per trail. The number of segments based on access points was 255, with an average length of approximately one-half mile. Variation in estimated AADTT on these segments is shown in Figure 1. Potential monitoring segments were combined when estimated AADTT on adjoining segments were within 20%. This reduced the number of segments to 130 with an average length of .9 miles. TRPD staff familiar with the network then identified additional segments to combine, reducing the number of segments to 70, averaging 1.3 miles in length. The final design included plans for short-duration monitoring on trails to be built in the near future, increasing total trail miles to 155 divided into 109 segments.

The monitoring plan proposes nine permanent sites, along with short-duration monitoring on all other segments (Figure 1; 5). Staff selected the sites to represent a range of volumes, probable use patterns, and geography across the trail system, but short term monitoring was not undertaken to determine whether the locations have recreational or commuter patterns. Analyses showed all existing permanent stations had mixed-utilitarian or mixed-recreational traffic patterns. Since its completion, TRPD has not invested in implementation of the plan, but the agency has worked with the Minnesota Department of Transportation to install one new permanent counter.

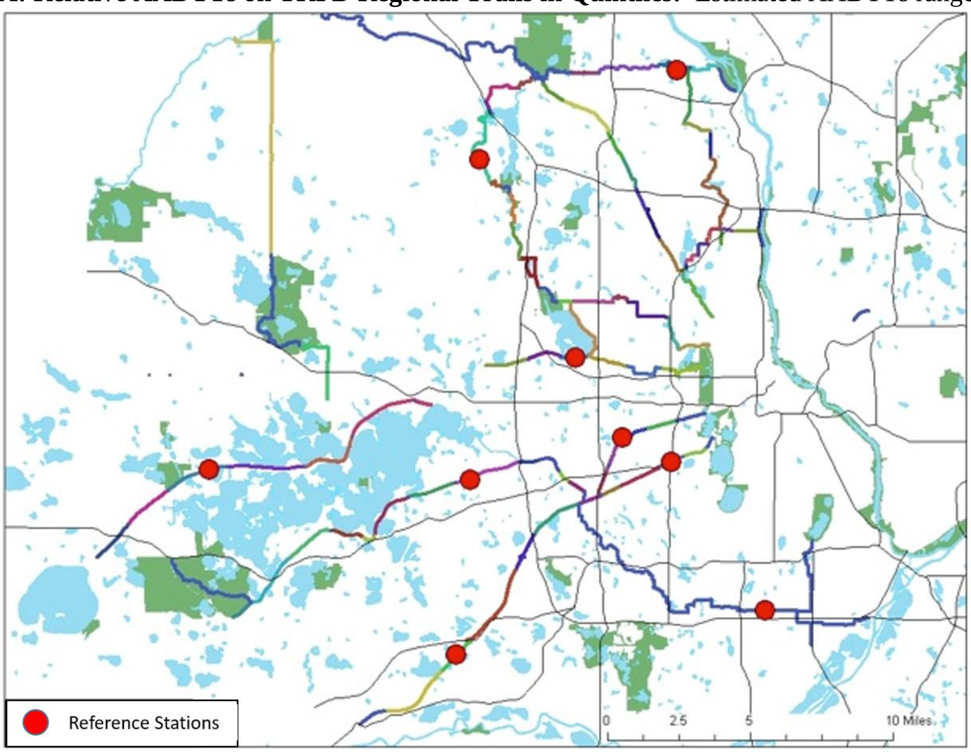
Mid-Ohio Regional Planning Commission (MORPC). MORPC, the City of Columbus, the Rails to Trails Conservancy, and other local agencies have monitored trail traffic for several years using both passive and active infrared monitors. Together, they documented significant levels of trail use at particular sites and increases in trail use over time but had not monitored all trails or produced estimates of traffic flows throughout the Central Ohio greenway network. In 2014, MORPC led efforts to expand trail traffic monitoring. Their approach, which built on past efforts, explicitly followed TMG guidelines and included seven major steps (4, 6):

1. Select monitoring devices;
2. Select continuous monitoring locations;
3. Segment the network for short-duration monitoring;
4. Complete short-duration monitoring on segments without continuous monitors;
5. Clean and validate data;
6. Derive factors for extrapolation of short-duration counts and estimate AADTT for segments; and
7. Calculate trail miles traveled (TMT; segment AADTT x segment length).

