Evaluation of Floating Treatment Wetlands for Potential Use in the Tahoe Keys Lagoons

March 30, 2017

Evaluation of Floating Treatment Wetlands for Potential Use in the Tahoe Keys Lagoons

Prepared for

Tahoe Keys

Tahoe Keys Property Owners Association
South Lake Tahoe, California

Prepared by

Sierra Ecosystem Associates

TAHOE KEYS INTEGRATED MANAGEMENT PLAN

March 30, 2017

Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

Floating treatment wetlands (FTW) are floating mats implanted with hydroponically sustainable plants. FTW are a relatively new method of treatment to reduce both nutrient concentrations and suspended sediment particles in a body of water. Previously, FTW have been used to treat stormwater retention ponds, municipal wastewater treatment ponds and agricultural and farm lagoons with varying levels of success.

The evaluation of currently approved aquatic weed control methods and newly developed methods for the control of the prolific aquatic weeds found in the Tahoe Keys lagoons is a high priority for the Tahoe Keys Property Owners Association (TKPOA). As such, the TKPOA conducted a literature review of previous FTW uses and outcomes. Collected data was assessed with respect to potential use in the Tahoe Keys lagoons.

As illustrated in the results of the literature review, FTW can act as a passive filtration system. For example, a Biohaven® Floating Island (2 ft by 1 ft by 7 inches) was able to remove up to 10,600mg of nitrate per day, 273mg of ammonium per day, and 428mg of phosphate per day from a 30 gallon tank with 20 gallons of water (Stewart et. al 2008) when ambient air temperatures are within the optimum growing range. Microbial transformation and uptake by the bacteria and fungi growing along the bottom of the floating mat and plant roots, as well as macrophyte assimilation, act as the primary mode of nutrient removal while suspended roots act to slow water flow and aid in the settling of suspended particles.

The compiled information shows that there has never been a study using FTW in Northern California or at an elevation similar to that of South Lake Tahoe. This means that native plants able to survive hydroponically would need to be assessed to determine what species, if any, is most capable of both removing nutrients from the water column and surviving on the floating mat and in a configuration (e.g. area, geometry and scale) that is compatible with beneficial uses of the Tahoe Keys lagoons. The use of FTW may be beneficial in the Tahoe Keys lagoons as multiple studies have shown results illustrating lower nutrient concentrations and total suspended solids in a water body after use. However, it is likely that FTW may be too obtrusive for use in the Main and Marina lagoons of the Tahoe Keys, where there is heavy boat traffic, narrower channels and numerous docks. As such, installations of FTW may be possible in the Lake Tallac Lagoon where there are no narrow navigation channels or motorized boats.

Uptake of nutrients by FTW in South Lake Tahoe would be restricted to between June and August due to temperature and light fluctuations that produce optimal conditions for plant growth. Lastly, the wide variety of waterfowl that tend to rest on docks, shores and any space available on boats may pose a problem for FTW maintenance as these birds would likely use the FTW in a similar manner, and likely cause damage to the plants or the mat and may in fact contribute to nutrient loading within the floating islands.

In the future, a field study in the Lake Tallac Lagoon could be conducted in order to evaluate different possible plants and their nutrient uptake capabilities in order to determine the most appropriate plants for FTW in this setting. The large areal coverage of the FTW combined with the short growing season in Lake Tahoe limits the utilization of this weed control method. It's also important to recognize that data on nutrient uptake derived from small, shallow systems do not necessarily predict or properly represent uptake and nutrient removal dynamics in much deeper systems with nutrient rich substrates (hydrosoil).

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: the 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.

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 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 Integrated Management Plan for Aquatic Plants (IMP) and a Nonpoint Source Plan for Water Quality (NPS Plan) be implemented by the TKPOA (Lahontan 2014). The IMP describes approaches for the control and management of invasive aquatic plant species in the Tahoe Keys lagoons. As part of the IMP, the TKPOA is investigating currently approved methods of macrophyte control as well as additional new methods, including FTW, to reduce nutrients and fine sediment particles in the water column.

