2018 Lake Tahoe Nearshore Aquatic Plant Status Report

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Abstract

Goals and objectives for Lake Tahoe have been adopted by nearshore resource managers through various planning documents at Lake Tahoe to maintain the biological integrity of the lake’s nearshore environment. Submerged aquatic plants (SAV) are an important biological component within Lake Tahoe’s nearshore context. To understand the current lake-wide status of SAV, this survey was conducted using comprehensive field surveys and remote sensing data. Field surveys found that quadrat and transect methodologies provided insight about aquatic plant species presence throughout the Lake Tahoe basin. The majority of vegetated transects and quadrats were reported along the southern and western portions of the lake with non-native plant presence greatest in the southern portions of the lake. Field data and map products derived from high-resolution topobathymetric data and 4-band imagery were used in Object Based Image Analysis to automate the extraction SAV features and estimate the full extent of these features across the area of interest. Initial results indicated that the combination of comprehensive field surveys with remote sensing data products can aid managers in identifying the location and status of SAV throughout the area of interest. The field data were especially valuable in characterizing species composition and relative abundance of different SAV, including invasive aquatic plants. Although initial automated mapping efforts show promise, additional interactions with nearshore managers are needed to adapt processes to best meet regional needs.

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Introduction

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 the survey and planning associated with submerged aquatic vegetation (SAV), including invasive aquatic plants. 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."

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 conditions and threshold standard emphasize Tahoe agencies' collective goals to restore and maintain a 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 existing goals and standards is a specific numerical target or range of conditions 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 Tahoe Aquatic Plant Monitoring Program is intended to gather, analyze, and report information relative to SAV populations in Lake Tahoe with an emphasis on collecting data that can be used to target locations for invasive aquatic plants control efforts. An element of the monitoring program includes this status report to provides results of the first comprehensive lake-wide aquatic plant survey using both diver survey data and the interpretation of high-resolution remote sensing data. The intent of this lake-wide survey is to provide a baseline view of the current status of plant communities across the entirety of Lake Tahoe as well as some of the marshes and tributaries that are linked to Lake Tahoe.

In addition to characterizing the current extent and distribution of aquatic plants, this survey effort is intended to help guide the Lake Tahoe Aquatic Plant Monitoring Plan. The monitoring plan will incorporate the lessons learned from this first monitoring effort to help frame a path forward such that future monitoring can be performed in an efficient manner that compliments this effort and builds a robust dataset that resource managers can use to gauge the effectiveness of invasive plant control efforts and plan future control efforts.

This document provides the methods and results associated with a comprehensive aquatic plant survey completed in 2018 with the goal to address the following questions:

- Question #1: *What is the status of the extent (area) of invasive and native aquatic plant beds within Lake Tahoe's nearshore?*

- Question #2: *What is the status of the distribution (spatial arrangement) of invasive and native aquatic plant beds within Lake Tahoe's nearshore?*

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

- 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 and standards. Moving forward, subsequent monitoring efforts in accordance with the Aquatic Plant Monitoring and Evaluation Plan can be used to study the temporal trends associated with the above guiding questions.

Survey Area

The Tahoe Region is located on the border of the states of California and Nevada, between the Sierra Crest and the Carson Range (Figure 1). Approximately two-thirds of the Region is in California, with one-third within the state of Nevada. The Tahoe Region contains an area of about 501 square miles, of which approximately 191 square miles comprise the surface waters of Lake Tahoe.

The area of interest for this survey effort in large part adhered to the nearshore boundary definition identified by Heyvaert et al. (2013). 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 (sampling frame) is generally represented in Figure 2, and included other features connected to Lake Tahoe's nearshore such as marinas, embayments and other suitable aquatic plant habitat associated with stream mouths or freshwater marshes.

Methods

In Situ and Remote Sensing Survey Components

Two types of aquatic plant survey effort were applied to the 2018 aquatic plant survey, including diver surveys which sampled line transects distributed throughout the survey area (Figure 1), and a nearshore-wide aquatic plant census conducted via interpretation and mapping of remotely sensed data and verified with in-situ diver observations. The nearshore-wide aquatic plant mapping component provided for a 2018 "baseline" status estimate of aquatic plant beds around Lake Tahoe's nearshore zone, while transect surveys allowed for training and validation of remotely sensed data, and established locations for annual surveillance for tracking trends in aquatic plant beds. The sampling frame (i.e., survey area) and habitat stratification scheme used for diver line-transect surveys was the same as that used for the nearshore-wide census. Four strata were used to divide the aquatic plant population into meaningful sampling units that included open-water nearshore, marinas and embayments, major tributaries, and marshes.

Aquatic Plant Field (In Situ) Surveys

Aquatic plant field (in-situ) surveys were performed by diving, snorkeling, or observing aquatic plants from the surface. All four sampled strata had field survey components. In the sections below, the various in-situ methodologies employed are described. Following the description of the field methods, strata-specific application of the survey methods is provided.

Transect Method

Transects were the primary means used to sample for plant presence. They were also used to determine percent cover of aquatic vegetation and relative percent cover among the various species of aquatic plants identified. Transects were placed within each stratum in accordance with the draft monitoring plan and methods identified for each stratum. Strata specific methods are provided in the below sections. Transects were placed in the field by using a GPS to navigate as closely as possible to one end of the proposed transects. The survey team then made observations along the transect by diving, snorkeling, or walking the transect.

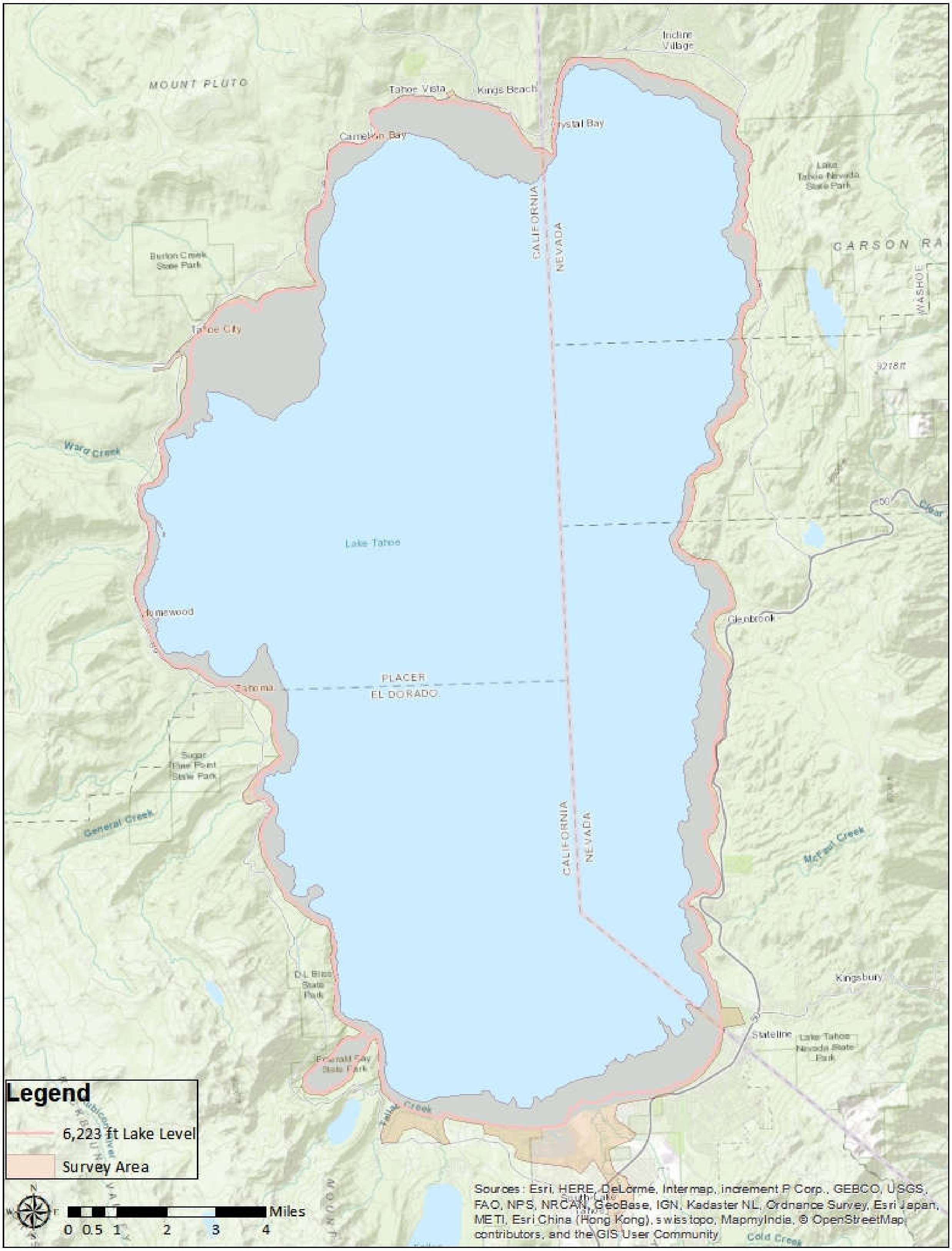

Figure 1. Aquatic plant survey boundary (shaded grey) relative to the 6,223 ft natural rim lake level (shown in pink). The lakeward boundary reflects the 21m (~69ft) bathymetric contour.

At the start of each transect survey, a marker buoy was deployed, and a start waypoint was taken using a GPS mounted marker buoy. Depending on water depth, the marker buoy was either positioned by the research vessel or on foot by the research team. Once the start of the transect was recorded, the diver/observer would anchor a lead line to the base of the start buoy and use a compass bearing to swim, snorkel, or walk the lead line to the end of the transect. Depending on the habitat, transect end points were determined by a designated transect length or water depth reached. At sites where no vegetation was present, the transect was administered without the use of a lead line and relied solely on compass navigation to complete the transect.

Feature data collected along transects included vegetation species presence, debris presence, vegetative fragment presence, vegetation height, and debris thickness. The features were noted with each change in vegetation or debris bottom cover. A change in bottom feature cover was indicated any time the feature or group of features changed. For instance, a change in a plant bed from a single species to a mixture of species would be noted and delineated relative to the transect. Additionally, substrate was often noted.

Feature data were collected relative to each transect by either of two methods to determine the line intercept distance and position for each feature occurrence. Feature intercepts were either determined by direct recording with a space-based augmentation system global positioning system SBAS GPS or dead reckoning by using a tape measure as the transect such that position can be recorded relative to the transect start point. When dead reckoning was utilized, the SBAS GPS was still used to accurately depict the start point. The transect-plant intercept distances were recorded in real time where tape measures were used or were calculated in ESRI ArcMap GIS software after plotting the SBAS GPS collected waypoints that delineated feature start and end points. Individual plants and aggregations of mixed species beds were noted when intercepted even when the intercept distance was minimal (e.g. less than 1 m). If multiple small plants or plant patches were intercepted with gaps in between occurrences, a 1-m minimum distance rule was applied. The rule was that multiple individual plants were considered part of the same patch if there was not more than a 1-m gap between individuals. Once a gap was larger than 1 m, or a different species was encountered, a new record was recorded.

In addition to the above transect data, the presence of all plant species observed along a transect were noted regardless of whether the species was intercepted by the transect. This increased the data value of performing the survey because it allowed recording of information even if a species (or group of species) was not intercepted yet were observed. This can happen in areas with very low plant density such that the transect does not intercept all species observed during a transect survey. Observers kept a separate record of species observed during transect sampling. In addition to vegetation, observers maintained a record of observed fish and invertebrate species.

Quadrat Point Intercept Method

In habitats where vegetation was observed to have species mixed at small spatial scales, quadrat (point intercept) sampling was performed. Quadrats allowed for finer-scale observation of relative plant cover and species composition. The quadrat measured 0.5 m x 0.5 m and covered a 0.25-m^2 area. Vegetation coverage was recorded within transects by using a 16-intercept grid on 10 cm centers within the quadrat. The point intercept protocol is outlined in Elzinga et al. (2001). At each intercept the plant species directly under the intercept were recorded. It was possible to record multiple species at the same intercept given some species formed a canopy over other species. Within a quadrat, percent cover was calculated for each plant species as the number of intercepted points by the species divided by 16. Percent cover for each species on a transect was calculated as the average percent cover of all quadrats placed on the transect. Additional quadrats were enumerated without being part of a transect in cases where additional data were sought for validation of remote sensing data.

Open-Water Nearshore Survey Stratum

Survey of the open water nearshore stratum included the lakeward water area from the lake surface elevation at the time of the survey (approximately 6,230ft) to the depth contour of approximately 6,161ft. Diver transects were established approximately perpendicular to the shoreline and extended from the shoreline to a depth that did not extend beyond 69-ft deep. Within this stratum, both targeted and systematic transects were established. Targeted transects were established at known infestations of invasive aquatic plants, suspected infestations, or areas likely susceptible to establishment of invasive aquatic plants. Areas targeted were informed by nearshore managers. Target areas included:

- Truckee River (lakeward of dam at Tahoe City)
- Glenbrook
- Zephyr Cove
- Zephyr Point
- Round Hill Marina
- Nevada Beach (lakeward of Burke Creek mouth)
- Edgewood (lakeward of Edgewood Creek Mouth)
- Timber Cove Pier
- Upper Truckee River (lakeward of Upper Truckee River mouth)
- Baldwin Beach (between Taylor Creek and Tallac Creek)
- Emerald Bay (at opening to bay)
- Avalanche Beach (near mouth of Eagle Creek in Emerald Bay)
- Meeks Bay (lakeward of Meeks Marina)
- Tahoe Tavern
- Camp Richardson (parallel to marina pier)

Systematic transects were established approximately every 3 km around the lake. The sampling of systematic transects was the same as the layout used for targeted transects (i.e. approximately perpendicular to shoreline, extending from shoreline to a depth of approximately 69 ft). In instances where a targeted transect was within 3 km of a systematic transect, the transect spacing would be reset and the next systematic transect placed 3 km from the targeted transect. This meant the maximum spacing between nearshore transects was 3 km with shorter inter-transect distances possible due to the placement of targeted transects. Transect positions were established and mapped prior to field work. However, in limited situations and after the originally planned transect survey, a limited number of additional survey transects were established at areas identified by divers or nearshore managers for the purpose of resolving aquatic invasive plant occurrences or to provide additional data for the interpretation of remote sensing data. These additional transects were placed shore parallel through shallow-water plant beds. These additional transects occurred at Camp Richardson, Baldwin Beach, and offshore of Olympic Drive (northwest shore near Tahoe Tavern).

The transect methodology described above was applied to all nearshore transects. Quadrat data were collected opportunistically on or near transects to provide data to help train the classification of aquatic plant patches through remote sensing data interpretation. Quadrats were not collected on transects in the nearshore stratum to provide vegetation cover (relative abundance) or species composition data. The transect intercept data were used to determine percent cover of plant species by dividing the total length a species intercepted along any given transect by the total transect length.

Marsh Survey Stratum

Four freshwater marshes were identified by managers as providing suitable habitat for submerged aquatic plants, including: 1) Upper Truckee Marsh, 2) Pope Marsh, 3) Taylor Creek Marsh, and 4) Tallac Creek Marsh. To establish long-term transects (and transects for training and validating remote sensing data), all open-water features (ponds, backwaters and tributaries) were identified in GIS from available imagery. To establish locations for line transects, a 150 X 150 m systematically spaced point grid was intersected over imagery of the marsh stratum. Points that intersected water were randomly selected as starting points for 50-m transects. Once the transects starting points were selected, the orientation of each transect was randomly established to ensure continued co-occurrence with water surface. A maximum of 4 transects per marsh were delineated.

Transects within the marsh stratum were surveyed using the same methods outlined for the transect survey method outlined above. Quadrat sampling was tested at Upper Truckee Marsh by systematically sampling along the transects by placing a quadrat every 5 m. Quadrat methods followed those outlined above. Quadrat data were only used to support the LiDAR mapping; quadrat sampling results are not provided in the results as they were not consistently applied across the stratum.

Marinas and Embayments Survey Stratum

This stratum was sampled with transects and transect positions were chosen in a manner like that for the marsh stratum. A 150-m point grid was overlaid over the open water body portion of the marina or embayment being studied. Points that intersected with open water were randomly selected as the starting point for transect layout. Transects were nominally 50-m long and were oriented randomly based on the available azimuths that could support a 50-m transect. The transect sampling intensity was variable in marinas and embayments; intensity varied dependent upon multiple factors such as level of current invasive plant knowledge, desire to track infestations to support control programs, obstructions to navigation, and size of the marina/embayment.

Quadrats were not collected in marinas and embayments as part of the primary field sampling. However, quadrat data were collected opportunistically while working within embayments and marinas to collect data for validation of remote sensing data.

Marinas and embayments were defined as areas where nearshore littoral currents and processes might be interrupted by anthropogenic or natural features such as headlands, rock jetties, or sheet-pile barriers. These features can result in increased water temperature associated with increased residence time of water or provide alterations in current patters that create areas where seeds and vegetation fragments can settle. The marinas and embayments chosen for the survey were targeted based on input from nearshore managers whom identified a need to target marinas and embayments with known or suspected plant beds and to help provide data for training and validation of remote sensing data.

Marinas and embayments target for sampling included:

- Lakeside Marina (not sampled in 2018 due active control efforts)
- Lakeside Beach (between sheet pile and beach area), chosen for training remote sensing data
- Ski Run Marina, chosen for training remote sensing data
- Tahoe Keys Marina - known invasive plant occurrence, chosen for training remote sensing data

- Tahoe Keys Homeowners - known invasive plant occurrence, chosen for training remote sensing data
- Meeks Marina - known invasive plant occurrence, chosen for training remote sensing data
- Obexer's Marina
- Homewood Marina
- Fleur Du Lac Marina
- Sunnyside Marina
- Tahoe City Marina
- Star Harbor
- Carnelian Bay (Sierra Boat Company Marina)
- Tahoe Vista Boat Ramp
- North Tahoe Marina
- Crystal Bay Homeowner Marinas 1, 2, & 3
- Sand Harbor
- Secret Cove
- Logan Shoals
- Cave Rock Boat Launch
- Elk Point Homeowners (embayment north of Elk Point Marina)
- Elk Point Marina (not sampled in 2018 due active control efforts)
- Logan Shoal's Marina (access was denied to this location and thus not sampled in 2018)
- Wovoka Bay

Major Tributaries Survey Stratum

This stratum was surveyed to determine the extent of aquatic plant bed connectivity between the Lake Tahoe open-water nearshore stratum and major tributaries that flow into Lake Tahoe. The survey sites were chosen through consultation with resource managers. Survey sites targeted within the stratum included:

- Eagle Creek
- General Creek
- Blackwood Creek
- Ward Creek Mouth
- Truckee River outlet
- Upper Truckee River
- Burke Creek
- Taylor Creek
- Tallac Creek
- Glenbrook Creek
- Edgewood Creek
- Snow Creek
- North Canyon Creek

Data were collected at stream mouth and stream outlet sites along the thalweg from the respective tributary mouth to approximately 500 m upstream or until a >1% grade was reached. Transects were completed by walking, swimming on snorkel, and diving on SCUBA dependent on site terrain and channel depth. The transect sampling methods followed those detailed above.

Quadrats were sampled along the transects within this stratum because the survey team felt the scale at which plant beds changed with regards to species composition and abundance was too fine to effectively survey using the transect intercept method alone. The quadrats within this stratum were placed systematically every 10 m along the transects. Quadrat sampling methods were the same as those outlined above.

In-Situ Data Evaluation

Aquatic plant data was summarized by comparing plant coverage among strata and among transects within a stratum. Quadrat data were analyzed for relative dominance by species across a stratum and was compared to transect data. Quadrat data for major tributaries sampling were used to generate rarefaction curves in EstimateS (Colwell 2013). A rarefaction curve was used to assess species richness from the results of sampling. The generated curves illustrate the relationship between sampling intensity and discovery of unique species. The curves can inform the need to perform similar sampling intensity or modified intensity in the future.

Aquatic Plant Mapping

Remote Sensing Data

Topobathymetric LiDAR and 4-band Imagery Acquisition and Processing

Light Detection and Ranging (LiDAR) data and digital imagery was collected in September of 2018 for the Lake Tahoe area of interest (as shown in Figure 2). The survey area included the transition zones between the upland landscape with elevation ranges of 6,229 to 6,250 feet and the aquatic zone with up to 65 ft of observed depth. Conventional near-infrared (NIR) LiDAR was fully integrated with green wavelength (bathymetric) LiDAR in order to provide a seamless upland/aquatic topobathymetric LiDAR dataset. In addition, 4-band (red, blue, green, and near-infrared) digital imagery were collected. These datasets were collect using a manned Cessna Caravan. The report in Appendix A provides contract specifications, data acquisition procedures, processing methods, and analysis of the final datasets, including accuracy assessment, depth penetration, and density.

Unmanned Aircraft System Imagery Acquisition and Processing

Small unmanned aircraft systems (UAS), more commonly called drones, were used to capture high-resolution color imagery for selected sites – targeting imagery collection at sites within marsh, stream mouth and marina/embayment strata. The primary purpose of collecting this imagery was to aid in the interpretation of LiDAR data and airborne imagery that were collected at the survey area scale. To acquire UAS imagery, both fixed-winged (eBee Sensefly Plus platforms) and multi-rotor (DJI Mavic Pro 2) UAS platforms were used – the choice of one platform over the other was dictated by staging area constraints. In general, the fixed-winged platform was used for larger, open tree canopy areas where sufficient area for aircraft takeoff and landing was available, such as at marshes. The multi-rotor platform was used otherwise. All flights were performed by a FAA certified UAS pilot according to FAA Part 107 regulations for uncontrolled airspace. All UAS images were collected at approximately 399 ft above ground level. Images collected overlapped with each other by 75% latitudinally and 60% longitudinally. UAS images collected for each site were processed with Pix4D photogrammetry software (https://www.pix4d.com/) to produce 2D orthoimage mosaics (orthorectified visible spectrum images in GeoTIFF format). Resulting UAS orthomosiac images were then georeferenced to ground features in common in the 4-band airborne imagery.

Aquatic Plant Feature Extraction

Aquatic plant feature extraction centered on using the remotely sensed data acquired for this project to map and quantify subsurface (submerged) and surface aquatic vegetation. Surface vegetation was defined as photosynthetically material that is at or near the water surface and is visible in the near infrared portion of the electromagnetic spectrum. In general, surface vegetation is at the water's surface or within the first 10cm depth. Examples from the Tahoe Keys are shown in Figure 2. Whereas surface vegetation is detectable using imagery alone, subsurface vegetation requires a combination of aerial imagery and LiDAR bathymetric bottom reflectance to avoid confusion with substrate materials (Figure 3).

Figure 2. Example of aquatic surface vegetation observable in the 2018 aerial imagery displayed as a color infrared composite. Location: Pope Marsh (left) Tahoe Keys Homeowner's Lagoon (right).

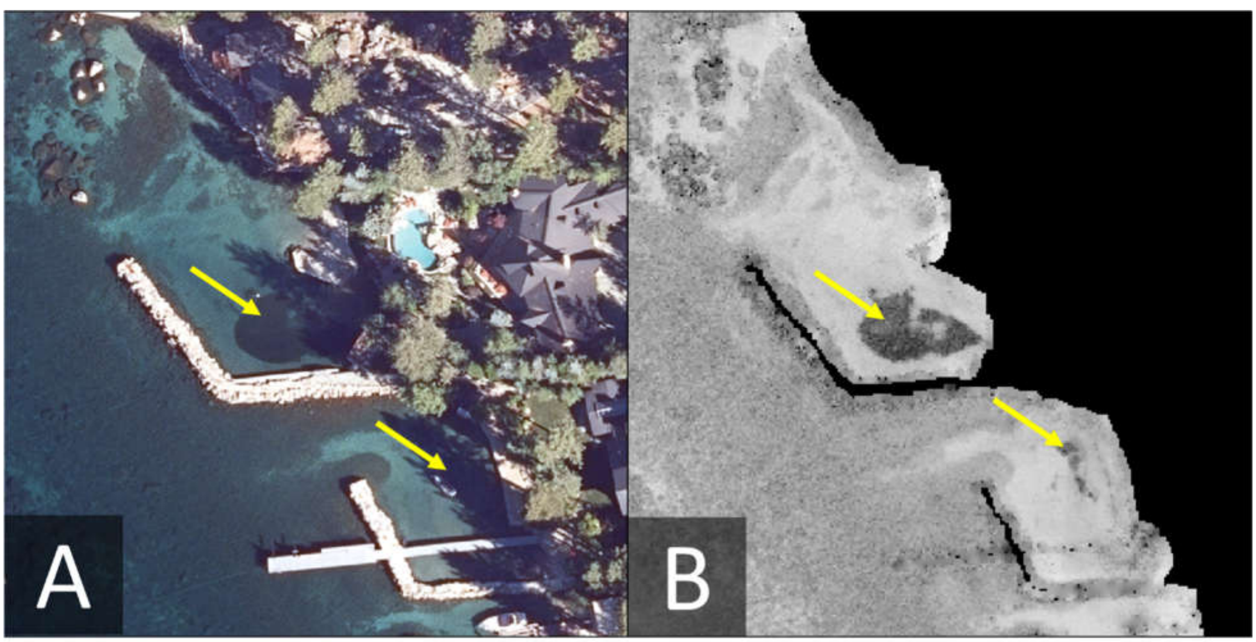

Figure 3. Eurasian watermilfoil locations overlaid on a 2018 aerial imagery true color composite and the LiDAR bathymetric bottom reflectance. Location: Wovoka near Pine Point Drive on east shore of Lake Tahoe.

The overall aquatic plant mapping workflow, which involved incorporating the imagery and LiDAR into an automated system is presented in Figure 4.

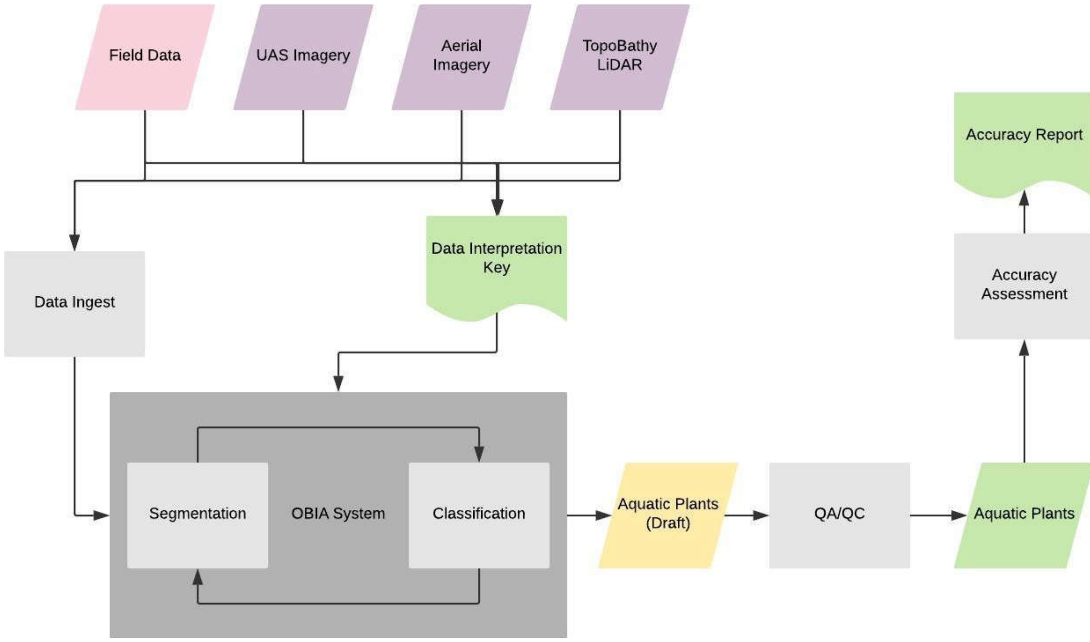

Figure 4. Remote sensing feature extraction workflow.

Data interpretation keys were developed to guide the feature extraction process (Figure 5). These keys were developed using a combination of field diver data and local knowledge. They served as the foundation for guiding aquatic plant feature identification.

Figure 5. Sample data interpretation key for aquatic vegetation mapping. Location: Wovoka near Pine Point Drive, east shore of Lake Tahoe.

Automated feature extraction centered on mapping subsurface and surface vegetation erring on the side of errors of commission (i.e., including aquatic vegetation that may not actually occur at a location), with the rationale that the resulting data should help to identify areas of concern for follow-on mapping (e.g., using UAS) or field verification. The feature extraction methods relied on 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. This approach especially important for improving the 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. These factors enabled the integration of the LiDAR, imagery, and derived vector data layers collected in 2018.

The rule-based expert system functioned by assimilating segmentation and classification algorithms into a workflow that increased the amount of contextual information available for feature extraction as the rule set progressed. A portion of the rule-based expert system is shown in Figure 6. Below we present individual examples of how the rule set operated for both subsurface and surface vegetation.

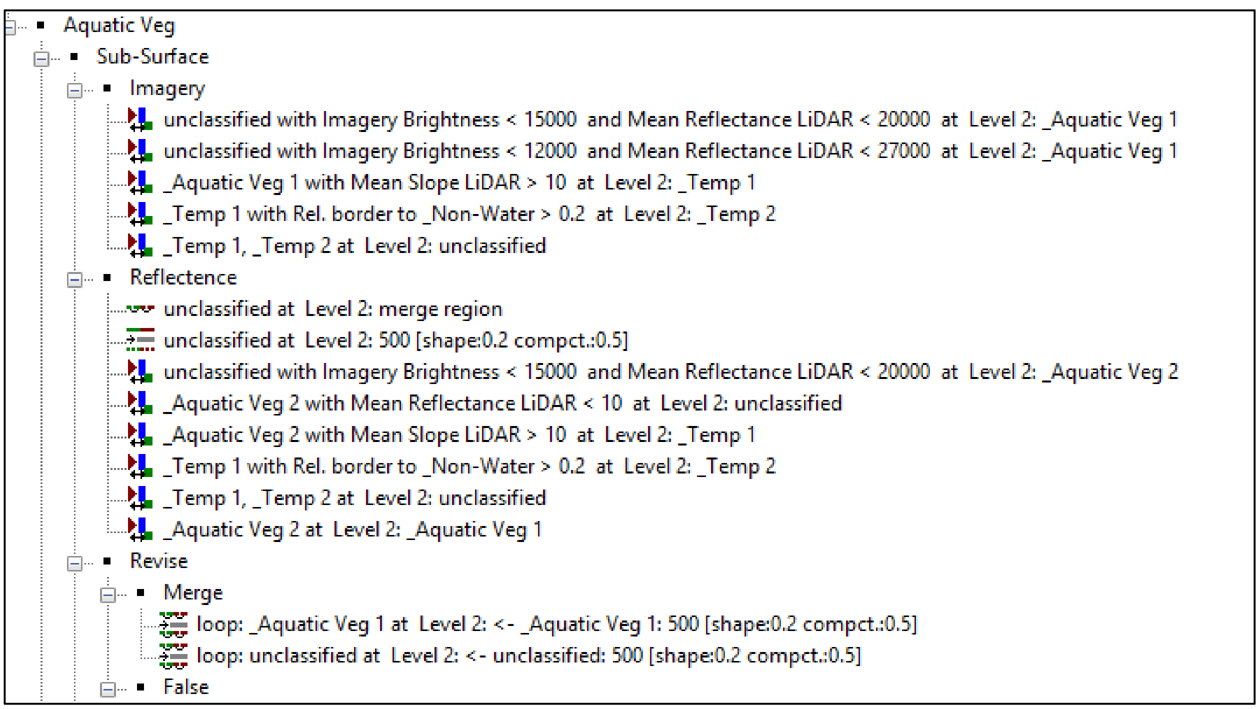

Figure 6. A portion of the rule-based expert system used for aquatic vegetation mapping at Lake Tahoe.

The primary data used for subsurface aquatic vegetation mapping is shown in Figure 7 and included, aerial imagery, LiDAR bathymetric bottom reflectance, LiDAR derived topobathymetric digital elevation model and slope derived from the digital elevation model. These datasets consist of both passive (imagery), and active (LiDAR) remotely sensed data. The imagery, when rendered in true color, provides the most natural rendition of Lake Tahoe. The acquisition, which was done at times with minimal waves, provided excellent penetration of the water column. The two chief limitations of using the imagery are that submerged aquatic plants mimics dark substrate material (such as boulders/cobbles/rocks and pockets of organic material [e.g., pine needles, etc.]) and shadows from trees along the shoreline obscured a clear view of the lake bottom. The LiDAR reflectance provided a clearer view of the lake bottom, with most types of aquatic vegetation appearing darker than surrounding features, but data gaps do exist, and the reflectance values were not balanced across flight lines, resulting in data inconsistencies. The LiDAR topobathymetric data helped to distinguish substrate materials such as boulders and cobble that often appear tonally similar in both the aerial imagery and LiDAR reflectance. Boulder and cobble substrates tended to exhibit higher slope values than aquatic plants – this information was used to inform aquatic mapping.

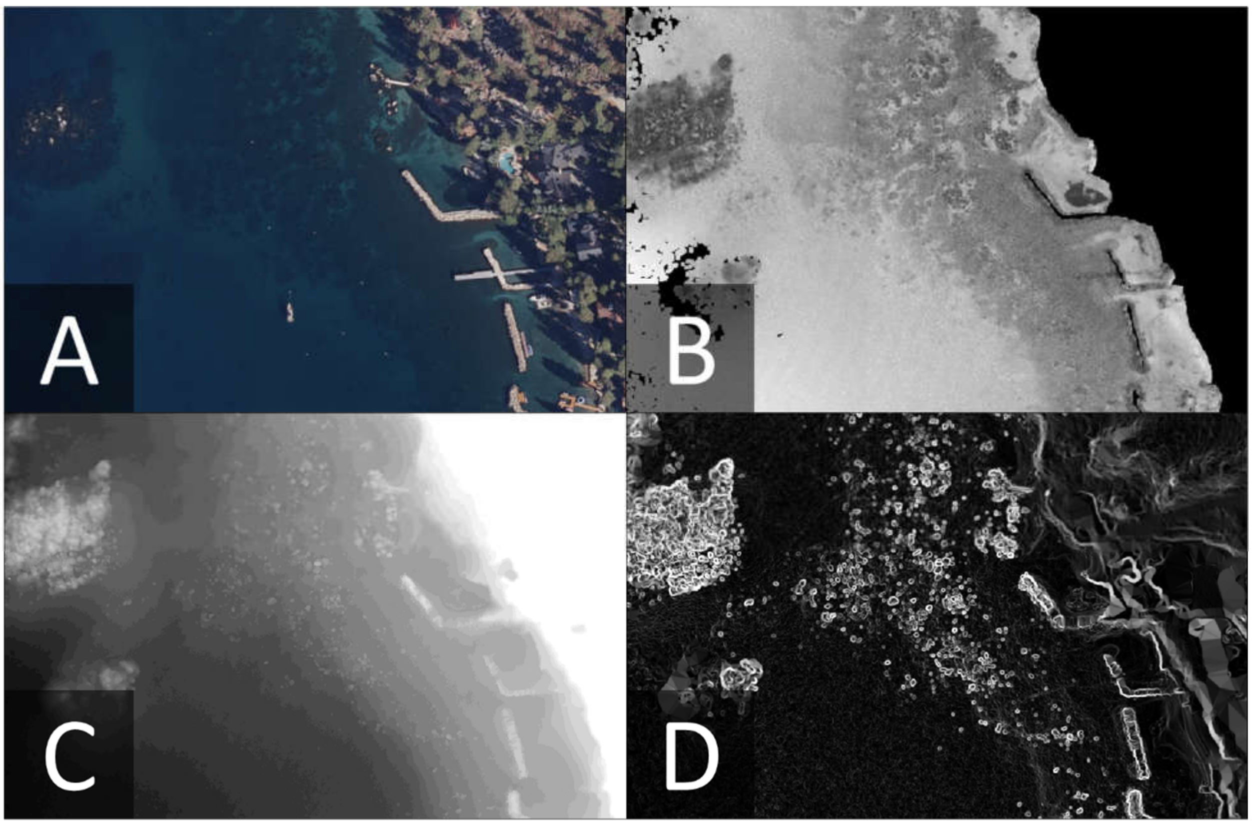

Figure 7. Primary data layers for subsurface aquatic vegetation mapping. Aerial imagery (A), LiDAR bathymetric bottom reflectance (B), LiDAR topo/bathy elevation model (C), and slope derived from the LiDAR topo/bathy elevation model. Location: Wovoka near Pine Point Drive, east shore of Lake Tahoe.

A step-by-step example of how submerged aquatic features were extracted is presented in Figure 8. The first step involved generating image objects through the implementation of a segmentation algorithm. These image objects, generated from the pixel values in the imagery and LiDAR reflectance, contain attributes of all the source input datasets (Figure 7). Examples of these attributes include the mean imagery brightness, standard deviation of the LiDAR reflectance, and maximum depth. The first phase of the rule set focused on classifying features that are not aquatic vegetation. This includes the land, docks, boats, and boulders sticking out of the water. The second phase centered on initial feature extraction, classifying subsurface aquatic vegetation that exhibited expected tonal characteristics in both the imagery and LiDAR reflectance. A follow-on routine used more stringent criteria to classify aquatic vegetation features close to the shoreline that are obscured by shadow in the imagery using only the LiDAR reflectance. To eliminate false positives, mainly boulder/cobble areas with high slope, the substrate was classified then contextual routines were employed to eliminate false positives.

