2016 Baseline Water Quality Report for the Tahoe Keys Lagoons

Volume 1.

March 27, 2017
2016 Baseline Water Quality Report for the Tahoe Keys Lagoons

Volume 1.

Prepared for

Tahoe Keys

Tahoe Keys Property Owners Association
South Lake Tahoe, California

Prepared by

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TAHOE KEYS INTEGRATED MANAGEMENT PLAN

March 27, 2017
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EXECUTIVE SUMMARY

The Tahoe Keys Property Owners Association (TKPOA) began collecting baseline data on water quality in 2016 to help inform the Tahoe Keys Integrated Management Plan (IMP). As part of this program, periodic water quality samples were collected that tested for many parameters to assess ambient water quality conditions in the lagoons. Both in situ measurements and lab analyzed samples were taken at 13 locations to provide a representative set of data for the lagoons.

In addition to baseline data, the 2016 program sets protocols for future years’ sampling so that direct comparisons can be made. Previous data collected in and around the Tahoe Keys was intermittent and used varying protocols making comparisons with historical data difficult.

The results of the water quality testing for the 2016 program showed a significant, but not unexpected, difference between the water quality of Lake Tahoe and that of the Tahoe Keys lagoons. Higher temperatures, greater turbidity, and increased levels of nitrogen and phosphorus were found within the lagoons. Results illustrate that total phosphorus and total nitrogen levels in the water column were above the water quality objectives set forth by the Lahontan Board that apply to all of Lake Tahoe’s waters. Monitoring results also show that sediment in the Tahoe Keys lagoons (see separate Sediment Monitoring report) have low levels of nitrogen as nitrate-nitrogen and nitrite-nitrogen, often below detectable limits. However, relatively high levels of ammonia were determined in the analyzed sediment.

Limited water movement combined with shallower depths allow for greater light penetration and warmer water temperatures, which enhance habitat conditions for invasive aquatic macrophytes such as Eurasian watermilfoil and curlyleaf pondweed, both of which can be found in abundance in the Tahoe Keys lagoons. Once established, the macrophytes contribute to the continued deterioration of water quality by outcompeting native plants, releasing nutrients, including phosphorus, into the water column, and adding fine sediment layers through years of growth and decay. Absorption of nitrogen and phosphorus by rooted macrophytes likely occurs more readily via roots than leaf absorption from the surrounding water column. Unrooted macrophytes (specifically coontail) in the Tahoe Keys likely utilize the available nitrogen and phosphorus in the water column, available due to a combination of atmospheric deposition, groundwater flow, and macrophyte nutrient cycling. Impaired water quality in the Tahoe Keys not only impacts ecosystem, recreation, and aesthetic values, but it also creates habitat for other non-native and invasive species (e.g., warm water fish).

By continuing data collection in future years for the Tahoe Keys lagoons, the TKPOA will be able to assess the effectiveness of the IMP. As macrophyte control measures are implemented, water quality samples will help determine the benefits to water quality. Macrophyte control should lead to clearer waters with lower nutrient levels and overall improved ecosystem health.
1.0 INTRODUCTION

The Tahoe Keys, a residential and commercial development located along the south shore of Lake Tahoe, is comprised of three water features: Lake Tallac Lagoon (a storm water collection basin for South Lake Tahoe), the Main Lagoon (western water access for most residences of the Tahoe Keys), and the independent, separately owned Marina Lagoon (eastern water access for the Keys Marina, other commercial, and many townhome residences of the Tahoe Keys). Both the Main and Marina lagoons have direct connections to Lake Tahoe via the West and East channels, respectively. Figure 1 shows the locations of these water features.

Figure 1. Overview of the Tahoe Keys Lagoons

The Tahoe Keys encompass 172 acres of waterways with 1,529 homes as well as townhouses, marinas, and a commercial center. Property in and around the Tahoe Keys lagoons is controlled by multiple landowners and waterway land ownership includes individual property owners, association ownership (e.g., TKPOA common property and Tahoe Keys Beach and Harbor Association), and commercial and governmental ownership. Through various agreements, TKPOA maintains the waterways for boating and other recreation. This ownership pattern adds management complexity. TKPOA has no legal or other authority to require others to participate in the Integrated Management Plan or implement best management practices.
Since the 1980’s, the Tahoe Keys lagoons have had an increasing problem with the growth of aquatic plants, also referred to as aquatic macrophytes, to the extent that the growth of these plants are significantly impacting the aquatic ecosystem, private and commercial boating, other recreation, and the aesthetics of the Tahoe Keys. The three macrophytes of greatest concern are the non-native Eurasian watermilfoil (*Myriophyllum spicatum*), curlyleaf pondweed (*Potamogeton crispus*), and the native coontail (*Ceratophyllum demersum*). While aquatic plants are generally beneficial to aquatic ecosystems, providing habitats and nutrients for benthic invertebrates, fish, and waterfowl, unchecked proliferation of invasive species can be harmful and leads to monocultures that crowd out native plants and host non-native fish species. These aquatic plants present risks to swimmers, wrap around boat propellers, impair water quality, and can be carried to other parts of Lake Tahoe by boats, waterfowl, and winds.

Until the 1980s, the waterways were largely clear with only native plants. Harvesting was not necessary. In the 1980s, Eurasian watermilfoil became well-established, requiring the start of harvesting. Eurasian watermilfoil expanded rapidly and was followed in 2003 by the first appearance of curlyleaf pondweed. Today, the lagoons are more than 90 percent infested with the invasive plants. TKPOA now must harvest the boating channels June through September every year to maintain 3 to 5 feet of navigational clearance.