**Figure 1. Variation in estimated AADTT on TRPD trails and proposed locations of permanent monitoring stations.**




**A: Relative AADTTs on TRPD Regional Trails in Quintiles:** Estimated AADTTs range from 8 to 1758.




**B: Segment Definitions and Proposed Permanent Count Reference Stations:** Color changes along the trails identify different segments based >20% difference in traffic between segments and professional judgment of a TRPD manager.

MORPC partners defined 67 trail segments on the 10-trail, 111-mile system following guidelines in the TMG (13) and procedures used in other monitoring studies (1, 4). Segments averaged 1.7 miles in length, in part because population density was a factor in segmentation, and segments were longer in rural areas. Because permanent counters were in place on six segments, short-duration counts on 61 segments were needed. No new permanent stations were added. Subsequent analyses showed that all permanent monitoring location had mixed traffic patterns but that some short-duration sites had recreational and commuter patterns.

MORPC's monitoring program is ongoing and regional partners are using results to build support for expansion of regional greenways. Researchers subsequently have used results to build and validate facility demand models (4).

Arrowhead Regional Development Commission (ARDC). In the summer of 2015, ARDC planners collaborated with MnDOT, the Sawtooth Mountain Clinic, and the University of Minnesota to monitor traffic on every mile of the Gitchi-Gami Trail (GGT) along Lake Superior in northeastern Minnesota (7). The GGT currently includes 29 miles in six unconnected sections; when completed, the GGT will be 86 miles long. Monitoring was initiated to enable trail stakeholders and partners to plan and manage the trail more effectively and to provide information for future monitoring. The monitoring design involved adaptation of FHWA (13) procedures and included two reference or control sites and 21 short-duration monitoring locations approximately 1 to 2 miles apart (Figure 2). Because the GGT is not plowed and receives very limited use in winter, ARDC chose to estimate summertime average daily trail traffic (SADTT) rather than AADTT. Monitoring was completed between May 23 and September 8 in order to capture Memorial Day and Labor Day traffic; short-duration counts were taken for a minimum of 10 days. All monitoring was done with active infrared monitors, and all counts were adjusted for occlusion. Short-duration counts were extrapolated using a "day-of-summer" approach based on the day-of-year approach (25). SADTT estimates ranged from 36 to 201 across segments (Figure 2).

ARDC planners are using monitoring results to support grant applications and to prioritize segments for funding. The ARDC is replicating the monitoring in 2016.

Rails to Trails Conservancy, Inc. Midwest Office. The Midwest Office of RTC is working with the Power of 32, an economic development initiative in 32 counties in four states (Maryland, Ohio, Pennsylvania, and West Virginia) to implement a comprehensive regional trail network. The RTC worked with researchers to design a monitoring program that would enable characterization of traffic volumes on 1,056 miles of existing trails (8). To identify monitoring locations, GIS was used to create points at one-mile intervals along the entire network. One-half mile buffers were created around each point, and geospatial data were assembled within the buffers. Each buffer was classified into one of five distinct groups that capture major variations in contextual characteristics: urban, suburban, low intensity development / rural, forest, and parks. Classification was based on factor analysis derived from sixteen contextual measures using a k-means clustering approach. The team experimented with different clustering approaches by varying both the number of classes and the number of factors used in the algorithm. The final classification was determined through interpretation of statistical outputs, visual interpretation of classification results overlaid on aerial photography and GIS layers, and consultation with RTC staff familiar with on-the-ground conditions. A stratified random sampling approach was used to select six locations from each of the five classes for a total of thirty monitoring locations. RTC personnel reviewed the selected locations to verify feasibility of access and monitor placement (Figure 3).

