Watson Lake Reservoir Management Plan

Prepared for

CITY OF PRESCOTT

Public Works Department
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Prescott, AZ 86301

Prepared by

wood.

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November 2020

Watson Lake Reservoir Management Plan
City of Prescott
Public Works Department
Prescott, Arizona

Submitted to:

City of Prescott
Prescott, Arizona

Submitted by:

Wood Environment & Infrastructure Solutions, Inc.
Phoenix, Arizona

November 2020

Project No. 3720156008

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City of Prescott
Public Works Department
430 North Virginia Street
Prescott, Arizona 86301

Attn: Ben Burns, City of Prescott
Matt Killeen, City of Prescott

Re: Watson Lake Reservoir Management Plan
City of Prescott
Public Works Department
Prescott, Arizona

Section 303(d) of the Clean Water Act (CWA) requires that states compile a list of surface waters that do not meet applicable water quality standards (WQS). The Arizona Department of Environmental Quality (ADEQ) then must develop Total Maximum Daily Loads (TMDLs) for waterbodies on the 303(d) List. TMDLs set the amount of the given pollutant(s) that the waterbody can withstand without creating an impairment of that surface water's designated beneficial use(s). The City of Prescott (City) is named in two TMDLs, identified as:

- Watson Lake TMDL: Total Nitrogen, Dissolved Oxygen (DO), pH & Total Phosphorus Targets - Finalized February 2015 (Open File Report OFR-14-03)
- Final Upper Granite Creek Watershed *Escherichia coli (E. coli)* TMDL November 2015 (Open File Report 14-08)

The Upper Granite Creek Watershed drains into Watson Lake; therefore, it's impaired status is of concern and must be taken into consideration when addressing the Watson Lake TMDL.

Since 2015, Wood Environment & Infrastructure Solutions, Inc (Wood), has been supporting the City by performing a wide range of activities. the Watershed Pollutant Reduction Plan (WPRP) and Watson Lake Reservoir Lake Management Plan (LMP). The objective of the LMP is to identify scenarios and actions the City can take to achieve cost-effective reductions in the target pollutants. Significant activities performed to support this effort include:

- developing a TMDL Action Plan;
- planning and performing lake water, lake sediment, street dirt, and watershed *E.coli* sampling and analysis;
- developing a lake sediment profile;
- developing a Watershed Water Quality Model using Loading Simulation Program (LSPC) and the SIMplified Particulate Transport Model (SIMPTM);

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- developing a hydrodynamic and water quality model of Watson Lake Reservoir using CE-QUAL-W2 Version 3.72 computer program (W2); and
- delivering a series of Technical Memos documenting the progress of activities performed.

The culminating effort of the aforementioned activities (as well as several others not listed above), is the development of this LMP and the Upper Granite Creek Watershed Pollutant Reduction Plan (WPRP). These Plans do not seek to re-present previous work efforts, but rather provide guidance to the City as a result of previous activities.

Should you have any questions regarding this draft report, please do not hesitate in contacting the undersigned.

Respectfully submitted,

Wood Environment & Infrastructure Solutions, Inc.

Reviewed by:

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ACRONYMS

A&Wc	aquatic and wildlife (cold water)
A&We	aquatic and wildlife (ephemeral)
A&Wedw	aquatic and wildlife (effluent-dependent water)
A&Ww	aquatic and wildlife (warm water)
AAC	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
ADOT	Arizona Department of Transportation
AF	acre-feet
AgI	agricultural irrigation
AgL	agricultural livestock watering
AMA	Active Management Area
APHA	American Public Health Association
AZGF	Arizona Game and Fish Department
City	City of Prescott
CWA	Clean Water Act
DO	dissolved oxygen
DWS	domestic water source
E.coli	Escherichia coli
FBC	full-body contact
FC	fish consumption
LMP	Watson Lake Reservoir Lake Management Plan
PBC	partial-body contact
TMDL	Total Maximum Daily Loads
WEF	Water Environment Federation
WIP	Watershed Improvement Plan for the Upper Granite Creek Watershed
WQS	water quality standards

1.0 BACKGROUND

Section 303(d) of the Clean Water Act (CWA) requires that states compile a list of surface waters that do not meet applicable water quality standards (WQS). Total Maximum Daily Loads (TMDLs) must be developed for waterbodies on this list (the 303(d) List). TMDLs set the amount of the given pollutant(s) that the waterbody can withstand without creating an impairment of that surface water's designated beneficial use(s).

