2017 Baseline Water Quality Report for the Tahoe Keys Lagoons

Volume 1

April 19, 2018

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Volume 1

Prepared for

Tahoe Keys

Tahoe Keys Property Owners Association
South Lake Tahoe, California

Prepared by

sea
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TAHOE KEYS INTEGRATED
MANAGEMENT PLAN

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EXECUTIVE SUMMARY

The Tahoe Keys Property Owners Association (TKPOA) continued collecting baseline data on water quality in 2017 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. A 14th site was added after a cyanobacterium outbreak in a section of the Tahoe Keys Main Lagoon was seen in the first weeks of August. Cyanobacteria testing started at site 14 in the latter part of August and continued to be sampled weekly by TKPOA staff until the end of October.

The results of the water quality testing for the 2017 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 2017 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 collected during the spring sampling event, demonstrating at least a 6% increase at each site excluding Site 9 (where samples were unable to be collected due to water depth) from 2016 to 2017.

Limited water movement in the lagoons, 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 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, shallow groundwater inflow from up-gradient urban areas, 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 an 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 (a storm water collection basin for urban storm water runoff from 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), commercial, and governmental ownership. Through various agreements, TKPOA maintains the waterways for boating and other recreation. This ownership pattern adds management complexity since 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*) and curlyleaf pondweed (*Potamogeton crispus*), and the native coontail (*Ceratophyllum demursum*). 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 Water Quality Management Plan (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. While the circulation system has not operated since the late 1990s, the TKPOA has voluntarily conducted regular water quality monitoring of these parameters in 2016 and 2017 to help inform the development of its IMP.

The results of the 2017 Baseline Water Quality Program continue to aid in the establishment of an inventory for several water quality and sediment parameters. The 2016 and 2017 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 2017 sampling season ran from April to October with samples being collected from 13 different sites. A 14th site was added after a cyanobacterium algal bloom in a section of the Tahoe Keys Main Lagoon was seen during the first weeks of August 2017. Cyanobacteria monitoring started at Site 14 in the latter part of August and continued to be sampled weekly by TPKOA staff until the end of October.

2.1 Overview of Program

Twelve water quality parameters were measured during 7 sampling events over the course of the aquatic plant growing season from Late April 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, which have 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 considered the key nutrients for the regulation of macrophyte productivity (Boyd 1971). For this reason, multiple forms of both were monitored during the course of the Baseline Water Quality Program in 2016 and 2017. 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

Constituent	Method of Measurement	Units	Brief Description
Depth	YSI ProDSS and water level sounder	Feet	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.
pH	YSI ProDSS.	N/A	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.
Specific Conductance	YSI ProDSS	µs/cm	Measure in micro Siemens per centimeter (µS/cm) of dissolved ionic particles in the water. Acts as a good indicator of Total Dissolved Solids.
Dissolved Oxygen	YSI ProDSS	ppm	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).
Temperature	YSI ProDSS	˚C	Temperature, in degrees Celsius (˚C), of the water when sample and data were collected. Aquatic macrophytes begin growing in water around 10˚C (Smith et al. 1990). Numerous biological and chemical processes are influenced by temperature changes.
Turbidity	YSI ProDSS	FNU	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).
Ortho-phosphorus	SM 4500-P E	mg/L	Dissolved inorganic phosphorus that is readily available for aquatic plants and algae.
Total Phosphorus	SN 4500-P E	mg/L	Amount of all forms, dissolved and particulate, of phosphorus present in the sample.
Nitrate-Nitrogen	EPA 300.0	mg/L	Amount of nitrogen bound to a nitrate ion present in the sample.
Nitrite-Nitrogen	EPA 300.0	mg/L	Amount of nitrogen bound to a nitrite ion present in the sample.
Total Kjeldahl Nitrogen	EPA 351.2	mg/L	Measure of ammonia and organic forms of nitrogen.
Total Nitrogen	Calc.	mg/L	Sum of all forms of nitrogen, including Nitrate-Nitrogen, Nitrite-Nitrogen, and TKN.

2.1.2 Site Selection

Water and sediment (TKPOA 2017b) were 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.

Figure 2. Water Quality and Sediment Sampling Sites

2.1.3 Sampling Schedule

The monitoring program began April 27th, 2017 and ended on October 16th, 2017 with water samples being collected monthly.

Precipitation, discharge into Lake Tahoe, and daily temperature were monitored throughout the season. Sediment samples were collected twice, once in spring (May 29th) and once in fall (October 16th).

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. WET Lab is certified as an environmental test laboratory accredited by the California Water

Boards pursuant to the provisions of the Health and Safety Code (HSC) Division 101, Part 1, Chapter 4, Section 100825, et seq.

TKPOA utilized WET Lab for test supply delivery, including: coolers, sample containers, and any necessary preservatives. The samples were collected either on Mondays, Thursdays, or Fridays and were hand delivered to WET Lab or the WET Lab courier service collected them the following day.

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 April 2017 and the initiation of field sampling. The following section provides information on the required equipment utilized for water quality sampling and the methods used by the TKPOA Water Quality field crews 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 (weighted rope with one foot measurement increments to determine water depth.)

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, 100 FNU, 1000 FNU), DO (ppm), and conductivity (1 mS/cm, 100 mS/cm, 1000 mS/cm), occurred monthly before sampling and were logged in the YSI Calibration record (See Appendix B).

The conductivity and temperature probe on the YSI ProDSS failed prior to the WQ-04 sampling event on 7/31/17. An YSI model 556 was borrowed from Tahoe Resource Conservation District (TRCD) until the conductivity/temperature probe was fixed and returned by the manufacturer on October 13th 2017. The YSI model 556 was able to monitor depth, pH, specific conductance, dissolved oxygen, and temperature but not turbidity.

Figure 3. YSI ProDSS

Image property Xylem Inc. 2016

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, TKPOA Water Quality field staff verified sampling materials delivery and scheduling of courier service for next day sample pick up or hand delivery.

The YSI calibration log was double checked. If calibration was required, calibration was performed by TKPOA Water Quality staff according to manufacturer's instructions.

On the day of sampling, and 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.

The sampling locations were selected in 2016 to generally represent the lagoons as a whole. After determination of sampling locations, each site was marked via GPS and physical markers were identified to repeat sampling location proximity.

Next, bottles were labeled. For each site, there were 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. Powder free nitrile gloves were worn before handling/opening sampling bottles and before any sampling process began. Collection bottle labels were double checked for the appropriate label for the collection site and analysis type.

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 numbers stabilized. 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 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.

Figure 4. Use of Sample Pump

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. Once samples are received and opened by WET Lab, WET Lab confirms that the received samples arrived at the appropriate temperature before any testing is performed. This information is documented on the lab results when returned from WET Lab after all testing is completed.

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. Lab data, YSI data collection sheets, and calibration logs were also printed and compiled into the water quality binder for easy access.

After the sampling is completed, and all lab analyses are returned from WET Lab, data from the YSI ProDSS datasheet and lab results are entered into an electronic water quality database. Data entered from the YSI ProDSS datasheet include the site number, time of sample, depth to the bottom of the water column, depth of the measurement, pH bottom, pH middle, pH surface, electrical conductivity, dissolved oxygen, temperature, and turbidity. WET Lab results that are entered into the water quality database include the site number, orthophosphorus, total phosphorus, total nitrogen, nitrate nitrogen, and total kjeldahl nitrogen. The staff member that enters the data into the water quality database records the date at which the data was entered including their name in the box labeled “data entered by”.

Table 2 depicts water sampling time schedules for all water sampling events that occurred in 2017. Looking at each sample site, the times that sites were sampled occur relatively close to the same time of day. Sampling time frames generally have a 2.5 hour variation between each event with the exception of Site 9, which showed the largest time variation of 3 hours and 37 minutes. In future years, TKPOA Water Quality staff will work to keep sampling timeframes within the same hour at each site throughout the sampling season (e.g., Site 3 will always be sampled between 9:00 and 10:00).

Table 2. Water Sampling Time Tracker 2017

Water Sampling Time Tracker 2017								
Site #	**4/27/2017**	**5/29/2017**	**6/29/2017**	**7/31/2017**	**8/28/2017**	**9/25/2017**	**10/16/2017**	**Greatest Time Variation Between Sampling Events (Hours)**
1	8:35	10:15	10:05	10:15	10:10	9:35	8:30	1:45
2	10:05	10:55	11:00	10:59	11:15	10:20	11:25	1:20
3	8:20	10:00	9:30	9:47	9:50	9:15	8:00	2:00
4	10:22	11:15	11:25	11:30	11:48	10:52	11:58	1:36
5	14:08	13:48	13:30	13:30	13:18	12:12	14:25	2:13
6	11:15	12:00	12:00	12:07	12:31	11:40	13:38	2:23
7	14:20	13:42	13:20	13:41	13:27	12:20	14:45	2:25
8	11:04	11:45	11:45	11:52	12:16	11:20	13:00	1:56
9	13:47	10:47	10:50	10:49	11:00	10:10	10:50	3:37
10	10:27	11:10	11:15	11:22	11:37	10:45	12:18	1:51
11	9:37	10:40	10:40	10:44	10:51	10:05	10:30	1:14
12	9:15	10:25	10:20	10:24	10:38	9:45	9:49	1:23
13	9:30	10:30	10:30	10:30	10:25	9:55	10:10	1:00
14					12:07	11:10	12:50	1:40

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, and Lake Tahoe. A table was then produced with averaged values for each parameter (refer to Table 3, page 23).

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 at which measurements were taken. In general, average pH for bottom, mid-depth, and surface readings in the Main Lagoon, Marina Lagoon, and Lake Tallac were between 8 and 9. Average pH values for Lake Tahoe were between 7 and 8 (Table 3). pH values exceeded 10 several times during the course of the season, reaching a maximum value bottom-depth of 11.22 at Site 5 during the July 31st sampling event. During data collection, pH values greater than 12 were recorded. However, these data points were deemed as outliers (invalid readings) and not included in the averaging of values.

Figure 5 (below) depicts averaged pH values per sampling location. The averaged values are taken from the 7 sampling events that occurred in 2017. The corresponding dot size relates to the pH values, where smaller dots represent lower values, and larger dots represent higher values. Site 2, Site 4, and Site 6 have the highest averaged pH recorded, while Site 1 and Site 13 had the lowest averaged pH values recorded in the 2017 growing season.

Figure 5. 2017 Average pH Data per Site

3.2 Temperature

The average values for the Main Lagoon, Marina Lagoon, and Lake Tallac were 15.14°C, 13.99°C, and 11.81°C, respectively. The minimum temperature in the Main Lagoon was 8.90°C, recorded at Site 9 on April 27th. The maximum temperature was 21.50°C recorded at Site 6 on June 29th. Similarly, the minimum temperature for the Marina Lagoon was 9.90°C, recorded at Site 1 on April 27th. The maximum temperature was 21.25°C, recorded at Site 3 on August 28th. Site 5, in Lake Tallac, had both the minimum and maximum temperature values of 6.30°C and 20.00°C, recorded April 27th and August 28th, respectively.

The minimum temperature recorded for the sample sites in Lake Tahoe (Sites 11, 12, and 13) was 6.80°C, collected April 27th, and the maximum temperature was 20.93°C, collected August 28th. The average temperature value for the three Lake Tahoe sites was 13.16°C.

Figure 6 (below) depicts averaged temperature values per sampling location. The averaged values are taken from the 7 sampling events that occurred in 2017. The corresponding dot size relates to the temperature values, where smaller dots represent lower values, and larger dots represent higher values. Site 3, Site 6, and Site 8 have the highest averaged water temperature, while Site 5 and Site 7 had the lowest averaged values recorded in the 2017 growing season.

Figure 6. 2017 Average Temperature Data per Site

Temperature data loggers ("Hobo Onset" loggers) were used at four locations in the lagoons to record water temperature approximately 10-20 cm from the bottom at one-hour intervals. The data from the loggers is useful in projecting timing in initiation and cessation of plant growth, and for revealing diurnal temperature changes. Due to the limited water movement within the lagoons, stratification of the water column into distinct thermoclines is often expected. However, due to the difference between nighttime and daytime temperatures, diurnal vertical mixing typically occurs. During the day, the water temperatures warm due to the shallow depths of the lagoons. At night, the air temperature drops and cools the surface enough so that it sinks to the bottom of the water column, creating vertical mixing (La Plante 2001, Anderson 2012).

The correlation between macrophyte growth and water temperature is well documented (Anderson Personal Communication 2017) and this data will be useful in planning management activities in the Tahoe Keys. As water temperature increases, the rate at which aquatic macrophytes grow also increases. This is a direct and positive correlation between water temperature and aquatic plant growth. Typically, rapid growth begins when temperatures exceed 10°C and continues to increase with rising temperatures (Smith et al. 1990, Lars Anderson personal communication 2017).

The temperature loggers were placed at the following locations: the entrance to the West Channel, the entrance to the East Channel, two private homeowner docks, and the mesocosm tanks (Figure 7). These locations were chosen to generally represent water temperatures near the source (channels) of incoming spring runoff water into the Keys lagoons, as well as typical sites away from the channels in the Main and Marina lagoons. The pattern of temperatures between the logger stations can also indicate how the sites may be linked hydraulically, or whether the temperature profiles are independently driven.

Figure 7. Locations of Temperature Loggers for 2017

Figure 8 (below) shows temperatures at the West Channel throughout the harvesting season between the latter part of May to the end of October. Temperatures of the water column begin to rise above 15°C towards the beginning of June and continue to rise until the middle of August when air temperature begins to cool, affecting water temperature. A cool storm front in early June caused a steep decline in temperature in the channel and in all stations nearly simultaneously (see Figures 8, 9, 10, and 11). This pattern matches the growing season of aquatic macrophytes between late May and late August.

Figure 8. West Channel 2017

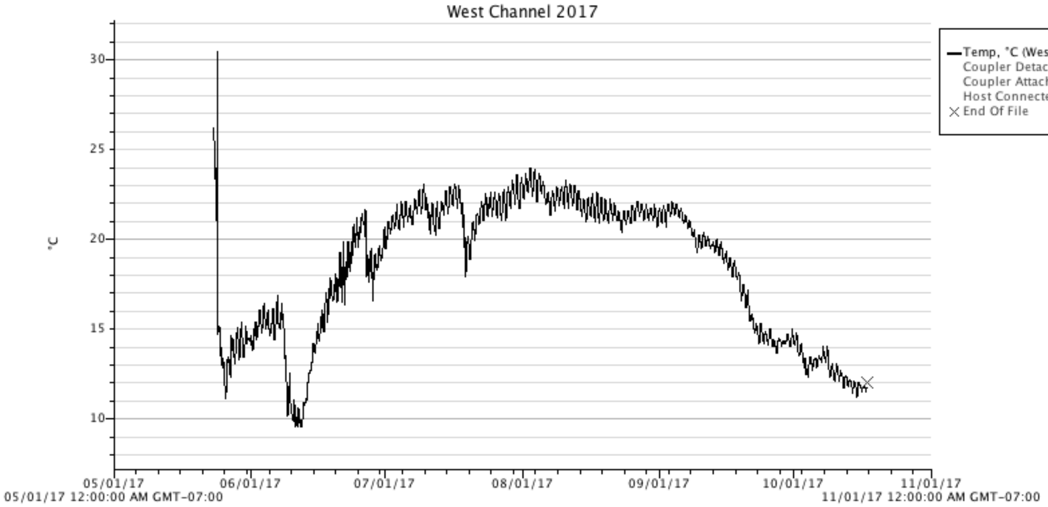


Figure 9 (below) depicts the water temperature in the entrance of the East Channel between the latter part of May until the end of October. Similar to Figure 8, Figure 9 shows an increase in temperature towards the beginning of June where the temperatures reaching maximum levels occur in the first week of August. The temperature can be seen to decrease towards the end of August.

Figure 9. East Channel 2017

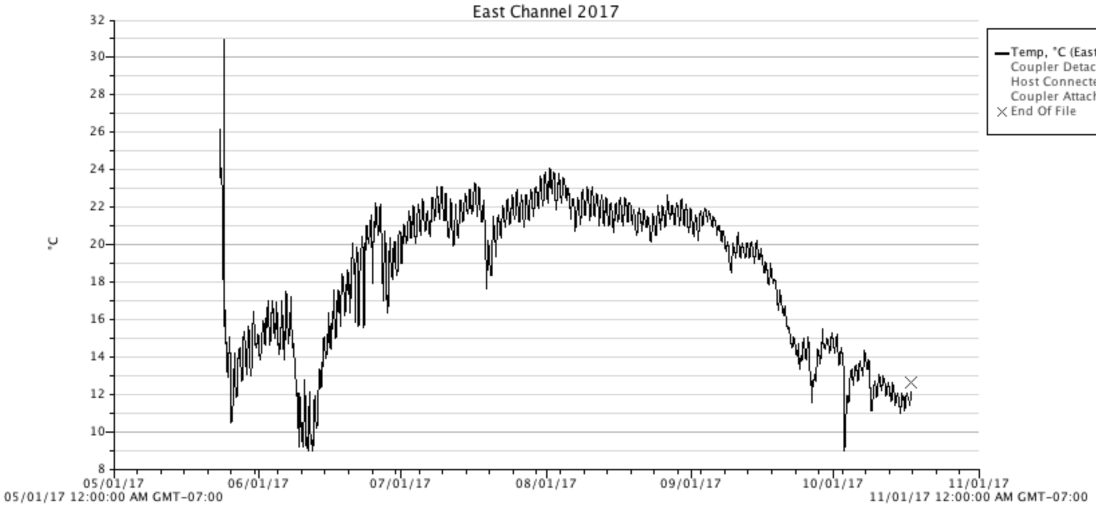


Figure 10 (below) shows temperature data from a homeowner's dock located inside the Marina Lagoon. This figure shows a steady temperature increase from the middle of June until August. This temperature data logger was apparently taken or became detached from its tether in early August, so there is no data available after that date.