RTC commenced monitoring in the fall of 2015; all 30 passive infrared monitors will be at these locations for a minimum of one year. The initial monitoring results are expected in 2017. Based on analysis of traffic patterns, results will be used to extrapolate traffic volume estimates throughout the network and to determine the need for relocation of permanent monitoring sites.

**Figure 2. Gitchi-Gami State Trail: Monitoring Locations and 2015 Summer Average Daily Traffic**

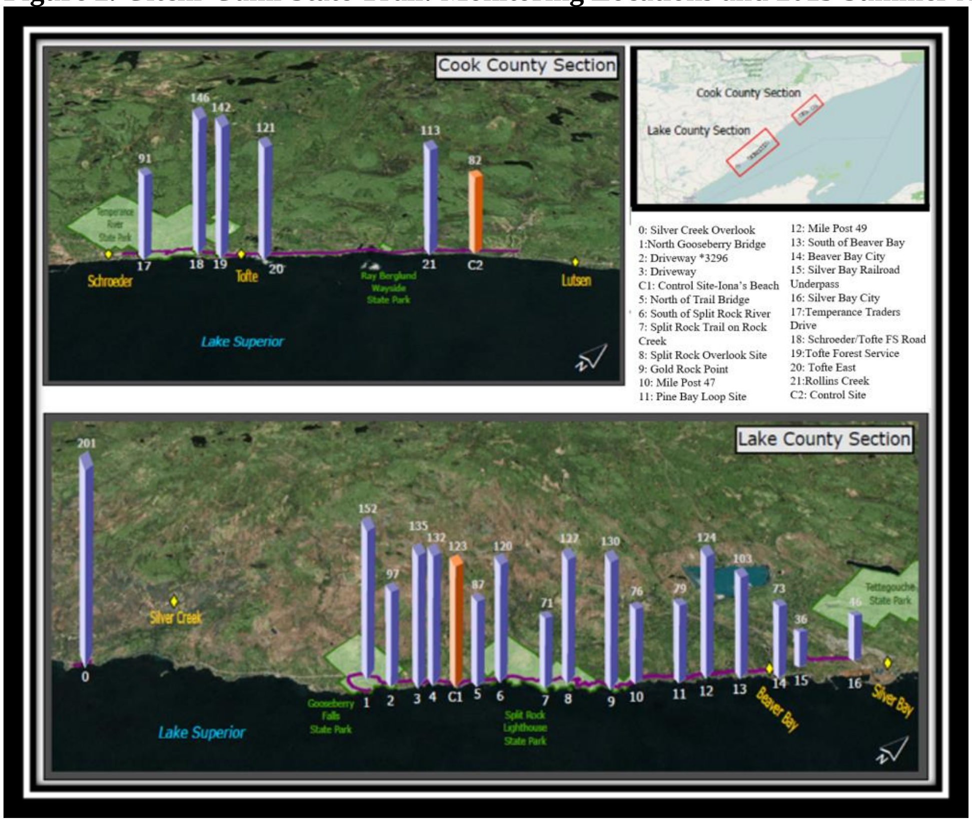
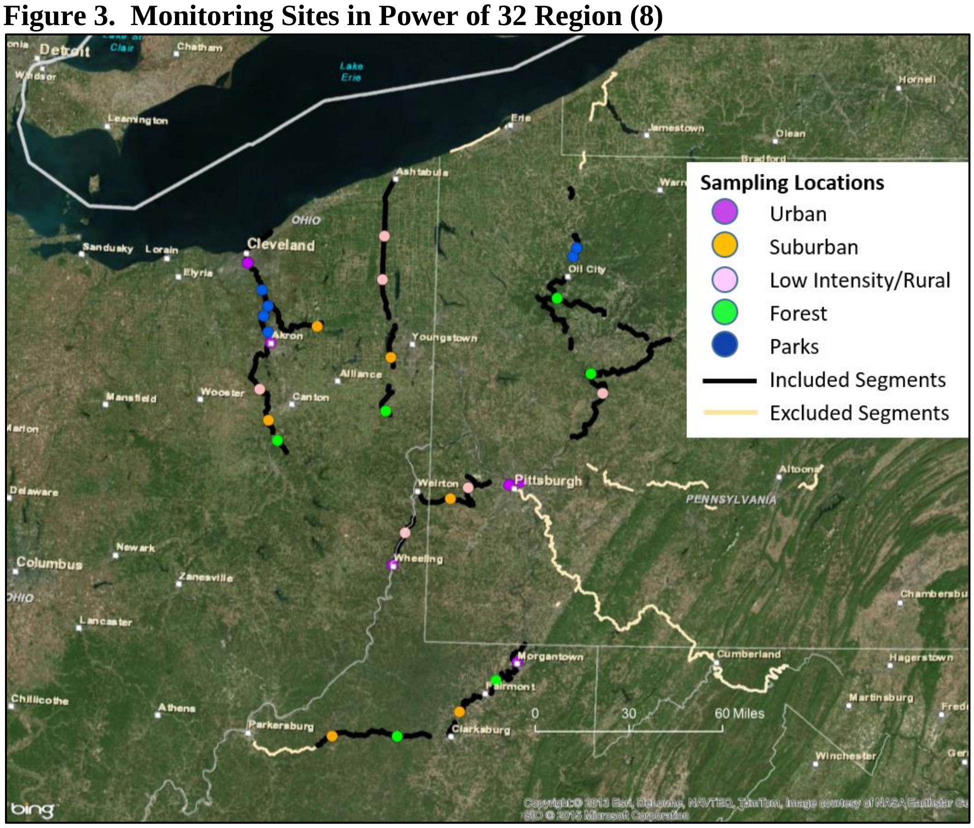



