I. Introduction

In preserving the beauty, serenity and recreational value of small lakes and ponds in the Sierra Nevada Foothills, residents face unique challenges in managing these natural resources as well as their individual properties. In order to ensure the continued aesthetic and recreational value of their lake, residents must seek a balance between their intended uses, and the existing biotic communities and processes that affect water quality.

Many communities create lake management plans (LMPs) that outline their goals and policies governing actions in and around their lakes. These LMPs often focus on the intended uses of the lake but necessarily include aspects of watershed management and support for the existing biotic communities that are required for clean water and a healthy ecosystem.

From the time a lake is formed, either by nature or man, it will gradually fill in with sediment. These sediments carry with them nutrients that intensify the growth of aquatic life forms; these plants, algae, bacteria and animals will in turn die and add to the layers of sediment at the bottom of the lake. Over the course of years, decades, and even millennia, a lake becomes increasingly shallow until eventually it fills in completely with sediment. This process of *aging* is called succession and it is brought on in part by eutrophication, an increase in the concentration of nutrients in the water column (Lawrence and Jackson, 1998). Without proper management (with few exceptions) lakes will eventually succumb to this natural cycle and disappear (Carpenter, 1981).

II. Study Area

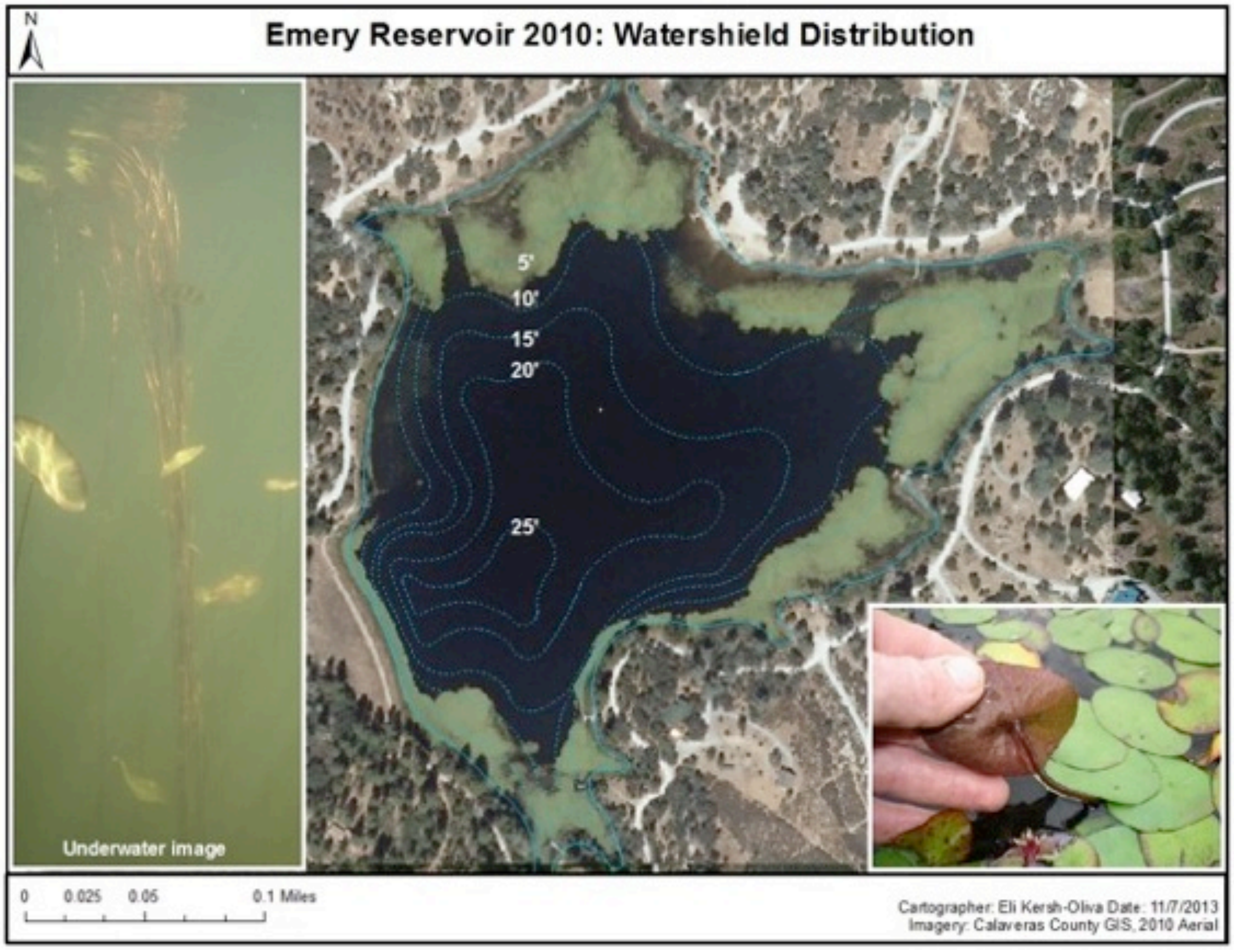
Emery Reservoir (Picture 1) is a privately owned, man-made reservoir within the M-24 Ranch Association located in the Sierra Nevada foothills of California. This reservoir has progressed through the stages of eutrophication and now the overgrowth of aquatic plants has begun to interfere with boating, fishing, swimming, and other intended uses. If the residents and property owners of M-24 desire its continued use, they will require an LMP that addresses the site-specific causes of eutrophication.

