Treatment Options and Engineering Controls for Aquatic Invasive Plant Mitigation

Prepared for

Tahoe Keys Property Owners Association

Draft Potential Treatment Options and Engineering Controls for Aquatic Invasive Plant Mitigation

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1 Executive Summary

As described in the 2016 Integrated Management Plan (IMP) for aquatic invasive plants, the Tahoe Keys Property Owners Association (TKPOA) has identified several objectives to be achieved through various control methodologies (1). The purpose of this report is to review specifically those potential control methodologies associated with the reuse and/or retrofit of the TKPOA's existing water treatment plant and circulation system, as well as the feasibility of implementing an impermeable barrier between the main lagoon and Lake Tahoe within the existing TKPOA West Channel which may, among other possibilities, provide for application of herbicide, dredging, or dewatering of the Lagoons by temporarily isolating the Lagoon from Lake Tahoe. The primary objectives identified for these control methodologies are the potential reduction of nutrients within the water column, thermal reduction of the Lagoon water body, and improved control of aquatic invasive plant fragments.

A brief summary of the control methodologies reviewed in this report, along with their relative assessment for feasibility, is included below:

Re-use of the Existing Water Treatment System (Clarifier and Circulation System)

- Biological Nutrient Removal (BNR) – While the existing water treatment system would lend itself to the conversion of a BNR process, the low nutrient concentrations in the Lagoon cannot reasonably be improved upon by current BNR technologies.
- Chemical-Physical Nutrient Removal – Because phosphorous is currently removed by chemical-physical processes in existing large scale operations elsewhere, this warrants additional consideration. It is possible, although not confirmed, that the Lagoon's phosphorous levels could be reduced despite being much lower than typical influent concentrations at existing chemical-physical nutrient removal operations. However, as described in section 2.1.B, phosphorous is probably supplied to the Lagoons via groundwater, in addition to other potential sources of the nutrient. Given this consideration, reducing phosphorous from the water column within the Lagoons may not prove advantageous depending upon the rate at which the nutrient is re-introduced via groundwater flow. Additionally, phosphorous would also need to be confirmed as the rate limiting nutrient within the Lagoons.
    - Capital Cost – $3,000,000 to $5,000,000
    - Operations and Maintenance Cost – $4,600 per day at 9.7 MGD
- Nitrogen Reduction – Nitrogen reduction was dismissed as nitrogen is not expected to be the rate limiting nutrient within the Lagoons, and current methodologies available for reducing nitrogen below its existing levels in the Lagoons are prohibitively expensive.

- Turbidity Reduction – the current Lagoon turbidity is at or better than the original design threshold of the clarifier system and as a result no improvement to the Lagoon turbidity is expected from reuse of the clarifier and water treatment system.

Use of Lake Tallac as a Facultative Treatment Pond

- Facultative ponds can achieve ammonia removal and reduction in wastewater strength (as measured by biochemical oxygen demand or BOD), however, they do not remove nitrogen or phosphorous at appreciable levels. Since facultative treatment provides little nutrient removal and would not improve upon the existing nutrient water quality in the Lagoons, this was not considered further.

Creation of Adjacent Wetlands

- Creating new sustained wetlands by pumping Lagoon water to the lands adjacent to the Lagoon – i.e. Pope Marsh to the west, or the Upper Truckee River floodplain to the east, appeared to have some merit initially. However, neither adjacent land owner is anticipated to be in favor of this land use, and this would also require the acquisition of new Lake Tahoe surface water rights. Subsequently this treatment option was not investigated further.

Re-use of the Existing Circulation System

- Thermal Reduction – Re-use of the existing circulation system for thermal reduction was considered. This would involve drawing (presumably) colder water from Lake Tahoe into the Lagoon via the circulation system and displacing the warmer Lagoon water back into Lake Tahoe or Lake Tallac. Because the water in Lake Tahoe immediately adjacent to the Lagoon is not cold enough to provide much benefit, a new deep water intake would be required at great cost. Both the economics and environmental impacts associated with this option result in the dismissal of Lake source thermal reduction.
    - Capital Cost - $3,520,000
    - Operations and Maintenance Cost - $30,00 to $60,000 annually
- Similarly, construction of a mechanical cooling system was also evaluated and quickly determined to be economically infeasible.
    - Capital Cost – $20,000,000
    - Operations and Maintenance Cost – NA
- Fragment Control – The circulation system has potential for re-use in fragment control, especially if coupled with new screening equipment to separate fragments from the water. This control mechanism warrants further investigation.
    - Capital Cost – $2,008,900

