Lake Tahoe Aquatic Plant Monitoring Program: Aquatic Plant Monitoring and Evaluation Plan

June 2, 2020

Prepared for:

Tahoe Regional Planning Agency
Dennis Zabaglo
Aquatic Resources Program Manager
128 Market St.
Stateline, NV 89449

TAHOE REGIONAL PLANNING AGENCY

Submitted By:

Marine Taxonomic Services, Ltd.
Lake Tahoe Office
1155 Golden Bear Trail
South Lake Tahoe, CA 96150

Prepared by:

Marine Taxonomic Services, Spatial Informatics Group, and Oregon State University

Dr. Robert Mooney, Vice President
Seth Jones, President & CEO

Marine Taxonomic Services, Ltd.
Headquarters: 920 Rancheros Dr., F-1
San Marcos, CA 92069

Tahoe Office: 1155 Golden Bear Tr.
South Lake Tahoe, CA 96150

Shane Romsos, Senior Scientist
Jarlath O'Neil-Dunne, Research Scientist

Spatial Informatics Group, LLC.
Headquarters: 2529 Yolanda Ct.,
Pleasanton, CA 94566 (Headquarters).

Tahoe Office: 3079 Harrison Ave. Office #17, Box #27
South Lake Tahoe, CA 96150

Dr. Christopher Parrish, Associate Professor
Ben Babbel, Graduate Research

Oregon State University
College of Engineering
116 Covell Hall
Corvallis, OR 97331

Recommended Citation:

Tahoe Regional Planning Agency. 2020. Lake Tahoe Aquatic Plant Monitoring Program: Aquatic Plant Monitoring and Evaluation Plan. Prepared by Marine Taxonomic Services, Spatial Informatics Group, Oregon State University. June 2, 2020. Contract #19C00001.

Table of Contents

Appendices

List of Figures

List of Tables

1. Monitoring Background

Goals and Objectives of the Aquatic Plant Monitoring and Evaluation Program

The Aquatic Plant Monitoring Program (APMP) is intended to gather, analyze, and report information relative to aquatic plant populations in Lake Tahoe, with an emphasis on collecting data that can be used to guide control efforts for aquatic invasive plants. The goals for the APMP are summarized below:

- The APMP seeks to maximize coordination between nearshore management and regulatory agencies and minimize duplicity of monitoring efforts and overall costs. Roles and responsibilities in the APMP are defined and understood. The APMP includes this monitoring plan as a core guidance document that includes processes to coordinate aquatic plant data collection, analysis, and reporting. The monitoring program ensures that available funds are appropriately invested to collect and report the most relevant status and trend information required to support management and policy decisions, meet agency monitoring needs, and facilitate public understanding.
- Implementation of the aquatic plant monitoring and evaluation plan will result in a significant source of synthesized monitoring information that characterizes the status and changes in aquatic plants in Lake Tahoe that is sought after and relied upon by agencies, stakeholders, and the public to increase their understanding, and inform their decisions and actions.
- The APMP seeks to maintain long-term, stable funding at a level commensurate with carrying out necessary data collection, data management, and reporting program elements.
- The APMP shall be adaptable and include processes for amending or adding program or plan elements to improve its performance and relevancy as needed over time.
- The APMP will consistently use quantifiable indicators and measures to assess aquatic plant conditions that are meaningful to resource managers and are reported in a manner understandable by decision makers, stakeholders and the public.
- The monitoring program shall use best available science and technology to collect new data, conduct analyses, manage information, evaluate conditions, and make meaningful monitoring results available in a timely fashion.

Monitoring and Evaluation Plan Purpose

Policy and management of Lake Tahoe's nearshore zone is guided by a desired condition statement articulated in Heyvaert et al. (2013) and the Tahoe Regional Planning Agency (TRPA) adopted Threshold Standards. Within this context, goals and objectives for aquatic plants can be inferred and used to focus this monitoring plan. Through a broad agency and stakeholder review and acceptance process, Heyvaert et al. (2013) defined a "desired condition" for the Lake Tahoe nearshore zone as:

"Lake Tahoe's nearshore environment is restored and/or maintained to reflect conditions consistent with an exceptionally clean and clear (ultra-oligotrophic) lake for the purposes of conserving its biological, physical and chemical integrity, protecting human health, and providing for current and future human appreciation and use."

From the desired condition, Heyvaert et al. (2013) further refined an overarching ecological and aesthetic objective statement related to aquatic plants as:

"Maintain and/or restore to the greatest extent practical the physical, biological and chemical integrity of the nearshore environment such that water transparency, benthic biomass and community structure are deemed acceptable at localized areas of significance."

As part of the 2012 TRPA Regional Plan update, a water quality threshold management standard for aquatic invasive species was adopted to:

"Prevent the introduction of new aquatic invasive species into the region's waters and reduce the abundance and distribution of known aquatic invasive species. Abate harmful ecological, economic, social and public health impacts resulting from aquatic invasive species."

Taken together, the desired condition, objective statement, and threshold management standard emphasize Tahoe agencies' collective goals to restore and maintain a functional native plant and animal species composition within Lake Tahoe's nearshore zone and reduce the distribution and extent of aquatic invasive species. However, absent from the existing goals, objective statement and threshold management standard is a specific numerical target that is desirable to be achieved in the region for aquatic plants. Despite this gap, it can be inferred that agencies want to use monitoring data to quantitatively demonstrate a reduction (through annual status and trend analysis) in the extent and distribution of invasive aquatic plants, and the maintenance of native aquatic plants over time.

The purpose of this monitoring and evaluation plan is to provide appropriate protocols and detailed information required for guiding nearshore managers in consistently collecting, quantifying, and reporting on the status and trends in aquatic plant bed composition, relative abundance/density (percent cover), extent, and distribution at Lake Tahoe's nearshore zone, marinas, and tributaries. By design, the monitoring plan is a stand-alone document that can be implemented by either agencies or contractors that have the necessary human resource capacity and skillsets. In addition, the plan is intended to be a living document where new or revised field protocols, analysis, or reporting approaches can be included over time.

The monitoring plan provides the necessary guidance to answer the following monitoring questions at Lake Tahoe:

Question #1 (extent): *For lake-wide surveys, what is the status of the extent (area) of invasive and native aquatic plant beds within Lake Tahoe's nearshore zone, and how is the extent of these plant beds changing over time (trend)?*

Question #2 (distribution): *For lake-wide surveys, what is the status of the distribution (spatial arrangement) of invasive and native aquatic plant beds within Lake Tahoe's nearshore zone, and how is the distribution of these plant beds changing over time (trend)?*

Question #3 (abundance/composition): *For sites where aquatic plants have been documented through lake-wide surveys, what is the status of their relative species abundance/composition (e.g., percent cover, stems/unit area) and how is percent relative species abundance/composition changing over time (trend)?*

Question #4 (new establishment of invasive species): *Is there evidence of new aquatic invasive plant bed establishment? If so, where and how extensive are new plant beds?*

Answers to these questions will help nearshore managers to focus management and policy actions designed to achieve nearshore desired conditions, objectives and standards.

Synthesis of Previous Research and Monitoring Findings

Lake Tahoe is an oligotrophic (nutrient poor) system; it naturally has few aquatic plant species and its substrate is generally void of submersed, floating, and rooted aquatic plants (Heyvaert et al. (2013). Because of this natural situation, past resources managers implemented efforts attempted to enhance the fishery through establishment of aquatic vegetation. Heyvaert et al. (2013) summarized these past efforts in their report:

"*During the 1920's and 1930's the Mt. Ralston Fish Planting Club released invertebrates, fishes, and stocked aquatic plants such as water lilies, water hyacinth, and parrot feather into the numerous higher elevation lakes, likely including the Tahoe basin. The intentional introductions were meant to improve food and cover conditions for fishes in the generally rocky and sandy bottom waters. It is likely the stocking of plants also continued until the 1950's as biologist, Shebley, from the California Fish and Game indicated that they were introducing invertebrates such as salmon flies, Gammarus spp., and aquatic plants but he didn't specify the taxa. As late as 1961, Nevada Fish and Game introduced Vallisneria (likely water celery, V. americana) into the lake to improve fish and cover conditions in the lake. Thirty plants were anchored to the bottom in 1-1.75 m of water at 3 locations (Skunk Harbor, Glenbrook Bay, and Logan Shoals) but they did not establish."*

Historic information (>30 years ago) on the occurrence of native plants at Lake Tahoe nearshore is lacking although Frantz and Cordone (1967) reported macroscopic hydrophytes (deep-water aquatic plants) in Lake Tahoe to a depth of 500 ft. The plant beds consisted of algae, mosses and liverworts. Most were concentrated at depths from 200 to 350 ft. Only *Chara sp.* occurred in areas as shallow as 20 ft. Other deep-water hydrophytes were restricted to depths below 50 ft.

Loeb and Hackley (1988) described the distribution of submerged macrophytes from a study effort conducted in 1986, primarily at the south shore of Lake Tahoe near the Tahoe Keys and Upper Truckee Marsh. In general, their research found that the occurrence of macrophytes (vascular submerged aquatic plants) was rare at Lake Tahoe. The most dominant species observed during their study included: Eurasian watermilfoil (*Myriophyllum spicatum*), Richardson's pondweed (*Potamogeton richardsonii*), curly-leaf pondweed (*Potagometon crispus*), coontail (*Ceratophyllum demersum*), Canadian waterweed (*Elodea canadensis*), and *Carex sp*.

Since Loeb and Hackley (1988), additional survey efforts have been implemented for aquatic plants at Lake Tahoe, mostly focused on the detection of non-native invasive plants. The first surveys were conducted by Dr. Lars Anderson (United States Department of Agriculture – Agricultural Research Service) in 1995 and continued intermittently through 2005 (Anderson and Spencer 1996, Anderson 2006). In 1995, Anderson reported 13 nearshore sites in Tahoe that contained Eurasian watermilfoil, with 17 sites observed in 2000, 22 sites in 2003 and 26 sites in 2005 (Figure 1). In 2011, Eurasian watermilfoil was detected at 23 sites, whereas in 2012, 18 sites were detected.

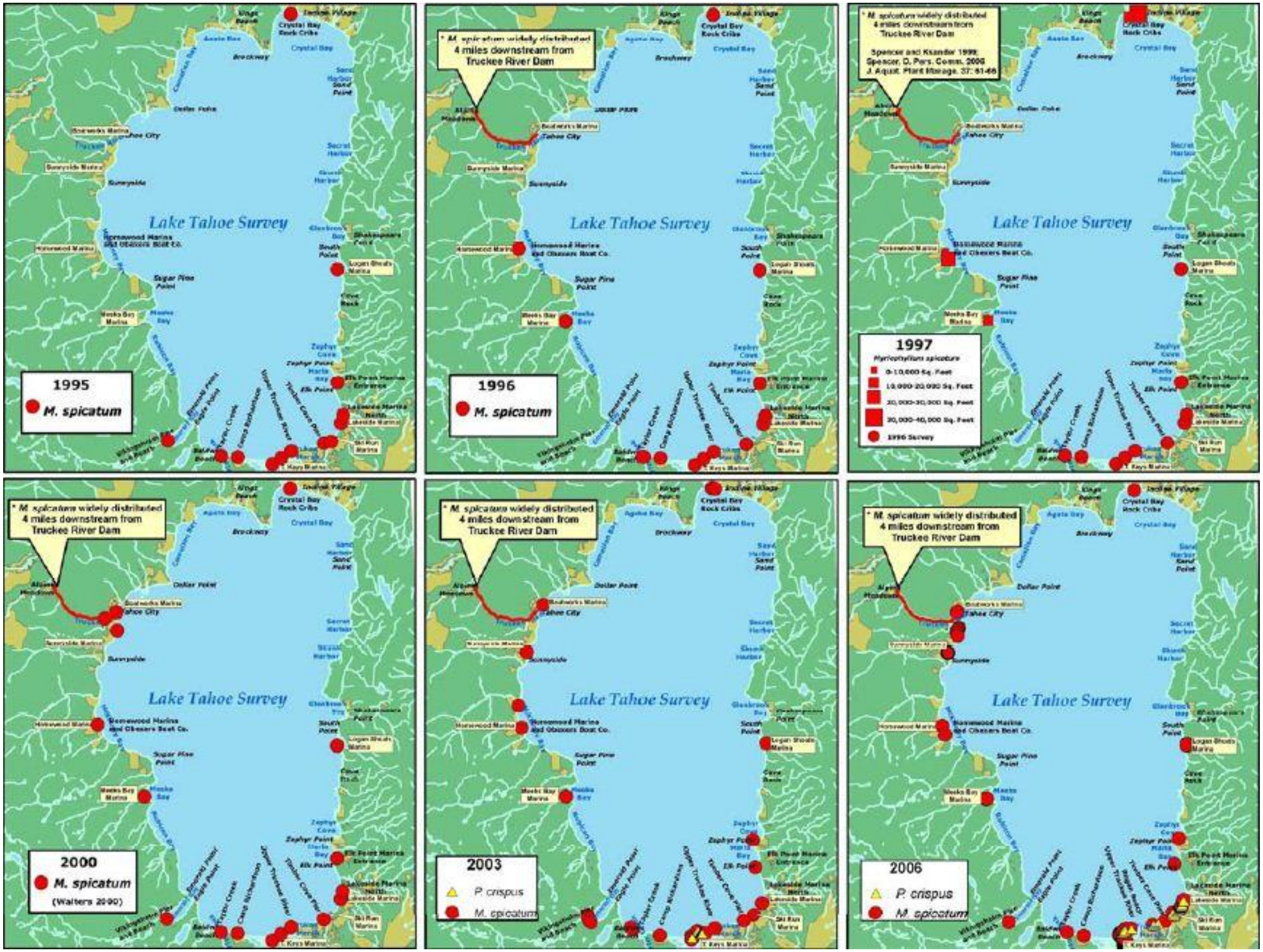

Figure 1. Maps showing changing distribution of the aquatic invasive plants at Lake Tahoe, 1995 to 2006. Source: Lars Anderson unpublished report (2006).

As noted above, subsequent surveys conducted by Dr. Anderson documented an increase in occurrence (new plant beds) of Eurasian watermilfoil, primarily expanded to the west shore of Lake Tahoe, with a couple of sites on east and north shore near Incline Village. Dr. Anderson found that curly-leaf pondweed had become established within the Tahoe Keys homeowner's marina.

The 2009 Lake Tahoe Region Aquatic Invasive Species Management Plan (USACE 2009) provided a synthesis of information related to the status of aquatic plants, with interest on submerged aquatic invasive species such as Eurasian watermilfoil and curly-leaf pondweed. Using bottom substrate, water depth and slope gradient from shoreline, the 2009 plan estimated that there were approximately 11,350 acres of suitable habitat at Lake Tahoe for focal aquatic invasive plants.

In 2012, *Sierra Ecosystem Associates* with *Infiniti Diving Service* conducted scuba and snorkel aquatic plant surveys (transects) at sixteen selected sites (covering approximately 524 acres, surveyed depth was 2 to 30 feet, 8 survey days) with a focus on detection of Eurasian watermilfoil and curly-leaf pondweed. The objective was to characterize the presence, extent and biomass of these species at survey sites. The technology was useful in characterizing species occurrence at Ski Run and Emerald Bay.

Wittmann and Chandra (2015) summarized the history and status of aquatic invasive species as an element of a comprehensive implementation plan for AIS control efforts. Like others, Wittmann and Chandra (2015) identify that Eurasian watermilfoil and curlyleaf pondweed are the only known submerged aquatic invasive plant species at Lake Tahoe. Their review noted that Lake Tahoe's benthic zone supported several *Characeae spp*., mosses, liverworts and filamentous algae species to depths up to 400m. Native macrophytes, such as Andean milfoil (*Myriophyllum quitense*), Canadian waterweed, coontail, Richardson's pondweed and leafy pondweed are also found in Lake Tahoe.

Chandra and Caires (2016) conducted an aquatic plant survey along continuous transects around Lake Tahoe's shoreline at 5 and 2 m bathymetric depth contours in 2014 (intermittently from August 30 to October 11). Transect surveys did not include marinas or stream mouths, or the area around Vikingsholm pier or beach at Emerald Bay. Chandra and Caires (2016) compared their results with Dr. Lars Anderson's surveys (conducted between 1995 and 2006) and found that plants were not encountered in most areas of the lake where they were found in various surveys from 1988-2012. Plants in the 2014 survey were only encountered in the southern part of the lake and were composed of a native/non-native mix.

System Understanding

According to Wittmann et al. (2015) and Tahoe Resource Conservation District personnel, native aquatic plants that currently occur in Lake Tahoe include:

- Andean milfoil (*Myriophyllum quintense*)
- Common bladderwort (*Utricularia macrorhiza*)
- Canadian waterweed/common waterweed/western waterweed otherwise known as "Elodea" (*Elodea canadensis)*
- Coontail *(Ceratophyllum demersum)*
- Leafy pondweed *(Potamogeton foliosus)*
- Muskgrass (*Chara spp.)*
- Northern milfoil *(Myriophyllum sibiricum)*
- Richardson's pondweed (*Potamogeton richardsonii*)
- White water buttercup (*Ranunculus aquatilis*)

Aquatic invasive plants that currently occur in Lake Tahoe include:

- Curly-leaf pondweed (*Potamogeton crispus*)
- Eurasian watermilfoil (*Myriophyllum spicatum)*

The diagram shown in Figure 2 generally shows the factors, processes and actions (left side of the diagram) that affect the region's ability to achieve goals (right side of the diagram) for aquatic plants, with additional emphasis on those factors that affect the occurrence of aquatic invasive plants. The desired condition, goals and objectives for aquatic invasive plants is drawn from TRPA's Threshold Standards (TRPA Resolution 82-11) and the Lake Tahoe Nearshore Evaluation and Monitoring Framework (Heyvaert *et al*. 2013).

Changes in the occurrence of aquatic plants are driven by both natural factors and processes (shown in green, Figure 2) and human-derived land uses and practices (shown in orange, Figure 2). These factors and processes are known as "drivers." Management and policy actions (shown in yellow, Figure 2) that can mitigate detrimental human land uses and practices are linked to appropriate drivers and are intended to either fully or partially mitigate the influences of human land uses and practices that drive aquatic invasive plant occurrences throughout Lake Tahoe's nearshore zone. The conceptual model shown in Figure 2 can aid in identifying where within the system monitoring effort could be assigned.

Monitoring Approach Rationale

The monitoring approach prescribed for aquatic plants is designed to quantify the presence/absence, composition, extent and distribution, and percent cover (relative abundance) of submerged aquatic plants (macrophytes) in Lake Tahoe's nearshore zone. The proposed methods are at an appropriate scale relative to the chosen indicators and likely available funding. The sampling scales range from nearshore-wide survey of individual aquatic plant bed boundaries to stratified systematic *in situ* transect sampling for a nearshore-wide characterization of aquatic plants. Combined, the methods and sampling schedule prescribed are intended to provide as complete as possible a picture of aquatic plant status and trends within budget constraints.

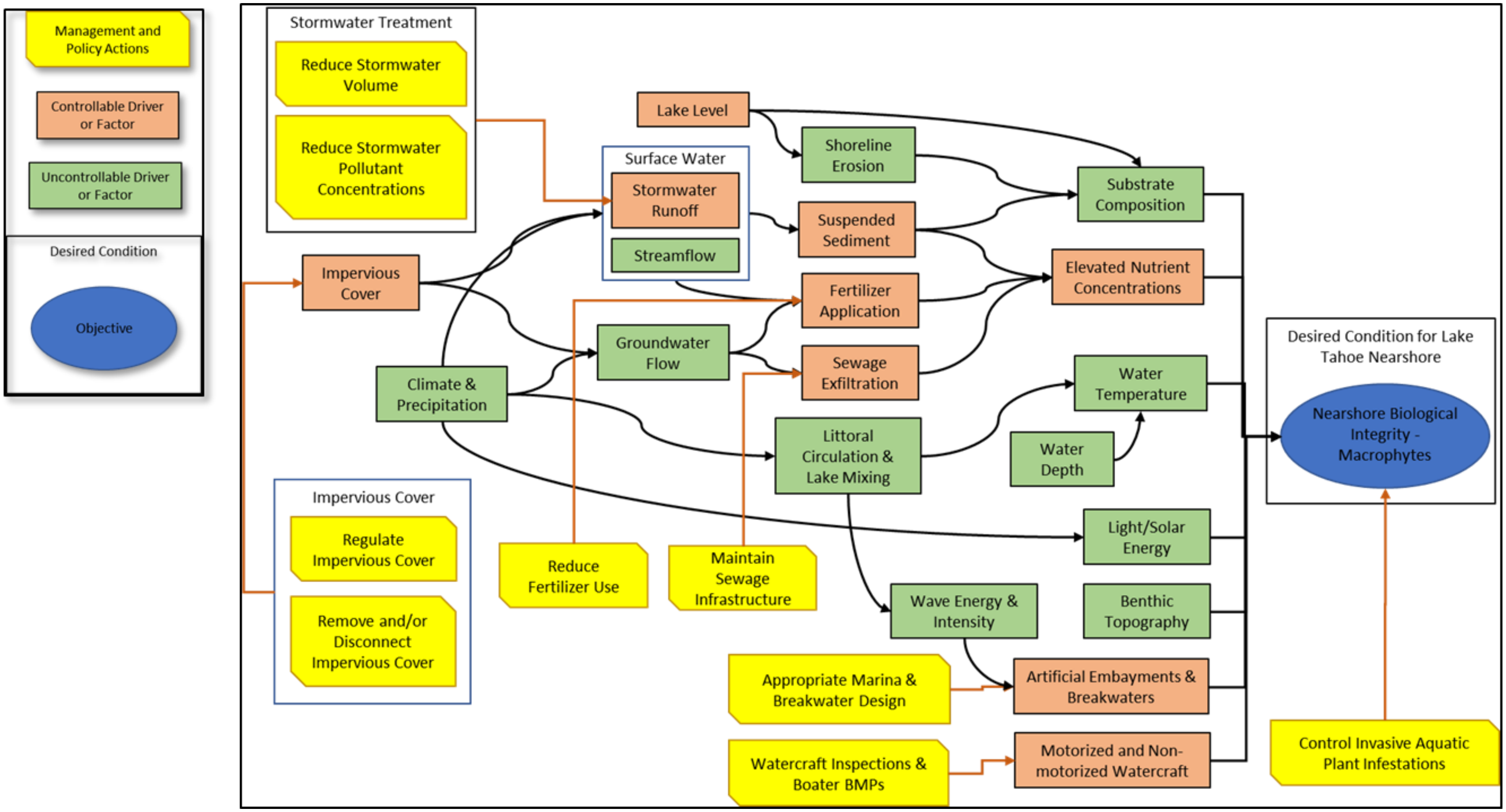

Figure 2. Conceptual model showing a general understanding of the controllable and uncontrollable factors and activities that affect the region's ability to achieve desired conditions and objectives associated with aquatic plants in Lake Tahoe's nearshore zone. An explanation of each factor and activity is provided in Appendix A.

2. Indicator Monitoring Information

Indicators

The indicators selected for aquatic plant monitoring provide information that nearshore managers need to advise decisions related to management of aquatic plants. Indicators selected for the monitoring plan are important to track because they can be used to objectively answer monitoring questions outlined in this monitoring plan and provide managers with information necessary to identify where interventions are needed, especially for submerged aquatic invasive plants.

Aquatic Plant Bed Presence (or Absence)

This indicator provides the coarsest level of aquatic plant bed characterization in that it only communicates whether a plant bed has been detected (or not) at a location within the area of interest at a given point in time. Presence/absence data can be obtained through the interpretation of remote sensing data, hydroacoustic, *in situ* surveys via boat, line transect surveys, point intercept surveys or through "citizen science" programs where individuals record aquatic plant bed observation into a web-based data repository platform (e.g., League to Save Lake Tahoe's "*Eye's on the Lake*" Program). These data are usually represented as a point feature on a map across the area of interest. Additional sampling effort would be needed to assign other attributes to presence/absence data. For example, the ability to assign species composition to individual plant beds may be possible if: 1) rake samples of plant bed are taken and species identified from samples, 2) plant beds can be identified and discriminated from remotely sensed data, or 3) diver surveys conducted by qualified biologists identify plant bed species composition via point intercept or line intercept sampling.

Aquatic Plant Bed Extent

This indicator measures the surface area (extent) of submerged aquatic plant beds at a point in time. The spatial location of plant beds is a byproduct of collecting these data. When measured consistently over time, an increase in area of aquatic beds would indicate an expansion, and a decrease would indicate a contraction. For aquatic invasive plants, demonstrating a contraction in extent would indicate conditions are improving, while an increase would indicate otherwise. The unit of measure for this indicator is area (e.g., acres or square feet or square meters). Similar to presence and absence data, the ability to assign species composition attributes to individual plant beds may be possible if: 1) different plant bed types can be identified and discriminated from remotely sensed data, 2) rake samples of plant bed are taken and species identified from samples, or 3) surveys conducted by qualified biologists identify plant bed species composition via point intercept, quadrat, or line intercept sampling.

Aquatic Plant Bed Distribution

This indicator is used to characterize the arrangement of aquatic plant beds across the area of interest (i.e., Lake Tahoe's open-water nearshore, marinas, embayments, and major tributaries). These data show where aquatic plant beds are in space and time, how many plant beds there are per unit of area, and how sparsely or densely distributed they are from each other (average distance). Typically, these data are depicted for a point in time graphically, usually on a map, and are a byproduct of collecting extent or presence/absence data. When this indicator is collected over time, a time series of aquatic plant bed spatial distribution can be geographically represented for comparison for each time the indicator is measured.

Aquatic Plant Relative Species Abundance/Composition

This indicator is a measure of how common or rare an aquatic plant species is relative to other species in a defined location, such as a plant bed or location (e.g., Tahoe Keys Marina). Percent cover or stem counts by species for each plant bed could be used to quantify this indicator for an individual plant bed or unit area. If assessment of relative species abundance/composition for each plant bed is demonstrated to be too time consuming/costly, aquatic plant beds could be simply attributed as either percent cover categories of native vs. non-native. Snorkel or dive surveys/transects or point intercept of plant beds (e.g., delineated from remotely sensed data) or locations (e.g., Tahoe Keys Marina, Elks Point Marina, Tallac Marsh) would provide the most direct method to enumerate each plant bed's relative species abundance/composition. Alternatively, rake samples could be used (via point intercept) to characterize relative species abundance/composition for a plant bed or defined location. However, catch per unit effort can be dependent on species morphology.

New Establishment of Aquatic Invasive Plants

This indicator is used to quantify and identify the location of newly establish aquatic invasive species. The indicator can be measured using a variety of methods including thorough interpretation of remotely sensed data, hydroacoustic surveys, divers or rake surveys via line transects or point-intercept methods. Certainty with regards to establishment of new species or new infestation areas of existing species relies on having a prior survey with enough confidence to state the species or infestation area was previously negative for the indicator. The nearshore-wide survey performed as the first step of this monitoring plan is intended to meet this criterion.

Description on Indicator Limitation

Although indicators identified in this monitoring plan for use in characterizing aquatic plant status and trends is well established in the literature and useful for aquatic resource managers, these indicators do have some limitations. Indicators identified in the monitoring plan do not measure or diagnose the underlying drivers of aquatic plant condition. For example, water temperature and depth, substrate condition, nutrient concentrations and turion or plant fragment abundance are measurements that may help to forecast the occurrence of aquatic plants in the future, or to explain the current extent and distribution of aquatic plants. These measures are not explicitly prescribed in this monitoring plan; however, such measures could be added as resources and/or demand for the information emerges.

