

Evaluation of Mechanical Control Methods for Aquatic Weeds in the Tahoe Keys Lagoons



March 27, 2017

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TAHOE KEYS INTEGRATED
MANAGEMENT PLAN

March 27, 2017

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EXECUTIVE SUMMARY

The Tahoe Keys Property Owners Association (TKPOA) researched a variety of alternative aquatic weed control methods during the 2016 growing season. Alternative mechanical methods were part of this analysis, including mechanical harvesting, rotovating, weed rolling, bottom sweeping, chains, and shredders.

Of these methods, the most plausible for utilization in the Tahoe Keys lagoons includes harvesting, rotovating, and weed rolling. Mechanical harvesting has been occurring in the Tahoe Keys since the 1980's. Both rotovating and weed rolling affect turbidity in the treated area, by either tilling the sediment or disturbing the top layer of the sediment to remove aquatic weeds.

The information collected from the research conducted during 2016 will help determine future control methods used for management of aquatic macrophytes in the Tahoe Keys lagoons and will also be included in the TKPOA Integrated Management Plan (IMP) update.

1.0 INTRODUCTION

The Tahoe Keys is a residential and commercial development along the south shore of Lake Tahoe, California. The Tahoe Keys provides direct access to Lake Tahoe through two main channels that also connect with a series of smaller lagoons within the development. The Tahoe Keys 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. Figure 1 shows the locations of these water features.

Figure 1. Overview of the Tahoe Keys Lagoons



The Tahoe Keys encompass 172 acres of waterways with 1,529 homes as well as townhouses, marinas, and a commercial center. Property in and around the Tahoe Keys lagoons is controlled by multiple landowners and waterway land ownership includes individual property owners, association ownership (e.g., TKPOA common property and Tahoe Keys Beach and Harbor Association), and commercial and governmental ownership. Through various agreements, TKPOA maintains the waterways for boating

and other recreation. This ownership pattern adds management complexity. TKPOA has no legal or other authority to require others to participate in the Integrated Management Plan or implement best management practices.

Since the 1980's, the Tahoe Keys lagoons have had an increasing problem with the growth of aquatic plants, also referred to as aquatic macrophytes, to the extent that the growth of these plants are significantly impacting the aquatic ecosystem, private and commercial boating, other recreation, and the aesthetics of the Tahoe Keys. The three macrophytes of greatest concern are the non-native Eurasian watermilfoil (*Myriophyllum spicatum*), curlyleaf pondweed (*Potamogeton crispus*), and the native coontail (*Ceratophyllum demersum*). While aquatic plants are generally beneficial to aquatic ecosystems, providing habitats and nutrients for benthic invertebrates, fish, and waterfowl, unchecked proliferation of invasive species can be harmful and leads to monocultures that crowd out native plants and host non-native fish species. These aquatic plants present risks to swimmers, wrap around boat propellers, impair water quality, and can be carried to other parts of Lake Tahoe by boats, waterfowl, and winds.

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

In 2016, the TKPOA completed the IMP for Aquatic Weeds to fulfill the obligations of the Waste Discharge Requirements (WDRs) issued by the Lahontan Regional Water Quality Control Board (LRWQCB). The IMP describes how to combine the currently approved methods of aquatic plant control to manage the growth of the invasive weeds as effectively as possible. As part of the IMP, TKPOA proposed to investigate in detail additional methods of aquatic plant control including researching mechanical control of weeds.

This paper reviews the primary categories of mechanical methods used to control aquatic weeds: harvesting; rototilling or rotovating; and weed rollers, bottom sweepers, and chains. These methods are described in terms of level of control, length of time control lasts, and effects on the aquatic habitat. Mechanical methods have been studied and critiqued at different levels, associated with how widespread their use is. Impacts on categories such as benthic habitat and water quality for studies conducted in a strict side-by-side comparison to determine the effectiveness of all available mechanical control methods has not been reported.

Some mechanical methods, such as harvesting, have been used for many years at various locations in the United States. The impacts of harvesting are well-documented. Other mechanical methods of control are used on a more limited basis and impacts under various conditions have not been as critically evaluated.

2.0 TYPES OF MECHANICAL CONTROL OF AQUATIC MACROPHYTES

Mechanical control requires the use of specialized machinery that is designed to cut, dislodge or severely damage plants. Plants are cut at a specified depth and typically are removed off site. In some cases, cut plant fragments are masticated and left in place.