The Waste Discharge Requirements (WDRs) permit that was issued to the TKPOA by the Lahontan Regional Water Quality Control Board’s (LRWQCB) Executive Order No. R6T-2014-0059 specifies that the TKPOA improve the control of aquatic invasive plants in the Tahoe Keys lagoons and that an IMP for Aquatic Plants and a Nonpoint Source Plan for Water Quality (NPS Plan) be implemented by the TKPOA (Lahontan 2014). The Monitoring and Reporting Program for the WDRs specifies that water quality parameters including dissolved oxygen, temperature, nitrate and nitrite nitrogen, ammonia, total ammonia, total Kjeldahl nitrogen, total phosphorus, and orthophosphorus be collected and analyzed for the Tahoe Keys lagoons during use of the circulation system. The TKPOA voluntarily added the 2016 Baseline Water Quality Program.

The results of the 2016 Baseline Water Quality Program established an inventory for several water quality and sediment parameters. The 2016 baseline data will be used in future years to detect changes in water quality resulting from aquatic plant control methods implemented under the IMP or changes in inputs to surface waters from activities undertaken as part of the NPS Plan.
2.0 TKPOA BASELINE WATER QUALITY PROGRAM

The Baseline Water Quality Program was initiated in 2016 to produce baseline data for nutrient concentrations, turbidity levels, and other water quality parameters during the course of the growing season (generally April/May through September/October annually). The program was initiated in the early spring of 2016, collected data from 13 locations, and continued into fall 2016 before field operations ceased.

2.1 Overview of Program

Fifteen water quality parameters were measured during 12 sampling events over the course of the aquatic plant growing season from early May to mid-October (Table 1). The following section describes the selection of sampling sites, sampling schedule, monitored parameters, and lab analysis details.

2.1.1 Monitored Parameters

Parameters measured at each of the thirteen sites for water quality include: depth (of water column and mid-depth), pH (of surface, mid-point, and bottom), specific conductivity, dissolved oxygen (DO), temperature, turbidity, orthophosphorus, total phosphorus (TP), nitrate-nitrogen, nitrite-nitrogen, total Kjeldahl nitrogen (TKN), and total nitrogen (TN).

Amino acids, urea, uric acid, nitrate, nitrite, ammonium, dissolved nitrogen gas and nitrous oxide are forms of nitrogen typically found in a body of water. Phosphorus forms in freshwater include soluble reactive (ortho) phosphorus and inorganic phosphorus. Most phosphorus in nature is found as phosphate, including orthophosphorus, and has a high affinity to bind with cations that possess positive charges (especially iron). This includes binding to sediment or clay particles, called sorbed phosphorus, which is often the case in aquatic ecosystems.

Nitrogen and phosphorus are the key nutrients for the regulation of macrophyte productivity (Boyd 1971). This is the reason that multiple forms of both were monitored during the course of the Baseline Water Quality Program in 2016. For water quality, collected samples were analyzed for nitrate-nitrogen, nitrite-nitrogen, TKN, TN, orthophosphorus, and TP. Table 1 below summarizes all monitored parameters.
### Table 1. List of Monitored Parameters

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Method of Measurement</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>YSI ProDSS and water level sounder</td>
<td>Depth, in feet, of water level. Used to determine mid-depth, for sample collection and YSI, as well as monitoring of snowmelt and potential runoff.</td>
</tr>
<tr>
<td>pH</td>
<td>YSI ProDSS.</td>
<td>Measure of acidity or alkalinity of water, with pH 7 being neutral. Surface, mid-point, and bottom were collected during the season to monitor effects of plant biomass on overall pH.</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>YSI ProDSS</td>
<td>Measure in micro Siemens per centimeter (µS/cm) of dissolved ionic particles in the water. Acts as a good indicator of Total Dissolved Solids.</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>YSI ProDSS</td>
<td>Amount (in parts per million) of oxygen present in water. An important parameter in water quality assessment due to its influence on aquatic organisms. Concentrations of DO that are either too high or too low can be harmful to aquatic life and can affect water quality (Fondriest Environmental Inc. 2016).</td>
</tr>
<tr>
<td>Temperature</td>
<td>YSI ProDSS</td>
<td>Temperature, in degrees Celsius (°C), of the water when sample and data collected. Aquatic macrophytes begin growing in water around 50°C. Numerous biological and chemical processes are influenced by temperature changes.</td>
</tr>
<tr>
<td>Turbidity</td>
<td>YSI ProDSS</td>
<td>According to the USGS, turbidity is the measure, in a liquid, of clarity. In this case measured in Formazin Nephelometric Unit (FNU). Turbidity is caused by phytoplankton, algae, clay, silt, and fine suspended particles in the water column that scatter light (Perlman 2016). Higher levels of turbidity scatter more light and can cause a reduction in photosynthetic activity and lower the concentration of oxygen in the water body. Wildlife in the ecosystem can also be negatively impacted by higher levels, sometimes leading to low survival rates (Lenntech 2016).</td>
</tr>
<tr>
<td>Ortho-phosphorus</td>
<td>Lab analysis</td>
<td>Dissolved inorganic phosphorus that is readily available for aquatic plants and algae.</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>Lab analysis</td>
<td>Amount of all forms, dissolved and particulate, of phosphorus present in the sample.</td>
</tr>
<tr>
<td>Nitrate-Nitrogen</td>
<td>Lab analysis</td>
<td>Amount of nitrogen bound to a nitrate ion present in the sample.</td>
</tr>
<tr>
<td>Nitrite-Nitrogen</td>
<td>Lab analysis</td>
<td>Amount of nitrogen bound to a nitrite ion present in the sample.</td>
</tr>
<tr>
<td>Total Kjeldahl Nitrogen</td>
<td>Lab analysis</td>
<td>Measure of ammonia and organic forms of nitrogen.</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>Lab analysis</td>
<td>Sum of all forms of nitrogen, including Nitrate-Nitrogen, Nitrite-Nitrogen, and TKN.</td>
</tr>
<tr>
<td>Organic Matter</td>
<td>Lab analysis</td>
<td>The concentration of carbon and nutrients in sediment as proteins, fats, carbohydrates, and nucleic acids derived from animal and plant detritus (Logan and Longmore 2015).</td>
</tr>
</tbody>
</table>