Sampling Design

This section provides the rationale and documentation of the monitoring plan extent, the sampling intensity, geographic distribution of monitored locations, and schedule of when sample collection and surveys will be performed.

Survey Area

The survey area for this monitoring program adheres to the nearshore boundary definition identified by Heyvaert et al. (2013), with some exceptions. Heyvaert et al. (2013) defined Lake Tahoe's nearshore for purposes of monitoring and assessment: "*to extend from the low water elevation of Lake Tahoe (6223.0 feet Lake Tahoe Datum) or the shoreline at existing lake surface elevation, whichever is less, to a depth contour where the thermocline intersects the lake bed in mid-summer; but in any case, with a minimum lateral distance of 350 feet lakeward from the existing shoreline."* The depth contour "*where the thermocline intersects the lakebed*" is approximately 21 meters (69 feet; Heyvaert et al. 2013). The survey area is represented in Figure 3. The Heyvaert et al. (2013) definition does not explicitly include lake features such as marinas or suitable aquatic plant habitat associated with tributaries or freshwater marshes. Marinas occur within Heyvaert (2013) definition based on the 6,223-ft elevation, however, they need to be further defined in terms of degree of exposure to in-lake littoral process. As such, marinas and embayments are defined as those open water areas that are connected to Lake Tahoe and the perimeter is buffered from in-lake littoral processes by a land mass, jetty, or other structure.

Stream mouth and freshwater marsh areas that interface with Lake Tahoe are of concern with regards to aquatic invasive plants as these areas have been demonstrated to provide suitable habitat (e.g., Tahoe RCD/UCD monitoring of Truckee River outlet). Therefore, marshes and major tributaries with suitable habitat are included as survey strata for the purposes of this monitoring plan. Suitable habitat associated with the major tributaries stratum are defined as being, 1) within 500 m of Lake Tahoe, 2) are connected to Lake Tahoe via tributary water flow (typically throughout the year), 3) are generally wider than 1.5m, and 4) have a gentle topographic profile configuration (<1% slope). Fresh water marsh areas identified by nearshore managers for monitoring include Upper Truckee Marsh, Pope Marsh, Taylor Marsh and Tallac Marsh.

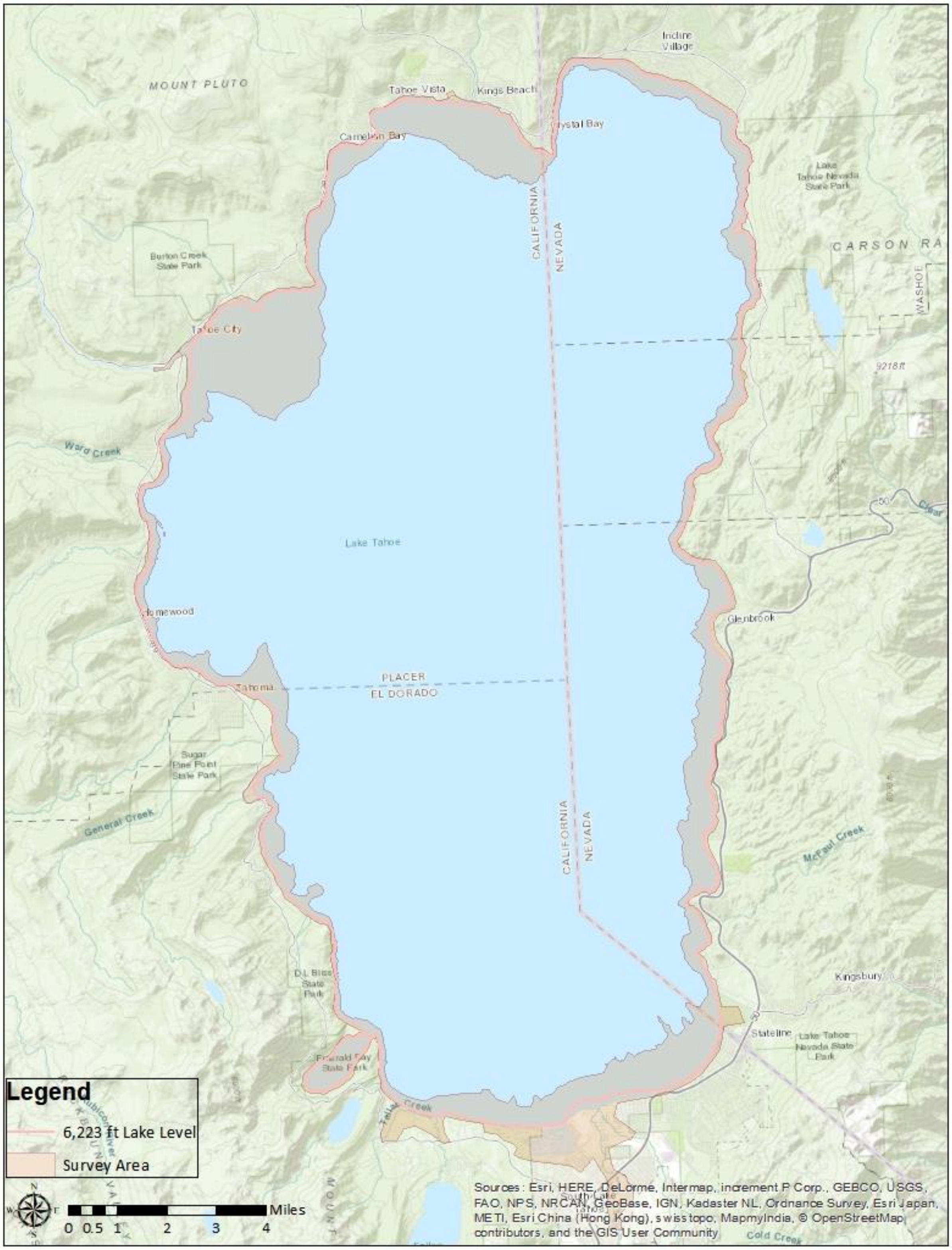

Figure 3. Aquatic plant monitoring boundary (shaded) relative to the 6,223 ft natural rim lake level (shown in pink). The lakeward boundary reflects the 21m (~69ft) bathymetric contour.

Data Collection Protocol(s)

Two levels of aquatic plant survey effort (spatial design) are applied to the APMP and each is performed on a different temporal scale. Once every five years a nearshore-wide aquatic plant survey is conducted via interpretation and mapping of remotely sensed data in combination with *in situ* diver sampling. Annually, only an *in situ* diver survey (or a reasonable surrogate) is performed following targeted and a stratified systematic sampling of transect lines with incorporated quadrats. The nearshore-wide aquatic plant survey (i.e., the combination of remote sensing imagery analysis with diver surveys) attempts to provide for a "baseline" status quantification of all aquatic plant beds around Lake Tahoe's nearshore zone. The transect surveys allows for training and validation of remotely sensed data, and annual surveillance to establish trend information and the detection of new infestations of aquatic invasive plants. The sampling frame (i.e., survey area) and habitat stratification scheme used for line-transect surveys conducted in intervening years will be the same as that used for the nearshore-wide survey. Four habitat strata are used to divide the aquatic plant population into meaningful sampling units, including open-water nearshore, marshes, major tributaries, and marinas and embayments.

The reasons for stratified sampling include:

- The identified strata are functionally different, are exposed to different environmental and human factors, and are easily partitioned. Stratification reduces variation in measurements and thus provide smaller error in estimation.
- The aquatic plant population density varies greatly within the Lake Tahoe nearshore, stratified sampling will ensure that estimates can be made with equal accuracy in different parts of the nearshore, and that comparisons of strata categories can be made with equal statistical power.
- Field logistics and measurements are more manageable and/or more cost effective when the nearshore aquatic plant population is grouped into strata.
- Estimates of aquatic plant parameters by identified strata is desirable by nearshore managers to better prioritize interventions.

For reasons related to unequal sampling effort, data reliability and statistical confidence, data supplied through citizen monitoring efforts (e.g., League to Save Lake Tahoe's "*Eyes on the Lake*") are not formally included in this monitoring program. Nonetheless, there is potential value in these data as they could provide information on the location of new aquatic plant beds and should be reviewed each year by managers to confirm and add to the observations documented during the implementation of the formal monitoring program. Also note that there is potential for the *Eyes on the Lake Program* to participate in the APMP if participants are appropriately trained and implement monitoring efforts according to protocols prescribed herein.

Nearshore-Wide Aquatic Plant Survey

Remote Sensing Data Acquisition

The general approach to remote sensing for monitoring of aquatic plants in Lake Tahoe involves a multi-modal, multi-temporal strategy, using the technologies listed in Table 1. The motivation for this approach is that it enables long-term monitoring over broad spatial extents (i.e., the entire lake and surrounding tributaries), coupled with high resolution, rapid acquisition at targeted treatment areas or "hot spots."

Table 1: Remote sensing modes and revisit cycles for Lake Tahoe monitoring plan.

Data Type	Acquisition Platform	Specifications	Revisit cycle
Ultra-high-resolution multispectral imagery	UAS	1-3 cm pixel resolution (ground sample distance); spectral bands: red, green, blue, and near infrared	≤ 1 year, at priority sites, and/or as needed
Very-high-resolution multispectral imagery	Airplane (manned aircraft)	20 cm pixel resolution (ground sample distance); spectral bands: red, green, blue, and near infrared	~5 years
Topobathymetric LiDAR elevation data (digital elevation models and point clouds) and lakebed relative reflectance	Airplane (manned aircraft)	10 pts/m^2 nominal point density, RMSEz ≤ 15 cm	~5 years
High-resolution multispectral imagery	Satellite	0.5 -1.0 m; spectral bands: red, green, blue, and near infrared	As needed

Satellite imagery and imagery acquired from conventional aircraft are very well-established, well-understood types of remote sensing data. The other two technologies listed in Table 1, UAS and topobathymetric LiDAR, are currently less familiar to many people, and are further described below:

Unmanned Aircraft Systems (UAS or drone):

Small unmanned aircraft systems (UAS), commonly called drones, are a rapidly emerging technology for remote sensing, surveying, and mapping. In 2016, the Federal Aviation Administration (FAA) implemented Part 107 of the Title 14 of the Code of Federal Regulations, facilitating use of UAS within the National Airspace. Operating within Part 107, certified remote pilots can operate small UAS (up to 55 lb) in uncontrolled airspace and up to 400 ft above ground level without a waiver in unrestricted air space. UAS are most advantageous for project sites up to ~5 km^2 (1,200 ac) and can typically be rapidly deployed at reasonable cost.

For aquatic vegetation monitoring, UAS imagery should be acquired for selected locations as warranted (e.g., targeting marshes, major tributaries and marinas and embayments strata) and to complement the *in situ* field sampling. Output products from the UAS flights and subsequent processing in structure from motion (SfM) photogrammetric software include orthorectified image mosaics, raster surface models, and 3D point clouds suitable for ingestion into GIS. When coupled with high-precision GPS techniques, such as RTK and PPK, UAS imagery can be processed to deliver data products that have horizontal accuracies in the range of 1-3cm. The limitation of UAS in the context of aquatic mapping is that orthorectified mosaics cannot be produced for areas of water where there are no fixed features for image to image matching. This generally limits the ability of UAS-derived geospatial products to the nearshore environment although individual geotagged images can be produced for any location.

Topobathymetric LiDAR:

Topo-bathymetric LiDAR is an airborne remote sensing technology that enables efficient acquisition of nearshore bathymetry from an aircraft overflying the project site. Ranges from a green-wavelength, water-penetrating laser are measured from the aircraft to the bottom of the water body and combined with pointing angles and trajectory data from a global navigation satellite system (GNSS) and an aided inertial navigation system (INS) to provide accurate 3D data. As compared to boat-based acoustic echosounder surveys, airborne topo-bathymetric LiDAR can often be collected in a fraction of the time (Guenther 2007). In many coastal areas, the utility of topobathymetric LiDAR data is limited by water clarity, but the clear waters of Lake Tahoe make the Tahoe nearshore ideally suited for topobathymetric LiDAR data acquisition. The combination of topobathymetric LiDAR and multispectral imagery provides the ideal combination of both passive and active remotely sensed data for mapping aquatic vegetation. Specifications for airborne remote sensing equipment and data acquisition are presented in Appendix B.

It is cost-prohibitive to acquire topobathymetric LiDAR and aerial imagery for the entire ~19,500-acre survey on an annual basis. As indicated in Table 1, an effective and cost-efficient strategy for long-term remote sensing monitoring is to acquire topo-bathymetric LiDAR and multispectral imagery for the entire nearshore zone at intervals of multiple years (e.g., every 5 years), then supplement these data with targeted data acquisition with unmanned aircraft systems (UAS) in high-priority sites at more frequent intervals. UAS data acquisition is fast and cost-effective for small areas in addition to yielding imagery products with a higher spatial resolution than is typically possible with other airborne and spaceborne sensors. The complementary nature of topobathymetric LiDAR and UAS will enable efficient monitoring, covering the ranges of spatial and temporal scales needed for effective decision making.

Remote Sensing Image Calibration

Assessments of the remotely sensed data should be performed to assess both spatial accuracy and thematic (classification) accuracy. A variety of methods can be used to assess the positional accuracy, depending on how the remotely sensed data are georeferenced. In the case of the topo-bathymetric LiDAR, the data will be directly georeferenced using post-processed Global Navigation Satellite System (GNSS)-aided inertial navigation system (INS) on the aircraft, and an empirical accuracy assessment will be performed by land surveyors employed by the remote sensing data acquisition contractor using ground check points surveyed with real time kinematic (RTK) GNSS and/or a total station. The project team should work with the acquisition provider on total propagated uncertainty (TPU) procedures to further assess the LiDAR point clouds. For the UAS data processed in structure from motion (SfM) photogrammetry software, it is more likely that georeferencing will be based on GNSS ground control points (GCPs) distributed throughout the scene (Figure 4) than on direct-georeferencing using precision GNSS (carrier-phase based relative positioning using dual-frequency receivers) with aided INS on the remote aircraft.

Figure 4. Surveying ground control points (GCPs) for UAS SfM photogrammetry using GNSS and total station.

The thematic (classification) accuracy of the benthic habitat maps should be assessed using standard methods frequently employed in remote sensing. Reference data should be acquired for each class during the diver *in situ* data collection (see below), with a subset of the *in situ* data specifically held aside for the classification accuracy assessment (where "held aside" means that this subset of the reference data will not be used in any other part of the processing and analysis). An error matrix - also known as a "confusion matrix" - should be generated and the results reported using standard metrics, to include overall accuracy, user's accuracy, producer's accuracy, and kappa coefficient (Congalton, 1991; Lillesand et al., 2014).

In Situ Data Collection for Image Classification and Accuracy Assessment

The *in situ* data collected by divers are divided into two groups: 1) training (classification) data and 2) reference (accuracy assessment) data. 'Training' data is used to develop the benthic habitat maps and the 'reference' data is used to assess the accuracy of the benthic habitat maps. Data collected through diver surveys is the source data for these purposes. Regardless of how the data are used to train or refine mapping data, the data will be collected in a standardized fashion following method outlined below. A data dictionary outlining field data collected during *in situ* surveys is provided in Appendix C.

In Situ *(Field) Sampling Frames and Data Collection*

The sampling frame for this monitoring program includes the Lake Tahoe nearshore as defined survey area above (and Figure 3) which includes marinas, marshes and major tributaries. The sampling frame extends beyond the Lake Tahoe nearshore to capture plant species that may occur in marinas, tributaries and marshes that are connected to the Lake Tahoe nearshore. It is important to note however that the Heyvaert et al. (2013) definition includes a minimum lateral distance of 350 feet lakeward from the shoreline in the event the nearshore was deeper than 21 meters within 350 feet from shore. While that criterion will be preserved for the LiDAR data collection, diver transects do not extend beyond the 21-meter isobath.

Data collected along all transects within the sampling frame will include line intercept distance and position for each plant bed occurrence (Figure 5). Position will either be determined by direct recording with GNSS or dead reckoning by using a tape measure as the transect such that position can be recorded relative to the transect start point. The transect-plant intercept distance will then be recorded. Individual plants will be noted when intercepted even when the intercept distance is minimal (e.g. less than 1 m). If multiple small plants or plant patches are intercepted with gaps in between occurrences, a

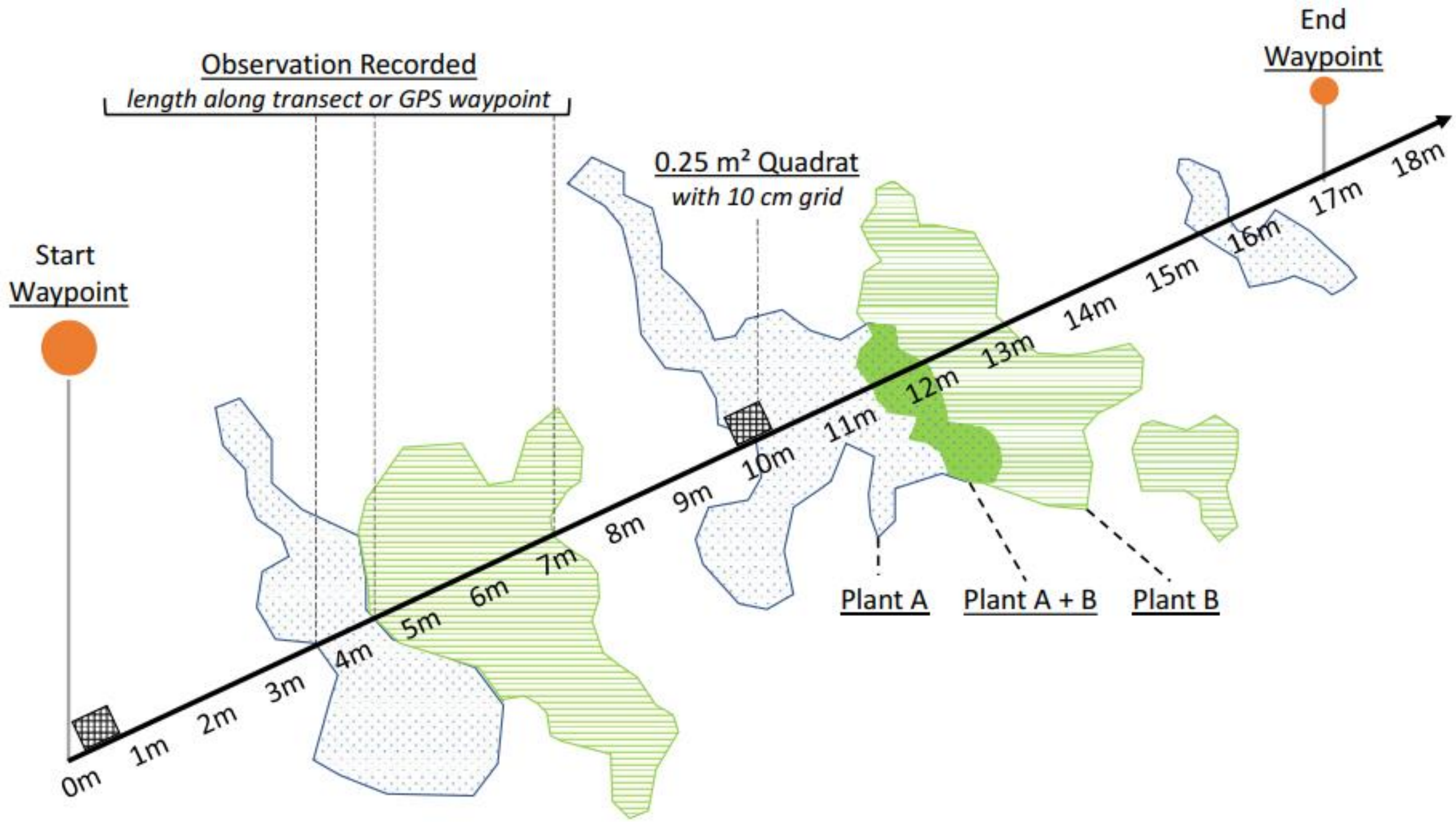

Figure 5. Illustrated depiction of plant cover methodology for collection of *in situ* data.

1-m minimum distance rule will be applied. The rule is that multiple individual plants will be considered part of the same patch if there is not more than a 1-m gap between individuals. Once a gap is larger than 1 m, or a different species is encountered, a new record will be recorded. Within an intercepted plant bed, species composition will be noted. When species composition of a plant bed changes, the transect intercept point will be recorded so that relative species cover can be approximated.

Quadrats will be systematically placed along transects to allow finer-scale resolution of relative species cover. Quadrat sampling will utilize a 0.25 m^2 quadrat laced with line on 10-cm centers to form a grid. When placed over plant beds, each grid intercept is evaluated relative to any species found directly beneath the intercepts. Quadrats shall be spaced no greater than 10 m. In cases where short transects are monitored (less than 100 m) or conditions warrant, lower spacing between quadrats may be warranted. The placement and use of transects and quadrats within the sampled strata are described within the below strata-specific methods.

In addition to the above transect data, divers will note the presence of all plant species observed during the dive. This increases the data value of performing the survey because it allows recording of information even if a species (or group of species) are not intercepted yet are observed. This can happen in areas with very low plant density such that the transect does not intercept all species observed during a dive. Moreover, it allows collection of other data on non-target groups such as fishes and invertebrates. Observers will merely keep a separate record of species observed during transect sampling.

Four strata will be sampled within the monitored sampling frame; the strata include open-water nearshore, marshes, major tributaries, and marinas and embayments. The prescribed methods for sampling within the strata are provided below.

Open-water Nearshore In situ Strata and Data Collection

The nearshore open water is one of the four strata to be surveyed as part of the *in situ* survey portion of aquatic plant mapping. Existing information will be reviewed with resource managers and used to guide transect layout for targeted sampling. Targeted transects will generally be chosen by managers at or near known aquatic invasive plant infestation areas because the sampling under this program can provide important information to help inform control efforts. In addition to transects for targeted sampling in the open-water nearshore stratum, transects will be established systematically every 3 km of shoreline. The combination of systematic and targeted transects means that in some cases inter-transect distance may be less than 3 km. When a targeted transect lands between systematic transects, the distance from the targeted transect to the neighboring systematic transects shall be no more than 3 km.

The open-water nearshore transects shall be placed perpendicular to shore so that plant occurrence can be evaluated across the depth gradient. This will help determine the habitat preferences of the invasive and native plant species within Lake Tahoe. Transects will span the width of the nearshore open water stratum where they are placed such that transect length will vary across the nearshore boundary. In some cases, shore-perpendicular transects may be implemented to increase information on plant bed composition. The start and end point of each transect will be recorded with the use of GNSS. The list of open-water nearshore monitoring transects shall include those listed in Table 2. An example of the resulting transect layout is provided for a section of the sampling frame in Figure 6.

Table 2. Table of proposed open-water nearshore transect start/stop coordinates. Coordinates are UTM Zone 10, NAD 83.

Habitat Name	Transect	Category	Start Coordinates		Stop Coordinates	
			Point X	Point Y	Point X	Point Y
Baldwin Beach Lakeward	BBL001	Systematic	754345.92	4314495.86	754468.77	4314795.76
Cedar Flat Lake ward	CF001	Systematic	751474.72	4344505.20	751650.81	4344510.56
Chamber's Landing Lakeward	CHL001	Systematic	747310.18	4328851.00	747569.61	4328985.66
Crystal Bay Systematic Lakeward 1	CRBY001	Systematic	758919.94	4347214.43	759040.01	4347180.98
Crystal Bay Systematic Lakeward 2	CRBY002	Systematic	760643.01	4348630.43	760617.01	4348400.86
Crystal Bay Systematic Lakeward 3	CRBY003	Systematic	763280.17	4347444.10	763486.43	4347726.82
Dollar Point Lakeward	DLP001	Systematic	750900.13	4341925.34	751177.61	4342056.87
Deadman's Point Lakeward	DMP001	Systematic	762878.65	4333205.92	762705.20	4333364.26
Emerald Bay Mouth 1	EBS001	Systematic	751134.98	4315157.40	751197.95	4315248.92
Emerald Bay Avalanche Beach 2	EBS002	Systematic	752566.33	4317028.68	752472.27	4316206.33
Eagle Point Lakeward	EPS001	Systematic	753108.38	4316960.38	753151.68	4316981.09
Flick Point Lakeward	FLP001	Systematic	753062.45	4346207.20	753252.62	4346088.72
Gold Coast Lakeward	GCS001	Systematic	750161.58	4321573.81	750268.36	4321640.61
Glenbrook Lakeward	GLBL001	Systematic	764652.71	4330972.32	764078.10	4331111.85
Hidden Beach Lakeward	HIDB001	Systematic	764789.53	4345476.55	765182.24	4345565.82
Homewood Lakeward	HW001	Systematic	745429.97	4330847.89	745579.56	4330884.21
Logan House Creek Lakeward	LHC001	Systematic	764282.28	4328342.88	764185.61	4328343.69
Lincoln Park Lakeward	LINP001	Systematic	763920.27	4325290.85	763210.28	4325574.06
Lake Forest Lakeward	LKF001	Systematic	748892.54	4340864.18	751191.05	4339145.77
Meeks Bay Lakeward	MBL001	Systematic	749121.92	4324836.12	749234.75	4324891.85
Meeks Bay Point Lakeward	MBS001	Systematic	749718.96	4324261.69	749793.68	4324218.88
Nevada Beach	NBL001	Systematic	764036.92	4318633.25	763905.35	4318598.30
Rubicon Point	RPS001	Systematic	751670.92	4319425.14	751737.64	4319433.05
Secret Harbor	SHAR001	Systematic	765068.04	4337958.74	764635.86	4337960.13
Sand Harbor Point Lakeward	SHS001	Systematic	764799.20	4343065.91	764488.99	4342779.49
Skunk Harbor	SKH001	Systematic	764230.42	4335625.25	764033.67	4335762.72
Sugar Pine Point	SPP001	Systematic	749726.51	4327351.23	750100.31	4327152.53
Stateline Point	STP001	Systematic	757763.31	4346177.01	756942.76	4345606.52
Thunderbird Lakeward	THB001	Systematic	765170.09	4340734.76	765102.65	4340836.48
Tahoe Tavern	TTL001	Systematic	746975.85	4338166.91	747596.54	4337967.24
Tahoe Vista Lakeward	TVIS001	Systematic	755044.74	4347306.73	754855.58	4346245.50
Zephyr Point Lakeward	ZPL001	Systematic	763165.97	4321304.97	762960.78	4321306.37
Camp Richardson Lakeward	CRL001	Targeted	756542.45	4314131.62	756608.04	4315062.82
Camp Richardson Parallel	CRP001	Targeted	756601.58	4314148.38	756552.60	4314157.94
Edgewood Lakeward	EGWL001	Targeted	764285.70	4317624.02	763596.95	4317582.89
Round Hlll Marina	RHM001	Targeted	763910.47	4320030.62	762982.24	4320162.23
Ski Run Lakeward	SRL001	Targeted	763524.00	4315722.58	762939.05	4316933.89
Sunnyside Marina Lakeward	SUN001	Targeted	746066.76	4336110.64	746218.28	4336127.40
Timber Cove Lakeward	TCL001	Targeted	762909.34	4315330.69	762295.40	4316471.42
Tahoe Key Homeowner Lakeward	TKHOL001	Targeted	758806.99	4313975.29	758316.29	4314731.92
Tahoe Keys Marina Lakeward	TKML001	Targeted	759410.92	4314272.59	758996.17	4315167.21
Truckee River Lakeward (above dam)	TROL001	Targeted	746744.37	4339210.23	747885.47	4339151.38
Upper Truckee River Lakeward	UTRL001	Targeted	759937.34	4314471.37	759655.74	4315519.18
Zephyr Cove Lakeward	ZCL001	Targeted	764163.45	4321889.97	763245.11	4322135.87

