Monitoring Outdoor Recreational Quality and Public Access

STATE OF THE LITERATURE & BEST PRACTICES

PREPARED BY:

Derek Kauneckis, Ph.D.
Associate Research Professor, Division of Earth and Ecosystem Sciences, Desert Research Institute

José Sánchez, Ph.D.
Research Economist, USDA Forest Service, Pacific Southwest Research Station

Michelle Carr, MS
Oak Ridge Institute for Science and Education (ORISE) Fellow, USDA Forest Service, Pacific Southwest Research Station

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Summary

This document provides part two of the Sustainable Recreation Monitoring and Evaluation Plan project. It outlines a framework and recommendations to address three emerging management challenges in the Lake Tahoe Basin: 1) a lack of outdoor recreational activity data to meet current management needs, 2) new types of data to account for changing visitation pressure, and 3) a need for long-term monitoring to track future conditions and measure the impact of management changes.

A **framework of core principles** for data collection at Lake Tahoe was developed based on best practices discovered around the world. These include:

- All new data collection sites should be directly connected to management actions.
- Increase effort to directly communicate the use of data for management.
- New data collection should be co-located with existing and new sensors.
- More than count data is required for many management questions.
- Site selection and data types should be incorporated into regional scale outdoor recreation models.

There are **eleven recommended actions** for the development of an effective, future-oriented outdoor recreational activity monitoring system:

- Select representative monitoring sites across activity areas.
- Identify capacity metrics for each priority site.
- Deploy co-located activity sensors in combination with mixed methods.
- Develop standardized data collection survey instruments.
- Conduct *The Lake Tahoe Outdoor Recreational Activity Survey* every 5-10 years across both summer and winter seasons.
- Incorporate big data for baseline.
- Create a cross-agency, cross-sector data collection coordination team.
- Aggregate and report data at a single accessible location.
- Utilize an off-the-shelf crowdsourced app to collect and coordinate status reports in real-time.
- Establish an *Outdoor Recreation Innovation Working Group* to coordinate with research partners and draw increased funding.
- Identify small-scale high-impact monitoring experiments with research partners.

A survey assessing data needs across the outdoor recreation community revealed the greatest demand was for user count data, site impacts, and mobility decisions. The report discusses the importance of aligning data collection with emerging technology to provide information to both the management community and site users, and a review of how Vehicle Miles Traveled (VMT) data is used at other recreational destinations. An example of applying the recommended actions in the short term (less than 1-year) and medium to long-term (5-10 years) is provided below. A theoretical illustration of multi-method data collection, the co-location of sensors, and integration with big data (mobility) services is applied to Sand Harbor Nevada State Park.

Example Application of Recommended Actions

Short Term Actions	Medium and Long Term	Recommended Action	Specific Activity	Management Goal
●		Select representative monitoring sites across activity areas.	Select one or more of the below high priority outdoor recreational sites: Sand Harbor, Emerald Bay, Zephyr Cove, Nevada Beach (See following example for Sand Harbor).	• Collect representative baseline data on outdoor activities.
	●		Incrementally expand monitoring with additional sites to measure diversity of activities and users.	• Expand data to provide site counts toward basin scale representative modeling.
●		Identify capacity metrics for priority sites.	Use existing PAOTs and/or Multicriteria Framework.	• Determine empirical metrics for site crowding.
●		Deploy co-located activity sensors in combination with mixed methods.	Install new trail counters on sites at entry points. Associate with hand counts, surveys, mobility data for cross-validation.	• Understand changes in outdoor activities over time. Allocate staff resources to match demand. Sensor calibration.
●		Develop standardized data collection survey instruments.	Utilize Nevada Division of State Parks Sand Harbor Survey Instrument as first version to administer to other sites.	• Collect demographic and user experience data, track change over time. Match resources to continue high value experiences.
	●	Conduct The Lake Tahoe Outdoor Recreational Activity Survey every 5-10 years across both summer and winter seasons.	Coordinate surveys to validate trail counters, hand counts, and mobility data. Once validated, rely on automated systems.	• Understand outdoor use patterns and changes, project future needs, allocate staff and infrastructure investments at a basin scale.
●		Incorporate big data for baseline.	Use for basin scale metrics. Validate using co-located onsite measurements.	• Generate basin scale basinline data on outdoor activities. Develop basin scale model of outdoor activities.
	●	Create a cross-agency, cross-sector data collection coordination team.	Create task-focused team to coordinate data collection at priority site(s) and compare across sites.	• Coordinate basin scale data collection, sensor funding and deployment, use of volunteer labor, and other resources.
	●	Aggregate and report data at a single accessible location.	Begin reporting outdoor recreational activity data at the basin scale.	• Provide data repository for sharing, comparing, and engaging monitoring and data collection efforts.
	●	Utilize an off-the-shelf crowdsourced app to collect and coordinate status reports in real-time.	Evaluate existing crowdsource platforms for sharing information among field staff and volunteers.	• Create an alert system to record and notify when site capacity (trash, parking, trails) is exceeded and coordinate response.
	●	Establish an Outdoor Recretion Innovation Working Group to coordinate with research partners and draw increased funding.	Partner with one or more researchers in region to pursue novel funding for innovation research.	• Incorporate emerging technologies, approaches, and models to build Lake Tahoe specific applications.
	●	Identify small-scale high-impact monitoring experiments with research partners.	Create a running list of monitoring questions of broad interest to stakeholders for funding/research parternship focus.	• Improve funding for monitoring deployment, build site and regionally specific predictive models of outdoor use, increase connection between management goals and basin research activities.

Example of site level monitoring for Sand Harbor, Nevada State Park System

Line-of-sight boat landing and water arrival count. *Establish estimate of boat visitors as a percent of total visitors. Requires one day of manual counts.*

Install IR trail counter along Tahoe East Shore Trail. *Provides estimate of trail arrivals. Undifferentiated bike and pedestrian traffic.*

Install Video AI Counter (emerging technology). *Provides estimate of pedestrian vs. bike arrivals. Validate against IR and hourly hand counts.*

Collection of gate entry data. *Provides vehicle arrival count data that can be used to estimate total site visitation.*

Re-administer Nevada State Park Survey during line-of-site and trail hand counts. *Provides demographic and visitor decision making data.*

Conduct single representative day data collection across each source. Use data sources to validate mobility data provided by service providers such as Placer.ai. Once accuracy and errors are identified, costly methods such as manual counts are no longer requires and the validation and calibration methods can be replicated on sites with different activities and characteristics.