Figure 10. Homeowner Dock inside Marina Lagoon

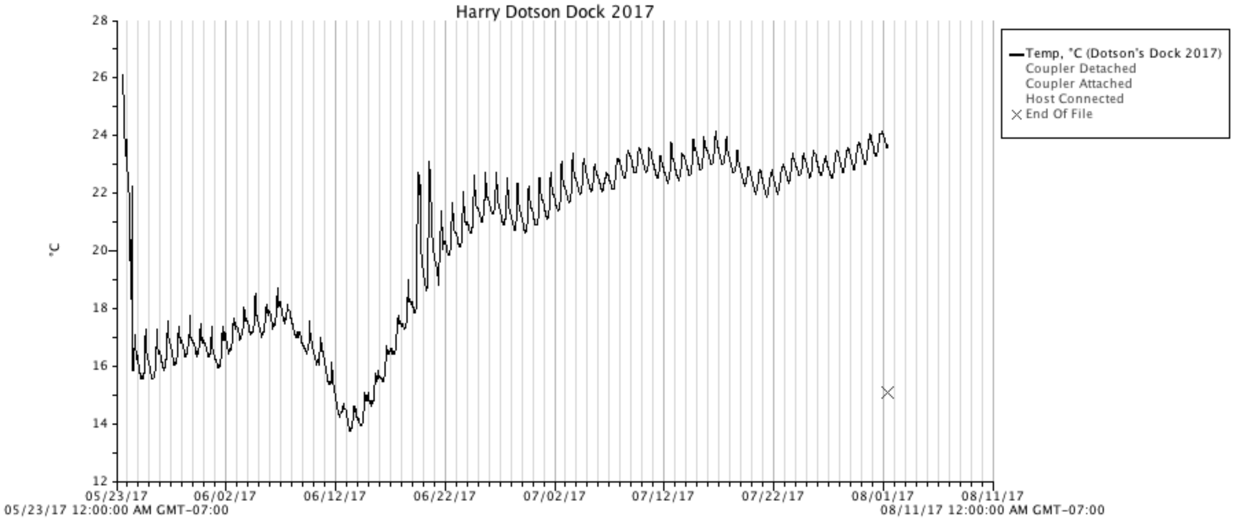


Figure 11 (below) depicts temperature data from another homeowner's dock located inside the Main Lagoon. Like the other sites, increased temperature changes can be seen in the latter part of June. Temperature continued to increase until the first week of August where it is considered to be maximal, and began to fall as air temperature for the Tahoe area began to decrease.

Figure 11. Homeowner's Dock inside Main Lagoon

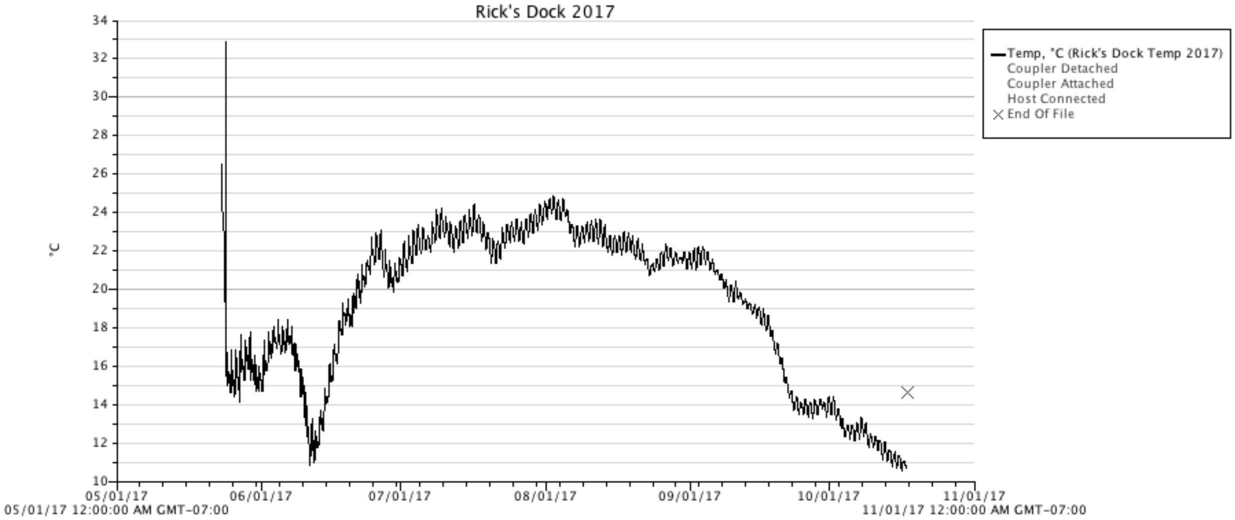


Figure 12 (below) shows the temperature data for the mesocosm tanks for 2017. The mesocosm tanks are an isolated system, with daily flows of cooler water from Lake Tallac; Figure 12 temperature data reflects this. There are greater daytime and nighttime temperature differences due to the isolation of water in a mesocsom tank and their shallow water levels (approximately 24 inches deep). However, this range spanned the optimal growing temperatures for macrophytes and biomass was produced throughout the experiment in nearly all of the untreated control plants.

Figure 12. Mesocosom Tank 2017

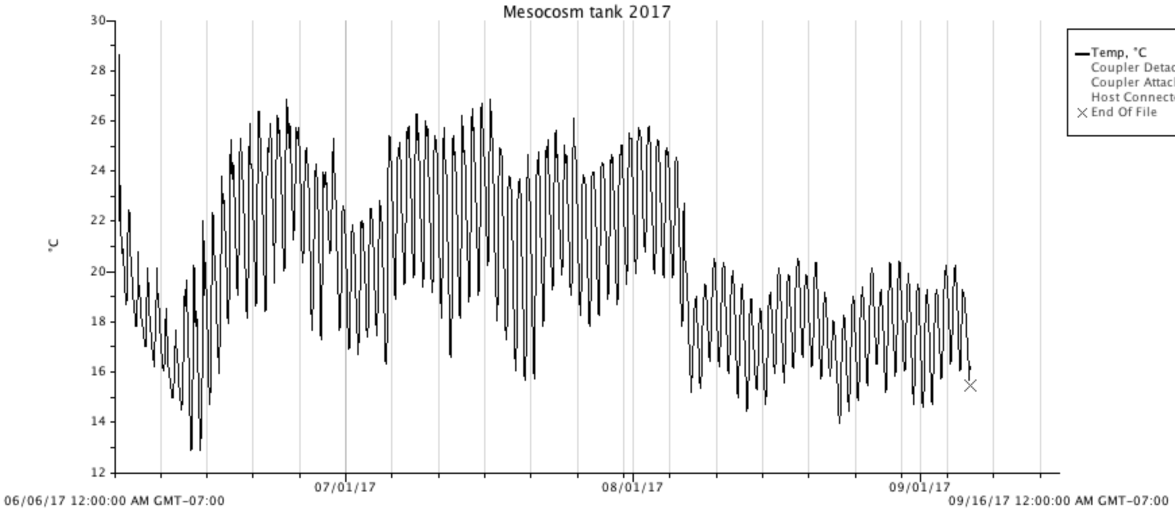


Figure 13 (below) depicts a hydroacoustic data scan that measures biomass and biovolume cover of the channels in the Tahoe Keys Main Lagoon. In this figure, color coordination shows the percentages of macrophyte cover, where red shows a greater amount of cover, green a medium amount of cover, and blue a lesser amount of cover. This scan is from early August when water temperatures are recorded to be greatest throughout the growing season. Averaged water temperatures for the month of August were recorded to be 21°C.

Figure 13. Hydroacoustic Scan August 2017

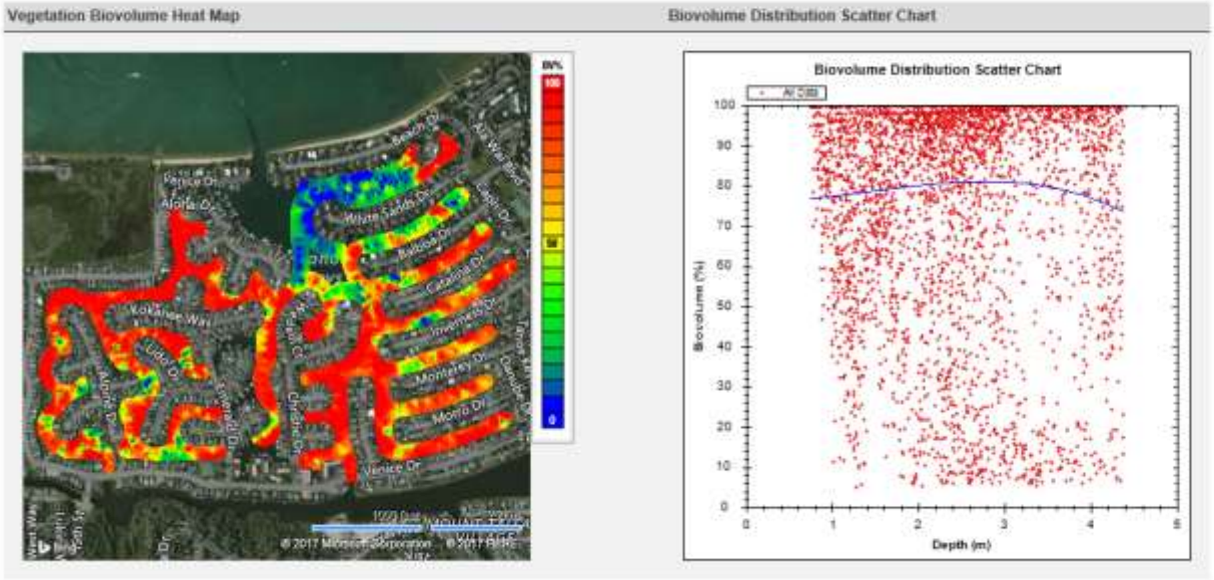
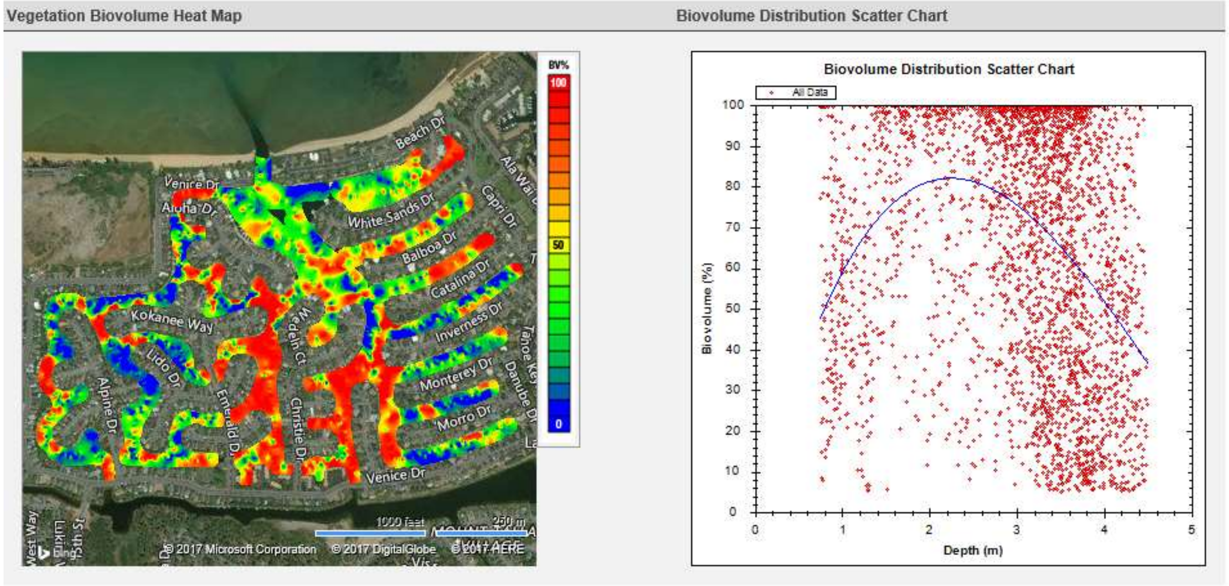


Figure 14 (below) depicts the hydroacoustic data scans for the early part of October 2017. This scan was taken when water temperatures in the Lagoon were among some of the lowest during the entirety of the growing season. Averaged recorded temperatures for the month of October were 10.6°C. As water temperature begins to decrease, the percent biomass observed begins to decrease.

Figure 14. Hydroacoustic Scan October 2017



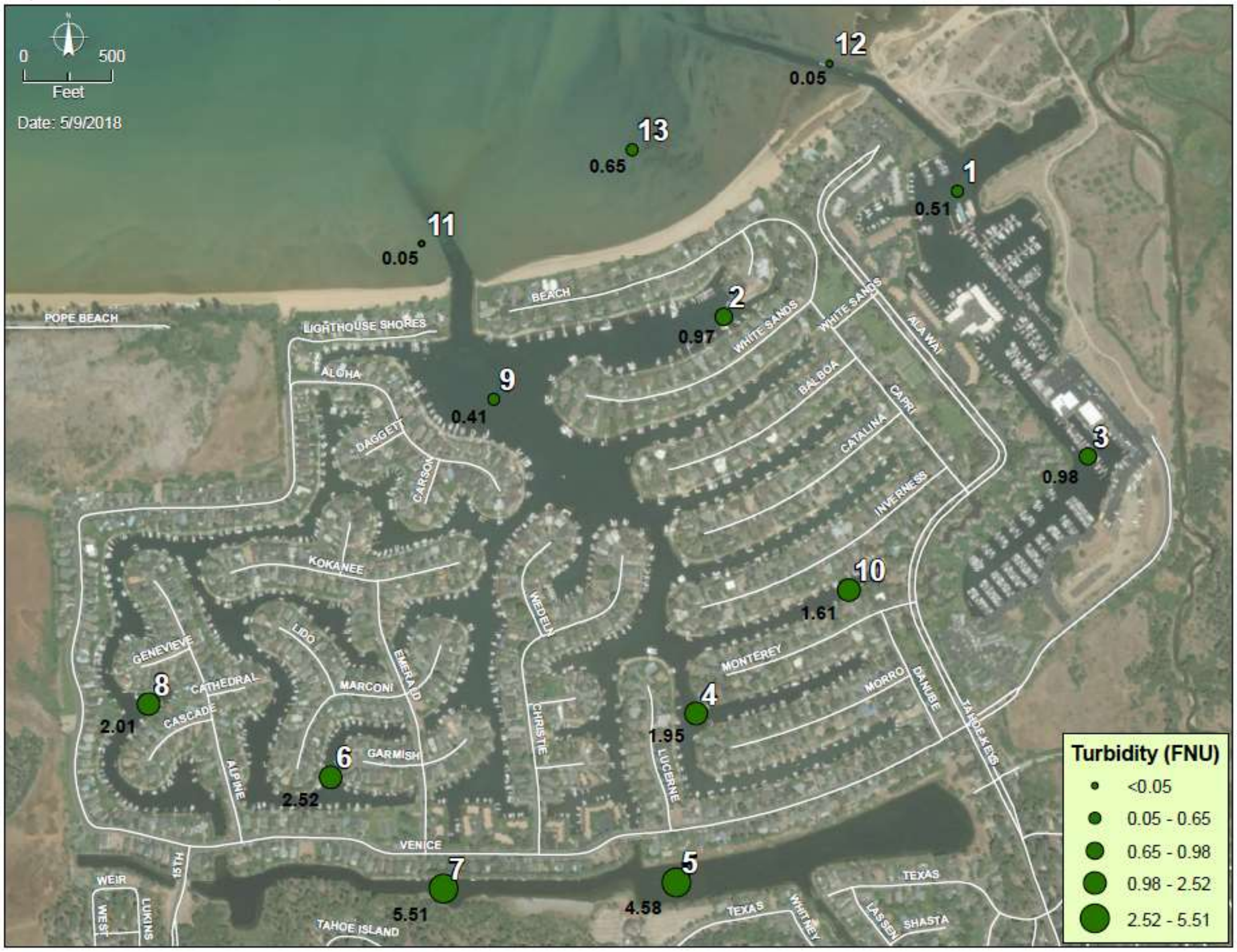
3.3 Turbidity

The average values for the Main Lagoon and the Marina Lagoon of the Tahoe Keys were below 1.70 FNU, ranging from 0.92 to 1.61 FNU. The average turbidity value for Lake Tallac was 4.65 FNU for this years' harvesting season. Minimum values for the Main Lagoon, Marina Lagoon, and Lake Tallac were -0.10, -0.10, and 0.20 FNU, respectively, while the maximum values logged were 5.40, 3.50, and 22.10 FNU, respectively. The highest recorded value, 22.10 FNU was recorded at Site 7 on June 29th. The averaged value for the three Lake Tahoe sites was 0.24 FNU. The minimum value was -0.30 FNU while the maximum value was 1.60 FNU.

Many turbidity sensors require a specific distance from the face of the sensor area to the bottom of the calibration cup in order to avoid interference from the cup itself during the calibration process. If an improper distance between the face of the sensor and the bottom of the calibration cup occurs, it will result in higher offsets during the calibration process because the sensor will see the bottom of the cup as turbid. As a result, this often contributes to a range of negative turbidity readings in the field especially in low turbidity environments (McDermand 2017). The negative values that are seen in the 2017 sampling year are primarily found in Lake Tahoe proper sampling sites where turbidity FNU is expected to be close to zero. A slight calibration offset is likely contributing to the negative turbidity readings recorded in 2017. In 2018, TKPOA Water Quality staff will take greater care in the calibration of the turbidity sensor to help reduce the negative values. The negative values that were recorded in 2017 were at sites where turbidity was expected to be at or slightly above zero, so these negative values are not believed to have much effect on the accuracy of the data set.

Figure 15 (below) depicts averaged turbidity values per sampling location. The averaged values are taken from the 7 sampling events that occurred in 2017. The corresponding dot size relates to the turbidity values in FNU, where smaller dots represent lower values, and larger dots represent higher values. Site 5 and Site 7 have the highest averaged turbidity readings, while Site 11 and Site 12 had the lowest averaged values recorded in the 2017 growing season.