**Figure 3. Monitoring Sites in Power of 32 Region (8)**



Parks and Trails Council of Minnesota. The Minnesota Department of Natural Resources (MDNR) maintains a network of 19 trails that are partially or completely developed, 18 of which support multiuse traffic. These 18 trails include over 650 miles of hardened or paved surface. In the summer of 2015, a nonprofit advocacy organization, the Parks and Trails Council, completed a series of manual counts to provide order-of-magnitude estimates of trail use, mobilize local volunteers, and highlight the need for expanded counting (9).

The monitoring strategy involved dividing the trails into 15 to 25 mile segments, recruiting volunteers, and counting for a minimum of 10 hours on each segment, including peak-hours on weekdays and weekends. The Council chose locations purposefully based on three factors: expected patterns of use, accessibility, and volunteer safety. Most locations were near a city, trail head, park, or junction. The final plan included 35 segments, but only 25 ultimately were counted because volunteers could not be recruited for some segments. The Council followed MnDOT guidelines for manual counting and adapted procedures outlined by the FHWA (13) and Hankey et al. (25) to extrapolate counts to non-winter ADTT. Non-winter ADTT was estimated because most trails are not plowed and receive little use in winter. The extrapolation procedures involved six steps (9, p. 14):

1. *Estimate average weekday (or weekend) traffic using hour-long field counts;*
2. *Estimate monthly average daily traffic using average weekday (or weekend) traffic;*
3. *Estimate annual average daily traffic using monthly average daily traffic;*
4. *Estimate annual traffic using annual average daily traffic;*
5. *Estimate non-winter use by subtracting November-March use; and*
6. *Estimate margin of error.*

All factors used to extrapolate counts were obtained from analyses of year-round trail traffic on other multiuse trails in Minnesota.