Mechanical methods are non-selective, meaning that all plants within the targeted area are subject to removal, cutting or other physical disruptions.

2.1 Harvesting

Aquatic plant mechanical harvesters are large machines that remove the upper portion of the aquatic plants, typically between five and ten feet below the surface of the water (see Figure 2). Cut weeds can be transferred to holding platforms and be taken to areas approved for disposal.

Harvesting is widely used and has been the primary means of control in the Tahoe Keys lagoons since the 1980s. Harvesting reports show that the amount of aquatic plants harvested in the Tahoe Keys lagoons has dramatically increased. This increase in harvested plant material is consistent with other surveys and reports that show a spread of the infestation. In Minnesota, a study of Lake Minnetonka reported that harvested areas had reduced biomass for approximately six weeks when compared to control areas, however the harvested areas had significantly higher growth rates for the remainder of the growing season (Crowell 1994).

Adverse environmental impacts of harvesting have been documented. There are reports that harvesting results in some fish, turtle, and invertebrate mortality. Furthermore, some researchers predict that removing plant material would reduce nutrient availability (SFEI 2004). Macrophytes found in littoral zones are often used as indicators of changes to nutrient concentrations in an aquatic ecosystem (Melzer 1999) and can also be utilized in biofiltration and the removal of heavy metals or excess nutrients from the water column (Engel 1990; Upadhyay et al. 2007). As the plants are harvested and fragments removed, the available nutrients typically released back into the water column during senescence and decay (Smith et al. 2000) for reuptake by algae or macrophytes are removed from the aquatic system.

Increased fragmentation of aquatic macrophytes by harvesting has been reported (TKPOA 2014), which is of particular concern for the invasive Eurasian watermilfoil which can easily reproduce from small fragments. After harvesting, the growth rate and resultant biomass of Eurasian watermilfoil increases when compared to unharvested areas (Crowell 1994). The increase in density is a direct result of removing the growing tips, or meristems, which forces more side growth from the remaining plant stems.

Harvesting is also used to control aquatic weeds where turbidity is a concern, such as in kokanee spawning areas, or where there is recreational boat traffic that would be impeded by other methods such as rototilling (Dunbar 2009).

Figure 2. Mechanical Harvester



2.2 Rototilling or Rotovating

Rototilling underwater or rotovating describes underwater tillage of aquatic plants. Like tilling on land, rototilling tills the hydrosol to remove plants, particularly roots and rhizomes. This requires specialized machinery that can access aquatic weeds either from shore, or more typically, from a barge. The depth that the unit tills depends on the size of the tines used and typically rotovators till eight to 10 inches into the sediment or hydrosol. Rotovators are not usually fitted to collect fragments of plants or rhizomes created by tilling.

Rototilling is commonly used in British Columbia but is used less often elsewhere. In the Okanagan Basin, Eurasian watermilfoil is routinely controlled by rototilling in the fall and mechanical harvesting in the spring. Harvesting only is applied in areas where increased turbidity is a concern for impacts to the aquatic habitat. Specifications for rototilling include avoiding areas with known underwater obstacles such as underwater pipelines. Rototilling is scheduled in the Okanagan Basin for fall and winter when the Eurasian watermilfoil plants are dormant (Dunbar 2009).

Figure 3. Rotovator.



ROTOVATING HEAD
Image Property of DK Environmental © 2014

The estimated cost to rotovate in the Tahoe Keys lagoons using the Aquamog is between \$15,000 and \$35,000 per acre (McNabb 2016), depending on site conditions/acreage.

2.2.1 Rototilling and Water Quality

Tilling on land gives the advantage of clearing weeds for the intended crop and loosening and oxygenating the soil to promote plant growth. Topsoil particles can be lost when they become airborne. These same processes take place with underwater tilling: aquatic plants are removed, the hydrosol becomes loosened, but instead of wind, water currents can move fine silt and sediment particles away from the rototilled area.

The Okanagan Basin Water Board Management Plan for Eurasian watermilfoil gives a thorough review of the impacts of rototilling on turbidity. The Okanagan Plan states that turbidity at the treatment site is high and that, with sandy hydrosol, the turbidity is at background levels approximately 110 yards away. The Okanagan Basin Water Board has tried different methods to mitigate or contain the turbid water caused by rototilling, but has not found a truly satisfactory method that both reduces the levels of turbidity at and near the treatment site and which does not hinder treatment operations (Dunbar 2009).

