Tahoe Environmental Observatory Network

Executive Summary

Design and Implementation Recommendations

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TEON Executive Summary

Introduction

Lake Tahoe, a world-class natural resource merits a world-class environmental monitoring system. This report presents initial recommendations for the establishment of the Tahoe Environmental Observatory Network (TEON) to serve the basin for decades to come. An interdisciplinary team of scientists developed a basin-wide monitoring system to generate robust data source on the status and change of environmental quality and ecosystem resilience for the Lake Tahoe basin ecosystem. TEON builds on historical and extant research and monitoring efforts to provide a comprehensive source of information to managers, researchers, and the public on past and current conditions in the basin, and future changes.

Landscape scale changes to the forests surrounding Lake Tahoe will have a large impact on many drivers of forest health, watershed integrity, biodiversity, and ultimately lake condition. The location and magnitude of future changes to this system are uncertain, driving the need for an improved understanding of ecosystem health and vulnerabilities over time, and for a mechanism for early warning that can lead to timely response and help guide strategic investments in management treatments to improve conditions. The combination of these tasks, along with input from managers responsible for monitoring environmental quality in the basin (notably TRPA and LTBMU), will provide the framework for developing a robust monitoring system for the basin.

Managers have struggled to develop an effective and informative comprehensive monitoring system for upland ecosystem conditions. The most robust and consistent monitoring programs in the basin have pertained to Lake Tahoe clarity, stream sediment delivery, some threatened and endangered species, air quality, and forest inventory (as per the US Forest Service national FIA program). Basin-wide ecosystem conditions that are mandated for attention by managers, but a lack of consistent, coordinated investment generally falls into one of the following categories: forest health, fire risk and threat, biodiversity, carbon, climate vulnerability/adaptation, habitat connectivity, aquatic invasive species, and drought vulnerability.

Goals and Objectives

The primary goal of TEON is to provide a comprehensive and informative source of information on the status and change in ecosystems across the basin. A secondary goal is to provide an early warning system for ecosystem conditions in the basin and a safety net for forest ecosystems, upland aquatic ecosystems, biodiversity, as well as for Lake Tahoe. TEON is envisioned to be spatially and topically broad and inclusive, to address various information needs to address multiple agency missions and mandates. Another objective of TEON is to support the monitoring objectives and information needs of local agencies to the degree possible.

Finally, TEON design recommendations are intended to leverage the many research and monitoring investments that have occurred in the basin over the past several decades and provide a rich source of data that new and ongoing monitoring efforts can build upon. Historical data provide a baseline of comparison for understanding the direction, magnitude and location of current and future change, as well as clues as to why conditions are changing. Historical data can help scientists and managers anticipate future locations and magnitudes of change that may occur over the next several decades.

TEON is designed to accomplish these outcomes through a combination of broad-scale and focused sampling design and data collection. Basin-wide monitoring is intended to provide a foundational understanding of the status and change of key metrics of ecosystem conditions at the landscape-level. Sentinel watersheds are intended to provide a more in-depth understanding of the magnitude, drivers, and consequences of change and the process-based linkages among connected and interdependent resources within and across watersheds.

Basin-wide Monitoring

Near-term objectives for basin-wide monitoring are to establish a current-day snapshot of conditions across a wide array of ecological features that also can be used as a point of comparison to evaluate change from past to present and present to future. Longer-term objectives for basin-wide monitoring are to identify spatially explicit and resource-specific patterns of change that can be used to improve understanding of the drivers, consequences, and mitigation strategies of change.

In general terms, basin-wide monitoring would be based on a combination of remotely sensed data and field-based data. Remotely sensed data are most commonly available across all lands, so 100% coverage across the basin and typically at 30-m resolution reflecting the resolution of most (freely available) satellite imagery. Sampling designs are required when monitoring is based on a sample of sites (as opposed to all sites), and the design parameters then determine which sites are selected for sampling. Most broadscale monitoring efforts use a combination of remotely sensed and field-based data sources, and so the grid cells may also become a scale at which these two different sources of data are both represented or summarized.

A broad-scale, omnibus, and efficient monitoring design needs to have a core set of sample sites that can be subset for analysis and augmented to address specific resource conditions, enabling scientists and managers to characterize different resources at different scales and levels of precision, and adjust to changing needs over time. A robust survey design has the following properties: probability-based, spatially representative, balanced and simple, and flexible to accommodate potential changes in the future (Theobald et al. 2007). Square and hexagonal grids are most commonly used to generate the systematic sample grid. Ideally, whatever grid type is used, it is scalable to meet the sampling intensity needs of different resources.