Picture 1: Emery Reservoir, 2013

Prior to 1965, the watershed surrounding the lake was relatively undisturbed by development. Since then, dozens of homes and roads have been built within the watershed. Coinciding with this development was the progression of the lake along the continuum of eutrophication. Over the last 25 years, the increased abundance of aquatic plants began to interfere with the recreational and aesthetic value of the lake. Various methods of control were employed to combat plant overgrowth only to find those infestations regrown or replaced by different species the following season.

History of Aquatic Plants in Emery Reservoir

The members of the M-24 Ranch Association have been attempting to control the spread of aquatic plants for the last two decades. Their primary concern has been the overgrowth of Watershield (Bresenia shreberi), a perennial rhizomatous herb with floating leaves that is rooted on the lakebed. It can be identified by a coating of mucus on the petioles (stems) and a dark reddish-colored underside to its oval-shaped leaves.



Map 1: Distribution of Watershield in 2010

Additionally, the petiole attaches to the center of the leaf, which is another important characteristic that distinguishes it from similar-looking plants like Fragrant Water-lily (Nymphaea odorata) or Yellow Floating Heart (Nymphoides peltada) whose petiole attaches at the leaf's perimeter (Map 1 – pg 4).

Some members of M-24 believe that Watershield was introduced to the lake in 1993 by a firefighter helicopter's water bucket, though early visitors to the lake recalled that a Waterlily type plant was present in the 1940s, and that it interfered with swimming in Shady Cove, and Coot's Cove (more detail is included in Appendix C).

Watershield is a native Californian plant that has been observed throughout most of the United States, southern Canada and elsewhere. It can establish itself in slow-moving water, lakes and ponds up to a depth of 10 feet. Its growth season starts in May, it typically blooms white flowers between June and September, and dies off in late fall or in winter (DiTomaso et al., 2003). Watershield propagates by seed, plant fragments, and a vegetative rhizomatous rootstalk. Rhizomes technically are not roots; rather they are modified stems. Rhizomes branch out underground perpendicular to the shoots, as they grow laterally they will sprout multiple new shoots. Unlike plant roots, when a rhizomatous rootstalk is cut and fragmented into pieces it retains the ability to sprout new shoots and develop into a new plant.

Naturally, many plants are transported to waterbodies via waterfowl that spread undigested seeds or carry fragments of the plant stuck to their bodies and feet. Additionally, humans can also be responsible for transporting plant fragments and seeds if they are stuck to boots, watercraft, or other equipment. Watershield is present in abundance in several ponds and small lakes near Emery Reservoir, primarily to the southeast. If the plants were not already present in Emery Reservoir prior to 1993, it would have likely been transported eventually via waterfowl or human activity.