The Challenge

Lake Tahoe is renowned for its crystalline waters nestled in the majestic Sierra Nevada Mountains providing a wide range of world class outdoor recreational activities. Lake Tahoe is facing visitation pressures similar to many of the world's most popular destinations and increased interest in outdoor recreation is challenging infrastructure and management created for the recreational uses of the past decade. The Lake Tahoe management community is proactive and has identified data and monitoring needs to better inform decisions:

- There is a lack of activity data to meet specific management needs.
- New types of data are needed to account for changing use pressures.
- Long-term monitoring required to generate baseline data to track future conditions and measure the impact of management changes.

This report provides part two of the Sustainable Recreation Monitoring and Evaluation Plan Project. The first part, *Monitoring Outdoor Recreational Quality and Public Access in the Lake Tahoe Basin: State of the Literature and Best Practices*, presents the results of an extensive review of technique, approaches, and metrics for monitoring outdoor recreational activities and measuring sustainability. This report presents eleven specific recommendations for the creation of an effective outdoor activity monitoring system to collect the types of data needed to address current and emerging management challenges. Few regions are as well-prepared as Lake Tahoe to create an outdoor recreational monitoring system, and if just a handful of the recommendations suggested here are implemented Lake Tahoe can become a global leader in sustainable outdoor recreation management.

The Project

The Sustainable Recreation Monitoring and Evaluation Plan Project brings the best available scientific research and knowledge to the development of a plan for the Lake Tahoe Basin. The Phase 1 Report presented the results of extensive research on metrics, indicators, and best practices in measuring and monitoring outdoor recreational activities. This included examining current data on recreational activity change, developing a conceptual model of factors impacting visitation, a literature review of indicators and metrics, and illustrative examples from comparative regions on best practices. The effort resulted in the most extensive assessment of methods, technologies, and approaches for monitoring outdoor recreational activities.

There is a need for baseline data to track recreation patterns and visitation rates over time, information on what type and when site capacity is exceeded, early identification of where new infrastructure may be needed, and sociodemographic information on the types of recreational users, their behavior, and the effectiveness of environmental education and management efforts. These were broken down to ten management objectives identified in the first phase of the project.

Management Objectives

- Monitor environmental impacts of outdoor recreational activities (on-site and basin scale).
- Identify when site infrastructure is exceeded (parking, trash, etc.) during both peak use and surge events.
- Identify trends in recreational activities, informal trails, and emerging sites to anticipate infrastructure needs.
- Create data to support surge management and reallocating overflow visitors.
- Monitor the impact of crowding on user experience.
- Evaluate effectiveness of stewardship and information campaigns.
- Monitor to support multimodal transportation options to recreational sites.
- Evaluate the effectiveness of different interventions across sites.
- Increase experimentation with technologies, techniques, and policies with partner organizations.
- Provide a consistent periodic reporting mechanism on outdoor recreation activities.

The monitoring framework and recommendations are designed to support these objectives.

A Framework for Monitoring and Evaluation

Several principles for new data collection on outdoor recreational activities were identified during the course of the project. These principles are intended to guide rigorous data collection efforts in order to improve integration with management, increase public awareness of the importance of better data to inform decision making, and expand sensors and data collection sites to inform regional representation.

- All new data collection sites should be directly connected to management actions.
- Effort on communication of the use of data for management.
- Data collection efforts should be co-located with existing or new sensors.
- More than count data (site survey, experience, recreational choices, etc.) is required for most management questions.
- Site selection and data types should be incorporated into a regional scale outdoor recreation model.

There is a perception that more science and data is not improving the challenges Lake Tahoe faces. While the evidence suggests science has played an important part in the remarkable success in management and cross-jurisdictional collaboration, explicit management actions associated with new data collection efforts will build a stronger narrative of responsiveness to public concerns. Attention to messaging around a basin-wide monitoring system can help increase broader engagement. Co-location and cross-validation of counters, sensors, and survey data is the current state-of-practice with increased automated systems and emerging technologies being checked against hand counts and established sensors. The increasing sophistication of the types of questions being asked by the management community around

demographics, user decisions, and experience requires more than visitation counts and activities types. The need for a basin-scale measures of outdoor recreational activity levels, change over time, site overflow and surge impacts necessitates that new monitoring sites should be selected as representative of the region and provide important data points for regional modeling. Lake Tahoe already has a very advanced trail monitoring system and additional collection sites should be selected to provide data points for basin-scale monitoring.

Monitoring Recommendations

Recommendations for deploying an effective outdoor recreational monitoring program were developed based on an extensive review of best practices found in other outdoor recreation destination locations, current research literature, and suitability for the specific management issues in the Lake Tahoe Basin. The eleven actions are grouped into three types: Lake Tahoe Basin-wide Data Collection, Coordination of Outdoor Recreation Information, and Development of Partnerships around Outdoor Recreational Data and Management Analysis. It includes recommendations for the location and types of physical sensors for data collection, social science methods for capturing activity and demographic information, and organizational infrastructure to support integrating with the workflows of public agencies and volunteer groups to manage data collection into the future for long-term monitoring. Detailed examples are provided for each recommendation.

I) Lake Tahoe Basin-wide Data Collection

a. Select representative monitoring sites across activity areas.

A representative sampling strategy for an area as large and diverse as the Lake Tahoe Basin needs to balance scientific rigor and management needs. We suggest an intentional sampling strategy guided by management priorities, while selecting monitoring sites to account for the region's diversity. Sampling data collection should account for both summer and winter seasons, although most management challenges occur during summer. The list of recreational areas to include was drawn from outdoor recreational hotspots identified in earlier studies and discussions with managers in the region. The specific management issues vary according to the location, but include parking capacity, trash and litter, high levels of use, crowding, and the compatibility of activities. Based on a convergence of data needs, management discussions, and other criteria several sites were determined to be core to a basin-wide monitoring system. The criteria used to select each site is included in parenthesis.

Outdoor recreation sites recommended for monitoring

- Emerald Bay Lookout [Most visited site, multiple activities including sightseeing, hiking, and near other important recreational locations].
- Sand Harbor State Park [Second most popular site, multiple uses and well-connected via trail system].

- Nevada Beach [Heavy use, diverse shoreline uses].
- Eagle Falls Trail [Most popular unpaved trail, near Emerald Bay Lookout].
- Mount Rose Meadows [Winter use area, connects to Tahoe Rim Trail system].
- Upper Truckee River [Heavy summer congestion, trailhead and river uses].
- Tahoe City Public Beach [Walking trail from Tahoe City, diverse activities].
- Lakeview Commons [Walking trail from South Lake Tahoe, diverse activities].
- Brockway East Trailhead [Heavy use unpaved trail, connects to Tahoe Rim Trail system].
- East Shore Trail Incline Village [Existing TRPA paved trail use counter, connector to East Shore Trail system].
- Mixed Use Path Camp Richardson [Existing TRPA paved trail use counter, high use trail section].
- Mixed Use Path Lakeview Commons [Existing TRPA paved trail use counter, combined with activity monitoring and survey data collection at Lakeview Commons].
- Truckee River Trail [Existing TRPA paved trail use counter, connects to North Shore Trail system].
- Zephyr Cove [Recent changes in reservation system, existing trash data].
- Christopher's Loop North, Tahoe Rim Trail [Existing TRTA unpaved trail use counter, highest use section of Tahoe Rim Trail].