2.2.2 Effectiveness of Rototilling

Rototilling can reduce the biomass of Eurasian watermilfoil by over 80% and the treated area can remain weed-free for a year or more (Dunbar 2009). Rototilling can encourage the growth of curlyleaf pondweed, if present, by reducing competition and encouraging the spread and sprouting of turions and seeds, which may not be removed with the roots of the aquatic macrophytes.

Depth of the tilling head or tines affects the results and, also, the cost of treatment. Underwater obstacles can limit the use of the rotovator. While duration of control can be up to a year or more, regrowth can be widespread as rototilling creates habitat, especially for rooted aquatic macrophytes (Chisholm 2007).

2.2.3 Examples Where Rototilling Has Been Used

2.2.3.1 Box Canyon Reservoir, Pend Oreille County, Washington

Rototilling has been used since 1986 to remove Eurasian watermilfoil and curlyleaf pondweed in approximately 200 acres. Monitoring studies showed that stem densities decrease immediately after treatment by as much as 90%, but that densities return to pre-treatment levels after a year or more. Control of curlyleaf pondweed has proven less successful and population levels have increased by approximately 20 times over pretreatment levels one year later. Overall, rototilling effectiveness has been variable. The method appears to promote re-infestation by fragmenting the plant and leaving behind plant propagules that re-establish in the treated area. Rototilling removes plant cover for fish, results in changes in water temperature, light penetration, and dissolved oxygen levels (Pend Oreille 2005).

2.2.3.2 Okanagan Lakes Chain

The Okanagan Basin Water Board (OBWB) has been responsible for controlling Eurasian watermilfoil in the Okanagan lake system since the 1970s. Rototilling takes place during fall when plants are in or near the dormant phase and when there is reduced volume of plant material that can entangle the machinery. The rototilling machines are custom designed and built locally for the OBWB (Dunbar 2009).

Rotovating occurs every 18 to 24 months, with roughly 200 acres treated per year (Pend Oreille County 2005). The rotovating arm is lowered up to 4.5 meters and multiple passes are often required in order to fully remove roots and rhizomes from the treatment area (Dunbar 2009). Typically, rotovating removes all plants following multiple passes. For example, in 1986 stem density following treatment using rotovating decreased from 90% to 63% (Gibbons 1988). However, regrowth of aquatic macrophytes, such as Eurasian watermilfoil, in treated areas is often unpredictable and uneven (Dunbar 2009), with revegetation of mainly milfoil and curlyleaf pondweed occurring after one year (Pend Oreille 2005).

2.3 Shredding

This method of aquatic weed control is used to manage both submerged and emergent weeds that restrict navigation or flood control in waterways. Cutters are mounted on small barges which are more maneuverable than larger, traditional harvesters. The equipment shreds the weeds with front-mounted cutters and removes the resultant detritus from the water. However, shredders cannot completely eradicate weeds, because roots, rhizomes, seeds and turions are left behind to grow (USACE 2012).

Figure 4. Mechanical Shredder



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Recent concern regarding the spread of aquatic weeds via viable plant fragments led to the development of shredders capable of grinding or crushing fragments into pieces that are no longer believed viable. These machines are not easily obtained for commercial use (Madsen 2000).

According to a study conducted in the San Joaquin Delta in the early 2000's, the cost of one mechanical shredder is between \$11,500 and \$19,100 and the per acre treatment cost is between \$200-900 (Greenfield et al. 2006).

2.3.1 Shredding and Water Quality

The shredding of aquatic weeds without the removal of created debris may lead to nutrient cycling directly into the water column via decomposition of fragments (James et al. 2002). Shredding can cause the resuspension of sediment, decomposition of plants in the lake, and floating plant material. However, the amount of nutrients released into the water column is small relative to other sources, including runoff and atmospheric deposition (Madsen 2000).

2.3.2 Effectiveness of Shredding

Shredding is a non-selective short term management method. Generated fragments, unlike with mechanical harvesting, are not collected. The maneuverability of the barge in comparison with a mechanical harvester is advantageous. Shredders are therefore able to more accurately pinpoint and target smaller vegetation populations than mechanical harvesters (USACE 2012). Shredding provides immediate relief from dense populations of aquatic weeds. However, the generation of viable fragments limits management.