Floating Islands International and Beemats LLC International are two well-known manufacturers and distributers of FTW. In addition to the research done individually by these companies, universities including Clemson University and the University of Washington have conducted research on different configurations and effectiveness of FTW. This paper describes these two types of manufactured FTW, summarizes the findings of the university studies, and evaluates the potential use and benefits of FTW in the Tahoe Keys lagoons.

2.0 FLOATING TREATMENT WETLANDS

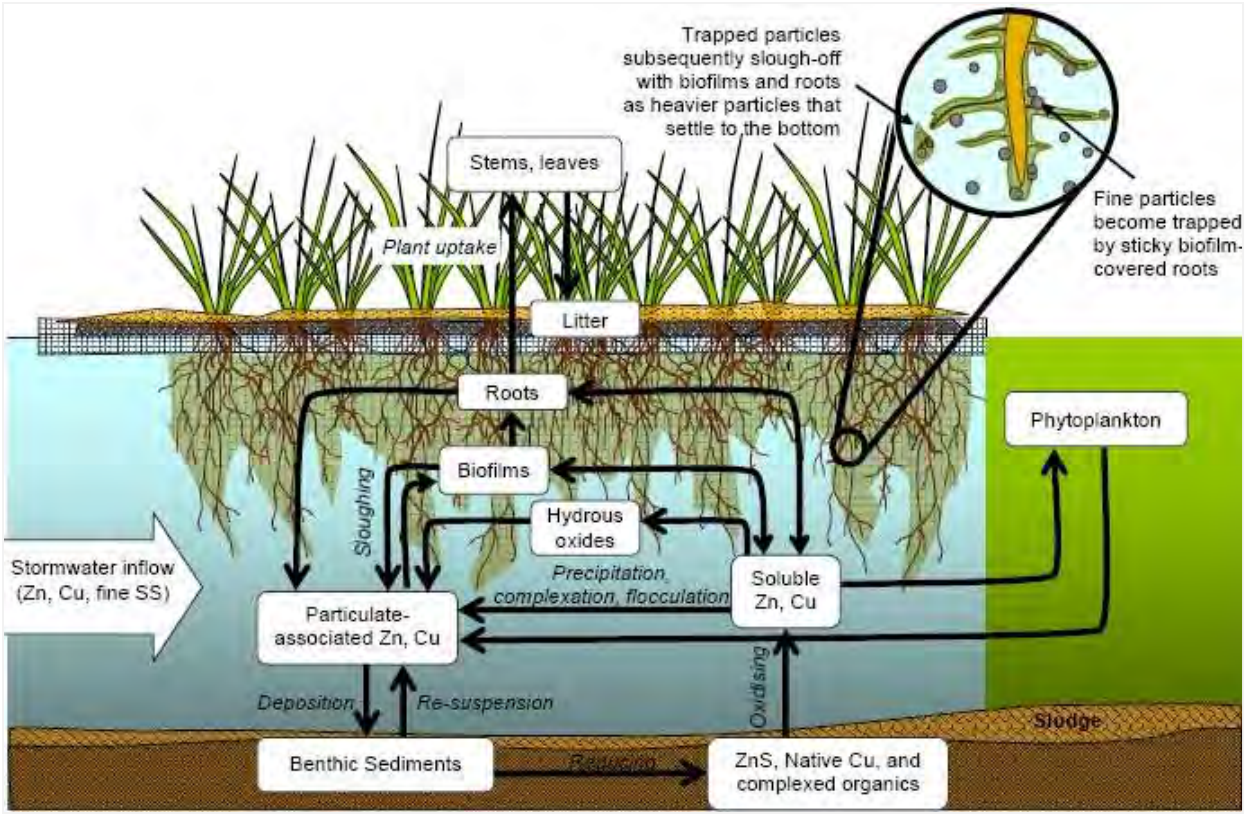
Natural wetlands play an important role in filtering stormwater or irrigation runoff through the trapping of sediments, the uptake of nutrients by wetland flora (Raumann et al. 2008) and by acting as sites of denitrification (Carpenter et al. 1998). The processes of ammonification, nitrification and denitrification, driven by microbial activities and the presence of oxygen, are responsible for the transformation between the various forms of nitrogen. The organic nitrogen amino acids are transformed to ammonia through ammonification. Ammonia is subsequently converted to ammonium in acidic solutions. The process of nitrification converts ammonium to nitrate while denitrification transforms nitrate into nitrogen gas (Saeed et al. 2012).