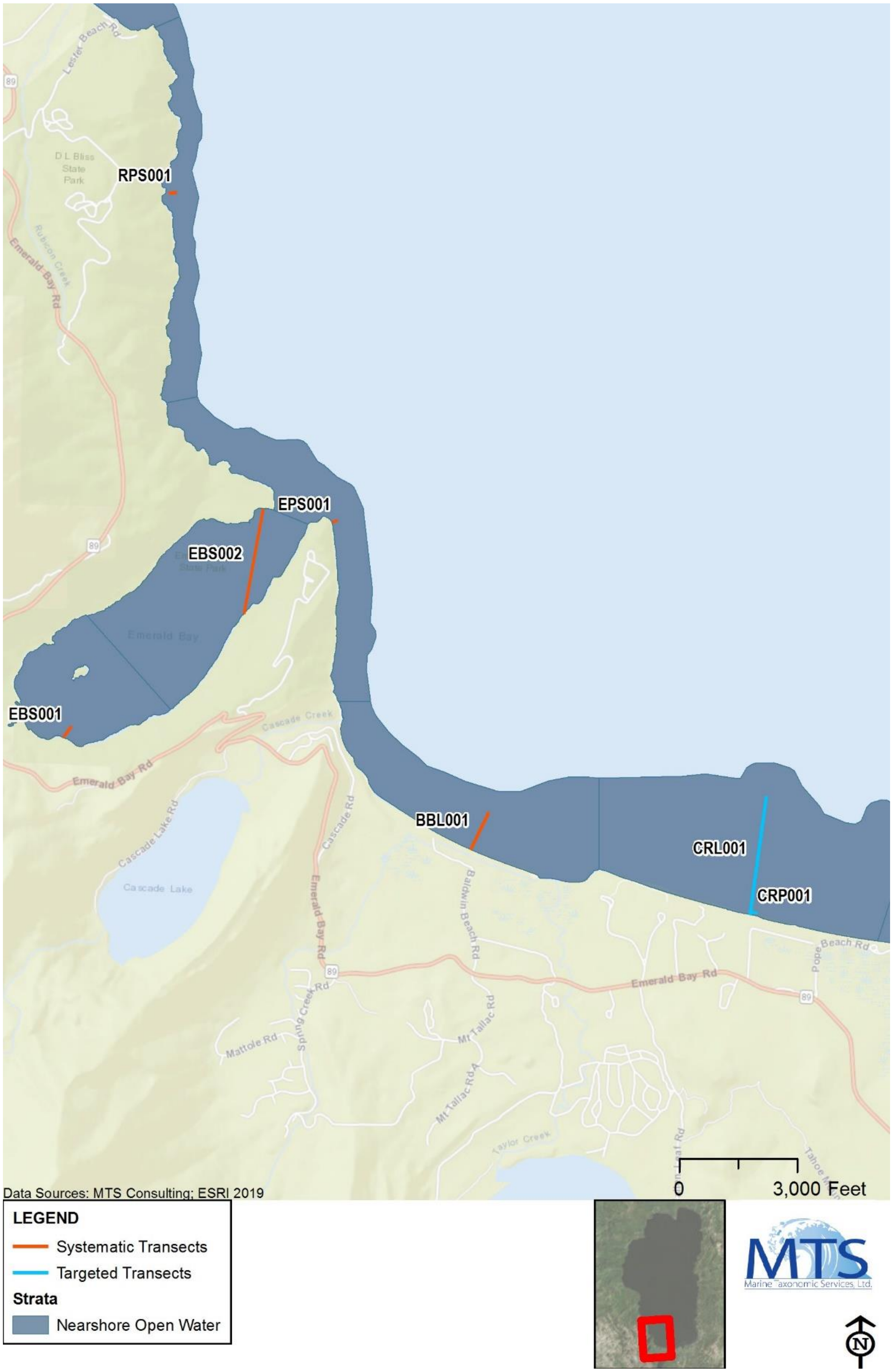

Figure 6. Example of the layout of open-water nearshore transects in a southwest portion of Lake Tahoe that includes Emerald Bay.

Resource managers may amend this list as future data may highlight specific areas of concern. It is suggested that to the extent practical transects be retained within the monitoring program to support trend analysis. Thus, transects may be added, but should only be removed with careful consideration of the lost value associated with tracking trends and infestations over time.

Transect sampling in the open-water nearshore stratum shall be performed by SCUBA divers during nearshore-wide survey efforts. Transect intercept data shall be used to determine estimates of plant cover and relative plant cover. These will be determined by divers noting the species present in plant beds within sections of the transect. When the species distribution changes, the divers shall note a new line intercept section and the species present. Plant height data will be collected within each transect segment. Quadrats will not be sampled within the open-water nearshore strata to due to dive time constraints relative to air supply and the physiological effects of diving for extended periods of time.

Surveys performed in non-survey years shall use SCUBA divers or a mixture of SCUBA divers and lower cost methods. SCUBA divers shall be used for monitoring any transect where plant beds were previously identified. Alternative methods for any monitoring transect expected to be negative for plants include towed video, remotely operated vehicle, or autonomous underwater vehicle. Once a previously negative survey line is identified to have plants, divers shall survey the transect to determine relative plant cover and make accurate species identifications. For an evaluation of different data acquisition methods, refer to Appendix D.

Marshes In Situ Sampling Strata

Within the Lake Tahoe nearshore context, four freshwater marshes are identified as providing suitable habitat for submerged aquatic plants, including Upper Truckee Marsh, Pope Marsh, Taylor Creek Marsh, and Tallac Creek Marsh. To establish long-term monitoring transects (and transects for training and validating remote sensing data), all open water features (ponds, backwaters and tributaries) shall be delineated in GIS from available imagery. Transect locations shall be determined by intersecting a 150 X 150-m point grid over open water features. Starting points for transects will be selected randomly from those grid points that intersect with open water features. Transect headings shall then be randomly chosen from the possible headings that allow the transects to be placed unobstructed within the strata. The main stem of tributaries within the marsh complex will be established similar to major tributary transects[1].

Transect sampling in the marsh strata shall be performed by SCUBA, snorkel, or on foot, depending upon depth and conditions at the time of survey. Transect intercept data shall be used to determine estimates of plant cover and relative plant cover. These will be determined by survey personnel noting the species present in plant beds within sections of transects. When the species distribution changes, surveyors shall note a new line intercept section and the species present. Plant height data will be collected within each transect segment. All marsh transects shall be 50-m long. Quadrats shall be systematically placed along transects every 5 meters. The intent of quadrat sampling is to provide finer-scale species cover estimates given the complexity of aquatic plant communities at relatively small scales that make it difficult to capture variation in cover using transects.

[1] Transects were chosen using methods described here for the first nearshore-wide survey performed in 2018. These methods can be followed in the future to add additional transects if desired.

The initial list of marsh monitoring transects shall include those listed in Table 3. Resource managers may amend this list as future data may highlight specific areas of concern. It is suggested that to the extent practical, transects be retained within the monitoring program to support trend analysis. Thus, transects may be added, but should only be removed with careful consideration of the lost value associated with tracking trends and infestations over time. An example of the proposed transect layout is provided for a section of the sampling frame in Figure 7.

Table 3. Table of proposed marsh stratum transect start and stop coordinates. Coordinates are in UTM Zone 10, NAD 83.

Habitat Name	Transect	Category	Start Coordinates		Stop Coordinates	
			Point X	Point Y	Point X	Point Y
Pope Marsh 1	PM001	Targeted	758319.61	4313714.25	758361.68	4313741.04
Pope Marsh 2	PM002	Targeted	758019.60	4313863.61	758019.70	4313814.01
Pope Marsh 3	PM003	Targeted	757369.08	4313866.64	757419.72	4313864.98
Pope Marsh 4	PM004	Targeted	757869.39	4313263.48	757877.40	4313313.15
Tallac Marsh 1	TAL001	Targeted	753561.27	4313836.26	753519.67	4313863.32
Tallac Marsh 2	TAL002	Targeted	754080.59	4314492.15	754119.84	4314464.63
Taylor Creek Marsh 1	TAY001	Targeted	754719.70	4314163.24	754670.22	4314167.85
Taylor Creek Marsh 2	TAY002	Targeted	754871.46	4314309.69	754822.63	4314320.67
Upper Truckee Marsh #1	UTM001	Targeted	760270.06	4314464.69	760296.98	4314506.42
Upper Truckee Marsh #2	UTM002	Targeted	760119.51	4314465.37	760089.64	4314425.37
Upper Truckee Marsh #3	UTM003	Targeted	760570.81	4314613.50	760552.93	4314661.04
Upper Truckee Marsh #4	UTM004	Targeted	760079.68	4313891.92	760120.76	4313863.14

Figure 7. Example of the layout of marsh stratum transects in a southern portion of Lake Tahoe that includes portions of the Upper Truckee Marsh and Pope Marsh.

Major Tributaries In Situ Sampling Strata and Data Collection

Major tributaries are the third strata to be surveyed as part of the *in situ* portion of the AIS mapping program. These areas require an approach that allows flexibility for the sampling team as conditions will be highly variable across this stratum. The 500 m of the tributary that occurs above the Lake Tahoe high water line shall be identified and used to extend the monitored sampling frame to include the tributaries identified for sampling within this stratum.

Within the major tributaries stratum, transects will extend up the center of the identified tributaries. Transects will start at the Lake Tahoe high water line. Transects will terminate either 500-m upstream or once a gradient of greater than 1% is achieved.

The same data collection methods on the transects in this stratum shall be applied as those performed in the marsh stratum. Quadrats shall be collected on transects within this stratum in the same manner as those methods used for the marsh stratum. However, given the greater potential length of transects in this stratum, the 10-m minimum quadrat spacing criteria shall be used. Sampling teams may elect to collect quadrats at lower sampling intervals if desired.

The initial list of monitoring transects for major tributaries shall include those listed in Table 4. Resource managers may amend this list as future data may highlight specific areas of concern. It is suggested that to the extent practical, transects be retained within the monitoring program to support trend analysis. Thus, transects may be added, but should only be removed with careful consideration of the lost value associated with tracking trends and infestations over time. An example showing the transect layout for a portion of the stratum is provided as (Figure 8).

Table 4. Table of proposed major tributaries stratum transect start and stop coordinates. Coordinates are in UTM Zone 10, NAD 83.

Habitat Name	Transect	Category	Start Coordinates		Stop Coordinates	
			Point X	Point Y	Point X	Point Y
Blackwood Creek	BLK001	Targeted	745812.38	4332517.86	745407.95	4332512.51
Burke Creek	BRK001	Targeted	764053.05	4318626.48	764366.06	4318519.35
Edgewood Creek	EGW001	Targeted	764284.24	4317648.63	764784.68	4317776.62
Edgewood Creek Tributary	EGW002	Targeted	764467.70	4317543.59	764496.09	4317499.10
General Creek	GCR001	Targeted	749796.96	4326868.48	749690.96	4326740.87
Slaughterhouse Creek Mouth	NCYN001	Targeted	764043.15	4332327.84	764058.97	4332361.51
Snow Creek	SNW001	Targeted	755538.60	4347391.50	755504.82	4347643.58
Tallac Creek	TALC001	Targeted	754006.90	4314623.13	753697.92	4314427.59
Taylor Creek	TC001	Targeted	754897.26	4314321.28	754982.76	4313997.82
Truckee River (below dam)	TRO001	Targeted	746738.09	4339192.84	746374.25	4338866.00
Upper Truckee River	UPR001	Targeted	759918.28	4314518.93	760020.82	4313831.00
Ward Creek	WAR001	Targeted	745878.53	4334880.24	745837.13	4335060.71

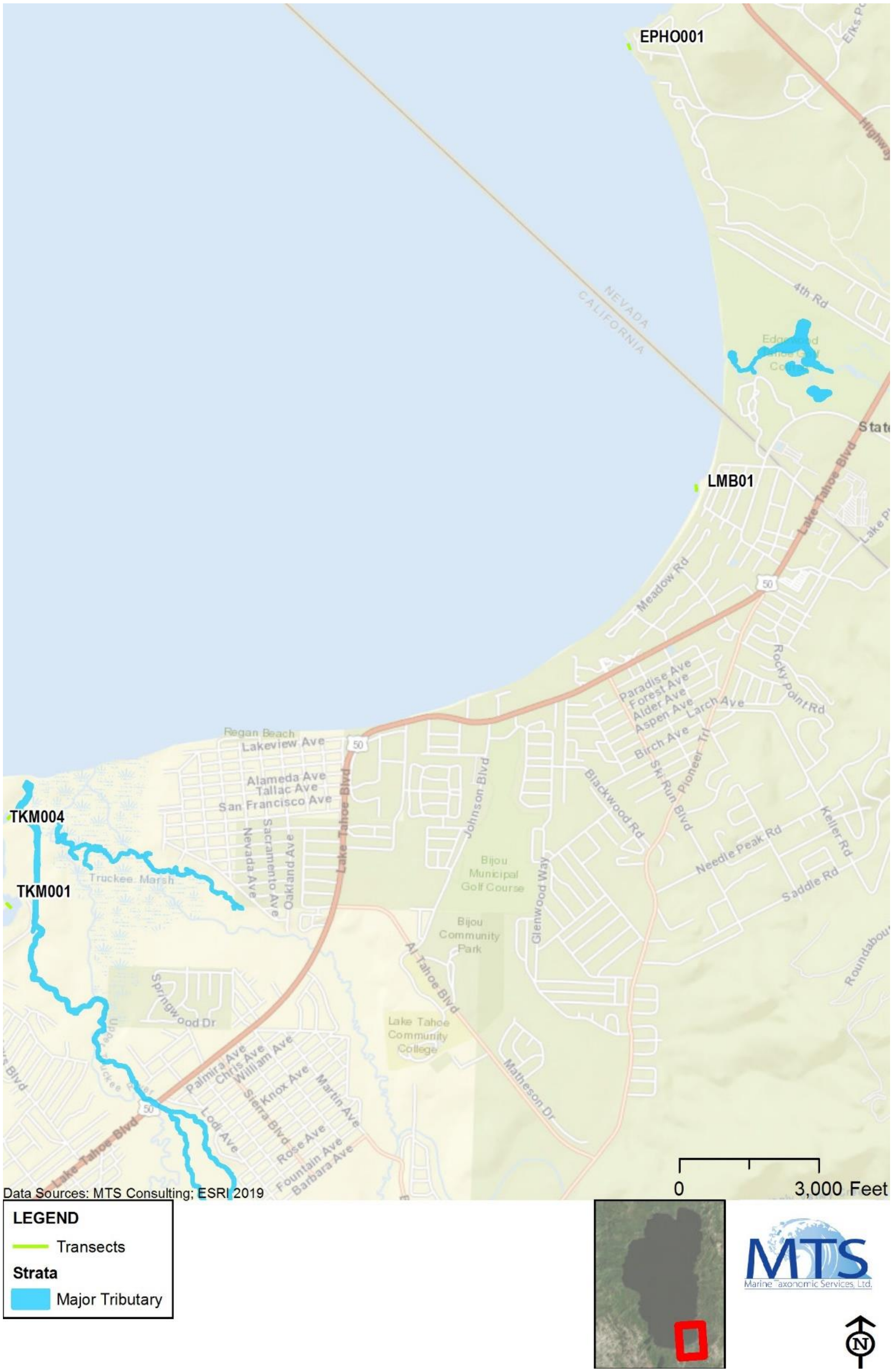

Figure 8. Example of the major tributaries stratum transects in a southeastern portion of Lake Tahoe that includes portions of the Upper Truckee River, Edgewood Creek and Burke Creek.

Marinas and Embayments In situ Sampling Strata and Data Collection

Marinas and embayments are those areas within the within the Lake Tahoe nearshore where natural or anthropogenic features alter littoral processes such as water currents and residence time. Such features include headlands and jetties where those features form an embayment with restricted connectivity to the rest of the Lake Tahoe nearshore. Establishing the marinas and embayments within the sampling frame to include for monitoring within the strata shall occur through consultation with resource managers. The intent of the selection process will be to obtain representative samples from marinas and embayments around the Lake Tahoe nearshore while allowing managers to choose those locations in a manner that permits immediate understanding of known infestation areas while retaining the ability to track plant population trends around the lake.

To establish long-term monitoring transects (and transects for training and validating remote sensing data), the chosen marinas and embayments shall be delineated in GIS from available imagery. Transect locations shall be determined by intersecting a 150 X 150-m point grid over the open water area within the marinas and embayments. Starting points for transects will be selected randomly from those grid points that intersect with open water features. Transect azimuths shall then be randomly chosen from the possible headings that allow the transects to be placed unobstructed within the strata[2].

Transect sampling in the marinas and embayments stratum shall be performed by SCUBA. Given the short length of transects in this stratum combined with typically restricted maneuverability of vessels, SCUBA divers likely provide the most efficient means of data collection. Transect intercept data shall be used to determine estimates of plant cover and relative plant cover. These will be determined by survey personnel noting the species present in plant beds within sections of transects. When the species distribution changes, surveyors shall note a new line intercept section and the species present. Plant height data will be collected within each transect segment. All transects in this stratum shall be 50-m long. Quadrats shall be systematically placed along transects every 5 m.

The initial list of marinas and embayments monitoring transects shall include those listed in Table 5. Resource managers may amend this list as future data may highlight specific areas of concern. It is suggested that to the extent practical, transects be retained within the monitoring program to support trend analysis. Thus, transects may be added, but should only be removed with careful consideration of the lost value associated with tracking trends and infestations over time. An example portion of the lake with proposed transects in the marinas and embayments stratum is provided as Figure 9.

[2] These methods were implemented to generate the proposed list of transects for the first nearshore-wide survey performed in 2018. The methods can be repeated as necessary to add future sampling locations and transects.

Table 5. Table of proposed marinas and embayments stratum transect start and stop coordinates. Coordinates are in Zone 10, NAD 83.

Habitat Name	Transect	Category	Start Coordinates		Stop Coordinates	
			Point X	Point Y	Point X	Point Y
Kasian Lakeward	KAS001	Systematic	745694.07	4333658.98	745824.64	4333633.04
Crystal Bay Embayment (East)	CBE001	Targeted	760480.97	4348674.52	760523.11	4348647.99
Crystal Bay Embayment (Mid)	CBM001	Targeted	760382.29	4348694.62	760419.35	4348663.95
Carnelian Bay Sierra Boatwarks	CBSB001	Targeted	751967.71	4345937.89	751964.56	4345988.84
Crystal Bay Embayment (West)	CBW001	Targeted	760220.29	4348685.70	760270.10	4348681.22
Cave Rock Boat Ramp	CRBR001	Targeted	764055.64	4326191.91	764076.49	4326144.97
Elk Point Homeowners	EPHO001	Targeted	763540.86	4319574.20	763521.67	4319615.37
Fleur Du Lac	FDLM001	Targeted	745535.81	4332044.18	745534.42	4332001.33
Homewood Marina	HWM001	Targeted	745795.96	4330025.10	745746.38	4330027.74
Lakeside Marina Beach	LMB01	Targeted	764165.36	4316709.54	764156.58	4316758.68
Meeks Bay Marina	MEM001	Targeted	749075.25	4324782.68	749032.30	4324810.82
North Tahoe Marina	NTM001	Targeted	755222.04	4347270.70	755270.95	4347268.04
Obexer's Marina	OBX001	Targeted	745883.77	4329752.92	745906.36	4329708.49
Secret Cove	SC001	Targeted	764984.07	4338461.43	765040.16	4338416.26
Sand Harbor 1	SH001	Targeted	765074.25	4343563.08	765027.00	4343541.49
Sand Harbor 2	SH002	Targeted	764896.76	4343373.13	764919.37	4343413.88
Sunny Side Private Pier	SSM001	Targeted	746256.55	4336564.74	746283.15	4336609.59
Star Harbor	STH001	Targeted	748656.55	4340934.62	748615.90	4340962.18
Tahoe City Marina 1	TCM001	Targeted	747384.11	4339820.75	747347.29	4339779.38
Tahoe City Marina 2	TCM002	Targeted	747401.63	4339705.10	747370.93	4339664.14
Tahoe Keys Homeowners Marina 1	TKHO001	Targeted	758319.55	4313110.61	758302.70	4313155.29
Tahoe Keys Homeowners Marina 2	TKHO002	Targeted	758723.78	4313824.01	758763.36	4313850.28
Tahoe Keys Homeowners Marina 3	TKHO003	Targeted	759085.83	4313359.05	759071.37	4313406.07
Tahoe Keys Homeowners Marina 4	TKHO004	Targeted	759368.90	4313712.17	759319.60	4313700.56
Tahoe Keys Marina 1	TKM001	Targeted	759862.49	4313688.73	759823.13	4313723.25
Tahoe Keys Marina 2	TKM002	Targeted	759627.21	4314036.37	759671.68	4314010.19
Tahoe Keys Marina 3	TKM003	Targeted	759623.62	4314149.85	759664.87	4314174.51
Tahoe Keys Marina 4	TKM004	Targeted	759825.92	4314307.82	759794.91	4314268.71
Tahoe Vista Boatramp	TVBR001	Targeted	754756.02	4347443.78	754782.59	4347401.11
Wovoka Cove	WNK001	Targeted	764037.12	4324821.39	763986.71	4324842.44

Figure 9. Example of the marinas and embayments stratum transects in a southeastern portion of Lake Tahoe that includes the Tahoe Keys Homeowners Marina and the Tahoe Keys Marina.

Data Management and Storage Protocol(s)

The elements below are intended to inform the first season of remote sensing and *in situ* data collection. Methods may be altered or added in subsequent years to allow resource managers to track trends without the expenditures associated with neasrhore-wide data collection. This document should be updated as protocols are altered in subsequent drafts of this document.

Remote Sensing Data Management

All remote sensing data acquired during the project should be maintained on data servers in at least two separate geographic locations and backed up nightly to avoid data loss. For example, in 2018, remote sensing data were stored on local hard drives and servers located at Oregon State University, University of Vermont-Spatial Analysis Lab, Spatial Informatics Group offices, Quantum Spatial offices and at TRPA, as well as on *Box* and *Dropbox* servers. Data access should be limited to project personnel and consistent file naming and directory structures should be maintained. Preservation of and access to project data will be achieved in several ways. Final reports and data products should be made available via an open access digital repository for gathering, indexing, disseminating and archiving project reports (in 2018, ScholarsArchive@OSU (SA), Oregon State University's Open Access system was considered for use; SA content is openly available via persistent URLs, and all datasets are assigned a permanent, unique identifier (DOI) to ensure discoverability and access in perpetuity). Regardless of whether an open access system is used for aquatic plant monitoring related document dissemination, all project data should be delivered to TRPA for archival and dissemination via their EIP website (e.g., https://laketahoeinfo.org/). Papers and presentations stemming from the monitoring program (target journals include the *Journal of Coastal Research* and *Remote Sensing of Environment*) should also be made available through an open source platform. Project metadata should conform to Federal Geographic Data Committee standards.

In Situ Data Management

The *in situ* data will be collected either on an android based tablet or on paper data forms in the field (see Appendix C for proposed data dictionary). In the case of tablet collected data, the database will be exported via email immediately upon the end of each day of field work. This will ensure that the data exist on both the collecting tablet as well as within the email server (Microsoft 365™). Once per week, staff should review, edit as necessary, and compile the week's data. The data should be entered into an ArcMap as a database of geographically referenced transects with corresponding classification data showing species, line intercepts, and percent transect cover (intercept). The ArcMap database will be stored on Sharepoint™ (a Microsoft™ internet-based data storage service). When paper data forms are used, they will be photographed and emailed to the project manager at the end of each day. At the end of the week they should be similarly entered into ArcMap and stored.

Inventory of Resource-Specialized Equipment and Personnel Skills

Remote Sensing Personnel and Equipment

Personnel requirements for the remote sensing portions of the project include FAA Part 107 remote pilot certification for UAS (drone) pilots, expertise in airborne LiDAR, direct georeferencing, SfM photogrammetry, and photography. American Society for Photogrammetry and Remote Sensing (ASPRS) certifications in LiDAR, UAS and/or photogrammetry are desirable qualifications. UAS used in acquiring data must be capable of flying pre-planned flight lines and acquiring high-quality images at pre-planned photo stations, providing at least 75% overlap (endlap and sidelap). Imagery should be high-resolution (>

10 MP), avoiding fisheye lenses, and imagery logged in raw format, when possible. When acquiring imagery of the substrate, it is important to avoid specular reflection from the water surface and to acquire imagery in illumination conditions that facilitate viewing through the water to the substrate. Good imagery of the substrate can typically be achieved using increased overlap (endlap and sidelap), with sun angles between 30° and 45° and low wind/wave conditions being recommended.

Equipment requirements for field surveys to acquire ground control points (GCPs) and check points include survey-grade GNSS (i.e., capable of carrier-phase based relative positioning using dual-frequency or multi-frequency receivers) and total stations. Acquisition firms shall adhere to applicable state licensure requirements for survey work.

UAS data acquisition requires the use of both multi-rotor and fixed-wing UAS platforms with RGB cameras. UAS platforms that have on-board GPS that support RTK/PPK enhanced location accuracy will be important for selected missions. Traditional RGB sensors will be preferable in most instances although there may be mapping missions in which multispectral cameras that can image in the red edge and NIR portions of the electromagnetic spectrum are preferable.

Vessel Operation, Diver Certifications and Associated Equipment

Personnel requirements for dive operations include vessel operators and SCUBA divers. All SCUBA divers should possess an open water SCUBA certification from a recognized certifying agency (e.g. PADI, NAUI). All field staff should be trained in CPR, first aid, and to provide emergency oxygen. Only staff cleared to operate vessels should be allowed to operate vessels.

Remote Sensing Data Analysis and Reporting

The remote sensing data analysis requires high-end processing workstations (e.g., high-speed multi-core CPU, high-end GPU, and sufficient RAM), as well as specialized software, to include Agisoft Photoscan, Pix4D, Esri ArcGIS, ERDAS IMAGINE, LASTools, Blue Marble Geographics GlobalMapper, Mathworks Matlab, and eCognition.

Analysis Protocol

Remote Sensing and UAS Image Classification

Aquatic vegetation mapping from multiple sources, such as imagery and LiDAR, begins with the development of an image interpretation key. The key, developed using the remotely sensed data and field collection, serves as the foundation for feature identification. In the process of developing the key it should be determined what classes can be mapped using the source data. Limitations such as resolution, timing, water conditions, species mixing, and lack of differentiating characteristics should all be considered when the key is developed. The key should provide clear examples of each class using each of the source data products. All personnel involved in the mapping should demonstrate proficiency in the identification of the requisite aquatic vegetation and substrate classes.