  - Operations and Maintenance Cost – $30,00 to $60,000 annually

Dredging and Dewatering

- Since both curlyleaf pondweed and Eurasion milfoil are rooting plants, much of their nutrients are derived from the benthic substrate, and the dredging and removal of this material therefore appeared promising. However, given the great surface area and resultant volume of material that would need to be removed from the Lagoon and disposed of outside the Tahoe Basin, the cost to complete the necessary dredging is prohibitively high.
  - Capital Cost – $23,905,700
- Similarly, it is not expected that the sediment removal could be accomplished through dewatering and mechanical removal (such as with loaders or graders as opposed to dredging) because of the difficulties in dewatering required to allow for a firm enough surface for equipment to operate on. A substantial volume of water would have to be continuously disposed of (estimated at a base flow rate of 1,356 to gallons per minute for a 9-foot drawdown) via multiple dewatering wells situated at several locations due to variations in the Lagoon bathymetry. It is uncertain at this time what impacts may occur to the existing bulkheads and other structures throughout the Lagoons under a loss of hydrostatic pressure due to dewatering and the physical removal of up to a foot of the benthic substrate. It is possible that differential settlement and subsidence could occur in areas adjacent to the Lagoon, and potential rotation or lateral slippage at bulkheads may also be possible. Additionally, the cost of disposal of sediment outside of the Basin is high and there is a concern that the removal would expose fine-grained soils that would not readily settle and require treatment for their removal.

Impermeable Barrier at West Channel

- Three options were considered for impermeable barriers across the West Channel: a frozen core dam, water inflatable cofferdams, and an impermeable curtain. These barriers could potentially add an additional measure of safety against the migration of herbicide into Lake Tahoe if employed whiled the hydraulic gradient is from the Lake to the Lagoons. These barriers may also facilitate a partial dewatering of the Keys.
- The frozen core dam, although the most watertight, is very costly and has been dismissed as a viable option.
  - Capital Cost – $2,444,725
- Inflatable cofferdams may have a small amount of leakage around the ends as well as through the sand under the dam. This leakage can be mitigated to a degree, and since the cost to purchase and install the cofferdams is reasonable, this impermeable barrier option warrants additional consideration.
  - Capital Cost – $325,500 for isolation only; $626,00 for 4’ drawdown

- Finally, a less costly and less watertight option is an impermeable curtain similar to a turbidity curtain. The leakage could be minimized; however, this curtain would be susceptible to significant leakage from inclement weather and is only a viable option for an impermeable barrier for short durations.
    - Capital Cost – $95,900

1.1 Preliminary Conclusions and Recommendations

While there initially appeared to be a reasonably achievable way to improve the Lagoon water quality via phosphorous removal, the probable introduction of additional phosphorous from groundwater inflow limits the likelihood of successful nutrient reduction. Further, reducing phosphorous levels (if achievable) is not expected to result in a reduction of rooting species of aquatic invasive plants due to their capacity to meet nutrient demands from the benthic substrate. If phosphorous removal could be achieved, there is some potential to reduce non-rooting aquatic invasive plants as well as to provide for reduction in the potential for algae blooms. Given this potential, the following items may warrant additional consideration and investigations as appropriate:

- Verify that phosphorus is indeed the limiting nutrient for plant growth. This will include bioassays to determine the phosphorous concentration at which plant growth is limited, as well as the plant species that are impacted by limited phosphorous.
- Quantify the actual value to the TKPOA of limiting the growth of un-rooted plants and algae. This is important as phosphorous removal may be expensive and is not anticipated to have an impacted on rooted aquatic invasive species.
- Because phosphorous is probably supplied via groundwater flow, effective phosphorous removal would have to be a continuous operation sized for the actual concentrations of phosphorous and rate of groundwater inflow. Quantifying both the rate of inflow and actual phosphorous concentration will, therefore, be necessary in order to properly size and design any new treatment works.

Additionally, water quality in the Lagoon may also be improved by implementing aquatic invasive plant species fragment controls. While fragment control does not address the main issue of aquatic invasive plant infestation, reducing their fragments from the water column provides a certain benefit of reducing the potential for their propagation elsewhere, including other areas beyond the Lagoon. The following items should be investigated further:

- Quantify the actual value to the TKPOA of fragment control (both in the lagoons and fragments that exit to Lake Tahoe). The treatment and circulation system evaluation shows that fragment control is potentially possible and the value needs to be determined to decide if it is economical.

- Perform a bathometric survey and/or reanalysis of LiDAR of the lagoons and Tallac Lagoon. This will determine volumes that will help with any treatment schemes and may be used to develop 2 or 3 dimensional hydraulic model.
- Develop a water model of the lagoons and circulation system to estimate mixing velocities with circulation and the mixing paths with various configurations or retrofits of the circulation system to optimize fragment control.

Finally, as there are viable options to provide an impermeable barrier on the West Channel to, on a temporary basis, isolate the Lagoon from Lake Tahoe, the following items should be investigated further:

- Quantify the surface water mixing between Lake Tahoe and the Keys – This is possible through recordation of water depth and velocity in the West Channel via Doppler equipment which TKPOA is now in the process of acquiring. This will help with the design of impermeable barriers as well as phosphorus removal.
- Perform additional detailed groundwater modeling to augment or build upon existing models performed by others (e.g. the USACOE groundwater model (9), or recent PCE plume fate and transport models) to better predict inflow to the Lagoons from groundwater. This will help with determining the actual water volumes that will need to be disposed of during isolation or partial dewatering, as well as an estimate of what level of partial dewatering is feasible. The eventual design and successful implementation of an isolation or partial dewatering plan will necessarily require better estimates of ground water inflow to the Lagoon.