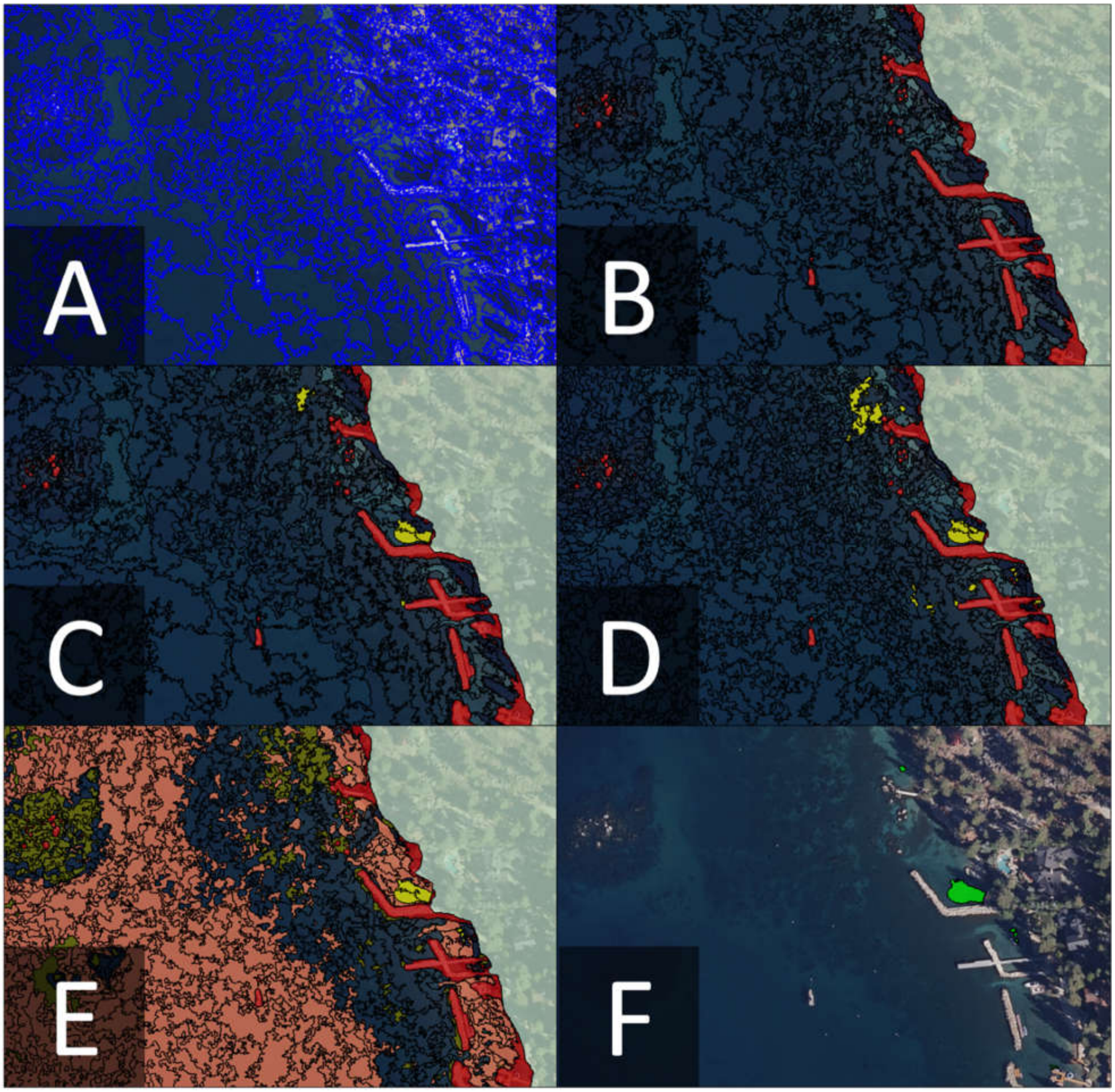

Figure 8. Subsurface aquatic vegetation feature extraction example showcasing the detection of Eurasian watermilfoil. Location: Wovoka near Pine Point Drive on the east shore of Lake Tahoe. A segmentation algorithm was used to generate objects from a combination of the imagery and LiDAR reflectance (A). Land and within-water features that are not plants are excluded from the analysis (B – land is olive-green, docks and boats are red). Aquatic vegetation that displays clear characteristics in both the imagery and LiDAR reflectance is identified (C – yellow features). Additional aquatic vegetation that is obscured in the imagery due to shadow but clearly observable in the LiDAR reflectance is added (D). Substrates that appeared similar to aquatic vegetation is mapped using topography (E – orange and green). Contextual routines are then employed to finalize the classification to get to likely submerged aquatic vegetation (F).

Surface aquatic plant feature extraction relied primarily on the aerial imagery, with LiDAR data only used to remove tree canopy overhanging the water. When the imagery is displayed as true color surface vegetation is barely detectable, but it does appear clearly when the imagery is displayed as a color infrared composite and in the Normalized Difference Vegetation Index (NDVI) derived from the imagery (Figure 9).

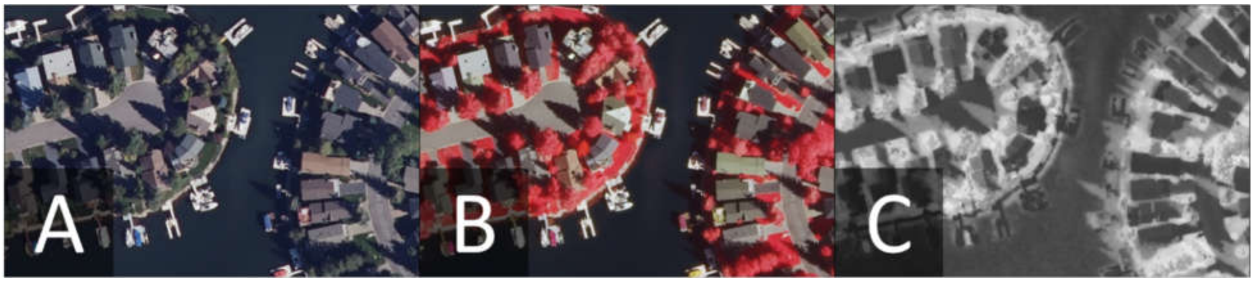

Figure 9. Primary datasets used for surface aquatic vegetation mapping. Aerial imagery displayed as true color (A) and color-infrared (B). NDVI derived from the aerial imagery (C). Location: Tahoe Keys Homeowner's Lagoon.

The process of extracting surface aquatic vegetation was more straightforward than the one used for subsurface vegetation. A step-by-step example is shown in Figure 10. As with the subsurface mapping, the first step was the generation of objects through the implementation of a segmentation algorithm. Land and other non-water features (docks, boats, trees) within the water were then excluded. Aquatic vegetation was classified based on NDVI threshold, but as tree canopy shadows had similar NDVI values, a series of rules using brightness and context were used to eliminate these false positives.

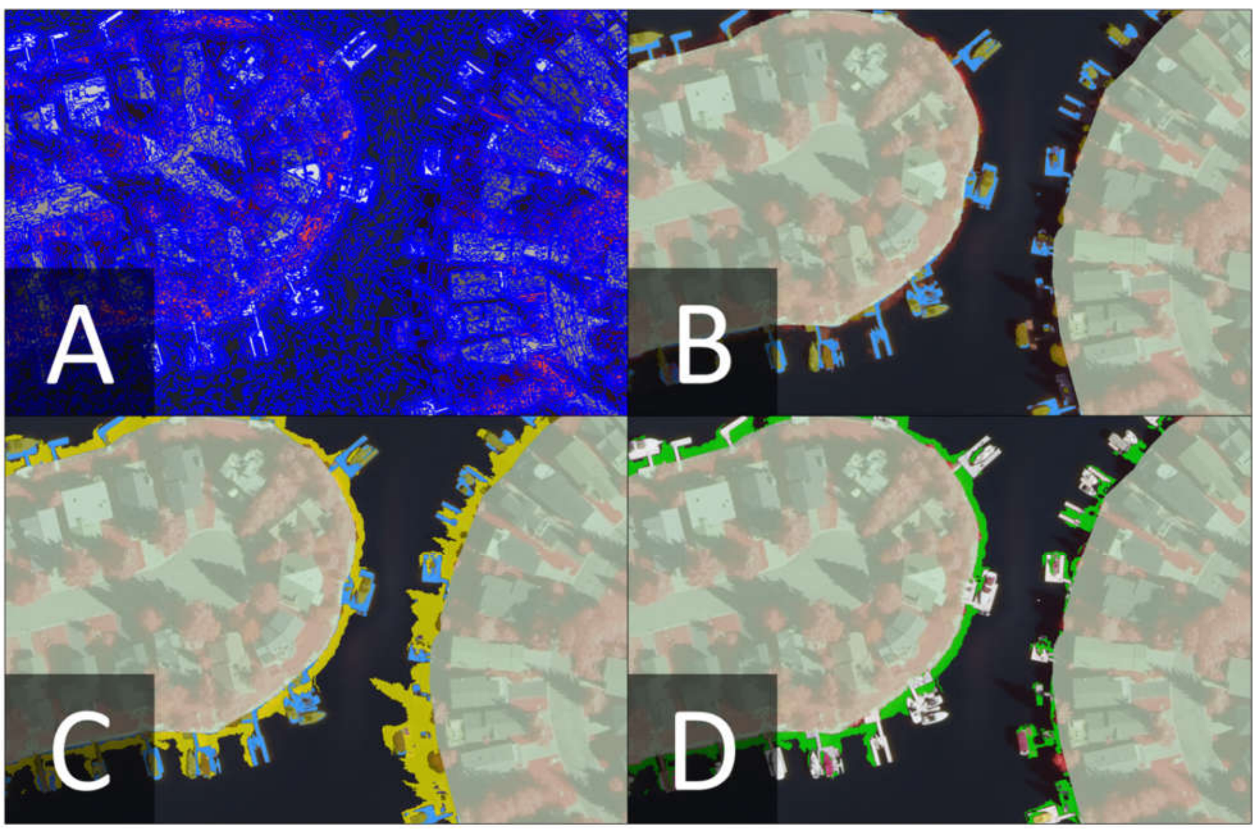

Figure 10. Images provide an example of the process used for extracting subsurface aquatic vegetation. Objects are generated from the imagery via a segmentation procedure (A – blue lines). Features that are not water are excluded (B – land is light olive green, tall features are brown, and other non-water features are blue). Candidate surface aquatic vegetation objects are classified (C – yellow). False positives (e.g., shadows) are removed revealing the distribution and extent of surface aquatic plants detectable with NDVI (D - green). Location: Tahoe Keys Homeowner's Lagoon.

Accuracy Assessment

Spatial accuracy assessment of the remotely-sensed data was performed by the data acquisition contractor where data were directly georeferenced using post-processed Global Navigation Satellite System (GNSS)-aided inertial navigation system (INS) on the aircraft, and an empirical accuracy assessment was 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 (see detailed methods described in Appendix A).

At this stage of the project, thematic accuracy assessment was qualitative, visually comparing the results to the field data to assess the strengths and limitations of the automated approach. However, a thematic (classification) accuracy will be performed after modeled plant extent and distribution maps (based on procedures outlined above) have been reviewed by the Project Oversight Team (POT). POT input will be extremely valuable in refining model parameters and thus improving the plant map accuracy. After POT input, the model will be rerun and a quantitative thematic (classification) accuracy assessment will be performed following Congalton (1991) and Lillesand et al. (2014). Reference diver transect, quadrat and opportunistic data for each stratum will be used, where a subset (10% – 20%) of the in-situ data will be held aside and will not be used in any other part of the processing and analysis. An error matrix - also known as a "confusion matrix" – will be generated and the results reported using standard metrics, to include overall accuracy, user's accuracy, producer's accuracy, and kappa coefficient.

Remote Sensing – Aquatic Plant Data Evaluation

Aquatic Plant Bed Presence (or Absence)

A binary classification map indicating presence/absence of aquatic plants was generated using the OBIA procedures described above. The map shows areas where there a high likelihood of aquatic plant presence based on expert knowledge that was translated into model inputs.

Aquatic Plant Bed Extent and Distribution

A binary classification map as described above (with a single "aquatic plant" class) was produced in a shapefile format to facilitate computation of area of submerged and surface aquatic plants. Area (acres) of aquatic plant beds were quantified throughout the open-water area (depicted in the 'water edge' data layer), and distributions shown graphically in a map. Aquatic plant extent (as a single class) was also summarized by water area within each stratum (Marsh, nearshore/open water, stream, and marina/embayment) and within 'survey zones' delineated from the water's edge data layer. Figure 11 shows an example of 'survey zones' delineated in the south shore of Lake Tahoe.

Aquatic Plant Relative Species Abundance/Composition

Relative aquatic plant abundance (measured as percent cover) was calculated as a single aquatic plant class for each sampling stratum and survey zone. To estimate plant species composition, averaged percent cover by species data derived from diver transect and quadrat sampling data were used to infer species composition within a survey zone that were sampled and had plant detections. Estimates of species composition are not provided for survey zones that were not sampled or were sampled with no plants detected.

Figure 11. An example area (overlooking Tahoe Keys area) showing 'survey zones' used to quantify different aquatic plant indicators.

Results

This section presents the results of the 2018 aquatic plant survey and mapping effort for the Lake Tahoe nearshore sampling frame as developed within the Lake Tahoe Aquatic Plant Monitoring Program: Aquatic Plant Monitoring Plan and the methods in this document. Aquatic plant transect and quadrat field sampling results are described within and between strata.

Aquatic Plant Field Surveys

A total of 107 transects and 521 quadrats were sampled to evaluate plant communities within the sampling frame. These included transects and quadrats that were part of the monitoring plan to evaluate the four sampled strata for vegetated cover as well as additional "opportunistic" samples collected to help validate the remote sensing (LiDAR) data. Sampling occurred between September 4th and November 1st, 2018 (

Percent coverage and species dominance along transects varied per strata (Figure 11). Overall plant cover was greatest in the marshes and lowest in the open-water nearshore transects. However, lower reported coverage in the open-water nearshore stratum may be explained by the placement of these transects as they were intentionally extended to depths where the potential to encounter vegetation was diminished. Additionally, the open-water nearshore stratum was the largest stratum and the only one that contained a systematic sampling element that forced sampling around the lake regardless of prior knowledge of plant establishment. This meant there was less bias towards sampling vegetated areas in the open-water nearshore stratum.

No single species was dominant across all strata types. Five plant species were observed across all strata types. Of the species observed across vegetated transects, average percent coverage by non-native species was highest in marinas and embayments (Figure 12). A table of percent coverage per transect by native or non-native plants is included as

	Transects				Quadrat				Total	
	Planned		Opportunistic		Planned		Opportunistic		Sampled	
Strata	Veg.	None	Veg	None	Veg	None	Veg	None	T's	Q's
Open-water Nearshore	8	40	5	0	0	0	15	0	53	15
Marinas & Embayments	15	14	0	1	0	0	15	0	30	15
Marshes	11	1	0	0	0	0	10	0	12	10
Major Tributaries	12	0	0	0	322	153	6	0	12	481

Table 2. Observed species average plant height ranged from 4 cm (*Naiad spp*.) to 100-cm tall (coontail) (Figure 13).

Table 1). Of the 107 monitoring transects surveyed, 47.6% had plants present along the transect and of the 343 quadrats sampled, 77.8% of them had plants present inside the quadrat bounds. The higher percentage of occurrence in quadrats relative to transects was due to the fact that most of the negative transects were in the open-water nearshore stratum and no planned quadrats were collected in the open-water nearshore stratum. There were 16 plant and algae species (or taxa) identified during the sampling across all strata (

Strata	Transects				Quadrat				Total Sampled	
	Planned		Opportunistic		Planned		Opportunistic			
	Veg.	None	Veg	None	Veg	None	Veg	None	T's	Q's
Open-water Nearshore	8	40	5	0	0	0	15	0	53	15
Marinas & Embayments	15	14	0	1	0	0	15	0	30	15
Marshes	11	1	0	0	0	0	10	0	12	10
Major Tributaries	12	0	0	0	322	153	6	0	12	481

Table 2).

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	Transects				Quadrat				Total	
	Planned		Opportunistic		Planned		Opportunistic		Sampled	
Strata	Veg.	None	Veg	None	Veg	None	Veg	None	T’s	Q’s
Open-water Nearshore	8	40	5	0	0	0	15	0	53	15
Marinas & Embayments	15	14	0	1	0	0	15	0	30	15
Marshes	11	1	0	0	0	0	10	0	12	10
Major Tributaries	12	0	0	0	322	153	6	0	12	481

Table 2. Observed species average plant height ranged from 4 cm (*Naiad spp*.) to 100-cm tall (coontail) (Figure 13).

Table 1. Transect and quadrat summary table by strata. Table includes planned sampling and opportunistic sampling elements and is sub-divided to show the number of transects with (Veg.) and without (None) vegetation. Opportunistic sampling was used to validate remote sensing data and is not included in the calculations of plant cover.

	Transects				Quadrat				Total	
	Planned		Opportunistic		Planned		Opportunistic		Sampled	
Strata	Veg.	None	Veg	None	Veg	None	Veg	None	T's	Q's
Open-water Nearshore	8	40	5	0	0	0	15	0	53	15
Marinas & Embayments	15	14	0	1	0	0	15	0	30	15
Marshes	11	1	0	0	0	0	10	0	12	10
Major Tributaries	12	0	0	0	322	153	6	0	12	481

Table 2. Table of average percent coverage by plant species among transects and quadrats. Note that strata averages are based on vegetated quadrats only.

	Average Percent Coverage By Transect and (Quadrat)			
Species	Open-water Nearshore	Marshes	Marinas & Embayments	Major Tributaries
Andean milfoil (AM)	4.62%			
Chara spp. (CH)	12.57%	0.73%	2.05%	8.17%(13.65%)
Common bladderwort (CB)	0.22%	37.17%	0.92%	7.60%(6.61%)
Coontail (C)	2.34%		17.06%	1.14%(2.21%)
Curly-leaf pondweed (CLPW)*	3.92%		0.38%	1.17%(0.88%)
Elodea (E)	2.88%		7.46%	9.53%(5.60%)
Eurasian watermilfoil (EWM)*	6.20%	3.99%	26.53%	5.52%(12.50%)
Filamentous green algae (FA)	1.20%	2.31%	15.56%	24.65%(25.03%)
Leafy pondweed (LP)	1.53%	7.82%	1.07%	2.24%(0.43)
Mares Tail (MT)		5.88%		1.44%(0.23%)
Naiad spp. (N)	2.50%		0.52%	0.21%(0.01%)
Northern milfoil (NM)		4.51%	0.72%	
Quillwort (QW)	2.90%			
Richardson's pondweed (RP)	0.54%		0.99%	
Various-leaved pondweed (VP)	1.89%	8.43%		
White water buttercup (WB)	0.20%	2.38%		2.85%(0.49%)

*: Indicates Non-native species; (): quadrat sampling-based cover estimate

Among transects, average species coverage relative to total plant coverage within strata shows that while some species may be observed along the transect on few occasions, their relative coverage when compared to total plant coverage is notable (Table 3, Figure 14). Eurasian watermilfoil accounted for 14.25% of total coverage relative to other encountered plant species in the open-water nearshore stratum and 36.22% in marinas and embayments. Filamentous green algae accounted for 38.20% of relative average "plant" coverage in major tributaries. Common bladderwort accounted for a 50.77% of plant coverage relative to total coverage in marshes.

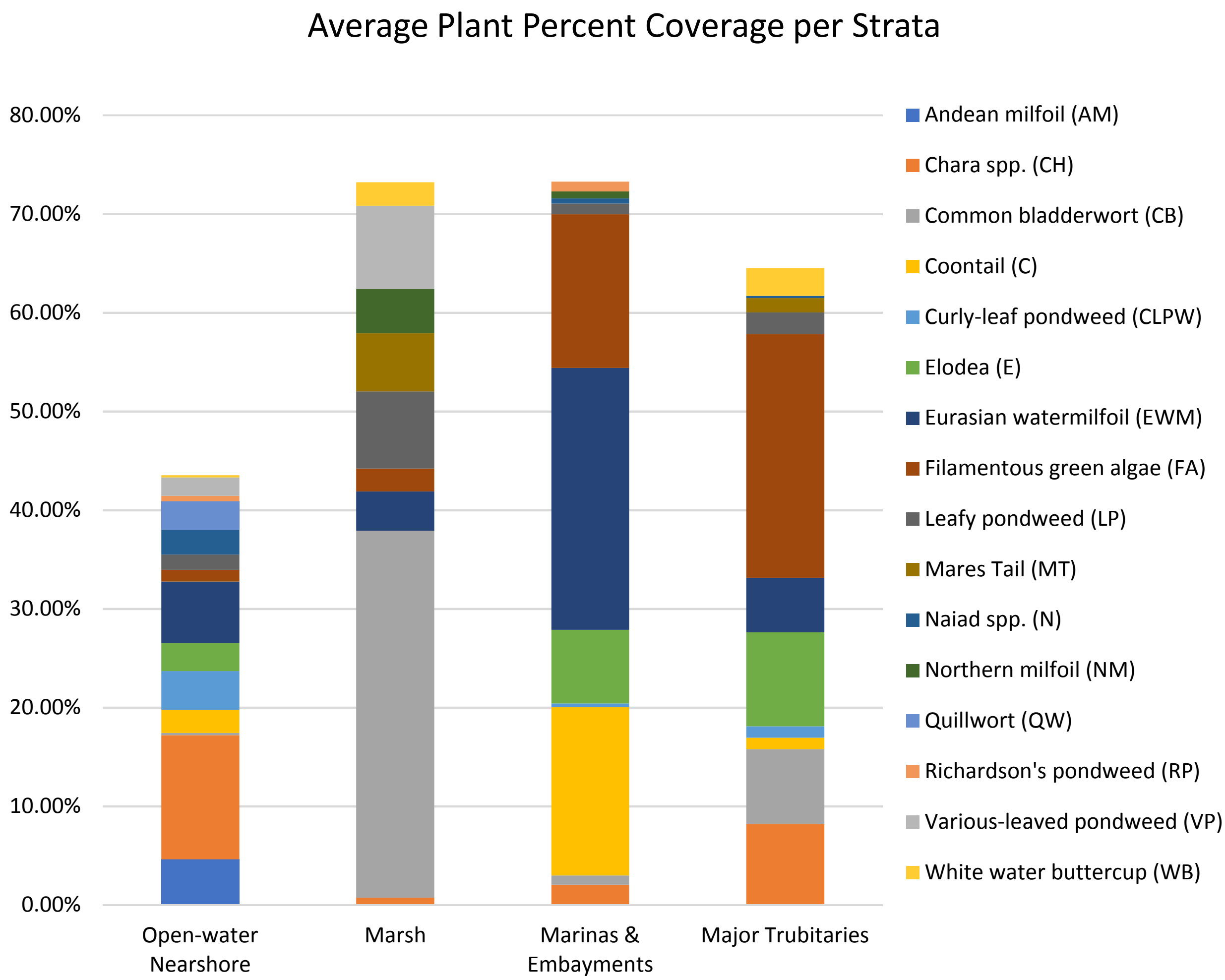


Figure 11. Stacked bar graph of transect average percent coverage by plant species per strata. Note that the values are averages of vegetated transects and do not include transects that were negative for plants.

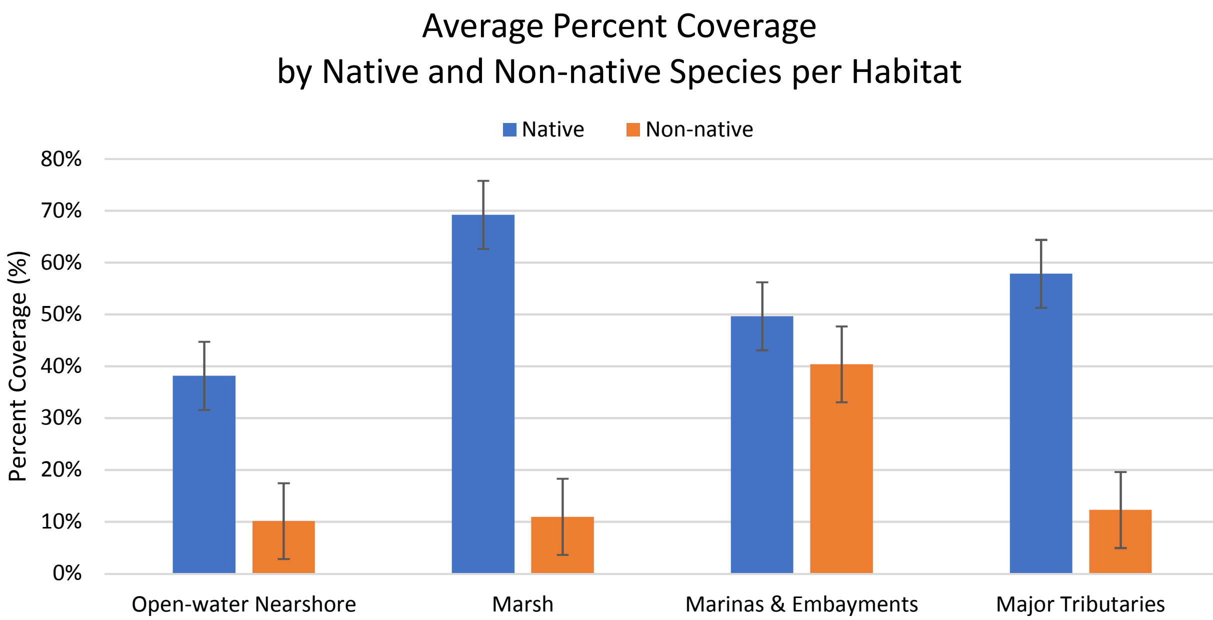


Figure 12. Average percent of native and non-native plants among vegetated transects per strata. Error bars represent one standard deviation from the mean.

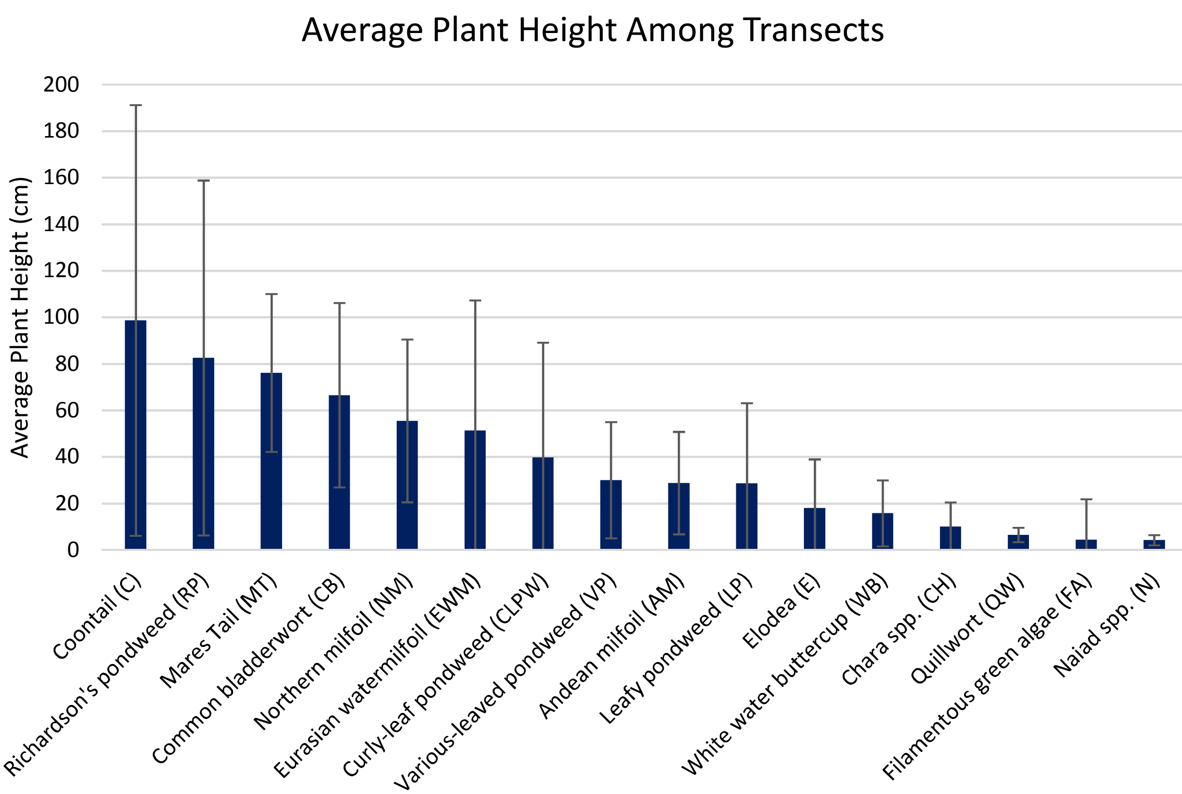


Figure 13. Average plant height across transects. Error bars represent one standard deviation from the mean.

Table 3. Table of relative coverage by vegetation species among transects and quadrats.

Species	Open-water Nearshore	Marshes	Marinas & Embayments	Major Tributaries
Andean milfoil (AM)	10.62%			
Chara spp. (CH)	28.88%	1.00%	2.79%	12.67%(24.27%)
Common bladderwort (CB)	0.51%	50.77%	1.26%	11.78%(14.55%)
Coontail (C)	5.38%		23.28%	1.77%
Curly-leaf pondweed (CLPW)*	9.02%		0.52%	1.81%(1.21%)
Elodea (E)	6.61%		10.18%	14.76%(12.33%)
Eurasian watermilfoil (EWM)*	14.25%	5.45%	36.22%	8.56%(17.25%)
Filamentous green algae (FA)	2.77%	3.15%	21.24%	38.20%(28.45%)
Leafy pondweed (LP)	3.52%	10.68%	1.46%	3.47%(0.94%)
Mares tail (MT)		8.03%		2.24%(0.50%)
Naiad spp. (N)	5.75%		0.71%	0.32%(0.02%)
Northern milfoil (NM)		6.16%	0.99%	
Quillwort (QW)	6.66%			
Richardson's pondweed (RP)	1.24%		1.35%	
Various-leaved pondweed (VP)	0.46%	3.25%		(0.01%)
White water buttercup (WB)	4.34%	11.51%		4.42%(0.46%)

*: Indicates Non-native species; (): quadrat sampling, quadrats sampled in marsh and marinas and embayments were utilized for ground truthing of LiDAR

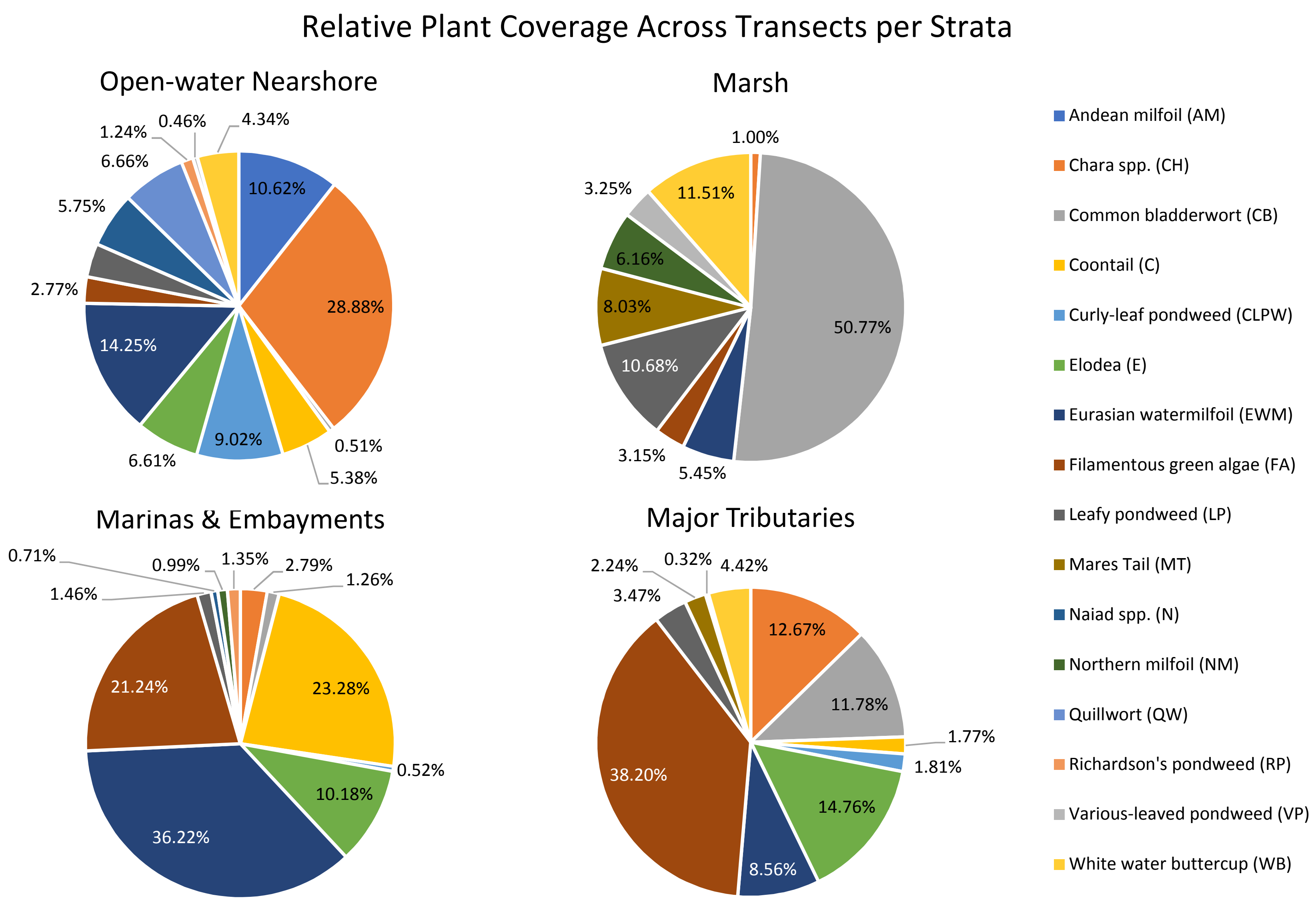


Figure 14. The above figure compares the average relative species cover per strata across transects.

Open-Water Nearshore Surveys

A total of 53 transects were swam within the open-water nearshore strata. 48 of the transects were planned and 5 transects were opportunistic. Vegetation was present on 8 of the planned transects and all of the opportunistic transects. The remaining 40 planned transects were unvegetated. Only planned transects are discussed relative to plant coverage. Transects with vegetation were concentrated near the south shore of Lake Tahoe (Appendix B). Commonly observed aquatic plant species included *Naiad* spp., leafy pondweed, Eurasian watermilfoil, *Elodea*, and *Chara* spp. (Figure 15). All of these species were identified on at least 60% of the vegetated transects within the open-water nearshore stratum. Eurasian watermilfoil was present along every vegetated transect in the stratum. Eurasian watermilfoil and *Chara* spp. had the greatest coverage compared to all other aquatic plant species observed along open-water nearshore transects. Tables of aquatic plant species coverage per transect are included in Appendix C. Quadrat point intercept measurements for plant coverage were not performed in this stratum. Other notable species observed while performing open-water nearshore sampling included Asian clam, bluegill, crayfish, lake trout, large-mouth bass, minnows, rainbow trout, Lohontan redside shiner, snails (*Planorbidae* sp. & *Physella* sp.), speckled dace, and Tahoe suckers (Appendix D).

Table 4. Transects sampled within the open-water nearshore survey strata.

	Transect	
Survey Location	**Planned**	**Opportunistic**
Baldwin Beach	BBL001	
Cedar Flat	CF001	
Chambers Landing	CHL001	
Camp Richardson	CRBY001	
Camp Richardson	CRBY002	
Camp Richardson	CRBY003	
Camp Richardson	CRL001	
Dollar Point	DLP001	
Deadman's Point	DMP001	
Emerald Bay	EBS001	
Emerald Bay	EBS002	
Edgewood	EGWL001	
Eagle Point	EPS001	
Flick Point	FLP001	
Gold Coast	GCS001	
Glenbrook	GLBL001	
Hidden Beach	HIDB001	
Homewood	HW001	
Kaspian	KAS001	
Logan House Creek	LHC001	
Lincoln Park	LINP001	
Lake Forest	LKF001	
Meeks Bay	MBL001	
Meeks Bay Point	MBS001	
Nevada Beach	NBL001	
Olympic Drive	OD001	
Olympic Drive	OD002	
Olympic Drive	OD003	
Olympic Drive	OD004	

Round Hill Marina	RHM001	
Rubicon Point	RPS001	
Secret Harbor	SHAR001	
Sand harbor	SHS001	
Skunk Harbor	SKH001	
Sugar Pine Point	SPP001	
Ski Run	SRL001	
Stateline Point	STP001	
Sunnyside	SUN001	
Timber Cove Pier	TCL001	
Thunderbird	THB001	
Tahoe Keys Homeowners Association	TKHOL001	
Tahoe Keys Marina Lakeward	TKML001	
Truckee River Outlet	TROL001	
Tahoe Tavern	TTL001	
Tahoe Vista	TVIS001	
Upper Truckee River	UTRL001	
Zephyr Cove	ZCL001	
Zephyr Point	ZPL001	
Baldwin Beach Point		BBP001
Baldwin Beach Point		BBP002
Camp Richardson		CRP001
Tahoe Keys Marina Point		TKMP001
Tahoe Keys marina Point		TKMP002

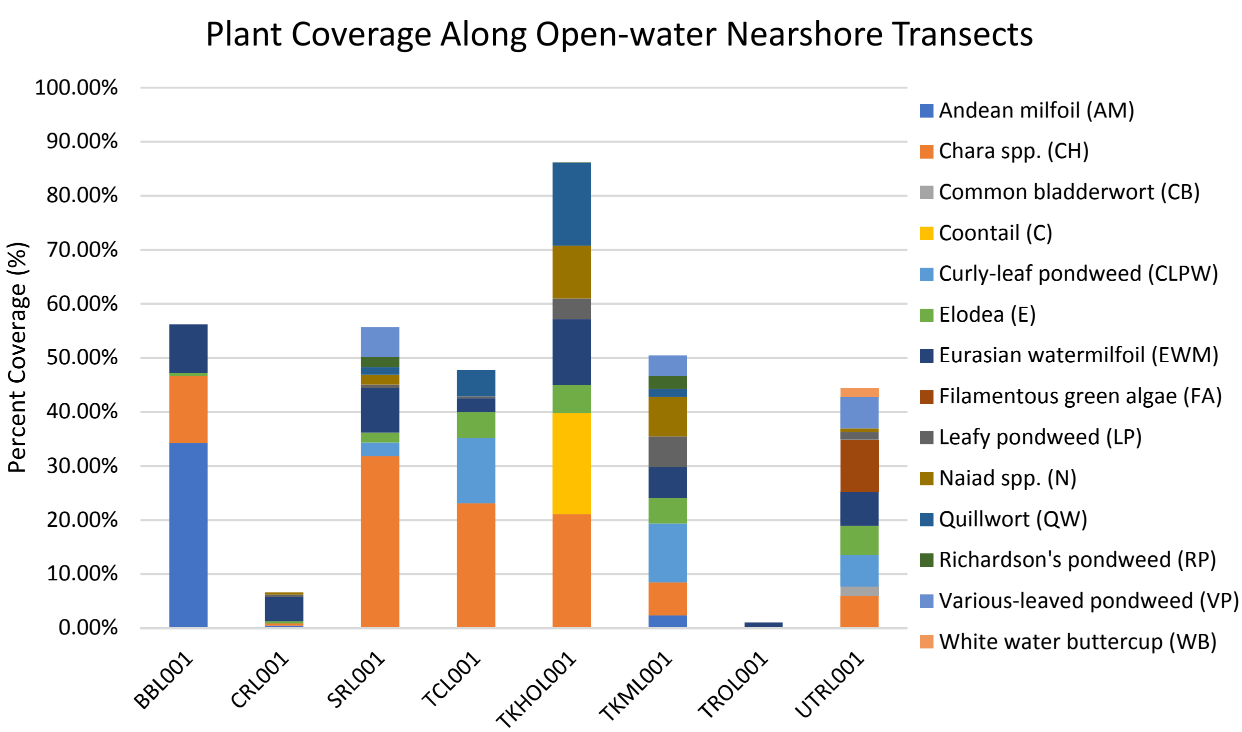


Figure 15. Stacked bar graph of species presence within open-water nearshore transects. Only transects with plants present are displayed in the above chart. Opportunistic transects are not included.

Marsh Surveys

A total of twelve transects were sampled within the marshes stratum (Appendix B, Table 5). All of the sampled transects were planned and performed in accordance with the specified methods. Eleven of the twelve transects had vegetative cover. Eight aquatic plant species were observed along marsh transects (Figure 16). Overall, plant coverage for most of the marsh transects was dominated by common bladderwort and mare's tail. A percent species coverage table for marsh strata is included in Appendix C. Animals observed while conducting field surveys in marshes included crayfish, lake trout, and snails (*Planorbidae* sp.& *Physella* sp.) (Appendix D).