In 2004, Watson Lake Reservoir (Lake) was listed as water quality impaired for high nitrogen, low dissolved oxygen (DO), and high pH; subsequent TMDL development added phosphorus loading to the Lake's pollutants of concern. Additionally, Granite Creek was listed for low DO in 2004, and was listed for *Escherichia coli* (*E. coli)* bacteria in 2010. Miller Creek was also listed for *E. coli* at that time. Butte Creek and Manzanita Creek have since been added in the 2012/14 303(d) list, also for *E. coli*. Aspen Creek, North Fork of Miller Creek, Banning Creek, Government Canyon, Slaughterhouse Gulch, North fork of Granite Creek, and two unnamed tributaries (AZ15060202-3333 [known locally as the Virginia St Wash], and AZ15060202-3313 [known locally as Ackers East]) were listed for *E. coli* in 2016. As each of these creeks drains into Granite Creek which ultimate drains into Watson Lake. Because of this connection, their impaired status is of concern and must be factored into this Watson Lake Reservoir Lake Management Plan (LMP).

The Arizona Department of Environmental Quality (ADEQ) has since finalized a TMDL document addressing nutrients within Watson Lake Reservoir. As a stakeholder in this TMDL, the City of Prescott (City) is required to implement measures to reduce the amount of these pollutants of concern entering the Lake from the City's stormwater discharges. This LMP is intended to comply with that requirement.

1.1 Designated Uses, Recreation, and Impact

ADEQ develops WQS for surface waters of the State, including lakes and reservoirs, and conducts monitoring to determine whether or not those standards are being met. These WQS are codified in Title 18, Chapter 11 of the Arizona Administrative Code (AAC.) and vary across the state depending on each waterbody's designated beneficial uses. Designated uses, as promulgated in AAC R18-11-104, are: full-body contact (FBC), partial-body contact (PBC), domestic water source (DWS), fish consumption (FC), aquatic and wildlife (cold water) (A&Wc), aquatic and wildlife (warm water) (A&Ww), aquatic and wildlife (ephemeral) (A&We), aquatic and wildlife (effluent-dependent water) (A&Wedw), agricultural irrigation (AgI), and agricultural livestock watering (AgL).

Watson Lake has the following designated uses: A&Ww, FBC, FC, AgI, and AgL. The Lake provides a number of recreational uses, including boating, fishing, hiking, and bird watching; however; full body contact recreation is not permitted.

Of the beneficial uses for which the Lake has been designated, two are considered recreational in purpose, FC and FBC. According to AAC R18-11-101.20, FC refers to "the use of a surface water by humans for harvesting aquatic organisms for consumption." AAC R18-11-101.21 characterizes FBC, or full-body contact, as "the use of a surface water for swimming or other recreational activity that causes the human

body to come into direct contact with the water to the point of complete submergence." It should be noted that while the Lake retains the FBC designation, the City continues to post the Lake with "No swimming" signs.
Recreational designated uses are typically applied to protect public health (i.e., against human illness from ingestion of or immersion in water). However, by their very nature, recreational designated uses also result in human impact on the environment, and the 2012 Watershed Improvement Plan for the Upper Granite Creek Watershed (WIP) found high levels of recreation to be a source of elevated *E. coli* in the watershed.

The presence of algae and submerged aquatic weeds directly impact the recreational uses, and low DO could be impacting game fish populations within the Lake. Key characteristics that affect the degree of impairment of the Lake include, but are not limited to, lake shape (morphometry), shoreline complexity, depth, and water level fluctuations, thermal stratification, historic and current nutrient loading, submerged weed and algae growth and decay, and composition and quantity of bed sediment.

1.2 Water Quality Issues

Watson Lake Reservoir has elevated concentrations of nitrogen and phosphorus that stimulate excessive algae and submerged weed growth during the warmer months. Uptake of carbon dioxide from the water by the aquatic plants results in significant pH increases. Death, settling, and ultimately decomposition of the biomass exert a heavy oxygen demand in the deeper waters, with oxygen concentrations approaching zero at the lake bottom. The Lake is currently under a TMDL for low DO near the benthic layer, pH excursions above the 9.0 SU limit, and excessive nutrient concentrations (total nitrogen and total phosphorus). Aside from these issues, the water quality at Watson Lake is suitable for A&Ww, FBC, FC, AgI, and AgL activities.