2 Nutrient Reduction

2.1 Re-use of the Existing Water Treatment Plant

The existing water treatment plant consists of a large 117-foot diameter circular clarifier and mechanical building. The clarifier is about 15.8 feet deep and equipped with a rotary suspended rake and baffle, launders, overflow, and sludge collection line. The mechanical building previously was used to store water treatment chemicals including coagulants, as well as chemical injection pumps and other equipment. The treatment system was originally constructed primarily to reduce total suspended solids and turbidity (2). Water was pumped to the treatment plant from two primary pump stations and mixed with a coagulant within the clarifier. The clarifier allowed for the coagulant to mix with suspended particles and settle as floc, ultimately to be removed as sludge after dewatering in the sludge drying beds, which are also located onsite.

Nutrient reduction was the first item considered for the re-use of the existing water treatment system. Because plants require nutrients in order to produce biomass, it is assumed that if nutrients within the Keys could be reduced to a limiting point to prevent plant growth, the aquatic invasive plants could be reduced or potentially removed. Phosphorous and nitrogen are the primary nutrients required by aquatic plants for growth, and subsequently these two nutrients were looked at in detail for the prospect of nutrient removal. Because phosphorous generally occurs at lower concentrations than nitrogen it is often considered to be the limiting nutrient – meaning that reduction of phosphorous may provide greatest impact to reduction in plant biomass production (3). Similarly, because some types of algae are able to fix dissolved nitrogen gas, nitrogen reduction alone may not provide any beneficial impact to the water quality (3).

Total phosphorous occurs in the TKPOA lagoons at an average concentration of 0.030 parts per million (ppm), and has been discretely sampled up to a maximum concentration of 0.12 ppm (4). Orthophosphate, which is the form of phosphorous readily available for biological uptake, is present at an average of 0.013 ppm within the Lagoons. The background concentration of total phosphorous in Lake Tahoe is .00265 ppm (5), while total phosphorous is present at an average of 0.015 ppm in Lake Tahoe at locations nearer to TKPOA (4). Orthophosphate is at non-detectable (less than 0.01 ppm) levels at these locations (4). The groundwater aquifer which provides inflow to the Lagoons has a background phosphorous concentration of 0.039 ppm (9).

2.1.A Biological Nutrient Removal

Initially, reusing the existing water treatment plant was evaluated for various types of retrofitting and conversion into a biological nutrient removal (BNR) system. BNR systems use biological and microbial processes to reduce nitrogen and phosphorous, most commonly in wastewater treatment applications. While a BNR conversion appeared promising at first, given the extremely low antecedent nutrient levels for both phosphorus and nitrogen in the lagoons, BNR conversion was dismissed as current technologies are not expected to provide any additional level of nutrient reduction.

2.1.B Chemical-Physical Nutrient Removal

Large scale reduction of total phosphorous is readily achieved through a chemical/physical process of coagulation and filtration. The coagulation process includes adding a coagulant that chemically or physically binds the phosphorous which may then be precipitated out of solution, with greater efficacies realized by filtration of the precipitates from the solution. Coagulation alone may, under the right circumstances, achieve a level of 0.3 ppm and further reduction of phosphorous requires polishing by physical filtration and may reliably only achieve a concentration of 0.1 ppm (3). While this is still well above the background concentrations within the Lagoon, the rated performance of coagulation/filtration processes are almost entirely derived from wastewater treatment operations which have influent phosphorous concentrations of 3 ppm or greater – substantially higher than the concentrations occurring in the Lagoon. In other words, it is not uncommon for coagulation/filtration processes to remove 85% or greater of the phosphorous contained in wastewater. It is unknown at this time if large scale phosphorous removal operations are currently achieving concentrations less than those present in the Lagoon. However, assuming that typical phosphorous reduction rates can be extrapolated from antecedent phosphorous levels in the source water, it is expected that an 85% removal rate may be possible for the TKPOA Lagoon as well.

Assuming that an 85% removal efficiency is possible even for the Lagoon's relatively low average phosphorous concentration of 0.035, the effluent phosphorous concentration would be 0.0051 ppm. In order to provide a single treatment of the Lagoon volume at 1669 ac-ft. (2), almost 544 million gallons of water would need to be treated. At 85% reduction, this would equate to roughly 115 pounds of phosphorous to be removed. The clarifier is designed to handle a maximum of 14 MGD (6). A reasonable average clarifier flow rate for chemical precipitation is 900 gallons per square foot per day (7); that is 6,700 GPM or 9.7 MGD. Based upon information provided by the Ohio EPA (8), the total cost per million gallons for chemical-physical phosphorus removal is about $470, or approximately $4,560 per day at a flow rate of 9.7 MGD, and would require about 56 days to treat one Main (West) Lagoon volume at a cost of $260,000. While this is not entirely appropriate for a surface water treatment operation, it does provide a benchmark for the potential cost of initial phosphorous removal.