Table 5. Transects sampled in the marshes survey strata. No opportunistic transects were sampled in marsh strata

Survey Location	Planned Transect
Pope Marsh	PM001
Pope Marsh	PM002
Pope Marsh	PM003
Pope Marsh	PM004
Tallac Creek Marsh	TAL001
Tallac Creek Marsh	TAL002
Taylor Creek Marsh	TAY001
Taylor Creek Marsh	TAY002
Upper Truckee Marsh	UTM001
Upper Truckee Marsh	UTM002
Upper Truckee Marsh	UTM003
Upper Truckee Marsh	UTM004

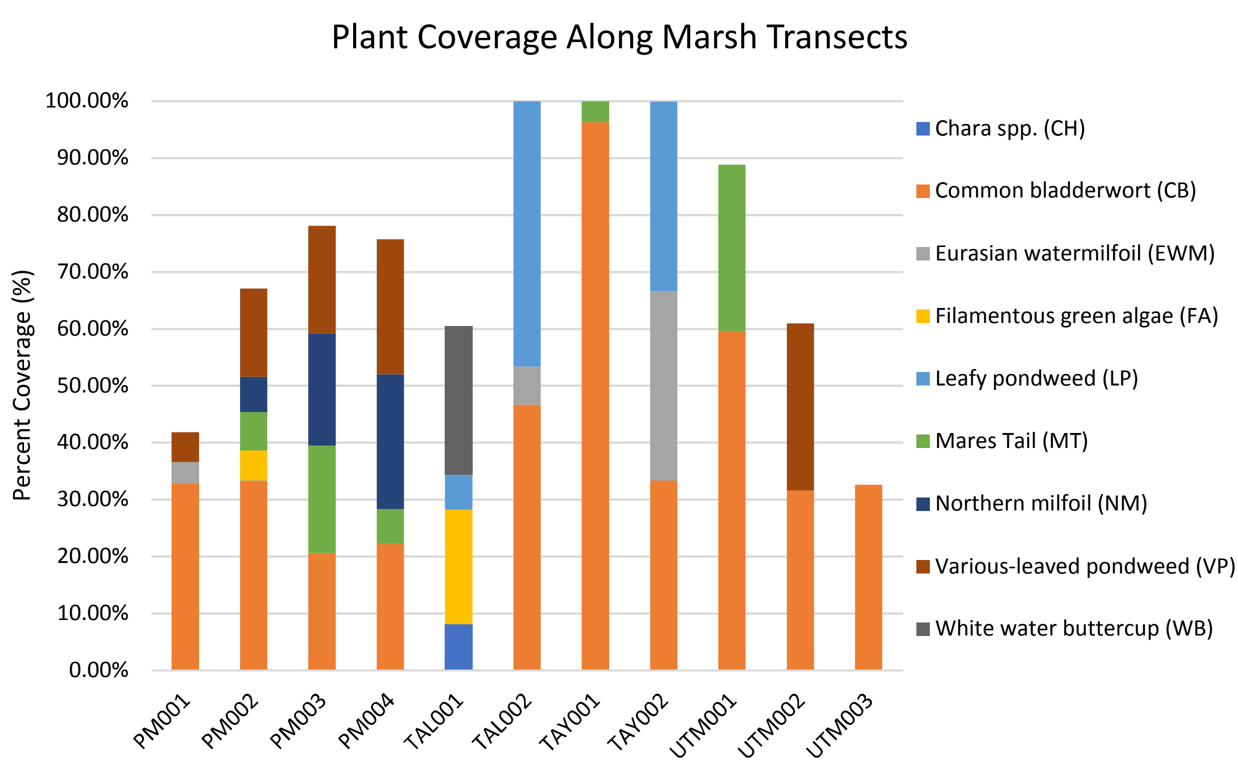


Figure 16. Stacked bar graph of species presence within marsh transects. Only transects with plants present are displayed in the above chart.

Marinas and Embayment Surveys

A total of 30 marinas and embayments transects were surveyed across 23 marinas and embayments (Appendix B, Table 6). One of the transects was an opportunistic transect. Of the 29 planned transects surveyed for plant coverage, 15 contained aquatic plants. Elk Point and Lakeside Marinas were not surveyed due to ongoing invasive aquatic plant mitigation installations (marina areas were covered with bottom barriers). Eurasian watermilfoil and coontail were observed to contribute to most of the plant cover along marina and embayment transects within the Tahoe Keys Homeowner's Lagoon (TKHO) and Tahoe Key Marina (TKM) (Figure 17). Two transects were observed to be entirely covered with filamentous green algae. Elodea was present on occasion along a few transects and was observed to be the only species contributing to plant cover in Fleur Du Lac Marina (FDL001). Percent cover by species are included in Appendix C. Animals observed while conducting marina and embayment field surveys included Asian clam, bluegill, brown trout, crayfish, minnows, rainbow trout, Lohontan redside shiner, and speckled dace (Appendix D).

Table 6. Surveyed transects within the marinas and embayments survey strata.

	Transect	
Survey Location	**Planned**	**Opportunistic**
Crystal Bay East	CBE001	
Crystal Bay Middle	CBM001	
Carnelian Bay (Sierra Boat Company)	CBSB001	
Crystal Bay West	CBW001	
Cave Rock Boat Launch	CRBR001	
Elk Point Homeowner	EPHO001	
Homewood Marina	HWM001	
Lakeside Beach	LMB001	
Meeks Marina	MEM001	
North Tahoe Marina	NTM001	
Obexer's Marina	OBX001	
Secret Cove	SC001	
Sand Harbor	SH001	
Sand Harbor	SH002	
Sunnyside Marina	SSM001	
Star Harbor Marina	STH001	
Tahoe City Marina	TCM001	
Tahoe City Marina	TCM002	
Tahoe Keys Homeowner	TKHO001	
Tahoe Keys Homeowner	TKHO002	
Tahoe Keys Homeowner	TKHO003	
Tahoe Keys Homeowner	TKHO004	
Tahoe Keys Marina	TKM001	
Tahoe Keys Marina	TKM002	
Tahoe Keys Marina	TKM003	
Tahoe Keys Marina	TKM004	
Tahoe Vista Boat Ramp	TVBR001	
Wovoka Bay	WNK001	
Fleur Du Lac Marina	FDL001	
Hurricane Bay		HBPond001

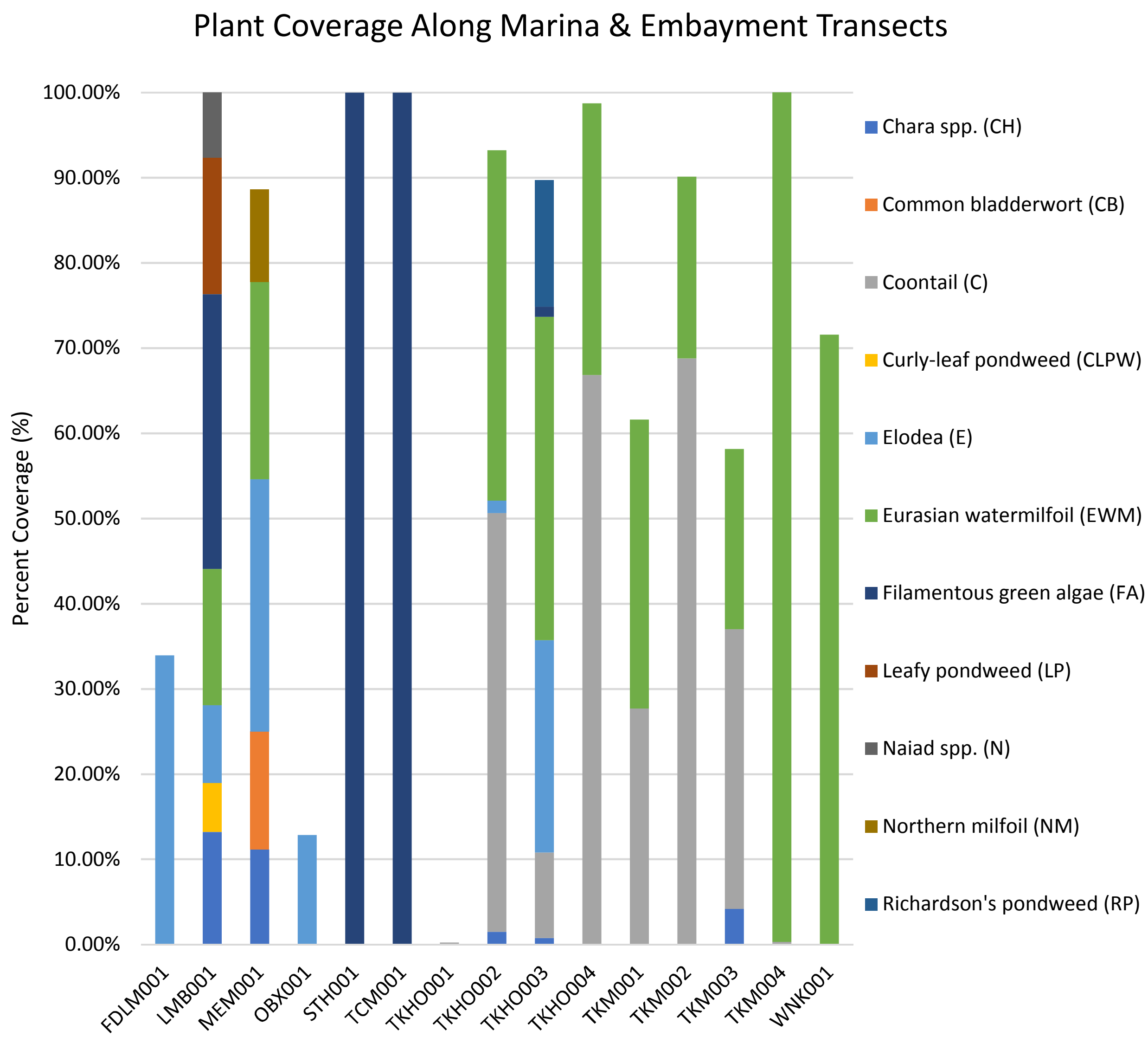


Figure 17. Stacked bar graph of species presence within marinas and embayments transects. Only transects with plants present are displayed in the above chart. Low values are not visible for TKHO001.

Major Tributaries Surveys

A total of 12 transects were surveyed in the major tributaries' stratum (Appendix B, Table 7) - plants were detected on all transects. Filamentous green algae dominated coverage along five transects (Figure 18). Many of the other transects were observed to include at least three species, much of the coverage contributions were attributed to *Elodea* and *Chara* spp., with lesser but still notable coverage by common bladderwart and curly-leaf pondweed. Percent plant coverage for stream data is included in Appendix C Edgewood Creek had the highest cover of the curly-leaf pondweed (AIS); the Upper Truckee River had the highest cover of Eurasian watermilfoil (AIS).

A total of 481 quadrats were placed along twelve stream transects. Aquatic plants were detected on 328 of the quadrats. Six of the 481 quadrats were opportunistic and are not included in plant coverage estimates. Of the 475 planned quadrats 322 were vegetated and 153 were unvegetated.

Filamentous algae was observed to have the greatest relative average percent cover among quadrats and accounted for 39.96% of quadrat intercepts (Figure 19). Native and non-native species were observed within stream quadrats. Native species accounted for 86.39% of all plants intercepted within marsh quadrats.

Species diversity and dominance is generally comparable between transect and quadrat methodologies. Among transects and quadrats filamentous green algae was dominant. Transect and quadrat field collection methods agree that a greater percentage of plant coverage was by native species. However, *Chara* spp. were over represented in quadrats relative to transects and the reverse was true for *Naiad* spp. Animals observed while conducting stream field surveys included crayfish, juvenile trout, lake trout, minnows, rainbow trout, Lohontan redside shiner, speckled dace, and Tahoe sucker (Appendix D).

Table 7. Transects surveyed within the major tributaries survey strata.

	Transect	
Survey Location	**Planned**	**Opportunistic**
Blackwood Creek	BLK001	
Burke Creek	BRK001	
Edgewood Creek	EGW001	
General Creek	GCR001	
North Canyon Creek	NCYN001	
Snow Creek	SNW001	
Tallac Creek	TALC001	
Taylor Creek	TC001	
Truckee River (west of dam)	TRO001	
Upper Truckee River	UPR001	
Ward Creek Mouth	WAR001	
Edgewood Creek		EGW002

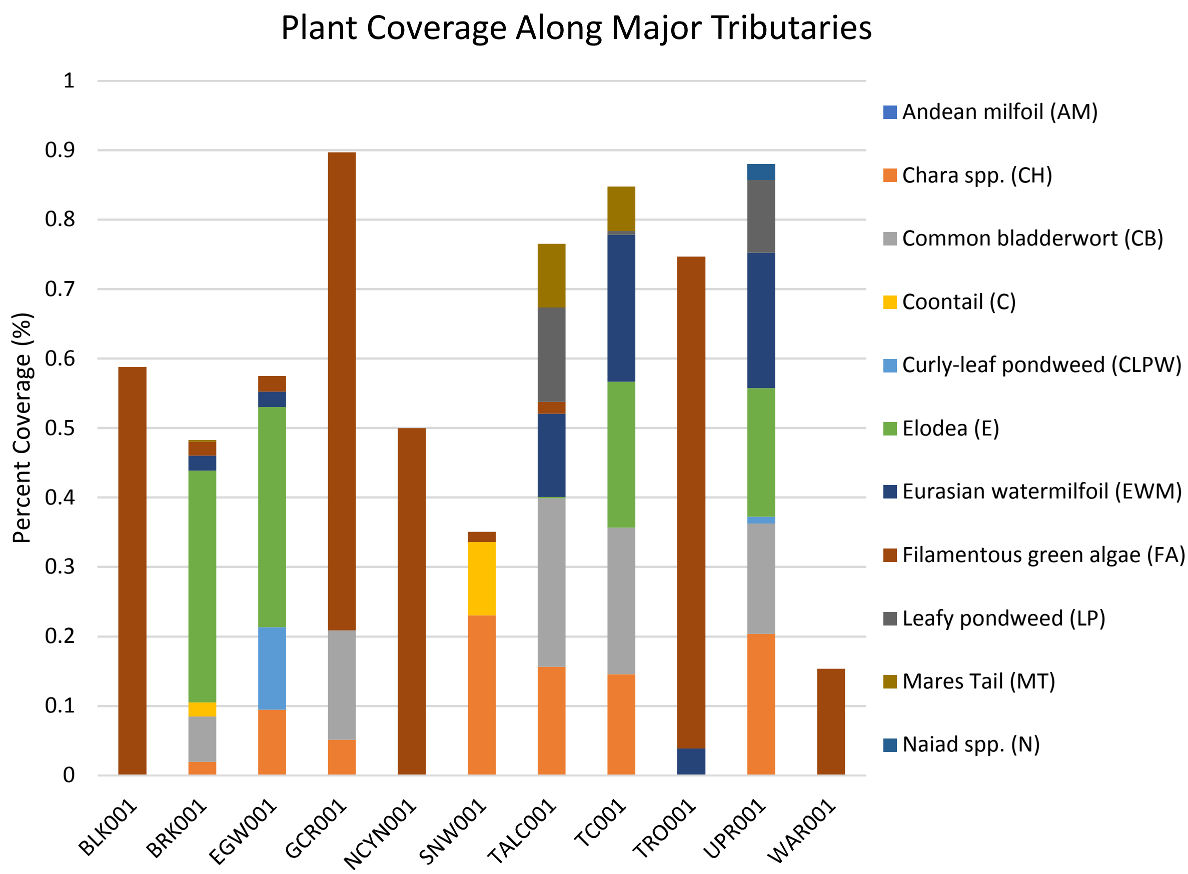


Figure 18. Stacked bar graph of species presence within Stream transects. Only transects with plants present are displayed in the above chart.

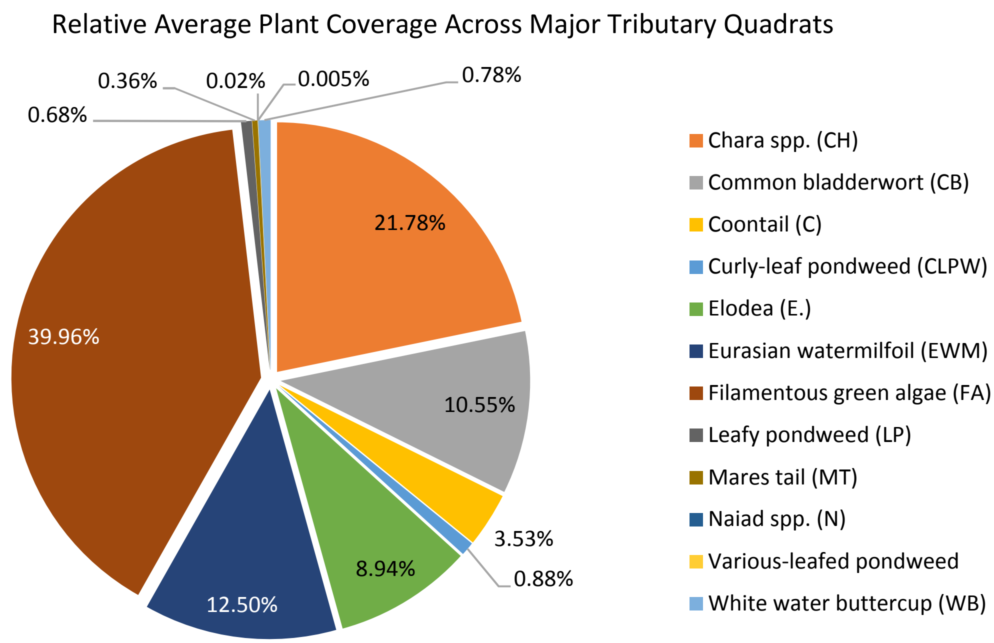
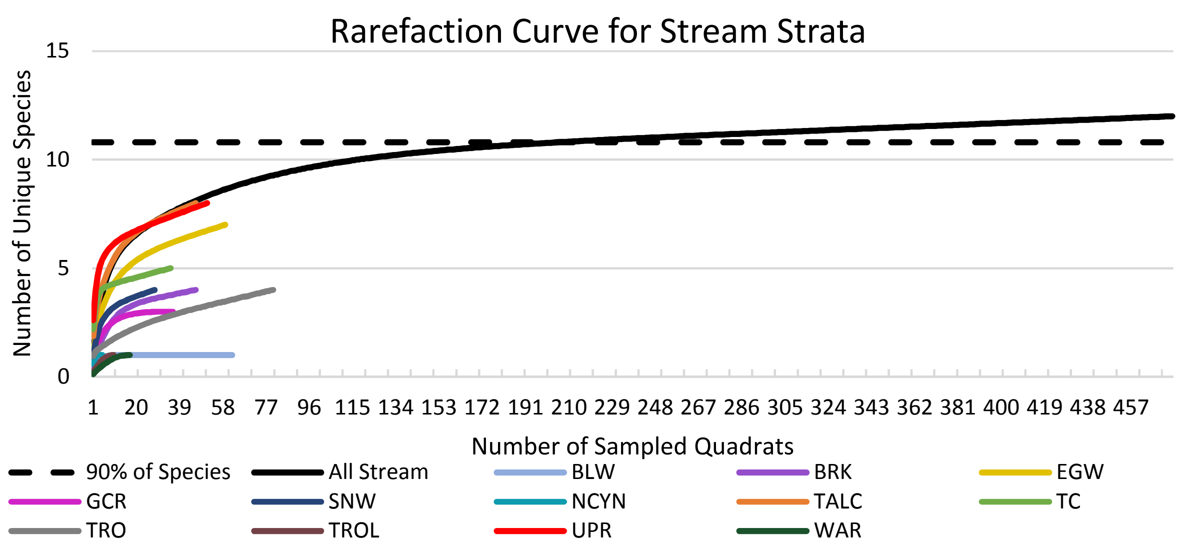


Figure 19. The figure above shows relative average species cover across quadrats per strata.

Rarefaction Data Evaluation

Based on the rarefaction curves, 12 unique species were observed in stream transects, to observe 90% of species within quadrats, 205 quadrats would need to be sampled (Figure 20). This indicates that when data are grouped for the stratum, many more quadrats were sampled than necessary to capture most of the species present. However, within each tributary, transect grouping results varied.

For Upper Truckee River (UPR) and Tallac Creek (TALC), where a maximum of 8 unique species were reported, 27 and 29 samples, respectively, are needed to capture 90% of observed species. In EGW, 32 samples are needed to detect 90% of the 7 observed species. Five species were observed in TC, to capture 90% of the observed species 18 samples are required. BRK, SNW, and TRO reported a total of 4 unique species, to capture 90% of the observed species 28, 18, and 43 samples are needed. Three unique species were reported for GCR, to observe 90% of species 13 samples are required. BLW, NCYN, TROL, and WAR had the lowest number of unique species observed. To observe 90% of species 5, 2, 7, and 11 samples, respectively, are required. Few quadrat samples were taken along NCYN, TROL, and WAR due to the short transect lengths. This means it could be argued that there were fewer species counted than present. However, review of the presence absence data supports the observation that there was only a single vegetation species present in each of these tributaries sampled areas.



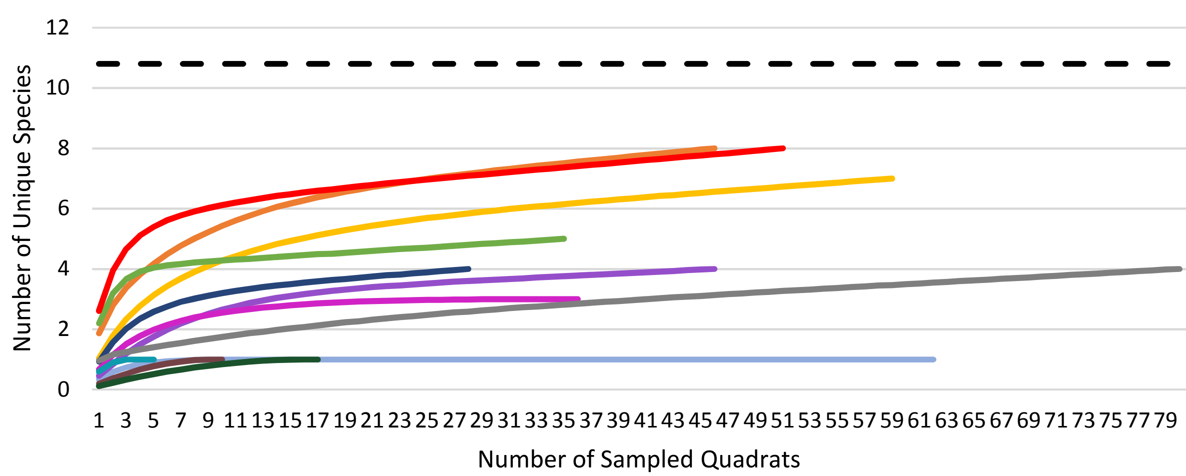


Figure 20. Rarefaction curve for stream data. The black dashed line indicates 90% of observable species for all quadrats administered within stream strata.

Aquatic Plant Mapping

Automated feature extraction routines were applied to the entirety of Lake Tahoe along with the major tributaries and marsh habitats within the survey area. Figure 21 shows the output of the automated process in the vicinity of Upper Truckee Marsh and lakeward. The mapped aquatic vegetation features in this area consist of polygons that are certainly aquatic vegetation, some that could be aquatic vegetation, along with some errors. The errors are largely confined close to the shore where detritus has similar characteristics to aquatic vegetation in both the imagery and LiDAR. Additionally, there appears to be errors in commission (inclusion of macrophyte aquatic plants when none are present) in offshore areas that correspond to rock substrates, especially on the north and east shores. It is likely the model is confusing periphyton (attached) algae with macrophytes. Additionally, there are notable omissions in those areas that correspond to locatons for which no LiDAR reflectance data existed. The water edge breaklines, which were derived from the LiDAR data provide an indication of where the submerged/subsurface vegetation mapping was not possible due to the absence of LiDAR.

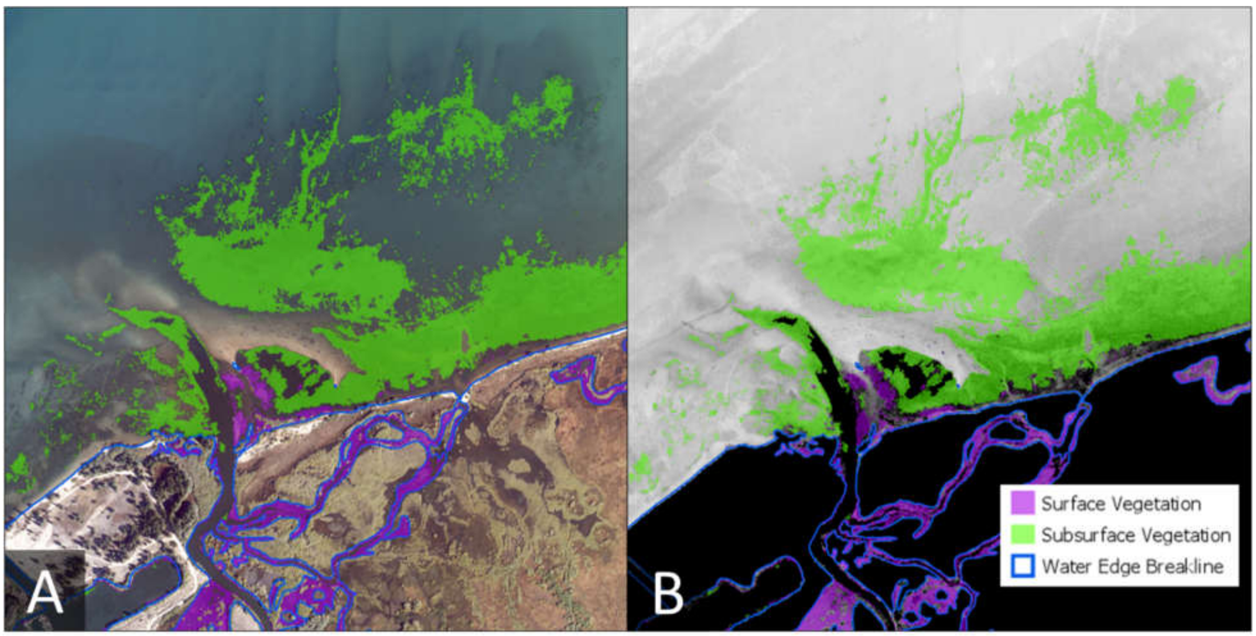


Figure 21. Aquatic subsurface and surface vegetation outputs from the automated system overlaid on the 2018 aerial imagery (A) and LiDAR bathymetric reflectance (B). Dark areas in the LiDAR reflectance are data voids. Location: Truckee Marsh.

Because there were no LiDAR reflectance data for the Tahoe Keys, the automated routine only extracted surface aquatic vegetation (Figure 22). The routine was successful in mapping the surface vegetation around docks and even some photosynthetically active material away from the shore. A few docks in shadowed areas with nearby tree canopy were likely falsely classified as aquatic vegetation (although it is common for aquatic vegetation establish under and around docks).

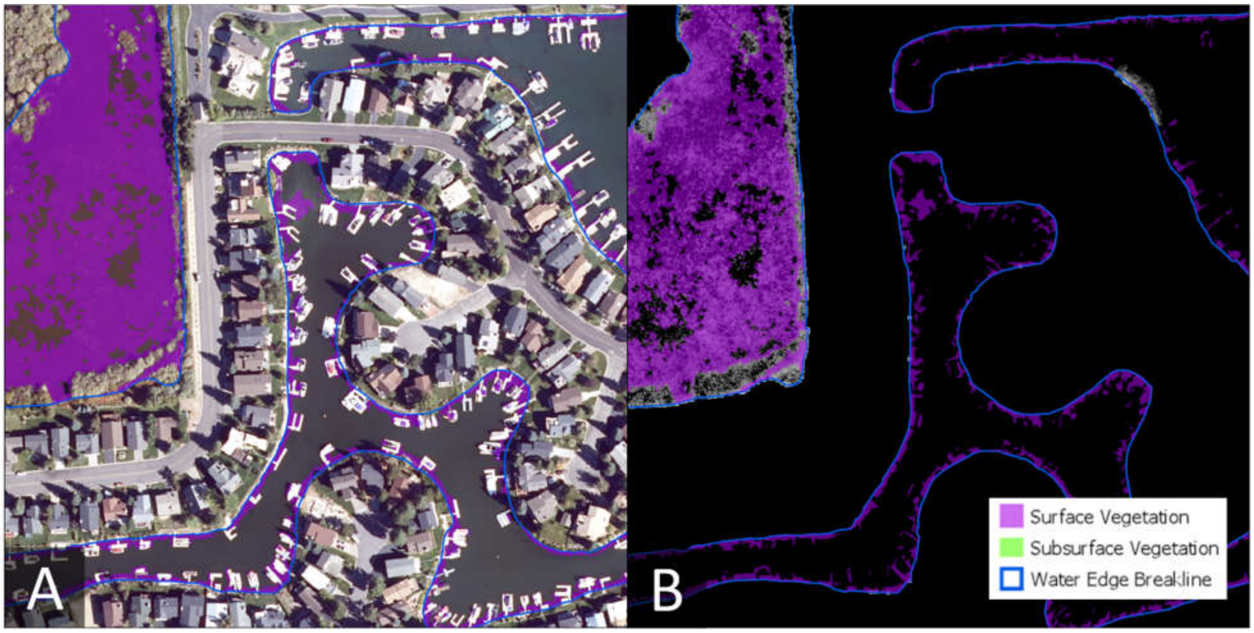


Figure 22. Example of surface aquatic vegetation in Pope Marsh (upper left in images A and B) and the Tahoe Keys Homeowners Lagoon (right side of images in A and B). The vegetation classification is overlaid on the true color imagery (A) and LiDAR void area. Blue line in both A and B is the water edge boundary produced from LiDAR data.

Further upstream along the Truckee River, only surface aquatic vegetation was classified due to inconsistency in the LiDAR data (Figure 23). The shallow water depth likely resulted in subsurface vegetation having a proximity to the surface leading it to be classified as surface vegetation.

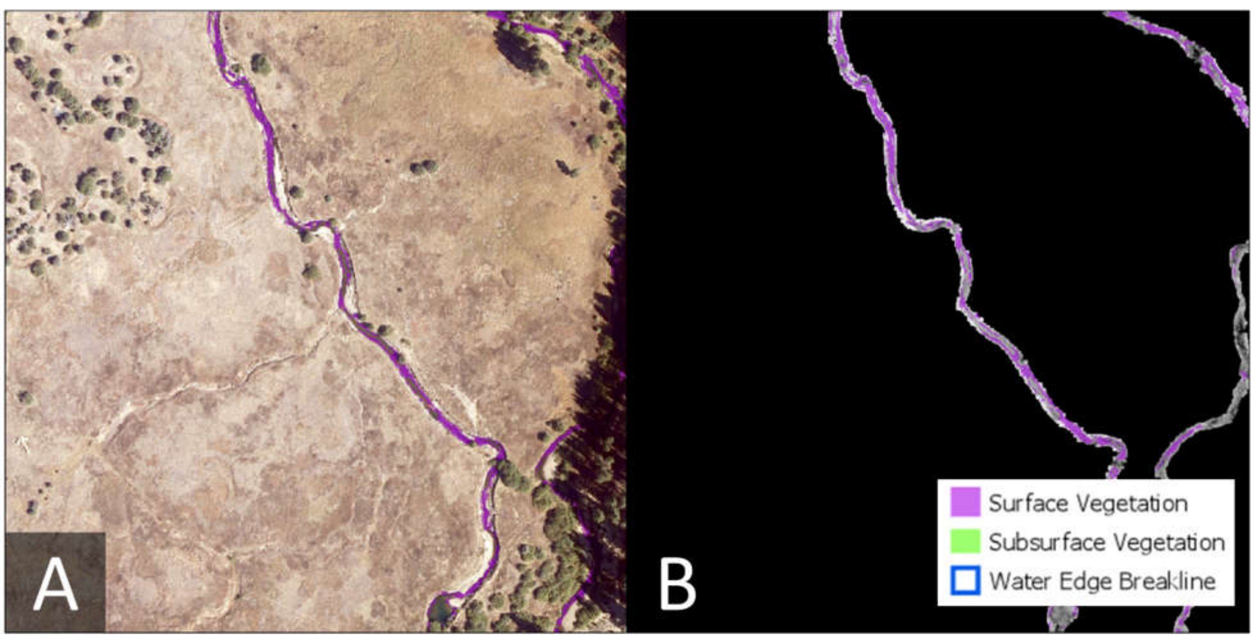


Figure 23. Aquatic vegetation extraction along the Upper Truckee River and Trout Creek in the Upper Truckee Marsh, South Lake Tahoe, CA.

The output from the vicinity of Kings Beach was indicative of the complexity of mapping aquatic vegetation in Lake Tahoe (Figure 24). There are some patches of submerged aquatic vegetation that were mapped and may be cause for concern. There are also some patches that were not detected that while having different tonal properties in the LiDAR reflectance than other known locations of aquatic vegetation, stand out from the surrounding substrate. Despite these realized and yet to be quantified errors, the automated OBIA mapping routine for submerged plants appears to yield good results in pure sand substrate situations typical of the south shore of Lake Tahoe - where there is a strong contrast in LiDAR reflectance values between plants and sand substrate. Sand/silt substrates are known to provide suitable habitat for invasive aquatic plants.

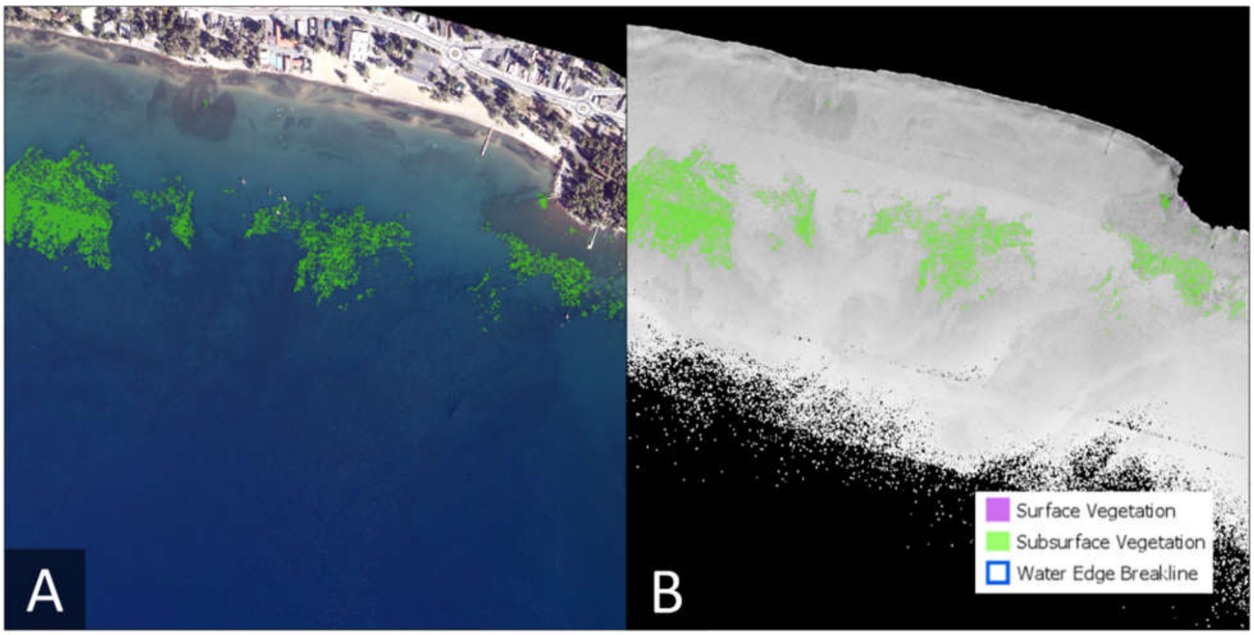


Figure 24. Results from the automated aquatic vegetation mapping in the vicinity of Kings Beach, north shore of Lake Tahoe.

Remote Sensing – Aquatic Plant Data Evaluation

Aquatic Plant Bed Presence (or Absence)

Based on automated mapping procedure performed, the potential presence of aquatic surface and submerged vegetation occurs most frequently in the south shore and northwest of Lake Tahoe (Figure 29). Figure 30 illustrates the modeled potential presence of surface and submerged aquatic plants in the south shore of Lake Tahoe. Figure 31 illustrates the modeled potential presence of surface and submerged aquatic plants in the north shore of Lake Tahoe. The presence of aquatic vegetation in the northwest area of Lake Tahoe is likely overestimated – and may in fact show the presence of periphyton algae. Figure 32 provides a close-up view of the modeled presence of aquatic vegetation within the Truckee River corridor near Tahoe City.

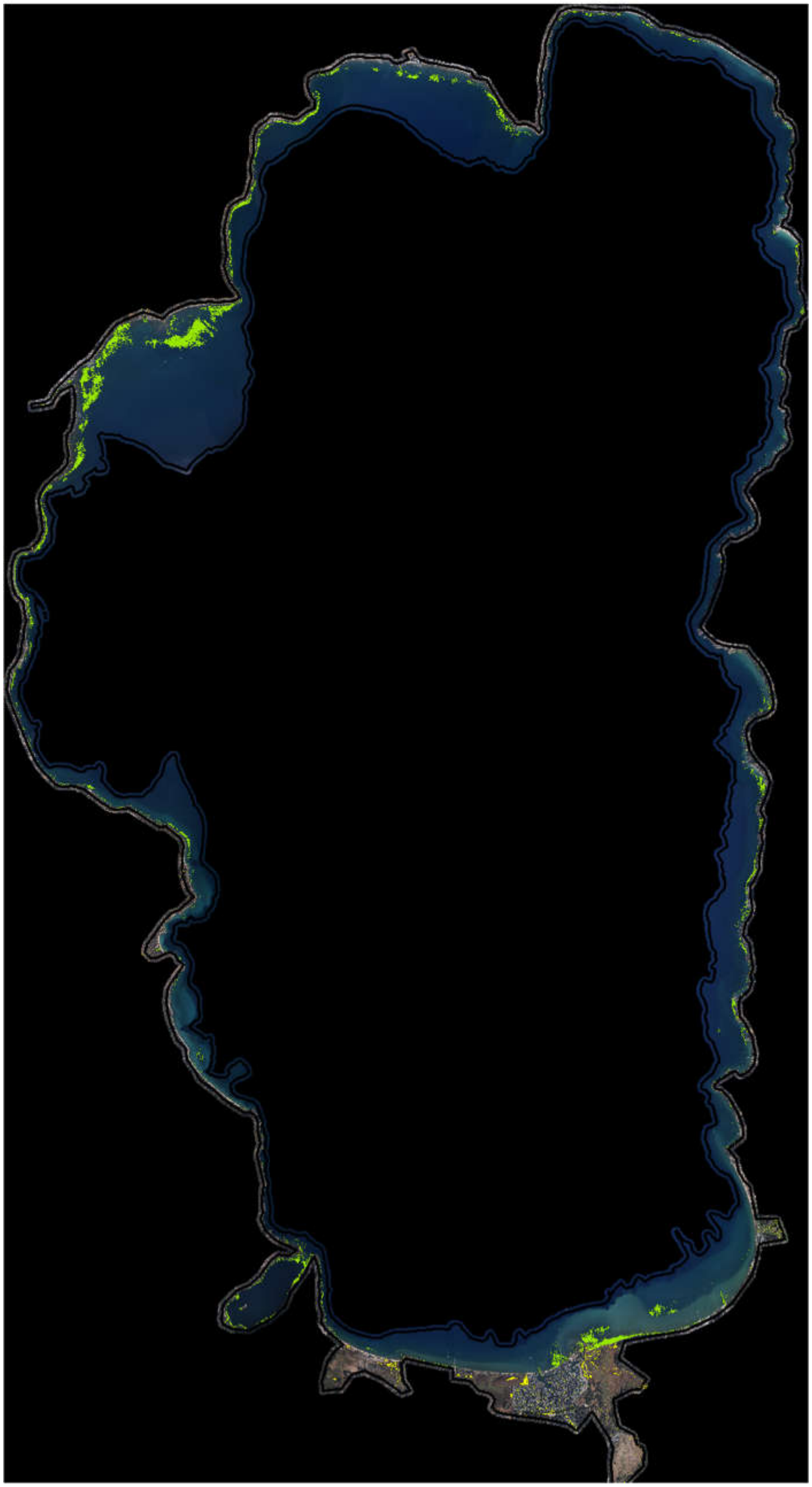


Figure 29. Modeled presence of submerged (green) and surface (yellow) vegetation in Lake Tahoe's nearshore and surrounding suitable habitats.