Figure 15. 2017 Average Turbidity Data per Site



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 with average TP values for the Main Lagoon, Marina Lagoon, and Lake Tallac at 0.043, 0.024 and 0.033 mg/L, respectively. The minimum TP values were 0.011, 0.012, and 0.019 mg/L, respectively, while the maximum values logged were 0.4, 0.052, and 0.046 mg/L, respectively.

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[1] 1 mg/L = 1 ppm

The averaged TP value for the three Lake Tahoe sites was 0.026 mg/L. The minimum value was 0.011 mg/L, while the maximum value was 0.074 mg/L.

Figure 16. 2017 Average Total Phosphorus Data per Site

Figure 16 (above) depicts averaged total phosphorus levels per sampling location. The averaged values are taken from the 7 sampling events that occurred in 2017. The corresponding dot size relates to the total phosphorus levels in mg/L, where smaller dots represent lower values, and larger dots represent higher values. Site 4 and Site 8 had the highest averaged total phosphorus levels, while Site 9, Site 11, and Site 12 had the lowest averaged values recorded in the 2017 growing season.

3.5 Nitrogen

The TN average values for the Main Lagoon, Marina Lagoon, and Lake Tallac were 0.60, 0.81, and 0.53 mg/L, respectively. The minimum value for the Main Lagoon was 0.22 mg/L while the maximum value was 1.6 mg/L. For the Marina Lagoon, the minimum value was 0.23 mg/L while the maximum value was 2.5 mg/L. Lake Tallac’s minimum value was 0.23 mg/L and the maximum value was 0.83 mg/L. The sites located outside of the Tahoe Keys, in Lake Tahoe, had values below the detectable limit except at Site 13. On August

28th, 0.24 mg/L was detected, but was below the detectable limit during all other sampling events for that site.

Figure 17 (below) depicts averaged total nitrogen levels per sampling location. The averaged values are taken from the 7 sampling events that occurred in 2017. The corresponding dot size relates to the total nitrogen levels in mg/L, where smaller dots represent lower values, and larger dots represent higher values. Site 1 had the highest averaged total nitrogen levels, while Site 11 and Site 12 had the lowest averaged values recorded in the 2017 growing season.

Figure 17. 2017 Average Total Nitrogen Data per Site

3.6 Dissolved Oxygen

The average values for the Main Lagoon, Marina Lagoon, and Lake Tallac were 10.22 ppm, 9.89 ppm, and 4.28 ppm respectively. The minimum DO value recorded in the Main Lagoon was 1.12 ppm. The maximum DO value recorded in the Main Lagoon was 15.45 ppm. Similarly, the minimum and maximum DO values for the Marina Lagoon were 7.59 ppm and 13.26 ppm, respectively. In Lake Tallac, the minimum and maximum recorded DO values were 0.71 ppm and 9.79 ppm, respectively.

The minimum DO value recorded for the sample sites in Lake Tahoe (11, 12, and 13) was 7.65 ppm and the maximum was 13.28 ppm. The averaged value for the three Lake Tahoe sites was 9.72 ppm.

Figure 18 (below) depicts averaged dissolved oxygen levels per sampling location. The averaged values are taken from the 7 sampling events that occurred in 2017. The corresponding dot size relates to the dissolved oxygen levels in ppm, where smaller dots represent lower values, and larger dots represent higher values. Site 2 and Site 4 have the highest averaged dissolved oxygen readings, while Site 5 had the lowest averaged levels recorded in the 2017 growing season.

Figure 18. 2017 Average Dissolved Oxygen Data per Site

Table 3. Averaged Water Quality Results 2017

	Main Lagoon				Marina Lagoon			
Measurement	Avg	Min	Med	Max	Avg	Min	Med	Max
pH - bottom	8.4	6.95	7.65	10.6	8.08	6.7	7.51	10.03
pH - mid	8.51	6.92	7.89	10.73	8.35	7.08	7.91	10.07
pH - surface	8.61	6.91	7.86	11.05	8.26	6.93	8	9.85
SPC (µs/cm)	99.09	70	99	145.5	89.42	84.2	94.9	112.2
DO (ppm)	10.22	1.12	10.63	15.45	9.89	7.59	10	13.26
Temp (^{0}C)	15.14	8.9	13.9	21.5	13.99	9.9	14.1	21.25
Turbidity (FNU)	1.62	-0.1	1	5.4	0.92	-0.1	0.5	3.5
Orthophosphorus	0.015	0.01	0.014	0.023	0.01	0.01	0.01	0.011
Total Phosphorus	0.043	0.011	0.031	0.4	0.024	0.012	0.022	0.052
Total Nitrogen	0.596	0.22	0.55	1.6	0.812	0.23	0.49	2.5
Nitrate	ND	ND	ND	ND	ND	ND	ND	ND
Nitrite	ND	ND	ND	ND	ND	ND	ND	ND
Kjeldahl Nitrogen	0.567	0.21	0.5	1.6	0.811	0.22	0.49	2.5

	Lake Tallac				Lake Tahoe			
Measurement	Avg	Min	Med	Max	Avg	Min	Med	Max
pH - bottom	8.25	6.46	7.07	11.22	7.77	7.19	7.88	8.25
pH - mid	8.18	6.55	7.08	10.9	7.79	7.25	7.83	8.3
pH - surface	8.18	6.57	7.48	10.5	7.73	7.13	7.82	8.24
SPC (µs/cm)	196.08	152.2	210.6	266	79.96	44.2	90	97
DO (ppm)	4.28	0.71	4.01	9.79	9.72	7.65	9.77	13.28
Temp (^{0}C)	11.81	6.3	11.65	20	13.17	6.8	13.9	20.93
Turbidity (FNU)	4.65	0.2	2.6	22.1	0.24	-0.3	0.1	1.6
Orthophosphorus	0.013	0.011	0.013	0.015	0.016	0.012	0.014	0.02
Total Phosphorus	0.033	0.019	0.035	0.046	0.026	0.011	0.019	0.074
Total Nitrogen	0.532	0.23	0.525	0.83	0.24	ND	ND	0.24
Nitrate	ND	ND	ND	ND	ND	ND	ND	ND
Nitrite	ND	ND	ND	ND	ND	ND	ND	ND
Kjeldahl Nitrogen	0.53	0.23	0.52	0.82	0.24	ND	ND	0.24

4.0 DISCUSSION

The water quality parameters pH, temperature, phosphorus, nitrogen, dissolved oxygen 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 2017 growing season.

Box-and-Whisker Plots are used to show a dataset distribution. The illustrated box in Figure 19 represents the upper quartile, median, and lower quartile for the dataset. Extending arms from the box represent the maximum and minimum dataset values.

Figure 19. Box-and-Whisker Plot

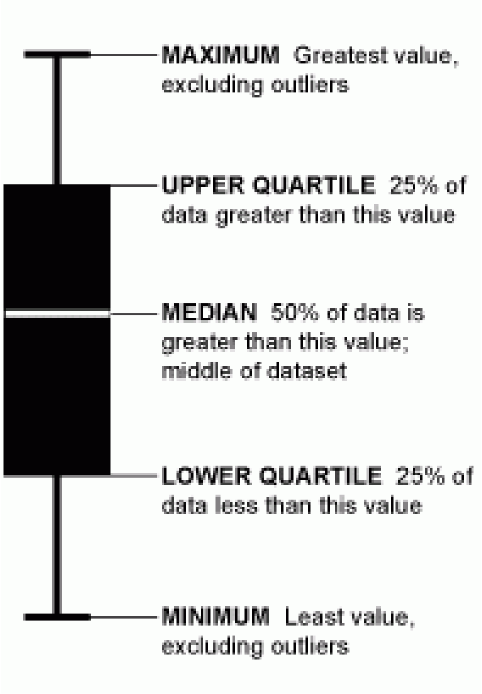

Image property of FlowingData.com ©2007-2016

An outliers review was conducted on pH and turbidity values as several of the recorded measurements were far outside the normal range of expected values. The averages given in the following sections were calculated after removal of the outliers. Of the 219 total pH samples taken during the year, 8 were removed from the calculated averages. A full detailed record of collected data values can be found in Appendix C.

4.1 Water Quality Objectives

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 often exceeds the WQO, as shown in Table 4.

Table 4. Tahoe Keys Annual Average Water Quality (2007 – 2017[2,3])

Year	Total Nitrogen (TN), mg/L	Total Phosphorous (TP), mg/L	Total Dissolved Solids (TDS) (mg/L)	pH	Turbidity (NTU)
2007	0.28	0.030	74	9.16	0.75
2008	0.15	0.033	84	7.67	1.46
2009	0.33	0.043	87	9.15	7.97
2010	0.20	0.019	101	8.87	1.20
2011	0.18	0.023	71	8.31	1.72
2012	4.57	0.019	no data	8.88	no data
2013	0.24	0.026	81	7.97	1.88
2016	0.397	0.025	25.8	9.12	1.56
2017	0.647	0.033	31.39	7.84	2.27
WQO	**0.15**	**0.008**	**60**	**7.0-8.4**	**3.00**

As stated in the water quality objectives, in Lake Tahoe, pH shall not be depressed below 7.0 nor raised above 8.4. The turbidity readings in Lake Tahoe shall not exceed 3 Nephelometric Turbidity Units (NTU). In addition, turbidity shall not exceed 1 NTU in shallow waters not directly influenced by stream discharges. Total Nitrogen should not exceed an average yearly value of 0.15 mg/L. Total Phosphorous should not exceed an average yearly value of 0.008 mg/L.

4.2 pH

The measure of acidity or alkalinity of water is called pH, where pH 7 is considered neutral. Values below 7 are considered acidic and values above 7, basic. 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).

Findings for pH from the 2017 sampling season are consistent with the Washington State Department of Ecology's statement. The pH readings recorded near the bottom of the water column were generally found to be more basic than that of the pH taken at mid-depth and surface levels. The Marina Lagoon was the only Lagoon which showed pH readings more acidic at the bottom of the water column than that of pH taken at mid-depth and surface depths. Figures 20, 21, and 22 (below) show pH measurements at the three recorded depths.

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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).

[3] Reliability of this data may be uncertain due to unknown methods and location of the sampling that took place from 2007-2013. Data taken in 2016 and 2017 followed strict sampling protocols and data was analyzed to remove outliers from the data set.

Figure 20. Box-and-Whisker Plot for Bottom pH

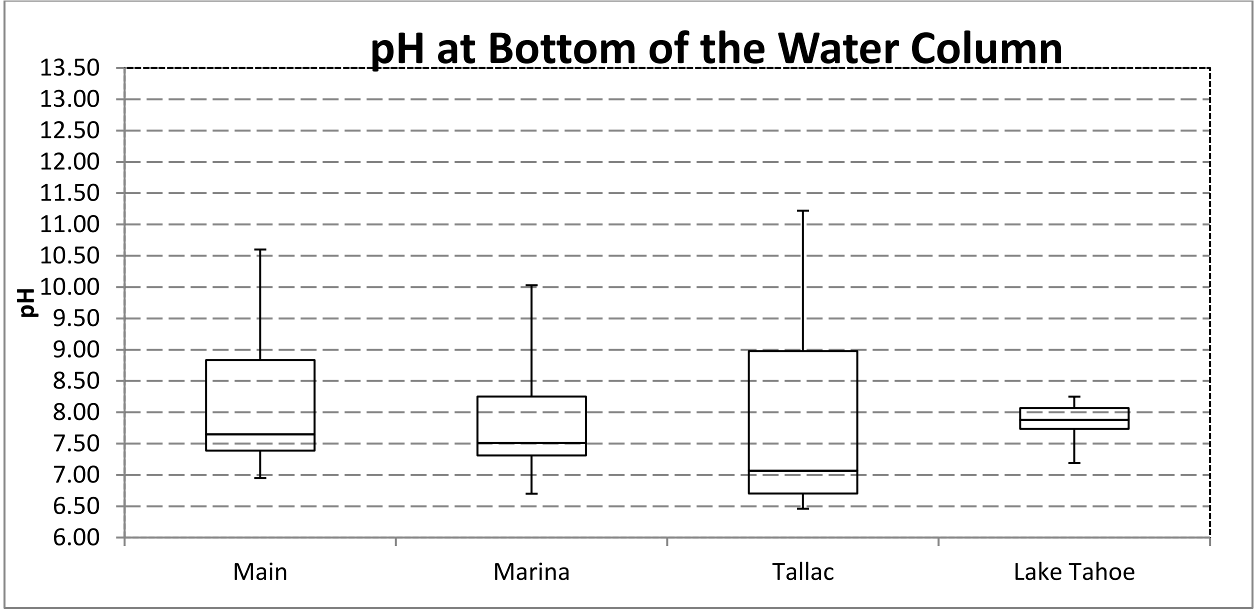


Figure 21. Box-and-Whisker Plot for Middle pH

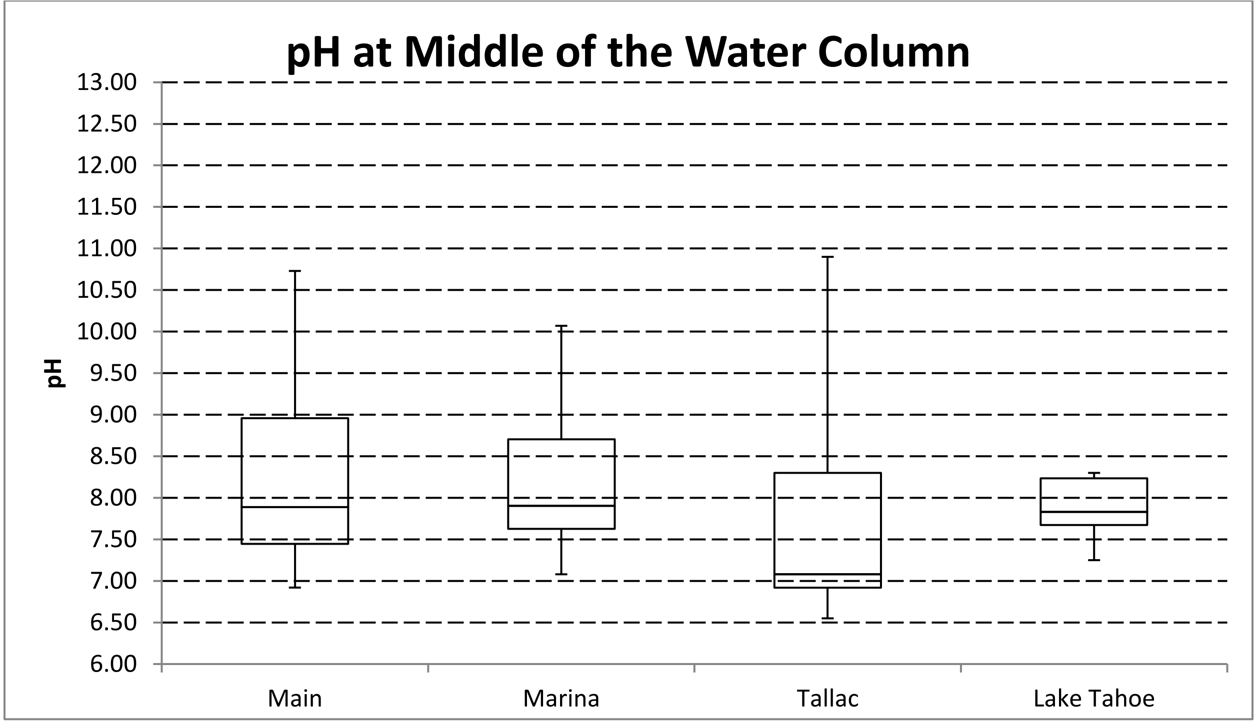
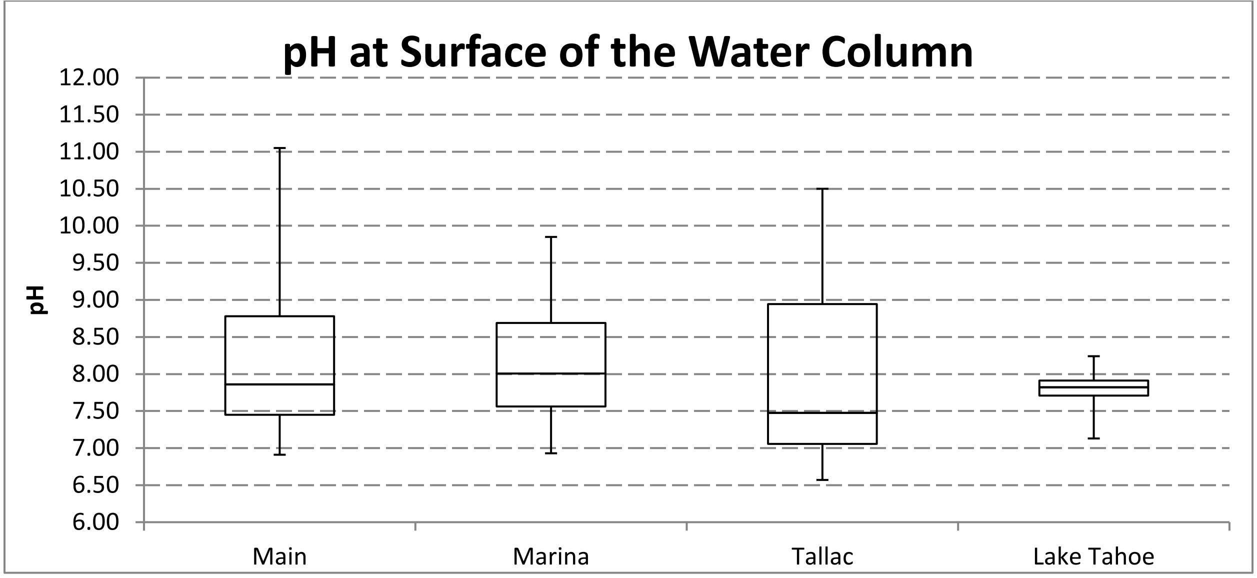


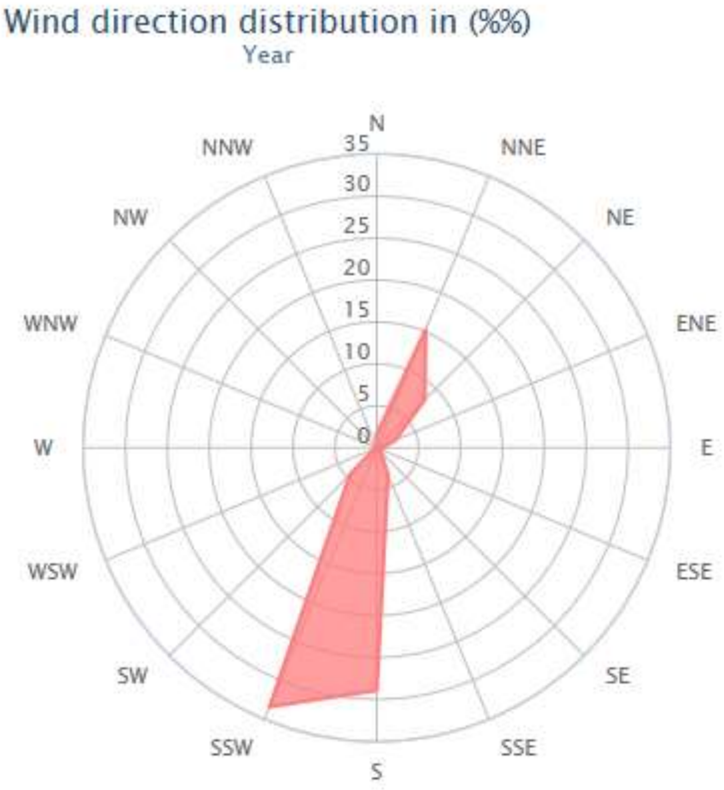
Figure 22. Box-and-Whisker Plot for Surface pH



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. This could explain why pH levels observed at the bottom of the water column at the Marina Lagoon are more acidic than that of the mid-depth and surface pH levels.