The State of California classifies Watershield as "Imperiled" and the California Native Plant Society has listed the plant as "rare or endangered". It is not known to cause infestations in canals or agricultural fields like other plant species that the state deems invasive (CNPS, 2012). This indicates that there is something unique to Emery Reservoir that allows the Watershield to become so abundant.

Past Management Activity

There are no published studies or reports about Emery Reservoir; some documentation was obtained from Board meeting minutes and from individual members who kept records, receipts and other materials detailing efforts undertaken by volunteers and property owners to eliminate the plant. At one point the HOA purchased a mechanical cutting device to mount on a rowboat and attempted to harvest the plants themselves. Unfortunately, due to the resilience of the rhizomes, the cutting may have only exacerbated the spread and density of the plants. There were also reports that individual residents tried spraying herbicides though there is no documentation of these activities and it is likely that these were small in scale and lacked a systematic approach thereby producing limited success.

In July of 2003 the HOA created a Lake Action Committee (LAC) to research "known options for lake improvement, and to learn more about the state of the lake." (M-24 Board

Meeting Minutes, July 2003). The "known options" included physical and chemical methods of altering the lakebed and/or water to remove the plants or reduce the spreading. To do this the LAC contacted several companies to submit proposals: Aquatic Environments, Duck Ponds Unlimited, and Aquatic Solutions.

Duck Ponds Unlimited (DPU) visited the lake that July. Their proposal was for a method called solarization. This is an aggressive method to control the growth of plants by lowering the water level of a lake and covering the exposed areas with plastic sheeting, which would raise the soil temperature to a sufficient heat to sterilize the soil and indiscriminately kill all species of plants. DPU further summarized the cost-benefit analysis of several other methods of plant control, these include:

1. Hand and/or mechanical removal of plants.
2. Lake drainage and/or dredging sediment from the lakebed.
3. Dye the water to limit sunlight penetration.
4. Chemical and biological controls to reduce nutrients.
    a. Alum – precipitate phosphorus and trap it in the sediment.
    b. Addition of bacteria to compete with plants for nutrients.
    c. Species introduction such as grass carp.
    d. Herbicides

In addition, the Company suggested creating a vegetation management and monitoring program to replant desirable species to prevent the reestablishment of invasive plants in the future. They further recommended hiring a full or part-time lake manager as key for the successful long-term health of the lake.

Aquatic Environments, Inc. visited the lake in September of that same year and was asked to provide a proposal for mechanical means of management. They proposed an annual management contract that included a combination of plant mowing and harvesting, herbicide use, and dredging. In addition to these in-lake methods the company also identified the watershed inflow areas that were "extremely silted in … as a result of years past inflow and storm events washing out sediment into the lake", and recommended repair of and redesign of drainage areas and creeks.