Figure 30. Modeled presence of submerged (green) and surface (yellow) vegetation in Lake Tahoe's nearshore and surrounding suitable habitats.

Figure 31. Modeled presence of submerged (green) and surface (yellow) vegetation in the northern region of Lake Tahoe.

Figure 32. Modeled presence of submerged (green) and surface (yellow) vegetation in the Truckee River Corridor near Tahoe City, CA.

Aquatic Plant Bed Extent, Distribution, and Relative Species Abundance/Composition

Automated aquatic plant modeling indicated that there are about 730 acres of submerged and surface aquatic plants within the open water portion of the survey area (Table 8). Plant beds ranged in area from approximately 4.35 ft^2 (minimum mapping unit) to 2.77 acres (mean patch size = 370 ft^2) distributed within 72,856 plant bed patches (Table 8). The nearshore/open water stratum appears to support the greatest estimated extent of submerged and surface aquatic plants (653 acres), however, plant cover is proportionately lowest in this stratum (Table 9). The marsh stratum had the highest proportion of submerged and surface aquatic plants with an estimated 67% cover (Table 9). In terms of aquatic plant distribution, the greatest aquatic plant coverage estimates were recorded at Lake Forest Shoreline (north shore), Tahoe City Shoreline (north shore) and Upper Truckee Shoreline survey zones (Appendix E). Extremely low aquatic plant cover was estimated for Sierra Boat Works, Crystal Bay East and Mid, and Obexer's Marina survey zones. Survey zones associated with the marsh stratum had the highest percent cover of surface and submerged aquatic plants (Appendix E).

Table 8. Initial summary statistics of mapped surface and subsurface/submerged aquatic vegetation within the water edge.

Class	Acres Subsurface Aquatic Vegetation Detected	Acres Surface Aquatic Vegetation Detected	Total
Total Acres	652.81	76.95	**729.76**
Min. Polygon Size (Acres)	0.0001	0.0001	
Max. Polygon Size (Acres)	0.53	2.77	
Average Polygon Size	0.014	0.003	
Std. Dev.	0.092	0.017	
Polygon Count	47,016	25,840	**72,856**

Table 9. Summary statistics of aquatic plant cover by strata.

Strata	Open Water Acres Within Stratum	Surface Water Plant Acres	Submerged Plant Acres	Total Acres Submerged and Surface Plants	Percent Cover
Marina/Embayment	285.37	19.51	7.87	27.38	9.59%
Marsh	53.95	36.23	0.17	36.40	67.48%
Nearshore Open Water	19,415.98	8.70	643.93	652.63	3.36%
Stream	46.98	12.00	0.83	12.83	27.31%
Total	**19,802.27**	**76.44**	**652.80**	**729.24**	**3.68%**

The ability to distinguish plant species (and thus characterize species composition) across the survey area from remotely sensed data was not possible. However, it was possible to infer species composition for survey zones where plant species-specific cover estimates were recorded. To do this we averaged diver transect and quadrat plant species cover data for survey zones (with plant detections) and multiplied these values by plant area data derived from the automated plant mapping effort. The results of this analysis yielded acreage estimates for each species detected by survey zone as illustrated in Table 10.

Table 10. Acreage estimates of different aquatic plants by survey zone. Acreages were calculated by multiplying the average percent cover values recorded through diver survey by the area of modeled plant extent for each survey zone.

Survey Zone	Andean Milfoil (AM)	Chara spp.	Clasping Pondweed (CP)	Common bladderwort (CB)	Coontail	Curly-leaf Pondweed *	Elodea	Eurasian Watermilfoil *	Filamentous Green Algae	Leafy Pondweed	Mares Tail	Naiad spp.	Northern milfoil	Quill Wart	Richardson's Pondweed	Sago Pondweed	Various-leafed Pondweed	White water Buttercup
Baldwin Beach	0.037	0.043	0.000	0.000	0.000	0.002	0.013	0.029	0.000	0.001	0.000	0.002	0.000	0.000	0.000	0.000	0.002	0.000
Blackwood Creek	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Burke Creek	0.000	0.011	0.000	0.010	0.002	0.000	0.015	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Camp Richardson	0.003	0.022	0.000	0.000	0.000	0.000	0.023	0.194	0.000	0.003	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Edgewood Creek	0.000	0.340	0.000	0.000	0.000	0.416	0.527	0.156	0.161	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.028
Fleur Du Lac	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
General Creek	0.000	0.010	0.000	0.010	0.000	0.000	0.000	0.000	0.055	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lakeside Marina Beach	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Meeks Bay Marina	0.000	0.149	0.000	0.051	0.000	0.000	0.559	0.358	0.000	0.000	0.000	0.000	0.069	0.000	0.000	0.000	0.000	0.000
Obexer's Marina	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pope Marsh	0.000	0.000	0.000	0.762	0.000	0.000	0.000	0.047	0.218	0.000	0.403	0.000	0.522	0.000	0.000	0.000	0.587	0.000
Ski Run Lakeward	0.000	0.032	0.000	0.000	0.000	0.020	0.004	0.014	0.000	0.007	0.000	0.009	0.000	0.006	0.020	0.000	0.014	0.000
Slaughterhouse Creek Mouth	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.160	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Snow Creek	0.000	0.006	0.000	0.000	0.007	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008
Star Harbor	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tahoe City Marina	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tahoe Key Homeowner Lakeward	0.000	0.007	0.000	0.000	0.030	0.001	0.008	0.005	0.000	0.010	0.000	0.030	0.000	0.052	0.000	0.000	0.000	0.000
Tahoe Key Homeowners Marina	0.000	0.094	0.000	0.000	1.579	0.000	0.460	1.568	0.051	0.000	0.000	0.000	0.000	0.000	0.633	0.000	0.000	0.000
Tahoe Keys Marina	0.000	0.010	0.000	0.000	0.075	0.000	0.000	0.237	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tahoe Keys Marina Lakeward	0.058	0.079	0.000	0.000	0.000	0.031	0.041	0.046	0.005	0.030	0.000	0.096	0.006	0.148	0.054	0.000	0.094	0.000
Tallac Marsh	0.000	0.062	0.000	0.045	0.000	0.000	0.000	0.020	0.035	0.025	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.013
Taylor Creek Marsh	0.000	0.782	0.000	1.530	0.000	0.000	0.347	1.437	0.000	0.440	0.160	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Survey Zone	Andean Milfoil (AM)	Chara spp.	Clasping Pondweed (CP)	Common bladderwort (CB)	Coontail	Curly-leaf Pondweed *	Elodea	Eurasian Watermilfoil *	Filamentous Green Algae	Leafy Pondweed	Mares Tail	Naiad spp.	Northern milfoil	Quill Wart	Richardson's Pondweed	Sago Pondweed	Various-leafed Pondweed	White water Buttercup
Timber Cove Lakeward	0.000	0.108	0.000	0.000	0.000	0.004	0.040	0.091	0.000	0.075	0.000	0.000	0.000	0.107	0.000	0.000	0.000	0.000
Truckee River (below dam)	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.047	0.489	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015
Truckee River Lakeward (above dam)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.056	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Upper Truckee Marsh	0.000	0.000	0.000	3.796	0.000	0.000	0.000	0.000	0.000	0.000	0.672	0.000	0.000	0.000	0.000	0.000	0.883	0.000
Upper Truckee River	0.000	0.297	0.000	0.150	0.000	0.011	0.598	0.380	0.475	0.046	0.000	0.314	0.000	0.000	0.000	0.000	0.000	0.000
Upper Truckee River Lakeward	0.000	0.901	0.000	0.274	0.000	0.286	0.509	0.464	0.260	0.644	0.000	0.658	0.000	0.000	0.000	0.000	0.789	0.337
Ward Creek	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wovoka Cove	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Acres	**0.098**	**2.952**	**0.000**	**6.628**	**1.692**	**0.771**	**3.162**	**5.154**	**2.257**	**1.282**	**1.239**	**1.112**	**0.597**	**0.313**	**0.707**	**0.000**	**2.369**	**0.402**

*: Indicates Non-native species

Discussion

Diver Survey

Using transect and quadrat methodologies the field team was able to collect various information pertaining to species presence, species condition, and other organisms observed within four different strata. Field surveys were conducted throughout the lake resulting in an expansive mapping effort of plant presence within the Lake Tahoe basin. Both of these methodologies were used to support LiDAR mapping and to provide greater insight than what areal mapping can allow for.

The use of both quadrat and transect methods allowed researchers to evaluate the pros and cons for each sampling method within a given habitat and to determine which methodology is best suited for this scale of mapping aquatic plants. The quadrat method is best suited for mapping aquatic vegetation across strata because it provides greater insight about species presence, species overlap, and overall coverage. The rarefaction curves indicated that quadrat sampling in major tributaries was sufficient to capture most of the observed species. It is suggested that future monitoring efforts utilize quadrats for plant bed composition (relative species cover) and transects to simply determine overall plant cover. This combination of methods may result in a loss of detection for some species where those species occur at low coverage. However, one of the benefits of using visual methods is that observers can note species in the area regardless of presence on the transect or within a quadrat. This allows to incorporation of species that occur in “trace” amounts.

If the rarefaction curves are used to evaluate sampling intensity where capture of 90% of species present is the goal, then 2,050 meters of transect would have to be surveyed with quadrats collected every 10 meters. This distance can be reduced if the interval between quadrats is decreased (e.g. 1,025 m of transect with quadrats at 5 m intervals). However, reduction of transect length can be problematic if habitat varies with distance upstream. To combat changes in habitat across the landscape, any future reduction in transect length should not be implemented in a manner that reduces the sampling frame. In other words, an increased number of shorter transects are suitable but must be spread out across the area to be sampled. Ultimately, it is suggested that the level of sampling effort be maintained for future sampling. This would allow not only capture of most species within the samples but also allow sufficient data for calculation of cover values for most species. However, the number of quadrats relative to transect length can vary with more quadrats per unit of transect length in areas with short transects and greater inter-quadrat distances along longer transects with an average sampling goal of one quadrat per 10 m of transect.

It should be noted that in this report, percent vegetation cover estimates by strata are based on vegetated transects. This means the estimates are not “true” strata averages. Rather, they represent the plant cover estimates in portions of the strata that are vegetated. To determine strata averages, one would simply multiply the cover estimates by the number of vegetated transects and then divide by the total number of planned transects. The cover estimates intentionally left out opportunistic transects because those transects did not always follow the same methods as outlined. For instance, open-water nearshore opportunistic transects ran “shore parallel” rather than perpendicular. This was done to capture more data on relative occurrence of vegetative species within plant beds. But by ignoring the depth gradient across the stratum, the cover estimates are biased high if used for calculating stratum averages. However, the data are valuable for validating the LiDAR classification of plant beds and for knowing the relative species cover in some areas such that the data were used to help determine the plant bed acreages extrapolated from the combination of in-situ and remote sensing data.

Remote Sensing

The imagery and LiDAR data acquired as part of this project represent a paradigm shift in the ability to not only map aquatic vegetation within Lake Tahoe, but to characterize the entire nearshore environment. The imagery, which was acquired under near-perfect conditions, is free of waves. This factor, along with the spatial resolution, make this imagery dataset superior to prior satellite image collects, which had a coarser spatial resolution and in some cases were acquired when there were waves that virtually obscured the subsurface. The LiDAR acquisition resulted in a host of useful products ranging from topographic/bathymetric surface models to reflectance data. These data collectively provide details on Lake Tahoe's nearshore environment that will likely render previous mapping initiatives obsolete. The challenge is to turn these data into information that is usable for resource managers to make decisions that enable them to quantify and track Lake Tahoe's aquatic vegetation.

The work completed so far succeeded in providing the most detailed and comprehensive accounting of Lake Tahoe's aquatic vegetation. Nevertheless, some limitations exist. These limitations can be divided into two general categories. The first is the data gaps that are present in the LiDAR data. While the LiDAR data are of excellent quality there exist data gaps in areas that are either known to or likely contain invasive aquatic species. These data gaps make automated feature extraction challenging as automated approaches require data consistency. The second is that aquatic vegetation mapping from remote data is a highly cognitive process that requires not only an understanding of the data, but local knowledge, the ability to extract information at multiple scales, and the expertise to adjust to the local scene data characteristics. For these reasons, we recommend that the work on aquatic vegetation mapping be continued, incorporating manual editing to improve the quality of the automated feature extraction.

Conclusions

Aquatic invasive plants were present across all strata. However, curly-leaf pondweed was not reported in marsh environments whereas Eurasian watermilfoil was present across all strata. Aquatic invasive species were reported more frequently in the southern and western portions of the lake. Generally, invasive plants species were present within the same transect or quadrat as native plant species.

Transect coverage provided spatial information pertaining to species location. However, due to the differences in strata surveyed, average coverage between open-water nearshore transects and all other strata appears to be much lower. While average coverage appears lower in open-water nearshore strata this is a function of transect length and strata type. In this case open-water nearshore transects were longer than most other transects and extended to depths where plant species were less likely to occur. Conversely, marsh and major tributary transects mostly occurred over highly vegetated areas where average coverage appears to be much greater due to the strata types.

Quadrat coverage provided additional spatial information and a secondary methodology by which to determine plant cover. While quadrats were not routinely sampled in open-water nearshore strata, marshes, and marinas and embayments, they did serve as a good indicator of aquatic plant coverage and presence of multiple species. In the future, it is recommended that quadrat sampling be implemented throughout all strata to create comparable results throughout. Employing quadrat-based sampling will reduce the plant coverage bias observed along lengthy transects where plants are not present, it will increase the resolution for species co-occurring at the same intercept.

On average the presence of non-native/invasive species was greater than native species within marinas and embayments and open-water nearshore strata. The only transect with plants that had no native species was at the Wovoka Bay where the marinas and embayments transect WNK001 was located (See

Appendix B, map 4 and Appendix C). All other transects where aquatic invasive plant species were observer also has native species present. Transects with mixed native and non-native plant communities were observed south of Wovoka Bay and continued clockwise around the lake until reaching Tahoe City Marina (map section 10). Transects with only native species were observed around the entirety of the lake. However, the occurrence of native only transects occurring near marinas and embayments and incoming water sources such as major tributaries decreased moving from the north to the south and at the south western portion of the lake. Numerous unvegetated transects occurred around the entirety of the lake.

The exotic and invasive Eurasian watermilfoil was present across all strata. The greatest average coverage by Eurasian watermilfoil was observed in the marinas and embayments strata. This result indicates that managers may want to increase the sampling intensity in the marinas and embayments strata in the future. Although plant cover was lower in the open-water nearshore strata, the expansive area within the strata means there are considerable areas with plants and invasive plants. The relative cover of Eurasian watermilfoil in the open-water nearshore strata was greater than 30% indicating that the species is a major structuring factor in the stratum.

The exotic and invasive curly-leaf pondweed was found in all strata except marshes. The highest average coverage by curly-leaf pondweed was observed in the major tributaries' stratum. The highest relative plant cover by curly-leaf pondweed was observed in the open-water nearshore stratum followed by the major tributaries' stratum.

Plant richness was highest in the open-water neashore stratum followed by, major tributaries, marinas and embayments, and marshes strata. Native species observed across all strata included *Chara* spp., common bladderwort, filamentous green algae, and leafy pondweed. Andian milfoil was only observed within open-water nearshore transects and was the only species to be observed within a single stratum.

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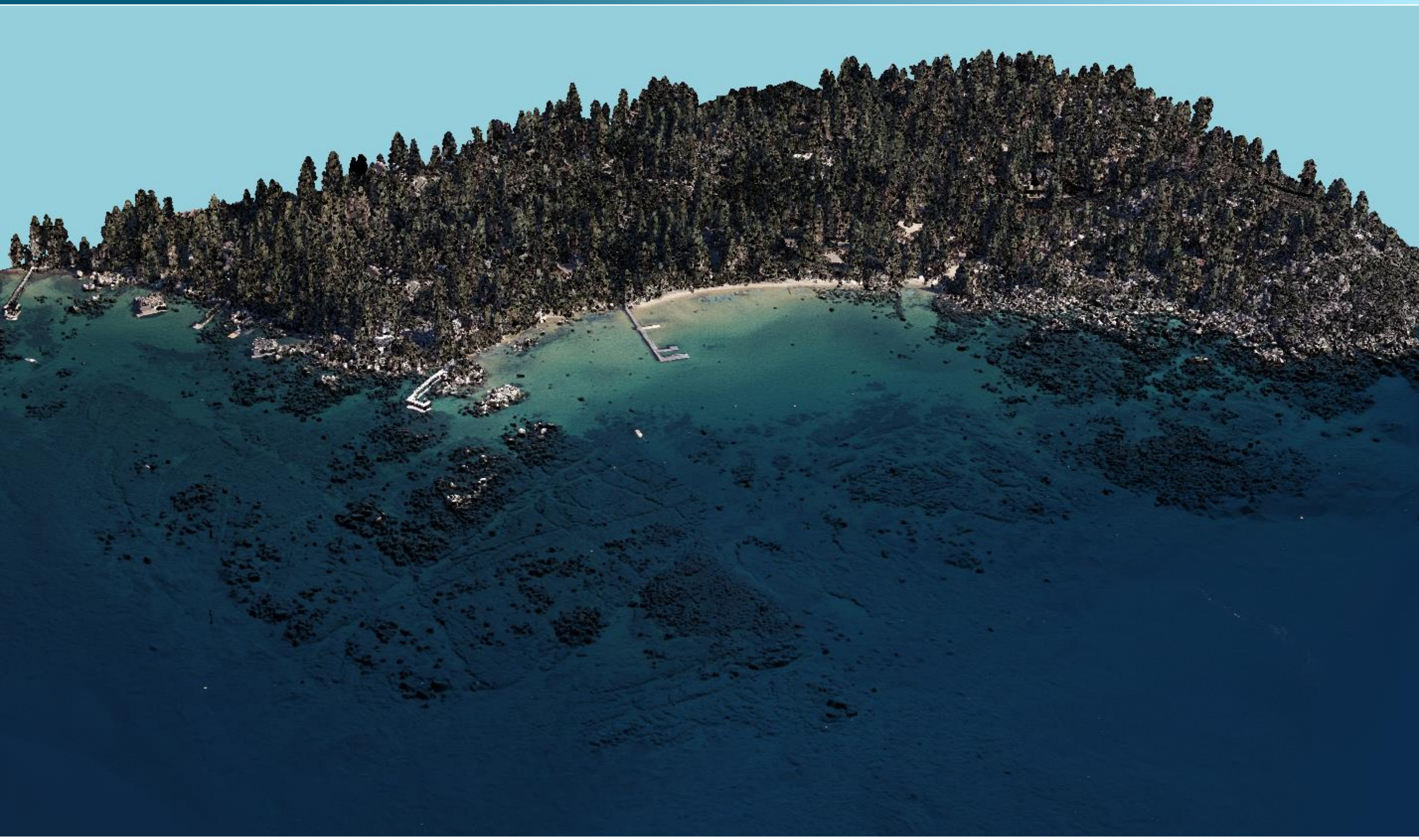
Appendix A -Topobathymetric LiDAR and Imagery Technical Data Report

December 21, 2018



Lake Tahoe, California and Nevada

Topobathymetric LiDAR and Imagery Technical Data Report

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Cover Photo: This view looks north and slightly east at Crystal Point. The California/Nevada state boundary runs directly through this cove in the northern portion of Lake Tahoe. This image was created by layering orthoimagery over top the LiDAR bare earth hillshade.

INTRODUCTION

This photo taken by QSI acquisition staff shows a view of GNSS Equipment set up over monument VLECK_1 to the southwest of the Lake Tahoe project site.

In July 2018, Quantum Spatial (QSI), in partnership with Oregon State University (OSU) was contracted by Spatial Informatics Group (SIG) to collect topobathymetric Light Detection and Ranging (LiDAR) data and digital imagery in the summer of 2018 for the Lake Tahoe site in California and Nevada. The Lake Tahoe area of interest attempts to encompass all suitable aquatic plant habitats within Lake Tahoe's near-shore, and includes the transition zones between the upland landscape with elevation ranges of 6,229 to 6,250 feet and the aquatic zone with up to 20 meters of observed depth. Conventional near-infrared (NIR) LiDAR was fully integrated with green wavelength (bathymetric) LiDAR in order to provide a seamless topobathymetric LiDAR dataset. Data were collected to aid SIG in object-based image analysis and benthic habitat classification.

This report accompanies the delivered topobathymetric LiDAR data and imagery. It documents contract specifications, data acquisition procedures, processing methods, and analysis of the final dataset including LiDAR accuracy, depth penetration, and density. Acquisition dates and acreage are shown in Table 1, a complete list of contracted deliverables provided to SIG is shown in Table 2, and the project extent is shown in Figure 1.

Table 1: Acquisition dates, acreage, and data types collected on the Lake Tahoe site

Project Site	Contracted Acres	Buffered Acres	Acquisition Dates	Data Type
Lake Tahoe, CA and NV	20,609	26,618	9/9/2018 - 9/11/2018, 9/16/2018	Topobathymetric LiDAR
			9/18/2018	4 band (RGB-NIR) Digital Imagery

Deliverable Products

Table 2: Products delivered to SIG for the Lake Tahoe site

Lake Tahoe LiDAR and Imagery Products Projection: UTM Zone 10 North Horizontal Datum: NAD83 (2011) Vertical Datum: NAVD88 (GEOID12B) Units: Meters	
Topobathymetric LiDAR	
Points	LAS v 1.4 Point Format 6 • All Classified Returns • Extra Byte storage (Amplitude, Reflectance, Pulse Shape Deviation, Submerged Refracted Vector Length, Angle of Incidence for Refraction, Bathymetric Flag)
Rasters	0.5 Meter ESRI Grids • Topobathymetric Bare Earth Digital Elevation Model (DEM) Bathymetric Voids Clipped • Topobathymetric Bare Earth Digital Elevation Model (DEM) Bathymetric Voids Unclipped • Highest Hit Digital Surface Model (DSM) • Lowest Hit Digital Surface Model (DSM) • Lakebed Relative Reflectance Model • Pulse Deviation Raster 0.5 Meter GeoTiffs • Green Sensor Intensity Images • NIR Sensor Intensity Images
Vectors	Shapefiles (*.shp) • Area of Interest • LiDAR Tile Index • Bathymetric Coverage Shape • Water's Edge Breaklines • Ground Survey Shapes
Digital Imagery	
Rasters	20 cm Aerial Imagery (4-Band) • Tiled Imagery Mosaics (16 bit) • AOI Imagery Mosaic (8bit) • Image Frames (16bit)
Vectors	Shapefiles (*.shp) • Air Target Points • Camera Exterior Orientations

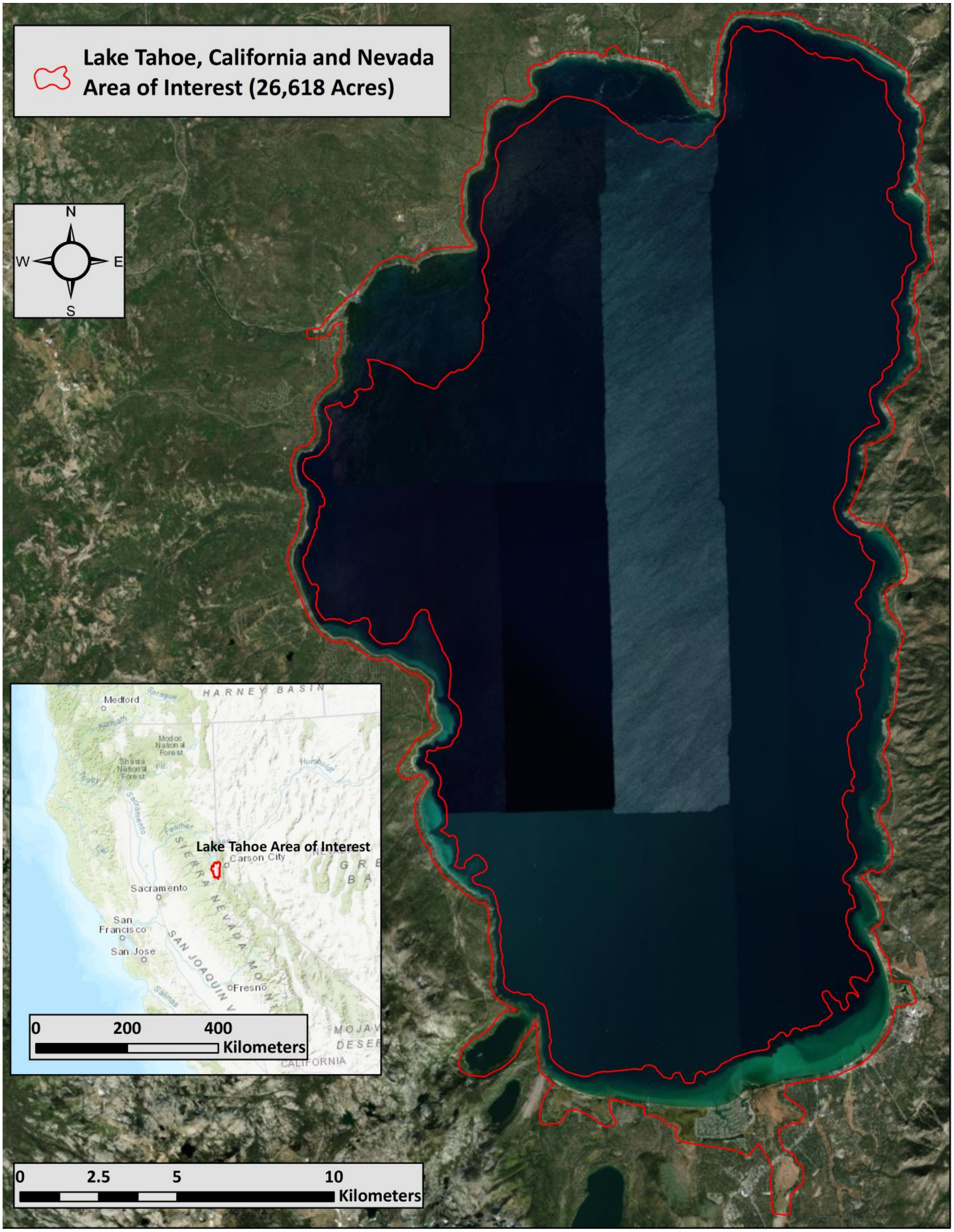


Figure 1: Location map of the Lake Tahoe project area in California and Nevada

QSI's Cessna Caravan

Sensor Selection: the Riegl VQ-880-G

The Riegl VQ-880-G was selected as the hydrographic airborne laser scanner for the Lake Tahoe project based on fulfillment of several requirements and considerations deemed necessary for effective mapping of the project site. A higher repetition pulse rate (up to 550 kHz), higher scanning speed, small laser footprint, and wide field of view allow for seamless collection of high resolution data of both topographic and bathymetric surfaces. A short laser pulse length allows for discrimination of underwater surface expression in shallow water, critical to shallow and dynamic environments such as the Lake Tahoe project area.

Planning

In preparation for data collection, QSI reviewed the project area and developed a specialized flight plan to ensure complete coverage of the Lake Tahoe LiDAR study area at the target combined point density of ≥12.0 points/m^2 for green and NIR LiDAR returns. Acquisition parameters including orientation relative to terrain, flight altitude, pulse rate, scan angle, and ground speed were adapted to optimize flight paths and flight times while meeting all contract specifications.

Factors such as satellite constellation availability and weather windows must be considered during the planning stage. Any weather hazards or conditions affecting the flight were continuously monitored due to their potential impact on the daily success of airborne and ground operations. In addition, logistical considerations including private property access, potential air space restrictions, water levels, and water clarity were reviewed.

Turbidity Measurements and Secchi Depth Readings

In order to assess water clarity conditions prior to and during LiDAR and digital imagery collection, QSI collected turbidity measurements, secchi depth readings, and wind speed and direction measurements. Readings were collected at five locations throughout the project site between September 8th and September 11th, 2018. Turbidity and wind observations were recorded twice to confirm measurements. The table below provides turbidity and secchi depth results per site on each day of data collection. Please note that all secchi depth readings were noted to have reached the bottom surface of the lakebed.

Table 3: Water Clarity Observations for LiDAR flights

Turbidity, Secchi Depth, and Wind Speed Observations									
Date	**Location**	**Longitude**	**Latitude**	**Turbidity Read 1**	**Turbidity Read 2**	***Secchi Depth (m)**	**LiDAR Mapped Depth (m)**	**Wind Speed (mph)**	**Wind Speed (mph)**
9/8	Kaspian Public Pier	-120.1574884	39.11468668	0.42	0.36	2.56	2.421	5.2 SSW	6.4 S
9/9	Beach House Retreat Pier	-119.9673934	38.94892637	0.5	0.44	1.86	1.858	2.9 NE	2.8 NNE
9/9	Beach House Retreat Pier	-119.9674484	38.94900034	0.34	0.28	2.0	1.910	2.4 N	3.9 NNW
9/9	EL Dorado Dock	-119.9771522	38.9448272	1.72	1.44	1.5	0.000	2.3 NNW	2.8 NNW
9/9	El Dorado Dock	-119.9773157	38.94506919	1.23	1.14	1.5	1.329	2.0 N	1.2 NNW
9/9	Beach House Pier	-119.967405	38.94885052	0.72	0.6	1.8	1.868	3.2 NW	2.8 NW
9/9	Beach House Retreat Pier	-119.9673791	38.94883103	0.5	0.42	1.8	1.869	4.1 N	5 N
9/10	Wolf Lodge Lakeside Pier	-120.0372997	39.23719672	0.37	0.42	~2	2.261	0	0
9/10	Wolf Lodge Lakeside Pier	-120.037336	39.23722074	0.24	0.36	2.4	2.154	11.5 SSW	12.2 S
9/11	Grove Street Pier	-120.1375979	39.17076215	0.5	0.44	2.9	2.890	9.6 WSW	10.1 SW

** Measurement is depth to the bottom surface due to observational depth limitations*

This photo taken by QSI acquisition staff shows a view of the water clarity conditions observed at the time of LiDAR acquisition.

Another photo taken by QSI acquisition staff showing wave conditions observed on September 10th, 2018, during LiDAR acquisition.

Airborne Survey

LiDAR

The LiDAR survey was accomplished using a Riegl VQ-880-G green laser system mounted in a Cessna Caravan. The Riegl VQ-880-G uses a green wavelength (ʎ=532 nm) laser that is capable of collecting high resolution vegetation and topography data, as well as penetrating the water surface with minimal spectral absorption by water. The Riegl VQ-880-G contains an integrated NIR laser (ʎ=1064 nm) that adds additional topography data and aids in water surface modeling. The recorded waveform enables range measurements for all discernible targets for a given pulse. The typical number of returns digitized from a single pulse range from 1 to 7 for the Lake Tahoe project area. It is not uncommon for some types of surfaces (e.g., dense vegetation or water) to return fewer pulses to the LiDAR sensor than the laser originally emitted. The discrepancy between first return and overall delivered density will vary depending on terrain, land cover, and the prevalence of water bodies. All discernible laser returns were processed for the output dataset. Table 4 summarizes the settings used to yield an average pulse density of $\geq$12 pulses/m^2 over the Lake Tahoe project area.

Table 4: LiDAR specifications and survey settings

LiDAR Survey Settings & Specifications		
Acquisition Dates	09/09/2018-09/11/2018, 9/16/2018	
Aircraft Used	Cessna Caravan	
Sensor Manufacturer	Riegl	
Laser	VQ-880-G	VQ-880G-IR
Maximum Returns	Unlimited, but typically not more than 7	Unlimited, by typically not more than 7
Resolution/Density	Combined Average 12 pulses/m^2	Combined Average 12 pulses/m^2
Aggregate Nominal Pulse Spacing	0.29 m	0.29 m
Survey Altitude (AGL)	500 m	500 m
Survey speed	110 knots	110 knots
Field of View	40^o	40^o
Mirror Scan Rate	80 Lines Per Second	Uniform Point Spacing
Target Pulse Rate	245 kHz	245 kHz
Pulse Length	1.5 ns	3 ns
Laser Pulse Footprint Diameter	35 cm	10 cm
Central Wavelength	532 nm	1064 nm
Pulse Mode	Multiple Times Around (MTA)	Multiple Times Around (MTA)
Beam Divergence	0.7 mrad	0.2 mrad
Swath Width	364 m	364 m
Swath Overlap	30 %	30 %
Intensity	16-bit	16-bit
Accuracy	$RMSE_Z \leq 15$ cm	$RMSE_Z \leq 15$ cm

All areas were surveyed with an opposing flight line side-lap of ≥50% (≥100% overlap) in order to reduce laser shadowing and increase surface laser painting. To accurately solve for laser point position (geographic coordinates x, y and z), the positional coordinates of the airborne sensor and the attitude of the aircraft were recorded continuously throughout the LiDAR data collection mission. Position of the aircraft was measured twice per second (2 Hz) by an onboard differential GPS unit, and aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft and sensor position and attitude data are indexed by GPS time.

A scenic photo of the project area, taken by QSI acquisition staff.

Digital Imagery

Aerial imagery was collected using an UltraCam Eagle M3 digital camera manufactured by Vexel (Table 5). The system is gyro-stabilized and simultaneously collects panchromatic and multispectral (RGB, NIR) imagery.

Table 5: Camera manufacturer's specifications

UltraCam Eagle M3	
Focal Length	100 mm
Data Format	RGBI
RCD Pixel Size	4.0 µm
Image Size	26,460 x 17,004 pixels
Frame Rate	1.5 sec (GPS triggered)
FOV	55 x 37 °

For the Lake Tahoe survey, 437 images were collected in 4 spectral bands (red, green, blue, and NIR) with 80% along track overlap and 60% sidelap between frames. The acquisition flight parameters were designed to yield a native pixel resolution of ≤ 20 cm. Orthophoto specifications particular to the Lake Tahoe photo project are in Table 6.

Table 6: Project-specific orthophoto specifications

Digital Orthophotography Specifications	
Spectral Bands	Red, Green, Blue, NIR
Resolution	20 cm pixel size
Along Track Overlap	≥80%
Cross Track Overlap	≥60%
Flight Altitude (MSL)	3,900 meters
GPS Baselines	≤25 nm
GPS PDOP	≤3.0
GPS Satellite Constellation	≥6
Image	16-bit tiff

Ground Control

Existing NGS Monument

Ground control surveys, including monumentation, aerial targets and ground survey points (GSPs), were conducted to support the airborne acquisition. Ground control data were used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final LiDAR data and orthoimagery products.

Base Stations

The spatial configuration of ground survey monuments and Continuously Operating Reference Stations (CORS) provided redundant control within 13 nautical miles of the mission areas for LiDAR flights. Monuments were also used for collection of ground survey points using real time kinematic (RTK), post-processed kinematic (PPK), and fast-static (FS) survey techniques.

Monument locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. QSI utilized one existing QSI monument, one existing NGS monument, two permanent Leica SmartNet Real Time Network (RTN) base stations, and one permanent California Surveying and Drafting Supply (CSRS) RTN base station for the Lake Tahoe LiDAR project (Table 7, Figure 2). QSI's professional land surveyor, Evon Silvia (CAPLS#L9401) oversaw and certified the utilization of all base stations.

Table 7: Base stations utilized for the Lake Tahoe acquisition. Coordinates are on the NAD83(2011) datum, epoch 2010.00

Base Station ID	Type	Latitude	Longitude	Ellipsoid (meters)
AE9844	NGS Monument	39° 04' 28.22179"	-120° 09' 15.89575"	1891.477
CATK	Leica SmartNet	39° 20' 07.82266"	-120° 10' 11.75362"	1796.983
IN1G	CSDS	39° 15' 07.68867"	-119° 58' 13.75923"	1948.479
NVCC	Leica SmartNet	39° 10' 50.94029"	-119° 45' 55.01447"	1419.697
VLECK_01	QSI Monument	38° 56' 59.31674"	-120° 05' 24.71476"	2036.664

To correct the continuously recorded onboard measurements of the aircraft position, QSI concurrently conducted multiple static Global Navigation Satellite System (GNSS) ground surveys (1 Hz recording frequency) over each monument. During post-processing, the static GPS data were triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS[1]) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

[1] OPUS is a free service provided by the National Geodetic Survey to process corrected monument positions. http://www.ngs.noaa.gov/OPUS/.

Ground Survey Points (GSPs)

Ground survey points were collected using RTK, PPK, and FS survey techniques. For an RTK survey, a roving receiver receives corrections from a nearby base station or Real-Time Network (RTN) via radio or cellular network, enabling rapid collection of points with relative errors less than 1.5 cm horizontal and 2.0 cm vertical. PPK and FS surveys compute these corrections during post-processing to achieve comparable accuracy. RTK and PPK surveys record data while stationary for at least five seconds, calculating the position using at least three one-second epochs. FS surveys record observations for up to fifteen minutes on each GSP in order to support longer baselines. All GSP measurements were made during periods with a Position Dilution of Precision (PDOP) of ≤ 3.0 with at least six satellites in view of the stationary and roving receivers. See Table 8 for QSI ground survey equipment specifications.

GSPs were collected in areas where good satellite visibility was achieved on paved roads and other hard surfaces such as gravel or packed dirt roads. GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads due to the increased noise seen in the laser returns over these surfaces. GSPs were collected within as many flightlines as possible; however, the distribution of GSPs depended on ground access constraints and monument locations and may not be equitably distributed throughout the study area (Figure 2).

Table 8: Ground survey equipment identification

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R6	Integrated GNSS Antenna R6	TRM_R6	Rover
Trimble R7 GNSS	Zephyr GNSS Geodetic Model 2 RoHS	TRM57971.00	Static

Aerial Targets

Aerial target points (ATP) were surveyed throughout the project area prior to imagery acquisition (Figure 2). A total of 51 points were surveyed to support aerial triangulation and accuracy assessment purposes. ATPs typically consisted of high visibility road markings such as stop bars or turn arrows as well as cement corners.