A study performed by the U.S. Army Corps of Engineers determined that phosphorous is supplied to Lake Tahoe through the area of the Tahoe Keys via groundwater interflow at an estimated average annual rate of 475,000 gallons per day; further much of this groundwater enters the Keys Lagoons (9). Coincidentally, the phosphorous concentration in the aquifer was quantified in that same report at 0.039 ppm, remarkably close to the Lagoon's existing phosphorous concentration. Treating groundwater interflow at this rate (approximately 330 GPM or 0.48 MGD) would cost an estimated $81,000 annually. As described above, in order to achieve the higher rates of phosphorous reduction, a filtration plant would need to be constructed near the clarifier in order to provide the additional phosphorous removal afforded by filtering out the chemically precipitated phosphorus. A new deep bed filter, along with the necessary treatment plant upgrades including chemical storage, seismic retrofits and verification of the operational capacity of the existing equipment, could cost as much as $3 to $5 million dollars (8).

Because the existing clarifier could readily lend itself to the process of coagulation, this treatment option warrants additional investigation. However, the potential for overdosing of a coagulant which could in turn contaminate the Lagoon is a risk. Common coagulants used in this application, such as lime, alum, ferric chloride, or polymers may present water quality concerns of their own if they were allowed to contaminate the Lagoon (10). In addition, coagulation produces a sludge which must be disposed of outside of the Tahoe Basin. Further, it should be conclusively determined that phosphorous is indeed the rate limiting nutrient for invasive plant species, and perhaps more importantly, determination of the concentration at which phosphorous becomes limiting must also be determined. Additional investigations should include a bioassay to determine the limiting concentration, then potentially a bench scale treatment tests to ascertain the reduction in phosphorous concentration reasonably achievable through coagulation and filtration.

It must also be mentioned that the reduction of nutrients within the water column likely will not impact the propagation or production of biomass of rooting plants, as these organisms are capable of deriving their required nutrients from the benthic layer via roots (11). In fact, sediment sampling in the benthic layer was employed at ten different locations within the Lagoon in both May and October of 2016. The sediment samples obtained in May indicate that, on average, ammonia (nitrogen source) was present in the benthic layer of the Lagoons at a concentration of 44 mg/kg (parts per million), while phosphorous was present at an average concentration of 118.5 mg/kg (12). The October samples had average concentrations of phosphorous and ammonia of 183.6 mg/kg and 51.8 mg/kg, respectively. Ammonia and phosphorous, at these concentrations, are sufficient to sustain rooted aquatic plants regardless of the dissolved nutrient concentrations (or lack thereof) within the water column (13).

This means that both Eurasian watermilfoil and curly-leaf pondweed are not expected to be impacted by the reduction of dissolved nutrients within the lagoons. Potentially those invasive plants that do not have root structure, e.g. – Coontail, could be effectively reduced if nutrients are identified to be the limiting factor for their propagation. Reducing nutrients in the water column has the added benefit of reducing the potential for algae blooms. Again, similar to other aquatic species, phosphorous is expected to be the limiting nutrient as algae are capable of fixing nitrogen gas dissolved in the water column, most probably from atmospheric deposition (3). Since nutrient reduction is not expected to impact the rooted aquatic invasive species it will be imperative to assess the relative value to TKPOA to pursue nutrient reduction on the basis of other water quality goals and should not be given precedent as a control method for the two primary species of concern as noted above.

2.1.C Nitrogen reduction

The reduction of nitrogen was similarly reviewed with respect to re-use of the existing clarifier and water treatment plant. Total nitrogen occurs in the TKPOA lagoons at an average concentration of 0.37 ppm, of which 0.36 ppm on average is comprised of total Kjeldhal nitrogen, while oxidized nitrogen, consisting of nitrates and nitrites, is present on average at a concentration of 0.04 ppm (4). Ammonia is not present in detectable concentrations, which means that the majority of the nitrogen concentration occurs as organic species in the Lagoon water which are not readily available for biological uptake (3). Lake Tahoe nitrates, as of 2015, were at an all-time high of 0.02 ppm (5). Reduction of oxidized nitrogen concentrations below the antecedent water quality is not expected to be practical or economical, requiring expensive technologies such as reverse osmosis or distillation. Similarly, and more importantly, for the reasons described above nitrogen reduction is not expected to be effective at reducing invasive plant growth, and is therefore not considered further.

2.2 Use of Lake Tallac Lagoon for Treatment Lagoon

Lake Tallac Lagoon sits generally just to the south of TKPOA Lagoons. The lake consists of approximately 23 acres of surface area as measured from aerial photographs and holds about 292 acre feet of water (2). Mechanical gates allow for emergency spilling of water into the Keys Lagoons during periods of high runoff and flooding and a lateral weir located on the west shore adjacent to Pope Marsh similarly allows for overtopping of flood waters to spill out of the Tallac Lagoon; otherwise the Lake Tallac Lagoon is a hydraulically isolated water body. Because of Tallac Lagoon's nearness to the Keys Lagoons and hydraulic isolation, it was considered for conversion to a treatment lagoon.