The list of sites is not intended to be comprehensive, but rather include the highest priority areas identified, those having the greatest overall impact on Lake Tahoe Basin recreational activities, and capture the diversity of uses. Additional sites can be added as needed, but this list would provide important anchor data points for long-term monitoring and modeling of basin-level visitation patterns. The specific metrics to be monitored at a site depend on the management need, but at a minimum should include visitation counts and site capacity overload metrics. Additional data on outdoor activity types, user demographics, and user experience can be collected as needed. Recommendations on the specific techniques for collecting data are discussed below.

b. Identify capacity metrics for each priority site.

A core metric needed at the Lake Tahoe Basin scale are indicators for when capacity at a recreational site has been exceeded. This has implications for the management of that site, planning for future infrastructure, and other sites that serve as spillover locations. The Tahoe Regional Planning Agency (TRPA) uses "Persons at One Time" (PAOT) capacity for individual parks and recreational sites. This is generally tied to infrastructure, particularly sewer capacity.

Capacity metrics need to have multiple dimensions and provide data at a minimum daily time period to reflect different management needs. Linking data collection to PAOT can provide a more dynamic perspective on infrastructure exceedance.

Based on conversations across the basin, hourly data would be preferred to determine the time of day a site reaches capacity, how that is changing over time, seasonality, or according to centers of different activities.

There are three capacity issues faced across sites: parking, trash receptacles, and crowding on beaches and trails. While there are technologies for alerting when parking lots are full, many of the crowded sites have staff that can more effectively report when lots fill. A simple off-the-shelf app (see IIc below) can be used to collect data from site attendants. Similarly, there are several smart waste products (Bigbelly, ecovision, wastevision.ai, etc.), and while structural bins are not bear resistant, internal bin sensors may be cost effective. However, an easier reporting metric is likely onsite staff reports, or crowdsourced reporting. Access could be restricted to staff and volunteers in order to ensure relevance of postings, or opened to visitors to report trash level. Curated data can signal staff or volunteer groups to respond.

Metrics for crowding as a site as a capacity issue are more complex. The daily number of users is a standard metric, often determined by infrastructure exceedance. The current PAOT system represents a traditional recreational site capacity metric. AECOM (2011) completed a capacity study for Sand Harbor State Park that utilized a multicriteria approach looking at physical/spatial characteristics, facility, ecological, and social capacities. Qualitative indicators were used to express capacity level rather than numeric indicators, with peak season exceeding physical/spatial and facility capacity, some concern around ecological, social only expressed at a couple of locations. Other methods have been developed to capture explicit perceptions of crowding that includes both visitors and local aesthetics and crowd expectations. The Capacity, Compression, and Comfort (CAPCOM2) model was utilized in Aspen Colorado's destination management plan (Aspen Destination Management Plan, 2021). CAPCOM2 uses an engagement process that gathers expected site conditions across different stakeholder groups to determine when a site has exceeded perceptions of crowding and overuse. A combination of CAPCOM2 and the multicriteria approach appears to be the best fit for the Lake Tahoe Basin.

c. Deploy co-located activity sensors in combination with mixed methods.

Hand counts and infrared (IR) sensors continue to be the most common technologies in use for collecting data on outdoor recreational site use. Hand counts are the most reliable, but are labor intensive and have limited utility for an area as large as the Lake Tahoe Basin, particularly for unstaffed outdoor recreational areas. Automatic IR counters, such as those currently employed along the paved bike lanes and used by the Tahoe Rim Trail Association (TRTA) on the Tahoe Rim Trail, do not necessarily distinguish different activities (bike vs. pedestrian vs. equestrian), equipment (ebike vs. manual), or gather any demographic and user experience information. New technologies offer increasingly more accurate and scalable count data (e.g., VisualCortex), however experience in the field suggests device failure, weather conditions, and the instability of companies offering novel technologies reduces their reliability.

Friends of Acadia, Acadia National Park, Maine

Thirty traffic and trail counters installed to monitor activity across the Acadia National Park.

Recreation technicians do in-person validating at all locations.

Used to predict behavior of park visitors.

Combined with reservation survey.

Utilized to monitor sensitive areas, correct anecdotal observations, and provide informational nudges to change behavior.

https://friendsofacadia.org/story/recreation-technician-understanding-vistors/

The recommendation is to deploy and coordinate reliable IR count data sensors, associate physical locations with hand counts and survey data collection in order to get representative samples, and co-locate emerging technologies with IR sensors to assess reliability and use multiple data sources to calibrate new technologies and models. A pilot site to assess the utility of the approach can be selected from an existing IR counter location (TRPA's paved trails or TRTA sensors) or from representative new priority locations. Co-locating survey data at the same sites, collecting information on activities, equipment used, demographics, and user experiences will allow these sites to be used as robust baseline data for tracking change into the future.

Secondary count and capacity data sensor considerations

Besides use and activity levels, two consistent management objectives were identified, exceedance of parking and trash capacity on sites. Several technologies were identified for reporting parking capacity, including video camera detectors, magnetic, and IR counters. While transportation remains a core component of recreational access, specific monitoring can be incorporated into the regional transportation plan. Trash capacity overflow was another secondary site capacity monitoring need identified. Technologies for monitoring trash were identified, including interior bin IR cameras and smart bin technology. However it was determined there are less expensive and more effective ways to quickly assess whether a bin is full (See recommendations for use of reporting apps in IIc).

Other monitoring needs discussed included watercraft and beach user counts. Similarly, several technologies can provide consistent count data including low altitude aerial photography combined with computer vision object identification and counters at boat launch sites. However, neither of these was considered a high priority management needs and increased data were not clearly associated with specific management decisions.

Tahoe Rim Trail Association, Tahoe Rim Trail

Expanding system of seventeen infrared (IR) and magnetic bicycle (MB) counters.

Provides best example of integrated multisite system at Lake Tahoe.

Location prioritization process.

Provides important lessons on instrument failure and data access.

https://tahoerimtrail.org/wp-content/uploads/2021/06/2020-Trail-Counter-Data-Report.pdf

d. Develop standardized data collection survey instruments.