Basin-wide Core Metrics

Forest/Shrubland Resilience - Pertains to terrestrial ecotypes. Forests and shrubland ecosystems are parsed into three elements: structure, composition, and disturbance. Ideally, monitoring measurements and reporting pertain to one or more metrics in each subdomain and across the three elements. Approximately 30 core metrics are recommended, consisting of a mix of field-based and remotely sensed data sources. Remotely sensed metrics are not dependent upon LiDAR, given its expense and infrequent availability. Rather, remotely sensed metrics are based on publicly available data that are refreshed annually. If LiDAR or other complementary remotely sensed data become available, they can be used to augment or validate primary data sources.

Fire Dynamics - The Fire Dynamics Pillar has two elements: severity and functional fire. Ideally, monitoring measurements and reporting pertain to one or more metrics in each subdomain and across both Elements. The metrics recommended reflect a combination of basic fire ecology and metrics identified as important to managers in the basin (see Lake Tahoe West draft monitoring plan, 2022). They include descriptions of fires that have occurred, fire histories, and estimated probabilities of fire intensity based on current forest conditions (i.e., fuel characteristics). Metric values can be derived using a combination of field-based data collection, remote-sensing, and modeling.

Carbon Sequestration - Carbon storage in natural and working landscapes is recognized as a vital contribution to meeting carbon sequestration and carbon neutrality goals at a range of scales from regional to national. Forests and meadows play an outsized role in sequestering and storing carbon in a manner that provides multiple additional ecosystem services. Eight core metrics were identified for carbon monitoring, focused on total carbon, live tree carbon, and meadow carbon (Table 3-8). Most of them can be readily estimated from satellite imagery when combined with modeling, and plot-based imputations are also able to estimate carbon, but provide some of the least accurate measures of carbon. LiDAR-based measures, when available. are particularly valuable for providing measures of biomass that can be converted to carbon.

Biodiversity Conservation - Understanding how plant and animal populations and communities have changed over time is a critical part of managing this system for resilience to climate change and other stressors. The Biodiversity Conservation Pillar includes both terrestrial and aquatic ecosystems. Current and future characteristics of populations and communities within the basin are not predictable based on broad vegetation associations and wetland ecosystem types, so "coarse filter" conservation and monitoring approaches alone based on major ecotypes will not provide a credible representation and conservation approach for biodiversity, particularly with changing climate. Field data on species occurrence will be needed to effectively monitor and conserve biodiversity in the basin. Twelve focal species were identified as core, with an additional eight metrics to describe species diversity and community integrity.

Wetland Integrity - Wetlands consist of meadows, marshes, streams, lakes, ponds, and riparian ecosystems distributed across the basin. Wetlands of the Tahoe basin are one of the most threatened habitats, and these habitats provide ecosystem services that are directly tied to Environmental Improvement Program goals. The fate of aquatic ecosystems in the basin have direct effects on Lake Tahoe. Approximately 15-20 metrics of wetland integrity metrics were identified as recommended, covering a combination of fundamental wetland ecology and metrics of specific interest to managers in the basin. Remotely sensed data will provide a wide range of valuable data for describing and tracking wetland conditions, but field data will also be needed for at least a subset of metrics.

Water Security - Water security encompasses all aspects of water as an available resource for ecosystems, including plants, animals, and people. Water security includes quality, quantity, form, and availability. We identified eight recommended core metrics of water security that can be derived from a combination of remotely sensed and field-based data, with a strong additional emphasis on snow, soil moisture, and water discharge rates and timing.

Air Quality - Air quality encompasses particulates, gases, and impacts on visual quality. Although health impacts are a substantial focus of air quality standards and monitoring, they are not included here as metrics. The five recommended core metrics are intended as a starting point for discussions about how best to represent these air quality conditions in a manner that is most aligned with regulatory requirements and target conditions.

Fire-adapted Communities - The fire-adapted community pillar includes the degree to which communities are at risk of wildfire and their preparedness (physically and organizationally). The five recommended core metrics address the threat of wildfire to communities as a function of risk of fire, and focus on both the WUI and non-WUI areas.

Sentinel Watershed Monitoring

Lake Tahoe's water quality in both the nearshore and the center of the lake is partly controlled by the contributing watersheds that compose the Lake Tahoe Basin, yet the linkages between the uplands and the lake through the streams are poorly understood. TEON identifies and establishes watersheds for monitoring terrestrial and upland aquatic processes to better understand controls over inputs to Lake Tahoe. Near-term objectives for sentinel watershed monitoring are to establish prototype systems for the collection of terrestrial and aquatic data and identify optimal mechanisms to make that data publicly available real-time or near real-time. Longer-term objectives are to establish a suite of sentinel watersheds (provisionally 6 to 8) around the basin to provide a more robust source of information about watershed dynamics and their consequences for Lake Tahoe.