While facultative lagoons can greatly reduce the strength of municipal wastewater, they would offer no improvement to the existing water quality of the Keys Lagoons as neither phosphorous nor nitrogen would be reduced. Potentially nutrient uptake by biomass (e.g. growth of algae) could be implemented in this lagoon. Water from the Keys Lagoons could be pumped to this Lagoon and then the nutrients in the water could be reduced by cultivating algae. The algae biomass would be harvested and disposed of outside the Basin. The water with reduced nutrient content would be returned to the Keys Lagoons. However, the production of objectionable odors, vector management issues, water color, and loss of suitable fish and wildlife habitat would all be substantially negative aesthetic impacts to property owners adjacent to Lake Tallac. Given these considerations, as well as having no impact on the rooted aquatic invasive species described above, this treatment option was summarily dismissed.

2.3 Creation of Adjacent Wetlands

The development or improvement of wetlands on adjacent lands for biological water treatment, including nutrient removal and TSS removal was considered. There exist suitable lands on both sides of TKPOA for the development of new or improved wetlands: Pope Marsh to the west, and the Upper Truckee River floodplain to the east. In this treatment option, water would be drawn from the Lagoons and pumped overland to the adjacent lands in a controlled, low velocity and shallow sheet flow. As the water would flow overland it would achieve natural attenuation of suspended solids and nutrient reduction as the native vegetation produced new biomass and further reduced flow velocity. Prior to reaching the Lake much of the flow would be percolating through the upper ground, allowing for natural filtering of suspended solids and attachment to soil of some other dissolved constituents. Because water would be continuously supplied to the new wetlands, this would have the added benefit of sustaining the wetlands during times of drought when they might otherwise be dry.

The United States Forest Service, the landowner of the adjacent Pope Marsh, is opposed to the discharge of Lagoon water for land application and so the creation or improvement of wetlands to the west of TKPOA is not viable (14). The California Tahoe Conservancy, the landowner of the adjacent Upper Truckee River, produced an Environmental Impact Report (EIR) for the Upper Truckee River Wetlands Restoration (15). The EIR presented four alternatives that were reviewed to find potential areas for cooperation that might benefit the CTC as well as the TKPOA goal of aquatic invasive plant reduction. All alternatives are for the restoration of the existing wetlands and not the improvement of wetlands or generation of new wetlands. These alternatives for cooperation indicate that the CTC does not desire to add any new water to the wetlands, including water from the Lagoons.

This is further complicated by the loss of some water due to evapotranspiration during overland flow which, in addition to the difficulty of quantifying the amount of lost water would also require the acquisition of a commensurate amount of Lake Tahoe surface water rights at potentially great cost – being estimated at approximately $15,000 per acre foot[1] (16). As a very gross estimate, Lake Tahoe loses an annual average of 46 inches per year to evaporation, which is typical of open water evaporation for most lakes in the Sierra portion of the Truckee River Watershed (17). Assuming that an average of 20 acres of open water within the new wetlands might be developed, as many as 76 acre-feet may be lost annually to evaporation alone, at an estimated cost of $1.15 million dollars. Given the lack of interest of the adjacent landowners, the need for acquiring surface water rights, and likely having no impact to the rooted aquatic invasive plant species, this treatment option is not considered viable.

[1] Based upon 2007 cost of $13,250 per acre foot.

3 Engineering Controls

3.1 Re-Use of the Circulation System

The existing circulation system, a substantial network of underground piping and valves, culvert lift stations, and two main pump stations, was originally intended to provide circulation and mixing within the lagoon presumably in an effort to improve water quality by decreasing turbidity, preventing stagnation and increasing mixing. The main pump station in the Lagoon has a nominal capacity of 24,000 GPM, while the Marina Lagoon pump station has a nominal capacity of 5,000 GPM (2). These two pump stations were used to draw water from their respective lagoons and pump to the existing clarifier where a coagulant was added. The existing clarifier, with a capacity of up to 14 MGD (6), was originally intended to reduce total suspended solids and turbidity within the Lagoon. Lake Tahoe turbidity occurs at an average of 0.21, but is present in the TKPOA lagoon at an average of 1.21 FNU (4). The clarity in the Lagoon is presently better than the original design threshold for the clarifier (2), so the re-use of the clarifier and circulation system is not expected to provide an improvement to turbidity levels.

3.1.A Thermal Reduction

Temperature has a significant effect on aquatic plant biomass production and plant propagation (11). The aquatic invasive plants in the Lagoon begin to experience a substantial increase in their rate of growth when the water temperature warms with the onset of spring. Reducing the water temperature of the Lagoon may provide for a reduction in plant growth (biomass production), or at least a reduction in the rate of plant growth (11), and a water temperature of 14°C (57.2°F) or less may begin to inhibit the rate of biomass production (18), although much colder water temperatures are probably required to have a significant impact on plant growth (11). While the invasive plant species have adapted to cold water environments like Lake Tahoe, as evidenced by the occurrence of invasive plant species in the bottom of the West Channel which has a bottom water temperature of about 14°C (4), the potential for reduction in the rate of growth of these invasive plants warranted additional investigation methods to reduce the water temperature.