There are a variety of techniques available for submerged aquatic vegetation mapping. These range from manual interpretation to automated feature extraction methodologies such as expert systems and machine learning. The most promising approach for mapping aquatic vegetation incorporate object-based image analysis (OBIA) techniques with expert knowledge. OBIA is the most accepted technique for extracting features from high-resolution remotely sensed data. OBIA focuses on groups of pixels that form meaningful landscape objects (Benz et al. 2004), effectively mimicking the way humans interpret landscape features by incorporating contextual cues such as contrast and adjacency. It is especially important for improving classification of objects whose pixel characteristics alone may not provide enough information to discriminate them from other features (O'Neil-Dunne et al. 2011). Furthermore, OBIA facilitates the fusion of imagery, LiDAR, and thematic data into a single, comprehensive aquatic vegetation and habitat classification workflow. Because the unit of analysis is the object rather than the pixel, OBIA approaches can integrate raster data of varying resolutions and are less sensitive to misalignments that are typical when LiDAR and imagery are jointly used in a feature-extraction workflow. The OBIA system should make use of training data from the *in situ* field collection in conjunction with segmentation, morphology, and classification algorithms to map aquatic vegetation. As no automated feature extraction technology is perfect, it must be coupled with manual review to ensure quality, consistency, and accuracy. Manual edits should address boundary issues, attribute assignment, and cartographic realism. Manual edits should be performed by trained image analysts who follow image interpretation keys, project standard, and capture guidelines. The output should consist of polygons, each with an attribute for the appropriate class.

Indicator Derivation, and Status and Trend Analysis

Aquatic Plant Bed Presence (or Absence)

One of the output map products from the OBIA described above should be a binary classification map indicating presence/absence of aquatic plants. This map product will be generated from the more detailed habitat map by collapsing all classes corresponding to different aquatic plant species into a single "aquatic plant" class.

Aquatic Plant Bed Extent and Distribution

The binary classification map described above (with a single "aquatic plant" class) will be provided in ESRI shapefile format to facilitate computation of areas (spatial extents). Areas of aquatic plant beds should be computed in square kilometers (or other area unit of measure – e.g., acres), provided as a proportion of total survey area, survey zones, or stratum, and distribution of plant beds shown graphically in a map product.

Aquatic Plant Relative Species Abundance/Composition

Aquatic plant abundance (measured as percent cover) is calculated as a single aquatic plant class for each sampling stratum and survey zone. To estimate relative species composition, averaged percent cover by species data derived from diver transect and quadrat sampling data should be used for each survey zone and stratum. Estimates of relative species abundance (acres) can be calculated by multiplying the area of aquatic plants by percent cover values derive for each survey zone and each stratum.

Analysis of Statistical Confidence or Uncertainty

Remote Sensing - Nearshore-Wide Aquatic Plant Bed Status Determinations

Empirical accuracy assessments (include spatial accuracy and classification accuracy assessments) and total propagated uncertainty (TPU) analysis should performed on the remotely-sensed data and derived geospatial data products, as described above. Classification accuracy of the aquatic vegetation mapping should follow a stratified sampling protocol, adhering to the guidelines established by Congalton (1991).

Intervening Year Sampling – Status and Trend Determinations

Results of imagery and topobathymetric LiDAR analysis performed in the first year can be used to inform UAS acquisition and transects in following intervening years to identify and track hot-spots or areas of rapid change. Evaluation of sampling and data acquisition techniques is evaluated in Appendix D. The results of that evaluation support in situ surveys through direct visual observations (e.g. diver, snorkel, or viewed from surface in shallow water). This determination takes into account the present desire of resource managers to have high-quality quantifiable data to inform decision making and provides for a consistent sampling technique necessary to track trends.

If funding is limited, it is suggested that to the extent possible, direct visual observation techniques be retained anywhere plants have been previously identified. Areas devoid of plants can potentially utilize lower cost and lower resolution methods until plants are identified. It is also possible (but with greater loss of data value) to eliminate a monitoring event and choose from the methods in Appendix D to provide the minimal data necessary to track specific areas of concern. Alternately, some of the evaluated methods can be added to this program to increase knowledge about specific plant beds in intervening years. For instance, a hydrographic survey or aerial drone survey can be used to refine the extents of a plant bed ahead of a treatment program.

The data acquisition data methods proposed in this document were chosen based on evaluation criteria outlined in Appendix D. That evaluation led to the development of methods and can also be used to guide future efforts when funding is limited or as goals change. It is important to understand the evaluation and the methods that were not chosen to appreciate the value of the chosen methods. The matrix that summarizes the evaluated plant data capture methods as provided in Appendix D is also provided as Table 6.

Reporting Protocol and Format

This section describes the format, process, schedule, and personnel communicating findings and recommendations resulting from the implementation of the aquatic plan monitoring plan. Three reports should be produced for the Aquatic Invasive Species Monitoring Program annually: 1) a Technical Report, 2) a Summary Report, and 3) a Findings and Recommendations Memo. The Technical Report is a formal report designed to convey technical information, such as appendixes, in a clear and efficient format. The Technical Report should be divided into sections and formatted for technical readers/managers that need access to different levels of information in order to assess the validity of the methods, results, and conclusions (see Technical Report Format below). The Summary Report is a succinct account of the technical report that focuses on the most salient results and conclusions for a general audience and for populating the Lake Tahoe INFO website (https://laketahoeinfo.org/). The Findings and Recommendations Memo is geared toward an executive level audience that provides the most relevant findings and recommendations from aquatic plant monitoring efforts. It should be developed with nearshore and aquatic plant working groups and include recommendations for management actions and improvement to the APMP.

Table 6. Summary of aquatic plant data capture methods by evaluation criteria and indicator detectability.

	Evaluation Criteria						Indicator Detectability				
Data Capture Method	**Effective Spatial Scale of Application**	**Skill Level to Implement**	**Data Capture (in situ or remote)**	**Cost/Unit Area (High, Medium Low)**	**Major Limitation(s)**	**Greatest Strengths**	**Presence - Absence**	**Extent**	**Distribution**	**Species Abundance/ Composition**	**New Invasive Species Detection**
Hydroacoustic	Small to Large	High	Remote	High	Unable to detect features in shallow water, time intensive transects, data processing time can be high, image quality between transect can be poor.	Nearshore-wide scale application, Rich data set	X	X	X		X
Remote Sensing	Small to Large	High	Remote	Moderate	Shorezone structures can obscure plant detection, data processing time can be high. Surface water clarity and turbulence can affect data quality.	Nearshore-wide scale application, all depths (<20m) detectable	X	X	X	Possible with high resolution data	X
Snorkel/Diver	Small to Medium	High	In situ	Moderate	Not cost-effective to deploy at scale	Capacity to directly measure attributes and intangibles	X	X	X	X	X
Video	Small to Medium	Moderate	Interme diate	Moderate	Startup costs dependent on method; quantification difficult and less accurate than other methods	Rapid assessment	X	X	Possible	Possible but time consuming and low resolution	X
Rake	Small to Large	Low	Inter-mediate	Low	Imprecise measurements, potentially highly inaccurate as plants can be missed or dislodge from rake on way to surface. Also risks spreading plant fragments.	Rapid assessment	X			X	
PONAR/Core	Small to Medium	Moderate	In Situ	High	Cumbersome equipment, unable to operate in certain settings (e.g., marsh)	Consistent sample draw, subsurface data	X		Possible	X	Possible
Vessel/boat	Small to Large	Low	Remote	Low	Subjective assessment, can be limited by vessel type	Rapid assessment	X	Possible	Possible	Partial	Possible
Visual	Small	Low	Remote	Low	Subjective assessment, not quantitative	Rapid assessment	X	Relative Measure	Possible	Partial	Possible

Reporting Format

Technical Report Format

The following provides a description of each section of the technical report. The technical report should make use of tables and figures where appropriate to summarize information. Stylistically, active voice and past tense verbs are most appropriate.

Title Page

The technical report includes the title of the report, report author(s), and the date of completion.

Acknowledgement

The section recognizes agencies, institutions and individuals that contributed to the monitoring effort. Funding sources should also be acknowledged in this section.

Abstract

The abstract provides a summary of the report including monitoring context, methods, results, and conclusions.

Table of Contents

This section includes a list of all tables, figures, section and subsection headings with associated page numbers.

Introduction

This section provides context to the reader and states the objectives of the report. This section leads seamlessly into understanding the report itself.

Study Area

This section describes where monitoring was conducted. Typically, a figure or figures of maps is/are included to graphically illustrate the boundaries of the survey effort.

Methods

This section provides a detailed description of what methods and analytical procedures were used to generate the data and results in the report.

Results

This section succinctly presents the results of the monitoring effort, typically with minimal discussion. The use of tables and figures in this section makes for an effective means of communicating survey results.

Discussion

The discussion section interprets the results as they are summarized. Logical deductions should be made, errors of or ambiguities in the data should be discussed, and causal relationships should be confirmed in the context of other references or observations made during the monitoring effort. Do not make sweeping generalizations or unsupported statements.

Conclusions and Management Implications

This provides a short, logical summary of the results and discussion developed in the main text and their likely management and/or policy implications that can be inferred.

Literature Cited

This section includes all referenced studies or reports, including sources of data used to infer results or conclusions. The citation includes the author name(s), publication or release date, report title, the journal or source, volume and pages referenced, for example:

> Omuto, C.T. and D.P. Shrestha. 2007. Remote sensing techniques for rapid detection of soil physical degradation. International Journal of Remote Sensing 28:4785-4805.

The Wildlife Society provides a recommended format for citations in the Literature Cited section (format examples provided in Cox et al. 2018, pages 60-67).

Appendices

Appendices are provided for additional supplemental and/or detailed material and information (e.g., data forms, data, etc.) which is required for full understanding of the report, but not required by a casual reader.

Summary Report Format

The Summary Report provides a succinct status summary for each aquatic plant indicator and formatted for a general audience with content needed to populate TRPA's Lake Tahoe INFO Dashboard (e.g., https://laketahoeinfo.org/Indicator/Detail/16/Overview). As such, each section should be brief and reference to the Technical Report and other references should only be made as appropriate. For each indicator monitored, the format for the Summary Report includes the following sections:

Indicator

This section is used to identify the indicator and briefly describe what the indicator measures and the associated measurement unit (e.g., area, acres, concentration, volume). This section also describes any standard(s) or target(s) that the indicator addresses.

Relevance

This section briefly discusses the reason(s) why the indicator is monitored.

Human and Environmental Drivers

This section briefly describes the human and natural factors and activities that influence indicator values.

Area Evaluated

The section briefly describes the survey area. A map is typically used to efficiently characterize the survey area.

Methods

This section briefly describes the methods used to measure and analyze the identified indicator.

Results

The results section provides a determination (and the rationale for the determinations) for 1) current status, 2) trend, and 3) confidence in the stated determinations for status and trend.

Current Indicator Status

Describes the current status of the indicator relative to the standard(s) or target(s) addressed (if applicable) and the supporting rationale for the status determination.

Trend Evaluation

Describes the magnitude and direction of change associated with the indicator through time. The narrative should also provide a rationale for the trend determination.

Confidence in Status and Trend Determinations

Provide an explanation of the level of confidence in determining the status and trend of the indicator, and rationale for why the assigned confidence level is appropriate.

Connecting Actions to Outcomes

Tahoe agencies use "Actions" (management and policy inputs), "Intermediate Results" (outputs) and "Outcomes" (performance measure and indicators) to evaluate progress towards achieving goals and demonstrate the value of EIP actions. Inputs are resources and activities, often measured in dollars, used to achieve objectives identified in a strategic plan. Outputs are quantifiable actions, products and services created using the inputs (e.g., miles of stream restored). Outcomes quantify the regional goal, intended result or desired end-points that occur from carrying out a program. Outcomes are of the highest importance (especially to the public) since they are most directly tied to benefits such as public health, regional environmental conditions, knowledge or behavior. EIP Performance Measures (PMs) provide quantified metrics to evaluate EIP performance, while status and trend (outcome) indicators are used to track, evaluate and report the status of end results over time. This reporting section ties EIP performance measures to regional goals.

Actions

This section briefly describes the management and/or policy actions that agencies are currently implementing and/or could implement to beneficially affect the indicator. The Lake Tahoe INFO Threshold Dashboard provides a web-linked list of EIP related performance measures that are used to measure Actions taken as part of the EIP Program.

Intermediate Results

This section briefly describes what Intermediate Results should be expected as a result of implementing Actions identified above. The Lake Tahoe INFO Threshold Dashboard provides a web-linked list of EIP related performance measures that are used to measure Intermediate Results.

Outcomes

Briefly describe what outcomes that should be expected as a result of aggregating Intermediate Results identified above. The Lake Tahoe INFO Threshold Dashboard provides a web-linked list of EIP related performance measures and regional indicators that are used to measure Outcomes.

Findings and Recommendations Memo

Prepared annually, the Findings and Recommendation Memo succinctly summarizes three to five key findings from that year's survey effort and any recommendations that should be considered by agency program managers or executives. Findings should point out new discoveries such as new infestation of invasive plants, new plant species detected, programmatic issues, or trends of concern. Recommendations should be geared to actions needed by managers or executives to address findings. The format for the Findings and Recommendation Memo should include the following sections:

Introduction
This section provides context for the memo. Include a succinct summary of the monitoring program, that year's survey efforts, date of activities, and who was involved.

Key Findings
Provide a bullet list of three to five of the most important findings related to the monitoring program and that year's survey effort.

Recommendations
Provide a recommendation for each key finding. Provide a table that includes the recommendation, funding needed to address the recommendation, how it will be addressed, who will implement the recommendation, and when the recommendation will be implemented or completed (as appropriate).

Reporting Process and Schedule
Each year, the reporting process begins after aquatic plant survey data and EIP performance measure data have been collected, quality checked and logged into their respective databases (see monitoring schedule section). Data compilation, quality checking, and analysis should begin immediate after field work has been completed - around October of each year, allowing for up to three months to complete (especially in years when a full nearshore-wide survey is conducted). Reporting then follows, allowing for up to a month to produce draft reports (i.e., Technical and Summary Reports). The reporting process includes the following steps:

1. Summarize and analyze aquatic plan survey data according to monitoring plan procedures
2. Summarize EIP Performance Measure data
3. Prepare Draft Technical Report
4. Prepare Draft Summary Report
5. Conduct Agency Workgroup Review (e.g., LTAISCC)
6. Prepare Final Technical Report
7. Prepare Final Summary Report
8. Prepare Findings and Recommendations Briefing
9. Present Findings and Recommendations Briefing to EIP Executives
10. Post reports/information to appropriate website(s)

Reporting Personnel

Technical Report
The Technical Report is prepared by the agency or institution that has implemented the monitoring plan and associated aquatic plant survey. Personnel should have experience in technical writing and report preparation, and a firm familiarity with the APMP.

Summary Report
Agency staff responsible for preparing annual and four-year (e.g., Threshold Evaluations) reporting products should be capable of summarizing the Technical Report and EIP Performance Measures then publishing/posting it in an appropriate format.

Findings and Recommendation Memo
The memo is prepared by the APMP Manager at TRPA and vetted by the appropriate aquatic plant working group (e.g., the Aquatic Invasive Species Coordination Committee [AISCC], Nearshore Aquatic Weed

Working Group [NAWWG], Nearshore Agency Working Group [NAWG], and Nevada Division of State Lands [NDSL]). Once the memo has been approved by working groups, it is presented to the Tahoe Interagency Executive group for discussion and decision consideration.

Monitoring/Reporting Schedule

The monitoring schedule is to conduct a nearshore-wide survey during the initial year (Year 0) and every fifth year thereafter. In intervening years – *in situ* transects and drone surveys would be implemented. The distribution of drone surveys should focus on areas with chronic infestations of invasive plants, areas with newly detected infestations of invasive species and other areas of interest determined by program leads. Table 7 below provides a generalized Gantt chart of key tasks and milestone for aquatic plant monitoring and reporting.

Table 7. Schedule of monitoring tasks by key dates and milestones.

Task	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Contracting (remote sensing analysis, field work, and technical reporting)												
Schedule and contract remote sensing data collection and processing (**note: this task only occurs every 5 years**)												
Mobilize field equipment, provide training to field personnel												
Collect *In situ* data												
Compile and QA/QC data and input into Database												
Summarize and analyze aquatic plant survey data according to monitoring plan procedures.												
Summarize EIP Performance Measure data.												
Prepare Draft Technical Report												
Prepare Draft Summary Report												
Agency Workgroup Review												
Prepare Final Technical Report												
Prepare Final Summary Report												
Prepare Findings and Recommendations Briefing												
Present Findings and Recommendations Briefing to EIP Executives												
Prepare Decision Memo to capture decisions made (i.e., actions and monitoring program adjustments)												
Update monitoring plan per decision memo												

Estimated Time and Cost Budgets

Full Nearshore-wide Survey Budget. The following table summarizes estimated time and costs associated with conducting nearshore-wide survey and mapping. Cost shown are expected to be incurred every 5th year of monitoring effort. Values subject to inflation.

Budget Item	Personnel Hours	Personnel Cost[a]	Data/Equipment/ Misc. Direct Costs	Line Item Cost Total
Remote Sensing Mapping				
Topobathymetric LiDAR and Multispectral Data Collection Acquisition, Processing and Analysis	200	$25,000	$135,000	$160,000
Drone Data Collection and Processing (25 targeted sites)	90	$11,250	$1,000	$12,250
Diver Surveys/*In situ* Data Collection	1150	$143,750	$25,000	$168,750
Reporting	150	$18,750	-	$18,750
Project Management	40	$5,000	-	$5,000
Total	**1,630**	**$203,750**	**$161,000**	**$364,750**

[a] Assumes average hourly rate of $125/hour.

Diver Survey Budget. The following table summarizes estimated time and costs associated with conducting nearshore-wide diver survey in intervening years when remote sensing data analysis does not occur. Values subject to inflation.

Budget Item	Personnel Hours	Personnel Cost[a]	Data/Equipment/ Misc. Direct Costs	Line Item Cost Total
Drone Data Collection and Processing (25 targeted sites)	90	$11,250	$1,000	$12,250
Diver Surveys/In situ Data Collection	718	$89,750	$20,250	$110,000
Reporting	104	$13,000	-	$13,000
Project Management	30	$3,750	-	$3,750
Total	**1,200**	**$117,750**	**$21,250**	**$139,000**

Cost/Benefit of Alternative Methods

To allow for the most in-depth data collection possible, the monitoring program should use trained biologists to directly observe aquatic plants on monitoring transects. Direct observation by field staff means that staff can observe the surrounding area while working to collect ancillary data that includes the collection of presence absence data beyond the organisms observed on the transect lines. While remote sensing techniques such as towed video, remotely operated vehicles, and autonomous underwater vehicles can be used to generate such data sets, they have a restricted field of view relative to the human eye. Thus, determining when to use one method over another is not just a cost consideration but also includes considering the shortcomings of one method and the potential value added by another.

In this program, there will likely be times when funds are limited, or resource managers wish to shift funds from monitoring to control efforts. Having additional methods at their disposal allows managers to balance funding levels with monitoring and treatment goals. Appendix D provides an evaluation of different data collection techniques that can be applied as necessary.

With consideration of the evaluation provided in Appendix D, the anticipated monitoring is to use *in situ* observations by SCUBA, snorkel, or direct observation (dependent upon habitat) whenever possible to determine plant bed composition and a course means of determining trends over time during non-survey monitoring years.

Although this monitoring plan provides guidance on the preferred methods outlined above, it is recognized that variable funding over time may limit what can be accomplished. For this reason, it is suggested that after the first lake-wide survey, *in situ* methods be adapted to conserve funding. It is suggested that the program can be modified to incorporate towed video transects for any nearshore or marina and embayment transect previously identified as negative with regards to plant presence. If a towed video transect is shown to be a technique that can identify plants, that transect could subsequently be visually validated by SCUBA. This strategy increases the risk of missing small or cryptic plants. However, when combined with prior observations and repeated surveys over time, this risk is managed appropriately.

The use of an autonomous underwater vehicle (AUV) would provide similar benefit as towed video. While towed video requires more staff to perform the field work, the AUV data need to be reviewed to confirm the absence of plants after the survey. Given the costs associated with AUV vehicles that are capable of accurate positioning, towed video is likely the better option. However, as technology advances and prices fall, AUV data collection will become a more cost-effective option.

In addition to the above strategy, citizen science programs such as "Eyes on the Lake" can be used to provide information relative to plant presence or absence. In the event of plant presence, follow-up surveys by biologists can be used to confirm and refine the dataset.

3. Program Documentation

Peer Review of Plans and Protocols

The section should describe range and depth of peer review completed on the monitoring plan and will be populated after the review of this draft final version by the project oversight team and others.

Historic Changes in Monitoring Program

This section will be developed as the program is implemented over time. The purpose of this section is to provide a narration of the significant events and changes made over the course of implementation the APMP.

Hazard Assessment and Critical Control Point (HACCP) Plan

A hazard assessment and critical control point (HACCP) plan is a management tool that provides a standardized method to identify nonnative species invasion risks and focus procedures that are being used to mitigate pathways of invasion. Understanding invasion pathways and developing plans to reduce non-target species and prevent biological contamination is necessary to avoid unintended spread of undesirable species. A HACCP developed for conducting aquatic plant surveys is provided in Appendix E.

Monitoring MOUs or Agreements

This section will be developed to provide documentation of MOUs or agreements that have been established to carry out the aquatic plant monitoring plan (e.g., property access, partnership/cost-share agreements research/collection permits).

Information Distribution Lists

This section will be developed to include a list of all stakeholders that have expressed interest in receiving information about the monitoring effort.

Glossary

As this document develops a glossary of aquatic plants, invasive species, and specific methodological terms will be added to a glossary.

4. Literature Cited

Aiken, S.G., P.R. Newroth and I. Wile. 1979. The biology of Canadian weeds. 34. Myriophyllum spicatum L. Can. J. Plant Sci. 59:201-215.

Anderson, L., 2006. Survey of Lake Tahoe for presence of Eurasian watermilfoil: USDAAgricultural Research Service Aquatic Weed Control Investigations, Annual Reports 1996 to 2005. Davis, CA.

Anderson, L., and D. F. Spencer. 1996. Survey of Lake Tahoe for presence of Eurasian watermilfoil: USDA

Agricultural Research Service Aquatic Weed Control Investigations, Annual Report. Davis, CA. Benz, U.C., P. Hofmann, G. Willhauck, I. Lingenfelder, and M. Heynen. 2004. Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information. ISPRS Journal of Photogrammetry and Remote Sensing 58:239-258.

Chandra, S., and A. Caires. 2016. Nearshore survey and protocol development for aquatic plants in the nearshore environment, Lake Tahoe, Nevada.

Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing of Environment 37:35-46.

Cox, A. S., A.S.C. Knipps, J. L. Wallace, T.E. Boal, P.R. Krausman, D.A. Haukos, and M. Ben-David. 2018. Journal of wildlife management, wildlife society bulletin, and wildlife monographs author guidelines. https://wol-prod-cdn.literatumonline.com/pb-assets/assets/19372817/TWSGuidelines2018-1526478784087.docx

Frantz, T.C., and A.I. Cordone. 1967. Observations on deep-water plants in Lake Tahoe, California and Nevada. Ecology 48: 709-714.

Guenther, G. 2007. Airborne LiDAR Bathymetry Digital Elevation. Model Technologies and Applications. In The DEM Users Manual, edited by D. Maune, 253–320. Bethesda, MD: American Society for Photogrammetry and Remote Sensing.

Heyvaert, A.C., Reuter, J.E., Chandra, S., Susfalk, R.B., Schaldow, S.G. Hackley, S.H. 2013. Lake Tahoe Nearshore Evaluation and Monitoring Framework. Final Report prepared for the USDA Forest Service Pacific Southwest Research Station.

Loeb, S. L., & Hackley, S. H. (1988). Distribution of submerged macrophytes in Lake Tahoe, California and Nevada, and the possible influence of groundwater seepage. *Internationale Vereinigung fur Theoretische und Angewandte Limnologie, Verhandlungen IVTLAP*, 23(4).

Lillesand, T., Kiefer, R.W. and Chipman, J., 2014. *Remote sensing and image interpretation*. John Wiley & Sons.

Madsen, J.D., L.W. Eichler and C.W. Boylen. 1988. Vegetative spread of Eurasian watermilfoil in Lake George, New York. J. Aquat. Plant Manage. 26:47-50.

O'Neil-Dunne, J.P.M., S.W. MacFaden, and K.C. Pelletier. 2011. Incorporating contextual information into object-based image analysis workflows. Proceedings of the ASPRS 2011 Annual Conference, Milwaukee, WI, USA. 1-5 May 2011.

Sierra Ecosystem Associates. 2012. Lake Tahoe Aquatic Plant Survey Project: 2012 Results. www.sierraecos.com.

TRPA (Tahoe Regional Planning Agency). 2014. Lake Tahoe region aquatic invasive species management plan, California - Nevada. 35 pp. + Appendices.

USACE. 2009. Lake Tahoe Region Aquatic Invasive Species Management Plan, California-Nevada. 84 pp+Appendices.

Wittmann, M.E. and Chandra, S. 2015. Implementation Plan for the Control of Aquatic Invasive Species within Lake Tahoe. Lake Tahoe AIS Coordination Committee, July31, 2015.Reno, NV.52pp.

Wittman, M. E., B.E. Kendall, C. L. Jerde, and L. W. J. Anderson. 2015. Estimating relative risk of within-lake aquatic plant invasion using combined measure of recreational boater movement and habitat suitability. PeerJ 3:e845; DOI 10.7717/peerj.845

Appendix – Table of Contents

Appendix - A Explanation of System Understanding

Desired Condition

Through a broad agency and stakeholder review and acceptance process, Heyvaert et al. (2013) articulated a desired condition for the Lake Tahoe nearshore zone as:

"Lake Tahoe's nearshore environment is restored and/or maintained to reflect conditions consistent with an exceptionally clean and clear (ultra-oligotrophic) lake for the purposes of conserving its biological, physical and chemical integrity, protecting human health, and providing for current and future human appreciation and use."

Objectives

From the desired condition, Heyvaert et al. (2013) further refined an overarching ecological and aesthetic objective statement related to aquatic plants as:

"Maintain and/or restore to the greatest extent practical the physical, biological and chemical integrity of the nearshore environment such that water transparency, benthic biomass and community structure are deemed acceptable at localized areas of significance."

As part of the 2012 TRPA Regional Plan update, a water quality threshold management standard for aquatic invasive species was adopted to:

"Prevent the introduction of new aquatic invasive species into the region's waters and reduce the abundance and distribution of known aquatic invasive species. Abate harmful ecological, economic, social and public health impacts resulting from aquatic invasive species."

Uncontrollable Factors

Primary Uncontrollable Drivers

Substrate Composition – both non-native invasive and native aquatic vegetation are most frequently detected in substrates composed of decomposed granite, coarse textured sand with some accumulated organic matter (Sierra Ecosystem Associates 2012).

Water Depth and Water Temperature – water temperature in Lake Tahoe's nearshore zone is on average greater than in deeper zones of Lake Tahoe. In the nearshore zone, littoral circulation and lake mixing differentially affect water temperatures. In general, water temperature in marinas and embayments during peak growth periods is higher than the open water nearshore zone, which create more suitable habitat condition for aquatic invasive plants.

Light/Solar Energy – aquatic plants require sunlight to synthesize foods from carbon dioxide and water. Water clarity and depth effect the amount of sunlight available for aquatic plants. In general, more sunlight is available in the shallower zone of Lake Tahoe.

Benthic Topography – the benthic topography around Lake Tahoe's nearshore varies considerably from relatively gentle topography near stream mouth deposition zones, to extremely steep slopes created from earth faults. In general, aquatic plants occur where benthic topography is gentle, and are absent for steep sloping benthic zones.