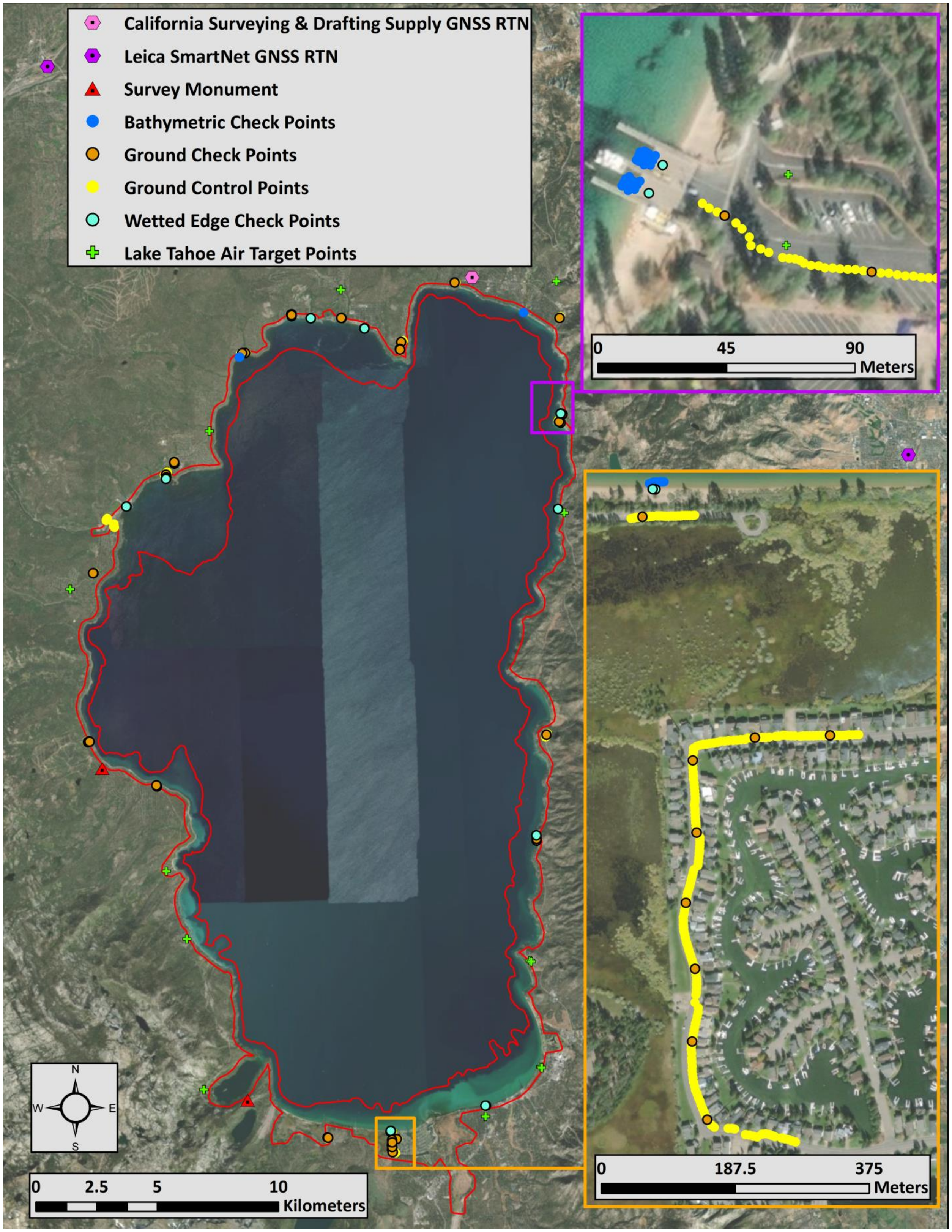
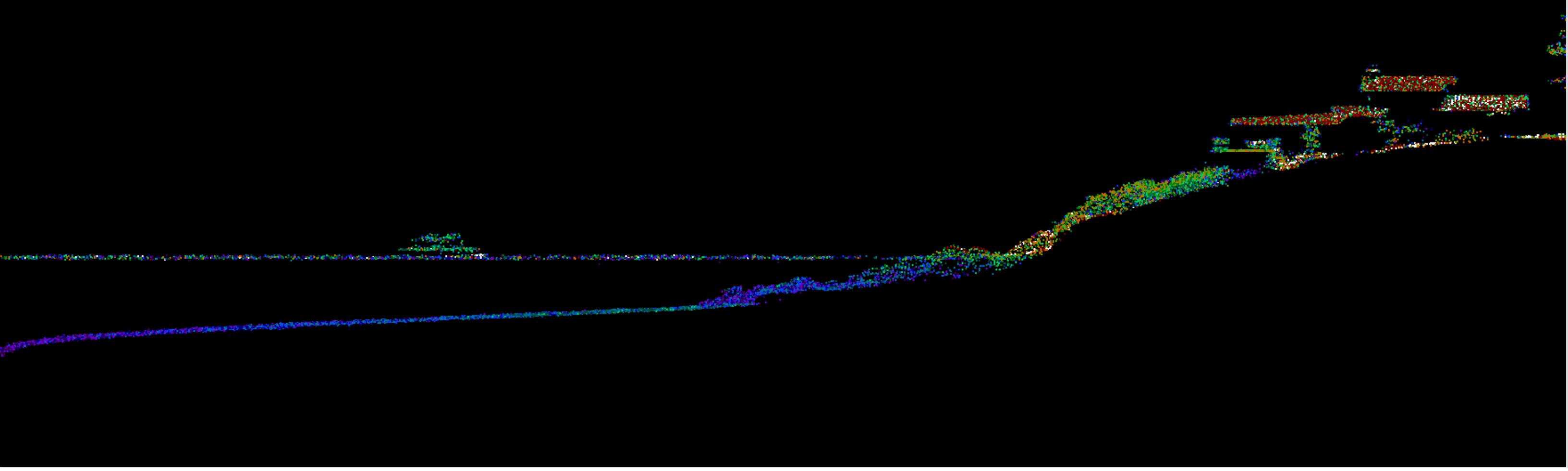


Figure 2: Ground survey location map

This LiDAR cross section shows a view of the Lake Tahoe point cloud colored by intensity value.



Topobathymetric LiDAR Data

Upon completion of data acquisition, QSI processing staff initiated a suite of automated and manual techniques to process the data into the requested deliverables. Processing tasks included GPS control computations, sensor calibration, smoothed best estimate trajectory (SBET) calculations, laser point georegistration, refraction corrections, laser swath adjustments for optimal relative and absolute accuracy, and LiDAR point classification (Table 9). A brief description of these tasks are displayed in Table 11.

Table 9: ASPRS LAS classification standards applied to the Lake Tahoe dataset

Classification Number	Classification Name	Classification Description
1	Default/Unclassified	Laser returns that are not included in the ground class, composed of vegetation and anthropogenic features
2	Ground	Laser returns that are determined to be ground using automated and manual cleaning algorithms
9	Water	NIR laser returns that are determined to be water using automated and manual cleaning algorithms
40	Bathymetric Bottom	Refracted Riegl sensor returns that fall within the water's edge breakline which characterize the submerged topography.
41	Water Surface	Green laser returns that are determined to be water surface points using automated and manual cleaning algorithms.
45	Water Column	Refracted Riegl sensor returns that are determined to be water using automated and manual cleaning algorithms.

Table 10: LiDAR processing workflow

LiDAR Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GNSS data. Develop a smoothed best estimate of trajectory (SBET) file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	POSPac MMS v.8.0
Calculate laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in *.las (ASPRS v. 1.4) format. Convert data to orthometric elevations by applying a geoid correction.	RiProcess v1.8.2 TerraMatch v.18 Riegl Automator v.1 (QSI proprietary)
Assign swath values and initial swath treatments to remove duplicates, ensure quality return values, perform edge clip, perform initial QC, and archive Riegl Extra Byte values for later restore.	Las Monkey 2.3 (QSI proprietary)
Import raw laser points into manageable blocks (approximately 500 MB or less) to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flight lines.	TerraScan v.18
Using ground classified points per each flight line, test the relative accuracy. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale) and GPS/IMU drift. Calculate calibrations on ground classified points from paired flight lines and apply results to all points in a flight line. Use every flight line for relative accuracy calibration.	TerraMatch v.18 RiProcess v1.8.2
Apply refraction correction to all hydrographic returns. Archive refraction-related Extra Byte values for later restore.	Las Monkey 2.3 (QSI proprietary)
Classify resulting data to ground and other client designated ASPRS classifications (Table 9). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground control survey data.	TerraScan v.18 TerraModeler v.18
Generate bare earth models as triangulated surfaces. Generate highest hit models as a surface expression of all classified points. Export all surface models as ESRI GRIDs at a 0.5 meter pixel resolution.	TerraScan v.18 TerraModeler v.18 ArcMap v. 10.2.2
Restore Riegl and refraction Extra Byte values that were stripped by off-the-shelf LAS processing software. Normalize lidar intensity values for depth and range to better represent submerged reflectance.	Las Monkey 2.4 (QSI proprietary)
Export reflectance and Extra Byte raster products as GeoTIFFs at a 0.5 meter pixel resolution.	TerraScan v.18 TerraModeler v.18 ArcMap v. 10.3.1 Las Product Creator 1.5 (QSI proprietary software)

Bathymetric Refraction

Green lidar pulses that enter the water column must have their position corrected for refraction of the light beam as it passes through the water and its resulting decreased speed. QSI has developed proprietary software (Las Monkey) to perform this processing based on Snell's law. The first step is to develop a water surface model (WSM) from the NIR lidar water surface returns. The water surface model used for refraction is generated using NIR points within the breaklines defining the water's edge. Points are filtered and edited to obtain the most accurate representation of the water surface and are used to create a water surface model TIN. A TIN model is preferable to a raster based water surface model to obtain the most accurate angle of incidence during refraction.

Once the WSM is generated, the Las Monkey refraction software then intersects the partially submerged green pulses with the WSM to determine the angle of incidence with the water surface and the submerged component of the pulse vector. This provides the information necessary to correct the position of underwater points by adjusting the submerged vector length and orientation. After refraction, the points are compared against bathymetric check points to assess accuracy.

Points that underwent refraction have been flagged with a value of one in the "bathymetry flags" LAS Extra Byte. The submerged vector length (post-refraction) and the angle of incidence with the WSM surface normal have also been stored in the Extra Bytes of each refracted point.

Intensity Normalization

Laser return intensity is generally a unitless measure of discrete return signal strength, stored as a 16-bit integer value from 0 to 65,535. Intensity values roughly correspond to the reflectivity of the surface, which is a function of surface material composition. The magnitude of intensity values can vary across similar surfaces due to variability in atmospherics, water clarity, range, submerged depth, and the angle of incidence on the object. The result is line to line inconsistency and streaking in the images that can reduce the utility of these data for analytics.

Raw point cloud data for the Lake Tahoe project was exported using the Riegl Amplitude[2], a non-normalized measure of the pulse voltage on a logarithmic scale. Point cloud intensities have been normalized to remove the variability introduced by pulse range and submerged vector length based on research provided by partners at Oregon State University (Figure 3).

Two sets of reflectance imagery have been provided; one with only depth normalization applied and one with depth and range normalization applied.

[2] Review this white paper by Riegl for more information on Riegl Amplitude: http://www.riegl.com/uploads/tx_pxpriegldownloads/Whitepaper_LASextrabytes_implementation_in-RIEGLSoftware_2017-12-04.pdf

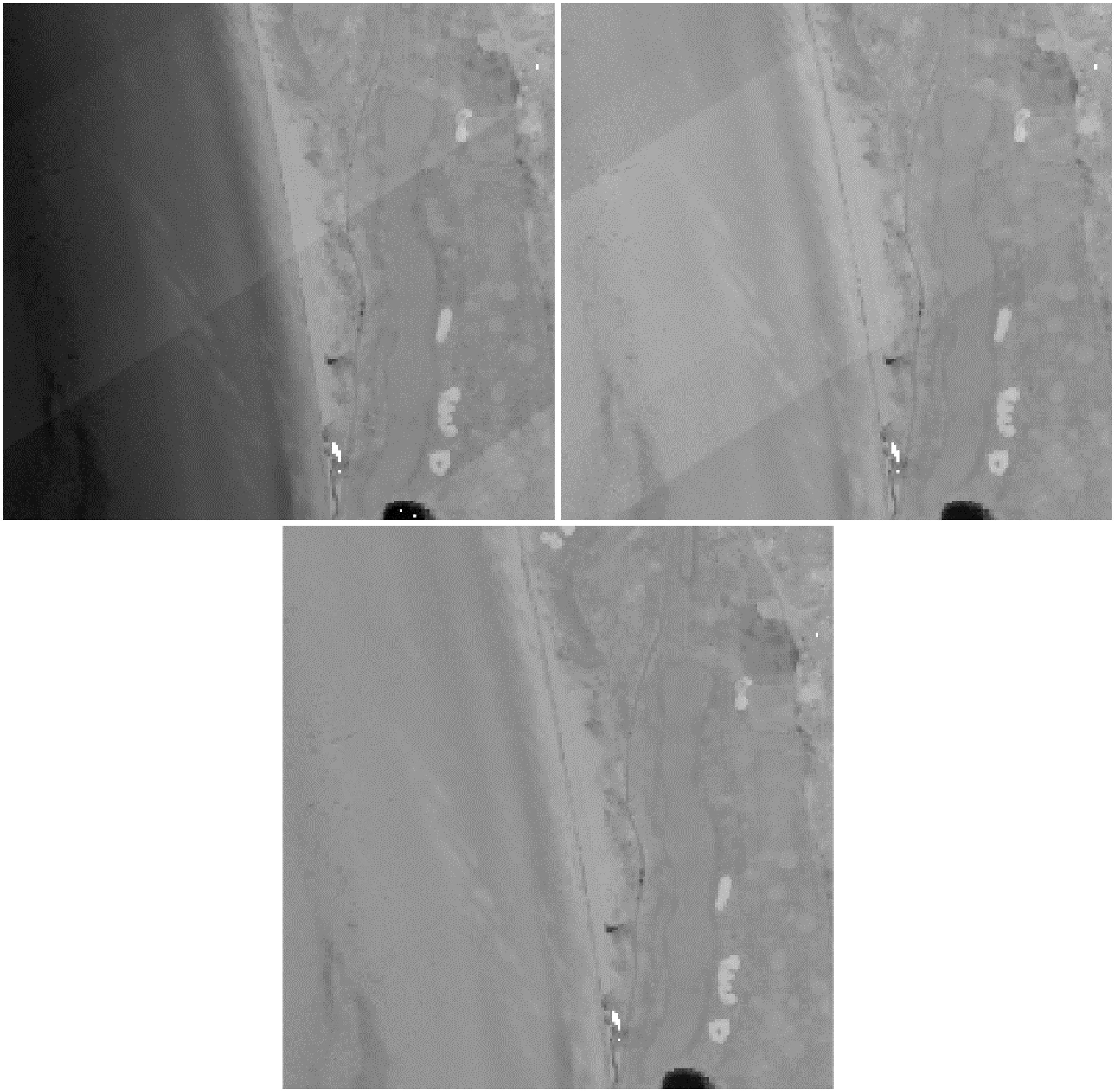


Figure 3: Intensity imagery before (left) and after (right) being normalized for range and submerged vector length. Imagery processing techniques can potentially be applied to remove the flightline edge artifacts in a future analysis not conducted for this delivery (bottom).

Some variability between flightlines is still present, even after automated normalization (Figure 4). Confounding factors include:

1. An inconsistent cross-swath darkening of intensities results in flightline edges presenting discontinuities in the intensity image.
2. Boat wakes and other surface wave patterns occasionally appear in the bathymetric bottom return intensities. These do not generally appear in adjacent flightlines.
3. Sun glint on the bathymetric bottom appears as localized patches of brighter bathymetric bottom patches. These do not generally appear in adjacent flightlines.

Imagery processing techniques of individual flightlines against adjacent flightlines can potentially remove many of these artifacts in a potential future analysis.

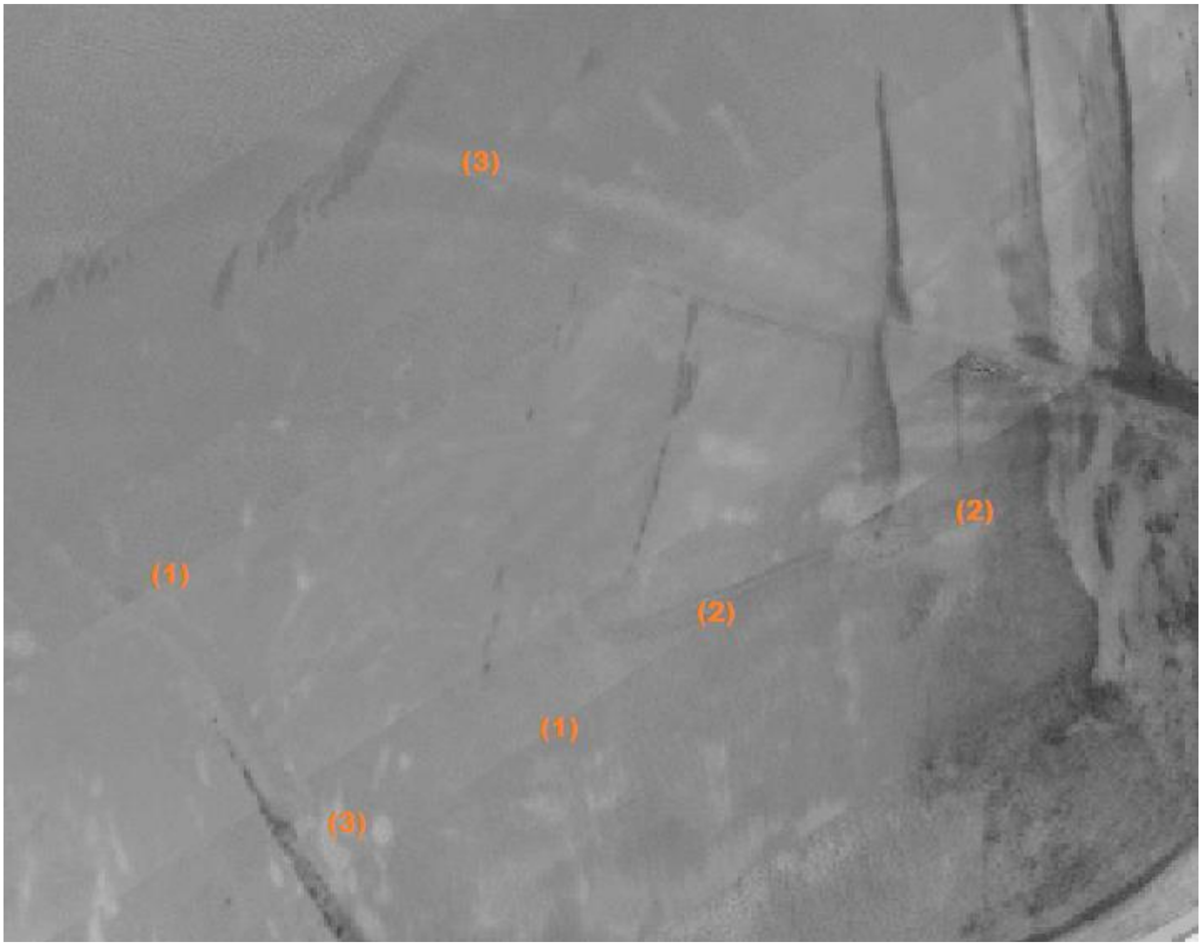


Figure 4: Intensity artifacts observed during intensity normalization to be considered during future analysis. Numbering corresponds to list above.

LiDAR Derived Products

Because hydrographic laser scanners penetrate the water surface to map submerged topography, this affects how the data should be processed and presented in derived products from the LiDAR point cloud. The following discusses certain derived products that vary from the traditional (NIR) specification and delivery format.

Topobathymetric DEMs

Bathymetric bottom returns can be limited by depth, water clarity, and bottom surface reflectivity. Water clarity and turbidity affects the depth penetration capability of the green wavelength 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. Although the predicted depth penetration range of the Riegl VQ-880-G sensor is 1.5 Secchi depths on brightly reflective surfaces, it is not unexpected to have no bathymetric bottom returns in turbid or non-reflective areas.

As a result, creating digital elevation models (DEMs) presents a challenge with respect to interpolation of areas with no returns. Traditional DEMs are "unclipped", meaning areas lacking ground returns are interpolated from neighboring ground returns (or breaklines in the case of hydro-flattening), with the assumption that the interpolation is close to reality. In bathymetric modeling, these assumptions are prone to error because a lack of bathymetric returns can indicate a change in elevation that the laser can no longer map due to increased depths. The resulting void areas may suggest greater depths, rather than similar elevations from neighboring bathymetric bottom returns. Therefore, QSI created a water polygon with bathymetric coverage to delineate areas with successfully mapped bathymetry. This shapefile was used to control the extent of the delivered clipped topobathymetric model to avoid false triangulation (interpolation from TIN'ing) across areas in the water with no bathymetric returns.

Intensity Images

In traditional NIR LiDAR, intensity images are often made using first return information. For bathymetric LiDAR however, it is most often the last returns that capture features of interest below the water's surface. Therefore, a first return intensity image would display intensity information of the water's surface, obscuring the features of interest below.

With bathymetric LiDAR a more detailed and informative intensity image can be created by using all or selected point classes, rather than relying on return number alone. If intensity information of the bathymetry is the primary goal, water surface and water column points can be excluded. However, water surface and water column points often contain potentially useful information about turbidity and submerged but unclassified features such as vegetation. For the Lake Tahoe project, QSI created several sets of intensity images:

1. Green Sensor Images:
    a. All bathymetric bottom and water column returns (40, 45), normalized by depth and range
    b. All bathymetric bottom and water column returns (40,45), normalized by depth
    c. All bathymetric bottom returns (40), normalized by depth and range
    d. All bathymetric bottom returns (40), normalized by depth
2. NIR Sensor Images
    a. All classifications (1, 2, 9), first returns only

Pulse Deviation Raster

The Riegl VQ-880-G scanners implements LAS extrabytes to export additional information pertaining to the pulse shape deviation. Riegl describes pulse shape deviation as a measurement of comparison between the pulse shape of the echo signal and “the pulse shape representing the so-called system response. […] The pulse shape deviation can be interpreted as the comparison of the area below the shape curve”, (LAS Extrabytes_Implementation_in RIEGL Software_2017-12-04) [3]. The measurement is stored as an unsigned 16 bit integer in the LAS file extrabyte format. The pulse deviation raster is created by taking the average value of pulse deviation measurements in a 0.5 square meter cell.

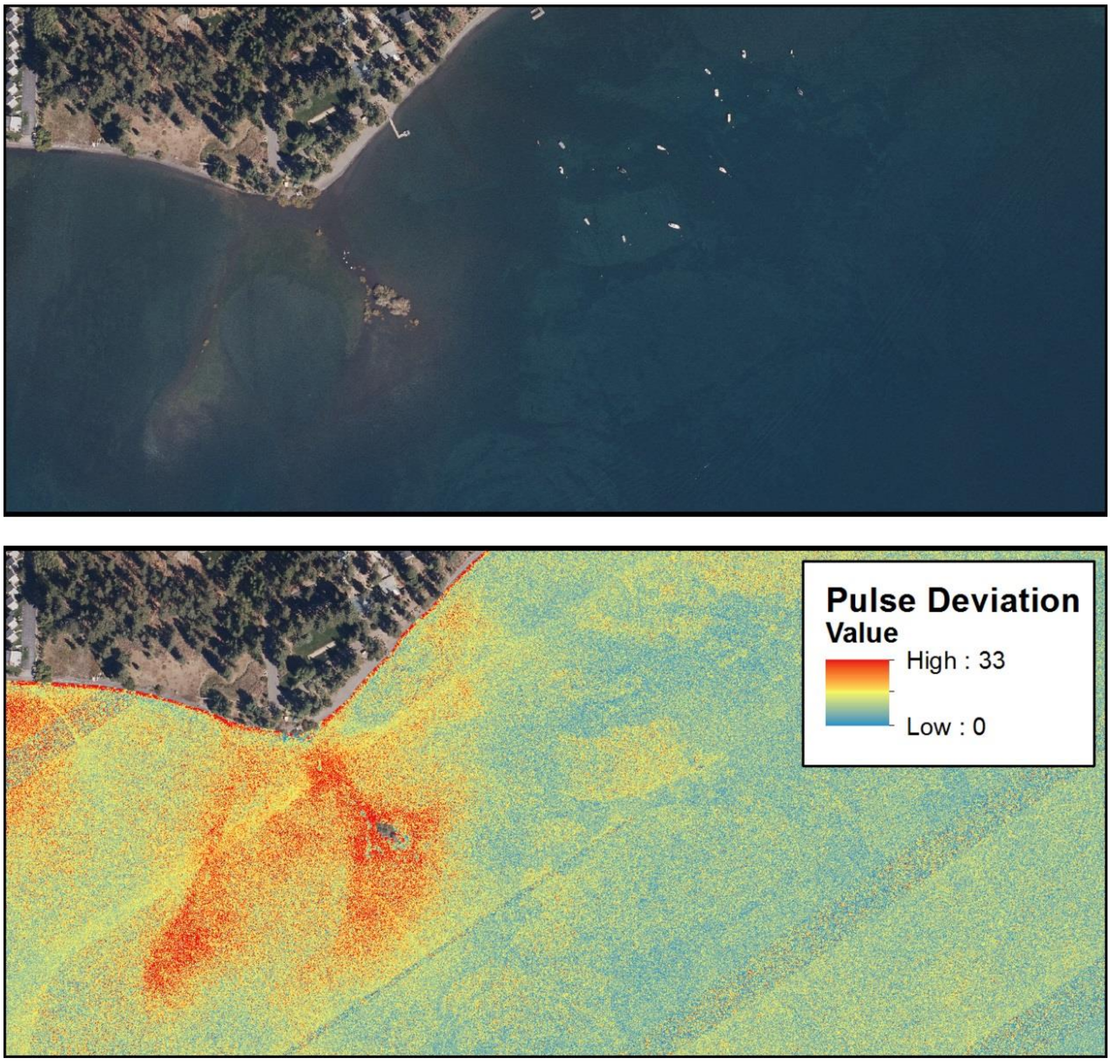


Figure 5: Sample image showing pulse deviation raster

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[3] http://www.riegl.com/uploads/tx_pxpriegldownloads/Whitepaper_LASextrabytes_implementation_in-RIEGLSoftware_2017-12-04.pdf

LAS Extrabytes

The point cloud is delivered in the LAS data format utilizing extrabytes to store additional attributes. 6 additional attributes stored as extrabytes are described in the variable length record of each LAS file.

Attribute (in order of position in the LAS file)	Description	Storage (raw)	Derivation
Amplitude	Echo signal amplitude [dB]	uint16	Riegl RiProcess
Reflectance	Echo signal reflectance [dB]	int16	Riegl RiProcess
Deviation	Pulse shape deviation	uint16	Riegl RiProcess
Refracted Depth	Submerged vector length	uint16	Las Monkey
Angle of Incidence	Angle from surface normal (deg)	uint16	Las Monkey
Bathymetric Flag	Bathymetric bit flag*	uint8	Las Monkey

**Implementation of the LAS domain profile for topobathy lidar. "0" indicates no refraction correction applied, "1" indicates that a correction was applied.*

Digital Imagery

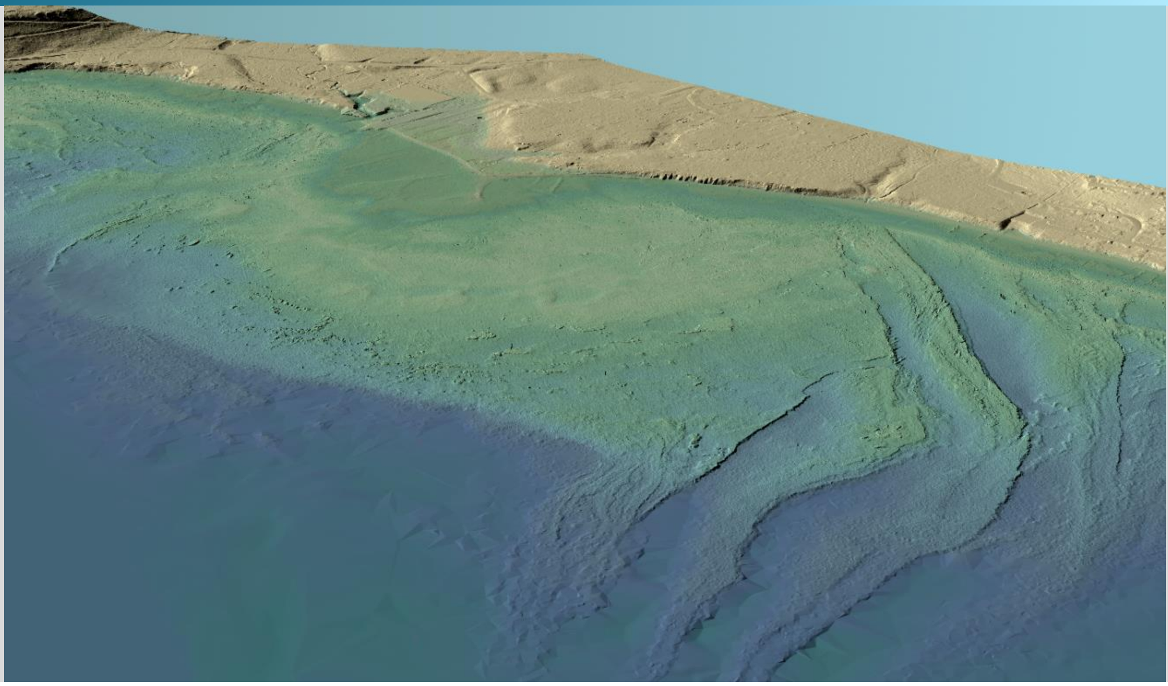
As with the NIR LiDAR, the collected digital photographs went through multiple processing steps to create final orthophoto products. Initially, images were corrected for geometric distortion to yield level02 image files. Next, images were color balanced and levels were adjusted to exploit the full 14bit histogram and finally output as level03 pan-sharpened 8bit TIFF images. Camera position and orientation were calculated by linking the time of image capture to the smoothed best estimate of trajectory (SBET). Within Inpho's Match AT softcopy photogrammetric software, analytical aerial triangulation was performed using ground control, automatically generated tie points, and camera calibration information.

Adjusted images were orthorectified using the LiDAR-derived ground model to remove displacement effects from topographic relief inherent in the imagery. The resulting orthos were mosaicked within Inpho's OrthoVista blending seams and applying automated project color-balancing. The final mosaics were inspected and edited for seam cutlines across above ground features such as buildings and other man-made features. Special care was taken to eliminate glare on the water surface. The processing workflow for orthophotos is summarized in Table 11.

Table 11: Orthophoto processing workflow

Orthophoto Processing Step	Software Used
Resolve GPS kinematic corrections for the aircraft position data using kinematic aircraft GPS (collected at 2 Hz) and Applanix Smartbase technology.	POSPac MMS v8.1
Develop a smooth best estimate trajectory (SBET) file that blends post-processed aircraft position with attitude data. Sensor heading, position, and attitude are calculated throughout the survey.	POSPac MMS v8.1
Create an exterior orientation file (EO) for each photo image with omega, phi, and kappa.	POSPac MMS v8.1
Convert Level 00 raw imagery data into geometrically corrected Level 02 image files.	UltraMap v4
Apply radiometric adjustments to Level 02 image files to create Level 03 Pan-sharpened TIFFs.	UltraMap v4
Apply EO to photos, measure ground control points and perform aerial triangulation.	Inpho Match AT v8
Import DEM, orthorectify and clip triangulated photos to the specified area of interest.	Inpho OrthoMaster v8
Mosaic orthorectified imagery, blending seams between individual photos and correcting for radiometric differences between photos.	Inpho OrthoVista/SeamEditor v8

This image shows a view of the Lake Tahoe bathymetry, created from the gridded topobathymetric bare earth model colored by elevation.



Bathymetric LiDAR

An underlying principle for collecting hydrographic LiDAR data is to survey near-shore areas that can be difficult to collect with other methods, such as multi-beam sonar, particularly over large areas. In order to determine the capability and effectiveness of the bathymetric LiDAR, several parameters were considered; depth penetrations below the water surface, bathymetric return density, and spatial accuracy.

Mapped Bathymetry and Depth Penetration

The specified depth penetration range of the Riegl VQ-880-G sensor is 1.5x the secchi depth; therefore, bathymetry data below 1.5x the secchi depth at the time of acquisition is not to be expected. In order to calculate overall max depth and to review depth results of bathymetric check point data, a water surface DEM raster was created by triangulating all ground and water surface points at a 1 meter pixel resolution. The triangulated topobathymetric DEM was subtracted from the water surface model to create a depth raster from which max depth was derived. The maximum depth recorded for the Lake Tahoe project was approximately 14.4 meters; the deepest recorded secchi depth (at lake bottom) was 2.9 meters. Further depth information for bathymetric check point data is included in Appendix B.

To assist in evaluating performance results of the sensor, a polygon layer was created to delineate areas where bathymetry was successfully mapped. This shapefile was used to control the extent of the delivered clipped topobathymetric model and to avoid false triangulation across areas in the water with no returns. Insufficiently mapped areas were identified by triangulating bathymetric bottom points with a maximum edge length of 4.56 meters. This ensured all areas of no returns (> 9 ft^2), were identified as data voids. Overall, approximately 41.6% percent of the mapped water body area within the Lake Tahoe project area was identified as “covered”.

LiDAR Point Density

First Return Point Density

The acquisition parameters were designed to acquire a cumulative average first-return density of 12 points/m^2. First return density describes the density of pulses emitted from the laser that return at least one echo to the system. Multiple returns from a single pulse were not considered in first return density analysis. Some types of surfaces (e.g., breaks in terrain, water and steep slopes) may have returned fewer pulses than originally emitted by the laser.

First returns typically reflect off the highest feature on the landscape within the footprint of the pulse. In forested or urban areas the highest feature could be a tree, building or power line, while in areas of unobstructed ground, the first return will be the only echo and represents the bare earth surface.

The average first-return density of the Lake Tahoe LiDAR project was 16.98 points/m^2 (Table 12). The statistical and spatial distributions of all first return densities per 100 m x 100 m cell are portrayed in Figure 6 and Figure 8. It should be noted that a data gap approximately 3 acres in size exists within the buffered boundary but outside the extent of the contracted boundary at the location of 120°6'30.027"W 38°57'2.491"N.

Bathymetric and Ground Classified Point Densities

The density of ground classified LiDAR returns and bathymetric bottom returns were also analyzed for this project. Terrain character, land cover, and ground surface reflectivity all influenced the density of ground surface returns. In vegetated areas, fewer pulses may have penetrated the canopy, resulting in lower ground density. Similarly, the density of bathymetric bottom returns was influenced by turbidity, depth, and bottom surface reflectivity. In turbid areas, fewer pulses may have penetrated the water surface, resulting in lower bathymetric return density.

The ground and bathymetric bottom classified density of LiDAR data for the Lake Tahoe project was 6.25 points/m^2(Table 12). The statistical and spatial distributions ground classified and bathymetric bottom return densities per 100 m x 100 m cell are portrayed in Figure 7 and Figure 9.

Additionally, for the Lake Tahoe project, density values of only bathymetric bottom returns were calculated for areas containing at least one bathymetric bottom return. Areas lacking bathymetric returns (voids) were not considered in calculating an average density value. Within the successfully mapped area, a bathymetric bottom return density of 15.81 points/m^2 was achieved.