Count data of the number of users at different outdoor recreational sites provides the single most valuable data for the widest array of applications and users. However, it does not provide insight into many of the questions being asked about outdoor recreational activities, visitor behavior, or demographics across sites. Survey instruments, and to a more limited extent, big data analytics, are the only methods that provide that information. Currently, there are several survey instruments deployed by different land use managers and other organizations at the Lake Tahoe Basin including the Forest Service's National Visitor Use Monitoring (NVUM), Nevada State Parks, and project focused surveys. While suited for their purpose, the high degree of variation in the sampling, locations administered, and question design means that there is little comparability across sites and no way to generalize data to the Lake Tahoe Basin scale. We recommend a small number of critical questions to be developed and used across all future survey instruments. This would create Lake Tahoe scale representative data to record current baseline information about users across different outdoor recreational sites and detect change. We recognize the existing needs across different jurisdictions and suggest basing core questions on existing survey instruments. A sample of core questions is provided in the Phase 1 Report, Appendix 2 - Core Socioeconomic and Stewardship Attitude Questions to Use on a Standardized Form.

e. Conduct *The Lake Tahoe Outdoor Recreational Activity Survey* every 5-10 years across both summer and winter seasons.

No survey data collection effort has been done at Lake Tahoe of outdoor recreation users at a scale that allows for generalizable data. Inferences are currently made from single site, individual agency data collection, or industry surveys. A dedicated effort should be made to get periodic snapshots of outdoor recreational activities and users every 5-10 years across both summer and winter seasonal activities. It would require deploying a data collection team across a selection of the representative monitoring sites discussed above (Ia). The time of survey data

collection would ideally capture both summer and winter activities, and occur during a representative average day or week. The time period selected needs to avoid potential bias in the type of visitor at Lake Tahoe (including the occurrence of special events such as golf tournaments or races) and peak use periods or surge events such at July 4th or Christmas Weekend. Periodic administration of the survey every 5 years would capture most significant changes. The survey can be administered with research partners and nonprofit organizations. Data collection with volunteer groups and reporting results can be used to engage the public in management challenges.

An associated recommendation is to develop a short survey to administer to outdoor recreation service providers. This would capture informal knowledge about change occurring to outdoor recreational activities, new types of equipment being used, and perceptions of crowding or development of new activity sites without supporting infrastructure. Much of this information may already be communicated in interpersonal networks, however documenting it will communicate it outside of those networks and bring it into the hands of land managers faster.

f. Incorporate big data for baseline.

Big data or crowdsource data is any source of unstructured data collected for one purpose and used for another. It includes social media, human mobility, health apps, and others. Through an exhaustive review of applications to outdoor recreation several use cases offer value for Lake Tahoe.

1. Mobility data for baseline map of locations and hotspots.

The use of mobility data has already been used at Lake Tahoe for mapping hotspots and high use recreational areas (Stantec, 2020, Hui et al., 2023). The complexity of mobility data often requires third parties to process and provide outputs. Most applications for management purposes appear limited to single time periods and have had limited use for analyzing change. It is useful as a snapshot of use areas, although it does not provide information about types of use, duration, or demographics. Mobility data gains in value when used repetitively at periodic sampling points in time, or aggregated and combined with other data sources (e.g., trail counters, census data).

2. Strava data used to map activities, locations, and frequencies of area uses.

Data from the activity app Strava is the most used in management, with a dedicated office, Strava Metro providing data on pedestrian and bicycle traffic to urban planners. When associated with location information Strava data can provide information on activities and use frequencies hourly. Strava data is being used for trail count monitoring for urban trail systems and tracking change over time. Application to public lands and wilderness trails would not take significant additional effort, although would require working directly with Strava's Metro team. Strava users come from certain recreation or demographic groups, which include higher use among cyclists, middle-aged users, and over-represents sport enthusiasts as opposed to casual

recreationalists. This will lead to biased results as certain segments of population or recreation users are not being captured by the Strava app. Young, elderly and lower socioeconomic status groups are under-represented based on recent assessments (Venter et al., 2023). The two approaches below are recommended instead for Lake Tahoe.

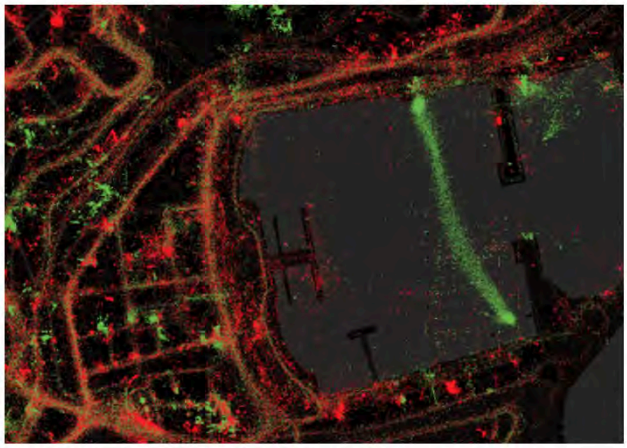
3. Strava data combined with trail monitors and predictive modeling.

The most promising use of Strava data is in combination with trail counters. Headwater Economics' use of monitor counts as validation of Strava data to generate a predictive model that can extend use to trails without counters (Lawson, 2023). The combination of trail count monitors, with Strava data, and predictive modeling appears to offer the best application of Strava data for accurate and reliable location and activity counts. The combination of activity data with physical trail count monitors is an increasingly popular approach.

4. Data aggregation combining mobility and census data.

Data aggregation firms combine mobility, census, activity tracker and other data sources to make inferences about demographics associated with activity types and locations. There were few applications to recreational management. However, one firm has recently used aggregate data to examine both natural protected areas and urban tourism applications to disaggregate locals vs. visitors based on origins, measure frequency and duration of visits, density of area use, difference in transportation modes, and watercraft type uses (www.citiprofile.com). Similar to other big data applications, multiple time periods are needed using similar data sources and models to understand change to the use patterns, rather than single period snapshots.

Monaco Tourism Behavior Study, France, Citiprofile



Combined mobility data with origin points to distinguish resident from visitor behavior.

Algorithms used to determine watercraft types.

Applications include impact of management programs to protect natural areas.

Visitors Locals

Courtesy: www.citiprofile.com

During the project other big data sources were examined, including social media scraping and other approaches, however none were found to offer rigorous predictive capacity, consistency across user groups and activities, or direct links to management concerns.

II) Coordination of Outdoor Recreation Information

a. Create a cross-agency, cross-sector data collection coordination team.