1.3 Plan Organization

This LMP is divided into two main parts. **Section 2.0** presents physical, chemical, and biological information on lakes and reservoirs, as well as specific information pertaining to Watson Lake Reservoir. **Section 3.0** provides details for those lake management practices that the City can implement to achieve compliance with the above-referenced TMDL. **Section 4.0** introduces the Field Reference Guide (**Attachment A**) which lake operators can utilize/reference when performing Lake activities. **Section 5.0** contains references utilized to develop this Plan. All figures mentioned within this Plan are contained in the **Figures** section following Section 5.0.

2.0 BASIC LIMNOLOGY AND LAKE MANAGEMENT

This section provides information on basic limnological principles and processes that impact water quality of lakes and reservoirs. These factors and processes must be reasonably understood to provide lake owners and operators with a knowledge base upon which they may depend to identify and analyze issues, identify and evaluate potential solutions, and select the optimal management methods that can improve water quality and preserve the designated uses of the surface water.

2.1 Lake Morphometry and Hydrology

The morphometric (shape and structure) characteristics of the lake and the hydrology of the watershed exert a strong influence on the aesthetic and environmental character of a reservoir. In situations of dammed confluences, such as Watson Lake, the lake morphology is dependent on the existing geologic structure. Steep, smooth rock walls near the dam allow for rapid water depth increases, whereas the opposite end of the reservoir has a much shallower grade. This allows for a variety of biological production, both flora and fauna, throughout the lake.

2.1.1 Climate and Elevation

Watson Lake is located in Prescott, Arizona at an elevation of 5,100 feet above sea level. The weather ranges between 50 and 90°F during summer months and between 20 and 60°F in the winter months. Strong summer storms contribute to annual precipitation of approximately 13-19 inches, with an average annual snowfall of 20 inches . Although there is some snowfall in the area, Watson Lake is not known to freeze during the winter.

2.1.2 Dimensions and Water Levels

As identified in past studies, Watson Lake occupies 192 surface acres, with a volume of 3,019 acre-feet. When full, Lake elevation is 5161 ft. The average depth of the Lake is 4.8 meters (15.7 feet).

In general, deep-water lakes (as defined by AAC R18-11-101.16 as having an average depth of more than 6 meters) have a greater assimilative capacity and are less prone to ecosystem imbalances caused by environmental perturbations than are shallow lakes. In shallower lakes, such as Watson Lake, aesthetic and water quality degradation appear at an accelerated rate, or in isolated coves within the waterbody. In terms of plant growth, shallower lakes are usually more productive than deeper lakes because more water is above the photic zone. The photic zone is that portion of the water column receiving sufficient light for supporting growth of aquatic plant life. When a lake has a relatively high proportion of the water column in the photic zone, the amount of organic material accumulated in the sediment is increased. Deeper lakes can provide a larger sink for deposition of solids arising from external sources as erosion, storm water runoff, and feed waters, and from internal sources as algae and decaying animals. Shallower lakes do not have as sufficient sink capacity.

2.1.3 Watershed Characteristics and Lake Water Sources

The Granite Creek watershed upstream of Watson Lake comprises an area of approximately 40 square miles and varies in elevation between 5,100 and 7,100 feet. Land uses within the watershed include commercial, residential, recreation, and some grazing.

Source water to Watson Lake includes other surface waters such as Granite Creek, irrigation return water, groundwater, domestic (potable) water, urban stormwater runoff, and possibly reclaimed and gray water. Source water is known to include leachate from unsewered areas and leakage from the sanitary sewer system. Surface, storm, septic leachate, and reclaimed water can contain large amounts of nitrogen and phosphorus. The Lake is also an area-wide flood water retention and conveyance feature and receives direct runoff from park grounds and facilities arising from precipitation or irrigation. Uncontrolled, such drainage can result in stagnant pools of water, shoreline erosion, and accumulation of sediment in the lake bottom. For many lakes, the ideal feed water is often not available due to expense or regulation. Management strategies must be based on the water quality anticipated for the impoundment.