The circulation system was evaluated initially for its potential to provide temperature reduction within the lagoon system. Because of the relatively warm waters in Lake Tahoe adjacent to the Lagoon (4), circulating water from the near-lake into the Lagoon will have essentially no thermal reduction impact. Therefore, a deep water intake was considered which would draw cool water from deeper in Lake Tahoe and circulate it within the lagoon. A deep water intake would consist of a ballasted HDPE pipeline extended outward from the Lagoon into the deeper (and cooler) waters of Lake Tahoe. A new deep-water intake sized for the Lagoon pump station capacity of 24,000 GPM, is determined to require a 36-inch diameter HPDE pipeline. The pipeline would need to be extended to an estimated depth of 150 feet in order to achieve consistently cool water (approximately 50-55°F) (5), requiring nearly 3,800 lineal feet of new pipeline based upon available USGS bathymetry. The estimated cost to construct this new intake is approximately $3,520,000. While construction of a new intake is physically feasible, the higher cost to construct the intake, together with the reality that colder water pumped into the lagoon would ultimately displace warmer water from the Lagoon back out into the Lake and develop a net outflow of warmer (and lesser quality) water from the lagoon make this alternative infeasible. Further, while reducing the water temperature may reduce the biomass of aquatic invasive plants, it is not expected to eliminate them from the Lagoons.

3.1.A.1 Mechanical Cooling

In order to cool the Lagoon's estimated volume of approximately 1669 ac-ft (2) at an assumed flow of 9.7 MGD, with a reduction in temperature from 18.9°C (66.02 °F) (4) to 14°C (57.2°F) would require about 2,500 tons of cooling. However, this is estimated to be insufficient to provide net cooling of the Lagoon due to thermal mixing with the rest of the Lagoon and the Lake. It would take approximately 56 days to provide for a complete turnover of the Lagoon at this flow rate. If the cooling system were sized to match the flow rate of the available pump stations, say 24,000 GPM, then an equivalent cooling tonnage of 8,800 tons would be required. Assuming an average electricity price of $0.13 per kW-hour, this system would cost approximately $8.6 million dollars to run for 90 days during the warmer summer months. Based upon industry publications (19), for cooling plants greater than 4,000 tons in capacity, average capital costs to construct range from between $2,300 and $2,900 per ton. Assuming the lower end, a new cooling plant would cost approximately $20 million to construct. Given the tremendous capital and operational costs, mechanical cooling was summarily dismissed as a viable engineering control.

3.1.B Fragment Control

The circulation system was also reviewed for use with aquatic invasive plant fragment control. Because the fragments of some invasive plants can propagate into viable organisms and are small enough to be distributed in the water by wind and current, control of fragments is an important consideration (13). Given the circulation system's relatively large hydraulic capacity, it may be possible to create general velocity gradients that could assist in fragment collection.

Additionally, the pump stations could be used to deliver fragment laden water to a new screening system where fragments could be collected for disposal. Given the general feasibility of this use, the next steps should include quantifying the relative value to the TKPOA for fragment control and evaluated against the anticipated cost of a fragment collection and disposal system. A simple system may consist of a series of static screens with manual cleaning; a more complex system could consist of automated rotary screens with mechanical cleaning. While capital, operations and maintenance costs will vary with design and the type of system employed, it is expected to generally cost less than $2 million dollars to construct and perhaps $250,000 to operate, annually. A preliminary estimate of probable cost is included in the Appendix.

If fragment control is determined to be of sufficient value to warrant further investigation, then hydraulic modeling of the lagoon using computational fluid dynamics (CFD) should be undertaken, including a detailed bathymetric survey or reanalysis of existing LiDAR. The CFD analysis will assist in determining the achievable velocity gradients for collecting fragments, as well as a determination of the efficacy of the system to operate during precipitation and wind events. The analysis will also assist in determining what modifications to the circulation system are necessary and where the most appropriate location of new infrastructure – e.g. intake weir structures, will be. The circulation system will also need to undergo operational tests and investigations to determine actual capacities and determine if any repairs are necessary. Similar to the water treatment plant re-use alternative, if the existing clarifier is to be re-used in conjunction with fragment control, it too will need to undergo operational testing and potentially seismic retrofitting.

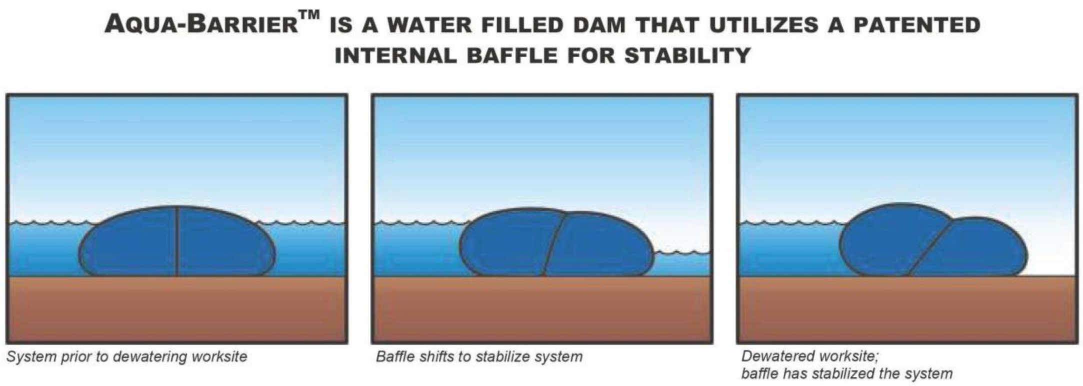
Because invasive plant fragments are generally of neutral buoyancy (neither sink nor float), the use of the clarifier is not expected to be the most efficient means of separating invasive plant fragments. However, if removal of invasive plant fragments is critical we recommend laboratory bench tests with typical TKPOA invasive plant fragments and treatment with various chemicals as well as dissolved air to promote either settling or floating. As described above, while the clarifier appears to be in relatively good condition, it is expected that seismic investigations, and potentially a seismic retrofit, will be required in order to comply with current codes. Additionally, much of the clarifier's mechanical components and intake pumps have not been run in several years, and a thorough vetting will be required and potentially a substantial repair effort may be required to bring the system into operation.