Secondary Uncontrollable Drivers

Climate and Precipitation – climate and precipitation affect surface water, groundwater, littoral circulation and lake mixing, and available solar energy in the nearshore zone. Therefore, climate and precipitation affect many factors that directly influence the occurrence of aquatic plants.

Groundwater Flow – Loeb and Hackley (1988) demonstrated that groundwater permeating into Lake Tahoe at a 2m depth created distinct differences in ammonium nutrient concentrations, where concentration were 0.7 to 1.2 times greater where aquatic plants were found compared to where they were not found.

Surface Water – the amount of surface water interacting with Lake Tahoe's nearshore zone is primarily driven by precipitation. Increased precipitation increases stormwater and streamflow delivery to Lake Tahoe resulting in increased delivery of sediments and nutrients that effect aquatic plant growth.

Shoreline Erosion

Littoral Circulation and Lake Mixing – Walter (2000) reported that Eurasian watermilfoil propagates primarily through vegetative fragments and not through seed germination. Water currents are capable of carrying fragments from source population to other suitable habitats where they can become established.

Controllable Factors

Primary Controllable Drivers

Elevated Nutrient Concentrations – Elevated nutrients can be natural (through freshwater marsh seepage into Lake Tahoe, or anthropogenic factors such as the over application of fertilizers, and subsequent delivery to Lake Tahoe through either stormwater or groundwater vectors. Loeb and Hackley (1988) demonstrated that groundwater permeating into Lake Tahoe at a 2m depth created distinct differences in ammonium nutrient concentrations, where concentration were 0.7 to 1.2 times greater where aquatic plants were found compared to where they were absent.

Artificial Embayments and Breakwaters – Wittman et al. (2015) found that the presence of Eurasian watermilfoil establishment appears to be limited by wave action in Lake Tahoe. Most Eurasian milfoil populations occur within protected areas such as marinas and embayments (Wittman el al. 2015)

Recreation; Motorized and Non-motorized Watercraft – According to TRPA (2014), recreational activities involving watercraft (including motor boats, personal watercraft, kayaks, canoes, and float tubes) and/or fishing are the most likely vectors for the introduction of AIS to the Region (inter-Region) and among waterbodies within the Region. Mechanized harvesting and motorized watercraft propellers cut up aquatic plants and create fragments that can be carried to other suitable habitats where they can become established.

Surface Water (Stormwater Runoff) -

Aquascaping and the Aquarium Trade - The use or dumping of non-native aquatic plants from outdoor water features and fish tanks poses a threat to Lake Tahoe's nearshore biological integrity

(TRPA 2014, Aiken et al. 1979, Madsen et al. 1988). Many species associated with this industry are not native to the U.S.

Secondary Controllable Drivers

Suspended Sediment – suspended sediment can affect water clarity and thus light availability to aquatic plants. Likewise, excess sediment delivery via stormwater runoff into Lake Tahoe can modify substrate composition in the nearshore.

Fertilizer Application – excess fertilizer applied to manicured landscape can leach into groundwater or runoff into stormwater causing increased nutrient concentrations favorable to aquatic invasive plants.

Sewage Exfiltration – leaky sewage infrastructure has the potential to leach into groundwater and create hotspots of increased nutrient concentrations. Consequently, affected areas may become more suitable for aquatic invasive plants and algae.

Lake Level – Lake levels can range from high water line of 6229.1ft in wet years to the natural rim of 6,223ft during drought years. Lake level can affect the availability of suitable habitat, where at low lake levels, different submerged substrate types (e.g., cobbles and boulders) become more dominant than at higher lake levels.

Surface Water (Stormwater Runoff) – Surface water from precipitation events and tributaries carries excess sediment and nutrients to Lake Tahoe. The Tahoe TMDL analysis showed that the majority of sediment particles entering the lake are carried by surface waters from local urban sources including from the application of road abrasives, road surface and tire degradation, and erosion of and tracking of sediments from unpaved urban surfaces.

Management and Policy Actions

Control Aquatic Invasive Plants – Control of existing infestation if aquatic invasive plants can help to mitigate the propagation of aquatic invasive plants. Bottom barriers have shown to be effective at controlling aquatic invasive plants.

Watercraft Inspections – Inspection and decontamination of watercraft before entering Lake Tahoe can prevent the introduction of aquatic invasive plants to Lake Tahoe.

Appropriate Marina and Breakwater Design – Marinas that are designed to allow for ample littoral water circulation appear to avoid significant invasive plant infestations. For example, the layout of Camp Richardson Marina that is based on a lakeward buoy grid is exposed to littoral currents that impact submerged aquatic invasive plants’ ability to establish. Similarly, breakwaters that allow for littoral water circulation may also be shown to be unsuitable for undesirable submerged aquatic plants.

Maintain Sewage Infrastructure – regular inspection and repair of leaky sewage infrastructure can avoid contaminating Lake Tahoe’s nearshore with increased nutrient concentrations.

Reduce Fertilizer Use – reductions in fertilizer use can be achieved by establishing native vegetation, or through reduced or eliminated application of fertilizers on manicured landscapes.

Impervious Cover - Regulate impervious cover by removing and/or disconnecting any impervious cover present.

Stormwater Treatment - Stormwater treatment can be accomplished through pollutant source controls, hydrologic source controls, and stormwater treatment. Pollutant source controls include actions that reduce the magnitude of pollutants either applied to urban surface and/or the amount of native soil erosion. Pollutant recovery actions, such as street sweeping of material trapped in the stormwater conveyance system are also considered pollutant source controls. Hydrologic source controls are actions that increase infiltration and stormwater flow separation, thereby reducing the volume and power of urban stormwater flow, and subsequently reducing the pollutant loads transported to the lake. Stormwater treatment actions rely on constructed infrastructure and other stormwater best management practices to capture and remove pollutants after they have been entrained in urban stormwater, such as sediment basins and stormwater vaults.

Appendix - B Remote Sensing Specifications

Topo-bathymetric LiDAR Acquisition & Processing

The area of interest is bound by the -21m bathymetric lakeward contour, the upland shoreland, and marsh areas located in south shore (as represented in Figure 2). Topo-bathymetric LiDAR data is acquired using the Riegl VQ-880-G hydrographic airborne laser system. The system contains a green wavelength (ʎ=532 nm) laser capable of penetrating water, and its high repetition pulse rate, high scanning speed, small laser footprint, and wide field of view together facilitate high resolution coverage of topographic and bathymetric surfaces. Additionally, the Riegl 880's short laser pulse length is ideal and critical for shallow-water systems, as it allows for effective discrimination between water and bathymetric surfaces which can be challenging when mapping near-shore, shallow, and dynamic aquatic environments.

Topographic and bathymetric LiDAR data is collected to produce a high-resolution topo-bathymetric data set (combined average ≥ 12 pulses/m^2) with a maximum scan angle of ±20° (off nadir; Table B-1). The Riegl system has demonstrated hydrographic depth ranging capability of 1.5 Secchi depth on bright reflective surfaces. The laser will not penetrate dense aquatic vegetation or turbid waters. Water clarity affects the depth penetration capability of the bathymetric laser with returning laser energy diminishing by scattering throughout the water column. Additionally, the bottom surface must be reflective enough to return remaining laser energy back to the sensor at a detectable level. Actual depth performance will depend on bottom reflectivity and water clarity at time of acquisition. Data should be collected during the best possible conditions for greatest likelihood of success, which include no fog/rain and any other conditions affecting water clarity, such as high winds.

Table B-1. Topo-Bathymetric LiDAR Specifications Summary

Sensor	Riegl VQ-880-G
Laser Wave Length	532 nm
Laser Pulse Diameter	28-53 cm
Swath Overlap	≥50% side-lap (100% overlap)
Field of View	40°, 20° circular scan
Intensity	16-bit
Data Recording	Discrete (On-Line) Full Wave Form

LiDAR processing tasks involve echo extraction; calculations of laser point position, relative accuracy, and flight line calibration; refraction correction; point classification; water surface extraction; and accuracy assessments. Derived topo-bathymetric DEMs are developed once the seamless topographic/bathymetric LiDAR point cloud is finalized for positional and classification accuracy. The LiDAR provider should identify and evaluate clarity and reflectivity as they interpret the dataset. Depths ranging beyond the sensor's detection capability will produce voids in the data set, and these should be identified in the dataset as well as evaluated in reporting. The LiDAR provider should assess the accuracy of the topo-bathymetric LiDAR system using bare earth and any shallow water check points collected during the survey.

The LiDAR provider should develop lakebed LiDAR-derived relative reflectance mosaics using algorithms previously developed for the monitoring program. These mosaics improve the predictive power of the benthic habitat classification.

4-Band Orthophotography Acquisition & Processing

Imagery should be collected with a large format digital camera in 4 bands (Red, Green, Blue, Near-infrared) with 80% along-track overlap, and ≥ 60% side-lap designed to minimize sun glint off the lake. Flight parameters should be adjusted to collect imagery with a native pixel size (ground sample distance) of 20 cm. Orthophotos should be collected under clear atmospheric and lake surface conditions with minimal cloud cover with sun angles between 30 and 45 degrees to minimize glint, and low or no wave activity. Table B-2 provides a summary of aerial photography specifications.

Table B-2. Aerial Photography Specifications Summary	
Spectral Bands	Red, Green, Blue, NIR
Pixel Resolution	20cm GSD
Horizontal Overlap	80%
Vertical Overlap	60%
Rectification	< 3 pixels RMSE (with control)
Delivery Format	8-bit, Tiled Geo-Tiff

Orthophoto processing workflow should be designed to bring raw digital imagery into seamless orthorectified mosaics. The first step in the process involves radiometric calibration of images to specific gain and exposure settings associated with each capture. Calibrated images should then be geometrically corrected for lens distortion and saved in TIFF format. Photo position and orientation should be calculated by linking the time of image capture, the corresponding aircraft position and attitude (provided by the integrated IMU/GNSS system), and the post-processed smoothed best estimate of trajectory (SBET) data. Automated aerial triangulation (AT) should be performed to tie images together and adjust the photo block to align with ground control. The image frames should be provided with minimal radiometric adjustments.

Orthorectification should be accomplished using known coordinates of photo-identifiable features within the study areas. Direct georeferencing typically results in accuracies of < 3 pixels (< 60cm) when compared to ground targets. Individual ortho-rectified TIFFs should be mosaicked ensuring that any remaining radiometric differences between images are corrected. All four bands will be rectified, mosaicked and edited concurrently as one process. Color balancing and detailed mosaic edits should target best visual appearance of the bands. Mosaic lines should be non-apparent by carefully blending and editing seam location.

Survey Control

One or more appropriate methods should be used to enable geo-spatial correction of aircraft positional coordinate data. These methods include conventional base supported ('BS') survey control, TerraPos® Precise Point Positioning ('PPP'), or Trimble® CenterPoint™ Post-Processed Real-Time Extended ('PP-RTX'). To verify LiDAR point calibration and enable accuracy assessment, the survey crew should collect ground check points (GCPs) using GPS-based real-time kinematic (RTK) survey techniques.

For an RTK survey, the survey crew should use a roving unit to receive radio-relayed corrected positional coordinates for all ground points from a GPS base unit set up over a survey control monument. The roving unit should record precise location measurements with an error (σ) of ≤1.5

cm relative to the base control. The survey crew should distribute a suitable number of hard, bare earth ground check points (GCPs) on level slope throughout project areas, as feasible given road access and GPS conditions.

For the topo-bathymetric acquisition control points will also be collected in shallow water in order to assess sub-surface accuracy of the bathymetric LiDAR. The feasibility and number of check points/cross sections will depend on access, bottom stability, and radio range on the RTK rover.

For the imagery acquisition, the survey crew should survey at least five (5) permanent photo-identifiable points as aerial imagery control locations in the survey area and use these for geo-spatial correction and evaluation of accuracy. The target accuracy to achieve should be < 3 pixels. The techniques for establishing all ground check points will be outlined in the Survey Report, including the identity, locations, and position residuals of all GCPs used to evaluate survey accuracy.

Timing of Remote Sensing Data Collection

An acquisition timeline should be scheduled between August 15th and September 15th based of peak growth of Eurasian watermilfoil and curly leaf pond weed. Data products should be delivered by remote sensing providers within 90 days of acquisition.

Coordinate System

The following projection, datums, & units were specified for the 2018 remote sensing data acquisition:

- Projection: UTM Zone 10N
- Horizontal Datum: NAD83 (2011)
- Vertical Datum: NAVD88 (Geoid12B)
- Units: Meters

Importantly, these data can be configured into whatever projection, datum, and units desired after they have been delivered.

Remote Sensing Data Product Deliverables

The following provides a list of deliverables that should be provided by the remote sensing data provider:

Topo-bathymetric Data Products

Point Cloud

- All Classified Returns*, LAS 1.4 format [NIR & Green all in one LAS file]*
- Point files should include the following fields: X, Y, Z coordinates, Return Intensity, Return Number, Point Classification (topographic ground, default, bathymetric ground, water column, water surface), Scan Angle, Adjusted GPS Time. Riegl calibrated reflectance and pulse shape deviation should be included as a point attribute (via ExtraBytes software).

Surface Models

- Topo-bathymetric Bare Earth Digital Elevation Model (DEM), 0.5 m resolution, *ESRI Grid format*
- Highest-Hit Digital Surface Model (DSM), 0.5m resolution, *ESRI Grid format*

- Lakebed relative reflectance Mosaic, 0.5 resolution, *ESRI Grid format*
- Intensity Images, 0.5 m resolution, *GeoTiff format [1 NIR and 1 Green]*
- Pulse Shape Deviation raster, 0.5m resolution, no normalization or calibration
- Raster of Depth, 0.5m resolution

Vector Features – Shapefiles

- 2D Water's Edge Breaklines, *shapefile format (polyline)*
- Bathymetric Coverage Polygon, *shapefile format*
- Survey Boundary, *shapefile format*
- Tile delineation, *shapefile format – 500m x 500m tile sizing*
- Ground Survey Points and Monument Locations, *shapefile or table format*

Multispectral Imagery and Reporting

Imagery

- 4-band Image geo-rectified image frames (16 bit), 20cm GSD/resolution or better, *GeoTIFF format*
- Orthophoto tiles (8 bit), 20cm GSD/resolution or better, *GeoTIFF format*

Vectors

- Survey Boundary, *shapefile format*
- Tile delineation, *shapefile format*

Reporting

- Methods, Results, Accuracy Assessments
- FGDC-compliant Metadata

Cost of Remote Sensing Data Acquisition and Products

Approximate cost of data acquisition and products will vary by provider. From the 2018 data acquisition, Table B-3 provides a cost estimate breakdown.

Lake Tahoe Nearshore, CA/NV (~19,500 acres)	Approximate Cost/Acre	Approximate Total Cost ($)
Vendor selection, contracting, coordination and administration (in-house)	30 – 40 hours	$5,000
Topo-bathymetric LiDAR Acquisition & Processing	$5.28	$103,000
Multispectral Orthoimagery	$0.98	$19,000
Project Total	$6.51	$127,000

Appendix - C Diver Dictionary

The following provides a description of the specific data that should be collected during diver surveys.

Date/Time (Day_Time) – The date and time at which the data point is logged.

Diver_ID - insert the name of the diver conducting the survey. If multiple divers are conducting survey, list all.

Transect ID (TranID) – the unique code (alpha-numeric) that identifies the transect for which data point applies. The lookup table for Transect ID for 2018 survey transect follows:

Transect ID	Location	Strata	Purpose
BBL001	Baldwin Beach Lakeward	Nearshore Open Water	Systematic
BBP001	Baldwin Beach Lakeward P1	Nearshore Open Water	Targeted
BBP002	Baldwin Beach Lakeward P2	Nearshore Open Water	Targeted
BLK001	Blackwood Creek	Stream	Targeted
BRK001	Burke Creek	Stream	Targeted
CBSB001	Carnelian Bay Sierra Boatworks	Marina/Embayment	Targeted
CBE001	Crystal Bay Embayment (East)	Marina/Embayment	Targeted
CBM001	Crystal Bay Embayment (Mid)	Marina/Embayment	Targeted
CBW001	Crystal Bay Embayment (West)	Marina/Embayment	Targeted
CF001	Cedar Flat Lake ward	Nearshore Open Water	Systematic
CHL001	Chamber's Landing Lakeward	Nearshore Open Water	Systematic
CRBR001	Cave Rock Boat Ramp	Marina/Embayment	Targeted
CRBY001	Crystal Bay Systematic Lakeward 1	Nearshore Open Water	Systematic
CRBY002	Crystal Bay Systematic Lakeward 2	Nearshore Open Water	Systematic
CRBY003	Crystal Bay Systematic Lakeward 3	Nearshore Open Water	Systematic
CRL001	Camp Richardson Lakeward	Nearshore Open Water	Targeted
CRP001	Camp Richardson Parallel	Nearshore Open Water	Targeted
DLP001	Dollar Point Lakeward	Nearshore Open Water	Systematic
DMP001	Deadman's Point Lakeward	Nearshore Open Water	Systematic
EBS001	Emerald Bay Mouth 1	Nearshore Open Water	Systematic
EBS002	Emerald Bay Avalanche Beach 2	Nearshore Open Water	Systematic
EGW001	Edgewood Creek	Stream	Targeted
EGW002	Edgewood Creek Tributary	Stream	Targeted
EGWL001	Edgewood Lakeward	Nearshore Open Water	Targeted
EPHO001	Elk Point Homeowners	Marina/Embayment	Targeted
EPS001	Eagle Point Lakeward	Nearshore Open Water	Systematic
FDLM001	Fleur Du Lac	Marina/Embayment	Targeted
FLP001	Flick Point Lakeward	Nearshore Open Water	Systematic
GCR001	General Creek	Stream	Targeted
GCS001	Gold Coast Lakeward	Nearshore Open Water	Systematic
GLBL001	Glenbrook Lakeward	Nearshore Open Water	Systematic

Transect ID	Location	Strata	Purpose
HIDB001	Hidden Beach Lakeward	Nearshore Open Water	Systematic
HW001	Homewood Lakeward	Nearshore Open Water	Systematic
HWM001	Homewood Marina	Marina/Embayment	Targeted
KAS001	Kapsian Lakeward	Nearshore Open Water	Systematic
LHC001	Logan House Creek Lakeward	Nearshore Open Water	Systematic
LINP001	Lincoln Park Lakeward	Nearshore Open Water	Systematic
LKF001	Lake Forest Lakeward	Nearshore Open Water	Systematic
LMB01	Lakeside Marina Beach	Marina/Embayment	Targeted
MBL001	Meeks Bay Lakeward	Nearshore Open Water	Systematic
MBS001	Meeks Bay Point Lakeward	Nearshore Open Water	Systematic
MEM001	Meeks Bay Marina	Marina/Embayment	Targeted
NBL001	Nevada Beach	Nearshore Open Water	Systematic
NCYN001	Slaughterhouse Creek Mouth	Stream	Targeted
NTM001	North Tahoe Marina	Marina/Embayment	Targeted
OBX001	Obexer's Marina	Marina/Embayment	Targeted
OD001	Olympic Drive 1	Nearshore Open Water	Targeted
OD002	Olympic Drive 2	Nearshore Open Water	Targeted
OD003	Olympic Drive 3	Nearshore Open Water	Targeted
OD004	Olympic Drive 4	Nearshore Open Water	Targeted
PM001	Pope Marsh 1	Marsh	Targeted
PM002	Pope Marsh 2	Marsh	Targeted
PM003	Pope Marsh 3	Marsh	Targeted
PM004	Pope Marsh 4	Marsh	Targeted
RHM001	Round Hill Marina	Nearshore Open Water	Targeted
RPS001	Rubicon Point	Nearshore Open Water	Systematic
SC001	Secret Cove	Marina/Embayment	Targeted
SH001	Sand Harbor 1	Marina/Embayment	Targeted
SH002	Sand Harbor 2	Marina/Embayment	Targeted
SHAR001	Secret Harbor	Nearshore Open Water	Systematic
SHS001	Sand Harbor Point Lakeward	Nearshore Open Water	Systematic
SKH001	Skunk Harbor	Nearshore Open Water	Systematic
SNW001	Snow Creek	Stream	Targeted
SPP001	Sugar Pine Point	Nearshore Open Water	Systematic
SRL001	Ski Run Lakeward	Nearshore Open Water	Targeted
SSM001	Sunny Side Private Pier	Marina/Embayment	Targeted
STH001	Star Harbor	Marina/Embayment	Targeted
STP001	Stateline Point	Nearshore Open Water	Systematic
SUN001	Sunnyside Marina Lakeward	Nearshore Open Water	Targeted
TAL001	Tallac Marsh 1	Marsh	Targeted
TAL002	Tallac Marsh 2	Marsh	Targeted

Transect ID	Location	Strata	Purpose
TALC001	Tallac Creek	Stream	Targeted
TAY001	Taylor Creek Marsh 1	Marsh	Targeted
TAY002	Taylor Creek Marsh 2	Marsh	Targeted
TC001	Taylor Creek	Stream	Targeted
TCL001	Timber Cove Lakeward	Nearshore Open Water	Targeted
TCM001	Tahoe City Marina 1	Marina/Embayment	Targeted
TCM002	Tahoe City Marina 2	Marina/Embayment	Targeted
THB001	Thunderbird Lakeward	Nearshore Open Water	Systematic
TKHO001	Tahoe Key Homeowners Marina 1	Marina/Embayment	Targeted
TKHO002	Tahoe Key Homeowners Marina 2	Marina/Embayment	Targeted
TKHO003	Tahoe Key Homeowners Marina 3	Marina/Embayment	Targeted
TKHO004	Tahoe Key Homeowners Marina 4	Marina/Embayment	Targeted
TKHOL001	Tahoe Key Homeowner Lakeward	Nearshore Open Water	Targeted
TKM001	Tahoe Keys Marina 1	Marina/Embayment	Targeted
TKM002	Tahoe Keys Marina 2	Marina/Embayment	Targeted
TKM003	Tahoe Keys Marina 3	Marina/Embayment	Targeted
TKM004	Tahoe Keys Marina 4	Marina/Embayment	Targeted
TKML001	Tahoe Keys Marina Lakeward	Nearshore Open Water	Targeted
TKMP001	Tahoe Keys Marina Channel P1	Nearshore Open Water	Targeted
TKMP002	Tahoe Keys Marina Channel P2	Nearshore Open Water	Targeted
TRO001	Truckee River (below dam)	Stream	Targeted
TROL001	Truckee River Lakeward (above dam)	Marina/Embayment	Targeted
TTL001	Tahoe Tavern	Nearshore Open Water	Systematic
TVBR001	Tahoe Vista Boatramp	Marina/Embayment	Targeted
TVIS001	Tahoe Vista Lakeward	Nearshore Open Water	Systematic
UPR001	Upper Truckee River	Stream	Targeted
UTM001	Upper Truckee Marsh #1	Marsh	Targeted
UTM002	Upper Truckee Marsh #2	Marsh	Targeted
UTM003	Upper Truckee Marsh #3	Marsh	Targeted
UTM004	Upper Truckee Marsh #4	Marsh	Targeted
UTRL001	Upper Truckee River Lakeward	Nearshore Open Water	Targeted
WAR001	Ward Creek	Stream	Targeted
WNK001	Wovoka Cove	Marina/Embayment	Targeted
ZPL001	Zephyr Point Lakeward	Nearshore Open Water	Systematic

Strata (Strata) – enter the strata that is being sampled. The datalogger should be set to auto-populate this field based on the Transect ID lookup table above. Strata include: marinas and embayments, open-water nearshore, major tributaries, and marshes.

Location (Location) – enter the general location where the transect/quadrat/opportunistic survey occurs. The datalogger should be set to auto-populate this field based on the Transect ID lookup table above. Otherwise, the user should be able to plug in locations not noted in the lookup table.

Waypoint Categories (WayCat)- Indicate the category of waypoint that is being recorded (dropdown):

- **Transect** – this category relates to the diver survey transect. Once this category type is logged, the data logger should be automatically directed to populate transect related data.
- **Segment** - this category relates observations made within a segment along a transect. Once this category type is logged, the transect id (TranID) should be automatically logged and the data logger should be directed to populate segment-related observations and data fields.
- **Quadrat** - this category relates observations made within a quadrat along a transect. Once this category type is logged, the data logger should be direct to populate transect related data.
- **Opportunistic** – This category relates to data points of opportunistic observation that typically are not associated with a transect, segment or quadrat and occur independent of established transects.
- **Other** – this category can relate to waypoints that do not fit within any of the categories described above. An example of a waypoint that falls within this category would include waypoints used to establish the boundaries of a polygon.

The following provides data needs for different waypoint categories:

For Transect Waypoint Type (TWPTType), record the following:

- **Transect Waypoint ID (TrnWPTID)** – the unique code (alpha-numeric), should be autogenerated in the data logger to ensure no two TrnWPTID have the same ID.
- **Transect Start Point ID** – applies only to the transect waypoint category; this waypoint is associated with a corresponding 'Transect Start Point' waypoint X and Y coordinates. There should be only one point that represent the Transect Start Point' and is should be coded as "1".
- **Transect Start Coordinate X (TranStrtX)** - UTM Northing for the start point of a transect
- **Transect Start Coordinate Y (TranStrtY)** - UTM Easting for the start point of a transect
- **Transect Intermediate Point ID -** applies only to the transect waypoint category; this waypoint is associated with waypoint X and Y coordinates for point within and along a transect. Transect Intermediate Points should be coded sequentially starting with the number "2" following the Transect Start Point, adding a next number until the Transect End Point.
- **Transect Intermediate Coordinate X (TranEndX)** - UTM Northing for the intermediate point of a transect. Should automatically correspond to each intermediate point id.
- **Transect Intermediate Coordinate Y (TranEndY)** - UTM Easting coordinate for the intermediate point of a transect. Should automatically correspond to each intermediate point id.
- **Transect End Point ID** - applies only to the transect waypoint category; this waypoint is associated with a corresponding 'Transect End Point' waypoint X and Y coordinates.
- **Transect End Coordinate X (TranEndX)** - UTM Northing for the end point of a transect
- **Transect End Coordinate Y (TranEndY)** - UTM Easting coordinate for the end point of a transect

For the Segment Waypoint Type (SWPTType), record the following:

- **Transect ID (TranID)** – the unique code (alpha-numeric) that identifies the transect for which segment data point applies. Once transect ID is entered into the data logger, this field should auto-populate. Use transect lookup table (above) to automate population of this data field.
- **Segment ID (Seg_ID)** – the unique code (alpha-numeric) that identifies a segment along a transect
- **Segment Start Point (SegStPnt)** – This point relates to the starting position of an observation (e.g., plant) and applies only to the 'Segment Start Point' waypoint category; this waypoint is associated with a corresponding 'Segment Start Point' waypoint X and Y coordinates. Segment Start Points should be coded as "1".
- **Segment Start Coordinate X (TranStrtX)** - UTM Northing for the start point of a segment
- **Segment Start Coordinate Y (TranStrtY)** - UTM Easting for the start point of a segment
- **Segment End Point (SegEndPnt)** - This point relates to the ending position of an observation (e.g., plant) and applies only to the 'Segment End Point' waypoint category; this waypoint is associated with a corresponding 'Segment End Point' X and Y coordinates. Segment End Points should be coded as "2".
- **Segment End Coordinate X (TranEndX)** - UTM Northing for the end point of a transect
- **Segment End Coordinate Y (TranEndY)** - UTM Easting coordinate for the end point of a transect
- **Aquatic Vegetation Present (AqVegPrst)** – Denote whether aquatic vegetation is present (if plant is present(s) = 'Yes', if plant(s) not present = No)
- **AIP Present (AIP)** – Denote whether observed plant is native or non-native. Use lookup table to automate this function.
- **Aquatic Plant Species (Species)** – If plants are observed, enter all species observed. The data logger should be set to allow for multiple entries. Use the lookup table below to select. If not noted, the data logger should be set to allow user to enter species not listed in the lookup table.