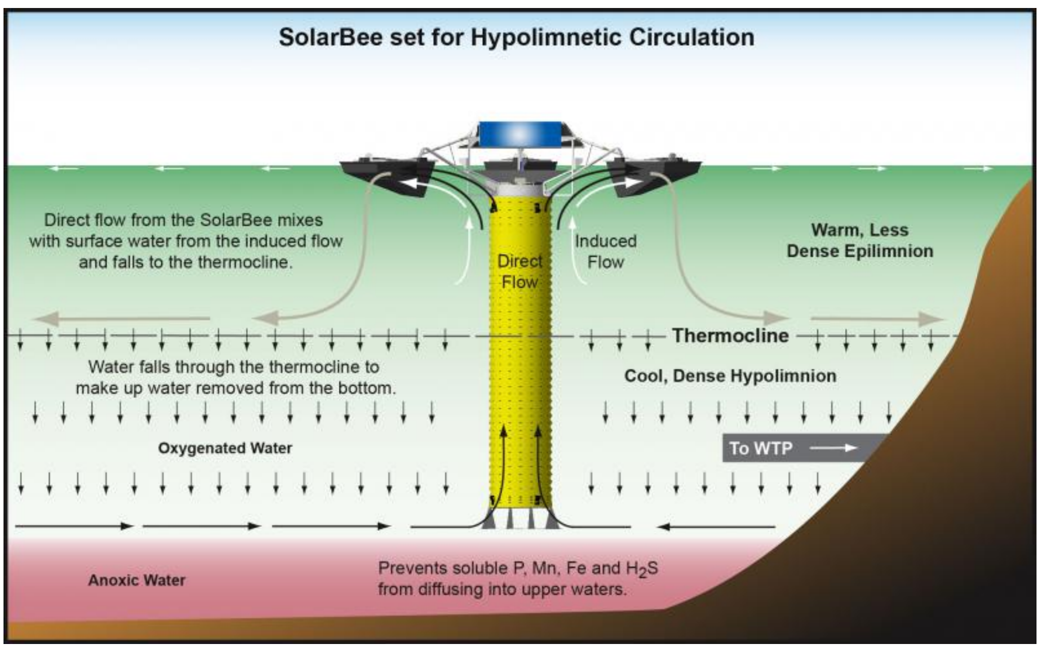
Aquatic Solutions, LLC. visited the lake in the Fall that year as well, and its proposal was ultimately the one chosen by the board. Dr. Chistopher Knud-Hansen, Ph.D., visited the lake in October and conducted water quality tests while there. He observed that the lake appeared "mature" with "extensive aquatic macrophytes growth". His water chemistry measurements revealed low levels of nutrients (nitrites and phosphates) in the water column and very low levels of dissolved oxygen on the bottom of the lake. His conclusion was that the lake was experiencing poor turnover and that low dissolved oxygen resulting in a buildup of nutrients in the sediment was likely the cause of the overgrowth of Watershield.

His recommendations for combating the overgrowth were a set of substrate modifications, including:

1. Competition for substrate: Distributing Stonewart (Chara spp.) around the lake. Stonewart is a submersed mat forming algae that looks like a plant and currently exists in the lake. It can be seen around the docks and shores growing in waters up to two or three feet deep. It was observed that in areas where mats had formed, Watershield was unable to sprout. One drawback to this method is that Watershield can grow in much deeper water (10') than stonewart, and therefore the competition would only be effective in areas shallower than two or three feet.
2. Substrate barrier: Areas for swimming and fishing and other selected spots could be covered with a porous or loose weave synthetic material known as a weed barrier and covered with sand (the material must be porous to allow for gases to escape). The barrier would extend to about six or seven feet in depth, but would not extend any further. This method would negatively affect the ecology of the treated locations but the remainder of the lake would be unaffected. This would be a more permanent method and the sandy substrate would make it more difficult for plants to root, and if they did they would be easier to remove.
3. Substrate aeration: Dr. Knud-Hansen hypothesized that the sediments on the lake bottom have a large organic component due to the accumulation of un-decomposed plant material. He asserted that this "organic rich substrate appears beneficial for Watershield growth and proliferation". He concludes that aerating the bottom sediments would reduce the organic fraction by speeding up their decomposition.

The LAC summarized the three proposals in a report to the board in November of 2003. In the report they reviewed basic principles of lake ecology such as water chemistry, the food web, and lake turnover. This report recommended that Dr. Knud-Hansen's proposal be accepted, and that the conclusion -- poor lake turnover and low dissolved oxygen –contributed to the overgrowth of Watershield.

The HOA chose Dr. Knud-Hansen's third substrate recommendation, aeration, and in 2004 entered into a rental agreement with a company to experiment with a device called a Solar Bee (Picture 2). This device is a solar powered circulator that draws water from the bottom of the lake to the surface. It was designed to increase dissolved oxygen concentrations in the hypolimnion (bottom) to reduce algae blooms, but the company that makes them, Medora Corp., was interested in testing the equipment's effectiveness on macrophytes (such as Watershield) and agreed to rent two devices to the HOA on a trial basis. The devices were installed in 2004. Board minutes reveal that the membership perceived positive impact on water quality and the reduction of algae, but ultimately felt they were ineffective at controlling the Watershield and the Solar Bees were removed prior to 2006.