FTW are man-made structures that utilize the filtering ability of natural wetlands. These structures are built using durable mats and aquatic plants. The FTW floats on the body of water and the plants are sustained hydroponically, as their roots are freely suspended under the mat in the water. The plants remove nutrients and fine particles and can improve the water quality (Wang 2014).

Studies to test the effectiveness of FTW to reduce nutrients in wastewater treatment ponds have illustrated the potential to be a sustainable and relatively low cost Best Management Practice (BMP). The installation of FTW, compared to no treatment and unplanted floating mats, has been shown to increase the rate of uptake and removal of nitrogen and phosphorus in stormwater retention ponds, municipal wastewater treatment ponds as well as agricultural and farm lagoons (Van de Moortel et al. 2010).

Algae, bacteria and fungi growing along the bottom of the floating mat and along plant roots, also known as a biofilm, are the primary mode of nutrient removal from water. The biofilm forms a large treatment area where microbial transformation and uptake, as well as macrophyte assimilation, occurs. As microbial activity is limited by substrate surface area, the greater the surface area of microbes the higher the nutrient uptake (Stewart et. al 2008).

Figure 1. Diagram of a Floating Treatment Wetland



Source: Floating Islands International

The processes of ammonification, nitrification and denitrification are all driven by microbial activities and the presence of oxygen, and are responsible for the transformation between the various forms of nitrogen in the water column (Saeed et al. 2012). The nutrients removed from the water column can become stored in plant tissues, which can be measured to determine removal efficiency of the macrophytes used in the FTW.

These microorganisms are greatly influenced by temperature changes, as the optimal temperatures for the process of nitrification falls between 61.7-89.6°F. The process proceeds very slowly below 41°F and above 104°F. Cooler climates inhibit the removal of nitrogen and organic compounds but can be aided by the use of artificial aeration (nitrification documented at 35.6°F with the assistance of artificial aeration) (Saeed et al. 2012). In a study by Wang et al. (2014) that assessed the nutrient removal ability of floating treatment wetlands, the total density of bacteria dropped significantly from 2.33 cells per gram dry artificial material to 0.56 x 10^8 cells per gram dry artificial material when the temperature fell below 59°F. Total nitrogen, ammonium-nitrogen, and phosphorus removal were highly influenced by change in temperature, with the most noticeable drop in nutrient removal falling between 41-59°F (Van de Moortel et al. 2010).

Plant tissues above the water control light attenuation, microclimate, and nutrient storage while the tissues submerged in the water column slow current, release oxygen, uptake nutrients, provide surface area for microorganism growth, and filter debris and suspended particles (Brix 1997). These suspended sediment particles in the water column are more readily bound with phosphorus molecules (Karjalainen et al. 2001) which can lead to the enhancement microbial activity (Sahoo et al. 2010) and the mobilization of inorganic nitrogen and phosphorus in the water column (Coats 2004).The floating mats shade the water underneath them, which lowers the pH, dissolved oxygen concentration, and temperature (Wang et. al 2014). The process of nitrification, the conversion of $NH_4 \rightarrow NO_2 \rightarrow NO_3$, requires the presence of oxygen and actually consumes alkalinity, causing a subsequent decrease in pH (Saeed et al. 2012).