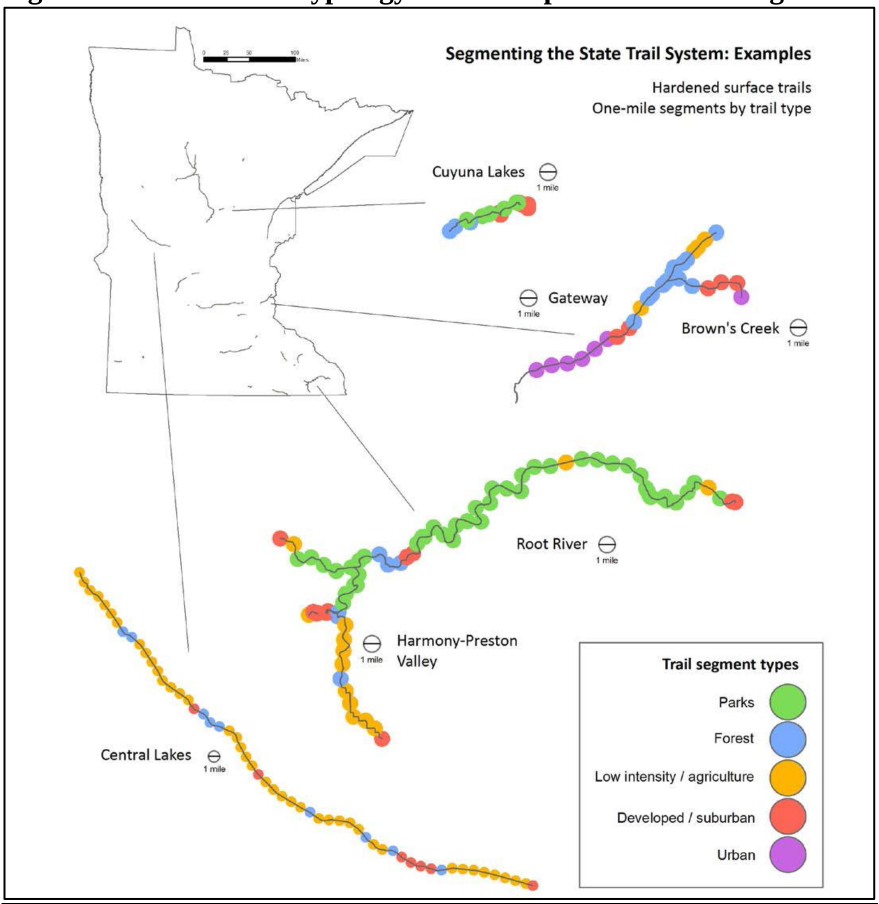
The Council noted four important limitations of the approach (9, p. 16): "small sample sizes, use of nonlocal adjustment factors for extrapolation, assumptions of daily traffic patterns, and the level of uncertainty associated with our estimates." To communicate these limitations, the Council described the estimates as "order-of-magnitude" and, based on studies of extrapolation error (24, 25), characterized the range of error as 40% either side of the estimate. The Council is using results to support its advocacy efforts and exploring the feasibility of using portable monitoring equipment from MnDOT for automated monitoring.

Minnesota Department of Natural Resources. MDNR, as noted, maintains a system of multiuse trails throughout Minnesota (10). Between 1996 and 2010, MDNR produced a measure of use for some its trails called user-hours that was obtained by driving or cycling along a length of trail, counting users, and assuming a standard duration of trail use per individual. In 2016, a graduate student team completed a study for MDNR to assess alternative strategies for monitoring trail use. The objectives were to provide a framework for selecting a new counting methodology, to outline key decisions in implementation, and to recommend an overall strategy.