2.2 Physical Factors

Climatology characteristics, especially temperature and wind, can exert an influence on natural phenomenon and lake processes.

2.2.1 Natural Circulation

Circulation of the lake water is one of the most important components of a lake management strategy. Horizontal circulation is advantageous because it eliminates problems associated with stagnation of water, particularly in isolated coves. Circulation can result from natural wind-induced lake currents and wave action or increased artificially by expelling pumped water vertically at the lake surface. Good circulation means algae mats are less likely to form, floating debris are less likely to create unsightly accumulations, and insect infestations are minimized. ,

Vertical circulation can also occur naturally. Most lakes in the southwest are monomictic. That is, the phenomenon of natural vertical mixing ("lake turn-over") is initiated only during one period of the year – usually in the autumn season. During the summer, surface water heats faster and warmer than deeper water. The different temperatures result in warmer, less-dense water "floating" on top of denser, colder water. That difference inhibits vertical mixing of the water layers and transfer of dissolved gases and chemicals between the layers. This condition is called thermal stratification. As autumn approaches, surface waters cool and eventually equal the temperature of the bottom waters. Following autumn lake turn-over, dissolved gases and chemicals freely mix in the water column. Watson Lake experiences rapid vertical mixing between September and October.

2.2.2 Temperature Stratification and Dissolved Oxygen

Most oxygen in a lake is derived from algal photosynthesis and absorption of oxygen from the atmosphere. Both occur at or near the surface of a lake where it is in contact with the atmosphere and where sufficient light exists to support algae growth.

When a lake becomes thermally stratified, oxygen is inhibited from mixing into the deeper waters because of the thermal stratification. Respiration and decomposition in the deep waters can deplete all or most of the oxygen faster than it can mix from the surface waters. This is especially true at night when oxygen is not replenished by photosynthesis. Respiration and decomposition rates are also greatest during the summer when water temperatures are the highest. This can lead to death of fish and zooplankton invertebrates and is a frequent cause of summer fish kills.

Loss of oxygen in the deep waters and especially above the sediment can result in the formation of ammonia and sulfide gases that are toxic to aquatic organisms. Anaerobic organisms produce the gases as a by-product of respiration. Additionally, the generated ammonia becomes a growth nutrient that can increase the rate of algae growth.

Thus, it is often beneficial to have a continuously mixed or at least well-oxygenated water column. This prevents anoxic conditions, diminishes kills of aquatic organisms and ammonia and sulfide releases to the water, and limits release from the sediment of phosphorus and other undesirable chemical constituents, thus limiting nutrient recycling.

2.2.3 Evaporation

The evaporation of surface water can play a major role in water loss from a reservoir or lake. However, because of the climate, the evaporation rate in Prescott is not considered a significant concern.

2.2.4 Residence Time

The hydraulic residence time is the flushing rate of a lake; i.e, approximately how long it takes for water to move from inflow to outfall, assuming plug flow. Outflows can be natural as to a river or stream or man-made as pumped removal for irrigation. There is no ideal retention time because of the myriad of physical, chemical, and biological factors that influence a lake system. In general, relatively long retention times permit development of more balanced ecosystems better able to assimilate or resist short-term changes in water quality. However, short duration retention times reduce sedimentation rates and accumulation of nutrients. From December through February Watson Lake shows weekly inflows about 20 percent; the last week of February has one large inflow “spike” of almost 120 percent (enough to more than flush the reservoir) followed by declining inflows that end mid-April. There are additional small inflows mid-July to mid-August. The City can store up to 4,600 acre-feet (AF) each year in Watson Lake and recharges between 2,100 to 2,800 AF each year between April 1 and Nov 30. The amount of water recharged depends upon how much precipitation has fallen. The recharge allowance is up to 3,861.26 AF; however, this typically is not realized. In addition to the average recharge from Watson Lake, Granite Dells Ranch is allotted up to 375 AF each year; however, they typically average approximately 300 AF.