According to a mesocosm study conducted by Van de Moortel et al. (2010), FTW cause less oxygen to diffuse into the water column, however, the release of oxygen from root mats created a higher redox potential which could allow for more oxygen consuming reactions. The shading produced by the mats prevents light from reaching the periphyton located along the bottom of the mesocosm tank that can decrease the rate of photosynthesis; however, the algae suspended in the water column were able to use the nutrients and there was a subsequent algal bloom in a few of the documented experiments.

3.0 FTW PLANTS

Important characteristics of plants that can be used in FTW include: whether they are native or non-native, perennial, terrestrial, a wetland plant or a plant that is able to thrive in a hydroponic environment, and the degree to which the plant roots have aerenchyma, tissue containing sufficient air space to allow for gas exchange and which provides buoyancy (Assessing floating treatment wetlands, 2014). The below table from the University of Clemson provides a list of plants that have been tested with regard to FTW application.

Pickerelweed and Softstem bulrush are often used in FTW studies although water primrose, giant bulrush, broadleaf arrowhead, Italian ryegrass, cattail, and rusty flatsedge have also been studied.

Table 1. List of Plants Tested with FTW Application

Common Name	Botanical Name
Canna	*Canna* 'Australia'
Cattail	*Typha latifolia*
Common willow	*Salix caroliniana*
Elephant ear	*Colocasia esculenta* 'Black Magic'
Florida canna	*Canna flaccida*
Giant reed	*Arundo donax*
Iris	*Iris laevigata* *Iris ensenata* 'Variegata'
Lizard's tail	*Saururus cernuus*
Maidencane	*Panicum hemitomon*
Napier grass	*pennisetum purpureum*
Red top	*Agrostis* sp.
Soft rush	*Juncus effusus*
Spikerush	*Eleocharis montana*
St. Augustine grass	*Stenotraphrum secundatum*
Swamp mallow	*Hibiscus moscheutos*
Thalia	*Thalia geniculata*
Tifton 85 bermuda grass	*Cynodon dactylon*
Wild millet	*Panicum milliaceum*

Source: Clemson University

4.0 APPLICATION IN THE TAHOE KEYS

4.1 Site-Specific Details

The Tahoe Keys lagoons are located at an elevation of 6,237 ft. In 2015, according to the 2016 State of the Lake Report, South Lake Tahoe experienced an annual daily high of 60.1˚ F and an annual daily low of roughly 33˚F, with the long-term mean for both minimum and maximum 30.3˚F and 56.3˚F respectively (TERC 2016). Furthermore, the average annual precipitation was 52.45 inches and the average annual snowfall was 408 inches (US. Climate Data 2016).

As previously mentioned, the Tahoe Keys is comprised of three water features including the Lake Tallac Lagoon, the Main Lagoon, and the Marina Lagoon. All three contain Eurasian watermilfoil, curlyleaf pondweed, and coontail. However, each have different characteristics. See figure 2 below for an overview of the Tahoe Keys lagoons.

Figure 2. Overview of Tahoe Keys Lagoon

The Lake Tallac Lagoon is a narrow 30 acre lagoon located on the southern edge of the Tahoe Keys. More than half of the shore is lined with homes, some with docks, and the use of motorized boats is currently prohibited. The Lake Tallac Lagoon is separated from the Tahoe Keys Main Lagoon fingers by a diversion structure, which is designed to be lowered (but not known to be operated) during high water events. Furthermore, the Lake Tallac Lagoon connects with Pope Marsh on its western edge, with high water exchanges into and from the marsh observed during certain hydrological conditions.

The Main Lagoon is located on the western edge of the Tahoe Keys and is directly connected to Lake Tahoe through the West Channel. It is a combination of connected lagoon fingers and coves that provide recreational access to Tahoe Keys residents and renters. There is limited public access and no commercial access from the Main Lagoon.

The Marina Lagoon is located towards the eastern portion of the Tahoe Keys and is directly connected to Lake Tahoe through the East Channel. It is relatively open with heavy boat traffic from commercial, governmental, academic research, and private boat uses. The Marina Lagoon, different then the two above mentioned water features, is not owned by the TKPOA.