2.3.3 Method Example – Sacramento-San Joaquin Delta, California

The Sacramento-San Joaquin Delta (Delta) is an inverted river delta, narrowing at its ocean point and branching progressively inland, and located on 1,150 square miles of floodplain that is fed primarily by the San Joaquin and Sacramento Rivers. The Delta is a tidal system composed of a network of lakes, sloughs, and channels that experiences a large water exchange every six hours. Water hyacinth was introduced to the Delta almost 100 years ago, and is too well of an established species for eradication (SFEI 2007).

In 2003 and 2004, two mechanical shredders were evaluated with respect to water hyacinth control and impacts on water quality. Both treatment events resulted in a significant reduction in water hyacinth but also had many viable fragments remaining following treatment. Nutrient concentrations in the water near the treatment sites increased. Specifically, orthophosphorus values in one site almost doubled and total phosphorus values at all sampled sites increased almost five-fold. Values for dissolved organic carbon doubled and Total Kjeldahl Nitrogen also increased, however, values were not statistically significant. Biological oxygen demand showed a significant increase and sustained these increased levels for several weeks following shredding operations (SFEI 2007).

2.4 Weed Rollers and Bottom Sweepers

These devices are dock-mounted, electrically-driven systems that use a rotating arm (up to 30 feet long) that rolls or drags along the sediment, moving forward and backwards in a 270-degree arc compressing sediment and plants. The system is usually installed and operated in early spring so that the rotating arm can periodically sweep over newly sprouted plants, thus maintaining a relatively clear area beneath the path of the sweeper. It is recommended that rollers be used once a week for sufficient plant control (SFEI

2004). Bottom sweepers can provide relief from aquatic plants in small areas adjacent to docks. They require a fixed mounting surface, such as a pier or dock.

Figure 5. Dock Mounted Weed Roller



Image Property of Weeders Digest ©2016

The individual cost of one dock-mounted weed roller is roughly \$4,000 per unit. Purchase of a sweeper system is approximately \$2,000 and can cover an area of approximately 1,360-4,160 sq. ft. (SFEI 2004).

2.4.1 Weed Rollers/Bottom Sweepers and Water Quality

Similar to Rotovating, topsoil particles are lost when they become suspended in the surrounding water column as the Weed Roller or Bottom Sweeper moves across sediment. This disruption of the upper layers of sediment results in increased turbidity levels, as well as the production of viable plant fragments, and disturbs bottom-dwelling organisms and spawning fish (SFEI 2004). 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). The extent to which this method affects water quality has not been thoroughly investigated.

2.4.2 Effectiveness of Weed Rolling/Bottom Sweepers

In general, weed rollers and bottom sweepers are a relatively new form of aquatic weed control method that has not been fully tested with respect to the level of viable plant fragments created from their use. It is recommended that these devices, once installed, are used weekly. The rollers travel along a pivot point which allows a 270-degree arc as well as the ability to be used in a variety of substrate types (AERF 2009). Repeated use leads to weakened plants, and eventual plant death with effects seen within the first week

of treatment (SFEI 2004). These devices are only effective at managing smaller areas individually.

Installation of either weed rollers or bottom sweepers to docks in the Tahoe Keys lagoons is possible, but likely not feasible. There are a total of 979 docks in the Tahoe Keys, many of which are privately owned. At a minimum, the purchase of one device for the installation of one at each dock would reach close to \$2 million to \$4 million.

2.4.3 Example - Sacramento-San Joaquin Delta, California

Two Weed Rollers (Lake Maids™), 20-foot and 36-foot, were tested in the Delta at two different marinas. Plant populations in both treatment areas were mainly composed of coontail and Brazilian elodea. The Lake Maids™ were left to operate 24 hours a day for a total of ten days. Water quality and generated plant fragments were monitored during the treatment period.

Overall, the plant population at each marina was significantly decreased following treatment with Lake Maids™. Statistical analysis showed that there were no significant changes in water chemistry after treatment. This may be due to the fact that Lake Maids™ utilize a loosely attached rake to scrape macrophytes and have limited to no direct contact with the sediment. During the test, plant fragments were present, however, after two days' fragmentation of plants greatly increased (David et al. 2006).