Figures 24 and 25 (below) illustrate the difference of both pH and temperature throughout the course of the sampling season. Site 9 (Figure 24) represents an open water area in the Main Lagoon, where mixing and flow of water into and out of the lagoon from Lake Tahoe occurs regularly due to close proximity, spring inflow from the lake during snowmelt runoff, summer outflow to the lake during lake elevation drops, and wind patterns. Based off of statistics on observations taken between 11/2006 - 01/2018 daily from 7am to 7pm from windfinder.com (Figure 23 below), 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, thermal stratification (between Lake Tahoe and the lagoons) and wind can greatly influence channel exchange (La Plante 2001).

Figure 23. Wind Rose Data from 11/2006-01/2018



In the following figures below (24-27 and 29), temperature data for the month of July is missing due a specific conductance sensor failure in the YSI DDS Pro (specific conductance and temperature are measured by a two-in-one sensor).

Figure 24. Open Water Area in Main Lagoon

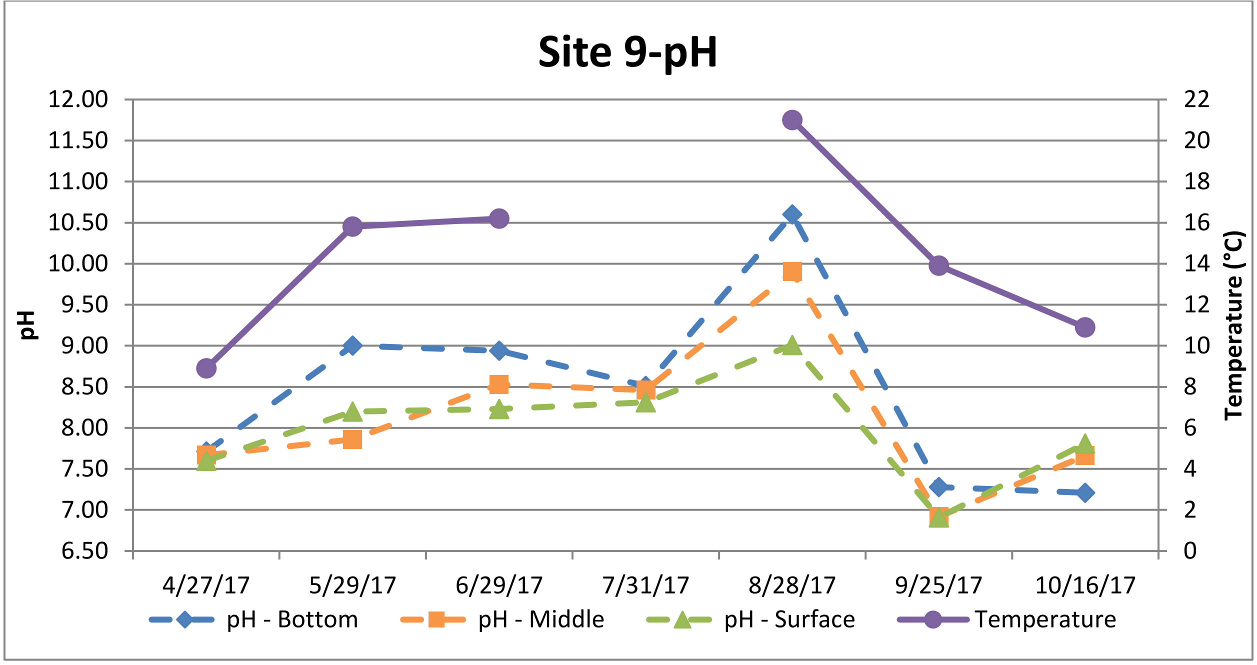
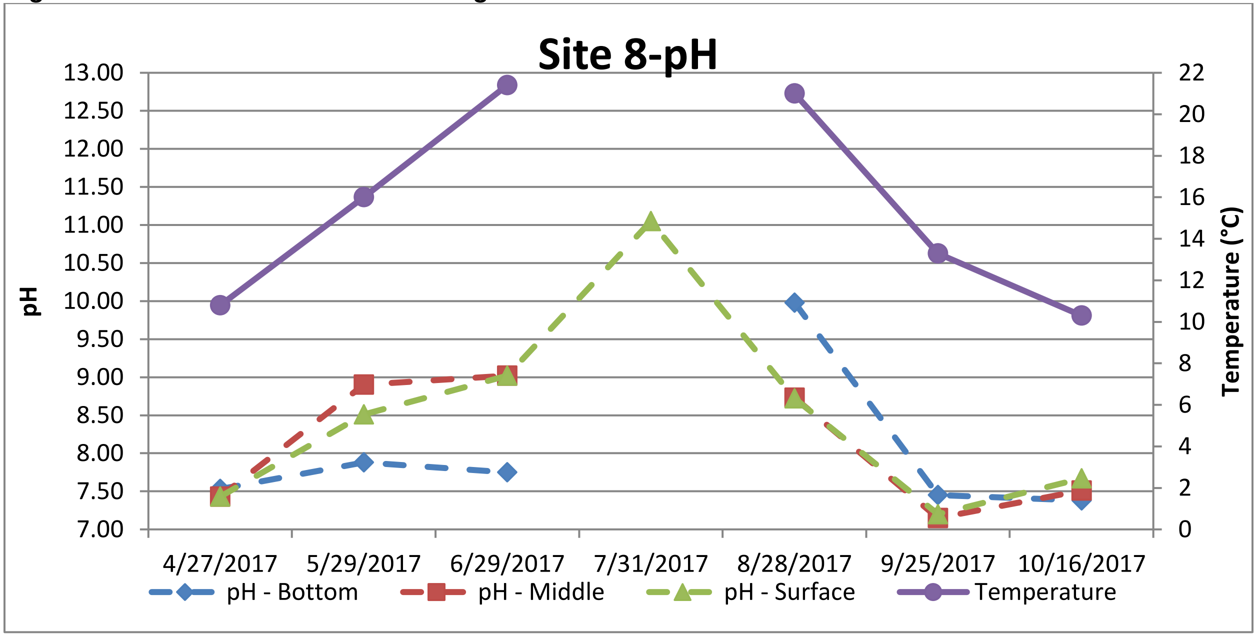


Figure 25 (below) depicts temperature and pH values for Site 8. This site represents a dead-end cove in the Main Lagoon, located near the southwest end of the Tahoe Keys. This site is relatively shallow (between 9’ and 15’), in a sheltered area, typically warmer due to greater light penetration.

Figure 25. Dead-End Cove in Main Lagoon



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 slightly more basic than that of the open water area.

Figure 26 (below) 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 vary throughout the harvesting season. Similar to pH readings taken during the 2016 sampling, from April through July the pH readings at the bottom of the water column were slightly more acidic than those readings at mid-depth and surface levels of the water column. However, in August 2017, although pH readings at all depths of the water column become significantly more basic, bottom pH readings for August become dramatically more basic and were observed to be more basic than mid-depth and surface measurements. This differs from 2016 data, which did show an increase in alkalinity but remained more acidic near the bottom of the water column than in mid- and surface readings.

Due to increased biomass during the peak of the growing season, the more basic pH levels are seen when photosynthesis and respiration occur at higher rates. This causes pH levels to be noticeably more basic than found at surface depths due to an increased CO_2 release. Similar to the readings shown in Figure 24, Figure 25 (above) is also representative of an open water area in the Tahoe Keys lagoons and has similar pH and temperature levels.

Figure 26. Marina Lagoon Sampling Site

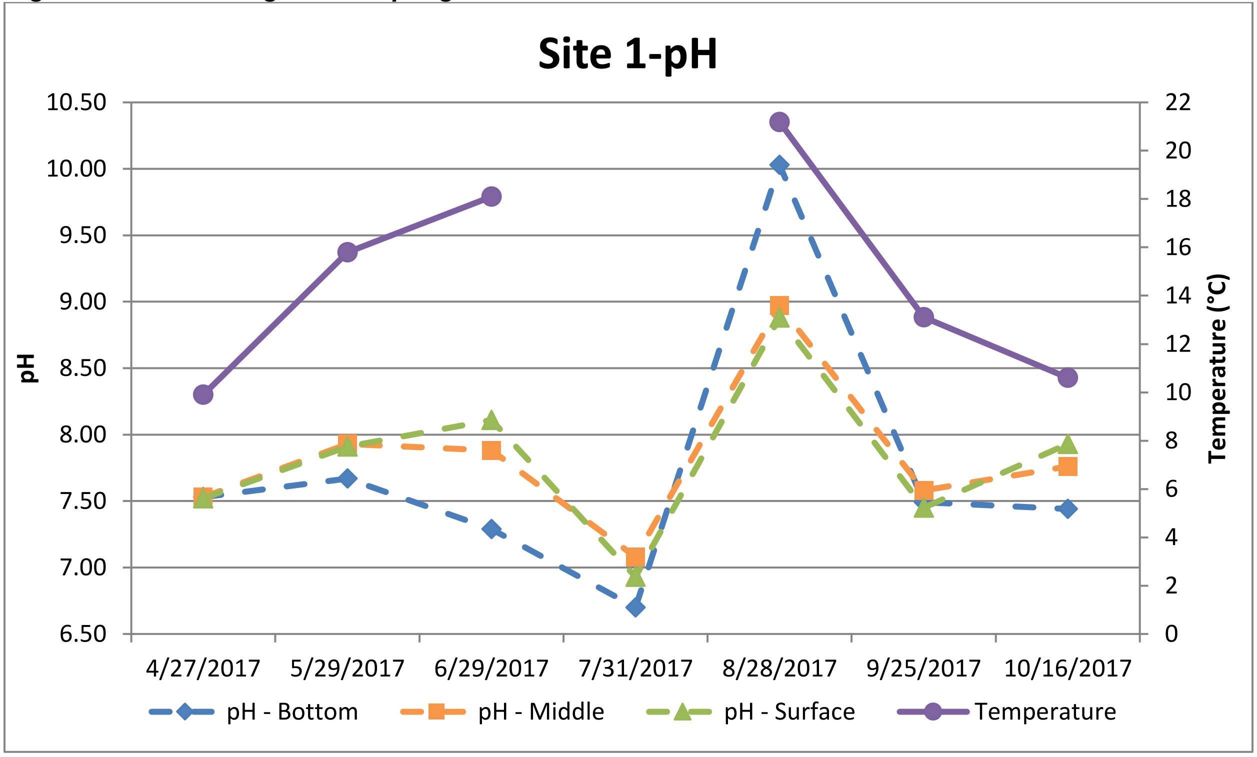
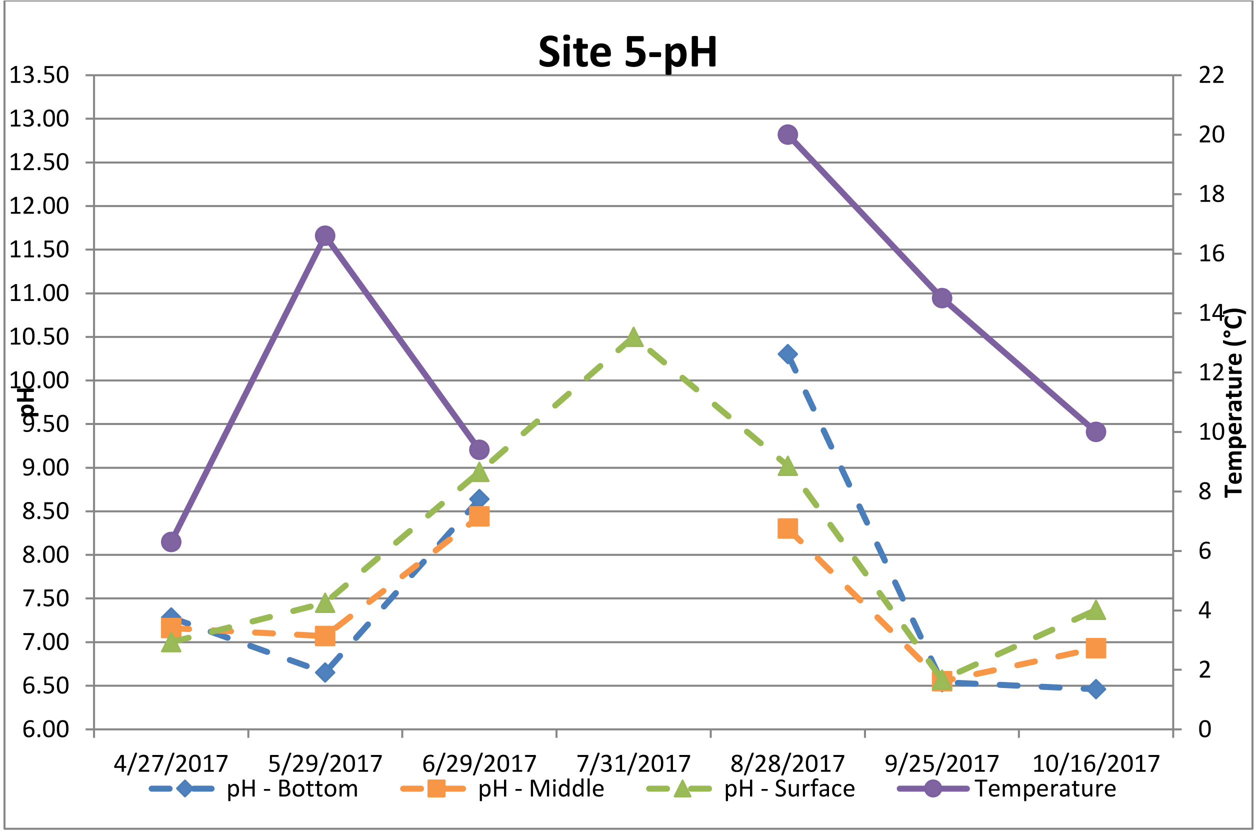


Figure 27 (below) depicts the changes of pH and temperature in Lake Tallac during the course of the 2017 growing season. Surface, mid-depth, and bottom depth pH readings were very similar from April to June before the peak invasive macrophyte growing season began. In August, readings taken near the bottom of the water column were noticeably more basic. Again, this is due to the increased biomass in the peak growing season caused by photosynthesis which increases CO_2 levels.

Averaged pH levels for the Marina lagoon and Lake Tahoe sample sites fall within the pH levels of 7.0-8.4 for water quality objectives set for the Lake Tahoe hydrologic unit. In the Main lagoon, pH levels for the bottom, middle, and surface of the water column are greater than the water quality objectives for Lake Tahoe. Lake Tallac's averaged pH levels all fall within the WQO set for pH.

Figure 27. Lake Tallac Lagoon Sampling Site



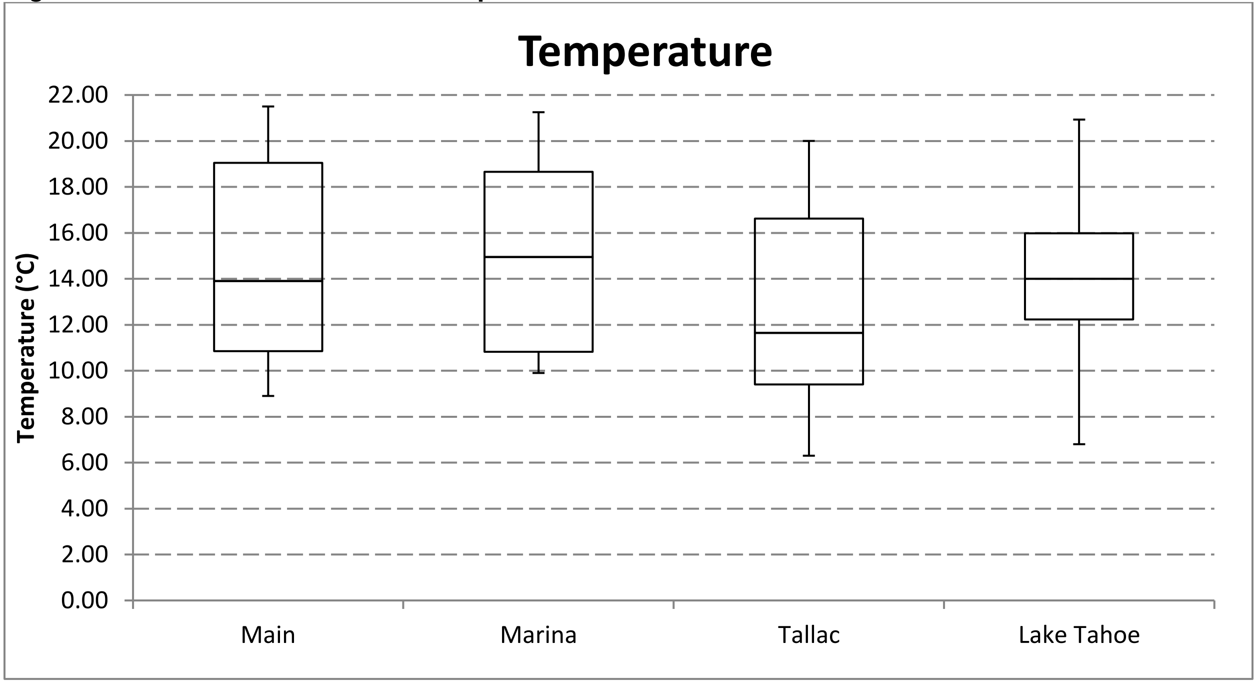
In comparison with 2016 pH average values, the average values determined from the 2017 sampling were more acidic. Some observers suggest that the decrease of pH from 2016 to 2017 may be due in part to the increased water levels during the 2017 sampling season. While this increased water level is believed to have caused the increase in sedimentary phosphorus and ammonia seen in the lagoons (TKPOA 2017d), the dilution effect of water caused a shift towards more neutral pH values (BBC 2014).