SppCode	SppName	Taxa	Status
AC	Asian clam (AC)	Mollusk	Non-native
AM	Andean watermilfoil (AM)	Plant	Native
BC	Brown bullhead catfish (BC)	Fish	Non-native
BG	Bluegill (BG)	Fish	Non-native
BT	Brook trout (BT)	Fish	Non-native
BWT	Brown trout (BWT)	Fish	Non-native
C	Coontail (C)	Plant	Native
CB	Common bladderwort (CB)	Plant	Native
CF	Crayfish (CF)	Invertebrate	Non-native
CH	Chara spp. (CH)	Plant	Native
CLPW	Curly-leaf pondweed (CLPW)	Plant	Non-native
CP	Clasping pondweed (CP)	Plant	Native
CRWF	Crows foot sp. (CRWF)	Plant	Native
CT	Lahontan cutthroat trout (CT)	Fish	Native
DAC	Dead Asian clam shell (DAC)	Mollusk	Non-native
DCF	Dead Crayfish (DCF)	Invertebrate	Non-native

SppCode	SppName	Taxa	Status
DF	Unidentified Plant	Plant	Unknown
E	Elodea sp. (E)	Plant	Native
EWM	Eurasian watermilfoil (EWM)	Plant	Non-native
FA	Filamentous green algae (FA)	Algae	Native
JT	JV trout (JT)	Fish	Non-native
KS	Kokanee salmon (KS)	Fish	Non-native
LM	Large mouth bass (LM)	Fish	Non-native
LP	Leafy pondweed (LP)	Plant	Native
LT	Lake trout (LT)	Fish	Non-native
M	Freshwater mussel (M)	Mollusk	Non-native
MO	Minnow (MO)	Fish	Unknown
MT	Mares Tail (MT)	Plant	Native
MW	Mountain whitefish (MW)	Fish	Native
N	Naiad sp. (N)	Plant	Native
NM	Northern watermilfoil (NM)	Plant	Native
PS	Paiute sculpin (PS)	Fish	Native
QW	Quillwort (QW)	Plant	Native
R	Richardson's pondweed	Plant	Non-native
RP	Richardson's pondweed (RP)	Plant	Native
RS	Redsided shiner (RS)	Fish	Native
RT	Rainbow trout (RT)	Fish	Non-native
S	Sago pondweed (S)	Plant	Unknown
SD	Speckled dace (SD)	Fish	Native
SM	Small mouth bass (SM)	Fish	Non-native
SN	Snail (SN)	Mollusk	Unknown
TS	Tahoe sucker (TS)	Fish	Native
UDF	Unknown pondweed (dwarf) (UDF)	Plant	Unknown
UGT	Unknown pondweed (grass tough) (UGT)	Plant	Unknown
UND	Unknown pondweed (not dwarf) (UND)	Plant	Unknown
UNL	Unknown plant (not leafy) (UNL)	Plant	Unknown
WB	White water buttercup (WB)	Plant	Native

- **Average Plant Height (Height)** – The average height in centimeters of each species observed along the segment.
- **Estimated Plant Cover (cover) –** enter the estimated plant cover (%)
- **Dominant Substrate Type (SubType)** – Select via dropdown the dominate substrate type that corresponds with segment or quadrat observation. The lookup table below provides a list of substrate type recorded during the 2018 survey.

Substrate Type	Substrate Class
Boulder	Substrate
Sand	Substrate
Cobble	Substrate
Gravel	Substrate
Log	Substrate
Mud	Substrate
Debris	Substrate
Plastic Pipeline	Infrastructure
Bedrock	Substrate
Cobble/Boulder	Substrate
Piling	Infrastructure
Road Intercept	Infrastructure
Sand, scattered logs	Substrate
Sand/Boulders	Substrate
Sand/Cobble	Substrate
Sand/Cobble/Boulder	Substrate
Sand/Debris	Substrate
Shelf	Substrate
Other	Substrate

For Quadrat Waypoint Type (WPTType), record the following:

- **Transect ID (TranID)** – the unique code (alpha-numeric) that identifies the transect for which segment data point applies. Once transect ID is entered into the data logger, this field should auto-populate. Use transect lookup table (above) to automate population of this data field.
- **Quadrat ID (Quad_ID)** – the unique code (alpha-numeric) that identifies a quadrat along a transect. Coding should include transect ID and unique value of the quadrat. No two quadrat along the same transect should have the same ID.
- **Quadrat Coordinate X (TranStrtX)** - UTM Northing quadrat point
- **Quadrat Coordinate Y (TranStrtY)** - UTM Easting for the quadrat point
- **Aquatic Vegetation Present (AqVegPrst)** – Denote whether aquatic vegetation is present (if plant is present(s) = 'Yes', if plant(s) not present = No)
- **AIP Present (AIP)** – Denote whether observed plant is native or non-native. Use lookup table to automate this function.
- **Aquatic Plant Species (Species)** – If plants are observed, enter all species observed. The data logger should be set to allow for multiple entries. Use the lookup table below to select. If not

noted, the data logger should be set to allow user to enter species not listed in the lookup table. Any new or unidentified plant species they shall be collected and flagged for identification.

SppCode	SppName	Taxa	Status
AC	Asian clam (AC)	Mollusk	Non-native
AM	Andean watermilfoil (AM)	Plant	Native
BC	Brown bullhead (BC)	Fish	Non-native
BG	Bluegill (BG)	Fish	Non-native
BT	Brook trout (BT)	Fish	Non-native
BWT	Brown trout (BWT)	Fish	Non-native
C	Coontail (C)	Plant	Native
CB	Common bladderwort (CB)	Plant	Native
CF	Crayfish (CF)	Invertebrate	Non-native
CH	Chara spp. (CH)	Plant	Native
CLPW	Curly-leaf pondweed (CLPW)	Plant	Non-native
CP	Clasping pondweed (CP)	Plant	Native
CRWF	Crowsfoot sp. (CRWF)	Plant	Native
CT	Lahontan cutthroat trout (CT)	Fish	Native
DAC	Dead Asian clam shell (DAC)	Mollusk	Non-native
DCF	Dead Crayfish (DCF)	Invertebrate	Non-native
DF	Unidentified Plant	Plant	Unknown
E	Elodea sp. (E)	Plant	Native
EWM	Eurasian watermilfoil (EWM)	Plant	Non-native
FA	Filamentous green algae (FA)	Algae	Native
JT	JV trout (JT)	Fish	Non-native
KS	Kokanee salmon (KS)	Fish	Non-native
LM	Large mouth bass (LM)	Fish	Non-native
LP	Leafy pondweed (LP)	Plant	Native
LT	Lake trout (LT)	Fish	Non-native
M	Freshwater mussel (M)	Mollusk	Non-native
MO	Minnow (MO)	Fish	Unknown
MT	Mares Tail (MT)	Plant	Native
MW	Mountain whitefish (MW)	Fish	Native
N	Naiad sp. (N)	Plant	Native
NM	Northern watermilfoil (NM)	Plant	Native
PS	Paiute sculpin (PS)	Fish	Native
QW	Quillwort (QW)	Plant	Native
R	Richardson's pondweed	Plant	Non-native
RP	Richardson's pondweed (RP)	Plant	Native
RS	Redsided shiner (RS)	Fish	Native
RT	Rainbow trout (RT)	Fish	Non-native

SppCode	SppName	Taxa	Status
S	Sago pondweed (S)	Plant	Unknown
SD	Speckled dace (SD)	Fish	Native
SM	Small mouth bass (SM)	Fish	Non-native
SN	Snail (SN)	Mollusk	Unknown
TS	Tahoe sucker (TS)	Fish	Native
UDF	Unknown pondweed (dwarf) (UDF)	Plant	Unknown
UGT	Unknown pondweed (grass tough) (UGT)	Plant	Unknown
UND	Unknown pondweed (not dwarf) (UND)	Plant	Unknown
UNL	Unknown plant (not leafy) (UNL)	Plant	Unknown
WB	White water buttercup (WB)	Plant	Native

- **Average Plant Height (Height)** – In the average height in centimeters of each species observed within the quadrat.
- **Estimated Plant Cover (cover) –** enter the estimated plant cover (%) based on the number of quadrat cells interacting with plant.
- **Dominant Substrate Type (SubType)** – Select via dropdown the dominate substrate type that corresponds with segment or quadrat observation. The lookup table below provides a list of substrate type recorded during the 2018 survey.

For ‘opportunistic point’ and ‘other’ waypoint category, record the following.

- **Opportunistic Point ID (O_Pnt_ID)** – the unique code (alpha-numeric) that identifies a quadrat along a transect. Coding should include transect ID and unique value of the quadrat. No two quadrat along the same transect should have the same ID.
- **Quadrat Coordinate X (O_Pnt_X)** - UTM Northing quadrat point
- **Quadrat Coordinate Y (O_Pnt_Y)** - UTM Easting for the quadrat point
- **Notes** – log observation of point feature represented at point.

Appendix - D Data Acquisition Methods

Introduction

Knowing the status and trends in aquatic plant populations at Lake Tahoe has become increasingly important to nearshore managers due to the introduction and spread of Eurasian watermilfoil and curly-leaf pondweed. Aquatic invasive plants affect aesthetics, drainage, fishing, water quality, fish and wildlife habitat, human and animal health, navigation, recreation, and ultimately land values. For these reasons, the development of methods to detect, monitor, and assess these species is important to Lake Tahoe nearshore managers. Over the last 10 years, basin agencies have significantly invested in an invasive species prevention program and a program to control known infestations, including survey efforts to understand lake-wide extent of infestations, and the effectiveness of these programs (Wittmann et al. 2015).

Although several survey efforts have occurred at Lake Tahoe, the use of quantitative methods to monitor and assess aquatic plants has not been standardized at Lake Tahoe, and hence nearshore managers are pursuing the development of a monitoring plan that can be used to consistently guide the tracking of aquatic plant status and trends. This document serves as a foundation for framing an aquatic plant monitoring and evaluation plan for Lake Tahoe as it provides focus and context for the plan's content.

The design and implementation of a monitoring program is an iterative process involving a series of linked steps. Ideally, the design and implementation of a monitoring program follows seven steps as illustrated in Figure 1. Steps in the design and implementation of a monitoring program are interconnected and iterative, where managers should work through the steps sequentially. No step should be omitted as it could result in misleading data, inappropriate decisions, or ineffective use of time, money, and effort with no net programmatic benefit.

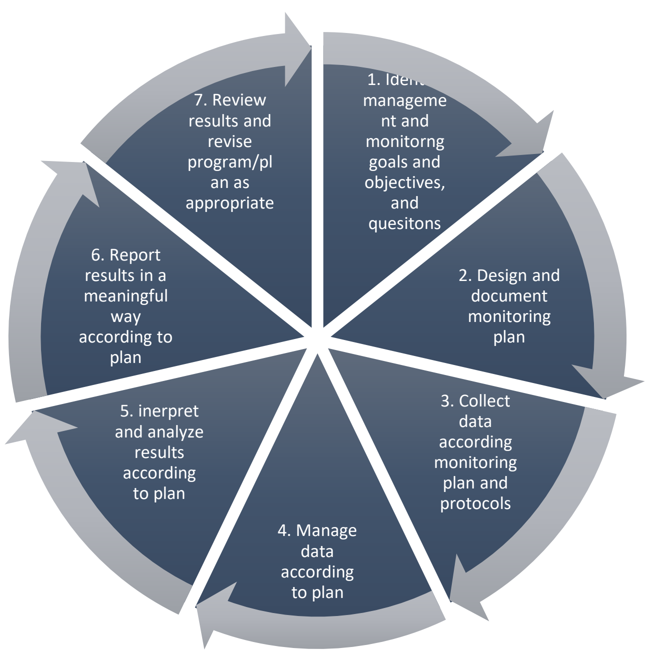

Figure 1. Diagram showing steps for the design and implementation of a monitoring program.

This document helps to address monitoring plan/program elements associated with steps 1 and 2 of the process diagram shown in Figure 1. Specifically, the objectives of this memo are to: 1) synthesize existing goals and objectives of aquatic plant management at Lake Tahoe as a basis for the aquatic plant monitoring plan and program, 2) provide a list of monitoring questions that managers need answered through the implementation of a standardized monitoring program and plan, 3) summarize the indicators that are most appropriate to answer monitoring questions, 4) give an overview and evaluation of survey methods and sampling design that can be used for aquatic plant monitoring and assessment, and 5) propose a sampling design and schedule that can be used to guide annual aquatic plant monitoring, evaluation and reporting.

Goals and Objectives of Aquatic Plant Management at Lake Tahoe

Policy and management of Lake Tahoe nearshore zone is currently guided by a desired condition statements articulated in Heyvaert et al. (2013), The Tahoe Regional Planning Agency's (TRPA) adopted Threshold Standards (TRPA 2012), and goals and objectives in the Lake Tahoe Aquatic Invasive Species Management Plan (TRPA 2014). Within this context, goals and objectives for aquatic plants can be inferred and used to focus this monitoring plan.

Through a broad agency and stakeholder review and acceptance process, Heyvaert et al. (2013) articulated a desire condition for the Lake Tahoe nearshore zone as:

"Lake Tahoe's nearshore environment is restored and/or maintained to reflect conditions consistent with an exceptionally clean and clear (ultra-oligotrophic) lake for the purposes of conserving its biological, physical and chemical integrity, protecting human health, and providing for current and future human appreciation and use."

From the desired condition, Heyvaert et al. (2013) further refined an overarching ecological and aesthetic objective statement related to aquatic plants as:

"Maintain and/or restore to the greatest extent practical the physical, biological and chemical integrity of the nearshore environment such that water transparency, benthic biomass and community structure are deemed acceptable at localized areas of significance."

As part of the 2012 TRPA Regional Plan update, a water quality threshold management standard for aquatic invasive species was adopted to:

"Prevent the introduction of new aquatic invasive species into the region's waters and reduce the abundance and distribution of known aquatic invasive species. Abate harmful ecological, economic, social and public health impacts resulting from aquatic invasive species."

The goals of the Lake Tahoe AIS Management Plan (TRPA 2014) are to:

- *Prevent new introductions of AIS to the Region.*
- *Limit the spread of existing AIS populations in the Region by employing strategies that minimize threats to native species and extirpate existing AIS populations when possible.*
- *Abate harmful ecological, economic, social, and public health impacts resulting from AIS.*

The objectives of the Lake Tahoe AIS Management Plan include:

- *Provide oversight of the implementation of the plan*
- *Prevent the introduction of AIS.*
- *Implement AIS monitoring and detection and respond to new infestations.*

- *Implement long-tern control of AIS*

Taken together, the desired conditions, goals, objectives and threshold standard emphasize Tahoe agencies' collective management goals to restore and maintain a functional native plant and animal species composition within Lake Tahoe's nearshore zone and reduce the distribution and extent of aquatic invasive species to the extent feasible. However, absent from existing goals, objectives and standard is a specific numerical target that is desirable to be achieved in the Region for aquatic plants. Despite this gap, it can be inferred that agencies want to use monitoring data to objectively demonstrate a reduction (through trend analysis) of occurrence of invasive aquatic plants, and the maintenance of native aquatic plants over time.

Goals and Objectives of the Aquatic Plant Monitoring and Evaluation Program

Goals for the aquatic plant monitoring program include:

- The aquatic plant monitoring program maximizes coordination between nearshore management and regulatory agencies and minimizes duplicity of monitoring efforts and overall costs. Roles and responsibilities in the program are defined and understood. The program includes a monitoring plan as central guidance tool that includes processes that coordinates funds and efforts, and ensures they are appropriately invested to collect and report the most relevant status and trend information to support decisions, meet agency monitoring needs, and facilitate public understanding.
- Implementation of the monitoring plan will result in a significant source of synthesized monitoring information that characterizes the status and changes in aquatic plants at Lake Tahoe and is relied upon by agencies, stakeholders, and the public to increase their understanding, and inform decisions and actions.
- The monitoring program has long-term, stable funding at a level commensurate with carrying out necessary data collection, data management, and reporting program elements.
- The program is adaptable and includes processes for amending or adding program or monitoring plan elements to improve its performance and relevancy as needed over time.
- Uses quantifiable indicators and measures to assess aquatic plant conditions that are meaningful to nearshore managers and are reported in a manner understandable by decision makers and the public.
- Utilizes best available science and technology to collect new data, conduct analyses, manage information, evaluate conditions, and make meaningful monitoring results available in a timely fashion.

Monitoring Questions, Indicators, and Survey Methods

Environmental indicators are used to show which way some key components of the environment are heading and because aquatic ecosystems are complex, indicators can help describe them in simpler terms that can be understood and used by decision makers. Indicators should be context-specific and assess issues directly. More often, however, measuring an indirect indicator is more feasible to measure and therefore more reliably monitored. Both the selection and acceptance of an indicator depends on resource manager's information needs and societal values. Indicators often work best and sometimes only in combination, where a single indicator does not alone tell you enough about environmental issue/factor of interest. Similarly, to quantify an indicator for aquatic plants, more than one survey method may need to be used. For example, to measure species composition of an individual plant bed, remotes sensing imagery would be used to locate and delineate the boundaries of the plant bed, and a line or point intercept method would be used to quantify percent species composition. Over the course of implementing a monitoring program, conditions change, objectives shift, or better indicators may be discovered. In these instances, it may be appropriate to change the indicators a program selects to monitor.

Monitoring Questions

The focus of this monitoring plan is to assess the status and trends of various indicators related to aquatic plants at Lake Tahoe's nearshore zone. Core to identifying appropriate indicators for a monitoring program is to be clear on the specific questions about the environment that the measuring system is designed to answer. In the end, a clear articulation of monitoring questions is fundamental to focusing monitoring efforts, which provides context for identifying appropriate indicators and monitoring methods. The following is a list of monitoring questions to guide the collection, evaluation and reporting of information important to nearshore managers.

Question #1 (extent): *For lake-wide surveys, what is the status of the extent (area) of invasive and native aquatic plant beds within Lake Tahoe's nearshore, and how is the extent of these plant beds changing over time (trend)?*

Question #2 (distribution): *For lake-wide surveys, what is the status of the distribution (spatial arrangement) of invasive and native aquatic plant beds within Lake Tahoe's nearshore, and how is the distribution of these plant beds changing over time (trend)?*

Question #3 (abundance/composition): *For sites where aquatic plants have been documented through lake-wide surveys, what is the status of their relative species abundance/composition (e.g., percent cover, stems/unit area) and how is percent relative species abundance/composition changing over time?*

Question #4 (relative biomass volume): *For sites where aquatic plants have been documented through lake-wide nearshore surveys, what is the status of the native and invasive aquatic plant bed relative biomass volume, and how is relative biomass volume of these plant beds changing over time?*

Question #5 (new establishment of aquatic invasive plants): *Is there evidence of new aquatic invasive plant bed establishment? If so, where and how extensive are new plant beds?*

Indicators

Once monitoring questions have been documented, the identification of indicators is relatively straightforward. The following provides a summary of aquatic plant indicators that can be used to answer identified monitoring questions and are of interest to nearshore managers at Lake Tahoe.

- **Aquatic plant bed presence (or absence)** – This indicator provides coarsest level of aquatic plant bed characterization in that it only communicates whether a plant bed has been detected (or not) at a location within the area of interest at a given point in time. Presence/absence data can be obtained through the interpretation of remote sensing data, hydroacoustics, *in situ* diver surveys via boat, line transect surveys, point intercept surveys or through "citizen science" programs where individuals record observations aquatic plant bed observation into a web-based data repository platform (e.g., League to Save Lake Tahoe's "Eye's on the Lake" Program). These data are usually represented as a point feature on a map across the area of interest. Additional sampling effort would be needed to assign other attributes to presence/absence data. For example, the ability to assign species composition to individual plant beds may be possible if: 1) spectral signatures of the plant beds can be identified and discriminated from remotely sensed data, 2) rake samples of plant bed are taken and species identified from samples, or 3) surveys conducted by qualified divers identify plant bed species composition via point intercept or line intercept sampling.

- **Aquatic plant bed extent** – This indicator measures the surface area (extent) of aquatic plant beds at a point in time. Spatial location data of plant beds are a biproduct of collecting these data. When measured consistently over time, an increase in area of aquatic beds would indicate an expansion, and a decrease would indicate a contraction. For invasive aquatic plants, demonstrating a contraction in extent would indicate conditions are improving; an increase would indicate otherwise. The unit of measure for this indicator is area (e.g., acres, square feet or square meters). Similar to presence and absence data, the ability to assign species composition attributes to individual plant beds may be possible if: 1) spectral signatures of the plant beds can be identified and discriminated from remotely sensed data, 2) rake samples of plant bed are taken and species identified from samples, or 3) surveys conducted by qualified divers identify plant bed species composition via point intercept or line intercept sampling.

- **Aquatic plant bed distribution -** This indicator is used to characterize the arrangement of aquatic plant beds across the area of interest (i.e., Lake Tahoe's nearshore, including marinas and major stream mouths). These data show where aquatic plant beds are in space and time, how many plant beds there are per unit of area, and how sparsely or densely distributed they are from each other (average distance). Typically, these data are depicted for a point in time graphically, usually on a map, and are a biproduct of collecting extent or presence/absence data. When this indicator is collected over time, a time series of aquatic plant bed spatial distribution can be geographically represented for comparison for each time period the indicator is measured.

- **Aquatic plant relative species abundance/composition** – This indicator is a measure of how common or rare an aquatic plant species is relative to other species in a defined location, such as a plant bed. Percent cover or stem counts by species for each plant bed could be used to quantify this indicator for an individual plant bed or unit area. If assessment of relative species abundance/composition for each plant bed is demonstrated to be too time consuming/costly, aquatic plant beds could be simply attributed as either percent cover categories of native vs non-native. Snorkel or dive surveys/transects or point intercept of plant beds (e.g., delineated from remotely sensed data) or locations (e.g., Tahoe Keys Marina, Elks Point Marina, Tallac Marsh) would provide the most direct method to enumerate each plant bed's relative species abundance/composition. Alternatively, rake samples could be used (via point intercept) to characterize relative species abundance/composition for a plant bed or defined location.

- **Aquatic plant relative biovolume** – this indicator can be used to characterize the relative mass of a plant bed or within a defined area of interest. For nearshore managers this may be an important indicator of aquatic invasive plants because it could indicate the level of effort that might be needed for control. The data are collected using either hydroacoustic or topobathymetric LiDAR technologies. Using these techniques, the distance between the water surface, top of the aquatic plants, and bottom of the water column are made. This along with extend data make it possible to estimate relative aquatic plant bed biovolume. The indicator is reported in cubic units (e.g., ft^3, m^3). For invasive aquatic plants, demonstrating a contraction in relative biovolume over time would indicate conditions are improving; an increase would indicate otherwise. Similar to presence/absence and extent data, the ability to assign species composition attributes to individual plant beds may be possible if: 1) spectral signatures of the plant beds can be identified and discriminated from remotely sensed data, 2) rake samples of plant bed are taken and species identified from samples, or 3) surveys conducted by qualified divers identify plant bed species composition via point intercept or line intercept sampling.

- **New establishment of aquatic invasive plants** – this indicator is used to quantify and identify the location of newly establish aquatic invasive species. The indicator can be measured using a variety of methods including through interpretation of remotely sensed data, hydroacoustic surveys, divers or rake surveys via line transects or point-intercept methods.

Survey Methods

There are number of survey methods that have been used for sampling aquatic plants to assess their extent, distribution, presence/absence, and/or relative species abundance/composition for a given water body. These methods range from relatively low cost and subjective visual estimation of plant occurrence and cover to higher cost remote sensing or hydroacoustic surveys that can characterize conditions at large and small water bodies, study sites within a water body, or waterbodies covering regional landscapes. When selecting a method, it is important to choose the method or combination of methods that will meet a monitoring program's objectives and are within the monitoring program's budget. Notably, methods that quantify aquatic plant characteristics in a repeatable way lend themselves to statistical analyses. Survey methods based in subjective characterizations (e.g., visual estimation, model-based estimation) may be less expensive, but cannot be quantified in a reliable way and thus not appropriate for statistical analysis. Regardless of the methods that are selected for answering monitoring questions identified for aquatic monitoring program, it is important to note that surveys conducted on and/or in water tend to be costlier compared to terrestrial investigation due to logistical consideration associated working on/in water (e.g., marine vessel, dive gear and personnel, fuel, etc.). The following describes different methods commonly used for surveying and sampling submerged aquatic plants.

Quantitative Survey Methods:

Line Transect

This method involves the use of snorkel/dive surveys where a tape or string laid along submerged substrate in a straight line between two points as a guide for consistently sampling aquatic plants in an area of interest. This method can be used to measure presence/absence, distribution, and relative species abundance/composition (e.g., cover, density), or to crudely estimate relative aquatic plant biovolume. Sampling measurements are usually confined to those aquatic plants that are touching the line. The method allows for the quantification of percent cover of plants, where the total length of the intersection between aquatic plants with the transect line is divided by to total length of the transect, then multiplied by 100. When combined with a quadrat, stem density can be quantified and estimated. Similarly, to characterize species composition, plants that intersect the line are identified and enumerated by transect length. This method is can be used in combination with other survey methods to enhance the attribution of aquatic plant beds. For example, if remote sensing is used to delineate aquatic plant bed extent, line transects can be established at those locations to assign relative abundance/composition values to the aquatic plant bed. For small water bodies or study sites, this method could be used exclusively for characterizing aquatic plant life. However, the method could be cost-prohibitive to rigorously apply to a large water-body such as Lake Tahoe.

Belt Transect

The belt transect method is similar to the line transect method but gives information on abundance as well as presence, or absence of species. It may be considered as a widening of the line transect to form a continuous belt, or series of quadrats. Belt transects are commonly used in biology to estimate the distribution of organisms in relation to a certain area. Surveyor records all the species found between two lines and how far they are for a certain place and how many of them there are. An interrupted belt transect records all the species found in quadrats (square frames) placed at certain intervals along a line. A belt transect usual yields more data than a line transect, however, a line transect can be sampled much quicker than a belt transect.

Point Intercept

The point intercept method (and line transect method) is typically used at small water bodies, study sites and at multiple locations within a water body to establish aquatic plant community characteristics or assess management efficacy. Point intercept surveys are typically conducted using a pre-selected grid of points at a user specified interval (Madsen 1999). Once a sampling grid (or points along a line transect) are establish in an area of interest, a GPS/GNSS is used to navigate to each point where a sampling hoop/quadrat (diver needed for this method) or plant rake is deployed to sample submersed vegetation. Notably, surveys are developed based on a given sampling design (e.g., random sample, systematic) which allow data to be statistically analyzed to compare changes in species occurrence over time or assess the effectiveness of management treatment. The point intercept method, like the line intercept method, can be used in combination with other methods (e.g., remote sensing, hydroacoustic surveys) to enhance the attribution of individual aquatic plant beds of areas of interest.

Of the data frame options, the line transect yields similar information that is provided by either belt transect and point-intercept and represents the most cost-effect of the options to implement in the field based on experience.