3.2 Impermeable Barrier

There are two primary impermeable barrier concepts that might be utilized at the West Channel. A profile of the West Channel is included in the Appendix. One concept would potentially allow for full or partial dewatering of the Keys and another one that only isolates the surface water of the Keys from the surface water of Lake Tahoe.

3.2.A Impermeable Barrier Allowing Full or Partial Dewatering

For an impermeable barrier that allows full or partial dewatering[2] two options have been considered: inflatable cofferdams and a frozen core dam. An inflatable cofferdam is two or more parallel plastic tubes inside a single fabric sleeve as illustrated below.



The plastic tubes are filled with water so that they extend above the adjacent water surface then the weight of the inflatable cofferdam retains the water on the one side and no foundation or anchoring is necessary. The installation would involve removing any sharp objects from the area, floating the pre manufactured and rolled dam into place in the West Channel, then inflating it with Lake Tahoe water using a pump. After installation, the Tahoe Keys might be dewatered by pumping.

Removal would be to first equalize the levels in the Keys and Tahoe; followed by pumping the water out of the inflatable dam back into Tahoe; towing the deflated dam to shore and lifting it out of the water and rolling it for future use. Installation and removal should require approximately 2 days each.

Preliminary engineering calculations have determined that for complete dewatering two separate dams would be required with each holding back approximately half the water depth or approximately 8.5 feet each at high Tahoe water level. At low Tahoe water level two dams would still be required but they would hold back approximately 5.5 feet each.

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[2] Dewatering will require continual pumping to remove groundwater that enters the lagoons. The required pumping rate is considerable and disposal of the pumped water is a concern as discussed elsewhere in this report.

In accordance with the Engineer's Estimate included in the Appendix, the initial purchase of the dams is estimated to be $310,000. Installation; maintenance of the dams for 20 days; partial dewatering; and removal is estimated to be $316,000 for a total of $626,000. All of these amounts include a 30 % contingency but do not include repairs to the circulation system (if any) or soft costs such as design and permitting. The inflatable cofferdam could be reused many times if stored indoors and carefully removed.

A Frozen core dam would involve excavating native sandy material and placing it in the West Channel then inserting refrigerant tubes and freezing the core of the dam as well as the underlying sandy material. Because this makes the sandy material under the dam as well as the dam watertight there will be lesser leakage. However, the cost to construct a frozen core dam (with a 30% contingency) is approximately $2,444,000 per the estimate of probable cost in the Appendix.

This cost is much more than an inflatable cofferdam. Further, because a frozen core dam will involve moving earthen materials within Lake Tahoe the permitting will be more difficult and construction times longer. It is noted that the major cost of this alternative is moving the native sandy material to build the unfrozen dam and not the cost of freezing it. Because of the expected groundwater infiltration as discussed below pumping will be necessary. Given that there will be pumps in place the pumping of the additional water that might leak past an inflatable cofferdam will not be significant.

If the Tahoe Keys were to be partially or fully dewatered groundwater is expected to enter the lagoons. In accordance with hydrogeological principals the rate at which groundwater enters depends upon many factors including: Tahoe's level; the groundwater level; the relative drawdown of the lagoons: and the properties of the soils. The best estimates might be obtained with a detailed and calibrated model. However, such a model would take significant time to complete and is beyond the scope of this investigation. Instead, a gross estimate using a more simplified model (20) has been made. This model requires inputs of the saturated horizontal and vertical conductivity; the relative drawdown; size of the lagoons; and the radius of influence of the groundwater surface elevation. The estimated values of the saturated horizontal and vertical conductivity are presented in the U.S. Army Corps of Engineers 2003 groundwater study (9)[3]. The other inputs are determined based on the physical dimensions of the Keys and engineering judgement. The model determines the following inflow rates that vary with the drawdown levels. Because these estimates come from a rough

[3] K_v = 0.5 ft/day and K_h = 50 ft/day for the Tahoe Keys area.

and uncalibrated model, based upon engineering judgement, it is appropriate to apply a factor of safety of 3 to the numbers below.