Sentinel watershed monitoring is intended to accomplish the following monitoring objectives: 1) trace the influences of water from snow and rain in the Lake Tahoe headwaters through soil, trees and rivers; 2) understand how rain and snow interact with soils to generate solutes, which are then transported to streams, undergo biogeochemical cycling and are eventually transported to Lake Tahoe; and 3) assess climatic conditions under the forest canopy, from headwaters to lakeshore.

The most valuable watersheds for sentinel watersheds are the seven that have USGS gauges and existing flow records (starting in the north and going clockwise around the basin): Third, Incline, Glenbrook, Trout, Upper Truckee, General, Blackwood, and Ward. Blackwood Creek and Glenbrook Creek were selected as the initial sentinel watersheds for TEON. The addition of the Upper Truckee watershed as a third sentinel watershed would have been a strong addition (the most differentiation from the other watersheds and greatest projected changes in future climates). However, due to logistical and financial constraints, Incline was selected as the third sentinel watershed, given that it is easy to access and in close proximity to the UNR campus so it serves an important secondary role as a demonstration site. Increasing the number of sentinel watersheds would strengthen the watershed monitoring dataset and confidence in observed relationships and trends.

Ten core metrics were identified as baseline data for sentinel watershed monitoring as initial investments in meeting the objectives of sentinel watershed monitoring. They address hydrodynamics directly (climate, precipitation, snow dynamics, water flow, nutrient loading, and oxygen) at various locations across the watershed (headwaters to mouth), and their relationship with biological response metrics (forest structure, plants and animals, carbon, fire).

Implementation Guideposts

The nuts and bolts of implementation cover an array of parameters and considerations that are touched on here: 1) spatial and temporal pattern of field data collection; 2) what entities are responsible for collecting which data sets and how are multiple entities being coordinated; and 3) data curation (quality control, integrity management, access).

Sustainability and Consistency

Sustainability and consistency are achieved through a balance of 1) identifying a set of core metrics (Tier 1) that provide a robust representation of pillar conditions; and 2) establishing a level of investment (institutions and funding) that is sustainable for at least the first 10 years. Monitoring does not need to be limited to the core set, rather additional data collection efforts can be modularized (Tier 2) so they build on the core set of data, but be funded and implemented individually, perhaps by a single agency, possibly funded by a non-government institution that has a particular interest in monitoring (e.g., Bear Aware for bear monitoring), and potentially less frequently or for shorter periods of time.

Sentinel watershed monitoring has a unique set of implementation considerations. The greatest value of sentinel watersheds is to have time series data for detailed measurements of multiple processes operating across the watershed. Generally, the investment in establishing a sentinel watershed has the greatest return on investment if data are collected for 10 or more consecutive years. The life of the equipment varies, but it is likely that technological advancement and the wear-and-tear of use would lead to replacing most equipment after 10-years.

Temporal Considerations

In terms of data considerations, generally the more frequent and comprehensive the resampling, the more sensitive the monitoring network will be to detecting change. The challenge is how best to allocate sample effort for field based metrics between more sites (better condition representation) and more frequent resampling (better change representation). Given the desirable balance of rigor and cost, panel designs tend to provide the best outcome of reducing error rates per unit of sampling effort. In short, a panel approach is a blend of the two approaches described above: an annual sample effort is established for a subset of sites, and the remaining sample effort alternates across different sites in different years – usually over a 5- to 10-year rotation period.

Sample Size Considerations

A tiered approach is recommended for building broad-scale monitoring sample size. The first step in this evaluation process would be to identify the ecotypes or components against which representation will be judged. Then strength of the representation of those components can be evaluated with each increment of additional samples.

Citizen Science for TEON

In addition to field-based and remotely sensed data collection to characterize species occurrence and habitat conditions, citizen science contributions can make a valuable contribution to systematically collected data. Ad hoc positive sighting data, such as those produced by iNaturalist or from other crowd-sourced photo collections can serve to provide data points for species or locations that are surprising and possibly early detections of change. Periodic events, such as Tahoe's Snapshot Day a bioblitz, Christmas bird counts or City Challenge, can serve to provide a more spatially comprehensive set of positive sightings to represent a point in time more comprehensively than the monitoring network. These types of citizen science contributions are particularly well-suited to the Lake Tahoe Basin because of the exceptionally high visitation it receives from nearby population centers, exponentially increasing the pool of potential contributors to any citizen science data stream.

Adaptive Management

Incorporating adaptive management into monitoring and project planning is especially important in the context of climate change. Adaptive management allows managers to account for the uncertainty that is inherent in climate change projections.