Picture 2: Solar Bee device

Over the next several years, the HOA began researching in earnest lowering the lake and excavating the lakebed to remove the Watershield at its roots (rhizomes). In a document titled "M24 Lake Restoration Committee Status Report, 3-29-07", an association member details a meeting with the Army Corp of Engineers, the Department of Fish and Wildlife and the EPA to discuss permitting for these activities. The determination was that excavation equipment could not enter the lakebed, but that a shore-based excavator could be used to reach into the lake. This was referred to in the document as the “clean bucket” method.

Later that year, this approach was used to remove some Watershield from the near shore areas as well as to reduce the cattails and bulrush that had been impeding members’ views of the lake. Several areas were excavated and the soil and reeds were piled along the shore or relocated to members’ properties to be used as topsoil. Some members reported positive results from these activities in the limited areas within the reservoir.

In 2009, the HOA again sought out professional help. Members revisited the research of the LAC and companies were again contacted for proposals. Aquatic Environments submitted a second proposal; the scope was reduced from their previous proposal to focus solely on mechanical removal of plant material. The second company was Clean Lakes, which proposed a combination of mechanical harvesting and herbicide treatment. Neither of the proposals were accepted, and the membership chose instead to continue removal of the plants through volunteer efforts, with some assistance from a local contractor called the Lake Doctor, who provided limited assistance with mechanical harvesting and spot herbicide treatments.

Over the two decades prior to 2012, the HOA had spent thousands of dollars and hundreds of volunteer hours addressing the overgrowth of the Watershield only to see all their progress lost the following year. In 2012, the HOA assembled a new committee, this time called the Lake Aquatic Weed Committee (LAWC). This group of primarily two individuals took immediate action with the systematic application of herbicides lake-wide. These members used an herbicide whose active ingredient was glyphosate, a systemic herbicide whose mode of action is to inhibit the plant’s ability to synthesize amino acids, effectively killing the plant.

These individuals spent 24 non-consecutive days treating between 1 to 4 acres of Watershield each application. According to the records from these activities, the two volunteers spent over 150 hours of their time and the application of approximately 31 gallons of product. The result was the effective control of the Watershield that season to a greater extent than had ever been achieved prior to that time. In 2013, during the same period as this study, spraying activity continued though to a much lesser extent – only 6 days of treatment using approximately 6 gallons of product.

Over the course of the two decades of documented activity in the reservoir prior to 2013, many hours and thousands of dollars were spent addressing the growth of Watershield with little success. Additionally, many more hours were spent researching, discussing and debating how to best control the Watershield. Review of the board minutes, email correspondences and other board materials suggests that, as a result of the many disagreements over the best course of action to take to control the plants, no one activity was supported or sustained long enough to become successful.

III. Objectives

This research will assist the property owners of the M-24 Ranch Association to reduce the overgrowth of aquatic plants (inhibit or reverse eutrophication) and sustain Emery Reservoir's intended uses by providing the information needed to develop an LMP with short-term and long-term goals that address the factors that contribute to eutrophication. The measurement of specific constituents within the reservoir and the observation of the physical characteristics of the reservoir and its watershed inform the categorization of the current trophic state of the reservoir as well as identify the potential factors that contributed to its eutrophication. A concluding set of recommendations is provided for the members of the M-24 Ranch Association to aid in the development of a range of management actions that will be required to not only implement an IPM approach for in-lake activities to control the plants but to target the causes of eutrophication by addressing the equally important land management aspects of an LMP.

The approach utilized for this study provides the empirical evidence needed to determine which trophic state Emery Reservoir is currently experiencing and to what extent the watershed and/or plant control methods have impacted it. Four investigations of the reservoir were conducted to provide this evidence.

1) Review existing sources of information about the study area.
    a. Land use history
    b. Previous and existing management activities within the reservoir.
2) Measure specific water quality parameters in order to determine the trophic state of the reservoir by comparing the results to Carlson's Trophic State Index.
3) Conduct a survey of the watershed to determine its potential impact on eutrophication.
    a. Geographic characteristics
    b. Geologic characteristics

c. Local weather and regional climactic.

4) Identify the plants within the reservoir and map their locations and determine their relative abundance. This will help to inform both the assignment of a trophic state and the recommendations section regarding an IPM approach.