Drawdown (ft)	1	2	3	4	5	6	7	8	9	10
Inflow (gpm)	402	521	640	760	879	998	1,118	1,237	1,356	1,475
Total Over 20 Days (af)	36	46	57	67	78	88	99	109	120	130

Groundwater will have to be pumped to maintain the dewatered level. It is expected that this water will be pumped into Tallac Lagoon because the water quality is not expected to meet the background quality of Lake Tahoe based upon the groundwater quality presented in the Lake Tahoe Basin Framework Study Groundwater Evaluation (21). Seasonal variations in precipitation levels generally produce more favorable conditions for dewatering during late summer and early fall, which could create conflicts with recreation and uses of the Lagoons, while dewatering during the winter or early spring may occur during higher runoff periods and potentially higher groundwater levels.

3.2.B Impermeable Barrier for Isolation

For only isolating the water in Lake Tahoe from that in the Tahoe Keys we recommend either inflatable coffer dams or a turbidity curtain. If an inflatable coffer dam is used the level in the Keys could be maintained several inches lower than that in the Tahoe allowing for no net leakage even if there are sudden changes in the Lake level from winds. With the inflatable cofferdam option water would be pumped from the Keys into Tallac lagoon to maintain the lower level in the Keys. The pumping rates are those estimated above for dewatering. Because these estimates come from a rough and uncalibrated model, based upon engineering judgement, it is appropriate to apply a factor of safety of 3 to the numbers above. Because the inflatable dam will only be maintaining a small difference in water elevation only one inflatable dam is required. In accordance with the engineer's preliminary estimate of probable cost in the Appendix, the cost of the initial purchase, installation, maintenance of the dam for 20 days, partial dewatering, and removal is estimated to be a total of $325,000. All of these amounts include a 30% contingency but do not include repairs to the circulation system (if any) or soft costs such as design and permitting. The inflatable cofferdam could be reused many times if stored indoors and carefully removed.

A less costly and also less watertight option is an impermeable curtain similar to a turbidity curtain. The leakage could be minimized by maintaining a small current from the Lake into the Keys through pumping at varying flow rates from the Keys to Tallac Lagoon. An analysis of the Lake Tahoe level data over the last 20 years as maintained by USGS has determined that the maximum drop in Lake Tahoe levels over a 20-day period is 0.7 feet and the maximum drop in one day is 0.01 feet. These are reasonable volumes and flow rates that could be conveyed to the Tallac Lagoon by pumps and stored there until the water infiltrates. However, if the level of Tahoe drops suddenly (in a matter of hours) because of winds the pumps may not keep up with the changes and there may be some leakage past the edges of the curtain.

In accordance with the engineer's preliminary estimate of probable cost in the Appendix, the cost of the initial purchase, installation including anchoring, maintenance of the curtain for 20 days, maintenance of a current from Tahoe to the Keys, and removal is estimated to be a total of $96,000. All of these amounts include a 30% contingency but do not include repairs to the circulation system (if any) or permitting. The curtain could be reused many times if stored indoors and carefully removed.

3.3 Dewatering and Dredging

It is speculated that much of the aquatic invasive plant problem might be abated by removing at least the top 12 inches of soil and plant debris in the bottom of the Lagoon. If this were to be completed as dredging with the water in the lagoons the estimated cost including dredging, dewatering of dredged material, and disposal outside of the basin is over 24 million dollars as presented in the engineer's preliminary estimate of probable cost in the Appendix. Therefore, it is not economically feasible. There is also the concern that the dredging could expose fine sediments that do not readily settle and could require treatment for removal at an additional cost. Stratifications and other bathymetric variations in the Lagoons create complexity for siting of dewatering wells. Potential variations in groundwater inflow at locations throughout the Lagoons may create further complexity for establishing an effective dewatering regimen.

Lagoon bottom sediment removal through dewatering and mechanical removal (such as with loaders or graders) was considered. This would require complete dewatering to at least one foot below the proposed lagoon bottom elevation to allow a firm enough surface for equipment to operate on. In accordance with the above estimates of groundwater inflow complete dewatering for 20 days, if completed at low water, would require disposal of up to 360 acre feet of groundwater (120 acre feet times a factor of safety of 3). This is more than the available capacity in the Tallac Lagoon and the quality is expected to not be sufficient for discharge into Tahoe. Therefore, there are no areas where this quantity of water could be disposed of. However, dewatering of a portion of the Lagoons each year may be possible with disposal to Tallac Lagoon.

Dewatering and mechanical removal of 1 foot of material with disposal outside of the Tahoe basin from one-fourth of the lagoons each year for four consecutive years has an estimated cost of over 23 million dollars as presented in the engineer’s preliminary estimate of probable cost in the Appendix. Therefore, it is not economically feasible. There is also the concern that the mechanical removal could expose fine sediments that do not readily settle and could require treatment for removal at an additional cost.

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5 Appendices

5.1 West Channel Profile

5.2 Engineer's Preliminary Estimate of Probable Costs

5.2.A New Deep Water Intake for Thermal Reduction

5.2.B Inflatable Cofferdam for Dewatering

5.2.C Frozen Core Dam

5.2.D Inflatable Cofferdam for Isolation

5.2.E Impermeable Curtain

5.2.F Dredging of the TKPOA Lagoon

5.2.G Screening Improvements