2.5 Chains

This method is a non-selective control method most commonly used to clear canal or channel systems by shearing all vegetation off the bottom. A chain, heavy enough to reach the bottom of the water column, is strung across the channel and is then dragged along the bottom, most often by trucks or tractors. This method requires unobstructed paths on both sides of the canal that allows the trucks or tractor to drag the chain for a relatively long distance (USACE 2012).

The estimated cost for the necessary materials for this method is at least \$2,000, which excludes equipment, vehicle and labor.

2.5.1 Chains and Water Quality

The dragging of heavy chains along the bottom of a channel or canal causes an increase in turbidity by stirring sediment as well as disturbing the aquatic species living in the treated area (USACE 2012).

2.5.2 Effectiveness of Chains

This method is effective in storm water and irrigation canals that have a relatively low water level and easy access from lands adjacent to the entire water surface. As the chain must be dragged through the water on either side by a vehicle, the width of the selected

site as well as obstacles along the shore are important to consider with respect to effectiveness (SFEI 2004).

3.0 SUITABILITY OF MECHANICAL METHODS FOR USE IN THE TAHOE KEYS LAGOONS

The mechanical methods described here can provide immediate, short-term relief from aquatic vegetation posing problems to navigation or recreation. Harvesting results in short-term improvements, while rototilling has been reported to provide control for up to a year or more. All impact light penetration and remove plant cover for fish, which is true for any effective method of aquatic plant control.

Suitability of mechanical control methods was evaluated on the basis of the following parameters:

Table 1. Section Location of Suitability Parameters in Summary

Section	Suitability Parameters
3.1	How well does the method control the suite of aquatic invasive plants prevalent in the Tahoe Keys?
3.2	What are the associated impacts to the benthic environment?
3.3	What are the associated impacts to water quality?
3.4	What is the risk of fish kill?
3.5	Is the method compatible with the current use and conditions of the Tahoe Keys lagoons?
3.6	Is the equipment available locally and are there professionals available to use the equipment?

3.1 Aquatic Plants in the Tahoe Keys Lagoons

In order to determine the suitability of the mechanical methods discussed in this report, it is important to reflect upon the development, growth, and lifecycle of the aquatic weeds found in the Tahoe Keys lagoons. The suite of invasive aquatic plants present in the Tahoe Keys lagoons includes Eurasian watermilfoil, curlyleaf pondweed, and coontail. Other aquatic macrophytes are present but comprise a smaller percentage of the aquatic plant population. The overall composition of the aquatic plant population varies from year to year which could be the result of changes in the growing conditions or due to unknown variables (TKPOA 2015).

3.1.1 Eurasian Watermilfoil

Eurasian watermilfoil (*Myriophyllum spicatum*) is the most widespread aquatic invasive plant in the United States. The plant can form a dense canopy at the surface of the water, out-competing other aquatic plants. Eurasian watermilfoil is an evergreen perennial plant which roots in sediment and grows completely underwater, typically at 15-foot depth but has been found as deep as 30 feet. Flowers form on short stems above the water surface and flowers produce up to four nutlets or seeds on each flower. Eurasian watermilfoil can form numerous viable seeds which can disperse readily and can spread by forming new root crowns from rhizomes growing in the sediment.

Eurasian watermilfoil is very similar in appearance to the native aquatic species, northern watermilfoil (*M. sibiricum*) and hybridization between the two species can occur. Both species spread readily by stem fragments formed naturally by abscission from the main plant or by breakage caused by wave action or feeding by waterfowl.

3.1.2 Curlyleaf Pondweed

Curlyleaf pondweed (*Potamogeton crispus* L.) is found in all of the lower 48 states and is considered naturalized throughout this range. Curlyleaf pondweed is a rooted perennial with a fast growth rate. The plant stem is very thin and long and dense infestations can entrap swimmers. Curlyleaf pondweed aggressively out-competes native submerged vegetation. Curlyleaf pondweed typically is found in more shallow waters at three to six feet depth but can be found in clear waters as deep as 20 feet. Curlyleaf pondweed reproduces primarily by turions and rhizomes but can also spread by stem fragments or seeds. Turions are modified reproductive buds that form prior to plant senescence in early summer. This species can overwinter thus giving these plants an advantage when temperatures rise and growth resumes in the spring.