4.3 Temperature

Temperature readings from the Tahoe Keys lagoons during the 2017 sampling season 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 12 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. Lake Tallac temperatures fell below Lake Tahoe and the Tahoe Keys lagoons this year likely due to increased levels of storm water and snow melt runoff. Lake Tallac is located directly south of the Tahoe Keys Main lagoon, is hydraulically separated from the Main Lagoon, and receives storm water runoff from urban lands to the south until it fills and overflows into Pope Marsh, which is located directly west of Lake Tallac.

Water quality objectives for Lake Tahoe state that the water temperature in the hypolimnion stratification zone should not exceed 15°C during the summer months. As shown in Figure 28 (below), the average temperatures for the Main lagoon, Marina lagoon, Lake Tallac, and Lake Tahoe this year all fell at or below this threshold set by the WQO.

Figure 28. Box-and-Whisker Plot Temperature



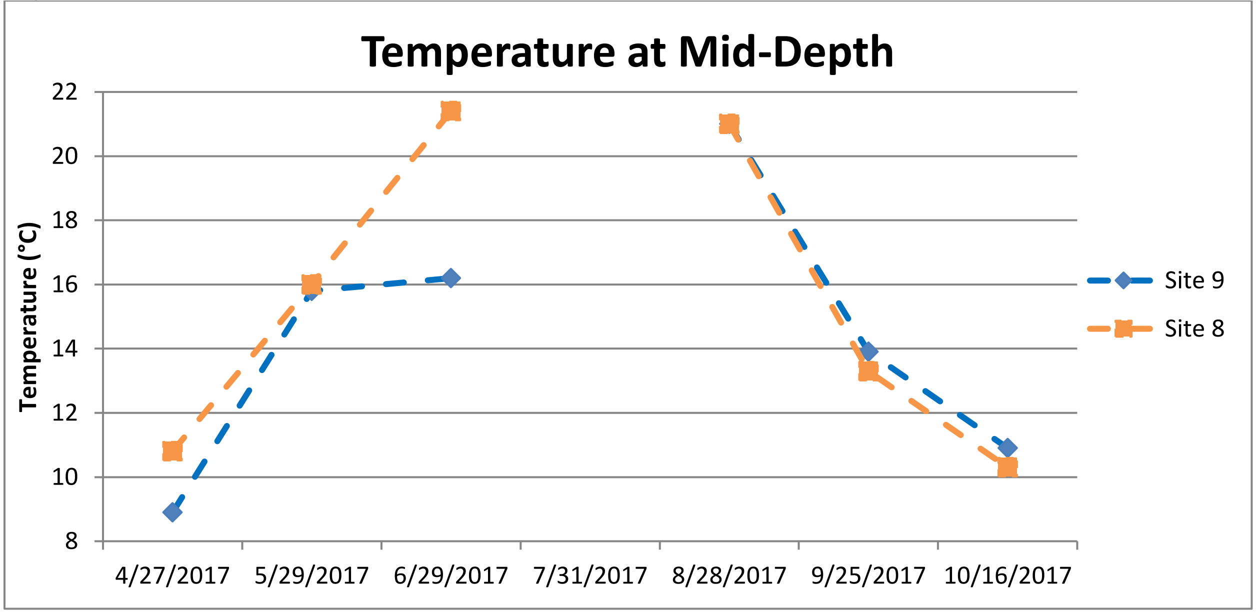
Of the sites located in the Tahoe Keys lagoons, there was a combination of both open water and dead end areas. Open water areas tended to be deeper than dead-end areas and have more opportunity for mixing or inflow of cooler water from the channels connecting the lagoons to Lake Tahoe.

Figure 29 (below) 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 in June when runoff and snow melt is still flowing into Lake Tahoe at a high rate. This difference is likely due to the shallower waters seen at Site 8. Site 9 likely shows lower temperatures in the month of June because it is located near the entrance of the West Channel.

The temperature profiles at all sites measured suggest that, by early June (2017), conditions for initial plant growth occurred and that temperatures/length of day drove accelerated growth throughout July and August. Temperatures declined below optimal growth conditions by the end of September, through the combination of cooling water and reduced day-length. This typically reduces growth and triggers onset of senescence.

The fact that an early June cooling storm and related temperature drop affected all sites simultaneously (Figures 8-11) suggests that even sites some distance away from the West Channel (i.e. the homeowners' docks) responded independently and locally to the atmospheric cooling; not solely as a result of a spike of cooler water entering the lagoon from Lake Tahoe proper. This is important to note because it shows that a singular storm event can have an effect on temperature in the Tahoe Keys Main Lagoon, and also shows that water temperature is not influenced only by water runoff or cooler water entering through the west channel.

Figure 29. Temperature at Mid-Depth



The rapid development of diurnal (diel) changes in temperatures near the bottom at all sites (Figures 8-11) strongly indicates vertical mixing within all parts of the lagoons, and is consistent with prior years' studies where the vertical distribution of Rhodamine WT dye was monitored. From the temperature data collected this year with the HOBO loggers and from the data collected during the 2016 and 2011 Rhodamine WT dye studies, there also appear to be other typical, seasonal temperature patterns as follows:

- During average (or even low) snow-pack/runoff years, the Tahoe Keys is gradually filled with cool Lake Tahoe water throughout spring to mid-summer. The greater the snow pack, the more the Tahoe Keys Lagoons fill, and the longer the inflow continues into the summer season.
- From late May to July, the near- bottom water column temperature rises rapidly, which in turn drives increased aquatic macrophyte growth. This is important because it is the near-bottom temperatures that directly affect aquatic plant growth in early spring.
- Large diurnal changes in air temperature drive vertical mixing of the water column due to dusk-to-dawn cooling that causes sinking of surface water. This mixing is observed most in shallow areas (e.g. 5 ft to 12 ft) (Rhodamine WT dye study 2011).
- Temperatures decline below optimal plant growth levels by mid-September to early October, but still support maintenance of biomass of Eurasian watermilfoil and coontail. Biomass begins to decrease and stays low from November to May.
- Taken together, the optimal control methods for aquatic plants need to be applied in spring to early summer in order to minimize biomass production throughout summer to fall, and then again in fall to stop overwintering of curlyleaf pondweed
- Overall, 2017 temperatures were cooler than those recorded in 2016. In 2016, average temperatures were 17.9°C where in 2017 average temperatures were 15.1°C. That is a difference of 2.8°C and may be due to the increased water levels and later seasonal snowmelt.

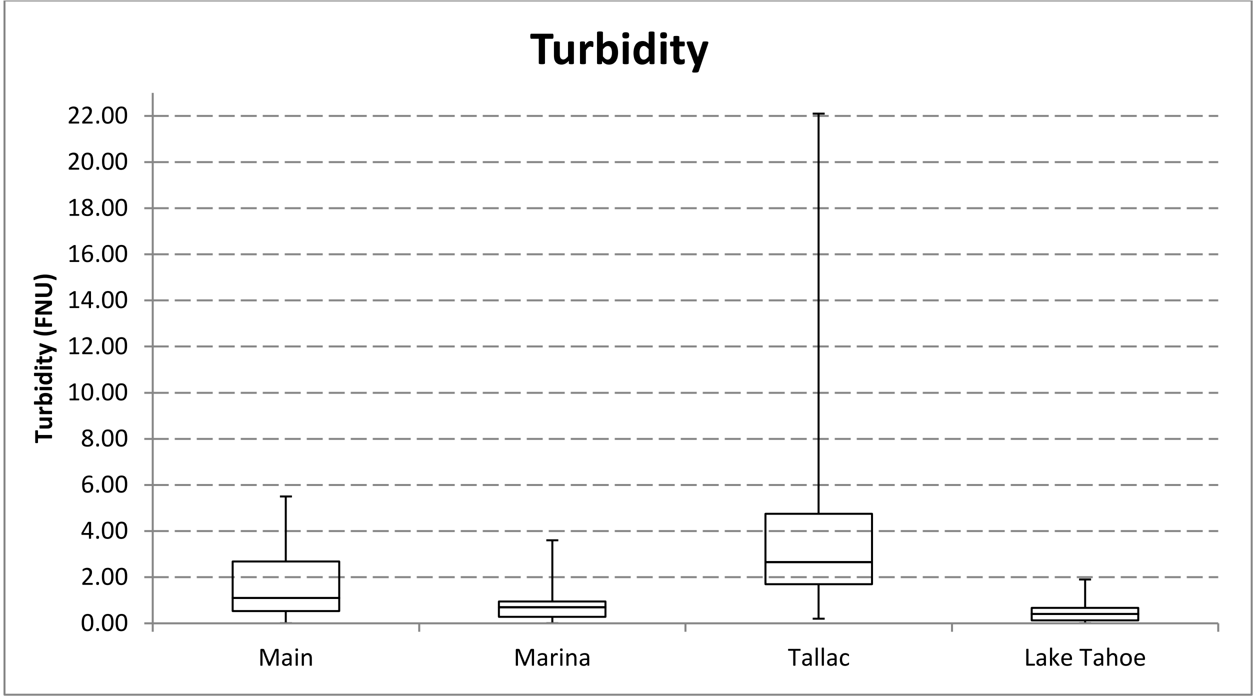
4.4 Turbidity

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 are due to a combination of plant and algae growth during the course of the growing season.

The average turbidity values taken from the Lake Tahoe Sites 11, 12, and 13 were similar from 2016 to 2017 (0.28 FNU in 2016 to 0.24 FNU in 2017). In contrast to 2016 values, the Main Lagoon had higher average turbidity than the Marina Lagoon. This may be in part due to the cyanobacteria bloom that occurred in the lagoons, primarily the Main Lagoon, during August 2017 and that lasted through a majority of September.

In 2016, the average turbidity value for Lake Tallac was greater than that of the Main and Marina lagoons. Similar to prior year readings, samples taken from Lake Tallac during the 2017 sampling season showed higher levels of turbidity (shown in Figure 30 below). Among all the Tahoe Keys Lagoons, Lake Tallac is the only water body where average yearly readings were observed to be above the 3.0 FNU WQO threshold. This may be due to the following: growth of coontail and Eurasian watermilfoil to the surface of the waterbody early in the season; or high levels of stormwater runoff and the associated nutrient inflow from City of South Lake Tahoe neighborhoods, which drain directly into Lake Tallac.

Figure 30. Box-and-Whisker Plot Turbidity



4.5 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, typically absorb necessary nutrients from the water column as they have limited to 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 significantly 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 (MPCA 2007, Water Research Center 2014).

For the 2017 season, TP and TN concentrations exceeded the WQO shown in Table 4 in the Main Lagoon, Marina Lagoon, and Lake Tallac. As shown in Table 3, even the minimum 2017 TP and TN values recorded for all sites in the Tahoe Keys were above the

WQO. The average values of orthophosphate, TP, and TN determined from 2017 season sampling were higher than those recorded in 2016. It is hypothesized that the increase in phosphorus and nitrogen from 2016 to 2017 may be due in part to the increased water level (and associated wetted lagoon perimeters) witnessed during the 2017 sampling season. The drought experienced throughout California impacted the Tahoe Basin and led to the exposure of shoreline in many parts of the Tahoe Keys lagoons. The hypothesis is that the lagoon shorelines collected nutrients while dry, and then released nutrients into the water column following the rise in water level which increased turbidity and settling of suspended particles on the bottom of the water column. Additionally, higher levels of runoff (surface and shallow groundwater) and the associated nutrient inflow could also be responsible for the rise in nutrient concentrations. As described earlier, only Lake Tallac receives substantial storm water inflow, but the Main Lagoon and Lake Tallac are believed to both receive shallow groundwater inflow from up-gradient urbanized areas, which may also be contributing nutrient inflow to these lagoons (USACE 2003).

Figures 31 and 32 (below) illustrate the difference in both nutrient levels and temperature throughout the course of the sampling season. Site 9 (Figure 31) represents an open water area in the Main Lagoon, where net inflow to the lagoon from Lake Tahoe is substantial during spring and early summer (during snowmelt runoff), there is net summer outflow to the lake as lake elevations drop. Seasonal wind patterns can also affect surface hydraulics and water exchanges. Figure 31 shows increased total nitrogen in August when water temperatures rise to their peak levels and net inflow to the lagoon stops from Lake Tahoe. Increased water temperatures and nutrient levels contribute to the accelerated macrophyte growth during the mid-summer season. In the following Figures below (31-34), temperature data for the month of July is missing due a specific conductance sensor failure in the YSI DDS Pro, which also measures temperature as a two-in-one sensor. The sensor was sent to the manufacturer for repairs and was functional by the following month of August.

Figure 31. Site 9 Nutrients

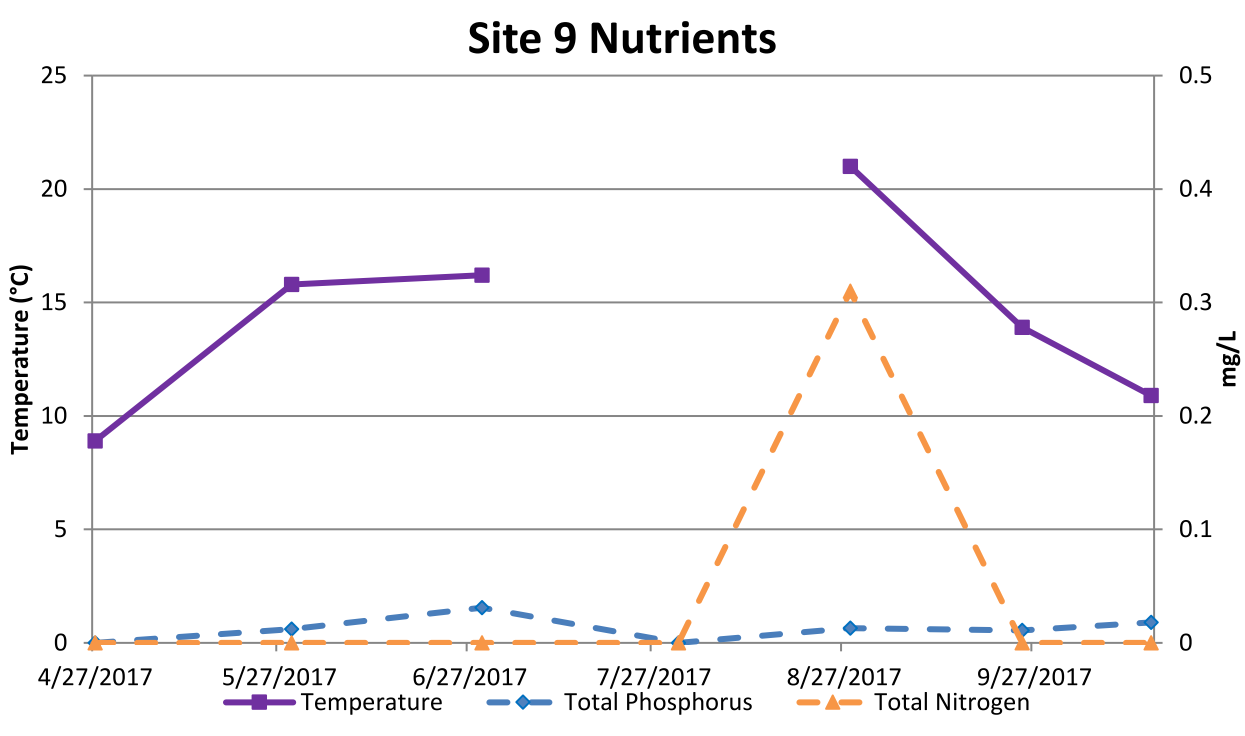


Figure 32. Site 8 Nutrients

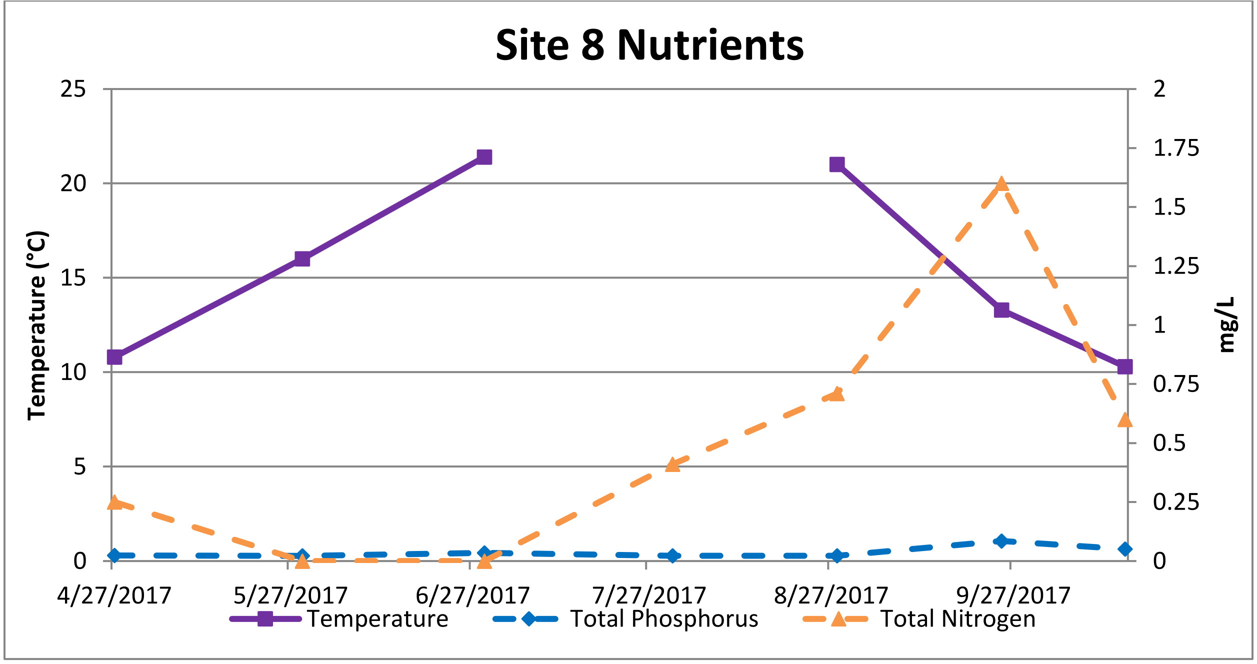


Figure 32 (above) depicts temperature and nutrient concentrations for Site 8. This site represents a dead-end cove in the Main Lagoon, located near the southwest end of the Tahoe Keys. This site is relatively shallow (between 9' and 15'), in a sheltered area, typically warmer due to greater light penetration. As temperatures begin to reach their peak in the beginning of July, total nitrogen levels begin to increase and reach peak concentrations in September. A rapid decrease in total nitrogen concentrations is recorded with a steady decline in water temperature by the end of the growing season in October when invasive macrophyte cessation occurs.