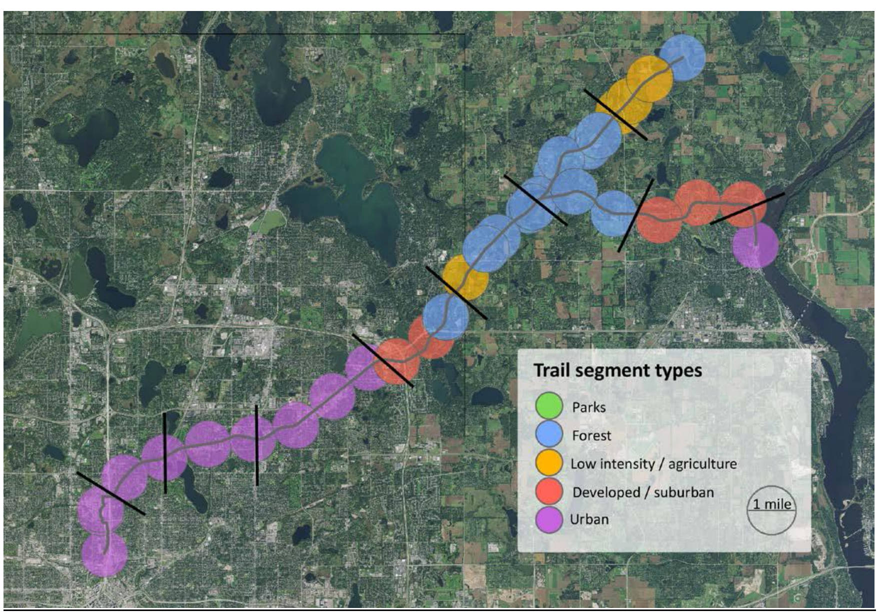
The study compared the user-hour method, manual counts of trail visitors using Metropolitan Council protocols, and manual and automated traffic monitoring using MnDOT and FHWA guidelines. They recommended MDNR implement a traffic monitoring approach and presented two alternatives that varied with respect to seven design elements: comprehensiveness, frequency, segmenting, count duration, technology, extrapolation method, and data management (10).

The team adapted the segmentation approach used by RTC for the Power of 32 region (8) in its design. The Grouping Analysis Tool in ESRI's ArcGIS was used to combine four categories of geospatial data (parkland, land cover, population, and street network connectivity) into a trail typology for a buffer along each mile of a 680-mile network (10). The final typology comprised five classifications: parks, forest, low-intensity/agriculture, suburban, and urban (Figure 4). The team illustrated how segments could be established using these classifications and other factors such as access points (Figure 4) but did not make final recommendations, noting that decisions about segments involve tradeoffs with other considerations, including available funding, accuracy of estimates, and monitoring frequency.

**Figure 4. MDNR Trail Typology and Example of Potential Segmentation**




**A: MDNR Trail Typology on Five Trails.**




**B: Example of potential segments along a trail.**

MDNR is evaluating options and will make decisions about implementation based on resource availability. MDNR also is collaborating with MnDOT and other agencies to place monitors on state trails and to use information from other automated trail monitors in interpretation of data.

Interact for Health. Interact for Health is a nonprofit organization with a mission to improve the health of residents of a 20-county, three-state region around Cincinnati, Ohio. As part of its active living initiative, Interact for Health is facilitating collaboration of trail operators and supporting development of a regional monitoring program. The monitoring design involves application of new tools developed from MORPC's monitoring results in Central Ohio. As noted, results from monitoring by MORPC were used to estimate a demand model (31). This regression model is being used to estimate AADTT on each mile of trail in the Cincinnati region. In addition, traffic patterns on the Columbus network are being analyzed to determine factor groups, and a new multinomial regression model is being estimated to predict the factor group (i.e, commute, recreational, or mixed) for each trail segment. The estimated AADTT ranges from 48 to 854. The factor group model estimates that 55% of the sites will have recreational patterns, 38% mixed patterns, and only 7% commute patterns. The idea is to identify consecutive segments in the same volume quartile and probable factor group and combine for test monitoring prior to pilot monitoring. Monitoring plans will be finalized in 2016 with the goal of initiating monitoring in 2017.