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.

4.2 Advantages

Studies have shown that the use of FTW as a passive filtration system reduces nutrients in the water column. Overall, average removal efficiency in test groups with FTW was 35% for ammonium-nitrogen, 42% for Total Nitrogen, 22% for Phosphorus, and 53% for chemical oxygen demand (Van de Moortel et al. 2010). Results of studies also show that in a tank containing 20 gallons of water FTW can remove up to 10,600mg of nitrate per day, 273mg of ammonium per day, and 428mg of phosphate per day (Stewart et. al 2008) when ambient air temperatures are within the optimum growing range.

In general, FTW are relatively easy to construct, plant and set. There are currently a few main manufactures and distributers of FTW. Water quality monitors can be attached to the floating mat. The floating islands also provide habitat for wildlife as well as being aesthetically pleasing (Brix 1997; CH2M Hill 2014).

4.3 Disadvantages

There has never been a study using FTW in Northern California or at such a high elevation. As such, the plants that could be used have never been studied before in this context. It is difficult to determine which plants could be employed in South Lake Tahoe, as the temperature and elevation of Tahoe vary from previous sites where FTW were tested. However, there are similar species native to the Tahoe Basin that could potentially be used. These plants include: *Salix actica* (arctic willow), *Iris* spp., *Typha latifolia* (cattail), and *Juncus effusus + var* (common rush).

As most plants are influenced by temperature and light fluctuations, in this setting the prime uptake of nutrients via plant growth would be limited to between June and the end of August/early September. Furthermore, the prime time for harvesting to ensure maximum nutrient/pollutant removal before degradation of plants would need to be perfected to prevent the release of nutrients back into the water column as the plants begin to decompose (Nahlik 2006).

Since 2010, Floating Islands International has conducted numerous studies on the treatment of ponds and lakes with FTW to reduce biological oxygen demand, chemical oxygen demand, total phosphorus, total nitrogen, and fine suspended particles. The majority of ponds treated in these studies were wastewater collection ponds or storm water retention ponds that were relatively shallow, between three to six feet in depth. Total water body area ranged from a minimum of 3600 ft^2 to a maximum area of 6.5 acres. The percent cover (amount of the waterway covered by FTW/ total amount of waterway) of FTW varied depending on the goal of the treatment combined with water depth and area.

For example, in a study conducted by Floating Islands International during 2011 in St. Gabriel, Louisiana, a municipal wastewater treatment pond was treated using FTW to reduce chemical oxygen demand, ammonia, and phosphate. This pond was a total of 5.1 acres with an average depth of three feet. FTW percent coverage was 0.7%, with an 8" thick FTW with a total of 1,560 ft^2 (Floating Islands International 2011). A similar study in Billings, Montana in 2011 was conducted in a 3,600ft^2 stormwater retention pond with a depth of four feet. The goal of the treatment was to reduce total suspended solids, chemical oxygen demand, total phosphorus, total nitrogen, copper, lead, zinc, oil and grease. 1,500 ft^2 FTW with a thickness of 8" was used, a percent cover of 42% (Floating Islands International 2011). Given the size of the Tahoe Keys lagoons, 172 acres of waterways in total, it would require a larger percent cover to produce a decrease in water column nutrient concentrations. Individual fingers of the Tahoe Keys lagoons could be treated as separate 'ponds' and percent cover could be calculated from previous studies and percent cover nutrient reduction rates as well as the 2016 Tahoe Keys Baseline Water Quality data (TKPOA 2016).

FTW anchored in a channel would affect the navigation of boats. Placement would be difficult in the narrower channels, where there would be less space for diversion around each island by boaters. The mats would need to be anchored to their designated position as wind, water flow, and boats would cause them to drift, potentially into docks. However, placement of FTW in the Lake Tallac Lagoon would have some but not all of the same constraints as those found in the Main and Marina Lagoons as there are no narrow channels or motorized boats to contend with.