This report will synthesize the current findings with the historical documentation of lake management activity and provide a scientific foundation that will guide the HOA in the development of a management plan. Numerous management strategies were evaluated in order to determine those that were best suited for the characteristics of the reservoir and the resources available to the HOA. The concluding data and recommendations will become a part of their LMP and aid in actively maintaining the reservoir in such a way as to ensure its recreational and aesthetic value in balance with a healthy ecosystem.

IV. Methodology

The goal of the methodology outlined below is twofold: first, to determine the current trophic state of the lake and second, to identify the potential role the surrounding watershed plays in that state. This methodology is modeled after that outlined in The Lake Pocketbook, produced by the Terrene Institute (Phillips et al., 2000). Together these data and observations will provide the empirical evidence needed to develop an LMP and will serve to inform the concluding set of recommendations for future management goals and actions.

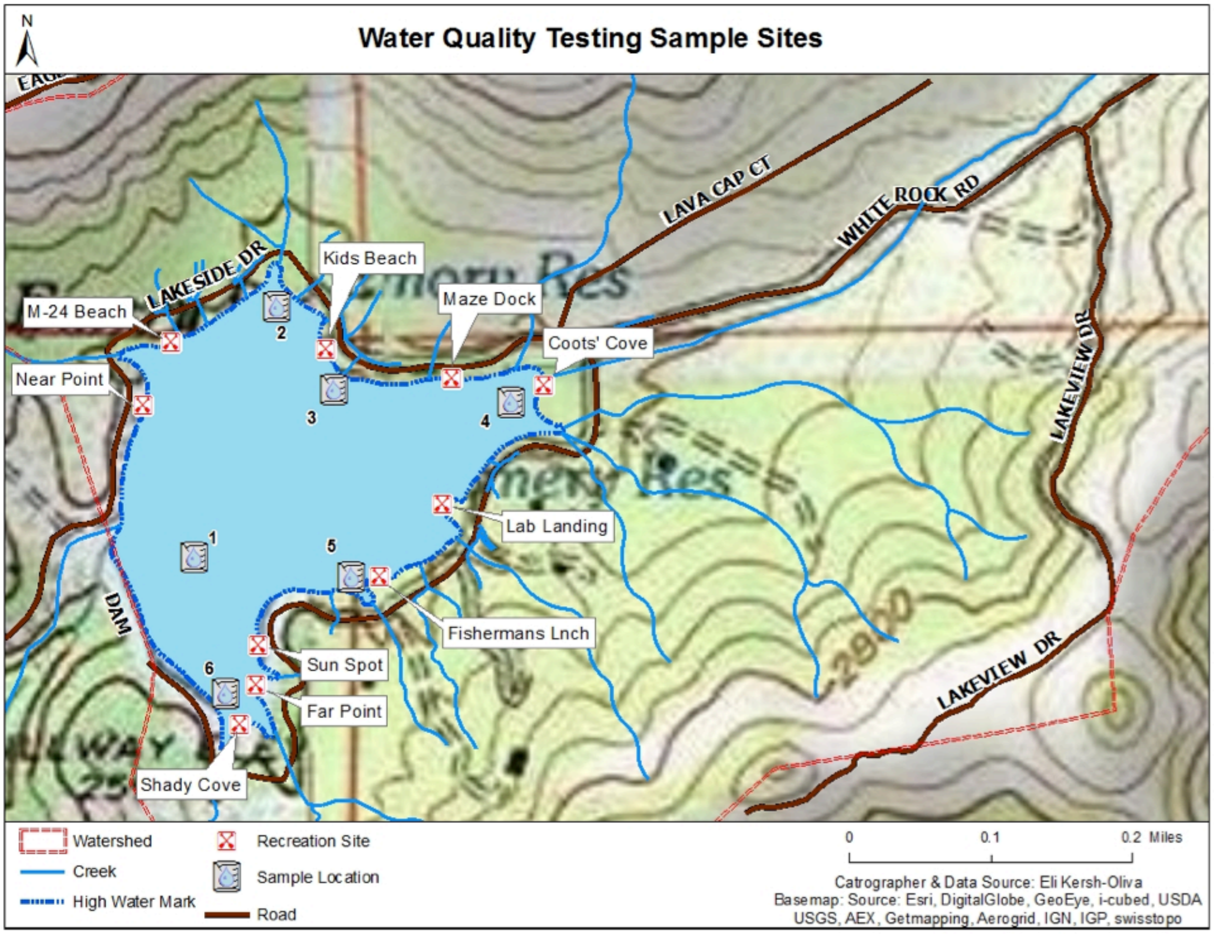
Aquatic Plant Identification and Mapping:

Plant identification is a vital component of successful lake management. Knowing which of the existing plants are an important part of the ecosystem and which ones may pose a threat will help the HOA to target appropriate species for control. Understanding propagation and lifecycles of relevant plants will inform which control methods are most likely to be successful and when to initiate them. The following steps were used in the identification and mapping of aquatic plants in Emery Reservoir.

- Samples of floating leaved plants were obtained from a canoe and transported to shore for identification. This process was ongoing from April to September.

- Submersed samples were collected while snorkeling the perimeter of the lake and across a transect from Near Point dock to Lab's Landing dock (Map 2 – pg 13). This process began when water temperature permitted in June and was ongoing through September.
- Samples were identified using the taxonomic guide from "Aquatic and Riparian Weeds of the West" (2003). Additional information was gathered on specific species from the following websites: USDA, the California Native Plant Society, Washington State Department of Ecology, the Weed Research & Information Center of University of California at Davis, and the California Invasive Plant Council.
- ArcGIS software from ESRI was used to make maps of relative location and abundance of plants lake-wide. One map was created for each month from June to August.
- The information gathered on each plant was compiled into a spreadsheet including the following fields.
    - Common and Scientific Plant Names
    - Type: Submersed, Floating, Emergent, Algae
    - Lifecycle: Perennial or Annual
    - Propagation
    - Presence, Extent, Distribution

Sample Locations:



Map 2: Sample Locations

Water was collected for testing based on an integrated sample method to establish lake-wide baseline conditions (Phillips et al. 2000). Six locations were chosen according to the following criteria:

- The first site, Site-1, was located near the deepest part of the lake to collect samples from the bottom and other strata.
- All other sites (2 through 6) were in areas with a large potential inflow from the watershed such as near a creek or culvert.
    - They were located near recreation sites such as beaches or docks.
    - The sites were isolated from one another by distance or physical features such as coves or peninsulas.

Water Quality:

The data collected was necessary to assign a trophic state to the lake and to provide averages and ranges so that continuing monitoring efforts can identify trends in the condition of the lake's water (Phillips et al. 2000). The samples were obtained from the six sample sites at approximately five feet below the surface. This required being far enough from the shore to have sufficient depth to avoid potential contamination from any disturbance to the bottom sediments (Holdren et al., 2001).

Additional samples were collected from Site 1 at a depth of 25 feet to determine the amount of dissolved oxygen near the benthic zone. All samples were obtained by attaching a bottle to a metal pole or rope and lowering it into the water. Each bottle was fitted with a cork top attached to a string so that it could be removed when submerged to the proper depth. The 200 ml plastic bottles were sterilized after each use and rinsed with water from their respective sites before collecting new samples.

The following chemical and biological constituents were measured: dissolved oxygen, pH, nitrites, and phosphorus. The following test kits were purchased from the Hach Company in order to measure these variables:

1. Test Kit Water Ecology & Limnology Model AL-36B, Product # 180202rr
    a. Dissolved Oxygen mg/L, pH (**Error! Reference source not found.**)
2. Test Kit Nitrogen Nitrite NI-15 Low Range 0.01-0.4 mg/L, Product # 218200
    a. Nitrites mg/L
3. Test Kit Ortho-Metaphosphate, PO-23 Range:0-40 mg/L, Product # 224902
    a. Phosphorus mg/L

Picture 3: Hach test kit

- Samples were immediately tested using the test kits while in the canoe or transported in a cooler to shore.
- Results were recorded on paper and later entered into a spreadsheet.