2.2.5 Sedimentation

Lakes accumulate bottom sediment as they age. A number of factors influence the sedimentation rate. Lake sediments are composed mainly of clastic material (sediment of clay, silt, and sand sizes), organic debris, chemical precipitates, or combinations of these. Depending on watershed activities and characteristics, materials that are detrimental to the ecological balance of the lake - e.g., excessive quantities of nutrients, heavy metals, pesticides, oil, and certain bacteria - can be deposited in lake sediment. These materials are potentially available for regeneration into the lake water and must be considered in any planning to abate lake pollution. Within the uppermost lake sediments, large volumes of pore water are often present that may have high concentrations of nutrients and other constituents and enhance the exchange potential with the lake’s water column. Sedimentation can reduce the volume of water in a reservoir and encourage growth of algae and submerged weeds. During the course of this project, sediment volume was approximated to be 414 acre-feet (668,393 cubic yards).

2.2.5.1 Sedimentation Rate

The relative abundance of each of the components listed above depends upon the nature of the local drainage basin, the climate, and the relative age of a lake. Some other factors include:

- Algae, weed, and zooplankton production in the lake,
- Chemical composition of the lake
- Shoreline erosion
- Atmospheric deposition
- Inflow loading
- Lake morphometry

2.2.5.2 Benefits of Reduction and Removal

The removal of sediment from the lake bottom can be beneficial. Physical removal of sediment can

- Reduce potential for recycling of nutrients,
- Increase lake depth,
- Increase the volume and proportion of water below the photic zone, and
- Reduce rooted aquatic plants and rooting substrate.

Sediment can be removed from lakes by a number of methods including suction dredging, mechanical dredging, and by utilizing coffer dams to allow for the use of terrestrial earthmoving equipment (see Section 3.2.2.

2.3 Chemical Composition

2.3.1 Inorganic Minerals

The mineral composition of the lake can impact productivity, oxygen concentrations, and pH (nutrients and alkalinity); potential metals toxicity (hardness), and irrigation quality (dissolved solids and ion composition). For Watson Lake, the nutrient composition is the most important component. Some of the basic parameters are described briefly below.

2.3.1.1 Turbidity

Turbidity refers to the suspended solids and color that limit how deep light penetrates the water. Common contributors are soil particles and algae. Fish, zooplankton and algae all can respond rapidly to changes in their environment resulting from fluctuations in turbidity. Increases in turbidity can clog or irritate gills of fish. For other aquatic fauna, turbidity may cause suffocation, abrasion, susceptibility to disease, impaired reproduction, and reduced availability of food resources. Higher turbidity can reducing the photic zone and thus reduce algae growth. This results in less oxygen produced and less food for zooplankton.

2.3.1.2 Hardness

Water hardness is a measure of the amount of calcium and magnesium in the water expressed as calcium carbonate. Hard waters tend to have greater buffering capacity (see alkalinity below) and can combine with or precipitate dissolved metals rendering them biologically inactive in terms of toxicity. This is beneficial in terms of protecting the fish and other aquatic organisms from runoff containing wear metal (engine wear) contaminants. However, the same chemical reaction decreases the efficacy of metal-based algaecides and requires higher algaecide application dosages.

2.3.1.3 pH and Alkalinity

Alkalinity is a measure of buffering capacity; the ability to prevent sudden changes in pH as a result of addition of acids or bases. Components of alkalinity include carbon dioxide, bicarbonates, carbonate, and hydroxide ions. pH is a measure of the hydrogen ion content of the water. The pH scale is based on acidity of the water and is recorded on a logarithmic scale from 0 to 14. At pH 7 water is considered neutral; at pH>7 water is considered basic or alkaline, and at pH <7 water is acidic. The components of alkalinity are in an equilibrium that is pH-dependent, with the following forms dominating at the following pH ranges:

pH <4	carbon dioxide
pH 4-8	bicarbonate
pH 8-10	bicarbonate & carbonate (typical range for Watson Lake during growing season)
pH>10	hydroxides

Generally, pH and alkalinity are controlled by the chemical composition of the sediments, source waters, and runoff that enter the lake. Most aquatic organisms prefer the pH range of 6.5 to 9.0. Rapid pH changes are characteristic of soft waters with poor buffering capacity (alkalinity). Alkaline or hard water lakes are usually more productive. Algae remove carbon dioxide from the water via photosynthesis and cause a shift in the alkalinity equilibrium toward bicarbonate and carbonates. The result is an increase in water pH. This was clearly seen in the during 2016-2017 Watson Lake sampling period which revealed pH above 10 in some cases.