#### 2.1.2 Site Selection

Water (and sediment, refer to TKPOA 2016b) was sampled at 13 sites in the Tahoe Keys lagoons. The sites for data collection included dead-end coves and open water areas to assess water quality and sediment variation by location. Using geo-referenced locations will allow future monitoring to occur at the same sites. Figure 2 shows all sampling sites.
for both water quality and sediment sampling. Refer to Table 2 for more information on sampling sites.

**Figure 2. Water Quality and Sediment Sampling Sites**

![Sampling Sites](image)

**Table 2. Summary of Sample Site Locations**

<table>
<thead>
<tr>
<th>Site Number</th>
<th>Location</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Marina Lagoon</td>
<td>Near entrance of the East Channel</td>
</tr>
<tr>
<td>2</td>
<td>Main Lagoon</td>
<td>At end of first cove in Main lagoon</td>
</tr>
<tr>
<td>3</td>
<td>Marina Lagoon</td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>Main Lagoon</td>
<td>Near southern end of Main Lagoon</td>
</tr>
<tr>
<td>5</td>
<td>Lake Tallac Lagoon</td>
<td>--</td>
</tr>
<tr>
<td>6</td>
<td>Main Lagoon</td>
<td>--</td>
</tr>
<tr>
<td>7</td>
<td>Lake Tallac Lagoon</td>
<td>--</td>
</tr>
<tr>
<td>8</td>
<td>Main Lagoon</td>
<td>Dead-end cove</td>
</tr>
<tr>
<td>9</td>
<td>Main Lagoon</td>
<td>Open water area</td>
</tr>
<tr>
<td>10</td>
<td>Main Lagoon</td>
<td>Dead-end cove</td>
</tr>
<tr>
<td>11</td>
<td>Lake Tahoe</td>
<td>Near West Channel</td>
</tr>
<tr>
<td>12</td>
<td>Lake Tahoe</td>
<td>Near East Channel and Upper Truckee River delta</td>
</tr>
<tr>
<td>13</td>
<td>Lake Tahoe</td>
<td>Between East and West Channels</td>
</tr>
</tbody>
</table>
2.1.3 Sampling Schedule

The monitoring program began May 9, 2016 and ended on October 12, 2016. Water samples were collected biweekly, from May through August. The sampling frequency decreased to one sampling event in both September and October. The last sampling was moved from the end of September to mid-October to coincide with sediment sampling.

Precipitation, discharge into Lake Tahoe and daily temperature were monitored throughout the season. Sediment samples were collected twice, once in spring (May 25) and once in fall (October 11).

2.1.4 Analytical Laboratory Testing

Western Environmental Testing (WET) Lab was selected to conduct the analysis of collected samples for constituents that could not be completed in the field. The analytical lab located in Sparks, NV was used because it serves the South Lake Tahoe area.

TKPOA utilized Wet Lab for test supply delivery, including: coolers, sample containers, and any necessary preservatives. The samples were collected either on Mondays or Wednesdays and the WET Lab courier service collected all samples on Tuesday or Thursday.

2.2 Materials and Methods

Specific equipment and supplies were required to perform both water quality and sediment sampling. The necessary items were obtained by the TKPOA prior to May 2016 and the initiation of field sampling. The following section provides information on the required equipment utilized for water quality and the methods used by the TKPOA Water Quality Department throughout the season.

2.2.1 Equipment

The following materials were required for water quality sampling:

- YSI ProDSS
- YSI Calibration Log
- Sample pump
- Pen/Pencil/Sharpie
- Sulfuric acid preservative
- Sample location map
- Calibration Solutions
- Sample bottle labels
- Cooler(s)
- 500mL bottles
- Wet ice
- Gloves
- 1 L bottles
- Water Quality Data Collection Sheet
- Portable battery
- Water level sounder

**YSI ProDSS Multiparameter Sampling Instrument**

The YSI ProDSS is a portable digital sampling system that has the ability to measure turbidity, temperature, conductivity, pH, optical dissolved oxygen and depth in an aquatic environment. It is designed for applications in surface water, groundwater, aquaculture, and coastal waters. Calibrations, using the calibration solutions for pH (4, 7, and 10), turbidity (0 FNU), DO, and conductivity (1000M), occurred monthly and were logged in the YSI Calibration record (See Appendix B).