In order for accurate cross-site comparisons there needs to be consistency in methods and instruments (monitoring devices, surveys, etc.). The diversity of recreational land management agencies presents a challenge to coordinating data collection. However, the high level of coordination already occurring across agencies in the Lake Tahoe Basin can be leveraged to create common data standards and data governance for collection, sharing, and aggregation. The coordination team should include all organizations with management responsibilities as well as those with interest in using the results.

b. Aggregate and report data at a single accessible location.

There is broad interest across outdoor recreational stakeholders in having access to information on outdoor recreational intensity, activities, and distribution. A single location to access data visualizations and trend reports would help coordinate across the basin. Beyond the research community, there is less interest in the raw data, but rather analysis of trends and change over time. Data visualization could be similar to the format of progress on the threshold indicators, EIP tracker, or customized to serve the needs of a basin-wide data collection coordination team.

c. Utilize an off-the-shelf crowdsourced app to collect and coordinate status reports in real-time.

While most interest is in the broad patterns of outdoor recreational change, some data can be directly observed and reported by field staff and volunteers. Rather than instrumentation or costly survey data collection a simpler solution is to have established lines of communication allowing daily reports from those with eyes in the field. Information on capacity overflow issues (ex: trash full, parking lot full, etc.) could easily be documented with a georeferenced photo on off-the-shelf crowdsourced apps shared among staff and volunteers. A commercial fixed format (ex: ClickFix) or customizable (ex: ArcGIS Crowdsource Reporter, Ushahidi) mobile device app dedicated to specific issues such as trash full alerts or lot capacity can provide a low cost and effective way to capture data over time. A publicly accessible crowdsourced app is not recommended at this time. Crowdsourced data apps require marketing to gain users, the types of data collected are often not related to the management need, data requires curation which can include cost of managing very heterogeneous data posts, data needs to be incorporated into organizational workflow to be used effectively, and user attrition is common. Rather than a publicly accessible app, it is recommended it be shared among limited field staff across agencies and possibly volunteer groups. This will avoid both rapid user attrition associated with crowdsourced apps and more focused curated reporting. There may be opportunities to link observations (e.g., trash full) to specific management actions (e.g., arrange pick-up) across multiple organizations including volunteer groups. Partners can explore opportunities for associating micropayment and other incentive systems with observation posts. The utility of a publicly crowdsourced app can be explored experimentally.

III) Develop New Partnerships around Outdoor Recreational Data and Management Analysis

a. Establish an *Outdoor Recreation Innovation Working Group* to coordinate with research partners and draw increased funding.

Lake Tahoe is an exceptionally data rich environment compared to most outdoor recreation areas, has a high level of collaboration across public agencies, and offers an unique opportunity for applied research, developing and experimentation with outdoor recreation technologies, and leveraging the long history of science at Lake Tahoe into funding for applied research. Several of the major science funding agencies have explicitly expressed calls for applications of novel technologies for community problem solving. Funding opportunities exist for artificial intelligence (AI) applications, data analytics, convergent research, socio-ecological systems analysis and others that can provide the support for developing Lake Tahoe as an outdoor recreation sustainability leader through applied research. Existing research partnerships with regional research institutes (DRI, UNR, UCD, etc.) offer the foundations for new research funding. Indeed, the configuration of organizations at Lake Tahoe already resembles the type of innovation ecosystem that funding agencies are attempting to create elsewhere.

b. Identify small-scale high-impact monitoring experiments with research partners.

There are multiple opportunities for applied research that can provide high-impact to outdoor management challenges. Small-scale outdoor recreation experiments can be scaled up to a basin-wide impact. Having these prioritized in a similar manner and process as in the EIP can facilitate the interaction with research partners in the region, help coordinate external funding and resources, and direct research in support of management challenges.

Delivering Data for All

A survey of stakeholder's interest in the types of data they needed to help serve their missions was administered to sixty-six organizations active in outdoor recreational management in the region. The majority of responses came from nonprofits (33%), followed by local or special district governments (28%), state government agencies (17%), for-profits (9%), and federal government agencies (5%) (Figure 1: Types of organizations included in survey).

The top five types of data of interest across all organizations were user counts (89%), site impacts (84%), mobility decisions (71%), adequacy of facilities (67%), and demographics of users (58%) (Figure 2: Types of data of most interest). The location of data collection to be of most use to the organizations surveyed included across multiple sites for comparison (71%), at specific types of sites such as trails and beaches (69%), and at specific activity areas such as hiking, relaxing, sightseeing (67%). This provides a framework for the spatial sampling needed

to make the data most useful for the broadest array of stakeholders (Figure 3: Location of data collection).

The temporal period for sampling and reporting data revealed monthly is most important (40%), followed by a three way tie between weekly (33%), seasonally (33%), and annually (33%), and a two way tie for the third place between daily (29%) and during peak periods (29%). This suggests daily collection is the smallest common temporal unit that can be aggregated up. Only 9% of respondents were interested in hourly data (Figure 4: How often should this data be collected).

The majority of respondents were not collecting outdoor recreational data (59%), while 41% were collecting some related data. Of the data being collected, only 10% is being archived on the Tahoe Open Data site. Some of this data is likely proprietary and owned by third parties so cannot be shared, but there exists space for increased data sharing (Figure 5: Are you already collecting outdoor recreational use data? Is it included in the Tahoe Open Data site?).

Technology continues to radically alter how we interact with information. While the primary purpose of data collection on outdoor recreational activities is to better inform recreational site managers, providing information to outdoor recreational site users directly will likely be a part of future trip planning and visitor management. Information around crowding, alternative site availability, and behavioral nudges are already embedding into location and travel apps. AI will rapidly make customizable trip planning more prevalent. The outdoor recreation management community should anticipate these uses and consider how data collection systems can support reducing crowding, sustainable behavior, and communicating stewardship ethics. Toward this goal, respondents were asked how information should be communicated to outdoor recreation users. Signage on entry points such as trailheads and parking lots (76%) was the most common response, followed by signage at recreational sites such as scenic overlooks and picnic areas (64%) and information posted on websites (62%). Importantly, getting information to users via a basin-wide app tied with information provided by recreational service providers at 52%. Lodging as the hub of information came in at 43%, followed by location specific mobile apps (38%) and having information posted on the most used travel and transportations apps such as TripAdvisor and Waze (36%) (Figure 6: How should information be communicated to outdoor recreation users?).

Use of Vehicle Miles Traveled (VMT) Data

Vehicle miles traveled (VMT) is a measure of the number of miles driven on roadways. It is a core sustainability metric used in regional planning. The Federal Highway Authority (2023) projects a total VMT increase at an average annual rate of 0.6% from 2019 to 2049. This increase will result in an increase in greenhouse emission, air pollution, and traffic congestion. For example, a recent study on VMT found an increase of 500 to 1,200 vehicles on days with hot temperature in the Sacramento Valley (Hui et al., 2023).To help reduce the impact of increasing VMT, California has passed Sustainable Communities and Climate Protection Act

(SB 375) that supports state climate goals by reducing greenhouse emission through transportation, housing, and land use planning (CARB, 2024).