Figure 33. Site 1 Nutrients

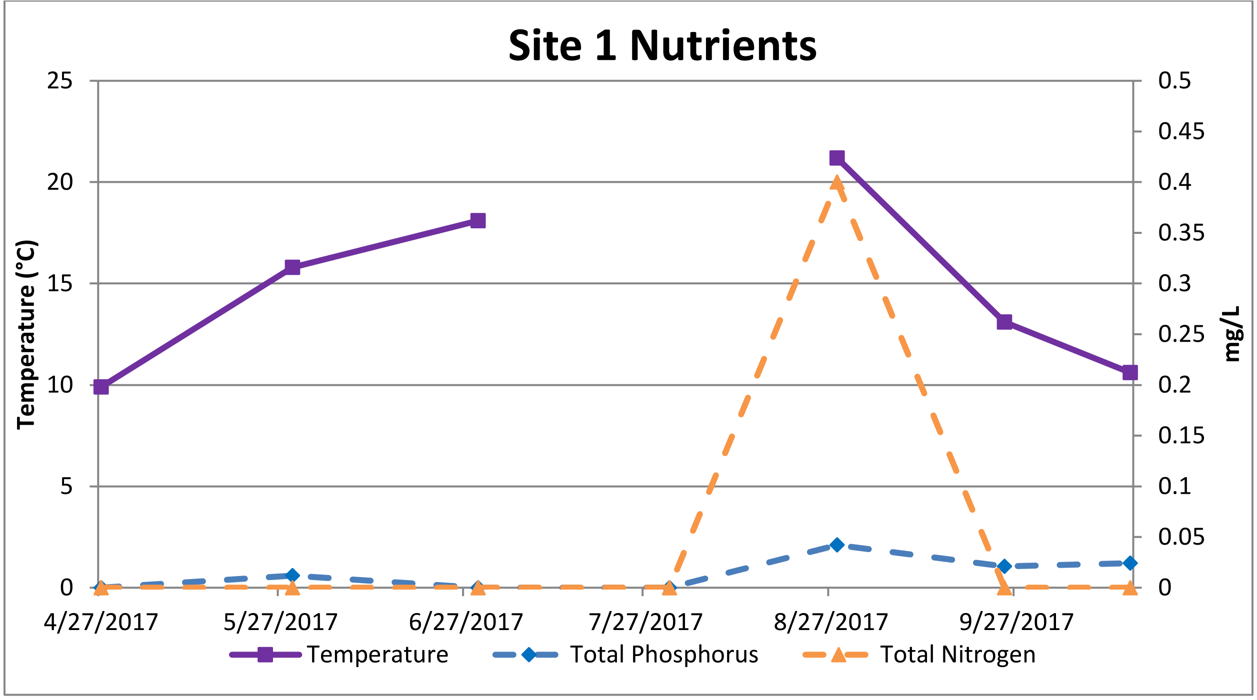


Figure 33 (above) depicts nutrient and temperature variation at Site 1 (located near the mouth of the East Channel) during the course of the sampling season. Nutrient concentration readings were very similar from April to June before the peak invasive macrophyte growing season began. In August, as water temperatures began to increase, both total nitrogen and total phosphorus concentrations show a substantial increase. Again, this is due to increased water temperature levels providing a more prolific habitat for accelerated macrophyte growth.

Figure 34. Site 5 Nutrients

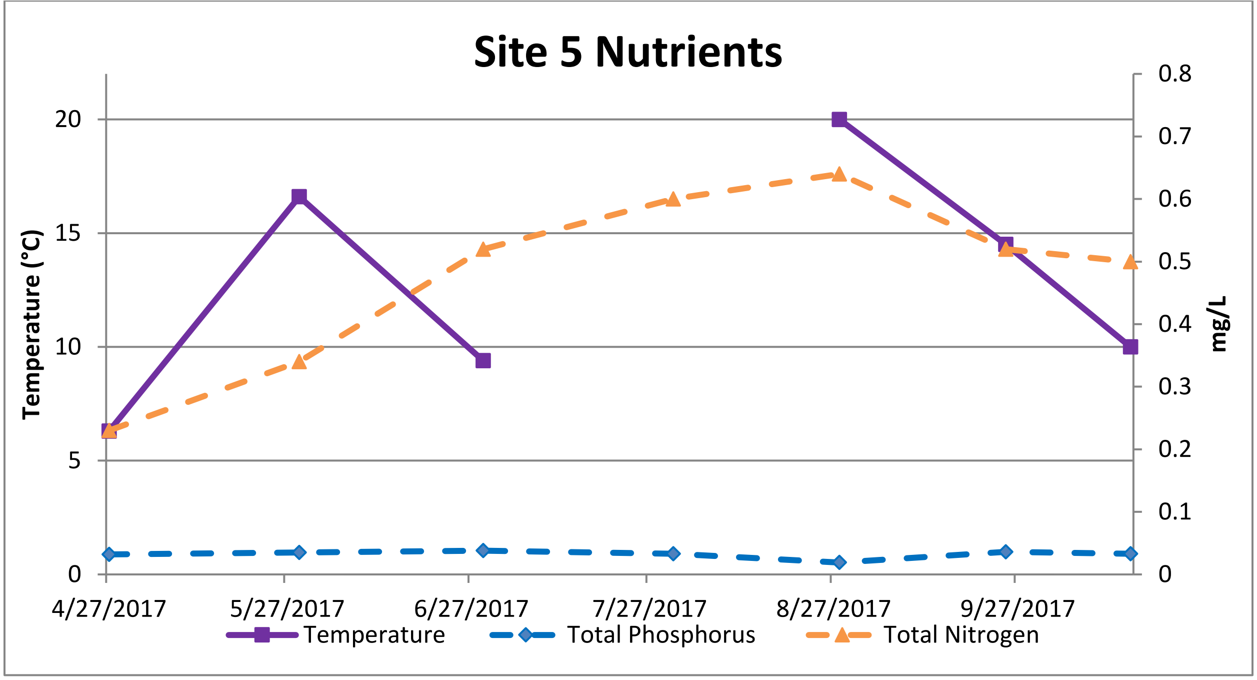


Figure 34 (above) depicts the changes of nutrient concentrations and temperature in Lake Tallac during the course of the 2017 growing season. Due to the nature of Lake Tallac, which has no surface hydraulic connection to Lake Tahoe or the Main Lagoon, and being a stormwater retention pond for portions of South Lake Tahoe and the Tahoe Keys, no mixing occurs with other water bodies. With high levels of stormwater runoff and the associated nutrient inflow, higher nutrient concentrations are to be expected for Lake Tallac.

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 available phosphorus was absorbed by the plants during the day, the rate of uptake decreased 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. By the end of the experiment, almost 0.50% of the tracer phosphorus (32P) 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, shallow groundwater inflow (aka interflow) 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. Wells, both deep and surface aquifers, were then monitored.

According to the USACE study, sub-region 2, which contains the Tahoe Keys, contributes approximately 1.2×10^6 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 phosphorous, 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 2017 TKPOA water quality results. 2017 orthophosphorus values recorded in the Tahoe Keys lagoons and Lake Tallac fell between 0.01 mg/L to 0.02 mg/L. The Main Lagoon had the most similar value to the estimated USACE average with an average of 0.015 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).

2016 and 2017 TKPOA monitoring data results and the USACE (2003) study seem to indicate potential nutrient contributions to Lake Tallac and the Main Lagoon via shallow groundwater inflow from up-gradient urban sources. 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 may be contributed from sources within and external to the lagoons.

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[3] mg/L = ppm

4.6 2016 vs 2017 Data Comparison

Figure 35 (below) shows a data comparison on a few key constituents between 2016 and 2017. pH levels in 2016 were more basic than those of 2017 which had pH levels that were slightly above neutral. Additionally, water temperature was 2.8°C warmer on average in 2016 when compared to 2017. Cooler water temperatures are due to a record setting precipitation winter of 2016 which caused the lake levels in the summer to rise 6 feet above the summer of 2016 (Lake Tahoe Water Level). With such a drastic change in water levels between the two years it is expected that pH levels and water temperature would decrease due to dilution. It would also be expected that turbidity and nutrient levels would decrease, but this is not what has been seen in 2017. Total phosphorous, total nitrogen, and turbidity all increased in 2017 when compared to 2016 and could be due to a variety of factors which include but are not limited to: increased biomass of invasive macrophytes over last year, increased water levels disturbing previously dry and exposed shorelines, increased influx of sediments and nutrients from runoff, and atmospheric deposition.

Figure 35. 2016 vs 2017 Data Comparison

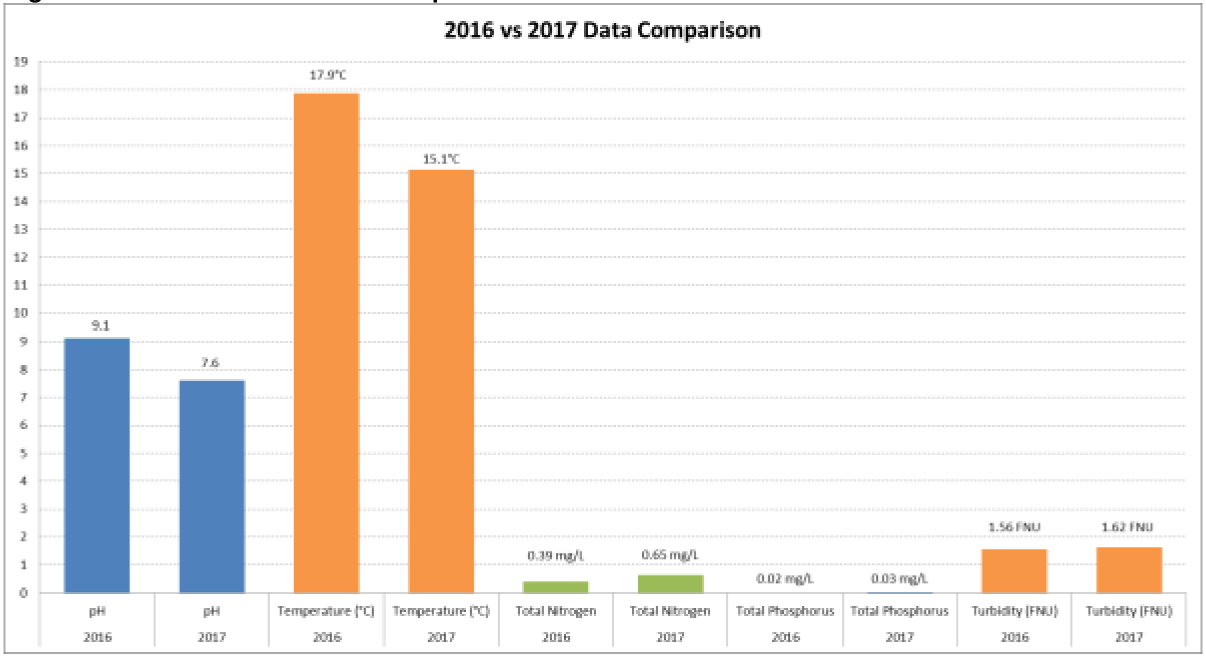


Figure 36 (below) depicts water quality data from 2016 and 2017 for some key constitutes in the Main Lagoon. The data from the invasive macrophyte growing seasons (2016-2017) between May through October were averaged by month to give a month to month overview of temperature, pH, turbidity, and dissolved oxygen. It should be noted that these averages come from 2 years of data, where in 2016, extreme drought provided low water levels in the Tahoe Key's Lagoons, while in 2017, extreme levels of precipitation in the winter months caused Lake Tahoe and the Tahoe Key's Lagoon water levels to rise significantly. When looking at temperature, it can be seen that water temperature rises in the months of June through August and pH also rises and becomes more basic in the same months. Turbidity increases and peaks in July when invasive macrophytes proliferate at accelerated rates due to optimal water temperature and sunlight availability. Similarly, dissolved oxygen levels begin to decrease in the months of June through to August when invasive macrophytes are releasing higher levels of carbon dioxide due to photosynthesis.

Figure 36. 2016-2017 Average Data per Month

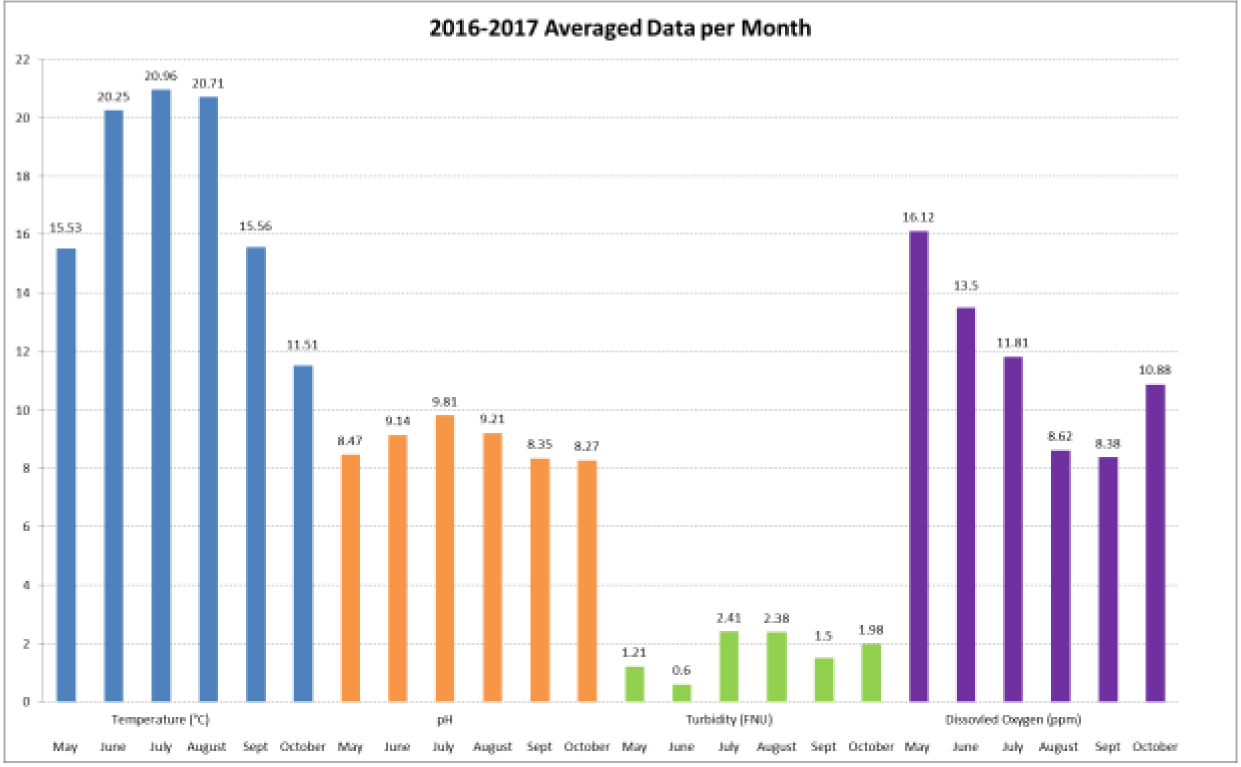


Figure 37. 2016-2017 Average Nutrients per Month

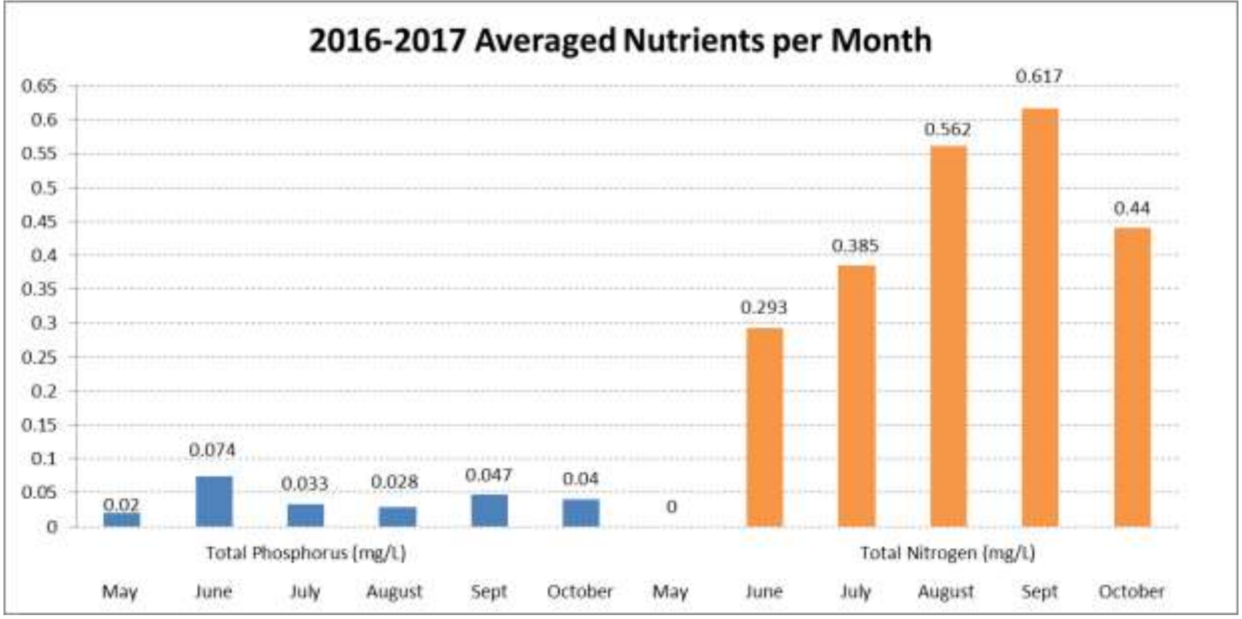


Figure 37 (above) depicts nutrient data from both 2016 and 2017, which are averaged by month for the Tahoe Key's Main Lagoon. Total phosphorus concentrations rise after the month of May when the invasive macrophyte growing season began. Total nitrogen concentrations start out in May as a non-detectable level and steadily increased in June through September before decreasing in October as the invasive macrophyte growing season came to an end.