While it is also an advantage to FTW, the provision of habitat for wildlife could also be a disadvantage. The Tahoe Keys contain a wide variety of waterfowl. These birds tend to rest on docks, shores and any space available on boats. As such, these birds would likely use the FTW in a similar manner, potentially damaging the plants or the mat.

4.4 Estimated number of FTW for use in the Lake Tallac Lagoon

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 2. Tahoe Keys Annual Average Water Quality (2007 – 2013)[1]

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
WQO	**0.15**	**0.008**	**60**	**7.0 - 8.4**	**3.00**

For the 2016 season, total phosphorus and total nitrogen concentrations exceeded the WQO shown in Table 2 in the Main Lagoon, Marina Lagoon, and the Lake Tallac Lagoon. According to the 2016 baseline water quality sampling results (TKPOA 2016) show that the Lake Tallac Lagoon in particular, on average, has a total nitrogen value of 0.36 mg/L and total phosphorus value of 0.026 mg/L during the course of the growing season. Total nitrogen values are twice the value given in the WQO, while total phosphorus values are roughly three times greater than the WQO.

To reduce nutrient values by 50%, calculations estimating the required number of FTW and percent cover can be conducted assuming a rate of total nitrogen (0.9 lbs $yr^{-1}ft^{-3}$) and total phosphorus (0.52 lbs $yr^{-1}ft^{-3}$) uptake from two Floating Island International studies (Floating Island International 2011a; Floating Island International 2011b), with results determined from observation since 2010, in combination with the estimated volume of water for the Tallac Lagoon. Calculations suggest that the installation of roughly 444,142

[1] 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).

FTW in the Lake Tallac Lagoon, equaling about 68% cover, could reduce the current average amount of total nitrogen by 50%. Furthermore, roughly 56,227 FTW (about 9% cover) could reduce current total phosphorus values up to 50% in the Tallac lagoon.

However, the above rate of uptake and amount of nutrients removed may vary due to limited growing season (approximately 3 months).

5.0 CONCLUSION

While it has been documented that the use of FTW can lower nutrient concentrations and total suspended solids in a water body, FTW would be too obtrusive for use in the Main and Marina lagoons of the Tahoe Keys, where there is heavy boat traffic and docks. However, the installation of FTW could benefit the 30 acre Lake Tallac Lagoon, where motorized boating is currently prohibited. Furthermore, the ratio of surface to volume is much higher in the previously cited studies compared to that of the Lake Tallac Lagoon or the Tahoe Keys lagoons. This ratio is important as it drives the dynamics of nutrient diffusion from sediment sources to the uptake sites (rhizosphere) of the cultured plants. Thus, a small volume: surface area results in close proximity of the sediment to the nutrient “sinks”, i.e. the plant roots and rhizosphere. These are typical conditions in shallow systems (few feet deep), but are not at all representative of the conditions in Tallac Lagoon, where depths may be 10 to 15 feet.

Previous studies have shown that a significant decrease in available nutrients was seen in a 30 gallon tank containing 20 gallons of water using one Biohaven® Floating Island. Calculations to determine 50% reduction in both total nitrogen and total phosphorus in the Lake Tallac Lagoon, to lower values near LRWQCB WQO to all waters in the Lake Tahoe region, have shown that reducing total nitrogen would require up to 68% of the surface area of the lagoon to be covered in FTW while a 50% reduction in current total phosphorus values would require a significantly less percent cover (roughly 9%). However, a limited growing season of 3 months before the harvesting and removal of FTW biomass from the system may change the relative amount of nutrients removed from the water column.

A field study in the Lake Tallac Lagoon could be conducted in order to evaluate different possible native plants and their nutrient uptake capabilities in order to determine the most appropriate plants for FTW specifically for the Tahoe Keys lagoons. Here, FTW could potentially be distributed across the lagoon at a relatively high percent cover without hindering recreational navigation.