There are plenty of policy ideas that can potentially help reduce VMT. Alternative transportation systems may help solve the issue of reducing greenhouse emissions as well as other benefits to visitors such as traffic congestion, parking shortages, and improving visitor's experience. For example, the National Park Service (NPS) has implemented alternative transportation systems in some of their parks with the goal of reducing vehicle congestion and emission. As of 2022, NPS has implemented a transit system in 52 parks (NPS, 2023). The majority (60%) of the transit system involve shuttles, buses, vans, and trams, while 39% use boats and ferries. The other 1% involves trains, trolleys, and aircrafts. Zion National Park has the highest number of passenger boarding (4.38 million) for shuttle service in 2022, followed closely by Grand Canyon National Park at 4.34 million (NPS, 2023).

There have been several studies analyzing alternative transportation systems to accommodate increasing visitation, decrease congestion, and improve visitor's experience. For example, Pettebone et al. (2011) examined the trade-offs Rocky Mountain National Park visitors were willing to make about transportation mode. Using a choice experiment, the authors found that visitors prefer private vehicles over park transit systems, but are willing to make trade-offs to ride the shuttle bus to avoid crowding along trails and vehicle traffic along the road. Taff et al. (2013) examined visitor perspective toward the alternative transportation system experience for Yosemite and Rocky Mountain National Parks. Their evaluation of attitudinal variables resulted in three salient factors: *ease* (e.g., feel safe, easy to find your way around park, and pleasant interactions with other visitors), *freedom* (easy to get to scenic overlooks/vistas, easy access to different areas of the park, and experience sense of freedom), and *stress* (e.g., feel stressed while traveling throughout the park, experience conflict with visitors using other kinds of transportation, feel crowded by other visitors, and have trouble finding parking). More recently, Spernbauer et al. (2022) conducted a review to provide managers with a comprehensive understanding of the effects and trade-offs of alternative transportation systems. Alternative transportation systems are posited as a viable management tool to achieve and maintain desired VMT metrics.

Similar studies have been conducted abroad, analyzing similar issues such as reducing traffic congestion and air pollution. For example, González et al. (2019) surveyed Teide National Park in Spain on a hypothetical park shuttle bus connecting main points of interest. The results suggest that visitors have a positive willingness to pay for reducing time spent finding a parking space and reducing time to start their visit. More recently, Curtale et al. (2024) surveyed southern Switzerland natural areas tourists' reactions to hypothetical sustainable transportation modes. They found that the introduction of park-and-ride with a shuttle service or a bike sharing system could help reduce car use from 65% to less than 20%.

The findings from previous studies may not be applicable for the Lake Tahoe Basin as the landscape, visitor demographics, and other factors differ in this region. However VMT data should be incorporated into data aggregation analysis and importantly, combined with monitoring data to develop regional models that can estimate site specific visitation levels based

on VMT dynamics. Additionally, a study to understand Lake Tahoe Basin residents and visitors outdoor recreational sites visitor preferences for alternative transportation systems should be linked to transportation planning in the region. The study could also focus on the trade-offs residents and visitors are willing to make to reduce parking issues, traffic congestion, greenhouse emission, and air pollution. Results from the study may help planning agencies determine the most efficient alternative transportation system for residents and visitors, which can be different.

Conclusions

If only half of the recommendations offered here are implemented, Lake Tahoe will have the most innovative and comprehensive outdoor recreation monitoring system in the world. The systems developed at Lake Tahoe can offer solutions to management challenges being faced by outdoor recreation tourism destinations everywhere. With coordination with research institutions in the region Lake Tahoe can be a laboratory for novel applications of emerging technologies, new approaches to data collection, and science driven management interventions.

Recommendations are clustered across three areas of activity: Lake Tahoe Basin-wide data collection, coordinating outdoor recreation information, and developing new partnerships around outdoor recreational data and management analysis. Toward basin-wide data collection a selection of representative outdoor recreational sites is offered that provides representative sampling across different site types (unpaved and paved trails, beaches, vista points), activities (hiking, biking, water activities), locations at hubs of trail networks, and across different user groups (families, outdoor enthusiasts, day trippers). Several approaches to capacity metrics are discussed. Co-location of new with established sensors and in combination with survey and user count methods is strongly recommended to validate and compare data collection methods. Standardization of survey instruments, or at a minimum a core set of common questions is suggested to improve the cross-site comparability of survey data. It is suggested a multi-site Lake Tahoe Basin Outdoor Recreational Activity Survey be conducted every 5-10 years to collect detailed data. The utility of big data for outdoor recreational management was found in two principle applications; using Strava data validated against monitor counts for predictive modeling, and data aggregation with mobility data.

Three actions to coordinate outdoor recreation data were suggested; creating a cross-agency cross-sector coordination team, reporting aggregate data at a single location, and utilizing an off-the-shelf crowdsource app to report site capacity exceedances among staff and volunteers. Efforts toward building new partnerships with the research community were suggested via developing an innovation working group to align agency needs with funding opportunities and identify small-scale high-impact experiments reflecting the interests of the management community.

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Disclaimer

The results presented here are best estimates based on our research and the options of the research team members only and do not represent positions of any affiliated organizations, advisory committee members, or other organizations and individuals consulted during this process. Mention of specific products or firms is not an endorsement of their services, but only inclusion of the full range of data collection tools and services currently available.