Curlyleaf pondweed forms dense mats at the water's surface which inhibits navigation and recreation. The dense mats limit light from reaching native vegetation and can inhibit oxygen exchange along the water column. These conditions reduce the populations of fish or aquatic invertebrates and can create conditions that promote mosquito habitat by removing predators and obstructing water flow.

3.1.3 Coontail

Coontail (*Ceratophyllum demersum*) is a native aquatic plant found nearly world-wide and throughout California up to 6,500 feet in elevation. In natural areas, coontail is considered beneficial and provides food and shelter to other aquatic species. However, it can develop very dense mats which inhibit water flow, interfere with recreation, and promote mosquito habitat.

Coontail is a submersed plant that lacks true roots. It can exist as a free-floating plant or it can form modified stems and anchor itself to other aquatic plants. Young plants readily detach from soil.

Coontail plants have slender stems with single branches at nodes. Coontail reproduces vegetatively, by stem fragments and turions, and by seed, although in cold water, plants produce few to no seeds (DiTomaso 2003).

3.1.4 Lifecycles and Concerns

The lifecycles of the three target plants differ in important ways and these differences can affect the strategies for management. All three plants undergo rapid growth in early to late spring when water temperatures begin to increase. All three species can form new plant colonies from vegetative fragments although Eurasian watermilfoil and coontail more readily proliferate from fragments as small as a few cm in length. All three can form fruits with seeds that are long-lived and their germination is generally limited, but the seed is long-lived. This means that a seed bank may persist for many years.

Curlyleaf pondweed's ability to form dispersive, vegetative structures called turions in spring provides the plant with a very effective dispersal mechanism during summer. A single shoot can form dozens of turions during spring and early summer. The turions typically sprout in early fall, root on the bottom and are ready for rapid growth the next spring.

All three problematic aquatic plants, Eurasian watermilfoil, curlyleaf pondweed, and coontail, are able to regenerate from plant fragments. Any mechanical method that leaves behind a fragment of the plant provides an opportunity for the aquatic plants to re-establish the population after the control activity is completed.

Rototilling, chaining, shredding, and mechanical harvesting produce thousands of viable plant fragments. Some programs actively work on improving methods to capture and sieve out the fragments (Dunbar 2009) while at other locations, the ongoing level of reestablishment is acceptable. Rototilling also dislodges the rhizomes and root crowns of aquatic plants, which can disperse and root either in new areas or re-establish in the newly cleared area where competition for resources has been removed.

3.2 Impacts to the Benthic Environment

Mechanical methods, with the exception of harvesting, disturb the hydrosol and therefore the benthic environment of the treated area. Rototilling, rolling, or chaining disrupt this habitat to a greater or lesser degree depending on the depth that the sediment layer is disturbed. These are the same impacts that are seen with dredging, which is a common activity. However, while the impacts of dredging are most often limited to a small area, rotovating would impact a relatively large area.

The benthic layer provides essential habitat for invertebrates and microbial populations on which other aquatic species depend. This layer also supports the growth of rooted native plants such as Northern watermilfoil, Elodea species, and other pondweed species.

3.3 Impacts to Water Quality

Disruption of the hydrosol by rototilling, chaining, or weed rolling, can lead to temporary, but potentially long-lasting increases in turbidity, depending on the particle size distribution of the hydrosol. Studies reporting impacts on turbidity from rototilling acknowledge that fine particles from silt, clay, or high organic content hydrosols will take more time to settle out and could travel longer distances from the treatment site, when compared to results from rototilling in sandy soils with larger, heavier particles (Dunbar 2009). For example, the average organic matter percentage determined from analysis for the Main, Marina, and Lake Tallac Lagoons were 10.1%, 9.4%, and 10%, respectively (TKPOA 2016a) with a large amount of organic content in the hydrosol from decomposed aquatic macrophytes, meaning that impacts from these mechanical control methods could be relatively long lasting.