Data Acquisition Methods:

Hydroacoustic

Hydroacoustic technologies can be used to detect the depth of a water body (bathymetry), as well as the presence or absence, abundance, distribution, and extent of submerged aquatic plants. Hydroacoustic sampling targets submersed aquatic plants by using echolocator that can record information from the transducer onto flash memory devices. Hydroacoustic surveys are typically conducted by systematically traversing transects with an appropriately equipped vessel and recording echo-sounded returns along the way. For large waterbodies like Lake Tahoe, this could be a significant undertaking due to the size of the area of interest and because the distance between transects can affect the quality of the results. Species specific information cannot be determined from hydroacoustic surveys alone - other sampling methods, like point intercept or line transect surveys are utilized to assign species composition values (Valley et al. 2015).

Remote Sensing

Similar to hydroacoustic data, high-resolution multispectral satellite or airborne imagery and/or Topobathymetric LiDAR with sufficient spatial resolution (< 1m) can be used can be used to detect the depth of a water body (bathymetry), as well as the presence or absence, abundance, distribution, and extent of submerged aquatic plants. The technologies are well-suited for efficiently characterizing conditions over a large study area, such as Lake Tahoe. Because of the complexity of detecting features that are underwater, a combination of remote sensing data types is used to improve confidence in aquatic plant detection and characterization. Topobathymetric LiDAR is an active sensor instrument that principally consists of a laser, a scanner, and a specialized GPS receiver. Airplanes and helicopters are the most commonly used platforms for acquiring LIDAR data over broad areas. Topobathymetric LiDAR systems allow scientists and mapping professionals to examine both natural and manmade aquatic environments with accuracy, precision, and flexibility. Topobathymetric LiDAR uses water-penetrating green light to also measure seafloor and riverbed elevations, including detection of submerged features such as aquatic plant beds and variation in submerged substrates. High-resolution multispectral imagery is produced by a "passive" sensor that measures reflected energy within several specific sections (also called bands) of the electromagnetic spectrum. Multispectral sensors usually have between 3 and 10 different band measurements in each pixel of the images they produce. Examples of bands in these sensors typically include visible green, visible red, near infrared. Landsat, Quickbird, IKONOS, Worldview III and Spot satellites are well-known satellite platforms that use multispectral sensors. High-resolution multispectral imagery can also be collected via airborne platforms, such as man- and unmanned aircraft. In general, airborne platforms provide higher resolution imagery (< 20cm) than satellite platforms (< 6m), and unmanned aircraft systems provide higher resolution imagery (< 4cm) than airborne platforms. Use and analysis of data derived from these platforms requires specialized training and expertise not commonly possessed by nearshore managers and thus require external support. One of the primary purposes of using remote sensing data is to delineate aquatic plant bed boundaries (extent) and distribution. A potential limitation of this technology is the difficultly to discriminate submerged aquatic plant species composition, hence the need to marry this method with *in situ* sampling methods.

Snorkel/Diver Surveys

Snorkel/diver surveys can be used to provide a direct measure of indicators of interest. Snorkel surveys are used in shallow water situation, while diver surveys are used in deeper water situation. Snorkel/Diver surveys are most commonly deployed in combination with line transect and point intercept methods to characterize aquatic plant bed relative species abundance/composition. Divers used in this instance require additional expertise/training in plant identification and sampling design. When snorkel/diver surveys are combined with GPS/GNSS technologies, they can be used to map plant bed perimeters and estimate extent. However, when used for this purpose, the application is usually limited to small water bodies or study areas. Diver surveys can offer intangible benefits to monitoring efforts as divers can make observations that are not necessary within the original scope of the monitoring effort, but of value to overall aquatic plant management – for example, observations of non-target aquatic invasive species.

Video Surveys

Video surveys are typically implemented from a vessel. The vessel can navigate a specific transect while video is either recorded or evaluated in real time. In the case of real-time observation, it is typically not possible to gather quantitative data. However, with the addition of scaling lasers and integration of geographic positioning data, it is possible to review the video at a later date and generate estimates of plant cover and relative species abundance. The time spent reviewing video footage can be considerable and the quality trade-off versus direct observations is typically only warranted when depth increases the cost of direct observation or creates safety concerns.

Additional video methods include use of a remotely operated vehicle (ROV) and autonomous underwater vehicle (AUV) with video. ROV surveys allow greater control over the viewing angle and the ability to slow down when features are discovered that warrant additional viewing time; however, the method is much slower than towing a camera from the survey vessel. AUV surveys can efficiently large numbers of transects. However, the video data must be reviewed after the fact such that sites must be revisited if features are detected that warrant additional views. Additionally, AUV equipment can be expensive if accurate positioning is desired.

Rake Surveys

Rake surveys are commonly used in combination with the point intercept method to sample submerged aquatic plants. This method has been used to estimate relative plant species composition and relative abundance when diver assisted surveys are outside the scope of the monitoring budget.

PONAR/Coring Surveys

Similar to the rake method, the PONAR grab sampler is a bottom sampling device used on vessels to study the composition of the submerged plants and bottom sediments of a lake (or river). This method is commonly used in combination with the point intercept sampling frame to sample submerged aquatic plants. The sampler provides a means to obtain a somewhat quantitative and undisturbed sample of the bottom material. It takes a "bite" of known surface area and penetration depth, provided that the bottom material is neither too hard or nor too soft. This method has been used to estimate relative plant species composition as well.

Vessel Surveys

Vessel surveys are probably best deployed for initial characterization of aquatic plant bed extent and distribution for an area of interest. In general, vessel surveys are semi-quantitative and not appropriate for a statistically robust monitoring program due to sampling error, but, when combined with GPS/GNSS technologies, could be used to delineate the extent of presence and absence of plant beds. Vessel surveys can be limited by water depth depending on the type of vessel used.

Non-quantitative Methods:

Generalized estimates of aquatic plant extent and composition can be achieved using visual observations while on the water looking into the water column. Visual estimation methods tend to be applied to waterbodies that are much smaller than Lake Tahoe, are subjective and not repeatable, with estimates variable across observers. As a result, there is reduced confidence in survey results and not appropriate for statistical analysis. Also, it can be difficult to estimate abundance or species composition of submersed aquatic plants through visual observation, and as such species are misidentified and/or over- or underestimated.

There are several different data capture methods that are relevant to monitoring aquatic plant populations at Lake Tahoe. No singular method outlined above will yield data needed to answer monitoring questions identified for the monitoring program (Table 1). One possible exception is use of the remote sensing method, where with the fusion of high-resolution multispectral data (from manned and unmanned aircraft platforms) and topobathymetric LiDAR shows promise (Table 1). Even with this possibility, the interpretation of imagery data needs to be validated with in situ data and the cost to implement this method each year would likely be above available budget. Instead, managers may want to consider combining data acquisition methods where, for example, remote sensing data are collected at a predetermined interval, say every 5 years, and dive surveys are collected during intervening years.

Considering this schedule, remote sensing data would provide the ability to establish a baseline of aquatic plant indicator status, and dive surveys could provide data on indicator trends.

Table 1. Summary of aquatic plant data capture methods by evaluation criteria and indicator detectability.

	Evaluation Criteria						Indicator Detectability					
Data Capture Method	**Effective Spatial Scale of Application**	**Skill Level to Implement**	**Data Capture (in situ or remote)**	**Cost/Unit Area (High, Medium Low)**	**Major Limitation(s)**	**Greatest Strengths**	**Presence - Absence**	**Extent**	**Distribution**	**Species Abundance/ Composition**	**Biovolume**	**New Invasive Species Detection**
Hydroacoustic	Small to Large	High	Remote	High	Unable to detect features in shallow water, time intensive transects, data processing time can be high, image quality between transect can be poor.	Nearshore-wide scale application, Rich data set	X	X	X		X	X
Remote Sensing	Small to Large	High	Remote	Moderate	Shorezone structures can obscure plant detection, data processing time can be high. Surface water clarity and turbulence can affect data quality.	Nearshore-wide scale application, all depths (<20m) detectable	X	X	X	Possible with high resolution data	X	X
Snorkel/Diver	Small to Medium	High	In situ	Moderate	Not cost-effective to deploy at scale	Capacity to directly measure attributes and intangibles	X	X	X	X	X	X
Video	Small to Medium	Moderate	Interme diate	Moderate	Startup costs dependent on method; quantification difficult and less accurate than other methods	Rapid assessment	X	X	Possible	Possible but time consuming and low resolution		X
Rake	Small to Large	Low	Inter-mediate	Low	Imprecise measurements, potentially highly inaccurate as plants can be missed or dislodge from rake on way to surface. Also risks spreading plant fragments.	Rapid assessment	X			X	Relative Measure	
PONAR/Core	Small to Medium	Moderate	In Situ	High	Cumbersome equipment, unable to operate in certain settings (e.g., marsh)	Consistent sample draw, subsurface data	X		Possible	X	Relative Measure	Possible
Vessel/boat	Small to Large	Low	Remote	Low	Subjective assessment, can be limited by vessel type	Rapid assessment	X	Possible	Possible	Partial	Relative Measure	Possible
Visual	Small	Low	Remote	Low	Subjective assessment, not quantitative	Rapid assessment	X	Relative Measure	Possible	Partial	Relative Measure	Possible

Spatial Designs

A spatial design describes how a sampling effort will be allocated across the area of interest over time. The most appropriate spatial design depends on your monitoring objectives (e.g., questions) and constraints (e.g., budget, access to sites) identified for a monitoring program.

Census

The census spatial design describes the location of all the sites comprising the domain of interest, in this case – all sites that have the potential to support aquatic plants within Lake Tahoe's nearshore area of interest. A census infers that all elements within an area of interest will be quantified/characterized. In some cases, it is feasible to conduct a census in a part of the population's domain, but not all. For example, only certain indicators of aquatic plants can be enumerated. In these cases, the term "restricted census" is applied, where part of the population domain can be censused, and part will be sampled using another type of design (e.g., survey).

Model-based

A model-based spatial design relies on selection of sites based on the need to estimate parameters or coefficients of a model that will be used to make the population estimates. Such models typically include one or more independent variables or covariates such as environmental conditions or habitat quality. Sites are generally selected along the important gradients governing the model parameters. A simple model might be a relationship between a population's growth rate and temperature. Sites might be selected at locations covering a thermal gradient over the range of the population's thermal tolerance. The model then would be used to estimate productivity across all sites in the domain. A restricted model-based spatial design refers to situations in which the selection of locations in part of the domain is guided by the candidate model, and locations in other parts are selected by other methods.

Survey

The term survey in the context of aquatic plant monitoring implies the use of a randomization rule in the selection of locations across the domain of interest with the caveat that all locations have a chance of being selected. Approaches available to achieve these criteria for monitoring natural resources include, for example simple random sampling or systematic sampling.

Opportunistic

An opportunistic design is where sites are selected based on site access or some other subjective criteria. This spatial design is sometimes used to gain an initial understanding of a population but is not recommended for a robust monitoring program.

A spatial design that managers may consider for the aquatic plant monitoring program would be to combine information generated through census and survey effort. By combining these spatial designs, managers would generate nearshore-wide survey information on the distribution and extent of aquatic plant as a component of census efforts, and more detailed information related to species composition through survey efforts. The timing and extent of census and survey efforts could be adjusted to best fit budget constraints. Model-based and opportunistic spatial design could yield helpful information, however, information generated may not scale to the granularity managers need to inform management decisions.

Sampling Designs

For "survey" or "restricted census" spatial designs, it is important to collect data using an appropriate sampling design to ensure that data are collected in a manner suitable for statistical analyses. Describing the sampling design is important in situations where you cannot conduct a complete census of a population of interest. Sampling designs commonly used for aquatic plant populations include: 1) completely random, 2) stratified-random, 3) systematic, and 4) stratified-systematic sampling designs. The following provides as summary of each sampling design.

Completely Random

A completely random sampling design is a sampling technique where a group of subjects (a sample) for study is selected from a larger group (a population). Each sample site or individual is chosen entirely by chance and each member of the population has an equal chance of being included in the sample. Completely random sampling is usually carried out when the study area is relatively uniform and/or very large. In general, a completely random design provides an unbiased selection of sampling locations. However, there are several limitations to this design in larger areas (such as Lake Tahoe). For example, a completely random selection of points may place points in inaccessible areas, and the sparsity of information these points would provide does not compensate for the added time it would take to sample them. Additionally, the field time required to sample random points can be significant and may be an inappropriate choice for large surveys. A random selection of points may result in the location of some points being clumped, leaving large areas under-sampled and has a high likelihood to under-sample stand-alone plant beds that would be sampled using other designs.

Stratified-Random

A stratified random sampling design is a sampling technique where a group of subjects (a sample) for study is selected from a larger group (a population). Each site or individual is chosen entirely by chance and each member of the population has a known, but possibly non-equal, chance of being included in the sample. A stratified sample is obtained by taking samples from each stratum or sub-group of a population. A stratified random design is typically utilized if a gradient in distribution exists in the area of interest, such as at Lake Tahoe where the density, composition, extent, and distribution of aquatic plants is variable depending on habitat setting (e.g., marina/embayment, stream mouth/marsh, exposed to open water). In such cases, the area can be divided into relatively homogenous units with sampling points randomly distributed within each unit.

Systematic

A systematic sampling design is a method of selecting sample members from a larger population according to a random starting point and a fixed, periodic interval, usually along a line or grid with a pre-determined spacing. Typically, every "nth" member is selected from the total population for inclusion in the sample population. Systematic sampling is considered random, as long as the periodic interval is determined beforehand, and the starting point is random. This design does not take separate samples from strata or sub-groups of a population. Aquatic plant monitoring practitioners find the systematic design works well for an initial survey of smaller water bodies or study sites as it will cover the entire water body and the observer is more likely to find most species. Also, if data such as water depth or Secchi depth is collected at sampling locations, the maximum depth of plant colonization can be determined, and the littoral zone delineated for future surveys.

Stratified-Systematic

Stratified systematic sampling design are generally used when the population is heterogeneous, or dissimilar, or where certain homogeneous, or similar, sub-populations can be isolated into strata. A stratified systematic design is typically utilized if a gradient in distribution exists in the study area, such as at Lake Tahoe where the density, composition, extent, and distribution of aquatic plants is highly variable depending on habitat setting (e.g., marina/embayment, stream mouth/marsh, open-water nearshore). In such cases, the area is divided into relatively homogenous units with sampling points (or line transects) distributed within each unit in a systematic way.

Of the sampling designs noted, the stratified-systematic design appears most appropriate because 1) the nearshore aquatic plant population at Tahoe is heterogeneous, 2) the aquatic plant population can be easily and repeatably stratified into sub-population units such as marinas and embayments, marshes, major tributaries, and open-water nearshore, and 3) the sampling design is relatively cost effective to implement.

Sampling Schedule

A sampling schedule (or temporal design) describes how sampling effort is allocated across time. Determining the sampling schedule depends on environmental factors, monitoring questions that need to be addressed, desired reporting frequency, monitoring budget and the granularity of information needed by nearshore managers. For long-term monitoring programs, it is important to define the sampling schedule within a given year (intra-annual sampling; e.g., hourly, daily, weekly, within a season, all seasons), and over multiple years (inter-annual sampling, e.g., years 1, 2, 3, n) – where variation in sampling effort/approach may occur to conserve budget yet yield sufficient information to inform management decisions. Defining the timing of intra-annual sampling helps to reduce variation in plant conditions due to seasonal differences and thus improves the statistical robustness when assessing differences in aquatic plant indicators across years. For example, for monitoring aquatic plant populations at Lake Tahoe, the peak timing for detecting and characterizing conditions is most ideal during the late summer to early fall season (August through September) because aquatic plants are at their maximum growth stage. For inter-annual monitoring, nearshore managers are often challenged with limited or variable budgets and thus the program can only afford to invest in intensive survey in certain years (e.g., every 5 years), and reduces survey efforts during intervening years. In this instance, managers can sustain a steady flow of monitoring information needed to effectively manage aquatic plants.

Interim Survey Sampling Options and Estimated Costs

The Aquatic Plant Monitoring and Evaluation Program developed the aquatic plant monitoring plan (plan) to guide a nearshore-wide aquatic plant survey at a set interval (e.g., every 5 to 8 years, depending on funding availability). In interim years, the plan prescribes using divers to resurvey established transects every year to track changes in aquatic plant composition, relative abundance (% cover) and distribution. The spatial scale of the nearshore-wide effort and the goals relative to data collection mean that methods to delineate aquatic plant bed extent must be combined with methods to determine plant bed composition and relative abundance in order to get a reasonable estimate of aquatic invasive species extent (acreage) and distribution. Monitoring events in between intensive nearshore-wide survey years can be performed at a reduced level of effort. The level of effort is dependent upon resource management needs and can mean eliminating specific elements or monitoring less frequently.

The protocol for performing an aquatic plant survey at the nearshore-wide scale was developed with consideration of the data quality and cost factors summarized in Table 1. Although high-resolution imagery and topobathymetric LiDAR data collection is relatively costly, it is arguably more cost-effective at the nearshore-wide scale of investigation because many of the fixed costs associated with mobilizing for data collection are minimized relative to other techniques that involve systematically moving and re-staging around the lake over multiple survey days. Similarly, although deployment of divers and other survey staff can be expensive, these methods provide for data-rich information in real time. *In situ* automated data collection methods, such as towed video cameras, require higher levels of post-processing and interpretation at reduced specificity (e.g., inability to consistently identify plant species, and measure relative abundance).

Alternative Sampling Methods

Although the monitoring plan prescribes nearshore-wide survey techniques that are viewed as a cost-effective and data-rich means of performing a nearshore-wide plant survey, it is recognized that aquatic resource managers may need to work at lower data resolution between intensive survey years to understand the rate of expansion in areas where control measures have not yet been implemented, to identify new plant populations, or to evaluate performance of control measures at locations where implemented. As such, resource managers seek alternative and more cost-effective methods that provide a means to capture nearshore-wide survey compatible data for tracking aquatic invasive plant populations. The following describes options (or alternative methods) that could be used in interim years in place to those prescribed in the plan to estimate aquatic invasive plants extent and distribution at the nearshore-wide scale.

Alternatives to remote sensing methods prescribed in the plan:

- *Multi-beam sonar*
- *Single-beam sonar*
- *LiDAR*
- *Manned aircraft, high-resolution multi-spectral imagery provided by imagery broker*
- *High-resolution multi-spectral satellite imagery*
- *Unmanned Aircraft System (UAS) high-resolution imagery*

LiDAR, multi-beam sonar, and single-beam sonar are all cost prohibitive to be performed on an annual basis at the nearshore-wide scale. Multi-beam sonar, single-beam sonar, and UAS all provide means to determine plant bed extent. However, when compared to LiDAR, they are best suited for smaller spatial scales (< 2,000 acres) where precise boundary data are needed to help inform specific control efforts. UAS is the most economical of these methods and can provide very high-resolution (<3.5 cm) imagery that can be used to delineate aquatic plant features. However, there is a drawback in that UAS image processing software is not able to spatially align and register photos when the feature of interest extends offshore (i.e., beyond fixed landscape feature such as piers, jetties, etc.). Given that the "best" method will vary based on site and scale, no attempt is offered to compare the cost effectiveness of these methods. Moreover, the methods arguably do not provide means for cost-effective detection of AIS within the sampling frame except for satellite imagery and manned aircraft imaging. Worldview 3 satellite imagery costs approximately $25 per square kilometer and provides 31-cm panchromatic resolution and 124-cm multispectral resolution, with daily revisits – a resolution sufficient for delineating aquatic plant beds. Manned aircraft imagery (e.g., available from Hexagon) likewise provides high-resolution (<30cm) multi-spectral imagery (~$11/square mile). The challenge with satellite and manned aircraft imagery is to capture data during cloud free days and calm (wake/wave free) lake conditions.

It is possible to provide meaningful interim year aquatic invasive plant data without needing to determine plant bed extent. For instance, aquatic invasive plant presence/absence data can be used to coarsely and quickly determine extents relative to more intensive nearshore-wide survey years. When aquatic invasive plants are discovered beyond the limits of the prior intensive nearshore-wide survey, the result indicates expansion of aquatic invasive plant bed extents. If an area is found to be free of aquatic invasive plant relative to a prior survey, that indicates a contraction.

Given that once nearshore-wide survey data are collected, it is reasonable that appropriate but less intensive data can be used to track change in the interim years. The basis for comparison is the nearshore-wide survey transect sampling. The transect sampling proposed as part of the monitoring program is generally systematic and allows for validation of remote sensing data while also providing an independent means to sample the lake and tributaries for aquatic invasive plants. The effective resolution in any given region is the inter-transect spacing. The level of detail collected on transects can be adjusted to save money while continuing to monitor aquatic invasive plants composition and relative cover.

The methods available to determine plant bed composition and relative extent across the landscape include different means of implementing transects and area based (quadrat) sampling. The means to implement methods include:

- *Visual via SCUBA, snorkel, wading to collect transect or area-based data*
- *Visual via towed camera (transect) or drop camera (area based)*
- *Visual via Autonomous Underwater Vehicle (AUV) to collect transect data*
- *Grab sampling to collect area-based data*

The visual methods proposed in the monitoring and evaluation plan include walking, wading, snorkeling, and SCUBA diving to place and observe transects. Aquatic invasive plant data are collected along the transect and quadrats are placed to gather additional percent cover data. This method provides the standard from which below variations are provided.

The first alternative to the proposed sampling methods is to tow a camera along the nearshore and embayments transects and to walk snorkel or SCUBA the length of tributaries within the guidelines established in the plan. The vessel towing the camera would make a series of stops to drop the camera to the bottom so that the team could reasonably identify the species present. At the end of each line, the team would provide an estimate of cover by species for the transect. Employing these methods speeds up the field effort because transects and quadrats are not physically placed to collect quantifiable data. Thus, the percent cover data are not directly relatable to the more intensive nearshore-wide survey data collection. However, the extent of aquatic plants and aquatic invasive plants relative to the nearshore-wide survey data can be compared and percent cover estimates can generally inform whether observations are consistent with prior nearshore-wide survey results. The method also saves time relative to AUV collected data because evaluations are made in the field instead of having to review video footage after the fact.

The second alternative to the proposed nearshore-wide survey methods is to employ an AUV instead of a towed camera. This method can only apply to nearshore and embayment transects. Tributaries would still have to be surveyed by walking, snorkeling or with SCUBA. The AUV would be programed to follow transects. It could then be placed in the water from the shore or from a vessel. Use of a vessel is the most efficient method as many of the transect locations are difficult to reach or more time consuming to reach from the road. Additionally, tributaries can be readily accessed via boat and sampled in between nearshore transects as they are encountered for efficiency. However, video footage cannot be viewed in real time and therefore there is no ability to adjust in real time to ensure positive species identifications are made. Although footage can be replayed at a faster frame rate to speed processing of negative transects, typical experience is that where plants require identification, the footage must be stopped and replayed to improve identification. These factors often balance out with the same amount of time spent for review as was required for video collection.

The final alternative is to perform grab sampling or spot checks with video. Grab sampling would use either a rake or clamshell style sampler to recover a sample of vegetation from the lakebed. One problem with rake or grab methods is that they cause fragmentation of plants and therefore can help spread invasive species. Thus, using a drop camera would be preferred unless the team were to decide that physical samples were necessary for species identification at any given sample site. Like the above alternatives, tributaries would still be surveyed using the sampling methods; this alternative only applies to the transects in the open-water nearshore stratum and the marinas and embayments stratum. In lieu of transects, drop camera or grab samples would be collected within the region of the nearshore-wide survey transects. The goal would be to confirm the presence or absence of previously identified species. The intent of this method is to provide the lowest cost alternative. This comes with the drawback that the reduction in area viewed makes it more likely that plant beds would be missed.

It should be noted that single-beam sonar can also be used to monitor transects for aquatic invasive plants. However, given that crew sizes would be similar to video methods, post-processing is required, and video validation would be required, the method does not offer a price or methodology improvement to any of the other methods being considered. The method does provide for a good means to evaluate smaller scale sites while providing good information for determining biomass; it just is not suitable at the scale required.

For the major tributaries and marshes strata, there is only a single reduced intensity alternative to the nearshore-wide survey methods. The alternative would eliminate physical use of transects and quadrats. Rather, the extent of vegetated area would be noted, the maximum extents of AIS species would be delineated, and a presence/absence log of vegetation species would be maintained. This is like the data collection intensity obtainable for the open-water nearshore and the marinas and embayments strata when using camera-based methods. Only presence or absence of vegetation species would be logged.

Scheduling Alternatives

Just as compromises can be made with regards to spatial resolution to save money, it is also possible to adjust the sampling schedule to save money. This would effectively mean reducing the temporal scale. The drawback is that a new invasive species or a new infestation area may go undetected for a greater period. However, if there is no alternative, sampling at reduced frequency can ensure that monitoring does occur at whatever temporal resolution is feasible. Some options for adjusting the temporal sampling scale are provided in Table 2.

Costs of Alternatives

Using the above methods and scheduling alternative as a guideline, costs are approximated and provided in the table below (Table 3). Reporting costs are assumed to be roughly equal across methods once data are compiled. The time allocated for office labor varies across methods to account for differences in data processing time associated with the data collection methods. For instance, more time is provided to review video footage for AUV transects.

Note that the costs are relative to expenses assumed at the time of writing this document. Inflation should be factored in based on when sampling is to occur. Alternately, if recent surveys have been performed using one of the methods, the costs for the others can be determined relatively by applying the appropriate percent difference between the estimated costs in Table 3. Ultimately, the actual costs to implement a given sampling event are dependent upon the contractor and/ r agency implementing the sampling.

Table 2. Options to reduce temporal sampling frequency of strata between intensive nearshore-wide survey events.

Options	Option Description	Notes
Prescribed in Plan	Survey all strata and established transects every year.	Provides annual and most accurate nearshore-wide assessment of composition, distribution, relative abundance, and good potential to detect new populations due to diver crew presence on the lake. Option assumes diver surveys.
Option 1	Survey all strata and established transects every 2 years.	Provides biennial assessment of composition, distribution, relative abundance, and good potential to detect new populations due to diver crew presence on the lake (every 2 years).
Option 2	Survey 50% of transects per stratum, randomly selected every year.	Provides annual assessment of composition, distribution, relative abundance, and reduced potential to detect new populations due to reduce sampling effort.
Option 3	Survey marina/embayment stratum in year 1, open-water nearshore stratum in Year 2, major tributaries stratum in year 3, and marsh stratum in year 4. Full nearshore-wide survey and mapping every 5th year. (note the choice of which stratum to sample can be assigned according to resource managers desire/need.	Provides assessment of composition, distribution, relative abundance, for each stratum every 4 years and all strata in 5th year when full nearshore-wide survey is completed
Option 4	Only survey strata of interest every year.	Provides annual assessment of composition, distribution, relative abundance, for selected stratum (or strata) every year and all strata in 5th year when full survey is completed. Data gaps will exist for strata not surveyed.
Option 5	Only survey strata of interest every 2 years	Provides biennial assessment of composition, distribution, relative abundance, for select strata every 2 years and all strata in 5th year when full survey is completed. Data missing for strata not surveyed.

Table 3. Cost summary of alternative lake-wide transect sampling methods. The "standard method" refers to the sampling protocols as developed in the Aquatic Plant Monitoring Plan.