Appendix 1: Stakeholder Data Demand Survey Results

Figure 1: Types of Organizations Included in Survey

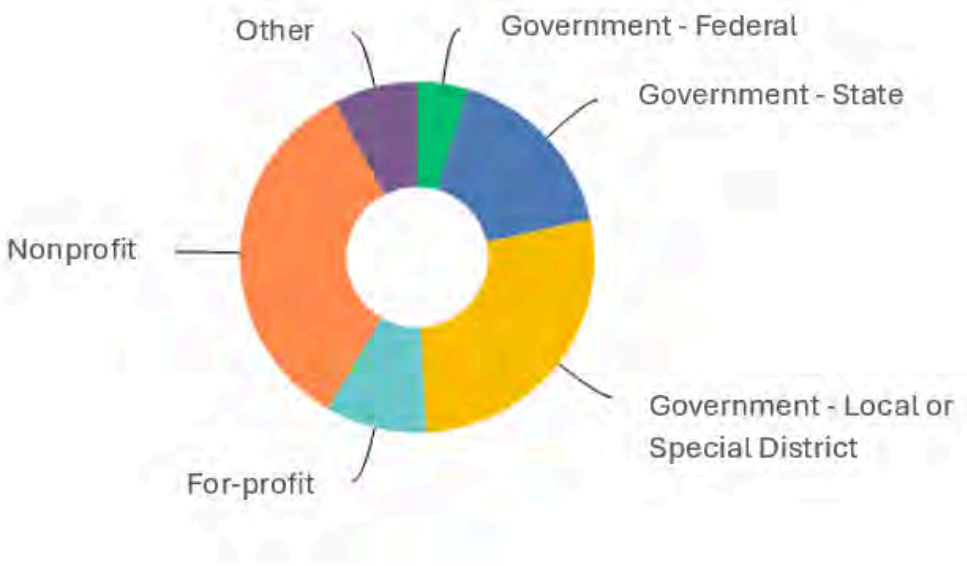

Figure 2: Types of Data of Most Interest

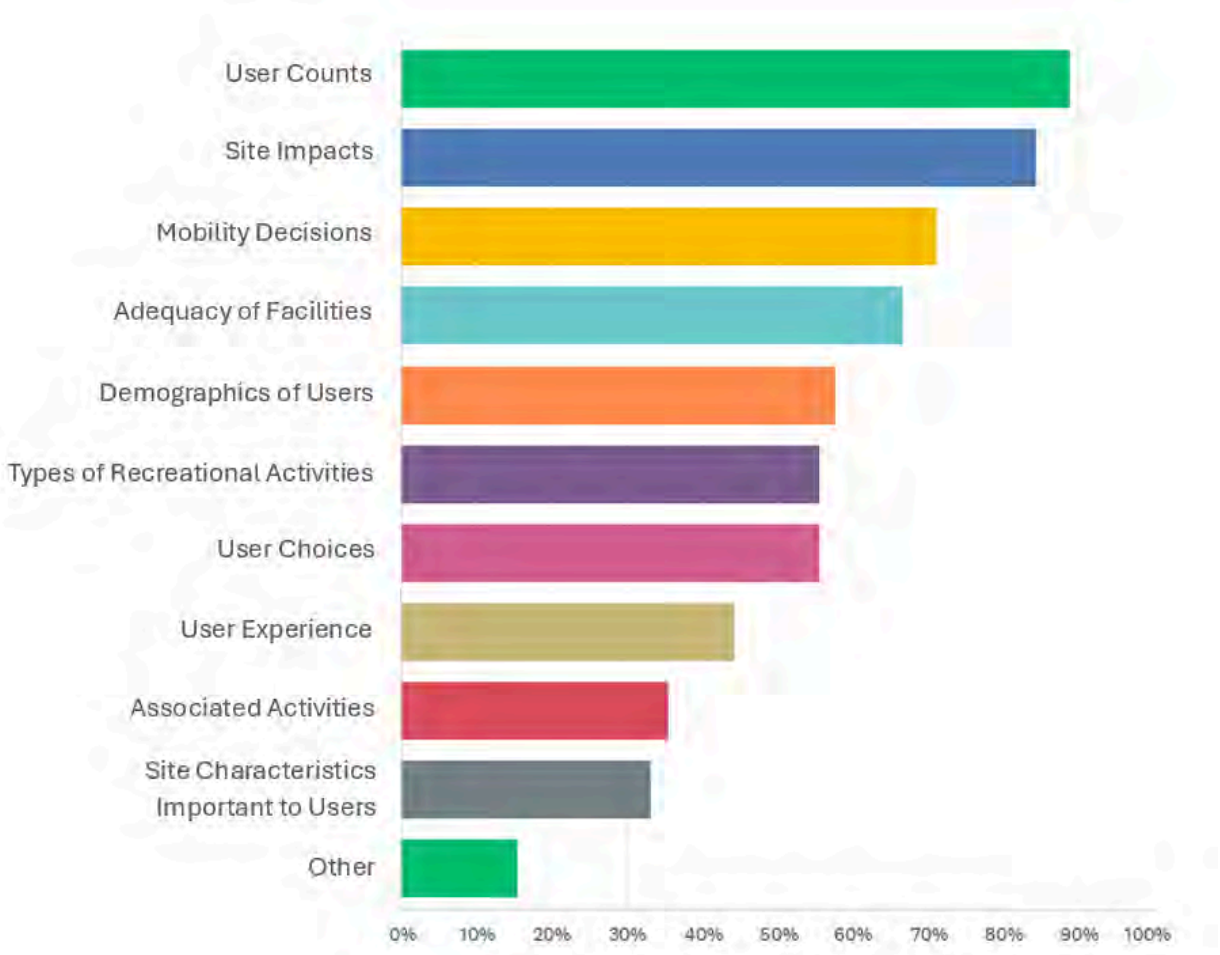

Figure 3: Location of Data Collection

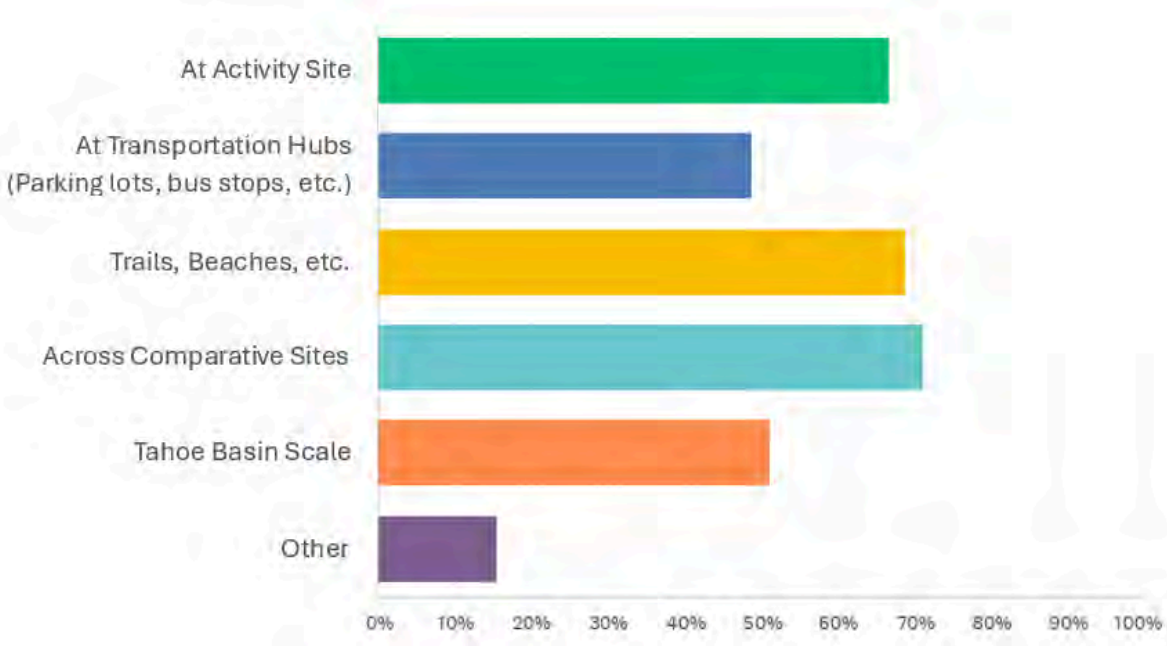

Figure 4: How Often Should this Data be Collected?