*Figure 3. YSI ProDSS*

![YSI ProDSS Image property Xylem Inc. 2016](image)

**Sample Pump**

The sample pump was designed and constructed by Dr. Lars Anderson. It is composed of PVC piping, PVC ¾ - inch tubing, jumper cables, and a bilge pump.
2.2.2 **Methods**

Prior to each sampling event, field staff verified sampling materials delivery and scheduling of courier service for next day sample pick up. The YSI calibration log was double checked. If calibration was required, calibration was performed according to manufacturer’s instructions. Appendix B contains the calibration record.

On the day of sampling, once on the boat with all necessary materials, the sample collector would complete the title section of the data sheet, indicating sample event number, boat driver, and sample collector. Lake elevation, Truckee River discharge, and recent weather conditions were recorded and later input into the water quality database.

Next, bottles were labeled. For each site, there was a total of four bottles, one set unpreserved (for analysis of inorganics) and the second set preserved with sulfuric acid (for nutrient analysis). Bottle labels were filled out with the following information:

- Company Name (TKPOA)
- Sample ID (WQ-instance number-site number A (B for duplicate)
  - ex: WQ-01-01A
- Sampled By (collector’s initials)
- Date of Sample
- Time of Sample

Depth of the sample site was determined with the YSI ProDSS or a water level sounder. This information was then used for the placement of the submersible pump at mid-depth in the water column. The sample pump was attached to the battery and water was left to run through the attached hose for at least one minute to flush the system prior to rinsing the collection bottles. Collection bottles were triple rinsed before collecting the actual sample, filling roughly three quarters of the bottle. After the samples were taken, sulfuric acid was added to the appropriate bottles and the samples were placed in a cooler filled with wet ice.

Additional data was collected at each site using the YSI ProDSS. The instrument was lowered into the water to mid-depth in the water column and left to run for roughly a minute, or until the graph at the bottom of the screen did not change. The temperature, DO, turbidity, electrical conductivity, and pH were then recorded onto the data sheet along with the site number, time, and depth. pH was then, similarly, recorded at the appropriate depths for the bottom and top of the water column.

The Chain of Custody (COC) Forms, supplied by WET Lab, were filled out completely by listing sample identifications, desired analysis, number of bottles, and type of sample. Completed COC forms can be found in Appendix D.
The forms were signed by the collector and dropped off at the TKPOA Pavilion. Samples were then picked up by a WET Lab courier or dropped off at the lab located in Sparks, NV within 24 hours of collection. Samples had enough ice to keep them cool, around 2˚-6˚C, until the pickup/drop off occurred.

Data from the data sheet was entered into the database workbook and the original hardcopy was scanned and sent to Sierra Ecosystem Associates (SEA) to be saved as an electronic copy. Once the analysis by WET Lab was completed, an electronic report was sent to SEA and the data was then entered into the database workbook.
3.0 RESULTS

Data entered into the water quality database was analyzed following the last sampling event in October. The information was averaged for sites located in the Main Lagoon, Marina Lagoon, Lake Tallac Lagoon, and Lake Tahoe. A table was then produced with averaged values for each parameter (refer to Table 3).

A complete record of collected data by site and date can be found in Appendix C.

3.1 pH

The average pH values varied between the three different depths in which measurements were taken. In general, average pH variables for mid-depth and surface readings in the Main Lagoon, Marina Lagoon, and the Lake Tallac Lagoon were greater than or roughly equal to 9 while the bottom of the water column fell to between 8.47 and 8.79.

Minimum values for mid-depth and bottom readings in the Main, Marina, and Tallac lagoons were below 8 whereas the minimum values for the surface of the water column were 8.82, 9.01, and 9.60. Furthermore, pH values exceeded 10 at least four times during the course of the season, reaching a maximum value mid-depth of 10.30 at Site 10 during the August 15 sampling event.

Values from the three Lake Tahoe sampling sites (Sites 11, 12, and 13) were around 8 for readings taken from the three specified depths. The minimum pH value was 7.66 and the maximum value was 8.35.

3.2 Temperature

The average values for the Main, Marina, and Lake Tallac Lagoons were 18.25°C, 17.54°C, and 17.85°C respectively. The minimum temperature in the Main Lagoon was 10.2°C, recorded at Site 9 May 23. The maximum temperature was 23.8°C recorded at Site 6 on August 1. Similarly, the minimum and maximum temperature for the Marina Lagoon was recorded at Site 1 and was 10.7°C (collected May 5, 2016) and 22.6°C (collected August 1, 2016), respectively. Site 7, in Lake Tallac, had both the minimum and maximum temperature values of 8.2°C and 23.6°C, recorded May 9 and August 1, respectively.

The minimum temperature recorded for the sample sites in Lake Tahoe (11, 12, and 13) was 10.9°C, collected May 25, and the maximum temperature was 20.5°C, collected August 15. The averaged value for the three Lake Tahoe sites was 16.72°C.

3.3 Turbidity

The average values for each lagoon of the Tahoe Keys were below 2 FNU, ranging from 1.28 to 1.93 FNU. Minimum values for the Main, Marina, and Tallac lagoons were 0.04,
0.8, and 0.9 FNU respectively while the maximum values logged were 3.4, 3.5, and 6.3 FNU. The highest recorded value, 6.3 FNU was recorded at Site 7 on May 9. The averaged value for the three Lake Tahoe sites is 0.28 FNU. The minimum value was 0.01 FNU while the maximum value was 1.60 FNU.