Strata	Classification	Standard Method	Towed Camera	AUV	Grab Sampling
Open-Water	Field Days	9	6	4	4
Nearshore	Crew Size	3	2	2	2
	Field Labor (hrs)	270	120	80	80
	Office Labor (hrs)	32	24	48	24
	Labor ($)	$37,750	$12,960	$11,520	$9,360
	Vessel ($)	$4,500	$3,000	$2,000	$2,000
	Equipment ($)	$450	$300	$8,000	$200
	Misc Expenses ($)	$1,800	$1,200	$800	$800
	Reporting ($)	$4,000	$4,000	$4,000	$4,000
	Subtotal ($)	$48,500	$21,460	$26,320	$16,360
Marinas &	Field Days	7	4	3	3
Embayments	Crew Size	2	2	2	2
	Field Labor (hrs)	140	80	60	60
	Office Labor (hrs)	24	16	24	16
	Labor ($)	$20,500	$8,640	$7,560	$6,840
	Vessel ($)	$3,500	$2,000	$1,500	$1,500
	Equipment ($)	$350	$200	$7,000	$150
	Misc Expenses ($)	$1,400	$800	$600	$600
	Reporting ($)	$3,000	$3,000	$3,000	$3,000
	Subtotal ($)	$28,750	$14,640	$19,660	$12,090

Strata	Classification	Standard Method	Reduced Sampling Intensity
Major	Field Days	7	5
Tributaries	Crew Size	2	2
	Field Labor (hrs)	140	100
	Office Labor (hrs)	16	16
	Labor ($)	$19,500	$14,500
	Vessel ($)	$3,500	$2,500
	Equipment ($)	$350	$250
	Misc Expenses ($)	$1,400	$1,000
	Reporting ($)	$3,000	$3,000
	Subtotal ($)	$27,750	$21,250
Marshes	Field Days	4	3
	Crew Size	2	2
	Field Labor (hrs)	80	60
	Office Labor (hrs)	16	16
	Labor ($)	$12,000	$9,500
	Vessel ($)	$2,000	$1,500
	Equipment ($)	$200	$150
	Misc Expenses ($)	$800	$600
	Reporting ($)	$3,000	$3,000
	Subtotal ($)	$18,000	$14,750

It is recognized that the need for information may vary across strata. For instance, having diver-collected information with full plant cover data along transects may be viewed as critical for the open-water nearshore stratum and the marinas and embayments stratum. Alternately, data collection in marshes and tributaries may be viewed as less necessary on an annual basis or because separate data collection events are occurring due to specific control efforts. For this reason, a list of the alternatives is provided as Table 4. The list allows resource managers to mix methods across strata and to perform reduced levels of effort even within methods. Each method provides for a 50% reduced effort option. This option allows managers to change costs by reducing the number of visited sites while maintaining a specified set of methods. For instance, every other transect could be performed moving around the lake to generally confirm prior intensive nearshore-wide plant survey results but at a lower resolution than performing monitoring at all transects.

The cost analysis shows that using the same transect methods proposed for intensive nearshore-wide plant survey years for the open-water nearshore and the marinas and embayments strata is the most expensive means of data collection. However, this method provides the highest data value. Using divers helps ensure correct species identification. Divers are also more capable of making other important observations. For instance, the field of view of a diver far surpasses that of video, this means a diver is much more capable of spotting a new invasive species or otherwise making a unique or important observation. This is extremely valuable when one considers that early detection can mean the difference between eradicating an invasive species or being relegated to continual control efforts in the future. Finally, this method provides consistency with data collected during nearshore-wide survey events.

The cost analysis combined with evaluation of methods shows that towed camera is the best alternative to utilizing divers for the open-water nearshore and the marinas and embayments transects. Towed camera is less expensive than AUV surveys because AUV data require more post-processing and the equipment is expensive. Towed camera otherwise provides the same information as AUV but with the added benefit of viewing data in real time; this allows for the field team to make decisions in real time to improve the information collected. Although drop camera and grab methods are the least expensive, their cost savings does not warrant the loss of resolution that comes with only making spot checks. If taking the time to visit multiple sites around the lake, it seems preferable to get higher data value. That means either diving or towing cameras; and whenever funding permits, divers should be used.

For major tributaries and marshes, the only suitable alternative to the nearshore-wide survey transect methods would be to reduce the level of effort. As noted above, presence/absence data and general extent of aquatic invasive plants can be readily collected without having to take the time to quantify cover relative to transects and quadrats as done during nearshore-wide survey years. Although the cost savings are relatively minor, the reduced level of effort may be sufficient for monitoring these areas between nearshore-wide survey years. Diverting the saved funds to higher quality data collection efforts in the nearshore and marinas may be a preferred alternative as monitoring those transects helps evaluate the overall status of aquatic invasive plant across the lake.

Finally, all options are provided with an additional option to reduce the number of sites visited. This is illustrated in Table 3 by providing all options with a sub-option of "reduce sites by 50%". This option allows managers to decide to sample a subset of transects between nearshore-wide survey years. For instance, instead of reducing the intensity of the data collection, fewer transects would be monitored. For instance, monitoring every other transect may still provide enough value between intensive survey years for managers to understand the overall level of infestation over time. Ultimately, all options have the reduced sampling option in case reduced intensity and reduced site monitoring is desired.

Table 4. Estimated cost totals by lake-wide transect sampling option with an option to reduce the sampled sites by 50%.

Strata and Sampling Options	Estimated Cost	Reduce Sites by 50%
Open-water Nearshore Sampling Options		
Open-water nearshore full sampling intensity	$ 48,500	$ 27,150
Open-water nearshore towed camera intensity	$ 21,460	$ 13,330
Open-water nearshore AUV intensity	$ 26,320	$ 15,560
Open-water nearshore grab sampling intensity	$ 16,360	$ 10,580
Marinas & Embayments Sampling Options		
Marinas & embayments full sampling intensity	$ 28,750	$ 16,575
Marinas & embayments towed camera intensity	$ 14,640	$ 9,220
Marinas & embayments AUV intensity	$ 19,660	$ 11,630
Marinas & embayments grab sampling intensity	$ 12,090	$ 7,845
Major Tributaries Sampling Options		
Major Tributaries full sampling intensity	$ 27,750	$ 16,075
Major tributaries reduced sampling intensity	$ 21,250	$ 12,625
Marshes Sampling Options		
Marshes full sampling intensity	$ 18,000	$ 10,900
Marshes reduced sampling intensity	$ 14,750	$ 9,175

It should be noted that the costs of performing diver transects in between more intensive survey years in the tables above is lower than the costs provided in the Aquatic Plant Monitoring Plan for nearshore-wide survey year monitoring. This is because the intensive survey year costs in the plan require additional data collection to validate remote sensing mapping results and additional data analysis and reporting to combine the different monitoring efforts into a report that provides plant bed extents and composition information.

The sampling variations are effectively multiplied by several factors. For instance, each of the methods above can be mixed and chosen as necessary across strata in either full or partial intensity. The assumed partial intensity is 50%; that is that 50% of the sites currently listed in the Aquatic Plant Monitoring Plan would be chosen at random (or at least chosen in a manner that mixes locations that are believed to be positive or negative for plant presence based on previous sampling. Additionally, resource managers can choose to implement monitoring every year or at a reduced temporal scale (refer to Table 2 for various options). The plan specifies monitoring transects every year. However, resource managers can choose to monitor specific strata each year, every other year, or at any interval suitable to meet management objectives and funding levels.

Although this alternatives analysis has focused on the *in situ* methods it was noted above that there are alternatives to remote sensing techniques. However, the various methods are not provided with detailed cost estimates because those alternative methods are generally suitable for variable monitoring scales as opposed to alternative methods for nearshore-wide survey years. It was also assumed in this analysis that remote sensing techniques were not prescribed or necessary for interim sampling. Some methods are best suited for before and after treatment monitoring of areas where control efforts are proposed. It is possible however to apply the remote sensing techniques at any time so that managers can get a view of plant bed extents without having to wait for an intensive sampling year. A combined implementation of UAS and satellite imagery would likely provide the best combination of resolution and costs for a large area mapping effort (20% or more of shoreline). Although costs are not completely developed due to multiple factors that must be considered at the time of sampling, Table 4 provides a general comparison of remote sensing methods and where possible estimates costs are provided.

Table 4. Expanded table of aquatic plant sampling methods with pros/cons and estimated costs.

				Metrics Measured				Costs	
Method	**Type**	**Pros**	**Cons**	**Relative Abundance (% Cover)**	**Distribution**	**Composition**	**Extent (area)**	**Estimated Cost ($ per acre) to Acquire Data**	**Nearshore-wide Cost Estimate ($)**
Diver transect sampling	In situ/field	High resolution and data value	Relatively high cost	X	X	X			$126,750
Video Camera Tows (transect)	In situ/field/remote	Reduced field time	Requires additional time to interpret data; can only be used in open water nearshore and marinas and embayments	Generally Determined	Generally Determined	Generally Determined			$36,100
Grab/rake sample (transects)	In situ/field	Low field effort	Unreliable data due to false negatives; can spread plant fragments; only used in open-water nearshore and marinas and embayments	Generally Determined	Generally Determined	Generally Determined			$20,000
Presence/absence (transect)	In situ/field	Good ability to detect presence; reduced cost	Loss of resolution for control treatment planning	Generally Determined	Generally Determined	Generally Determined			$80,000
Multi-beam sonar	In situ/field/remote	Good coverage in water greater than 10' deep.	Vessel and equipment costs can be significant at large scale; vessel-based mapping limited in rocky/shallow areas.	Generally Determined	X		X	$4,000	
Single-beam sonar	In situ/field/remote	Works at variety of depths; inexpensive means of obtaining biomass estimates	Mapping extents required interpolating data; at large scale vessel time can lead to high costs; mapping limited to vessel's ability to operate is shallow and rocky areas	Generally Determined	X		X	$3,000	
Manned aircraft, high-resolution multi-spectral imagery provided by broker	Remote Sensing	Low cost, high resolution, Multiple uses of data beyond AIS	Current year data not typically available. Difficult to resolve deeper plant beds occurrence in turbid conditions. Shadows can impact ability to resolve plant beds near shoreline	Generally Determined	X		X	$0.05	$1,000 + costs to process data and map plant beds
LiDAR	Remote Sensing	Multiple uses of data beyond AIS, derivative product improves models	Difficulty resolving derivative products in dark bottom and turbid water conditions	Generally Determined	Generally Determined		X	$6.11	$126,000 + costs to process data and map plant beds

				Metrics Measured				Costs	
Method	**Type**	**Pros**	**Cons**	**Relative Abundance (% Cover)**	**Distribution**	**Composition**	**Extent (area)**	**Estimated Cost ($ per acre) to Acquire Data**	**Nearshore-wide Cost Estimate ($)**
High-resolution multi-spectral satellite imagery (e.g., Worldview 3)	Remote Sensing	1-day satellite repeat visit	Lower resolution than airborne products, potential for unsuitable lake surface conditions. Difficult to resolve deeper plant beds occurrence in turbid conditions. Shadow can impact ability to resolve plant beds	Generally Determined	Generally Determined		X	$0.15	$3,000 + costs to process data and map plant beds
Custom ordered Manned aircraft, high-resolution multi-spectral imagery	Remote Sensing	Multiple uses of data beyond AIS, can constrain flights to optimal lake conditions with willing vendor	Flight window may co-occur with poor lake surface conditions. Difficult to resolve deeper plant beds occurrence in turbid conditions. Shadow can impact ability to resolve plant beds	Generally Determined	Generally Determined		X	$1.21	$27,000 + costs to process data and map plant beds
Unmanned Aircraft System (UAS) high-resolution imagery	Remote Sensing	Can time flight to optimize lake condition. high resolution - best suited for smaller project areas (<2,000 acres), not appropriate for nearshore-wide survey	Most expensive, small range, multiple flights needed for nearshore-wide effort, unable to mosaic imagery offshore of key points, significant data management required, and computation power needed. Difficult to resolve deeper plant beds occurrence in turbid conditions. Shadows can impact ability to resolve plant beds	Generally Determined	Generally Determined		X	$10	$206,090 + costs to process data and map plant beds

Conclusions

In this document we have summarized Regional monitoring and management goals for aquatic plants, monitoring questions and indicators relevant to nearshore managers, survey methods, spatial designs, sampling designs and schedule considerations. The management and monitoring goals and monitoring questions provide focus for the aquatic plant monitoring program, while the indicators we identified will yield information needed to guide decision related aquatic plant management. We've identified different survey methods for submerged aquatic plants, including commonly used sampling methods (i.e., point intercept and line transect) and data acquisition methods with varying degrees of application for the Lake Tahoe aquatic plant monitoring program due to the size of the area interest and budget considerations. As we move toward the drafting of the aquatic plant monitoring plan, the following considerations are important for optimizing the allocation of monitoring efforts:

- *Degree of certainty* - The level of confidence that you must have in the results of your monitoring program plays a significant role in determining the appropriate design. In general, the degree of certainty in monitoring results is lowest for opportunistic designs, intermediate for model-based and survey designs, and highest for nearshore-wide survey designs. It is lowest for opportunistic designs because it is difficult or often impossible to assess how well the chosen sample sites represent the overall population for which inferences are intended. Because of the non-statistical nature of sample site selection, it is often impossible to assess the degree of certainty of results from opportunistic sample sites because you cannot determine the precision or bias associated with inferences to entire populations obtained from data collected at opportunistic sample sites. The degree of certainty is intermediate for model and survey based spatial designs because they depend on a statistical sample with its associated uncertainty. In addition, model-based designs can be subject to unknown uncertainties associated with model assumptions. The degree of certainty is highest for nearshore-wide survey design because all members of the target population are sampled resulting in no or low sampling uncertainty or faulty assumptions about the representativeness of selected sites.

- *Cost* - The cost of monitoring program designs generally varies directly in relation to their degree of certainty. While the high degree of certainty provided by a complete nearshore-wide survey may be attractive, in many cases the cost associated with conducting a nearshore-wide survey over a large geographic area or for the entire study period will be prohibitive using traditional in situ sampling approaches. In the end, it is important to adopt a design that is within the available budget. This may mean a revision to monitoring objectives related the degree of certainty, indicators and/or spatial designs and scheduling to best meet budget constraints.

- *Flexibility* - Over the life of a monitoring program, there may be changes in the goals and objectives, monitoring technologies, allocated budgets, or other constraints. Some designs are more amenable than others to the modification that may be necessary to meet changes. For example, an initial objective that desires the quantification of biovolume may be determined unnecessary and instead measurements of factors driving the occurrence of invasive plants is more important. Similarly, a monitoring program design that allows you to add or subtract sites without biasing your results is more desirable than one that requires an entirely new design.

When considering spatial, temporal and sampling designs, and which method or methods to choose for the aquatic plant monitoring program it is important to consider the timing and resolution of information needed by nearshore managers to inform decisions, focal and non-focal species or species groups, the size of the area of interest, and life history characteristic of focal species. Applying these considerations to the Lake Tahoe aquatic plant monitoring program, nearshore managers need to be informed about the status of aquatic plant bed presence/absence, extent, distribution, species composition, biomass volume, and whether new invasive plant species are becoming established in the Region on an annual basis. Data collection and assessment completed on an annual basis will allow managers to rapidly respond to new infestation of invasive plants and understand trends in indicators of aquatic plants. At Lake Tahoe, information about both native and invasive aquatic plants are important, however, based on guidance provided in Lake Tahoe Aquatic Invasive Species Management Plan (TRPA 2014), information on invasive plant populations appears to be the priority.

Appendix - E Hazard Analysis and Critical Control Point (HACCP) Plan for the 2018 Lake Tahoe Aquatic Plant Program Status Report

Prevention of the Spread of Invasive Species Hazard Analysis and Critical Control Points (HACCP) Plan

Prepared for

Tahoe Regional Planning Agency

Prepared by

Marine Taxonomic Services, Ltd.

Date August 10, 2018 Version 1.0

MTS
Marine Taxonomic Services, Ltd.

Section 1. Project Description

Lake Tahoe is threatened by environmental degradation. Non-indigenous and invasive aquatic plant species (or aquatic invasive plants; AIP), specifically Eurasian watermilfoil (*Myriophyllum spicatum*) and Curlyleaf pondweed (*Potamogeton crispus*), impact the quality and condition of Lake Tahoe's nearshore environments including inlet marinas and stream tributaries. The establishment of AIP in nearshore areas can predispose those areas for the establishment of other undesirable organisms by changing substrate and habitat conditions. The distribution and abundance of various AIP are localized to certain areas based on factors such as proximity to the point of introduction, land-use (e.g., inlet marinas and boat ramps), stream inputs, littoral water circulation patterns, water depth, substrate type, and other features of the lake bottom.

The Tahoe Regional Planning Agency (TRPA) strives to protect this national treasure for the benefit of current and future generations. As a part of this effort, TRPA works with partner agencies to control Aquatic Invasive Species (AIS) in the Lake Tahoe Region. With the establishment of AIS in Lake Tahoe, attention has turned to controlling these AIP.

Working with the Near-shore Aquatic Weed Working Group (NAWWG) which is directed by the multi-agency Lake Tahoe Aquatic Invasive Species Coordinating Committee (LTAISCC), the Tahoe Resource Conservation District (TRCD) implements aquatic invasive plant control at Lake Tahoe to address the threat of infestation expansion and accompanying degradations. These aquatic resource managers need to know the lake-wide status and trends of aquatic invasive plants at Lake Tahoe to better gauge the overall effectiveness of invasive plant control and prevention interventions, and to more effectively target areas for control efforts-where new invasive plant growth is detected.

The 2018 nearshore-wide plant survey has been contracted to prepare and implement appropriate protocols and detailed information required to consistently collect, quantify, and report on the status and change in composition, relative abundance/density, distribution, and extent of native and AIP. Data will be collected with a combination of remotely sensed (the fusion of high-resolution multispectral imagery with topobathymetric LiDAR) and *in situ* (e.g., dive transects, diver tows, ROV/UAS) data to accomplish the monitoring objectives detailed in the TRPA Request for Proposals document.

Successful control of aquatic invasive plants in Lake Tahoe will require synchronized survey and control treatment efforts and repeated treatment of infestations on an annual basis to significantly reduce source populations of AIPs, and locally eradicate satellite infestations.

Section 2. Potential Invasive Non-native Species Assessment

List all relevant species that you have identified to be associated with the Operation Procedure.

Examples: Bluegill and Brown Bullhead Catfish	Vertebrates Bluegill Brook Trout Brown Bullhead Catfish Brown Trout Kokanee Salmon Lake Trout Large Mouth Bass Rainbow Trout Small Mouth Bass
Examples: *Crepidula fornicata* and *Rapana venosa*	Invertebrates *Corbicula fluminea*
Examples: *Alexandrium catanella*	Phytoplankton
Examples: *Undaria pinnatifada, Sargassum muticum* and *Spartina anglica.*	Eurasian watermilfoil Curly-leaf pondweed
Examples: Bacterial or virus pathogens	Pathogens

Section 3. Operation Procedures

List the steps involved in your activity. Only a simple, but complete, description of the procedure is needed. It is important to include all the steps undertaken. Use as many steps necessary to define your procedure.

Step 1	Load pre-cleaned dry dive equipment on pre-cleaned dry dive boat.
Step 2	Launch dive boat from the dock into transect site water.
Step 3	Dive team enters transect site water from dive boat with all gear.
Step 4	Dive team will survey transect site for native and invasive species. Hand pull of invasive plants will take place at low density sites where invasives are found.
Step 5	Dive team completes survey and exits transect site water with all gear. Rinse all dive equipment thoroughly with hot water. Team will transport any collected aquatic weeds to an off-site disposal area.

Section 4. Hazard Analysis Form

1. Activity Nearshore-wide survey procedure from Section 1	**2. Risks** Potential invasive species risk associated with this procedure	**3 Significance** Risks deemed significant (yes/no)	**4. Resourcing** Justify your decision in the significance assessment	**5. Exclusion** What control measures can be implemented to minimize risk	**6. Action** Is this step where action is required (yes/no)?
Operation Procedure Step 1 Load pre-cleaned dry dive equipment on pre-cleaned dry dive boat.	*Vertebrate species*	NO	Equipment may not have been cleaned thoroughly	Certify that all equipment has been thoroughly cleaned before loading	YES
	Invertebrate species *Corbicula fluminea*	NO	Equipment may not have been cleaned thoroughly	Certify that all equipment has been thoroughly cleaned before loading	YES
	Phytoplankton species	NO	Equipment may not have been cleaned thoroughly	Certify that all equipment has been thoroughly cleaned before loading	YES
	Eurasian watermilfoil *Curly-leaf pondweed*	NO	Equipment may not have been cleaned thoroughly	Certify that all equipment has been thoroughly cleaned before loading	YES
	Others	NO	Diseases spread by dirt/debris	Use sterilize procedures/methods	YES

1. Activity Nearshore-wide survey procedure from Section 1	**2. Risks** Potential invasive species risk associated with this procedure	**3 Significance** Risks deemed significant (yes/no)	**4. Resourcing** Justify your decision in the significance assessment	**5. Exclusion** What control measures can be implemented to minimize risk?	**6. Action** Is this step where action is required (yes/no)?
Operation Procedure Step 2 Launch dive boat from dock into transect site water.	*Vertebrate species*	NO	Dive boat cleaned thoroughly before loading	Certify that all equipment has been thoroughly cleaned before loading	NO
	Invertebrate species	NO	Dive boat cleaned thoroughly before loading	Certify that all equipment has been thoroughly cleaned before loading	NO
	Phytoplankton species	NO	Dive boat cleaned thoroughly before loading	Certify that all equipment has been thoroughly cleaned before loading	NO
	Eurasian watermilfoil *Curly-leaf pondweed*	NO	Dive boat cleaned thoroughly before loading	Certify that all equipment has been thoroughly cleaned before loading	NO
	Others	NO	Dive boat cleaned thoroughly before loading	Certify that all equipment has been thoroughly cleaned before loading	NO

1. Activity Nearshore-wide survey procedure (from Section 1)	**2. Risks** Potential invasive species risk associated with this procedure	**3 Significance** Risks deemed significant (yes/no)	**4. Resourcing** Justify your decision in the significance assessment	**5. Exclusion** What control measures can be implemented to minimize risk	**6. Action** Is this step where action is required (yes/no)?
Operation Procedure Step 3 Dive team enters transect site water from dive boat with all gear.	*Vertebrate species*	NO	Dive gear cleaned thoroughly before loading	Certify that all equipment has been thoroughly cleaned before loading	NO
	Invertebrate species	NO	Dive gear cleaned thoroughly before loading	Certify that all equipment has been thoroughly cleaned before loading	NO
	Phytoplankton species	NO	Dive gear cleaned thoroughly before loading	Certify that all equipment has been thoroughly cleaned before loading	NO
	Eurasian watermilfoil *Curly-leaf pondweed*	NO	Dive gear cleaned thoroughly before loading	Certify that all equipment has been thoroughly cleaned before loading	NO
	Others	NO	Dive gear cleaned thoroughly before loading	Certify that all equipment has been thoroughly cleaned before loading	NO

1. Activity Nearshore-wide survey procedure from Section 1	**2. Risks** Potential invasive species risk associated with this procedure	**3 Significance** Risks deemed significant (yes/no)	**4. Resourcing** Justify your decision in the significance assessment	**5. Exclusion** What control measures can be implemented to minimize risk	**6. Action** Is this step where action is required (yes/no)?
Operation Procedure Step 4 Dive team will survey transect site for native and invasive species. Hand pull of invasive plants will take place at low density sites where invasives are found.	*Vertebrate species*	NO	Dive gear cleaned thoroughly before survey	Certify that all equipment has been thoroughly cleaned before survey	NO
	Invertebrate species	NO	Dive gear cleaned thoroughly before survey	Certify that all equipment has been thoroughly cleaned before survey	NO
	Phytoplankton species	NO	Dive gear cleaned thoroughly before survey	Certify that all equipment has been thoroughly cleaned before survey	NO
	Eurasian watermilfoil *Curly-leaf pondweed*	NO	Dive gear cleaned thoroughly before survey	Certify that all equipment has been thoroughly cleaned before survey	NO
	Others	NO	Dive gear cleaned thoroughly before survey	Certify that all equipment has been thoroughly cleaned before survey	NO

1. Activity Nearshore-wide survey procedure from Section 1	**2. Risks** Potential invasive species risk associated with this procedure	**3 Significance** Risks deemed significant (yes/no)	**4. Resourcing** Justify your decision in the significance assessment	**5. Exclusion** What control measures can be implemented to minimize risk	**6. Action** Is this step where action is required (yes/no)?
Operation Procedure Step 5 Dive team completes survey and exits transect site water with all gear. Rinse all dive equipment thoroughly with hot water. Team will transport the aquatic weeds collected to an off-site disposal area.	*Vertebrate species*	NO	Dive team and equipment may be contaminated with invasives located in work area	Rinse with hot water, drain, dry, clean and inspect at risk equipment	NO
	Invertebrate species *Corbicula fluminea*	YES	Dive team and equipment may be contaminated with invasives located in work area	Rinse with hot water, drain, dry, clean and inspect at risk equipment	YES
	Phytoplankton species	NO	Dive team and equipment may be contaminated with invasives located in work area	Rinse with hot water, drain, dry, clean and inspect at risk equipment	NO
	Eurasian watermilfoil *Curly-leaf pondweed*	YES	Dive team and equipment may be contaminated with invasives located in work area	Rinse with hot water, drain, dry, clean and inspect at risk equipment	YES
	Others	NO	Diseases/pathogens could be on equipment	Clean and prepare gear for sterile treatment	NO

Section 5a. Hazard Control Form

Control measures to reduce risk

Action Point Unique Identifier	**Significant Risks (Yes/No)**	**Control Measure/s**	**Limits of each control measures**
Step 1 Load pre-clean dry dive equipment on pre-clean dry dive boat.	Equipment may not have been cleaned thoroughly Diseases spread by dirt/debris	Certify that all equipment has been thoroughly cleaned before loading	Visually examine equipment/gear and certify equipment for use is clean
Step 5 Dive team completes survey and exits transect site water with all gear. Rinse all dive equipment thoroughly with hot water.	Dive team and equipment may be contaminated with invasives located in work area Diseases/pathogens could be on equipment	Rinse with hot water, drain, dry, clean and inspect at risk equipment Clean and prepare gear for sterile treatment	Follow established decontamination process to clean all gear thoroughly

Section 5b. Hazard Monitoring Form

Monitoring protocols to be employed

Action Point Unique Identifier	**What is been monitored?**	**How will monitoring be progressed?**	**Frequency**	**Person Responsible**
Step 1 Load pre-clean dry dive equipment on pre-clean dry dive boat.	Visually inspect for invasive species	With magnification if needed	Every time the gear is loaded into the dive boat	Every member of dive team
Step 5 Dive team completes survey and exits transect site water with all gear. Rinse all dive equipment thoroughly with hot water.	Procedures used are removing unwanted species	Visual inspection	Every time the equipment is used	Every member of dive team

Section 5b. Hazard Response Form

Actions to be taken when control measures are not successful or are not met

Action Point Unique Identifier	Indicator/s	Action	Supporting Documentation (if any)	Verification/Outcome
Step 1 Load pre-clean dry dive equipment on pre-clean dry dive boat.	Presence of invasive species on equipment and gear	Will not use equipment that cannot be easily determined to be clean of aquatic invasives or disease/pathogens		
Step 5 Dive team completes survey and exits transect site water with all gear. Rinse all dive equipment thoroughly with hot water.	Presence of invasive species on equipment and gear	Will not use equipment that cannot be easily determined to be clean of aquatic invasives or disease/pathogens		