Temperature:

An alcohol thermometer (units in Celsius) attached to a measuring tape was lowered into the water to obtain its temperature.

- At the deepest sample site, measurements were taken at depth intervals of 5 feet.
- Surface temperatures were measured at all other sites at 1 foot and 5 feet below the surface.
- Measurements were taken at each site between the hours of 12:00 and 15:00, twice a month from March to September.
- Results were recorded on paper and later entered into a spreadsheet.

Visibility:

Visibility was obtained with a Secchi disk (Picture 4). This tool is a circular plate divided into quarters, with the color of each quarter alternating black and white. The disk is attached to a measuring tape and lowered into the water until it is no longer visible. It is generally accepted that the photic depth of a water column is 1.7 times the Secchi disk depth (Holdren et al., 2001).

Picture 4: Secchi Disk

Through the growing season, visibility is expected to decrease due to increases in lake productivity (algal growth).

- Secchi disk depth was only measured at the deepest sampling site – site 1.
    - Measurements were taken between the hours of 12:00 and 15:00, twice a month from March to September.
    - Results were recorded on paper and later entered into a spreadsheet.

Watershed Assessment:

In situ observation, aerial photographs, topographical maps, and GIS data were used to identify the potential impacts the watershed has on the lake. The groundtruthing of aerial photographs took place in March using a GPS enabled handheld computer running ArcPad 9. The device was also used to map the drainage patterns within the creeks, and along the roads and culverts that lead to the lake (Map 2 – pg 13). This data informed the choice of sample sites and was also instrumental in determining whether erosion and deposition of soils in certain areas was of concern to lake management. Notes and pictures of the observed features were taken in order to later develop the recommendations pertaining to watershed management.

The extent of barren soil and exposed bedrock was mapped using image classification tools within ArcInfo desktop. A historic aerial photo from 1954 was obtained from the USGS and a satellite image from 2012 was procured from ESRI; the images were georectified via control points using the ArcInfo's georeferencing tools. Training samples were selected to represent five different classes: water, ground cover, trees, barren soil, and roads. Using the Interactive Supervised Classification tools the pixels representing the rock and soils classes were extracted, combined, and converted to polygon features. Their surface areas were calculated to determine what percent of the total watershed surface area they constituted. The resulting polygons of each image were then subtracted from one another in order to depict the change in barren soil and bedrock over time.

Bathymetric Mapping of Lake Depths and Calculation of Lake Geometry:

An existing bathymetric map of the lake from 1967 was obtained but needed verification. This was done via a boat with a sonar depth finder; the soundings were entered into a GPS, and contours were then interpolated based on the data points. The resulting map was used to calculate the reservoir's surface area, volume and average depth.

The surface area of the lake was automatically calculated by the GIS application based on the high water mark. The formula in solid geometry for calculating the volume of a frustum of a circular cone is utilized by limnologists to compute the volume of a lake. The calculation consists of finding the volumes of successive layers of water (frustums), then summing them to obtain the total volume.

$$V = \frac{1}{3} H (A_1 + A_2 + (\sqrt{(A_1 * A_2)}))$$

V = volume of water

H = difference in depth between two successive depth contours

A_1 = area of the lake within the outer depth contour

A_2 = area of the lake within the inner contour line

The calculations were performed to obtain the results assuming the lake is full – at the high water mark, as well as when the lake is at its lowest level – the first five-foot contour below the high water mark.

In order to determine the average depth, sources suggest simply dividing surface area by volume. This statistical average would provide an unrealistic result, due to the assumption that a reservoir slopes uniformly like a cereal bowl. Therefore, instead, a weighted average was used to better account for the uneven slope throughout the reservoir.

$$\mathring{\mathbb{X}} = w_1 x_1 + w_2 x_2 + \ldots + w_n x_n$$

Where:

$\mathring{\mathbb{X}}$ = Average depth

w_n = The average depth of the area between two contours.

x_n = Area between two contours as a percent of the reservoir's total surface area.

The data and observations collected from the activities outlined in this methodology section provided the necessary background and evidence to assign a trophic state to the lake and to construct the set of recommendations that addresses the cause and/or source of problems facing the lake.