3.4 Phosphorus

All orthophosphorus average, minimum, and maximum values collected at every site during the course of the season were less than or equal to 0.02 mg/L\(^1\). TP values were slightly higher. Average TP values for the Main, Marina, and Tallac lagoons were 0.030, 0.019 and 0.026 mg/L respectively. The minimum TP values are 0.010, 0.010, 0.011 mg/L while the maximum values logged were 0.120, 0.048, and 0.120 mg/L.

The averaged TP value for the three Lake Tahoe sites is 0.015 mg/L. The minimum value was 0.011 mg/L while the maximum value was 0.023 mg/L.

3.5 Nitrogen

The TN average values for the Main, Marina, and Tallac Lagoons were 0.37, 0.46, and 0.47 mg/L respectively. The minimum value for the Main Lagoon was 0.22 mg/L while the maximum value was 1.10 mg/L. For the Marina Lagoon, the minimum value was 0.23 mg/L while the maximum value was 2.20 mg/L. The Lake Tallac Lagoon’s minimum value was 0.23 mg/L and the maximum value was 0.47 mg/L. The sites located outside of the Tahoe Keys, in Lake Tahoe, had values below the detectable limit.

3.6 Dissolved Oxygen

A YSI ProDSS DO sensor calibration error occurred in the beginning of the sampling season. Values recorded prior to June 2016 therefore have a large margin of error. Remaining values were converted to ppm from percent concentration.

The average values for the Main, Marina, and Lake Tallac Lagoons were 11.89 ppm, 10.89 ppm, and 9.98 ppm respectively. The minimum DO value recorded in the Main Lagoon was 6.73 ppm. The maximum DO value recorded was 22.99 ppm. Similarly, the minimum and maximum temperature for the Marina Lagoon was 7.57 ppm and 20.40 ppm, respectively. In the Lake Tallac Lagoon, the minimum and maximum recorded DO values were 0.02 ppm and 15.84 ppm, respectively.

The minimum DO value recorded for the sample sites in Lake Tahoe (11, 12, and 13) was 7.39 ppm and the maximum was 18.75 ppm. The averaged value for the three Lake Tahoe sites was 9.27 ppm.

\(^1\) 1 mg/L = 1 ppm
Table 3. Averaged Water Quality Results

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Main Lagoon</th>
<th>Marina Lagoon</th>
<th>Lake Tallac</th>
<th>Lake Tahoe*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg</td>
<td>Min</td>
<td>Med</td>
<td>Max</td>
</tr>
<tr>
<td>SPC (µs/cm)</td>
<td>161.76</td>
<td>95.50</td>
<td>170.45</td>
<td>245.10</td>
</tr>
<tr>
<td>DO (ppm)**</td>
<td>11.89</td>
<td>6.73</td>
<td>10.35</td>
<td>22.99</td>
</tr>
<tr>
<td>Temp (°C)</td>
<td>18.25</td>
<td>10.20</td>
<td>19.60</td>
<td>23.80</td>
</tr>
<tr>
<td>Turbidity (FNU)</td>
<td>1.28</td>
<td>0.04</td>
<td>1.20</td>
<td>3.40</td>
</tr>
<tr>
<td>Orthophosphorus</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>0.030</td>
<td>0.010</td>
<td>0.027</td>
<td>0.120</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>0.37</td>
<td>0.22</td>
<td>0.33</td>
<td>1.10</td>
</tr>
<tr>
<td>Nitrate</td>
<td>0.04</td>
<td>0.02</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>Nitrate</td>
<td>ND</td>
<td>0.00</td>
<td>ND</td>
<td>0.00</td>
</tr>
<tr>
<td>Kjeldahl Nitrogen</td>
<td>0.36</td>
<td>0.20</td>
<td>0.31</td>
<td>1.10</td>
</tr>
</tbody>
</table>

*Regular sampling of Lake Tahoe sites began on July 18, 2016
**DO was initially measured in % concentration. PPM is a calculated number.
4.0 DISCUSSION

The water quality parameters pH, temperature, phosphorus, nitrogen, and turbidity were specifically monitored throughout the season to observe monthly changes and potential yearly trends. Tables to compare various parameters over time as well as Box-and-Whisker Plots were created to depict the data collected during the 2016 growing season.

Box-and-Whisker Plots are used to show a dataset distribution. The illustrated box represents the upper quartile median, and lower quartile for the dataset. Extending arms from the box represent the maximum and minimum dataset values.

Figure 5. Box-and-Whisker Plot

Image property of FlowingData.com ©2007-2016

4.1 pH

pH is influenced by many variables including temperature and light availability. According to the Washington State Department of Ecology, the formation of dense macrophyte beds, such as those of coontail or Eurasian watermilfoil found in the Tahoe Keys lagoons, tend to block light, reduce oxygen concentration in the water, increase the water temperature, and increase pH (Washington State Department of Ecology 2016). However, findings of the 2016 sampling season determined that the pH recorded near the bottom of the water column was generally found to be lower than that of the pH taken at mid-depth and surface levels. Figures 6, 7, and 8 show pH at the three measured depths.
Figure 6. Box-and-Whisker Plot for Bottom pH

**pH at Bottom of Water Column**

![Box-and-Whisker Plot for Bottom pH](image)

Figure 7. Box-and-Whisker Plot for Middle pH

**pH at Middle of Water Column**

![Box-and-Whisker Plot for Middle pH](image)
Biological processes, photosynthesis and respiration as well as decomposition, of aquatic plants also play a role in determining pH of a waterbody though the release of different byproducts, including oxygen and carbon dioxide. The presence of carbon dioxide (CO$_2$) in water has been found to decrease pH (Fondriest Environmental, Inc. 2016). In dense beds, such as those found along the bottom of the Tahoe Keys waterways, where light is able to penetrate at high enough levels to promote photosynthesis and respiration, pH may be noticeably lower than found at mid-depth due to a combination of CO$_2$ release and a lack of water mixing.