The following figures (Figures 39-48) depict 2016 and 2017 averaged values for temperature, dissolved oxygen, turbidity, and pH for all sites in the Main Lagoon, Marina Lagoon, and Lake Tallac over the course of the growing season from April to October. For the Main Lagoon (Site 2, Site 4, Site 6, Site 8, Site 9, and Site 10) and Marina Lagoon (Site 1 and Site 3) as water temperature began to rise from April to May, a sudden spike in dissolved oxygen concentration was observed. As temperature rises, it created more optimal conditions for invasive macrophyte growth. Furthermore, as temperature began to rise above 15°C, dissolved oxygen concentrations began to decrease once Invasive macrophtyes become established in the water column. Dissolved oxygen decreased from June to September as invasive macrophtyes continued to grow until October, when water temperature decreased causing less than optimal growing conditions for invasive macrophytes. Turbidity levels stay relatively constant with some spikes in the July through September months when peak invasive macrophyte grow is observed. pH levels slowly increased from April to July/August and slowly began to return close to pre-growing season levels by October.

Figure 38. Average 2016 and 2017 Site 1 Data

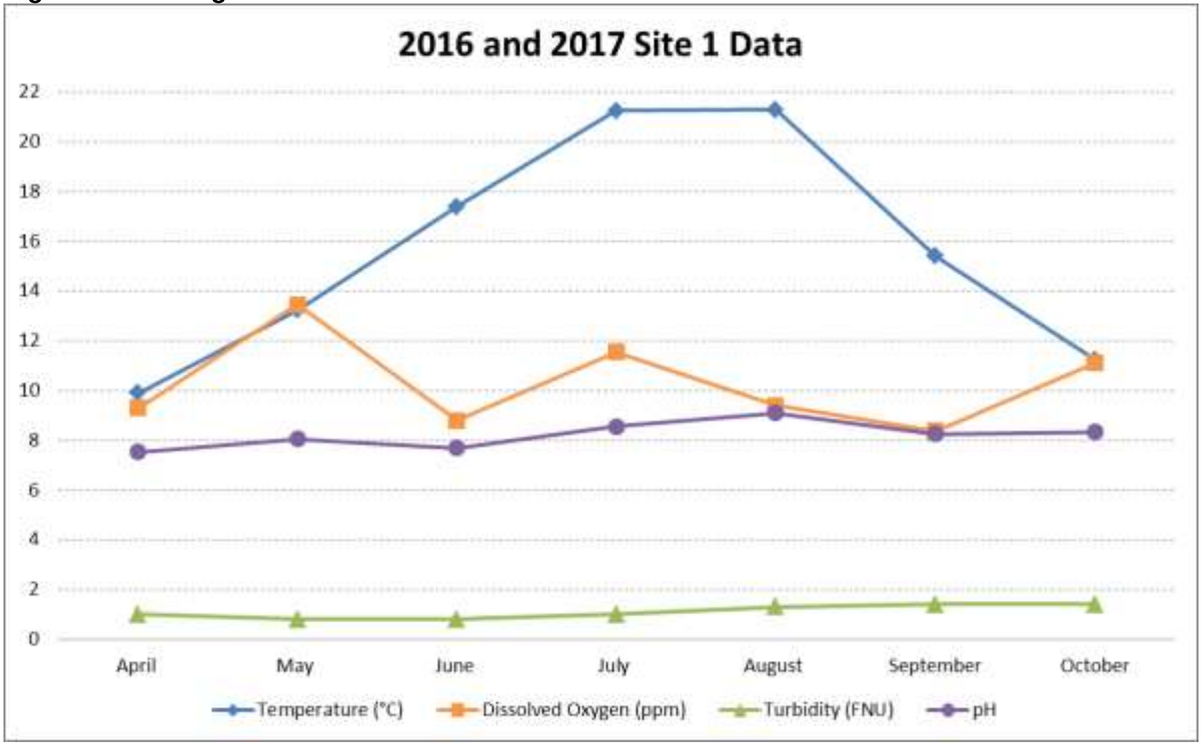


Figure 39. Average 2016 and 2017 Site 2 Data

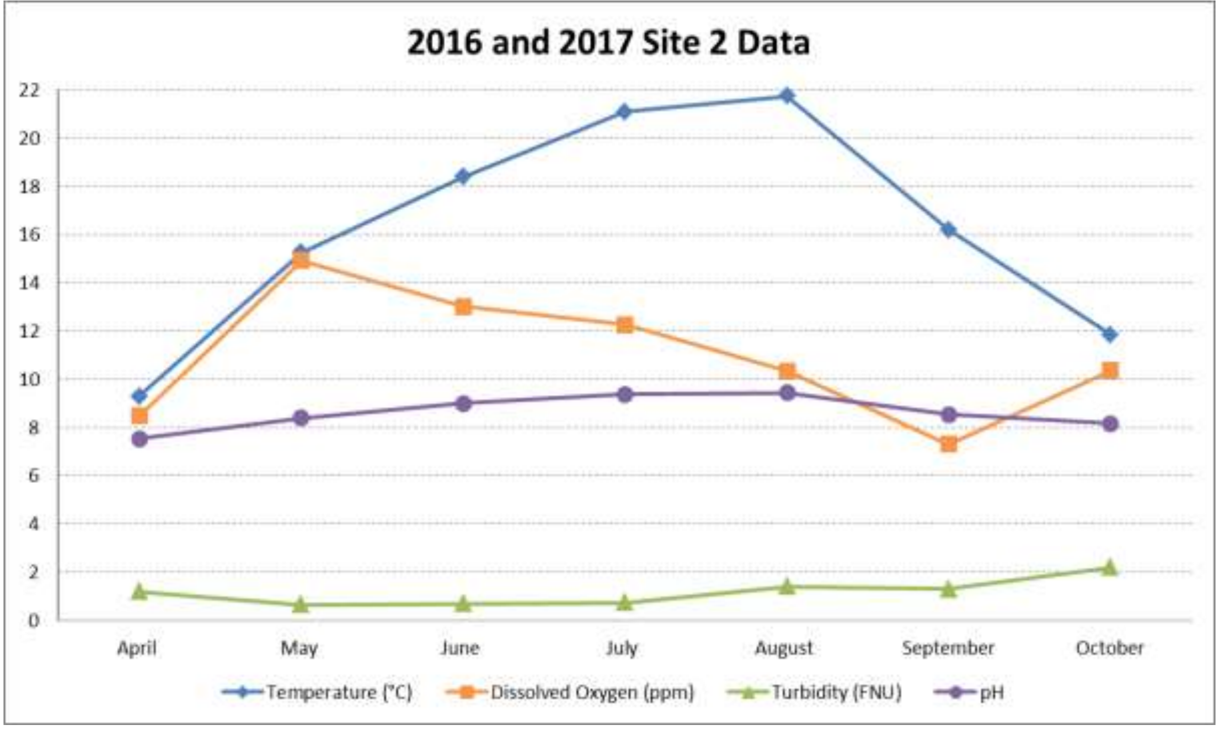


Figure 40. Average 2016 and 2017 Site 3 Data

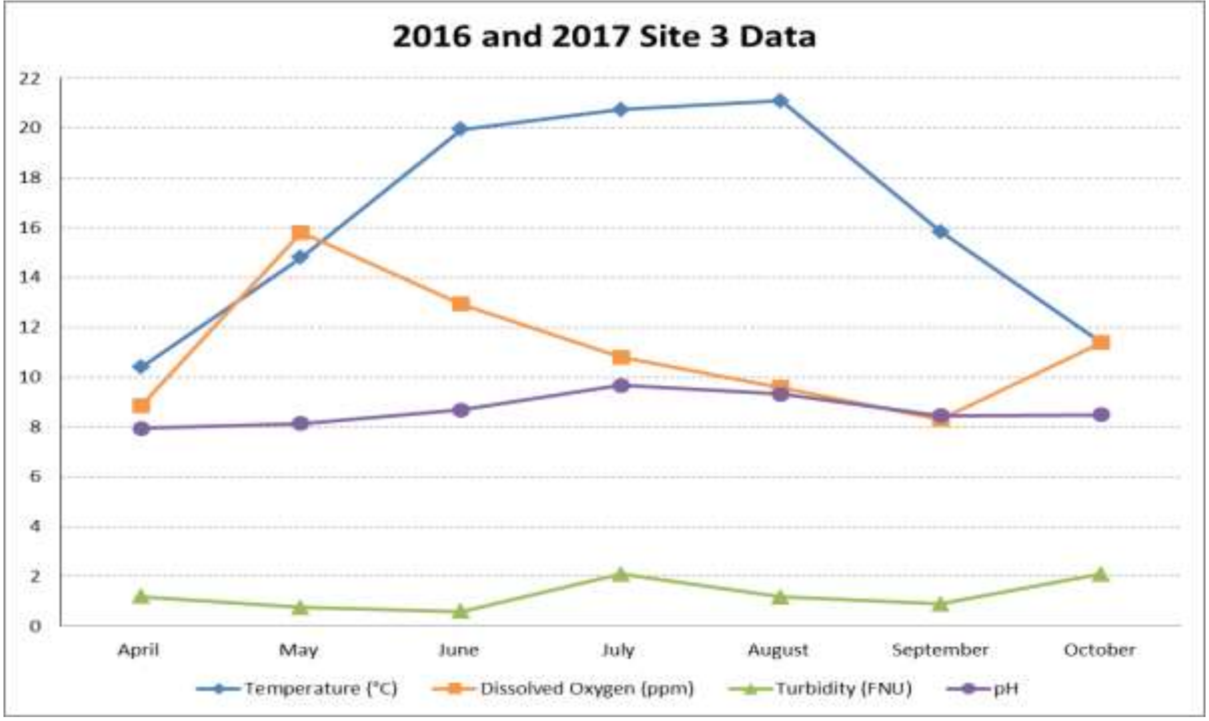


Figure 41. Average 2016 and 2017 Site 4 Data

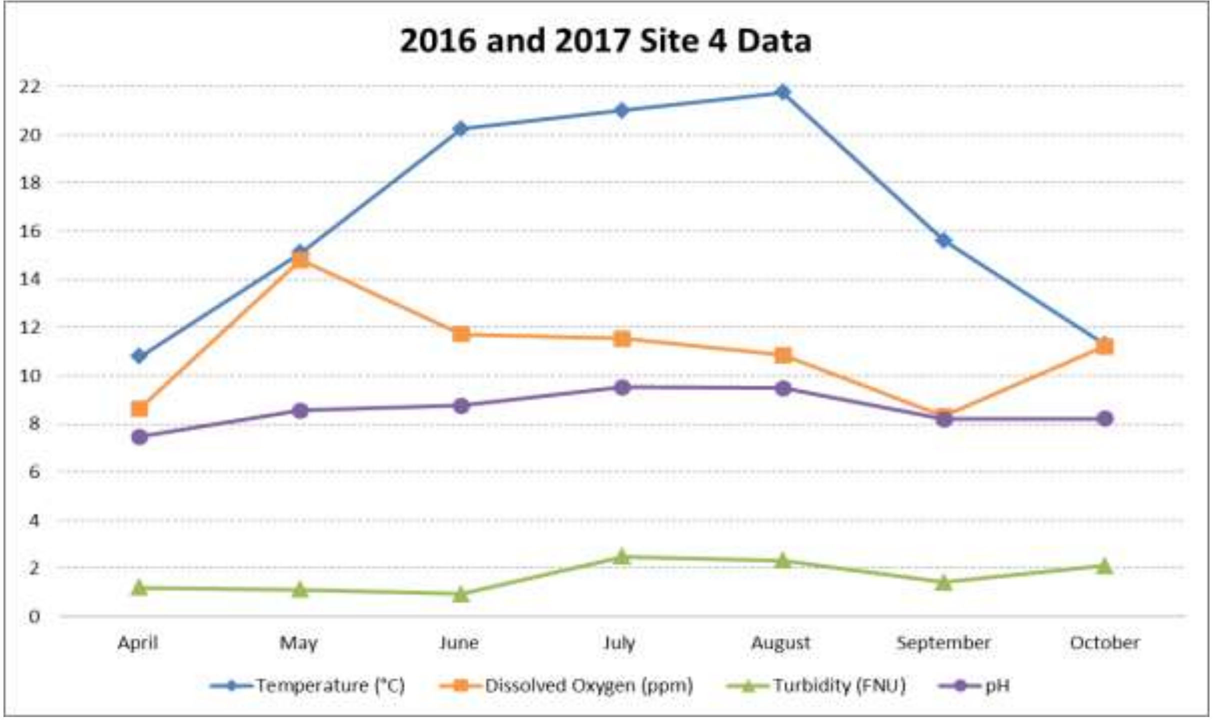


Figure 42. Average 2016 and 2017 Site 5 Data

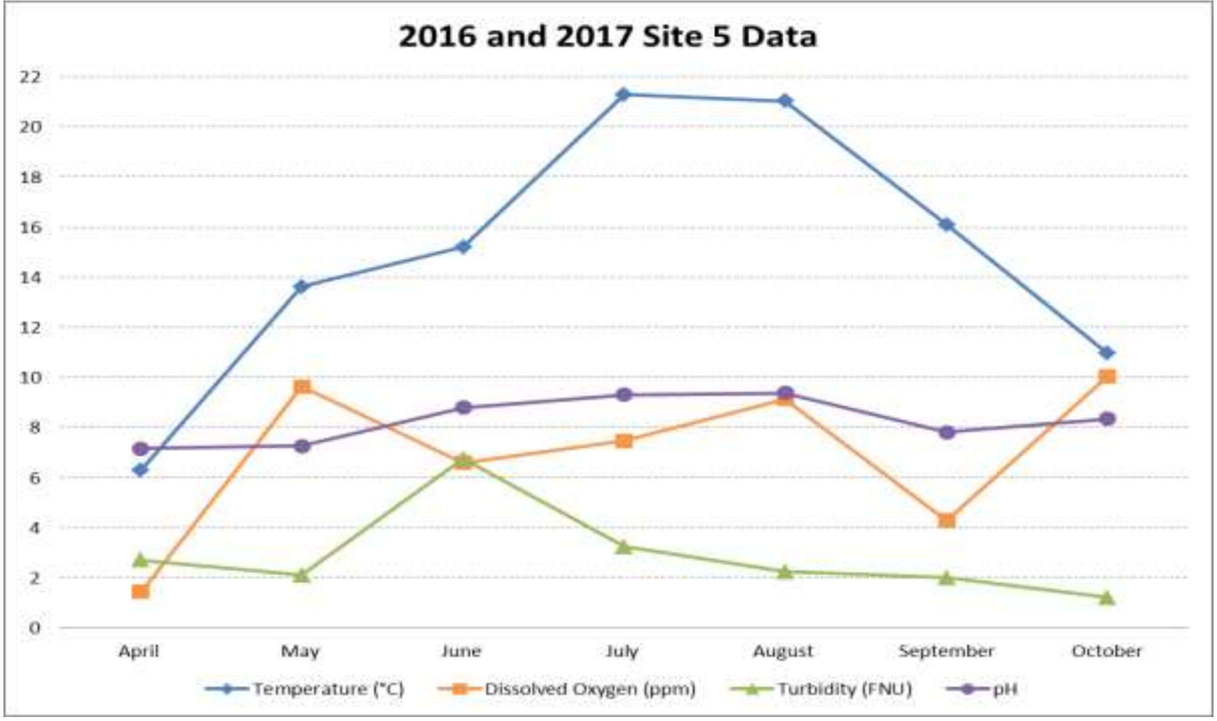


Figure 43. Average 2016 and 2017 Site 6 Data

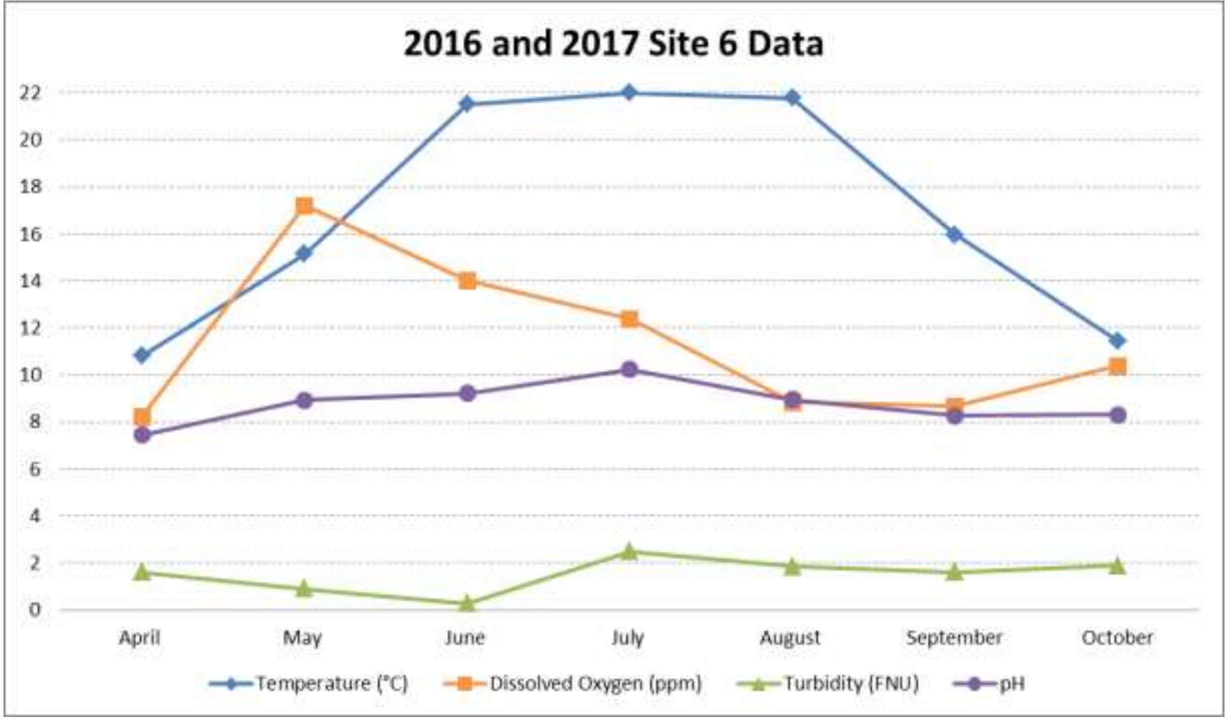


Figure 44. Average 2016 and 2017 Site 7 Data

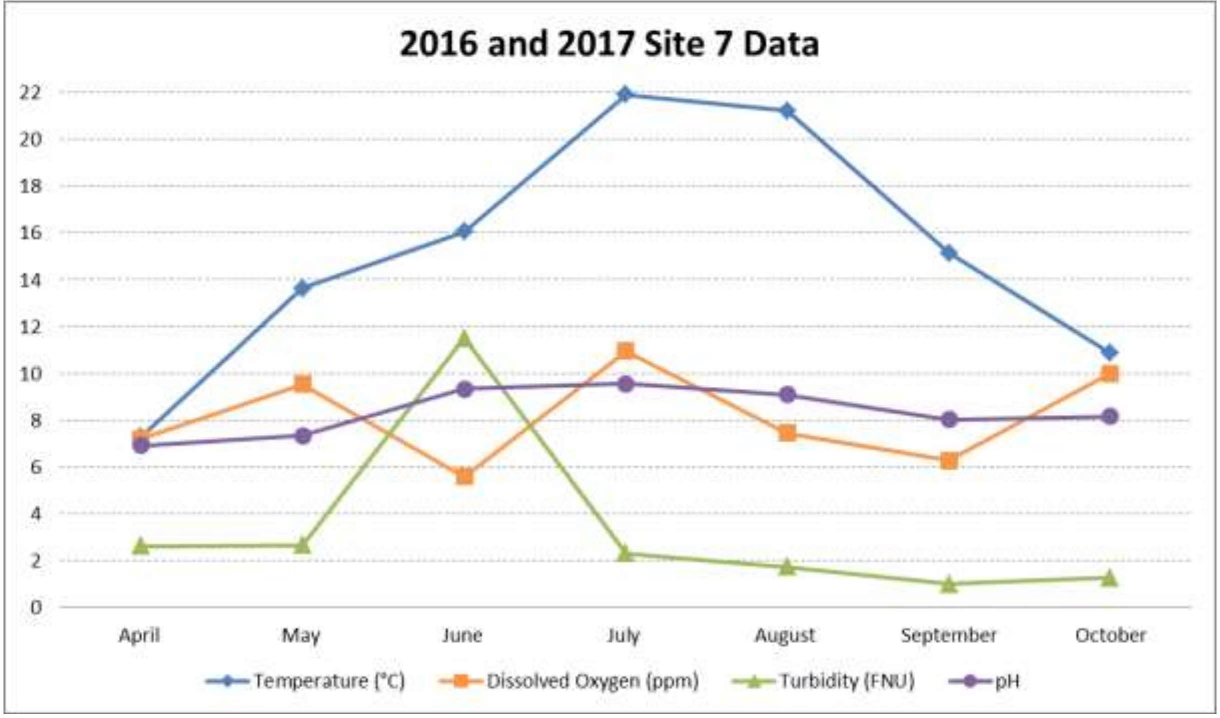


Figure 45. Average 2016 and 2017 Site 8 Data

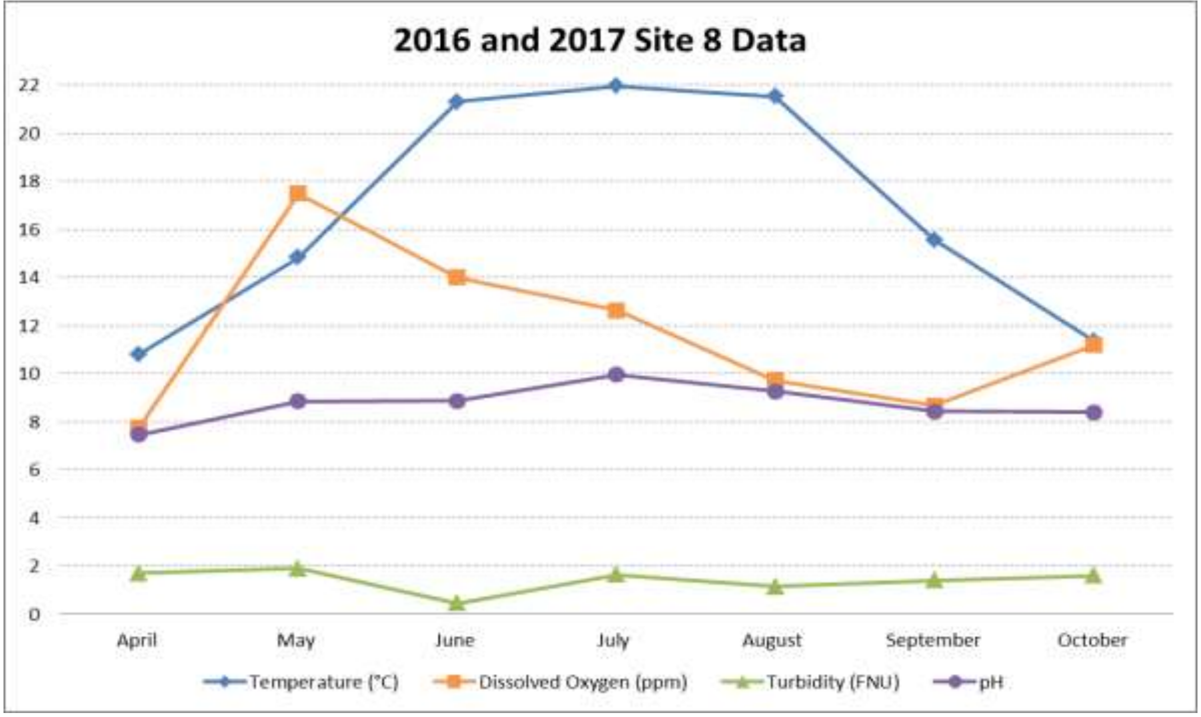


Figure 46. Average 2016 and 2017 Site 9 Data

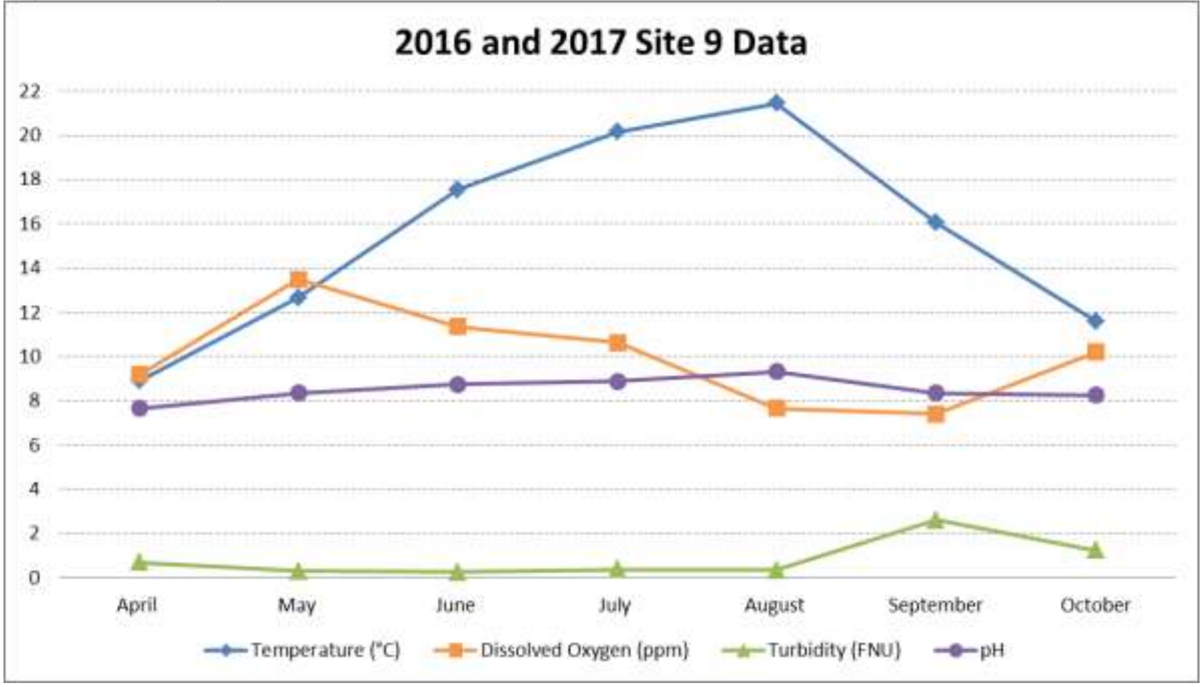
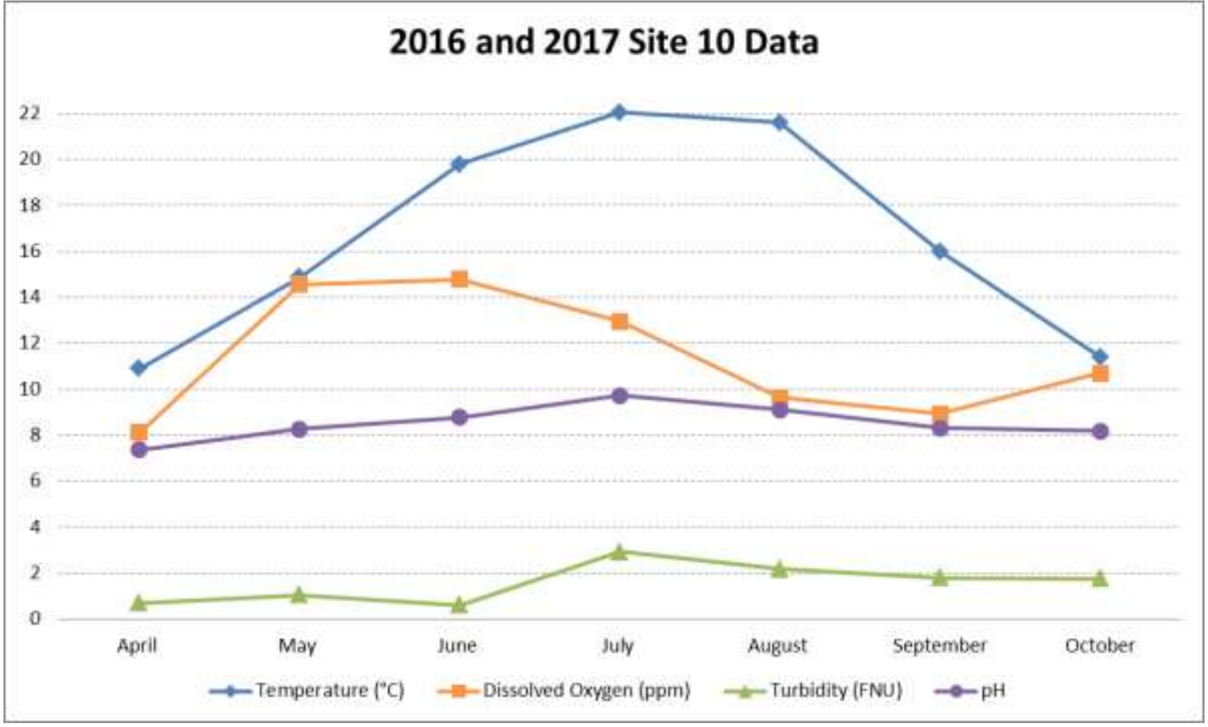


Figure 47. Average 2016 and 2017 Site 10 Data



5.0 CONCLUSIONS

The water quality data collected during the 2017 season adds to the baseline dataset for the Tahoe Keys lagoons. Previous data (pre-2016) collected in and around the Tahoe Keys Lagoons was infrequent, it did not document data collection methods, and in some cases, it was limited to only a few parameters. By collecting regular, consistent data during the spring through fall plant growing seasons for multiple parameters, over a series of years, comparative data can be used to assess the effects of various aquatic macrophyte control methods on changes in water quality and benthic habitat.

5.1 Summary of 2017

The data collected during both the Baseline Water Quality and Sediment (TKPOA 2017d) programs in 2017 show that the habitat of the Tahoe Keys lagoons is well suited to invasive plant (macrophyte) growth. 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 greater light penetration, contribute to the prolific growth of macrophytes throughout the lagoons.

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, are deposited in the Tahoe Keys lagoons via surface runoff, groundwater inflow, atmospheric deposition, and internal cycling by the dense aquatic macrophyte beds. The phosphorous molecules likely bind quickly to any cations that possess positive charges, which includes binding to sediment, or clay particles. Phosphorus is a crucial determiner of water quality, aquatic macrophyte growth, and recorded levels of both sedimentary and water column phosphorus, as well as nitrogen, was noticeably higher in 2017 than 2016. For example, average total phosphorus in the Main Lagoon was 0.030 mg/L in 2016 and 0.043 mg/L in 2017. Average total nitrogen for the Main Lagoon in 2016 was 0.37 mg/L and increased to 0.596 mg/L in 2017. Levels of phosphorus detected in the lagoons were, at times, an order of magnitude higher than that of Lake Tahoe. Trace levels of nitrogen were detected during one of the sampling events only at one sample site in Lake Tahoe proper, but samples taken from the Tahoe Keys Lagoons and Lake Tallac showed nitrogen concentrations at all of the sample locations.