Table 12: Average LiDAR point densities

Density Type	Point Density
First Returns	16.98 points/m^2
Ground and Bathymetric Bottom Classified Returns	6.25 points/m^2
Bathymetric Bottom Classified Returns	15.81 points/m^2

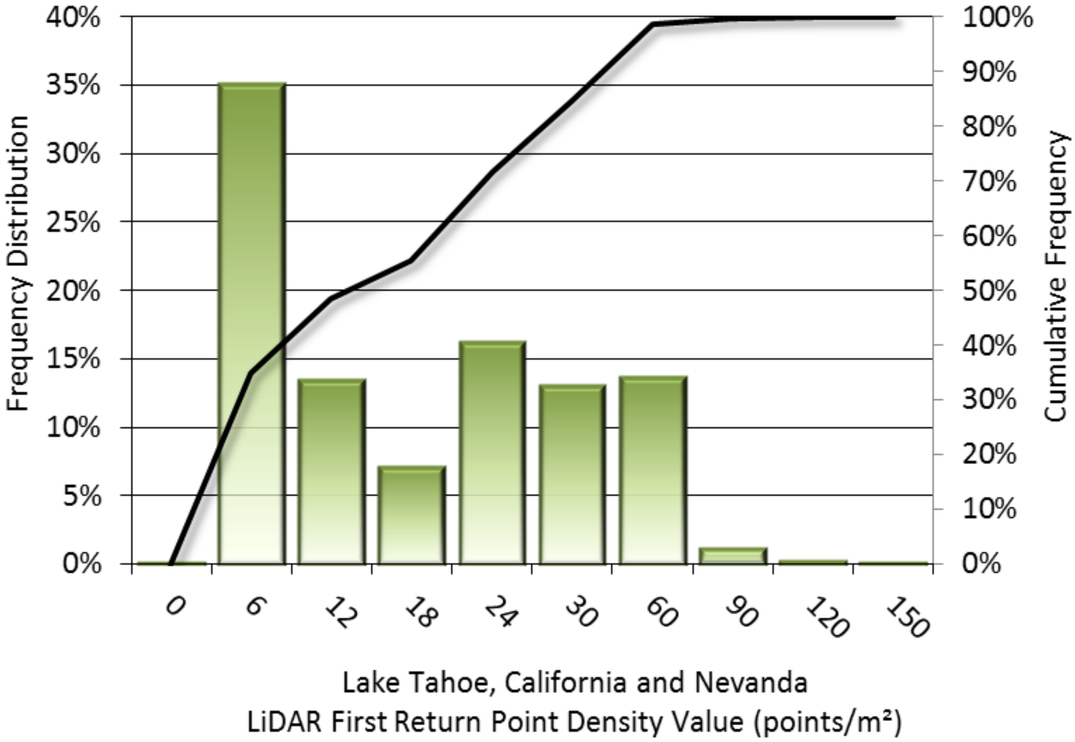


Figure 6: Frequency distribution of first return densities per 100 x 100 m cell

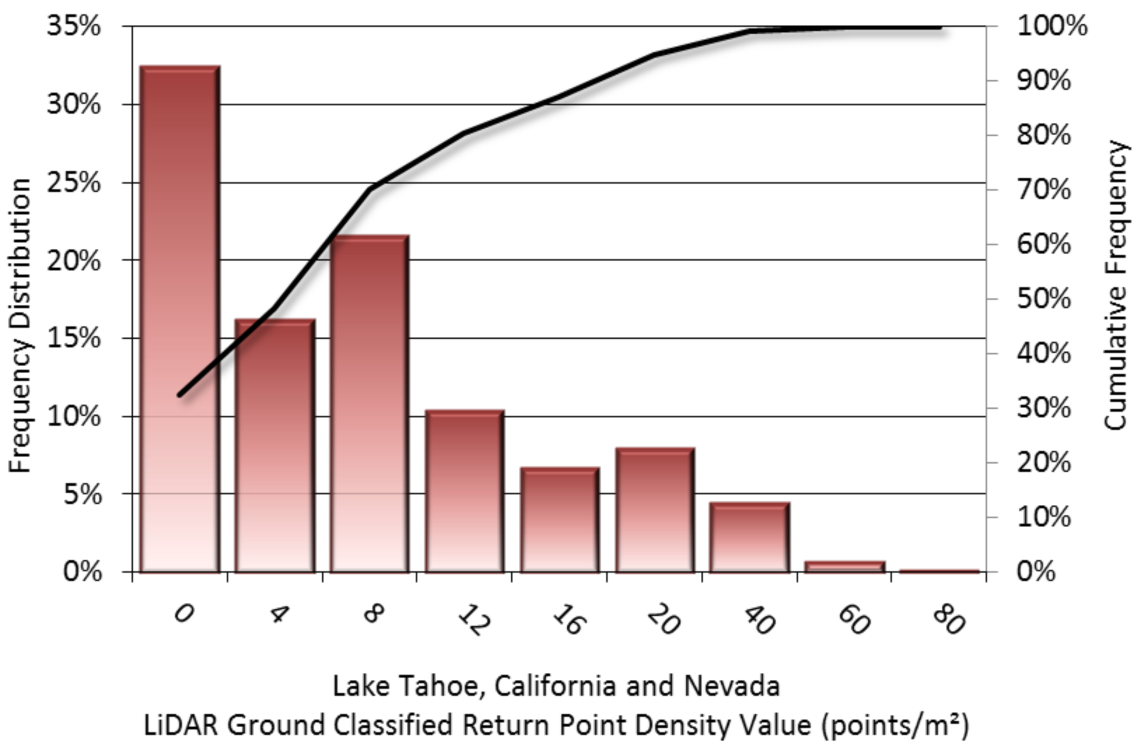


Figure 7: Frequency distribution of ground and bathymetric bottom classified return densities per 100 x 100 m cell

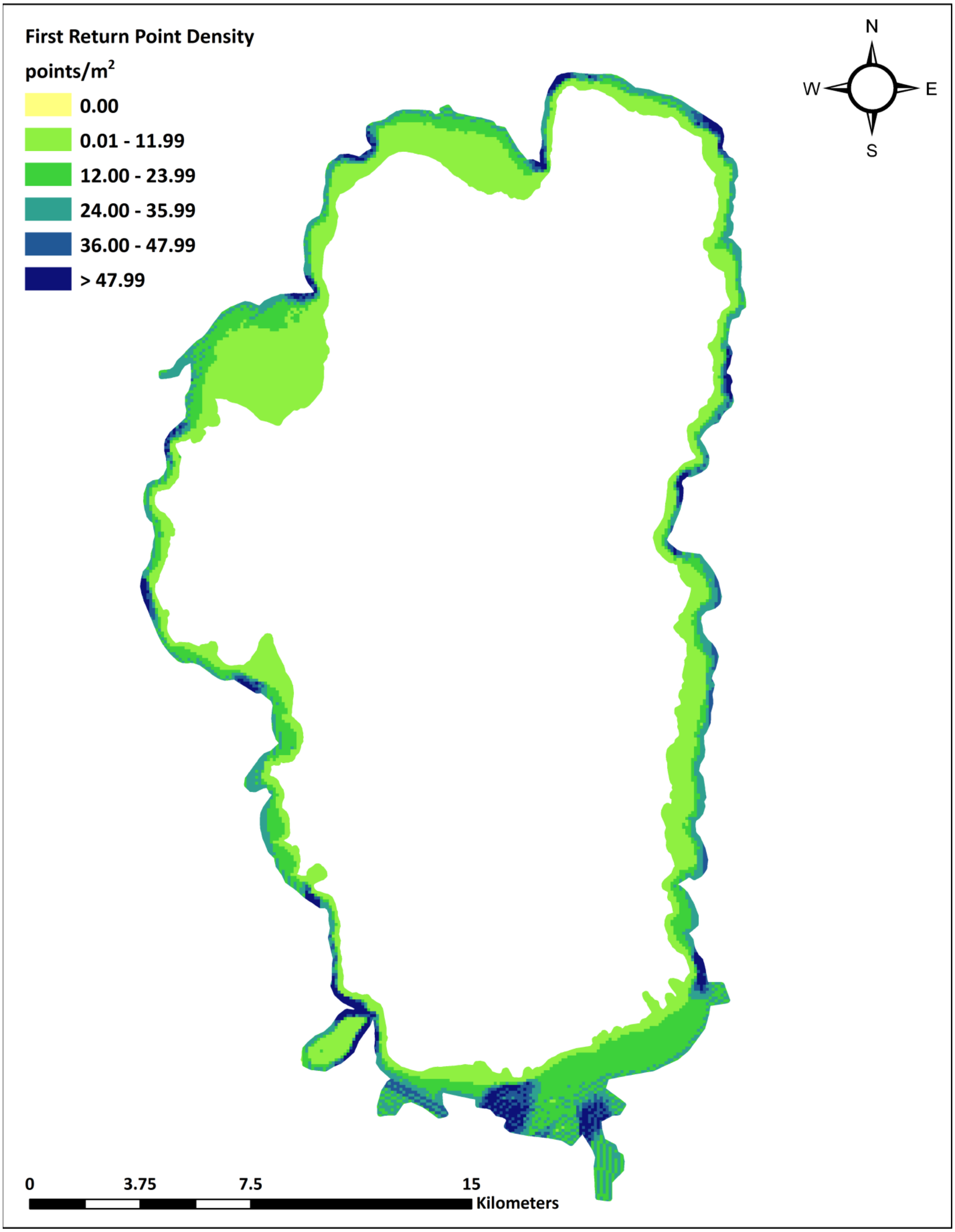


Figure 8: First return density map for the Lake Tahoe site (100 m x 100 m cells)

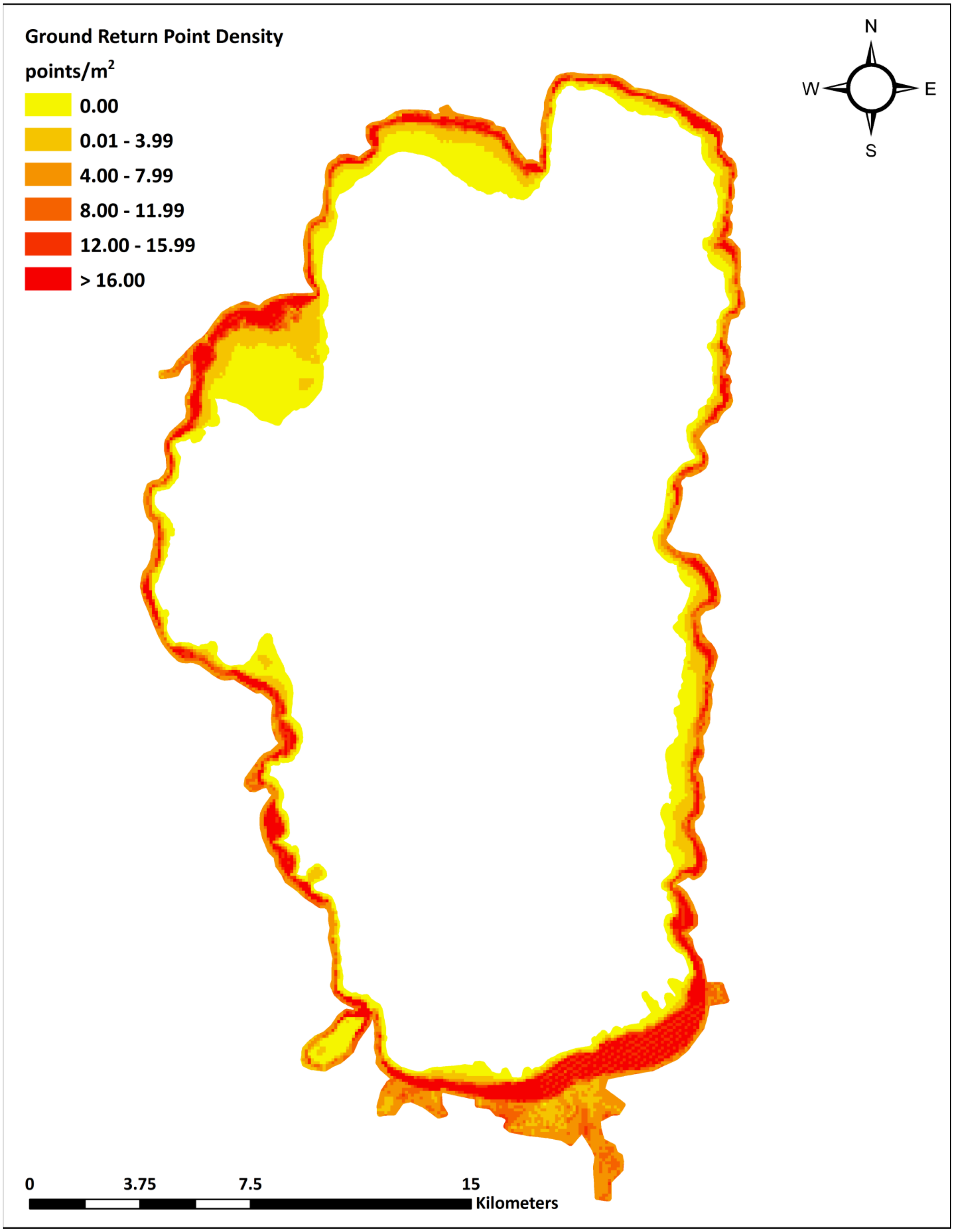


Figure 9: Ground and bathymetric bottom classified density map for the Lake Tahoe site (100 m x 100 m cells)

LiDAR Accuracy Assessments

The accuracy of the LiDAR data collection can be described in terms of absolute accuracy (the consistency of the data with external data sources) and relative accuracy (the consistency of the dataset with itself). See Appendix A for further information on sources of error and operational measures used to improve relative accuracy.

LiDAR Non-Vegetated Vertical Accuracy

Absolute accuracy was assessed using Non-vegetated Vertical Accuracy (NVA) reporting designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy[4]. NVA compares known ground check point data that were withheld from the calibration and post-processing of the LiDAR point cloud to the triangulated surface generated by the unclassified LiDAR point cloud as well as the derived gridded bare earth DEM. NVA is a measure of the accuracy of LiDAR point data in open areas where the LiDAR system has a high probability of measuring the ground surface and is evaluated at the 95% confidence interval (1.96 * RMSE), as shown in Table 13.

The mean and standard deviation (sigma σ) of divergence of the ground surface model from ground check point coordinates are also considered during accuracy assessment. These statistics assume the error for x, y and z is normally distributed, and therefore the skew and kurtosis of distributions are also considered when evaluating error statistics. For the Lake Tahoe survey, 44 ground check points were withheld from the calibration and post-processing of the LiDAR point cloud, with resulting non-vegetated vertical accuracy of 0.083 meters as compared to the unclassified LAS, and 0.073 meters as compared to the bare earth DEM, with 95% confidence.

QSI also assessed absolute accuracy using 836 ground control points. Although these points were used in the calibration and post-processing of the LiDAR point cloud, they still provide a good indication of the overall accuracy of the LiDAR dataset, and therefore have been provided in Table 13 and Figure 12.

Table 13: Absolute accuracy results

Non-Vegetated Vertical Accuracy			
	NVA - Ground Check Points (LAS)	**NVA - Ground Check Points (DEM)**	**Ground Control Points**
Sample	44 points	44 points	836 points
95% Confidence (1.96*RMSE)	0.083 m	0.073 m	0.076 m
Average	0.022 m	-0.010 m	0.003 m
Median	0.014 m	-0.015 m	0.003 m
RMSE	0.042 m	0.037 m	0.039 m
Standard Deviation (1σ)	0.037 m	0.036 m	0.039 m

[4] Federal Geographic Data Committee, ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA EDITION 1, Version 1.0, NOVEMBER 2014. http://www.asprs.org/PAD-Division/ASPRS-POSITIONAL-ACCURACY-STANDARDS-FOR-DIGITAL-GEOSPATIAL-DATA.html.

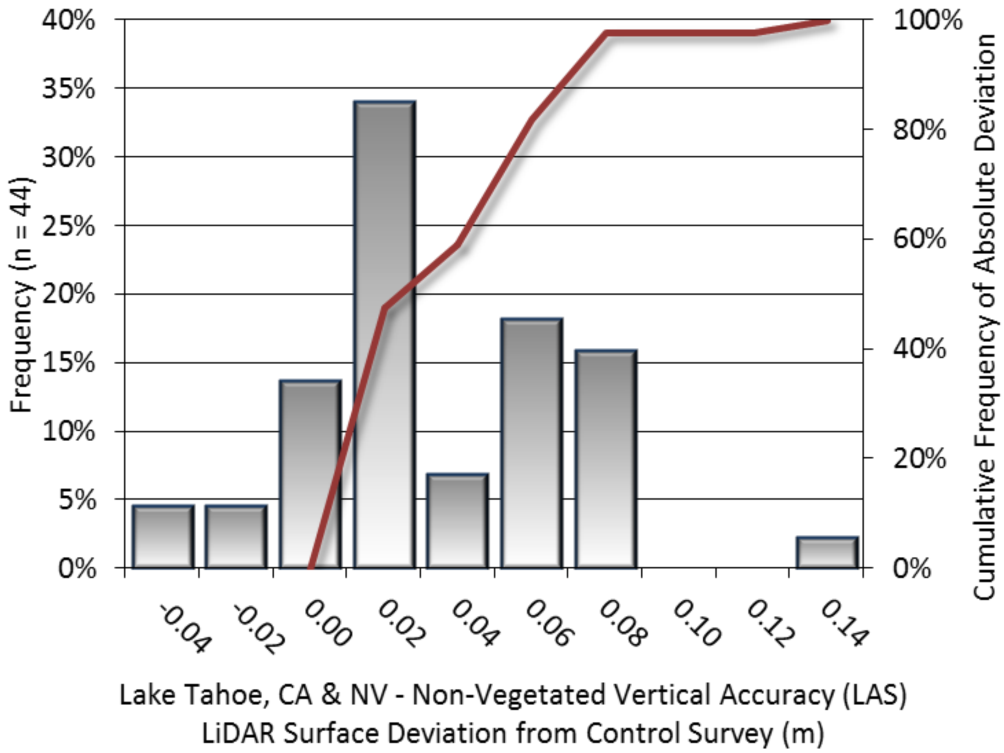


Figure 10: Frequency histogram for LiDAR unclassified LAS deviation from ground check point values

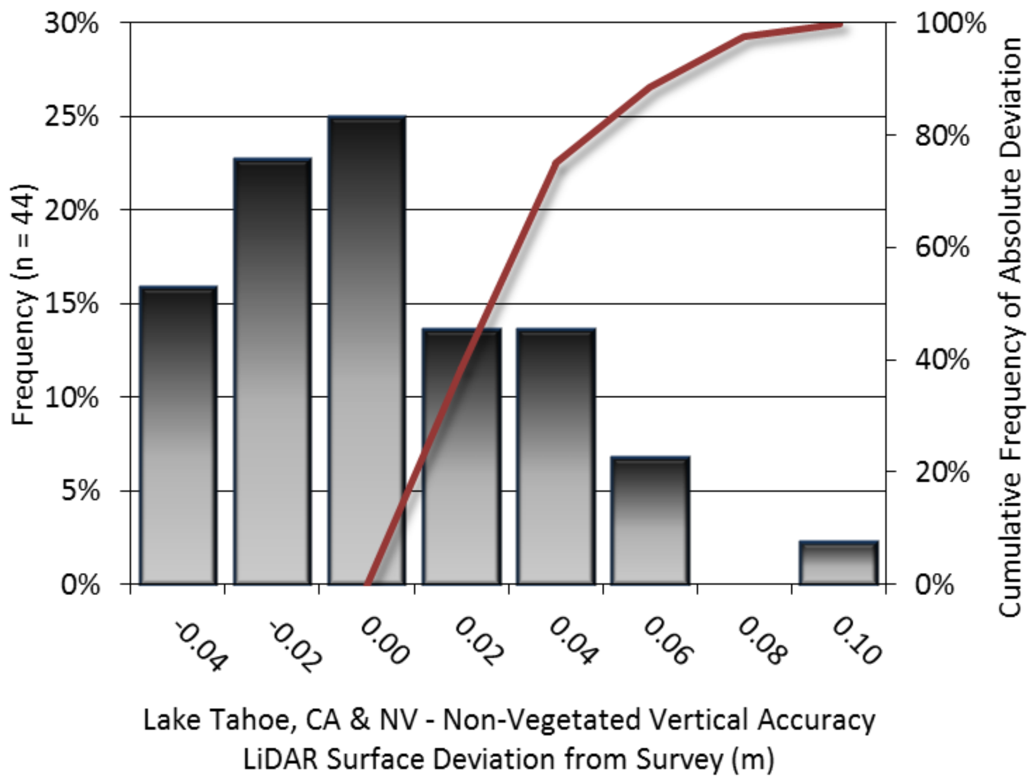


Figure 11: Frequency histogram for LiDAR bare earth DEM deviation from ground check point values

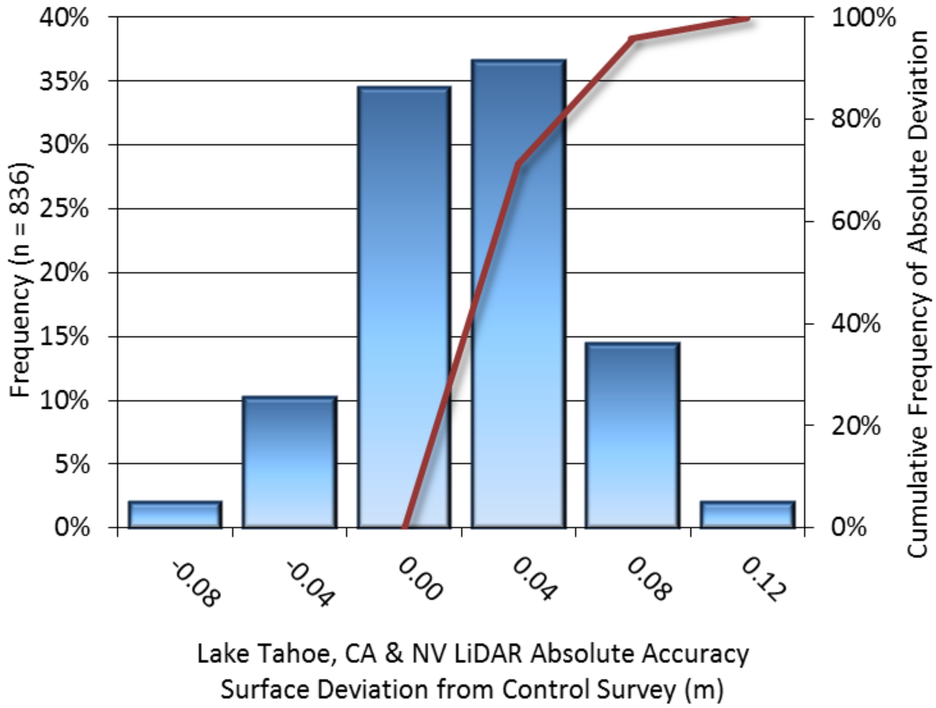


Figure 12: Frequency histogram for LiDAR surface deviation ground control point values

LiDAR Bathymetric Vertical Accuracies

Bathymetric (submerged or along the water's edge) check points were also collected in order to assess the submerged surface vertical accuracy. Assessment of 199 submerged bathymetric check points resulted in a vertical accuracy of 0.078 meters, while assessment of 17 wetted edge check points resulted in a vertical accuracy of 0.065 meters, evaluated at the 95th percentile (Table 14, Figure 13).

Table 14: Bathymetric Vertical Accuracy for the Lake Tahoe Project

Bathymetric Vertical Accuracy (VVA)		
	Submerged Bathymetric Check Points	**Wetted Edge Bathymetric Check Points**
Sample	199 points	17 points
Average Dz	0.016 m	0.016 m
Median	0.013 m	0.016 m
RMSE	0.043 m	0.043 m
Standard Deviation (1σ)	0.040 m	0.041 m
95th Percentile	0.078 m	0.065 m

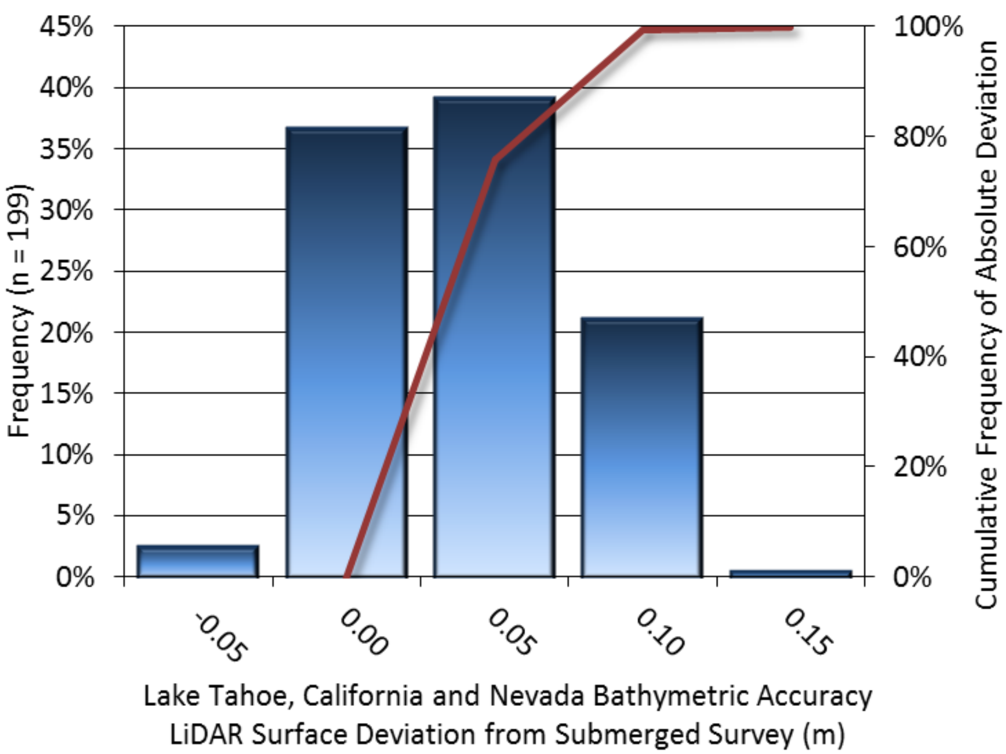


Figure 13: Frequency histogram for LiDAR surface deviation from submerged check point values

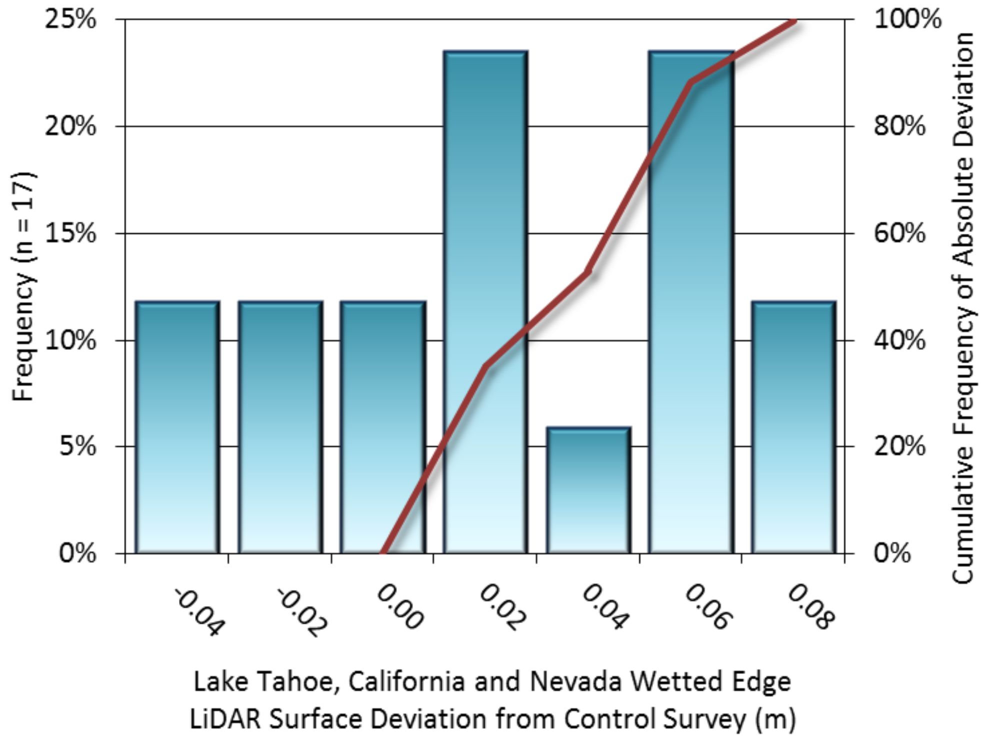


Figure 14: Frequency histogram for LiDAR surface deviation from wetted edge check point values

LiDAR Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the LiDAR system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the Lake Tahoe LiDAR project was 0.039 meters (Table 15, Figure 15).

Table 15: Relative accuracy results

Relative Accuracy	
Sample	424 surfaces
Average	0.039 m
Median	0.040 m
RMSE	0.045 m
Standard Deviation (1σ)	0.015 m
1.96σ	0.029 m

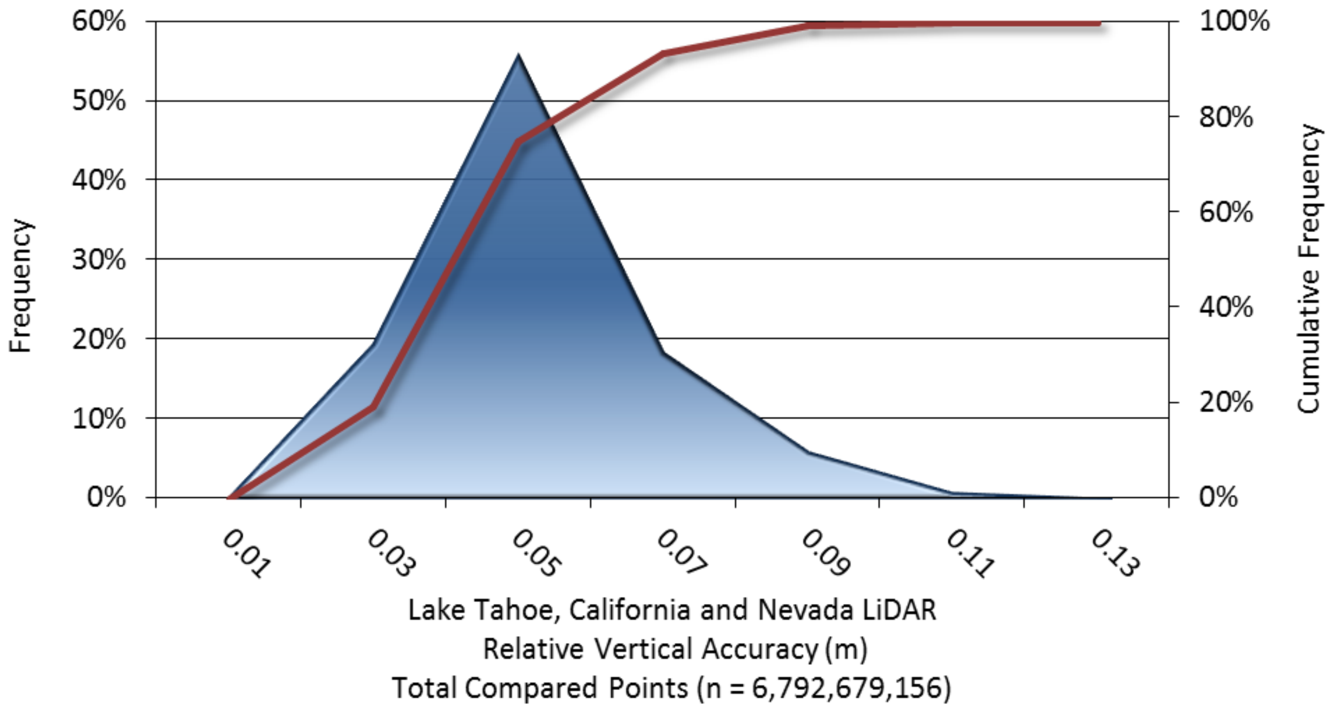


Figure 15: Frequency plot for relative vertical accuracy between flight lines

Analytical Aerial Triangulation Report

Overview

Aerotriangulation was performed in one block to support photogrammetric mapping efforts of Lake Tahoe. The block consisted of eleven flight lines and 437 images flown at a scale of 1:1,600 on September 18, 2018. Adjustments were made to ground control established by QSI referencing UTM Zone 10N, NAD83(2011) horizontal datum and NAVD 1988 vertical datum (Geoid12b). Digital imagery along with ground control and camera calibration data were used as input to Inpho's Match AT softcopy photogrammetry program. The digital camera utilized was an UltraCam Eagle M3. Of the 51 total surveyed air target points, 26 were used for aerial triangulation, 7 were withheld from the block adjustment as check points for accuracy assessment and 18 were designated as extraneous because of close proximity to neighboring air target points. Extraneous points are ATPs surveyed over the same ground feature, for example of the four ATPs surveyed at each corner of a stop bar only one would be used for control purposes. This redundancy helps when reviewing the orthos during QAQC and serves as a failsafe in the case that a ground control point fails precision requirements, see Ground Survey Points (GSPs) section for further details.

Control Points

Air target points used in the aerial triangulation adjustment are listed with their location in Table 16, their residuals are listed in Table 17 and RMSE values can be found in Table 18.

Table 16: Location of air target points used as control for aerial triangulation adjustment

Control Point Coordinates - 26 Total Points			
Point ID	Easting (m)	Northing (m)	Elevation (m)
AT003	764293.926	4316565.773	1900.197
AT005	763817.733	4320986.684	1921.554
AT007	764084.687	4326111.868	1901.447
AT008	764088.317	4326112.345	1901.455
AT009	764506.670	4330308.532	1960.341
AT012	764897.696	4348979.210	2021.048
AT015	765216.590	4339434.289	1969.787
AT016	765215.508	4339433.548	1969.644
AT021	755460.232	4313686.232	1909.447
AT022	750370.290	4315677.071	2019.331
AT023	750354.398	4315677.139	2019.253
AT024	750359.182	4315666.986	2018.777
AT029	748814.649	4324666.293	1902.337
AT032	745664.436	4330006.889	1902.391
AT036	761971.819	4314542.832	1909.109
AT038	759996.987	4308193.800	1919.482
AT039	759991.896	4308201.099	1919.405
AT041	758069.611	4313931.201	1900.360

Control Point Coordinates - 26 Total Points			
Point ID	**Easting (m)**	**Northing (m)**	**Elevation (m)**
AT042	750584.959	4342803.214	1932.363
AT043	750592.334	4342803.027	1931.909
AT044	750589.000	4342805.564	1932.078
AT045	746350.037	4339147.164	1914.524
AT048	746347.378	4339141.258	1914.527
AT050	765121.402	4343526.408	1901.860
AT051	756003.192	4348640.878	1959.280
AT052	756007.481	4348630.064	1958.729

Table 17: Residuals for air target points used as control for aerial triangulation adjustment

Control Point Residuals -26 Total Points			
Point ID	**Easting (m)**	**Northing (m)**	**Elevation (m)**
AT003	0.127	0.036	0.237
AT005	-0.009	-0.023	0.076
AT007	-0.042	-0.029	0.145
AT008	0.001	-0.007	0.101
AT009	0.058	-0.037	0.208
AT012	0.123	0.056	0.148
AT015	0.100	-0.072	0.238
AT016	-0.055	0.016	0.115
AT021	0.012	-0.058	0.271
AT022	-0.109	-0.007	0.243
AT023	-0.051	0.016	0.306
AT024	-0.064	0.025	0.279
AT029	0.019	-0.010	0.077
AT032	0.009	0.010	0.086
AT036	0.085	-0.038	0.191
AT038	0.015	-0.068	0.083
AT039	-0.008	-0.048	0.072
AT041	0.044	-0.008	0.221
AT042	-0.001	0.028	0.118
AT043	0.068	-0.014	0.167
AT044	0.041	-0.063	0.138
AT045	-0.024	-0.006	0.149
AT048	-0.055	-0.017	0.134
AT050	0.007	-0.012	0.262
AT051	0.011	0.061	0.165
AT052	-0.014	0.047	0.162

Table 18: RMSE for air target points used as control for aerial triangulation adjustment

Control Point RMSE - 26 Total Points		
meters		
X	Y	Z
0.058	0.038	0.183

Check Points

Air target check points withheld from the aerial triangulation adjustment are listed with their location in Table 19, their residuals are listed in Table 20, and RMSE values can be found in Table 21.

Table 19: Location of air target check points withheld from aerial triangulation adjustment

Check Point Coordinates - 7 Total Points			
Point ID	Easting (m)	Northing (m)	Elevation (m)
AT006	763860.81	4320932.552	1920.145
AT010	764490.472	4330287.835	1959.686
AT030	745601.281	4329991.779	1901.105
AT033	744850.941	4336294.445	2040.179
AT034	744844.571	4336284.12	2040.252
AT037	761973.179	4314563.174	1909.106
AT049	765120.737	4343501.692	1901.681

Table 20: Residuals for air target points withheld from aerial triangulation adjustment

Check Point Residuals - 7 Total Points			
Point ID	Easting (m)	Northing (m)	Elevation (m)
AT006	-0.089	-0.004	0.244
AT010	0.159	-0.118	0.608
AT030	0.020	0.071	0.302
AT033	-0.116	-0.170	0.702
AT034	-0.052	-0.055	0.736
AT037	0.152	0.004	0.220
AT049	-0.090	-0.143	0.600

Table 21: RMSE for air target points withheld from aerial triangulation adjustment

Check Point RMSE - 7 Total Points		
meters		
X	Y	Z
0.108	0.101	0.530

CERTIFICATIONS

Quantum Spatial, Inc. provided LiDAR services for the Lake Tahoe project as described in this report.

I, Ashley Daigle, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

____

Ashley Daigle
Project Manager
Quantum Spatial, Inc.

I, Evon Silvia, PLS, being duly registered as a Professional Land Surveyor in and by the state of California, hereby certify that the methodologies, static GNSS occupations used during airborne flights, and ground survey point collection were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between September 6 and 19, 2018.

Accuracy statistics shown in the Accuracy Section of this Report have been reviewed by me and found to meet the “National Standard for Spatial Data Accuracy”.

____

Evon Silvia, PLS L9401
Quantum Spatial, Inc.
Corvallis, OR 97330

Signed:

GLOSSARY

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed data set.

1.96 * RMSE Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed data set, based on the FGDC standards for Non-vegetated Vertical Accuracy (FVA) reporting.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma σ) and root mean square error (RMSE).

> **Absolute Accuracy:** The vertical accuracy of LiDAR data is described as the mean and standard deviation (sigma σ) of divergence of LiDAR point coordinates from ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y and z are normally distributed, and thus we also consider the skew and kurtosis of distributions when evaluating error statistics.
>
> **Relative Accuracy:** Relative accuracy refers to the internal consistency of the data set; i.e., the ability to place a laser point in the same location over multiple flight lines, GPS conditions and aircraft attitudes. Affected by system attitude offsets, scale and GPS/IMU drift, internal consistency is measured as the divergence between points from different flight lines within an overlapping area. Divergence is most apparent when flight lines are opposing. When the LiDAR system is well calibrated, the line-to-line divergence is low (<10 cm).
>
> **Root Mean Square Error (RMSE):** A statistic used to approximate the difference between real-world points and the LiDAR points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Data Density: A common measure of LiDAR resolution, measured as points per square meter.

Digital Elevation Model (DEM): File or database made from surveyed points, containing elevation points over a contiguous area. Digital terrain models (DTM) and digital surface models (DSM) are types of DEMs. DTMs consist solely of the bare earth surface (ground points), while DSMs include information about all surfaces, including vegetation and man-made structures.

Intensity Values: The peak power ratio of the laser return to the emitted laser, calculated as a function of surface reflectivity.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flight line.

Overlap: The area shared between flight lines, typically measured in percent. 100% overlap is essential to ensure complete coverage and reduce laser shadows.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured in thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the number of wave forms (i.e., echoes) reflected back to the sensor. Portions of the wave form that return first are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Real-Time Kinematic (RTK) Survey: A type of surveying conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

Post-Processed Kinematic (PPK) Survey: GPS surveying is conducted with a GPS rover collecting concurrently with a GPS base station set up over a known monument. Differential corrections and precisions for the GNSS baselines are computed and applied after the fact during processing. This type of ground survey is accurate to 1.5 cm or less.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Native LiDAR Density: The number of pulses emitted by the LiDAR system, commonly expressed as pulses per square meter.

Relative Accuracy Calibration Methodology:

Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each survey area.

Automated Attitude Calibration: All data were tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flight line and used for line-to-line testing. System misalignment offsets (pitch, roll and heading) and scale were solved for each individual mission and applied to respective mission datasets. The data from each mission were then blended when imported together to form the entire area of interest.

Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

LiDAR accuracy error sources and solutions:

Type of Error	Source	Post Processing Solution
GPS (Static/Kinematic)	Long Base Lines	None
	Poor Satellite Constellation	None
	Poor Antenna Visibility	Reduce Visibility Mask
Relative Accuracy	Poor System Calibration	Recalibrate IMU and sensor offsets/settings
	Inaccurate System	None
Laser Noise	Poor Laser Timing	None
	Poor Laser Reception	None
	Poor Laser Power	None
	Irregular Laser Shape	None

Operational measures taken to improve relative accuracy:

Low Flight Altitude: Terrain following was employed to maintain a constant above ground level (AGL). Laser horizontal errors are a function of flight altitude above ground (about 1/3000th AGL flight altitude).

Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return (i.e., intensity) is a function of laser emission power, laser footprint, flight altitude and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased and low flight altitudes can be maintained.

Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of $\pm 20^{o}$ from nadir, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.

Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day. During all flight times, a dual frequency DGPS base station recording at 1 second epochs was utilized and a maximum baseline length between the aircraft and the control points was less than 13 nm at all times.

Ground Survey: Ground survey point accuracy (<1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. Ground survey points are distributed to the extent possible throughout multiple flight lines and across the survey area.

50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the nadir portion of one flight line coincides with the swath edge portion of overlapping flight lines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.

Opposing Flight Lines: All overlapping flight lines have opposing directions. Pitch, roll and heading errors are amplified by a factor of two relative to the adjacent flight line(s), making misalignments easier to detect and resolve.

Appendix B - Bathymetric Check Point Depth

QSI extracted depth values from the generated LiDAR depth raster to the submerged bathymetric check point data, and then compared the dZ value between recorded check point elevations to the triangulated surface generated by the topobathymetric bare earth point cloud. Results of this comparison are provided in the table below.