Deposition of atmospheric nitrogen and phosphorus play a large role for aquatic ecosystems and accounts for a majority of dissolved inorganic nitrogen, total nitrogen and soluble reactive phosphorus present in Lake Tahoe (Jassby et al. 1994; Tahoe Environmental Research Center 2016). The notably higher, more basic pH recorded near the surface of the Tahoe Keys lagoons may be associated with atmospheric deposition. For example, ammonia at the surface acts as a base in aqueous solutions and pulls hydrogen ions from water to produce both hydroxide ions and ammonium (Shakhashiri 2008).
Figures 9 and 10 (shown above) illustrate the difference of both pH and temperature throughout the course of the sampling season. Site 9 (Figure 9) represents an open water area in the Main Lagoon, where mixing and flow of water into and out of the Tahoe Keys lagoons occurs regularly due to close proximity, spring inflow from the lake during snowmelt runoff, summer outflow to the lake due to lake elevation drops, and wind patterns. Lake Tahoe has a predominant daily wind (southwest) across the lake, away from the Tahoe Keys. While embayments, like the Tahoe Keys, are often protected from direct effects of wind across the surface of the waterbody, interactions between thermal stratification and wind can greatly influence channel exchange (La Plante 2001).

Site 8 (Figure 10) represents a dead-end cove in the Main Lagoon, located near the southwest end of the Tahoe Keys. This site is relatively shallow (between 3'5" and 7'7"),
in a sheltered area, typically warmer due to greater light penetration and therefore has a limited occurrence of mixing.

As previously mentioned, temperature in the dead-end cove was generally higher than that of the open water area. Additionally, pH in the dead-end cove was also generally more basic than that of the open water area.

**Figure 11. Marina Lagoon Sampling Site**

Figure 11 depicts the pH and temperature variation at Site 1 (located near the mouth of the East Channel) during the course of the sampling season. Surface and mid-depth pH readings were very similar while readings taken near the bottom of the water column were noticeably lower. Similar to the readings shown in Figure 9, Figure 11 is also representative of an open water area in the Tahoe Keys lagoons and has similar pH and temperature levels.
Figure 12 (above) depicts the changes of pH and temperature in the Lake Tallac Lagoon during the course of the 2016 growing season. Again, surface and mid-depth pH readings were very similar while readings taken near the bottom of the water column were noticeably lower. Interestingly, the line representing temperature follows a similar pattern to that shown by the surface and mid-depth pH readings. While temperature does not affect pH directly, it does increase solubility and distribution of ions and causes a shift in the range of pH where neutral may no longer be 7 (Fondriest 2016).

4.2 Temperature

Temperature readings from the Tahoe Keys lagoons were higher on average than those taken from the three Lake Tahoe sites (Sites 11, 12, and 13). While the Lake Tahoe sites all had shallower depths (less than 6 feet) than those of the Tahoe Keys sites, a combination of large water mass, seasonal snowmelt inflow, wind, and constant mixing contributed to the lower temperatures.
Of the sites located in the Tahoe Keys lagoons, there was a combination of both open water and dead end areas. Open water areas tended to be deeper than dead-end areas and have more opportunity for mixing or inflow of cooler water from the channels connecting the lagoons to Lake Tahoe.

Figure 14 represents the difference in temperatures at mid-depth in an open water area versus a dead-end cove. Site 8, located near the Southwest end of the Tahoe Keys, shows higher temperatures than Site 9, located near the entrance of the West Channel. This is likely due to the shallower waters, lower occurrence of mixing, and aquatic macrophyte density in the water column.
4.3 Turbidity

Turbidity is caused by phytoplankton, algae, clay, silt, and fine suspended particles in the water column that scatter light (Perlman 2016). Higher levels of turbidity scatter more light and can cause a reduction in photosynthetic activity and lower the concentration of oxygen in the water body (Lenntech 2016). Higher turbidity levels in the Tahoe Keys lagoons is due to a combination of plant and algae growth during the course of the growing season.

Figure 15. Box-and-Whisker Plot Turbidity

As seen in Figure 15, samples taken from the Lake Tallac Lagoon showed higher levels of turbidity. This may be due to the growth of coontail and Eurasian watermilfoil to the surface of the waterbody early in the season.

4.4 Nutrients

Nitrogen and phosphorus are the key nutrients for the regulation of macrophyte productivity (Boyd 1971). Aquatic plants are unique as they have the ability to uptake necessary nutrients through their roots or shoots, depending on nutrient demand and availability. Free-floating plants without roots, like coontail, must absorb all necessary nutrients from the water column as they have no connection to nutrient-containing sediment (Angelstein et al. 2008).