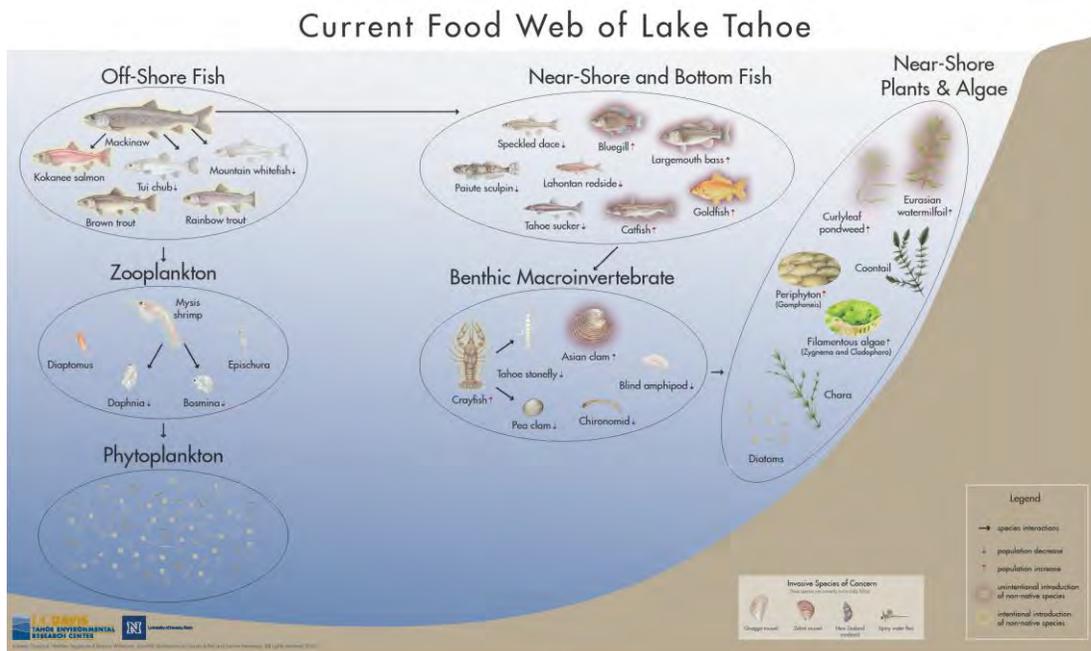
Turbidity is associated with higher levels of disease causing organisms, such as pathogens that can cause waterborne disease (Dunbar 2009; USGS 2016). The Okanagan Basin Plan has Best Management Practices (BMPs) that include ceasing operations if turbidity reaches unacceptable levels near municipal water intakes as standard disinfection may not be as effective for turbid water (Dunbar 2009). Increases in turbidity from silty soils could be problematic due to the slow dispersion of fine sediments with high organic content (Newroth 1986; AERF 2005).

Disturbing the sediment layer has the potential to release other elements into the water, depending on the existing characteristics. Elevated levels of phosphorous and aluminum in the hydrosols of the Tahoe Keys have been reported (CDFW 2004, TKPOA 2016a) therefore, the potential impacts to the surface waters of the Tahoe Keys lagoons should be studied before undertaking a project which has the potential to release harmful chemicals to the water (Gibbons 1988).

3.4 Risk to Fish

The aquatic animal communities of Lake Tahoe now consist of six zoobenthic taxa, five zooplankton species, and 14 fish taxa (Figure 6; TERC 2014). There are several non-native warm-water fish have been introduced to the Tahoe Basin for the purposes of sport fishing and other fish species have been introduced most likely through disposal of aquarium species into the waters. These non-native fish species include largemouth and smallmouth bass, bluegill, black crappie, brown bullhead catfish, golden shiner, common carp and goldfish. During a three-year Aquatic Plant Management Research Project (Ngai 2014) by University of Nevada at Reno (UNR) and California Department of Fish and Wildlife (CDFW), largemouth bass, bluegill and brown bullhead were the most prevalent species captured. Cold-water fish found in the Tahoe Keys during the UNR-CDFW study include the Mountain whitefish, Lahontan redbside, Lahontan speckled dace, Tahoe sucker, brown trout, rainbow trout and Lahontan Tui chub.

Figure 6. Current Food Web of Lake Tahoe



(Source: TERC, UNR)

Harvesting and rototilling can accidentally remove fish with the plant material and rototilling can disrupt spawning beds, remove fish cover, or directly harm the fish present (Dunbar 2009). However, overall, mechanical methods of aquatic weed control pose a low level of risk to fish populations, especially if there is a path of escape out of the treated area.