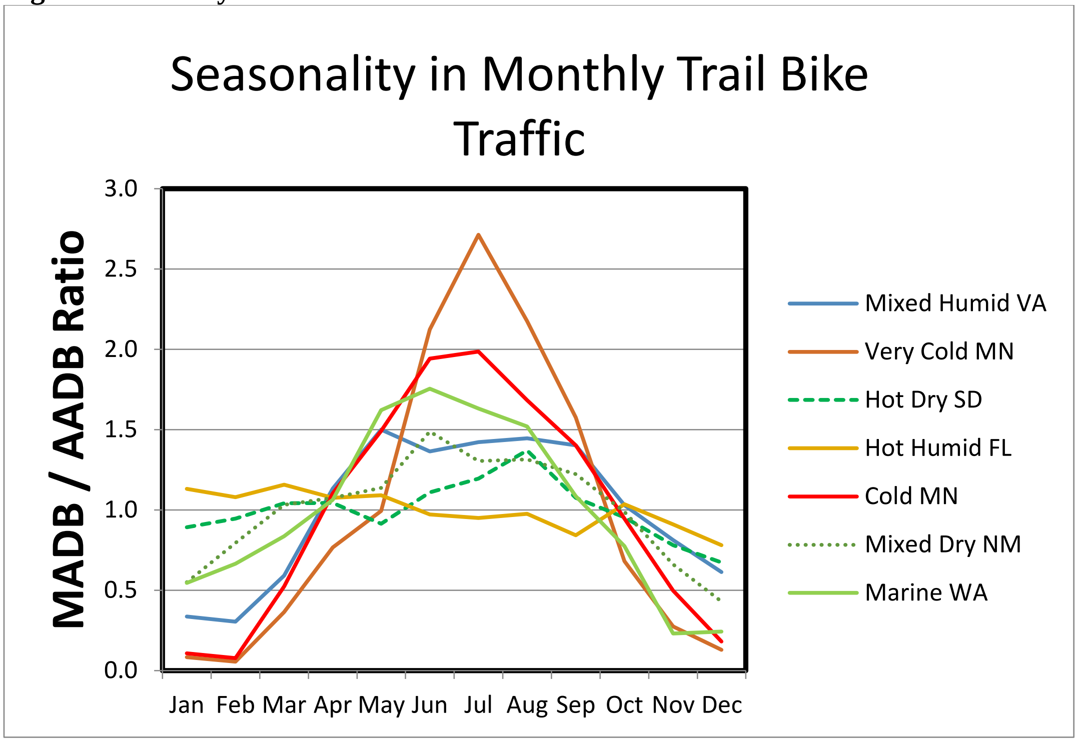
Rails to Trails Conservancy, Inc. RTC designed a monitoring program as part of its efforts to develop the Trail Modeling and Assessment Platform (T-MAP; 11,12). T-MAP is a research initiative to build new tools for urban trail development that can be applied in in each of seven continental climate zones identified by the U.S. Department Energy: very cold, cold, marine, mixed-dry, mixed-humid, hot-dry, and hot-humid (34). A key objective is to estimate regional factors for extrapolating short duration counts that reflect variations associated with different weather patterns. The initial sample included 50 locations in 14 cities with Census-designated urbanized areas and populations over 150,000. Cities were recruited based on staff knowledge of trail facilities and willingness to collaborate in installation of monitoring devices. The exact station locations were sited based on safety, security, suitability, and features (e.g., shrubs) that might affect performance of the monitoring equipment. Stations are located in: Portland, ME; Arlington, VA; Miami, FL; New Orleans, LA; Indianapolis, IN; Minneapolis, MN; Duluth, MN; Fort Worth, TX; Houston, TX; Albuquerque, NM; Colorado Springs, CO; Billings, MT; Seattle, WA; and San Diego, CA.

RTC has followed TMG (13) protocols for quality-assurance and data analysis. To date, monitoring results have been used to develop trail-specific and regional factors for bicycle, pedestrian, and mixed model traffic and to build mode-specific facility demand models. For example, Figure 5 illustrates variation in monthly factors of bicycle traffic in cities from each climate region (i.e., the ratios of monthly average daily bicyclists (MADB) to annual average daily bicyclists (AADB). These factors clearly show the importance of climate on seasonal variation in trail use.