The difference in water levels between October 2016 and October 2017 also may be partly responsible for the increase in nutrients present in the water column and sediment, as well as the difference in turbidity, temperature and pH values from the previous year data. The drought experienced throughout California in the previous 4 years impacted the Tahoe Basin and led to the exposure of shorelines in parts of the Tahoe Keys lagoons due to the historic low water levels. These shorelines likely collected nutrients during the dry years that were released into the water column following the high precipitation and rising lake levels from late 2016 into 2017. These higher levels of nutrients may be responsible for the cyanobacterial bloom that occurred in several locations in the Tahoe

Keys in August and September, as well as the dense growth of aquatic macrophytes (TKPOA 2017b).

Results of previous studies conducted in 2003 by the United States Army Corps of Engineers (USACE) suggests that shallow groundwater inflow 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 for the South Lake Tahoe area brings shallow 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 inflow.

Eurasian watermilfoil has been found to release 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 much more negative effect on water quality than the native plant 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 atmospheric deposition, surface water runoff, and groundwater.

5.2 Program Recommendations

Towards the end of the 2017 sampling season, several stakeholders began to recommend that TKPOA begin to measure vertical temperature and dissolved oxygen profiles at sampling sites over the course of 24 hours. This extended monitoring would better inform diurnal changes that can occur in the lagoons. This year, only pH levels were monitored at bottom, middle, and surface of the water column for all 13 sampling sites. Similar measurements of pH, temperature and dissolved oxygen at surface, mid, and bottom would also better inform technical evaluations of water quality changes associated with macrophyte growth.

In addition to the above, during a conference call with Dr. John Rodgers, toxicology expert from Clemson University (the discussion was on potential causes of the TKPOA August 2017 cyanobacteria bloom), it was suggested that future TKPOA water quality program activities include monitoring for oxidation-reduction potential (ORP) in the Tahoe Keys Lagoons. Monitoring for this parameter would give TKPOA the ability to better forecast negative changes in water quality sooner.

As TKPOA continues with its IMP adaptive management strategy, continued periodic water quality sampling will help 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 and more severe algal blooms.

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7.0 ABBREVIATIONS AND ACRONYMS

CO_2	Carbon dioxide
COC	Chain of Custody
DO	Dissolved oxygen
FNU	Formazin Nephelometric Unit
IMP	Integrated Management Plan
LRWQCB	Lahontan Regional Water Quality Control Board’s
mg/L	Milligram per liter
NPS Plan	Nonpoint Source Plan for Water Quality
ppm	Parts per million
SEA	Sierra Ecosystem Associates
TKN	Total Kjeldahl nitrogen
TKPOA	Tahoe Keys Property Owners Association
TN	Total nitrogen
TP	Total phosphorus
USACE	United States Army Corps of Engineers
WET Lab	Western Environmental Testing
WDRs	Waste Discharge Requirements
WQO	Water quality objectives

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