3.5 Compatibility with Current Use of the Tahoe Keys Lagoons

The Tahoe Keys is a mixed-use development with residential units and some commercial spaces. From the 1960s until the 1980s, the lagoons and waterways were largely clear and free of invasive weeds. Since the 1980s and the establishment of the weeds, the TKPOA has relied primarily on mechanical harvesters to remove aquatic plants. As of 2016, aquatic plant aerial coverage in the Tahoe Keys lagoons is approximately 90% (TKPOA 2016b). The primary use of the Tahoe Keys lagoons themselves is recreational boating and homeowners and occupants have private docks or have access to shared docks. Dense plant beds, similar to those found in the Tahoe Keys, can outcompete native plants for space and nutrients as well as damage the natural ecosystem by decreasing the water quality of the ecosystem, and pose as a safety hazard for boaters and impede navigation. The Tahoe Keys facility has some underground utilities and some of the alignments of the utilities are under the water of the lagoons.

Mechanical harvesting is currently used in the Tahoe Keys lagoons in order to maintain a sufficient Vessel Hull Clearance (VHC), the distance between the top of the plant canopy and the hull of a vessel. Encompassing other mechanical methods of aquatic plant control could not only improve current boat navigation in the lagoons by reducing the number of entangled boats but also potentially reduce the frequency of treatment.

In order to isolate and remove the plant fragments generated by mechanical methods, exhaustive screening and sieving must be done. Reduction of aquatic macrophyte biomass as well as free-floating fragments would improve the aesthetic character of the lagoons. Currently, the density of the weeds and subsequent algal growth cause the water to appear green/gray. If the method causes an increase in turbidity, the treated area should be isolated until levels return to acceptable limits. When disturbing the hydrosol, machine operators must avoid underwater obstacles which include pipelines, dock appurtenances, or debris such as lost anchors or other heavy objects. There are many areas in the Tahoe Keys lagoons with pipelines, other submerged obstacles, and constrained spaces between docks that prevent hydraulic cutting or tilling heads to maneuver and work efficiently.

3.6 Availability of Mechanical Equipment

The TKPOA has used mechanical harvesters for many years and this equipment is readily available. Rototillers are custom-made for Okanagan Lakes. One rototilling operator in Northern California has been identified, which is DK Environmental in Martinez. Weed rollers can be obtained from Crary WeedRoller PRO in North Dakota. Other efforts to identify suppliers or operators were not productive due to the limited and specialized (application-specific) nature of the equipment and operations.

4.0 SUMMARY AND CONCLUSIONS

There are many reports of mechanical control of Eurasian watermilfoil, the most prevalent of the aquatic invasive weeds. Control of this aquatic macrophyte is reported by others to last up to a year or more. There are fewer studies of control of curlyleaf pondweed by mechanical methods. This aquatic macrophyte might not be well-managed by mechanical means due to the persistence of the turions in the sediment layer and removal of the competing vegetation which could allow the turions to re-establish curlyleaf pondweed populations quickly.

Harvesting of aquatic plants will continue in the Tahoe Keys lagoons in future years. Other mechanical methods have limited application in the Tahoe Keys lagoons: rototilling could be used in relatively open waterways with few underwater obstructions where turbidity could be managed without interfering with boating traffic and where soil testing indicates that there is little or no risk of releasing toxic substances to the surface water. Weed rollers also have a limited application but could be installed by individual dock owners for small-scale management of aquatic plants. Small-scale testing of rototilling within the Tahoe Keys could produce important data regarding its cost effectiveness and efficacy for the control of plants specific to the lagoons.

5.0 ABBREVIATIONS AND ACRONYMS

AERF	Aquatic Ecosystem Restoration Foundation
BMPs	Best Management Practices
CDFW	California Department of Fish and Wildlife
Delta	Sacramento-San Joaquin Delta
IMP	Integrated Management Plan
LRWQCB	Lahontan Regional Water Quality Control Board
NPS Plan	Nonpoint Source Plan
OBWB	Okanagan Basin Water Board
SEA	Sierra Ecosystem Associates
SFEI	San Francisco Estuary Institute
TKPOA	Tahoe Keys Property Owners Association
USACE	United States Army Corps of Engineers
WDRs	Waste Discharge Requirements

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