More than half of available phosphorus and nitrogen (Melzer 1999) are moved into macrophyte tissues via root uptake. In most aquatic systems, the concentration of ammonium in the sediment is greater than that of the surrounding water column and is therefore the most common form of nutrient uptake for most aquatic plants (Smith et al. 1990). Most nitrogen absorbed by the plant is ammonium, as other forms of nitrogen are
either non-beneficial to aquatic macrophytes or require the expenditure of energy for uptake (Smith et al. 1990, Walstad 2014). Typically, the pool of available phosphorus in sediment is a hundred-fold of that found in the surrounding water column (Søndergaard et al. 2003), which makes uptake via roots and the mobilization of phosphorus so important. Phosphorus forms in freshwater include soluble reactive (ortho) phosphorus and inorganic phosphorus. Most phosphorus in nature is found as phosphate, including orthophosphorus, and has a high affinity to bind with cations that possess positive charges (especially iron).

The WDRs issued by the Lahontan Board for the Tahoe Keys lagoons included water quality objectives (WQO) that apply to all of Lake Tahoe’s waters. Based on limited available data from 2007 through 2013, the water quality of the Tahoe Keys lagoons rarely meets the WQO, as shown in Table 4.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Nitrogen (TN), mg/L</th>
<th>Total Phosphorous (TP), mg/L</th>
<th>Total Dissolved Solids (TDS), mg/L</th>
<th>pH</th>
<th>Turbidity (NTU)</th>
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<tr>
<td>2007</td>
<td>0.28</td>
<td>0.030</td>
<td>74</td>
<td>9.16</td>
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<td>2008</td>
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<td>0.033</td>
<td>84</td>
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<tr>
<td>2009</td>
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<td>9.15</td>
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<td>2010</td>
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<td>101</td>
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<tr>
<td>2011</td>
<td>0.18</td>
<td>0.023</td>
<td>71</td>
<td>8.31</td>
<td>1.72</td>
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<tr>
<td>2012</td>
<td>4.57</td>
<td>0.019</td>
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<td>8.88</td>
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<td>2013</td>
<td>0.24</td>
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<td>81</td>
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<td>1.88</td>
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<td>WQO</td>
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<td>0.008</td>
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<td>7.0 - 8.4</td>
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</table>

For the 2016 season, TP and TN concentrations exceeded the WQO shown in Table 4 in the Main Lagoon, Marina Lagoon, and the Lake Tallac Lagoon. As shown in Table 3, even the minimum 2016 TP and TN values recorded for all sites in the Tahoe Keys were above the WQO.

The elevated levels may be due to nutrient concentrations in runoff, atmospheric deposition or the adsorption of nutrients from plant tissues, or other factors combined with the alteration of pH and concentration of dissolved oxygen that occurs in dense canopy environments and allows aquatic plants to contribute phosphorus to the water column (Walter 2000). For example, common Elodea and Eurasian watermilfoil are both present in the Tahoe Keys and are known to release phosphorus during their growing periods (Moore et al., 1984).

The uptake and release of phosphorus by Elodea is dependent on light availability, photosynthesis and respiratory processes. In previous studies using radioactively tagged phosphorus (32P) for detection and measurement in mesocosms with Elodea, 36% of

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2 Data from TKPOA Self-Monitoring Reports under prior NPDES Permit. WQO = Lahontan Basin Plan Water Quality Objectives, Chapter 5 including Table 5.1-3. TN is the sum of nitrate nitrogen + nitrite nitrogen + Total Kjeldahl Nitrogen. Lake Tahoe is Clean Water Act Section 303(d) listed as impaired for Total Nitrogen (TN), Total Phosphorus (TP), and sediment (LRWQCB 2014).
available phosphorus was absorbed by the plants during the day, the rate of uptake decreasing over time, and the plants released phosphorus during dark periods (Angelstein et al. 2008). In a study by K. Walter (2000) using tracer phosphorus, it was determined that Eurasian watermilfoil and Elodea release oxygen, carbon dioxide, nitrogen, phosphates, silica, and other organic compounds during photosynthesis. Between the two macrophytes, it was determined that Eurasian watermilfoil releases more phosphorus than Elodea, at a rate of 4491.4 dpm/ plant/day. By the end of the experiment, almost 0.50% of the tracer phosphorus loaded into the microcosms containing Eurasian watermilfoil was leaked into the water column. Elodea leaked only 0.05% of the 32P into the water column. Furthermore, levels of ammonia-nitrogen and soluble reactive phosphorus were higher in microcosms with Eurasian watermilfoil. Overall, milfoil releases phosphorus into the water column during growth and senescence regardless of photoperiod causing spikes in chlorophyll A and nutrient concentrations (Walter 2000).

In addition to the release of nutrients from plants, groundwater inflow from the surrounding area may also contribute phosphorus and nitrogen to the Tahoe Keys lagoons from upslope residential, recreational, commercial, and ambient sources. In 2003, the United States Army Corps of Engineers (USACE) conducted a study of groundwater discharge in to Lake Tahoe using numerical modeling. Lake Tahoe was broken into regions and sub-regions. Once sectioned into sub-regions, the Tahoe Keys lagoons fell in sub-region 2 of the South Lake Tahoe region. Wells, both deep and surface aquifers, were then monitored. Only one well (050) was monitored for all forms of nutrients, including orthophosphorus and total phosphorus. Remaining wells were monitored for drinking water standards, providing information on total nitrate and nitrite.