Table 22: Bathymetric check point depth values

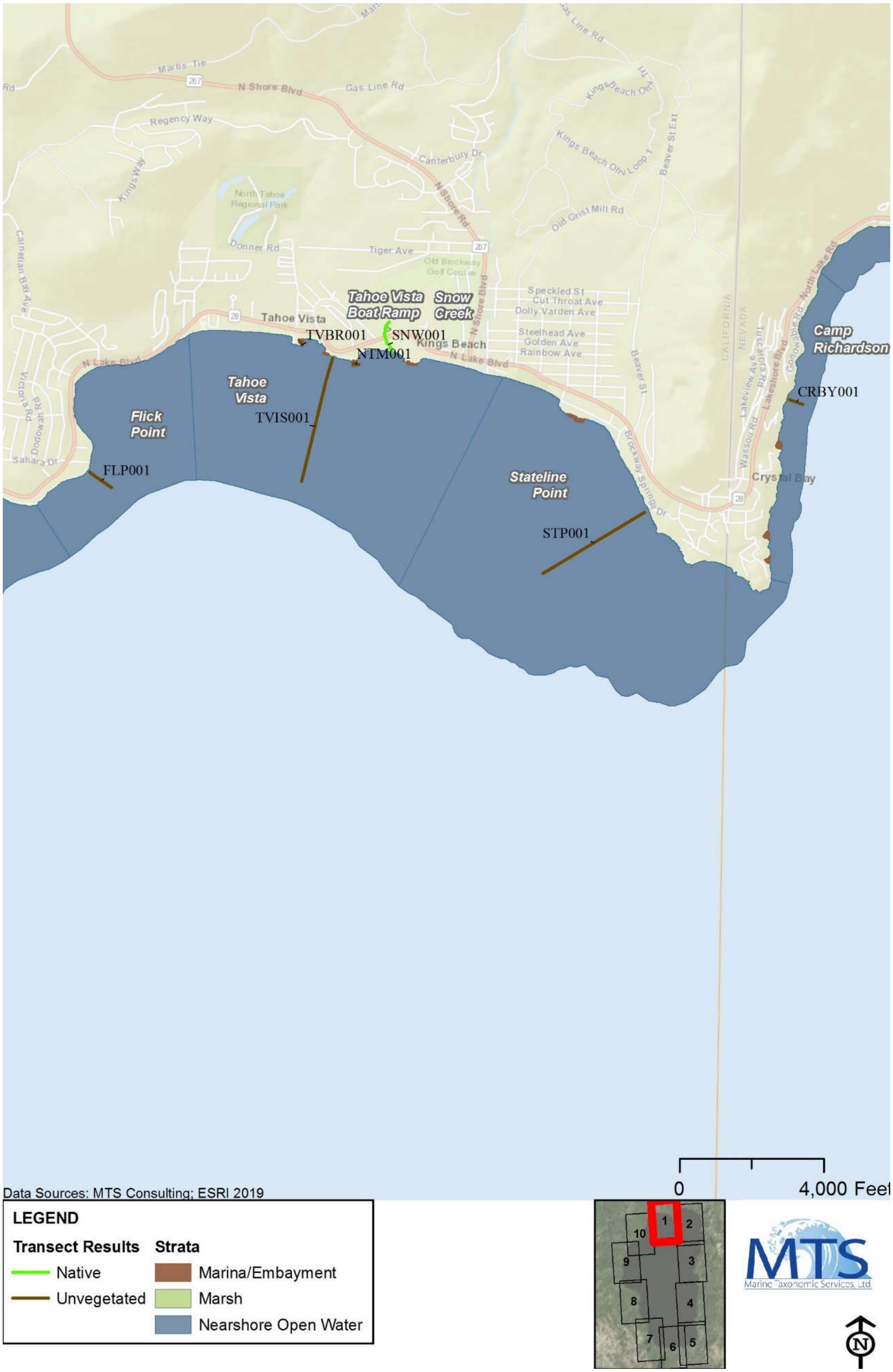
Submerged Bathymetric Check Point Depth Summary					
X	**Y**	**Z**	**Raster Depth**	**Check Point Dz**	**absDZ**
763552.295	4347687.234	1898.980	0.045	0.050	0.050
748800.321	4340833.220	1898.978	0.220	-0.038	0.038
764070.744	4326148.510	1898.785	0.445	0.015	0.015
764962.322	4339578.421	1898.366	0.723	0.004	0.004
747167.801	4339689.865	1898.733	0.425	-0.003	0.003
748800.376	4340831.832	1898.792	0.397	-0.052	0.052
763551.582	4347686.210	1898.798	0.282	0.032	0.032
747165.904	4339688.797	1898.660	0.482	0.030	0.030
764960.958	4339578.521	1898.331	0.742	0.009	0.009
764070.383	4326149.740	1898.624	0.592	0.006	0.006
762003.406	4315010.879	1898.710	0.428	0.000	0.000
747164.789	4339687.487	1898.529	0.611	0.071	0.071
764071.235	4326150.657	1898.504	0.661	0.036	0.036
763551.005	4347685.912	1898.736	0.340	0.034	0.034
748800.439	4340830.101	1898.504	0.590	0.016	0.016
764961.328	4339576.610	1898.294	0.794	-0.004	0.004
762000.591	4315010.898	1898.692	0.485	-0.002	0.002
761998.654	4315012.320	1898.519	0.577	0.071	0.071
764070.048	4326151.064	1898.407	0.771	0.053	0.053
747163.248	4339687.533	1898.579	0.561	0.021	0.021
748800.288	4340828.723	1898.330	0.843	0.010	0.010
763549.800	4347686.902	1898.758	0.366	0.002	0.002
764961.473	4339575.002	1898.209	0.912	0.001	0.001
747162.013	4339686.078	1898.511	0.593	0.049	0.049
764071.138	4326152.115	1898.299	0.862	0.041	0.041
761996.838	4315013.223	1898.529	0.606	-0.019	0.019
748798.357	4340828.553	1898.259	0.849	0.011	0.011
764959.920	4339577.179	1898.259	0.898	0.001	0.001
763548.861	4347687.836	1898.791	0.391	-0.001	0.001
761993.752	4315013.474	1898.396	0.711	0.084	0.084
747168.286	4339690.286	1898.681	0.436	0.069	0.069
764064.306	4326147.472	1898.633	0.492	0.027	0.027
764961.495	4339574.515	1898.176	0.963	0.024	0.024
748797.690	4340828.168	1898.223	0.914	-0.023	0.023
763548.108	4347689.039	1898.846	0.137	-0.006	0.006
747171.864	4339690.072	1898.646	0.413	0.074	0.074
763547.050	4347689.451	1898.850	0.290	-0.050	0.050
764964.432	4339573.622	1898.256	0.806	0.024	0.024
761990.625	4315012.040	1898.538	0.605	-0.018	0.018
748795.846	4340828.434	1898.235	0.958	-0.005	0.005

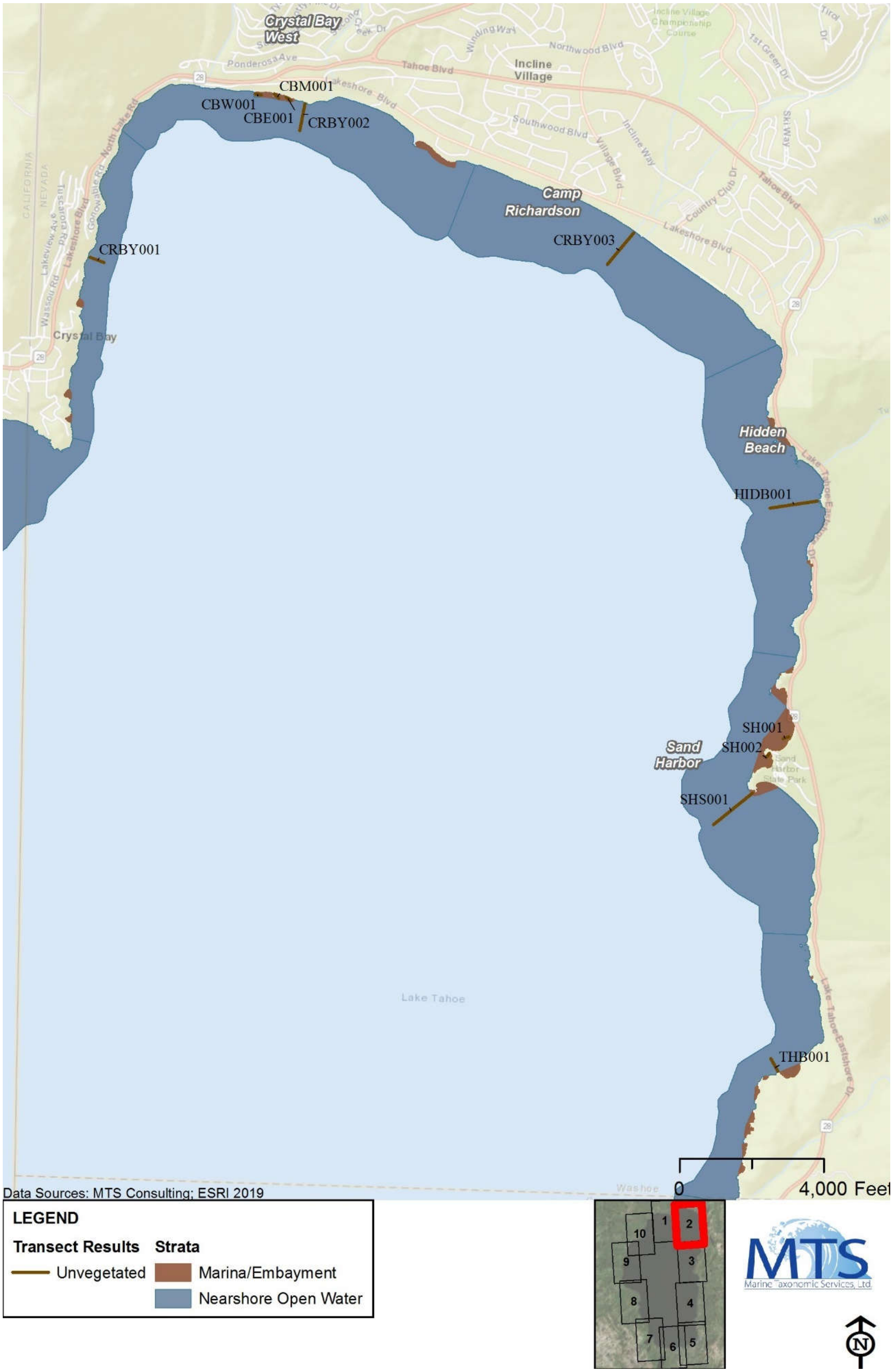
Submerged Bathymetric Check Point Depth Summary					
X	Y	Z	Raster Depth	Check Point Dz	absDZ
764064.888	4326149.493	1898.455	0.755	-0.005	0.005
747167.052	4339691.563	1898.844	0.215	0.066	0.066
764065.144	4326150.498	1898.266	0.847	0.064	0.064
761992.920	4315014.808	1898.354	0.737	0.056	0.056
763547.379	4347690.116	1898.941	0.053	-0.041	0.041
764964.933	4339571.652	1898.206	0.981	0.004	0.004
748793.995	4340828.654	1898.240	0.919	0.000	0.000
764063.221	4326149.989	1898.224	0.853	0.086	0.086
747164.451	4339691.140	1898.970	0.129	0.040	0.040
764964.561	4339570.153	1898.106	0.953	-0.026	0.026
761999.742	4315014.317	1898.506	0.642	-0.026	0.026
748791.589	4340828.605	1898.237	0.899	-0.017	0.017
763549.013	4347689.147	1898.950	0.032	-0.010	0.010
764063.160	4326150.758	1898.170	0.922	0.050	0.050
762002.418	4315013.782	1898.535	0.611	-0.025	0.025
763550.100	4347688.898	1899.016	0.026	-0.016	0.016
748793.734	4340828.061	1898.166	0.992	0.014	0.014
764966.659	4339568.099	1898.105	1.025	-0.005	0.005
747162.220	4339690.264	1898.966	0.211	0.004	0.004
764065.726	4326148.282	1898.580	0.585	0.070	0.070
748795.384	4340828.039	1898.200	0.995	-0.050	0.050
751822.302	4345847.903	1898.689	0.360	0.031	0.031
764967.412	4339568.233	1898.157	0.958	0.013	0.013
762004.646	4315013.763	1898.559	0.595	-0.009	0.009
764066.139	4326146.325	1898.828	0.262	0.072	0.072
751823.993	4345848.617	1898.630	0.365	0.070	0.070
764969.125	4339566.694	1898.218	0.890	-0.038	0.038
762006.954	4315015.348	1898.453	0.648	0.037	0.037
748797.657	4340827.410	1898.097	1.060	0.003	0.003
764064.611	4326145.059	1898.950	0.213	0.050	0.050
764968.217	4339570.843	1898.332	0.748	0.038	0.038
748795.687	4340829.171	1898.335	0.814	0.015	0.015
762010.878	4315017.109	1898.455	0.663	-0.015	0.015
751826.775	4345850.477	1898.767	0.377	-0.007	0.007
751828.690	4345851.306	1898.665	0.392	0.045	0.045
762013.026	4315017.174	1898.433	0.627	0.037	0.037
764066.580	4326145.332	1899.019	0.141	0.021	0.021
748794.768	4340830.214	1898.488	0.665	-0.018	0.018
764967.107	4339572.958	1898.370	0.631	0.010	0.010
764965.209	4339575.096	1898.337	0.721	0.083	0.083
751830.972	4345852.519	1898.684	0.338	0.036	0.036
762018.657	4315019.393	1898.387	0.739	0.033	0.033
764066.428	4326147.381	1898.738	0.416	0.012	0.012
748794.762	4340831.868	1898.711	0.465	-0.011	0.011
751832.713	4345853.282	1898.644	0.304	0.036	0.036
762021.121	4315018.905	1898.456	0.643	0.024	0.024
764963.518	4339576.754	1898.372	0.751	-0.022	0.022
748794.482	4340833.181	1898.893	0.238	0.007	0.007
762013.671	4315011.286	1898.766	0.450	-0.036	0.036
764962.374	4339577.677	1898.355	0.718	-0.035	0.035
748793.580	4340831.030	1898.574	0.533	0.006	0.006
751834.125	4345853.952	1898.716	0.464	0.004	0.004
751836.099	4345854.611	1898.592	0.468	0.078	0.078
762013.059	4315008.257	1898.852	0.252	0.038	0.038

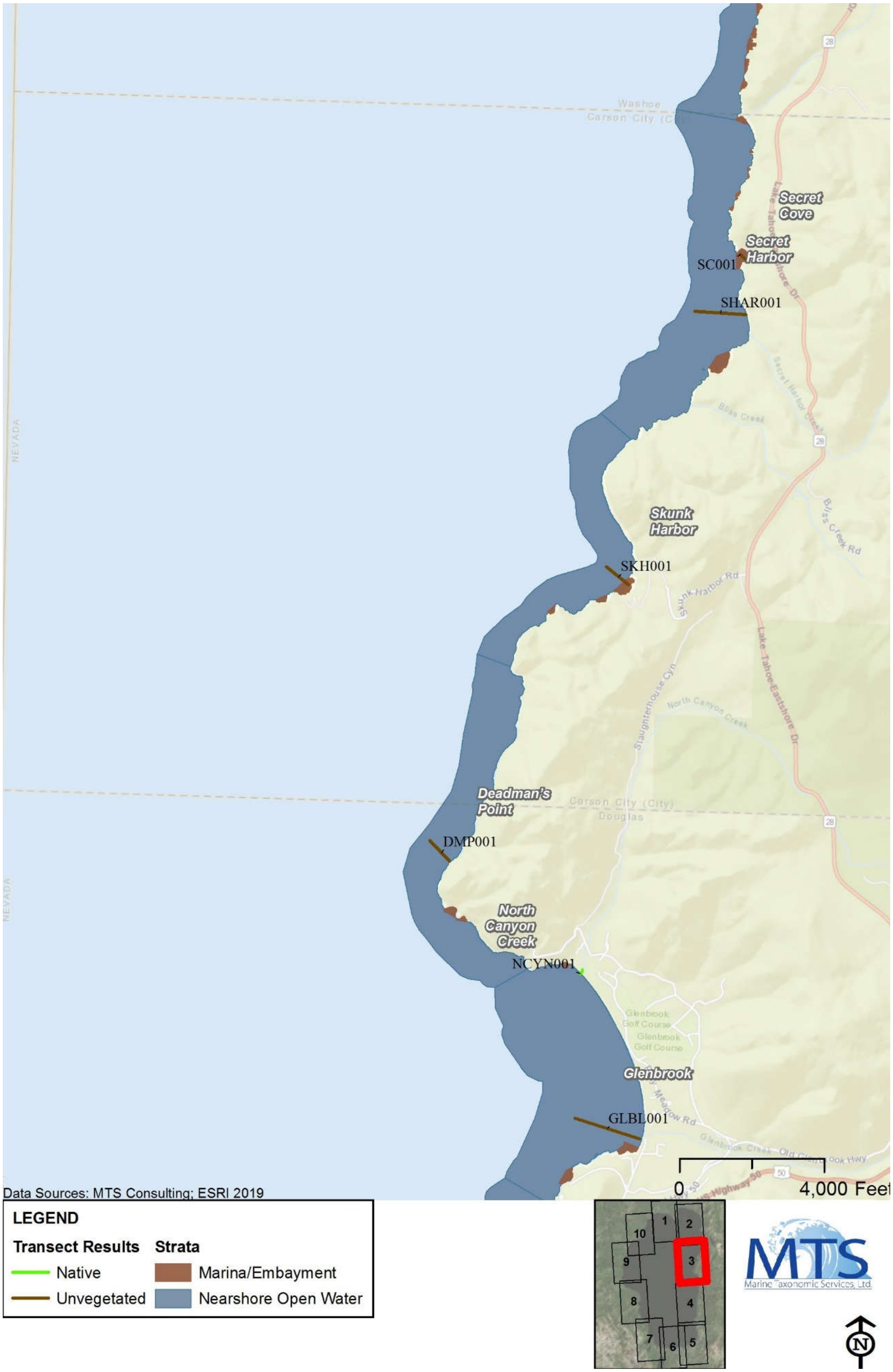
Submerged Bathymetric Check Point Depth Summary					
X	Y	Z	Raster Depth	Check Point Dz	absDZ
748793.417	4340829.625	1898.386	0.756	-0.026	0.026
764959.596	4339579.564	1898.339	0.790	-0.009	0.009
762010.553	4315007.490	1898.909	0.196	-0.029	0.029
764958.200	4339581.175	1898.289	0.850	0.021	0.021
751839.047	4345856.650	1898.769	0.307	-0.009	0.009
748794.772	4340827.033	1898.043	1.097	-0.003	0.003
751841.831	4345858.245	1898.865	0.209	-0.055	0.055
762008.595	4315008.627	1898.905	0.243	-0.025	0.025
748795.668	4340832.569	1898.824	0.332	-0.024	0.024
764957.519	4339582.420	1898.220	0.877	0.010	0.010
756977.876	4347036.984	1898.931	0.122	0.099	0.099
761964.158	4315010.294	1898.870	0.229	0.020	0.020
756976.473	4347036.726	1898.741	0.369	0.059	0.059
761963.320	4315010.941	1898.809	0.351	-0.029	0.029
756975.264	4347036.486	1898.596	0.508	0.054	0.054
761963.203	4315012.222	1898.594	0.527	0.006	0.006
756974.221	4347036.438	1898.486	0.548	0.034	0.034
761963.692	4315013.762	1898.418	0.752	-0.008	0.008
761963.978	4315014.554	1898.291	0.843	0.019	0.019
756973.269	4347036.080	1898.364	0.708	0.016	0.016
761965.206	4315014.618	1898.333	0.820	0.017	0.017
756972.470	4347036.031	1898.263	0.854	0.007	0.007
756972.355	4347035.064	1898.219	0.879	0.041	0.041
761966.455	4315014.735	1898.361	0.780	-0.001	0.001
756972.720	4347033.479	1898.238	0.926	0.052	0.052
761966.782	4315012.876	1898.593	0.500	0.037	0.037
756972.800	4347032.214	1898.210	0.967	0.040	0.040
761966.989	4315011.814	1898.741	0.352	-0.001	0.001
756972.963	4347030.984	1898.212	0.946	0.038	0.038
761966.079	4315010.889	1898.844	0.224	-0.004	0.004
756973.198	4347029.705	1898.221	0.898	0.039	0.039
761964.923	4315010.708	1898.831	0.298	0.009	0.009
756974.551	4347030.698	1898.377	0.719	0.043	0.043
761965.377	4315012.711	1898.620	0.520	-0.010	0.010
756974.398	4347031.891	1898.378	0.738	0.072	0.072
761966.334	4315013.399	1898.561	0.573	-0.021	0.021
756974.225	4347033.289	1898.401	0.705	0.039	0.039
761966.716	4315014.424	1898.415	0.709	-0.005	0.005
761966.868	4315012.099	1898.699	0.403	0.031	0.031
756974.882	4347034.354	1898.514	0.553	0.026	0.026
756976.684	4347034.335	1898.712	0.354	0.078	0.078
758061.679	4313976.765	1898.377	0.707	0.073	0.073
756977.329	4347032.252	1898.724	0.376	0.076	0.076
758063.056	4313976.916	1898.362	0.667	0.068	0.068
758064.585	4313977.755	1898.334	0.740	0.076	0.076
756976.083	4347033.791	1898.641	0.397	0.069	0.069
756975.795	4347031.889	1898.526	0.509	0.074	0.074
758065.797	4313978.404	1898.291	0.780	0.059	0.059
758067.188	4313978.813	1898.276	0.791	0.054	0.054
756977.280	4347034.781	1898.791	0.317	0.039	0.039
758068.446	4313978.988	1898.253	0.817	0.057	0.057
754770.486	4347447.323	1898.850	0.219	0.030	0.030
758069.712	4313978.708	1898.235	0.869	0.075	0.075
754769.270	4347446.769	1898.833	0.255	0.017	0.017

Submerged Bathymetric Check Point Depth Summary					
X	Y	Z	Raster Depth	Check Point Dz	absDZ
758071.008	4313979.027	1898.210	0.898	0.080	0.080
754767.926	4347446.202	1898.816	0.268	0.034	0.034
758072.638	4313979.276	1898.179	0.933	0.101	0.101
754767.855	4347445.168	1898.726	0.370	-0.016	0.016
758074.774	4313978.946	1898.207	0.831	0.093	0.093
754769.201	4347445.824	1898.694	0.399	0.046	0.046
758075.877	4313978.491	1898.261	0.814	0.079	0.079
754770.433	4347446.340	1898.718	0.375	0.042	0.042
758078.029	4313979.494	1898.203	0.889	0.087	0.087
754771.178	4347445.906	1898.608	0.480	0.062	0.062
758079.608	4313979.110	1898.194	0.858	0.096	0.096
754769.539	4347445.374	1898.628	0.482	0.032	0.032
754767.891	4347444.912	1898.641	0.453	0.059	0.059
758080.700	4313978.921	1898.246	0.845	0.034	0.034
754768.107	4347443.804	1898.464	0.644	0.076	0.076
758082.304	4313979.111	1898.225	0.851	0.055	0.055
754769.911	4347444.277	1898.464	0.647	0.056	0.056
754771.137	4347444.950	1898.530	0.645	0.020	0.020
754771.604	4347443.816	1898.347	0.779	0.023	0.023
754770.425	4347443.485	1898.318	0.786	0.072	0.072
754769.143	4347443.188	1898.324	0.786	0.046	0.046
754770.155	4347442.351	1898.231	0.938	-0.021	0.021
754771.409	4347442.647	1898.224	0.880	-0.004	0.004
754772.139	4347443.124	1898.202	0.910	0.048	0.048
754771.805	4347442.060	1898.134	0.984	-0.034	0.034
754770.781	4347441.741	1898.119	1.032	-0.019	0.019
765074.932	4343533.065	1899.006	0.171	-0.036	0.036
765074.045	4343531.475	1899.007	0.107	-0.057	0.057
765073.209	4343529.725	1898.997	0.152	-0.037	0.037
765070.889	4343529.833	1898.756	0.441	-0.046	0.046
765071.475	4343531.434	1898.723	0.470	-0.033	0.033
765072.173	4343532.684	1898.733	0.441	-0.043	0.043
765072.561	4343533.812	1898.721	0.473	-0.051	0.051
765071.147	4343534.641	1898.530	0.679	-0.050	0.050
765070.370	4343533.019	1898.531	0.662	-0.041	0.041
765069.094	4343531.061	1898.497	0.666	-0.047	0.047
765068.246	4343531.577	1898.395	0.802	-0.035	0.035
765069.098	4343533.070	1898.379	0.774	-0.049	0.049
765069.554	4343534.233	1898.359	0.765	-0.039	0.039
765069.495	4343524.123	1898.855	0.294	-0.025	0.025
765068.556	4343522.862	1898.813	0.295	-0.013	0.013
765067.665	4343521.257	1898.827	0.334	-0.027	0.027
765065.369	4343520.882	1898.597	0.564	-0.027	0.027
765066.004	4343522.585	1898.576	0.547	-0.026	0.026
765067.037	4343524.163	1898.602	0.521	-0.022	0.022
765065.787	4343525.677	1898.388	0.771	0.002	0.002
765064.908	4343524.028	1898.388	0.755	-0.038	0.038
765064.355	4343522.464	1898.424	0.735	-0.044	0.044
765063.194	4343522.499	1898.280	0.865	-0.030	0.030
765063.817	4343523.620	1898.301	0.871	-0.041	0.041
765064.480	4343524.883	1898.288	0.857	-0.058	0.058

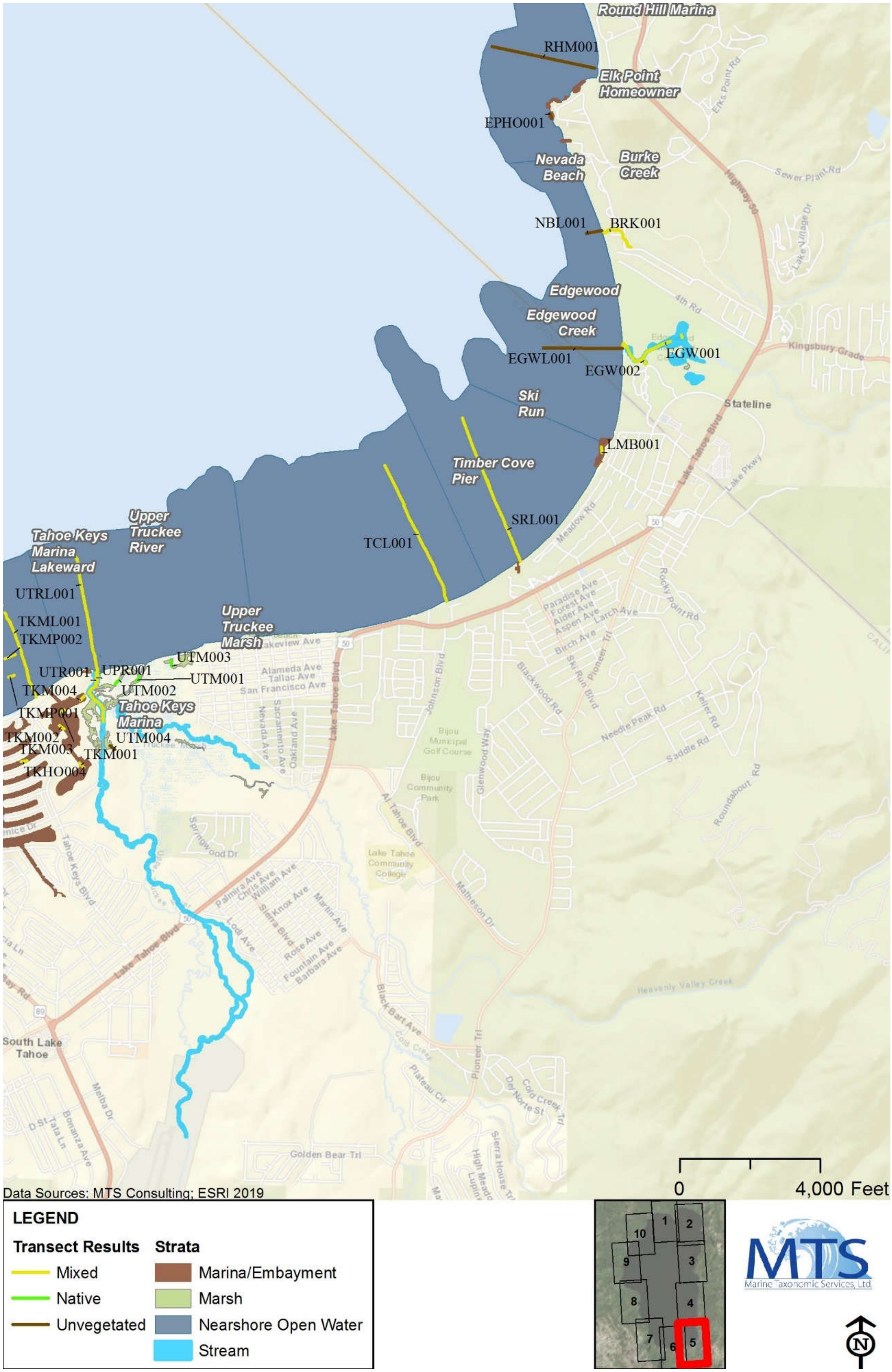
Appendix B -Transect Sampling Map Figures

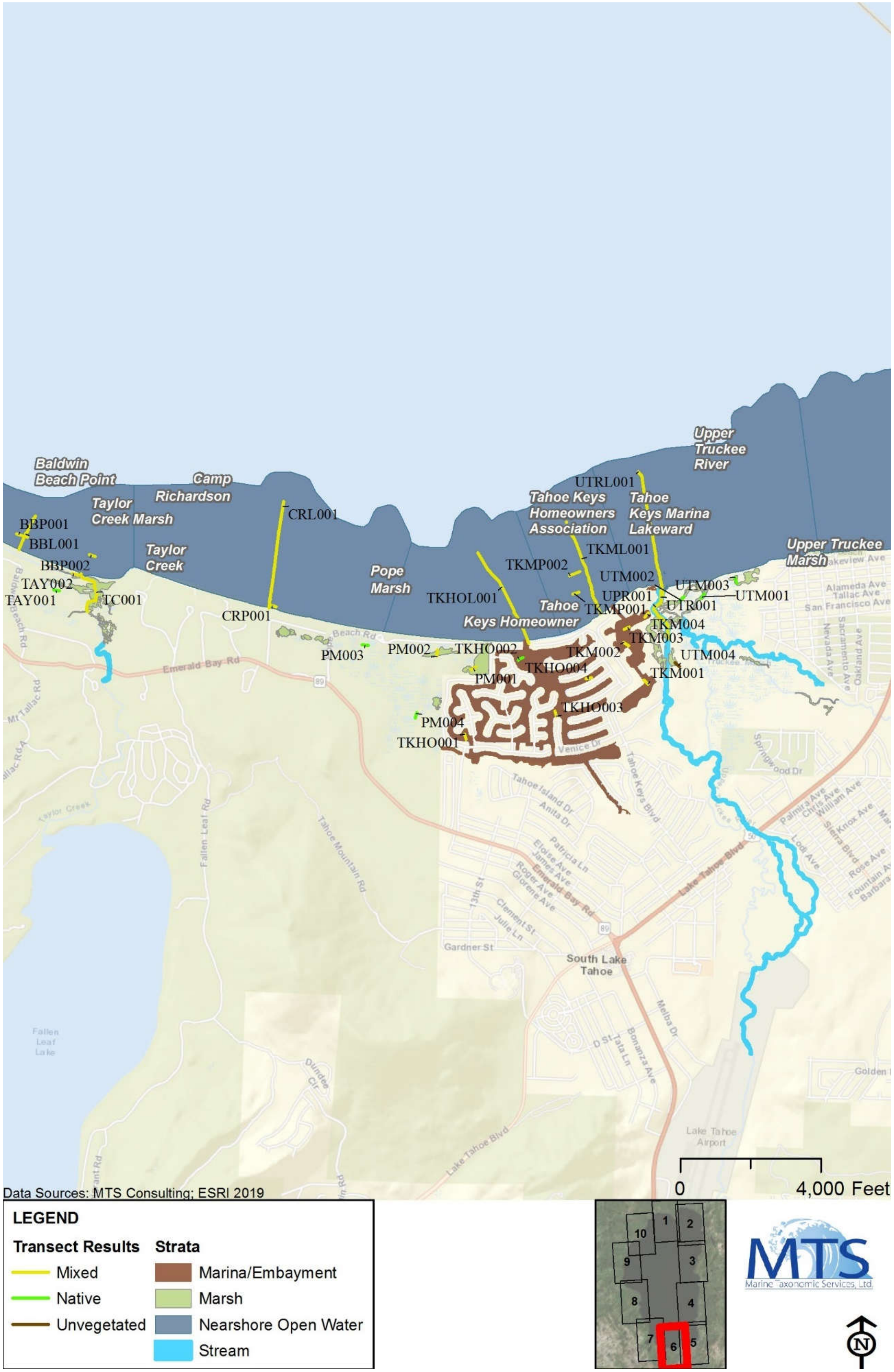

Tahoe Vista Boat Ramp
Snow Creek
Camp Richardson
TVBR001
SNW001
NTM001
Kings Beach
Tahoe Vista
TVIS001
Flick Point
FLP001
Stateline Point
STP001
CRBY001
Crystal Bay
CALIFORNIA
NEVADA
0
4,000 Feet
Data Sources: MTS Consulting; ESRI 2019
LEGEND
Transect Results
Native
Unvegetated
Strata
Marina/Embayment
Marsh
Nearshore Open Water
Marine Taxonomic Services, Ltd.

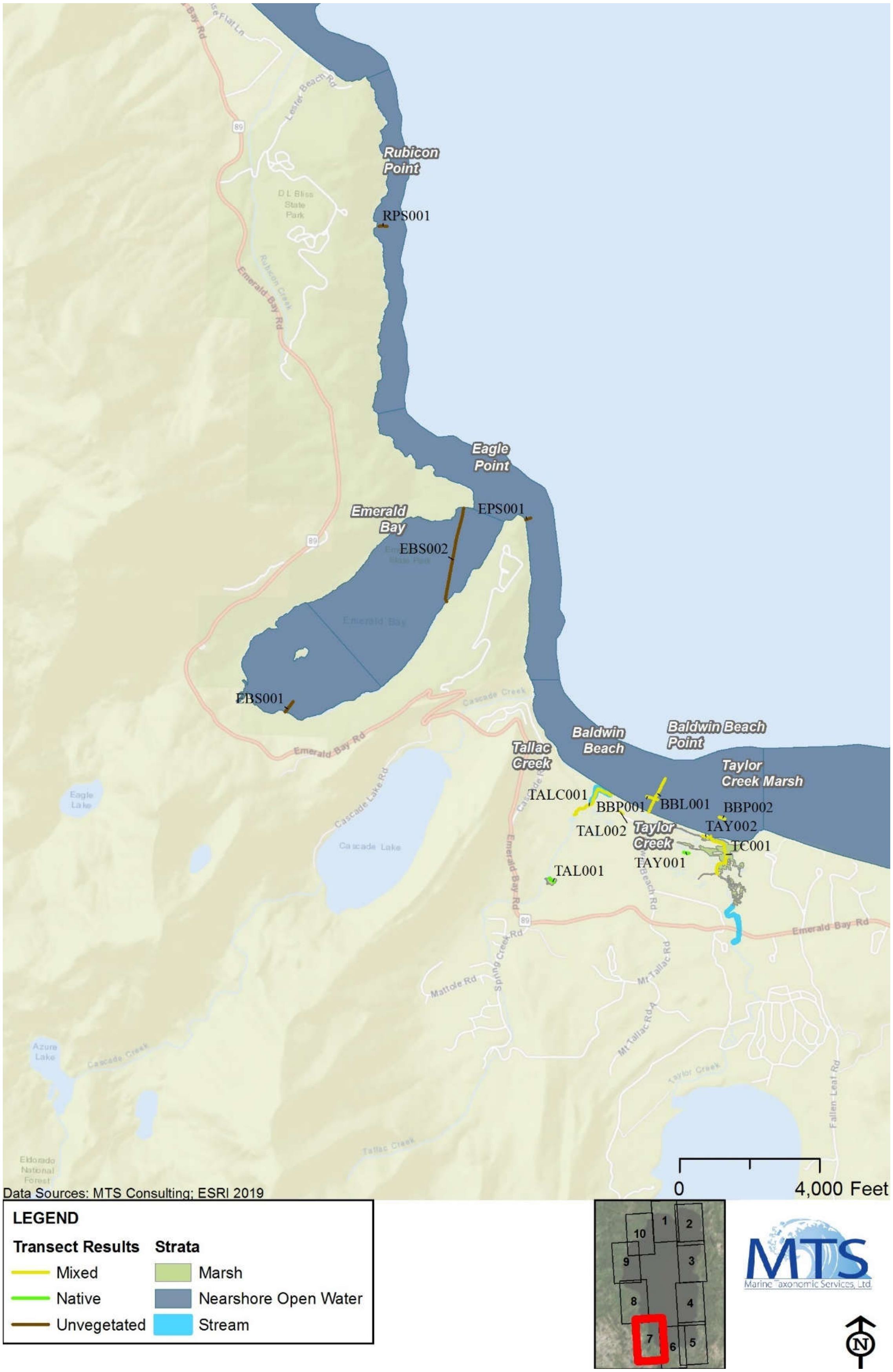

Crystal Bay West
Incline Village
CBM001
CBW001
CBE001
CRBY002
Camp Richardson
CRBY003
CRBY001
Crystal Bay
Hidden Beach
HIDB001
SH001
SH002
Sand Harbor
SHS001
Lake Tahoe
THB001
0
4,000 Feet
Data Sources: MTS Consulting; ESRI 2019
LEGEND
Transect Results
Unvegetated
Strata
Marina/Embayment
Nearshore Open Water
1
2
3
4
5
6
7
8
9
10
MTS
Marine Taxonomic Services, Ltd.
N


Secret Cove
Secret Harbor
SC001
SHAR001
Skunk Harbor
SKH001
Deadman's Point
DMP001
North Canyon Creek
NCYN001
Glenbrook
GLBL001
0
4,000 Feet
Data Sources: MTS Consulting; ESRI 2019
LEGEND
Transect Results
Native
Unvegetated
Strata
Marina/Embayment
Nearshore Open Water
1
2
3
4
5
6
7
8
9
10
MTS
Marine Taxonomic Services, Ltd.
N


Glenbrook
Logan House Creek
LHC001
Cave Rock Boat Launch
CRBR001
Lincoln Park
Lake Tahoe
LINP001
Wovoka Bay
WNK001
Zephyr Cove
ZCL001
Zephyr Point
Zephyr Cove
ZPL001
Round Hill Marina
RHM001
0
4,000 Feet
Data Sources: MTS Consulting; ESRI 2019
LEGEND
Transect Results
Non-native
Unvegetated
Strata
Marina/Embayment
Nearshore Open Water
1
2
3
4
5
6
7
8
9
10
MTS
Marine Taxonomic Services, Ltd.