Extreme changes in pH may cause stress or mortality in aquatic organisms. At low pH, solubility of otherwise bound metals such as aluminum increases and the metals concentration may become toxic to some organisms. At high pH, some chemicals as ammonia convert from a nontoxic ionized form to a toxic un-ionized (gaseous) form. As with hard water lakes, alkaline waters require higher dosages of copper-based algaecides for successful algae or macrophyte control.

Photosynthesis removes dissolved carbon dioxide from the water. In so doing, it causes a shift in the carbonate equilibrium toward bicarbonates and carbonates and forces the pH to rise. Thus, reducing algal photosynthesis assist in lowering pH. In the desert southwest, application of algaecide is a common approach to slowly and, at least temporarily, reducing the pH in a reservoir.

2.3.2 Nutrients and Eutrophication

Eutrophication is the process by which a body of water becomes enriched in dissolved nutrients (such as phosphates) that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen.

2.3.2.1 Nitrogen

Forms and concentrations of nitrogen (nitrite, nitrate, ammonia, and organic nitrogen) in the lake are controlled by the chemical and biological processes of the nitrogen cycle. **Figure 1** depicts the possible transformations of nitrogen in the environment. Plants primarily utilize ammonia and nitrate; however, atmospheric nitrogen can be used directly by some forms of cyanobacteria. Organic nitrogen constitutes the part of the total nitrogen that is incorporated into the plant and algae mass. The cycle is kept going by a continuous supply of ammonia that is released during the decomposition of plant and animal matter and of nitrogen that is fixed by cyanobacteria.

Overproduction of ammonia can harm the fishery. Ammonia exists in equilibrium between the ionized form (ammonium, $NH4+$) and the un-ionized or gaseous form (ammonia, $NH3$). The equilibrium is dictated by water temperature and pH; the warmer and the higher the pH, the greater the production of the gaseous form. The gaseous form is toxic to aquatic organisms.

2.3.2.2 Phosphorus

Phosphorus is often the nutrient in the least amount in water systems. Because its concentration often controls the amount of plant and algae growth in the lake, it is often the limiting nutrient. The sources of phosphorus in lake systems include the decomposition of plant and animal matter from the sediments, atmospheric deposition, or runoff into the lake (**Figure 2**). Much of the absorbed phosphorus in a water system, 20-60 percent, is excreted by plants and algae. Phosphorus cycles very quickly (as little as 1 to 8 minutes) through the algal cells and bacteria that are found in the upper waters. Phosphorus tends to compartmentalize, with a portion in the epilimnion where small (<70 um) organisms absorb phosphorus rapidly and where it is deposited rapidly, and a second section where the phosphorus is taken up by larger plants and animals and remains in the upper waters for a longer period.

Lakes that are not flow through systems, or have very long water detention times, are known as terminal lakes. While Watson Lake does experience higher turnover during winter months, there are also periods where there is very little outflow from the Lake. During these times with little outflow, the lake can temporarily take on some characteristics similar to terminal lakes. These lakes can suffer from nutrient accumulation over time due to external inputs such as the water source (nutrient rich reclaimed water), irrigation run off, storm water, as well as dust and dirt from erosion and storm fallout. Efforts should be taken to minimize the input of both phosphorus and nitrogen containing materials into the lake system. Discouraging or avoiding activities that attract waterfowl to the lake (due to high nitrogen and phosphorus in their waste) and controlling the amount of runoff containing ammonia, urea, and phosphate-based fertilizers discharging to the lake can help reduce the nutrient load.

2.3.2.3 Sources

The productivity of a lake is usually determined by the amount of plant matter produced, including macrophytes (submerged and emergent aquatic plants) and algae. Chlorophyll-a measurements are often used as a surrogate test to estimate the amount of algae in a lake. Lakes and ponds with high nutrient levels are called eutrophic and the process of nutrient enrichment is referred to as eutrophication. Those lakes with few plants and algae and relatively low concentrations of nutrients are termed oligotrophic. Those lakes with intermediate levels of plant growth and nutrients are termed mesotrophic. The general characteristics of oligotrophic and eutrophic lakes are provided in the table and figures below. The trophic status of a lake can be quantified by measuring the types and amount of algae present, the degree of water clarity, and the amount of phosphorus available for growth of algae. The trophic status of a lake will be an important means of tracking changes in water quality and the degree of success of corrective actions.