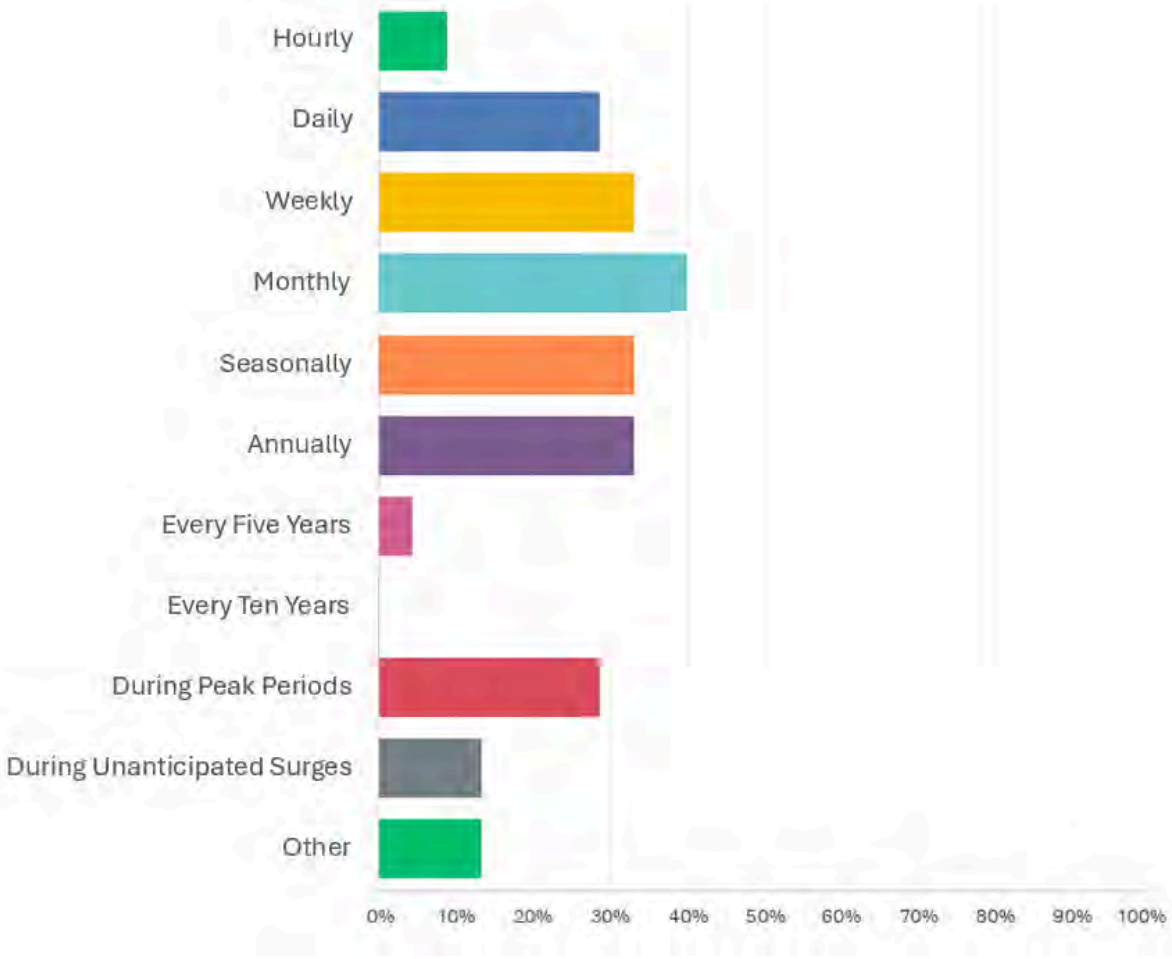

Figure 5: Are you already collecting outdoor recreational use data? Is it included in the Tahoe Open Data site?

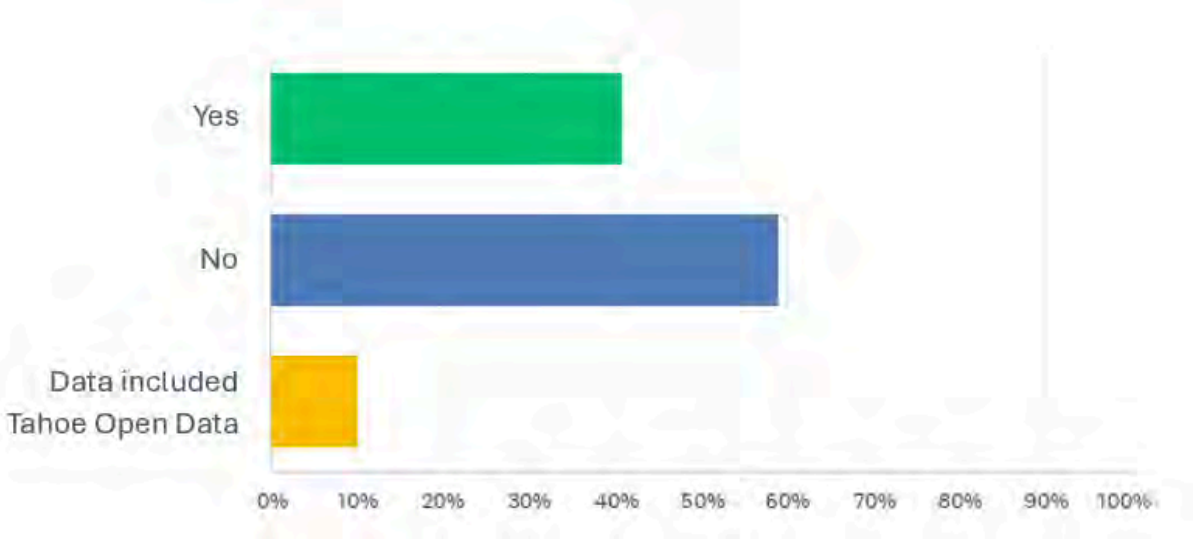

Figure 6: How should information be communicated to outdoor recreation users?