According to the USACE study, sub-region 2 contributes approximately 1.2 x 10^6 m^3/yr. of groundwater annually to Lake Tahoe, and much of that groundwater enters Lake Tahoe through the Tahoe Keys lagoons. The groundwater flow that does enter the lagoons is believed to originate within 2,000 m directly south of the Tahoe Keys. Overall, an estimated average annual interflow rate of 475,000 gallons per day brings an estimated 0.039 mg/L^3 of total phosphorus, 0.018 to 0.022 mg/L orthophosphorus, between 0.001 to 0.2 mg/L dissolved ammonia and organic nitrogen as well as 0.01 to 2.4 mg/L of dissolved nitrate (USACE 2003).

The concentrations of both orthophosphorus and TP reported in the 2003 groundwater flow study are similar to those found in the 2016 TKPOA water quality results. 2016 orthophosphorus values recorded in the Tahoe Keys lagoons fell between 0.01 mg/L to 0.02 mg/L. The Lake Tallac Lagoon had the most similar value to the estimated USACE average with an average of 0.02 mg/L orthophosphorus. The Marina Lagoon values had the lowest orthophosphorus and total phosphorus levels among the lagoons. This may be due to the position of the Marina Lagoon relative to the Upper Truckee River and wetlands as wetlands play an important role in filtering runoff through the trapping of sediments, the uptake of nutrients by wetland flora (Raumann et al. 2008) and by acting as sites of denitrification (Carpenter et al. 1998).

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3 mg/L = ppm
However, further study of groundwater hydrology, nutrient levels in wells surrounding and in the Tahoe Keys, and water circulation in the Tahoe Keys lagoons will need to be conducted to better determine the relative amounts of nutrients that are contributed from sources within and external to the lagoons.
5.0 CONCLUSIONS

The water quality data collected during the 2016 season establishes a baseline dataset for the Tahoe Keys lagoons. Previous data collected in and around the Tahoe Keys Lagoons was infrequent and in some cases, was limited to only a few parameters. By collecting regular, consistent data throughout the season on multiple parameters, future water quality samples can be used to assess the effects of various aquatic macrophyte control methods on changes in water quality.

The data collected during both the Baseline Water Quality and Sediment (TKPOA 2016b) Monitoring Programs show that the habitat of the Tahoe Keys lagoons is well suited to invasive plant (macrophyte) growth. The calmer waters and higher nutrient levels (specifically nitrogen and phosphorus which are the key nutrients for the regulation of macrophyte productivity (Boyd 1971)) relative to Lake Tahoe, along with warmer water temperatures, contribute to the prolific growth of macrophytes throughout the lagoons.

2016 total phosphorus and total nitrogen levels in the water column were above the water quality objectives set forth by the Lahontan Board that apply to all of Lake Tahoe’s waters. Phosphorus molecules, most often found in nature as phosphate, deposited in the Tahoe Keys lagoons via surface runoff, groundwater flow, atmospheric deposition, and internal cycling by the dense aquatic macrophyte beds likely binds quickly to any cations that possess positive charges (especially iron), which includes binding to sediment, or clay particles. Phosphorus is a crucial determiner of water quality and aquatic macrophyte growth. Levels of phosphorus detected in the lagoons was, at times, an order of magnitude higher than that of Lake Tahoe. Nitrogen was not detected in the Lake Tahoe samples but was detected in the lagoon samples.

In 2003, the United States Army Corps of Engineers released a study that suggests that groundwater flow in South Lake Tahoe likely supplies the Tahoe Keys lagoons and Lake Tahoe with phosphorus and nitrogen from recreational, residential, commercial, and ambient sources. Overall, an estimated average annual interflow rate of 475,000 gallons per day brings groundwater into the lagoons with concentrations of approximately 0.039 ppm of total phosphorous, 0.018 to 0.022 ppm orthophosphorus, between 0.001 to 0.2 ppm dissolved ammonia and organic nitrogen as well as 0.01 to 2.4 ppm of dissolved nitrate (USACE 2003). However, further study of groundwater hydrology, nutrient levels in wells surrounding and in the Tahoe Keys, and water circulation in the Tahoe Keys lagoons will need to be conducted to better determine the relative amounts of nutrients loaded into the Tahoe Keys via groundwater discharge.

Eurasian watermilfoil releases phosphorus into the water column during growth and senescence regardless of photoperiod causing spikes in chlorophyll a and nutrient concentrations. From results of previous studies conducted in mesocosm tanks using tracer phosphorus, it appears that Eurasian watermilfoil has a more negative effect on water quality than Elodea (Walter 2000), both of which are present in the Tahoe Keys lagoons. However, at this time it is unknown how much these plants are contributing to the elevated nutrient levels in the Tahoe Keys due to other sources including groundwater.
as described by the USACE (2003). Further study is needed of groundwater nutrient contribution, water quality fluctuations throughout the growing season, and macrophyte nutrient contribution to the water column.

With these nutrient sources and amounts, there are clearly excessive levels of nutrients to support the growth of all identified macrophytes regardless of the presence and extent of the non-native aquatic plants.

As the TKPOA continues with its IMP adaptive management strategy, it will be necessary to continue periodic water quality sampling in order to track progress of the program and assess the overall health of the ecosystem. As the biomass of the plant populations begins to decrease, there should be a detectable improvement of many water quality parameters. However, if the populations continue to grow unchecked, it is likely that the water quality in the lagoons will continue to deteriorate leading to further growth of macrophytes and potentially larger algal blooms.
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### 7.0 Abbreviations and Acronyms

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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
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<tr>
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<td>Formazin Nephelometric Unit</td>
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<td>mg/L</td>
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<td>Parts per million</td>
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