Round Hill Marina
RHM001
Elk Point Homeowner
EPHO001
Nevada Beach
Burke Creek
NBL001
BRK001
Edgewood
Edgewood Creek
EGWL001
EGW002
EGW001
Ski Run
Stateline
LMB001
Timber Cove Pier
SRL001
TCL001
Tahoe Keys Marina Lakeward
Upper Truckee River
UTRL001
TKML001
TKMP002
Upper Truckee Marsh
UTM003
UTR001
UPR001
UTM001
TKM004
UTM002
Tahoe Keys Marina
TKMP001
TKM002
UTM004
TKM003
TKM001
TKHO004
South Lake Tahoe
Data Sources: MTS Consulting; ESRI 2019
0
4,000 Feet
LEGEND
Transect Results
Mixed
Native
Unvegetated
Strata
Marina/Embayment
Marsh
Nearshore Open Water
Stream
1
2
3
4
5
6
7
8
9
10
Marine Taxonomic Services, Ltd.
N


Baldwin Beach Point
Camp Richardson
Taylor Creek Marsh
Taylor Creek
Pope Marsh
Tahoe Keys Homeowners Association
Tahoe Keys Marina Lakeward
Tahoe Keys Homeowner
Upper Truckee River
Upper Truckee Marsh
BBP001
BBL001
BBP002
TAY002
TAY001
TC001
CRL001
CRP001
PM003
PM002
PM001
PM004
TKHO002
TKHO004
TKHO003
TKHO001
TKHOL001
TKMP002
TKML001
UTRL001
UTM002
UPR001
TKMP001
UTR001
UTM003
UTM001
TKM004
TKM003
TKM002
UTM004
TKM001
South Lake Tahoe
Lake Tahoe Airport
Fallen Leaf Lake
0
4,000 Feet
Data Sources: MTS Consulting; ESRI 2019
LEGEND
Transect Results
Mixed
Native
Unvegetated
Strata
Marina/Embayment
Marsh
Nearshore Open Water
Stream
1
2
3
4
5
6
7
8
9
10


Rubicon Point
RPS001
D L Bliss State Park
Eagle Point
Emerald Bay
EPS001
EBS002
EBS001
Emerald Bay Rd
Cascade Creek
Tallac Creek
Baldwin Beach
Baldwin Beach Point
Taylor Creek Marsh
TALC001
BBP001
BBL001
BBP002
TAL002
Taylor Creek
TAY002
TC001
TAY001
TAL001
Cascade Lake
Eagle Lake
Azure Lake
Mattole Rd
Spring Creek Rd
Mt Tallac Rd
Fallen Leaf Rd
Eldorado National Forest
0
4,000 Feet
Data Sources: MTS Consulting; ESRI 2019
LEGEND
Transect Results
Mixed
Native
Unvegetated
Strata
Marsh
Nearshore Open Water
Stream
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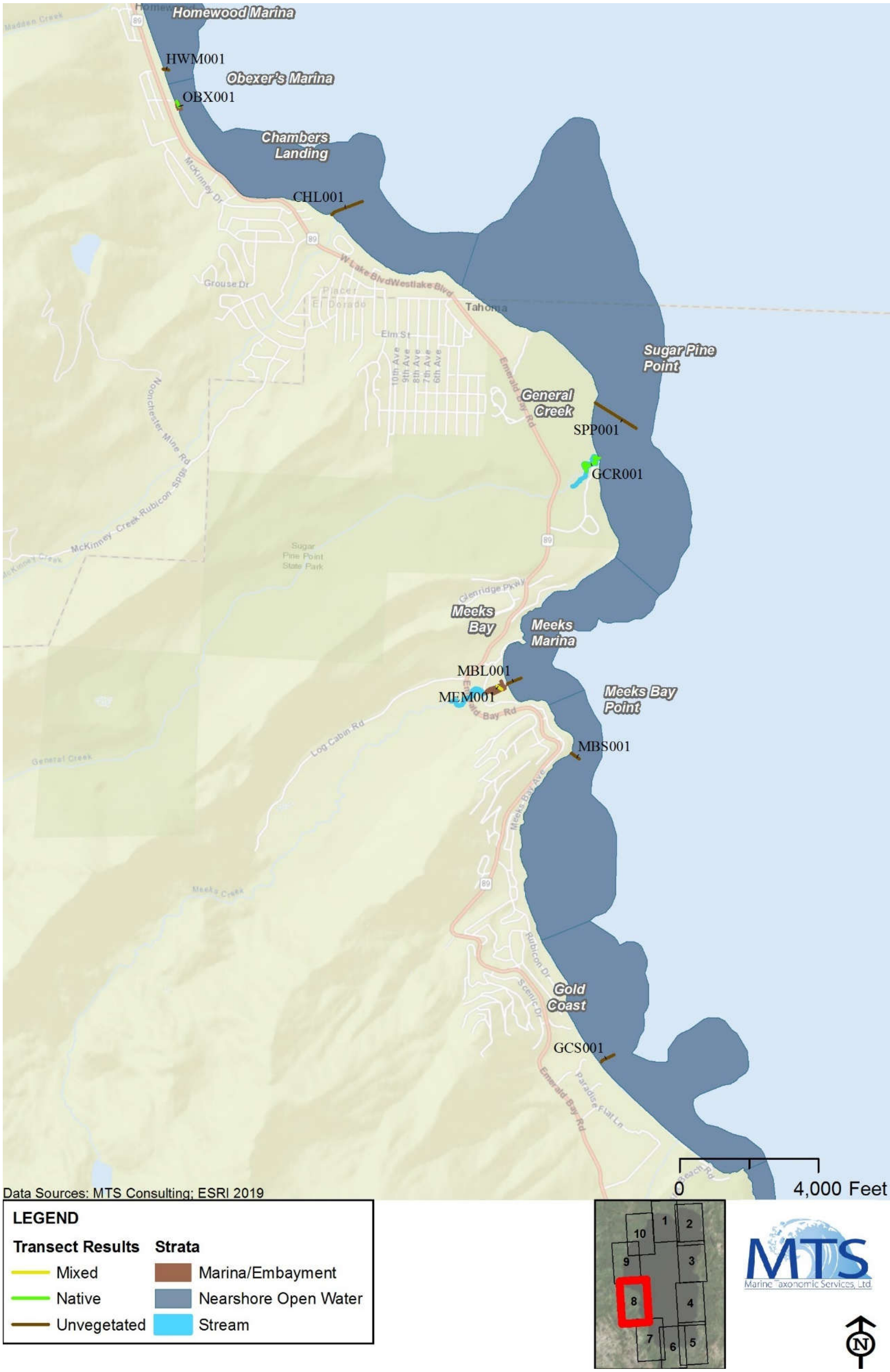
Homewood Marina
HWM001
Obexer's Marina
OBX001
Chambers Landing
CHL001
Tahoma
Sugar Pine Point
General Creek
SPP001
GCR001
Meeks Bay
Meeks Marina
MBL001
MEM001
Meeks Bay Point
MBS001
Gold Coast
GCS001
0
4,000 Feet
Data Sources: MTS Consulting; ESRI 2019
LEGEND
Transect Results
Mixed
Native
Unvegetated
Strata
Marina/Embayment
Nearshore Open Water
Stream
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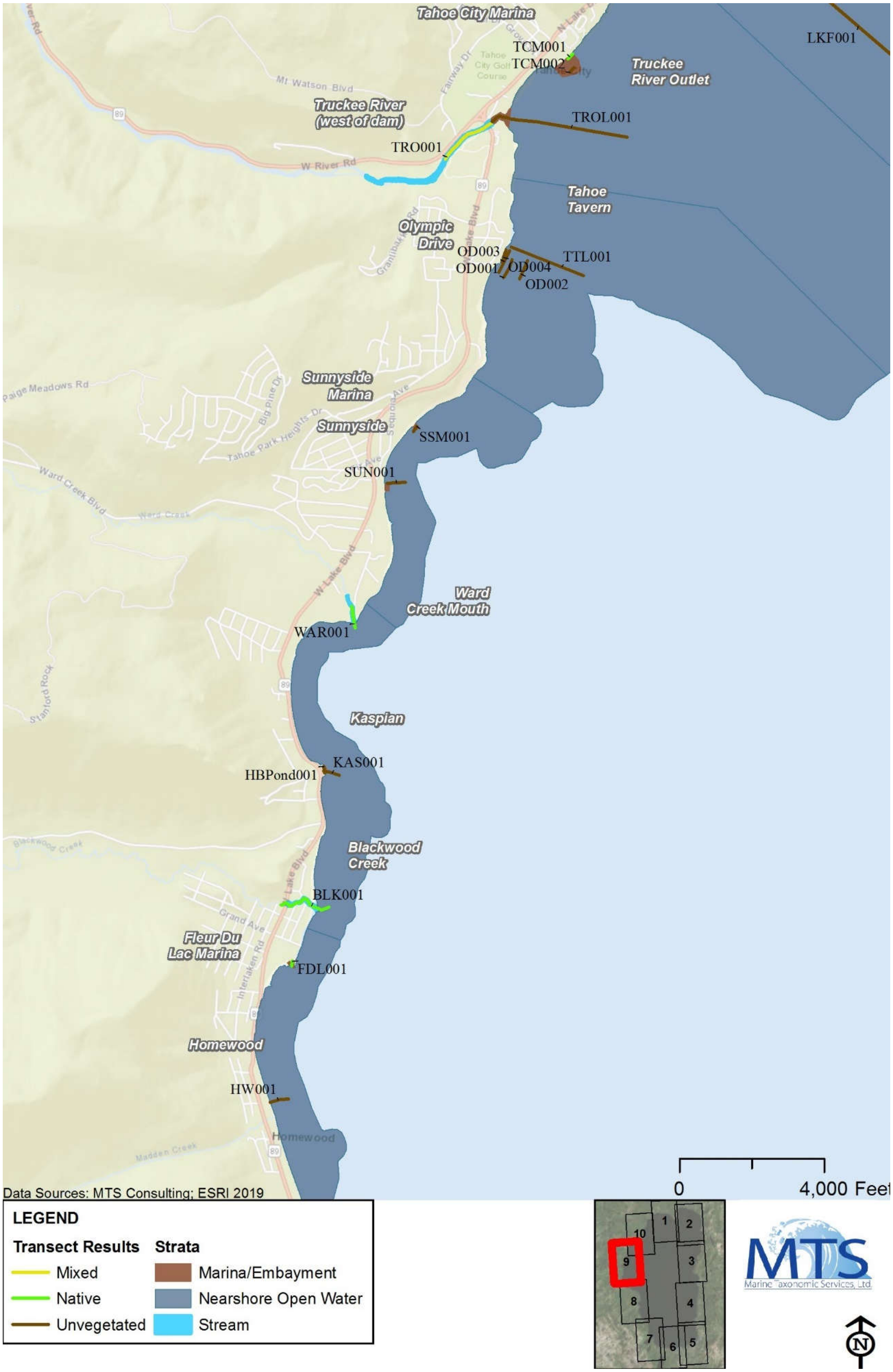
Tahoe City Marina
TCM001
TCM002
LKF001
Truckee River Outlet
Truckee River (west of dam)
TROL001
TRO001
Tahoe Tavern
Olympic Drive
OD003
OD001
OD004
OD002
TTL001
Sunnyside Marina
Sunnyside
SSM001
SUN001
Ward Creek Mouth
WAR001
Kaspian
KAS001
HBPond001
Blackwood Creek
BLK001
Fleur Du Lac Marina
FDL001
Homewood
HW001
Data Sources: MTS Consulting; ESRI 2019
0
4,000 Feet
LEGEND
Transect Results
Mixed
Native
Unvegetated
Strata
Marina/Embayment
Nearshore Open Water
Stream
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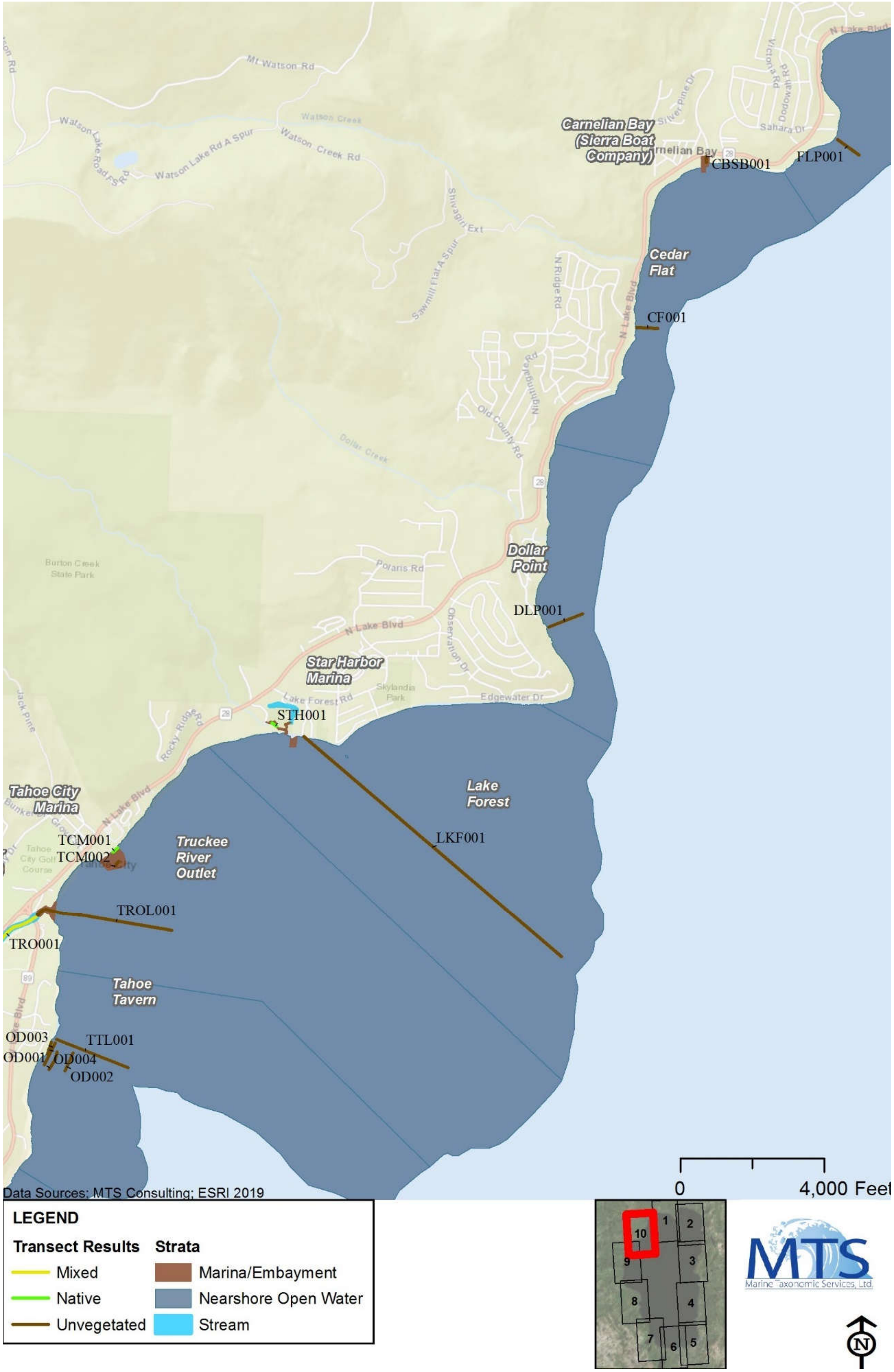
Carnelian Bay (Sierra Boat Company)
CBSB001
FLP001
Cedar Flat
CF001
Dollar Point
DLP001
Star Harbor Marina
STH001
Lake Forest
LKF001
Tahoe City Marina
TCM001
TCM002
Truckee River Outlet
TROL001
TRO001
Tahoe Tavern
OD003
OD001
OD004
OD002
TTL001
Mt Watson Rd
Watson Creek Rd
Watson Lake Rd A Spur
N Lake Blvd
Polaris Rd
Lake Forest Rd
Edgewater Dr
Observation Dr
Old County Rd
N Ridge Rd
Dollar Creek
Burton Creek State Park
Data Sources: MTS Consulting; ESRI 2019
0
4,000 Feet
LEGEND
Transect Results
Mixed
Native
Unvegetated
Strata
Marina/Embayment
Nearshore Open Water
Stream
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MTS
Marine Taxonomic Services, Ltd.
N

Appendix C - Transect and Quadrat Summary Tables

Transect table summarizing cumulative native and non-native plant coverage. Opportunistic Transects are not included.

STRATA	Transect	Native	Non-native
Major Tributaries	BLK001	58.76%	
Major Tributaries	BRK001	46.12%	2.16%
Major Tributaries	EGW001	51.02%	14.14%
Major Tributaries	GCR001	89.71%	
Major Tributaries	NCYN001	49.97%	
Major Tributaries	SNW001	53.67%	
Major Tributaries	TALC001	68.49%	11.95%
Major Tributaries	TC001	63.63%	21.11%
Major Tributaries	TRO001	72.01%	3.82%
Major Tributaries	UPR001	67.56%	20.45%
Major Tributaries	WAR001	15.31%	
Marinas & Embayments	LMB001	78.41%	21.74%
Marinas & Embayments	MEM001	65.44%	23.18%
Marinas & Embayments	OBX001	12.84%	
Marinas & Embayments	STH001	100.00%	
Marinas & Embayments	TCM001	100.00%	
Marinas & Embayments	TKHO001	0.20%	
Marinas & Embayments	TKHO002	52.08%	41.15%
Marinas & Embayments	TKHO003	51.73%	37.97%
Marinas & Embayments	TKHO004	66.84%	31.89%
Marinas & Embayments	TKM001	27.69%	33.90%
Marinas & Embayments	TKM002	68.79%	21.32%
Marinas & Embayments	TKM003	37.00%	21.17%
Marinas & Embayments	TKM004	0.30%	99.87%
Marinas & Embayments	WNK001		71.58%
Marinas & Embayments	FDLM001	33.94%	
Marsh	PM001	38.13%	3.71%
Marsh	PM002	66.86%	0.20%
Marsh	PM003	78.06%	
Marsh	PM004	75.69%	
Marsh	TAL001	60.45%	
Marsh	TAL002	93.33%	6.67%
Marsh	TAY001	100.00%	
Marsh	TAY002	66.59%	33.29%
Marsh	UTM001	88.81%	
Marsh	UTM002	60.96%	
Marsh	UTM003	32.58%	
Open-water Nearshore	BBL001	47.19%	8.99%
Open-water Nearshore	CRL001	2.04%	4.54%
Open-water Nearshore	SRL001	44.80%	10.82%
Open-water Nearshore	TCL001	33.11%	14.65%
Open-water Nearshore	TKHOL001	73.98%	12.16%
Open-water Nearshore	TKML001	33.81%	16.61%
Open-water Nearshore	TROL001		1.04%
Open-water Nearshore	UTRL001	32.19%	12.21%

Transect summary table of cumulative aquatic plant coverage by species.

STRATA	Transect	Andean milfoil (AM)	Chara spp. (CH)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares Tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Various-leaved pondweed (VP)	White water buttercup (WB)
Major Tributaries	BLK001	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	58.76%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Major Tributaries	BRK001	0.00%	1.91%	6.53%	2.03%	0.00%	33.36%	2.16%	1.99%	0.00%	0.30%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Major Tributaries	EGW001	0.00%	9.41%	0.00%	0.00%	11.91%	31.69%	2.23%	2.23%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	7.69%
Major Tributaries	GCR001	0.00%	5.08%	15.77%	0.00%	0.00%	0.00%	0.00%	68.86%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Major Tributaries	NCYN001	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	49.97%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Major Tributaries	SNW001	0.00%	23.03%	0.00%	10.53%	0.00%	0.00%	0.00%	1.50%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	18.61%
Major Tributaries	TALC001	0.00%	15.62%	24.28%	0.00%	0.00%	0.18%	11.95%	1.73%	13.56%	9.18%	0.00%	0.00%	0.00%	0.00%	0.00%	3.94%
Major Tributaries	TC001	0.00%	14.54%	21.11%	0.00%	0.00%	21.03%	21.11%	0.00%	0.55%	6.40%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Major Tributaries	TRO001	0.00%	0.00%	0.00%	0.00%	0.00%	0.05%	3.82%	70.80%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.16%
Major Tributaries	UPR001	0.00%	20.33%	15.92%	0.00%	0.96%	18.50%	19.49%	0.00%	10.54%	0.00%	2.26%	0.00%	0.00%	0.00%	0.00%	0.00%
Major Tributaries	WAR001	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	15.31%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	LMB001	0.00%	13.20%	0.00%	0.00%	5.74%	9.15%	16.00%	32.23%	16.05%	0.00%	7.79%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	MEM001	0.00%	11.13%	13.83%	0.00%	0.00%	29.64%	23.18%	0.00%	0.00%	0.00%	0.00%	10.84%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	OBX001	0.00%	0.00%	0.00%	0.00%	0.00%	12.84%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	STH001	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	TCM001	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	TKHO001	0.00%	0.00%	0.00%	0.20%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	TKHO002	0.00%	1.46%	0.00%	49.15%	0.00%	1.46%	41.15%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	TKHO003	0.00%	0.74%	0.00%	10.05%	0.00%	24.90%	37.97%	1.19%	0.00%	0.00%	0.00%	0.00%	0.00%	14.85%	0.00%	0.00%
Marinas & Embayments	TKHO004	0.00%	0.00%	0.00%	66.84%	0.00%	0.00%	31.89%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	TKM001	0.00%	0.00%	0.00%	27.69%	0.00%	0.00%	33.90%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	TKM002	0.00%	0.00%	0.00%	68.79%	0.00%	0.00%	21.32%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	TKM003	0.00%	4.17%	0.00%	32.83%	0.00%	0.00%	21.17%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	TKM004	0.00%	0.00%	0.00%	0.30%	0.00%	0.00%	99.87%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	WNK001	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	71.58%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marinas & Embayments	FDLM001	0.00%	0.00%	0.00%	0.00%	0.00%	33.94%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marsh	PM001	0.00%	0.00%	32.85%	0.00%	0.00%	0.00%	3.71%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	5.28%	0.00%
Marsh	PM002	0.00%	0.00%	33.14%	0.00%	0.00%	0.00%	0.20%	5.25%	0.00%	6.76%	0.00%	6.16%	0.00%	0.00%	15.54%	0.00%
Marsh	PM003	0.00%	0.00%	20.63%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	18.85%	0.00%	19.74%	0.00%	0.00%	18.85%	0.00%
Marsh	PM004	0.00%	0.00%	22.19%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.14%	0.00%	23.68%	0.00%	0.00%	23.68%	0.00%
Marsh	TAL001	0.00%	8.06%	0.00%	0.00%	0.00%	0.00%	0.00%	20.15%	6.04%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	26.19%

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STRATA	Transect	Andean milfoil (AM)	Chara spp. (CH)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares Tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Various-leaved pondweed (VP)	White water buttercup (WB)
Marsh	TAL002	0.00%	0.00%	46.67%	0.00%	0.00%	0.00%	6.67%	0.00%	46.67%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marsh	TAY001	0.00%	0.00%	96.30%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.70%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marsh	TAY002	0.00%	0.00%	33.29%	0.00%	0.00%	0.00%	33.29%	0.00%	33.29%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marsh	UTM001	0.00%	0.00%	59.61%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	29.20%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Marsh	UTM002	0.00%	0.00%	31.58%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	29.38%	0.00%
Marsh	UTM003	0.00%	0.00%	32.58%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Open-water Nearshore	BBL001	34.27%	12.28%	0.00%	0.00%	0.00%	0.64%	8.99%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Open-water Nearshore	CRL001	0.41%	0.41%	0.00%	0.00%	0.00%	0.41%	4.54%	0.00%	0.41%	0.00%	0.41%	0.00%	0.00%	0.00%	0.00%	0.00%
Open-water Nearshore	SRL001	0.00%	31.76%	0.00%	0.00%	2.54%	1.86%	8.28%	0.00%	0.58%	0.00%	1.83%	0.00%	1.40%	1.89%	5.47%	0.00%
Open-water Nearshore	TCL001	0.00%	23.05%	0.00%	0.00%	12.10%	4.79%	2.54%	0.00%	0.37%	0.00%	0.00%	0.00%	4.91%	0.00%	0.00%	0.00%
Open-water Nearshore	TKHOL001	0.00%	21.01%	0.00%	18.72%	0.01%	5.20%	12.15%	0.00%	3.89%	0.00%	9.77%	0.00%	15.36%	0.04%	0.00%	0.00%
Open-water Nearshore	TKML001	2.30%	6.13%	0.00%	0.00%	10.89%	4.75%	5.72%	0.00%	5.63%	0.00%	7.35%	0.00%	1.51%	2.37%	3.77%	0.00%
Open-water Nearshore	TROL001	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.04%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Open-water Nearshore	UTRL001	0.00%	5.90%	1.76%	0.00%	5.85%	5.37%	6.36%	9.63%	1.39%	0.00%	0.67%	0.00%	0.00%	0.00%	5.86%	1.61%

Appendix D - Species Presence Summary Table

Absent, **S**ingle, **F**ew, **M**any – Includes opportunistic transects

Strata	Transect ID	Animal																						Misc		Plant																						
		Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
Major Tributary	BLW00A	A	A	A	A	A	F	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	BRK00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	F	F	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A
	EGW00A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	M	M	A	A	A	A	A	A	A	A	M	A	A	A	F	M	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	GCR00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	S	A	A	A	A	A	M	A	M	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TALC00A	A	A	A	A	A	A	A	A	A	A	A	A	S	A	A	A	A	A	A	A	S	A	A	A	A	M	A	M	A	A	S	F	F	F	M	A	A	A	A	A	A	F	A	A	A	A	A
	TC00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	M	A	A	M	M	A	F	M	A	A	A	A	A	A	A	A	A	A	A	A
	TRO00A	A	A	A	A	A	A	A	A	A	A	F	A	M	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	M	M	A	A	A	A	A	A	A	A	F	A	A	A	A	A
	TROL00A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	UPR00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	M	A	A	M	M	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A

Strata	Transect ID	Animal																						Misc		Plant																						
		Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
	WAR00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	EGW00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	M	M	A	F	A	A	A	A	A	A	A	S	A	A	A	A	A	A
	NCYN00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	SNW00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	F	F	A	A	A	A
Marinas & Embayments	CBE00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	F	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	CBM00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	F	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	CBSB00A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	CBW00A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	CRBR00A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A

		Animal																						Misc		Plant																						
Strata	Transect ID	Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
	EPHO00A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	FDL00A	A	A	A	A	S	F	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	HWM00A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	S	M	A	A	A	A	S	A	M	A	A	A	A	A	A	S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	KAS00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	S	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	LMB00A	M	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	M	A	A	A	S	F	F	M	F	A	M	A	A	A	A	A	A	A	A	A	A	A
	MEM00A	A	A	A	A	A	S	A	A	A	A	A	A	S	A	A	A	A	A	A	A	A	A	A	A	A	M	A	F	A	A	M	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	NTM00A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	OBX00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	SC00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	SH00A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

		Animal																						Misc		Plant																						
Strata	Transect ID	Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
	SH00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	SSM00A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	STH00A	A	A	A	A	A	S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TCM00A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TCM00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TKHO00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TKHO00S	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	M	A	F	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TKHO00F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	F	M	F	A	A	A	A	A	F	A	A	A	A	A	A	A	A
	TKHO00M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Strata	Transect ID	Animal																						Misc		Plant																						
		Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
	TKM00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TKM00F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	M	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TVBR00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TKM00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A
	TKM00M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A
	WNK00A	S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Marsh	PM00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	M	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A
	PM00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	F	A	M	A	F	A	A	A	M	A	A	A	A	A	A
	PM00F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	M	A	M	A	A	A	M	A	A	A	A	A	A
	PM00M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	M	A	M	A	A	A	M	A	A	A	A	A	A

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Marine Taxonomic Services, Ltd.

Strata	Transect ID	Animal																						Misc		Plant																						
		Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
	TAL00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	M	F	A	A	A	A	A	A	A	M	A	A	A	A	A
	TAY00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A
	TAY00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	M	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A
	UTM00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A
	UTM00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A
	UTM00F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	UTM00M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	UTRL00A	A	A	A	A	A	S	A	A	A	A	S	A	A	A	A	A	A	A	F	A	A	A	F	A	A	M	A	M	A	M	M	M	A	M	A	M	A	A	A	A	A	A	A	A	A	A	A
	TAL00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	F	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A
Open-	BBL00A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	M	M	A	A	A	A	M	M	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Strata	Transect ID	Animal																						Misc		Plant																						
		Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
	BBP00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	F	A	A	A	A	M	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	BBP00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	M	M	A	A	A	F	M	F	A	F	A	F	A	A	A	A	F	A	A	A	A	A	A
	CF00A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	CHL00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	CRBY00A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	CRBY00S	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	CRBY00F	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	CRL00A	M	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	M	M	A	A	A	A	M	M	A	F	A	M	A	A	A	A	A	A	A	A	A	A	A
	CRP00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	S	A	A	A	A	F	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	DLP00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

		Animal																						Misc		Plant																						
Strata	Transect ID	Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
	DMP00A	F	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	EBS00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	EBS00S	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	EGWL00A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	EPS00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	FLP00A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	GCS00A	A	A	A	A	A	S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	GLBL00A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	HIDB00A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	HW00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Strata	Transect ID	Animal																						Misc		Plant																						
		Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
	LHC00A	M	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	F	A	A	A	S	A	M	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	LINP00A	A	A	A	A	A	F	A	A	A	A	S	A	A	A	A	A	M	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	LKF00A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	MBL00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	MBS00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	NBL00A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	OD00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	OD00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	OD00F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	OD00M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Animal

Strata	Transect ID	Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout
	RHM00A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	A	A	S	A	A
	RPS00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	SHAR00A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A
	SHS00A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	S	A	A	A	A	A	A
	SKH00A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A
	SPP00A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	SRL00A	M	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A
	STP00A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	F	A	A	F	A	A
	SUN00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TCL00A	M	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Misc

Transect ID	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)
RHM00A	M	A
RPS00A	A	A
SHAR00A	S	F
SHS00A	A	A
SKH00A	A	A
SPP00A	A	A
SRL00A	M	A
STP00A	A	A
SUN00A	A	A
TCL00A	M	A

Plant

Transect ID	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
RHM00A	A	A	A	A	A	F	A	M	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A
RPS00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
SHAR00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
SHS00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
SKH00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
SPP00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
SRL00A	A	M	A	A	A	F	M	M	A	M	A	M	A	M	M	A	M	A	A	A	A	A	A
STP00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
SUN00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
TCL00A	A	M	A	A	A	M	F	M	F	M	A	A	A	M	A	A	A	A	A	A	A	A	A

Strata	Transect ID	Animal																						Misc		Plant																						
		Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout	Dead Asian clam shell (DAC)	Dead Crayfish (DCF)	Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
	THB00A	A	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TKHOL00A	F	S	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	F	A	A	F	A	A	F	F	M	M	F	F	A	M	A	A	F	A	A	A	A	A	A	A	A
	TKML00A	M	F	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	M	A	M	M	A	A	A	M	M	M	M	M	A	M	A	F	M	A	M	A	A	A	A	A	A
	TKMP00A	A	S	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	S	F	A	A	A	A	F	F	A	A	A	F	A	F	M	A	F	A	A	A	A	A	A
	TKMP00S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	M	M	A	A	A	M	M	M	A	S	A	M	A	F	M	A	A	A	A	A	A	A	A
	TROL00A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	S	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TTL00A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	TVIS00A	A	A	A	A	A	F	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
	ZCL00A	M	A	A	A	A	A	A	A	A	A	A	A	F	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	M	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Strata	Transect ID	Animal																					
		Asian clam (AC)	Bluegill (BG)	Brook trout (BT)	Brown bullhead catfish (BC)	Brown trout (BWT)	Crayfish (CF)	Cutthroat trout (CT)	Freshwater mussel (M)	JV trout (JT)	Kokanee salmon (KS)	Lake trout (LT)	Large mouth bass (LM)	Minnow (MO)	Mountain whitefish (MW)	Paiute sculpin (PS)	Rainbow trout (RT)	Redsided shiner (RS)	Small mouth ball (SM)	Snail (SN)	Speckled dace (SD)	Tahoe sucker (TS)	Unknown trout
	ZPL00A	M	A	A	A	A	A	A	A	A	A	A	A	M	A	A	A	M	A	A	A	A	A

Strata	Transect ID	Misc	
		Dead Asian clam shell (DAC)	Dead Crayfish (DCF)
	ZPL00A	M	A

Strata	Transect ID	Plant																						
		Andean milfoil (AM)	Chara spp. (CH)	Clasping pondweed (CP)	Common bladderwort (CB)	Coontail (C)	Curly-leaf pondweed (CLPW)	Elodea (E)	Eurasian watermilfoil (EWM)	Filamentous green algae (FA)	Leafy pondweed (LP)	Mares tail (MT)	Naiad spp. (N)	Northern milfoil (NM)	Quillwort (QW)	Richardson's pondweed (RP)	Sago pondweed (S)	Various-leafed pondweed (VP)	White water buttercup (WB)	Coontail (C.)	Crows Foot (CRWF)	Elodea (E.)	Naiad sp. (N)	Quill Wart (QW)
	ZPL00A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A

Appendix E - Summary of modeled surface and submerged aquatic plant cover (acres) by survey zone at Lake Tahoe (2018).

Survey Zone	Survey Zone Acres	Submerged Plant Acres	Surface Plant Acres	Total Plant Acres	Percent of Survey Zone
Baldwin Beach	290.81	2.37	0.14	2.50	0.86
Blackwood Creek	1.19	0.00	0.10	0.10	8.76
Burton Creek	0.84	0.00	0.24	0.24	28.28
Camp Richardson	560.20	1.31	0.17	1.49	0.27
Carnelian Bay	457.59	28.38	0.16	28.54	6.24
Chamber's Landing	351.19	5.93	0.19	6.12	1.74
Cove East	6.33	0.00	5.26	5.26	83.07
Crystal Bay East	0.43	0.00	0.00	0.00	0.39
Crystal Bay Mid	0.93	0.00	0.00	0.00	0.10
Crystal Bay West	1.40	0.01	0.01	0.01	0.84
Deadman's Point	262.66	0.64	0.03	0.66	0.25
Dollar Point North	293.60	10.47	0.35	10.83	3.69
Eagle Point	236.01	8.80	0.57	9.36	3.97
Edgewood Golf Course	11.53	0.00	3.70	3.70	32.12
Edgewood Shoreline	342.42	0.17	0.04	0.21	0.06
Elk Point Homeowners	0.59	0.02	0.01	0.03	4.51
Elk Point Marina	0.55	0.02	0.00	0.02	3.79
Emerald Bay East	303.13	18.45	0.19	18.65	6.15
Emerald Bay West	179.85	8.23	0.25	8.48	4.72
Fleur Du Lac	0.55	0.21	0.00	0.21	37.63
Flick Point	329.65	18.77	0.14	18.91	5.74
General Creek	1.18	0.00	0.19	0.19	15.95
Glenbrook	386.65	5.45	0.20	5.65	1.46
Gold Coast	392.75	3.16	0.01	3.17	0.81
Gold Coast North	293.12	1.85	0.07	1.92	0.66
Hidden Beach	349.45	3.36	0.31	3.68	1.05
Homewood	213.38	5.99	0.05	6.03	2.83
Homewood Marina	0.22	0.11	0.00	0.11	48.36
Hurricane Bay	270.42	18.73	0.03	18.76	6.94
Incline Beach East	412.30	3.17	0.11	3.29	0.80
Incline Beach West	339.03	9.14	0.23	9.38	2.77
Kaspian Point	0.39	0.08	0.01	0.09	21.97
Lake Forest Shoreline	1,369.27	134.71	0.19	134.90	9.85
Lakeside Beach	2.65	0.23	0.00	0.23	8.64
Lakeside Marina	0.94	0.21	0.00	0.21	22.85
Lighthouse Shore	297.97	0.84	0.01	0.85	0.29
Lincoln Park Cove	0.35	0.04	0.01	0.06	16.05
Logan Shoals Marina	2.16	0.87	0.00	0.87	40.32
Logan Shoals Shoreline	632.05	15.26	0.26	15.52	2.46
Marla Bay/Cave Rock	829.99	17.02	0.23	17.25	2.08
Meek Bay	178.37	0.86	0.12	0.98	0.55
Meeks Creek	1.13	0.00	0.43	0.43	37.71
Meeks Marina	2.93	1.20	0.07	1.27	43.28

Survey Zone	Survey Zone Acres	Submerged Plant Acres	Surface Plant Acres	Total Plant Acres	Percent of Survey Zone
Near Sunnyside Marina	0.35	0.04	0.00	0.04	10.06
Nevada Beach	112.81	0.01	0.00	0.01	0.01
North Tahoe Marina	0.60	0.01	0.00	0.01	1.00
Obexer's Marina	0.81	0.00	0.00	0.00	0.13
Other Embayments/Coves	64.99	3.04	0.72	3.76	5.78
Pope Marsh	15.66	0.00	12.45	12.45	79.53
Roundhill Beach	267.84	0.49	0.07	0.56	0.21
Rubicon	140.82	0.61	0.15	0.77	0.54
Sand Harbor Beach	3.43	0.00	0.00	0.01	0.23
Sand Harbor Boat Ramp Cove	13.38	0.25	0.02	0.26	1.95
Sand Harbor Mid Cove	4.38	0.10	0.02	0.12	2.84
Sand Harbor Shoreline	345.87	4.22	0.24	4.46	1.29
Secret Cove	2.65	0.03	0.02	0.05	1.91
Secret Harbor	338.34	0.99	0.23	1.22	0.36
Sierra Boatwork Marina	1.78	0.00	0.00	0.00	0.14
Ski Run Marina	0.51	0.00	0.08	0.08	16.44
Ski Run Shoreline	456.77	2.97	0.02	2.99	0.66
Skunk Harbor	189.13	0.18	0.04	0.22	0.11
Snow Creek	0.44	0.00	0.13	0.13	29.17
Star Harbor	1.31	0.07	0.03	0.11	8.00
Stateline Point East	137.82	0.14	0.19	0.33	0.24
Stateline Point West	1,173.84	24.00	0.30	24.29	2.07
Sugar Pine Point	834.49	9.55	0.31	9.86	1.18
Sunny Side Marina	0.47	0.12	0.00	0.12	26.37
Sunnyside Shoreline	242.50	16.59	0.32	16.91	6.97
Tahoe City Dam	2.72	0.51	0.03	0.53	19.62
Tahoe City Marina	6.30	0.16	0.00	0.16	2.61
Tahoe City Shoreline	1,523.99	105.57	0.37	105.94	6.95
Tahoe Keys Back Lagoon	1.12	0.00	0.19	0.19	16.97
Tahoe Keys Homeowners Lagoon	133.12	0.21	16.86	17.06	12.82
Tahoe Keys Marina	30.87	0.13	1.22	1.35	4.36
Tahoe Keys Marina Shoreline	203.85	15.39	0.00	15.39	7.55
Tahoe Tavern	933.52	34.92	0.35	35.27	3.78
Tahoe Vista Boat Ramp	0.42	0.01	0.00	0.01	1.29
Tahoe Vista Shoreline	835.14	18.26	0.01	18.28	2.19
Tallac Marsh	1.27	0.00	0.43	0.43	33.43
Taylor Creek	1.01	0.01	0.62	0.63	62.70
Taylor Creek	1.39	0.00	0.31	0.31	22.24
Taylor Creek Marsh	15.70	0.16	8.01	8.17	52.06
Thunderbird	203.57	1.69	0.12	1.81	0.89
Thunderbird Cove	2.83	0.19	0.03	0.23	8.03

Survey Zone	Survey Zone Acres	Submerged Plant Acres	Surface Plant Acres	Total Plant Acres	Percent of Survey Zone
Timber Cove/El Dorado Beach	704.38	20.46	0.02	20.47	2.91
Truckee River	6.53	0.81	0.46	1.26	19.33
Upper Truckee Marsh	14.78	0.01	9.79	9.80	66.33
Upper Truckee Marsh TC	3.75	0.00	2.53	2.53	67.51
Upper Truckee River	13.73	0.00	2.98	2.98	21.73
Upper Truckee River Mouth	4.19	0.01	0.61	0.62	14.80
Upper Truckee Shoreline	542.82	54.30	1.52	55.82	10.28
Ward Creek	0.59	0.00	0.17	0.17	28.68
Wavoka Cove	0.43	0.06	0.01	0.07	15.71
Zephyr Cove	541.33	9.85	0.27	10.11	1.87
Zephyr Point	113.77	0.60	0.14	0.73	0.64
Total	**19,802.27**	**652.80**	**76.44**	**729.24**	**3.68**