6.0 LIST OF PREPARERS

The following individuals prepared the text presented in this report.

Name	Education	Role
Rick A. Lind	M.A. Geography (Water Resources) UC Davis B.A. Geography (Natural Resources) CSU Sacramento	Principal-in-Charge
Krystle Heaney	B.A. Geography (Physical) CSU Sacramento	Contributing Author
Kristen Hunter	B.S. Biology UC Davis	Primary Author
Lars Anderson, Ph.D	Waterweed Solutions Ph.D Plant Physiology/Cell Physiology/Aquatic Biology UC Santa Barbara	Contributing Author
Rayann La France	B.S. Criminal Justice CSU Sacramento	Document Editing, Formatting

7.0 ABBREVIATIONS AND ACRONYMS

BMP	Best Management Practices
FTW	Floating Treatment Wetland
IMP	Integrated Management Plan
LRWQCB	Lahontan Regional Water Quality Control Board
NPS Plan	Nonpoint Source Plan for Water Quality
TERC	Tahoe Environmental Research Center
TKPOA	Tahoe Keys Property Owners Association
WDRs	Waste Discharge Requirements

8.0 GLOSSARY

Ammonification	Transformation of organic nitrogen amino acids to ammonia
Denitrification	Nitrate reduction where nitrate (NO_3) is converted into nitrogen gas (N_2)
Macrophyte	Organism that is part of the macroscopic plant life of an aquatic ecosystem
Nitrification	Biological oxidation of ammonia (NH_3) to nitrite (NO_2) followed by oxidation of nitrite to nitrate (NO_3)
Rhizome	An underground stem, typically horizontal
Turions	Vegetative bundle, akin to an axillary bud containing meristematic tissue that can form anywhere on the macrophyte and be dispersed

9.0 REFERENCES

Bartucca, M.L., Mimmo, T., Cesco, S., and Buono, D.D., 2016. Nitrate Removal from Polluted Water by Using a Vegetated Floating System. *Science of the Total Environment*, Vol. 542. pp. 803-808.

Boyd, C.E., 1971. The limnological role of aquatic macrophytes and their relationship to reservoir management. American Fisheries Society.

Brix, H., 1997. Do Macrophytes Play a Role in Constructed Treatment Wetlands? *Water Science Technology*, Vol. 35, No. 5, pp 11-17.

Carleton, J.N., Gizzard, T.J., Godrej, A.N., and Post, H.E., 2005. Factors Affecting the Performance of Stormwater Treatment Wetlands. *Water Research*, Vol. 35, No. 6 pp 1552-1562

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N. and Smith, V.H., 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological applications*, *8*(3), pp.559-568.

CH2M Hill, 2014. Nutrient Removal from Reclaimed Water with Floating Treatment Wetlands.

Clemson Cooperative Extension, 2015. Plants for Floating Treatment Wetlands. Clemson University.

Coats, R., 2004. Nutrient and sediment transport in streams of the Lake Tahoe Basin: a 30-yr retrospective. *Gen. Tech. Rep. PSW-FTR-193*. Washington DC: USDA Forest Service.

DiTomaso, Joseph M., and Healy, Evelyn A., 2003. *Aquatic and Riparian Weeds of the West*. Oakland, Calif.: U of California, Agriculture and Natural Resources.

Floating Islands International 2011a. Floating Treatment Wetland Technology: Total Nitrogen Removal from Wastewater.

Floating Islands International 2011b. Floating Treatment Wetland Technology: Total Phosphorus Removal from Wastewater.

Floating Islands International 2011c. Nutrient Removal with Passive Floating Treatment Wetlands.

Floating Islands International 2011d. Floating Treatment Wetlands Remove Contaminants from Stormwater.

Floating Islands International 2011e. Demonstration of Treatment of Landfill Leachate using Floating Treatment Wetland Technology.

Floating Islands International 2011f. Eliminating Odors using BioHaven® Technology.