## INSIGHTS AND IMPLICATIONS FOR PRACTICE

Trail monitoring in the United States is expanding and evolving as the need for information on trail use grows. As the availability and accuracy of relatively low-cost automated sensors increases, trail management organizations continue to gain experience with monitoringThese organizations also learn from their peers. This review illustrates how public and nonprofit organizations have developed monitoring strategies for trails at local through multi-state levels. The rationales for monitoring tend to be similar: to document trail use, plan and prioritize new facilities, assess exposure to risk, inform operations and maintenance, and, in some cases, develop tools to help planners and advocates achieve programmatic goals. The approaches increasingly are variations of general monitoring principles outlined in the

**Figure 5. Monthly factors for trail traffic in seven climatic zones in the U.S.**




FHWA's TMG, but adapted to meet organizational needs, contextual considerations, and resource constraints. Because of these types of efforts, our understanding of trail traffic patterns is increasing. Most of these initiatives have relied on low-cost infrared sensors and therefore have been able to obtain only undifferentiated mixed-mode counts. The RTC's use of integrated infrared-inductive loop counters in its TMAP project provides separate counts for bicyclists and pedestrians, which is a step forward. Across the case studies presented, estimates of AADTT range over three orders of magnitude (i.e., from 13 to 3,754), with larger volumes measured in urban areas and lower volumes on more rural, destination trails or unconnected, short urban trails.

We can draw several insights from these cases that have implications for practice; for example:

- Monitoring systems evolve: most of organizations gained experience with monitoring at a few sites before moving to more comprehensive strategies. Familiarity with equipment, data analyses, and uses of the data seems to increase likelihood of more comprehensive initiatives, perhaps by justifying the cost of the equipment and staff time through demonstrated utility.
- Planners are using GIS, statistical analysis, and new demand models that estimate traffic volumes and patterns to inform decisions about segmentation of trails for monitoring.
- Manual and automated counts can be used productively to inform decisions about monitoring locations and to build support for more comprehensive monitoring networks.
- Project champions and collaboration in the design and implementation of trail monitoring networks is essential. Professionals from public and nonprofit organizations are working together to produce evidence to improve trail planning and management. Systematic outreach to organizations with shared interests and pooling of resources can help increase the likelihood that comprehensive monitoring will be initiated.

- Opportunities to increase monitoring efficiency exist. Among these cases, for example, strategies for network segmentation include consideration of length and access points (e.g., Indianapolis), adjacent land uses (e.g., RTC Power of 32, MDNR), and variation in estimated volumes along trail segments (e.g., TRPD). As more data become available and understanding of trail traffic patterns increases, it may be possible to use fewer segments to characterize networks.

We can also identify lessons learned from choices made as monitoring programs were implemented. For example, in Indianapolis, no short-duration sampling initially was undertaken. Trail traffic was monitored at all locations for more than a year: In retrospect, fewer resources could have been devoted to the initiative had guidelines for sampling been in existence. In several of the initiatives (e.g., Minneapolis, Columbus), existing monitoring sites were used as permanent sites without regard to traffic patterns or factor groups, mainly because of time constraints. As a result, permanent sites did not reflect all traffic patterns subsequently identified in more comprehensive monitoring. Judicious short-duration monitoring prior to implementation may lead to identification of sites for permanent monitoring that better represent the range of patterns within a network. Several of the networks initially have used segments of approximately one mile, adjusted for access points and other features, for short-duration monitoring. This approach may be too fine-grained depending on the geographic context: differences in traffic volumes across segments, particularly at low volume sites with less than 100 AADTT, may not be large enough to affect decisions. Longer segment lengths may be acceptable in some cases. All initiatives have wrestled with quality assurance, yet standardized approaches have not been implemented. Thoughtful consideration of these lessons potentially can improve the efficiency of future monitoring initiatives.

Despite the progress illustrated by these efforts, significant challenges remain. No monitoring has occurred on most trails in most communities in most states. This lack of monitoring is likely because most jurisdictions lack institutional champions, resources such as funding, expertise, and staff capacity, and collaboration with partners. Our cases show that each of these is important in mounting an effective program. Because monitoring has not occurred, most jurisdictions still lack the evidence base needed to strengthen trail planning and management and increase the efficiency of investments in trail systems. Continued efforts to share progress and innovations in trail monitoring are warranted.

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