Planning for uncertainty and adaptively managing allows managers to modify interventions based on updated scientific findings and climate projections, new management techniques, or technological advances. Explicitly scheduling evaluation and feedback timing and mechanisms will be important to the success of the network. Reporting and responding on a 5-year cycle strikes a good balance between the potential for change and the additional investment needed for data analysis and synthesis.

Data Processing, Storage and Access

Data management is critically important to the success of monitoring systems. Each set of core metrics and associated methods of data collection have a unique set of considerations in terms of data management. TRPA and UNR have substantial capacity and mission alignment to collaborate and support initial TEON implementation. Growth of the network can be managed, in part, by ensuring that adequate funding is requested and secured for data management, analysis, and reporting.

Lake Tahoe Basin Environmental Atlas

Many large landscapes find that portraying information in the form of an atlas based on intermediate sized units is a very effective and relatable way to portray conditions and report status and change. Using a size that conforms with much of the source data (30-m satellite imagery), argues for 900x900-m units as a good scale to use as the base (can always scale up or down), equating to ~1600 units across the basin. In order to populate the LTBE Atlas, data on each metric needs to be converted to a value that can be attributed to each unit, based on the conditions across the unit. The use of a fixed reporting unit as the foundation of the Atlas will result in all metrics being converted to compatible scales, which in turn generates a powerful data tool enabling the comparison of values across metrics within a unit and over time within and among units at a scale that is relatable. The spatial covariance of metric conditions relative to one another can be evaluated at a point in time and over time within and across units, which has substantial value:

- Enables agencies to speak to any combination of metrics that are relevant to their programs and projects,
- Enables scientists to study how and why metrics are changing over time and relative to one another, providing valuable clues about drivers of change and potential tipping points,
- Enables the public to adopt and/or track their favorite Atlas unit, and could even be the focus of contests for documenting biodiversity (e.g., biodiversity challenges) and/or restoration.

Summary of Recommendations

Basin-wide Monitoring

TEON Steering Group - Science and management oversight and support will be needed for TEON to be successfully implemented and sustained for a decade. A TEON steering group could serve this purpose, where the group would identify priority investments, funding opportunities, reporting review, and adaptive management processes.

Basin-wide monitoring - Identify desired minimum sample sizes, determine the degree to which existing or historical sample sites provide a representative sample for the basin, and adjust the sample as needed (drop and/or add sites to achieve a balanced sample).

Wetland Integrity – Form a technical working group to solidify core sample sites and metrics.

Lake Tahoe Environmental Atlas - Explore the potential value, utility, and structure of an environmental atlas for the Lake Tahoe basin

Biodiversity Conservation - Form a technical group to finalize core metrics for biodiversity and associated monitoring to sufficiently represent the suite of metrics, including consideration for historical and current monitoring activities.

Air Quality – Form a technical working group to solidify core sample sites and metrics.

Water security -Form a technical group to evaluate the current snow monitoring system and derive a recommended base monitoring system for snow monitoring as part of the TEON system.

Remotely sensed data - Leverage existing open-source remotely sensed data sources (LANDFIRE, CECS) and their derivatives (TreeMap) to provide the foundation of landscape-wide vegetation change metrics to the degree possible. Consider investing in LiDAR-imputed product from Planet Lab (Salo product line) directly or in partnership with institutions operating at larger scales (TCSI, Sierra Nevada). Consider investing in LiDAR and hyperspectral data on a periodic and regular basis (5 years, ideally) to serve as calibration for modeled products and to provide a periodic map product that can represent change in some metrics with high accuracy and precision.

Sample allocation across space and time - Establish a panel design for field data collection. Metrics, methods, and metric-specific sample sizes need to be drafted before an assessment of annual sample effort could be determined, sites selected, and then panel allocations made. An annual resample panel of at least 30 sites is suggested to bolster confidence in estimates of annual change.

Environmental stratification - To the degree possible, do not pre-stratify, but rather set systematic sampling criteria (number of sample sites per hexagon) to build sample sizes to represent major ecotypes of interest, and then augment that sample with additional targeted sample locations.

Sentinel Watershed Monitoring

Gauging stations - We recommend building upon the existing UGS gauging of streamflow to also include chemistry data that allow for understanding aquatic ecosystem health and nutrient loading to the lake.

Climate sensors - We recommend upland sampling of climatological data – particularly high-quality precipitation measurements – that builds upon and infills gaps in existing networks. A network of in-situ soil moisture and tree-stress measurements provides data streams that otherwise do not exist, and thus is particularly valuable for direct insights, and for locally ground-truthing remote-sensing data.

Intensified sampling - We recommend increasing the intensity of sampling for a subset of features to enhance our understanding of upland-aquatic linkages (wetlands and meadows) and to evaluate climate impacts by intensively sampling along elevational gradients (forest and biodiversity metrics).