Floating Islands International 2011g. Early-Stage Floating Treatment Wetland Technology to Achieve Nutrient Removal in Aerated Facultative Wastewater Treatment Lagoons.

Floating Islands International 2011h. Floating Treatment Wetlands Remove Nutrient Loads from Eutrophied Lake.

Floating Islands International 2011i. Phosphorus Reduction with Passive Floating Treatment Wetlands.

Floating Islands International 2013. BioHaven® Living Shorelines; BioHaven Floating Breakwaters.

Floating Island International 2014. Nutrient Removal with Active BioHaven® Floating Treatment Wetlands.

Jangrell-Bratli, A. S., 2011. *The Effects of Artificial Floating Wetland Islands on Water Quality in a Eutrophic Lake* (Doctoral dissertation, University of South Florida St. Petersburg).

Lahontan Regional Water Quality Control Board, 2014. Water Quality Certification and Waste Discharge Requirements for Tahoe Keys Property Owners Association. R6T-2014-0057.

Karjalainen, H., Stefansdottir, G., Tuominen, L., and Kairesalo, T., 2001. Do submerged plants enhance microbial activity in sediment? *Aquatic Botany*, 69(1), pp. 1-13.

Kim, J.G., Rejmánková, E. and Spanglet, H.J., 2001. Implications of a sediment-chemistry study on subalpine marsh conservation in the Lake Tahoe Basin, USA. *Wetlands*, *21*(3), pp.379-394.

Nahlik, A.M. and Mitsch, W.J., 2006. Tropical treatment wetlands dominated by free-floating macrophytes for water quality improvement in Costa Rica. *Ecological Engineering*, *28*(3), pp.246-257.

Raumann, C.G. and Cablk, M.E., 2008. Change in the forested and developed landscape of the Lake Tahoe basin, California and Nevada, USA, 1940–2002. *Forest Ecology and Management*, *255*(8), pp.3424-3439.

Saeed, T. and Sun, G., 2012. A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: dependency on environmental parameters, operating conditions and supporting media. *Journal of environmental management*, 112, pp.429-448.

Sahoo, G.B., Schladow, S.G., and Reuter, J.E., 2010. Effect of sediment and nutrient loading on Lake Tahoe optical conditions and restoration opportunities using a newly developed lake clarity model. *Water Resource Research*, 46(10).

Stewart, F.M., Mullholland, T., Cunningham, A.B., Kania, B.G., and Osterlund, M.T., 2008. Floating wetlands as an alternative to constructed wetlands for treatment of excess nutrients from agricultural and municipal wastes – results from laboratory scale tests. *Land Contamination and Reclamation*, Vol. 16, No. 1

Tahoe Environmental Research Center, 2015. Tahoe: State of the Lake Report 2015.

Tahoe Environmental Research Center, 2016. Tahoe: State of the Lake Report 2016.

TKPOA 2015. Integrated Weed Management Plan for the Tahoe Keys Lagoons, Public Review Draft.

TKPOA 2016. 2016 Baseline Water Quality Report for the Tahoe Keys Lagoons. Prepared by Sierra Ecosystem Associates.

US Climate Data, 2016. Climate South Lake Tahoe – California.

Van de Moortel, A.M., Meers, E., De Pauw, N. and Tack, F.M., 2010. Effects of vegetation, season and temperature on the removal of pollutants in experimental floating treatment wetlands. *Water, Air, & Soil Pollution*, *212*(1-4), pp.281-297.

Wang, C.Y. and Sample, D.J., 2014. Assessment of the nutrient removal effectiveness of floating treatment wetlands applied to urban retention ponds. *Journal of Environmental Management*, *137*, pp.23-35.

Wang, C.Y., Sample, D.J., and Bell, C., 2014. Vegetation effects of floating treatment wetlands nutrient removal and harvesting stratagies in urban stormwater ponds. *Science of the Total Environment*, 499, pp. 384-393.