Interactions of chemical and biological factors that determine the trophic status of a lake are listed in **Table 1.**

Table 1
Trophic Status Comparison

Condition	Eutrophic	Oligotrophic
Productivity	High	Low
Algae density	High	Low
Nutrient concentrations	High	Low
Hypolimnion oxygen content	Low	High
Sediment nutrient release	High	Low to none
Organic matter	High	Low
Light transparency	Shallow	Deep
Macrophyte density	High	Low

The growth of biological communities is dependent on the concentration of nitrogen and phosphorus, which are the primary plant nutrients. The flow charts below (**Figures 3A and 3B**) diagram the difference in nutrient loads between an oligotrophic lake and a eutrophic lake.

2.3.3 Metals and Other Contaminants

If concentrations become high enough, dissolved metals can become harmful to invertebrates and fish in lakes and reservoirs or may adversely impact the health of individuals that are in partial contact with the water. The physiological availability of the metals can be influenced by the hardness of the water. Generally, in softer water lakes, such as Watson Lake, a lower proportion of some metals in solution will be associated with bicarbonates and carbonates, making them less susceptible to precipitation and more available to aquatic organisms than in a harder water lake.

Other constituents of concern include herbicides, pesticides, and synthetic organic contaminants. They are listed in the surface water quality standards; however, these contaminants have not been reported as problematic in Watson Lake and, accordingly, are not specifically addressed in this LMP.

2.4 Biological Components

2.4.1 Algae and Weeds

Aquatic plants can be found in all types of surface impoundments. They serve an important role in aquatic ecosystems. They have a dichotomous relationship (benefits and detriments) with the environment that must be kept in balance in order to preserve the quality of the water systems for ecological and recreational uses. Some of the benefits and detriments of aquatic vegetation are listed in **Table 2**.

Table 2
Beneficial and detrimental effects of aquatic plants

Plant	Benefits	Possible detriments
Planktonic algae	Oxygen production Zooplankton food (food chain)	Aesthetic deterioration Post-bloom fish kills
Filamentous algae	Oxygen production	Aesthetic deterioration Odors Clog irrigation system
Submerged macrophytes	Improve water clarity (nutrient uptake) Oxygen production Fish habitat and food	Physically obstruct lake Interfere with fishing and boating
Emergent macrophytes	Wildlife habitat and fish Improve water quality (nutrient removal) Aesthetic enhancement	Loss of lake volume Insect attraction Waterfowl attraction
Floating macrophytes	Aesthetics (flowering plants only)	Reduce light Physically obstruct lake Interfere with fishing and boating

2.4.1.1 Importance

Aquatic plants can be broken into two basic forms: algae composed of unicells, colonies, or filaments, and vascular plants (macrophytes or aquatic weeds) that include forms that are submerged, emergent, or floating. Their form and growth habitat are important characteristics in their dispersion and possible management strategies. Aquatic plants provide dissolved oxygen to the water, absorb nutrients, provide refuge for fish, create habitat for macroinvertebrates, and supply food for some fish, macroinvertebrates, and waterfowl. Conversely, aquatic weeds can become a nuisance by obstructing boating and fishing areas and reducing aesthetic value. They can increase water pH and add organic matter to the sediment and consume dissolved oxygen during decomposition.

2.4.1.2 Forms of Algae

Algae may be one-celled organism (unicells), colonies (multiple cells held together in a matrix, or filaments (branched or non-branched chains of cells). This affects how they grow, where they develop, and what management techniques can be successful.

There are eight taxa or divisions of algae that are common to Arizona lakes and reservoirs.

Cyanobacteria, sometimes called blue-green algae (Cyanophyta): These algae lack differentiation in cellular organization (prokaryotic). They are typically filamentous or colonial in form, with mucilaginous sheaths around the cells. Many filamentous forms have specialized vegetative cells called heterocysts which can fix (absorb) atmospheric nitrogen. Some are known to produce dangerous neurotoxins.

Green algae (Chlorophyta): This is a diverse group that includes flagellated, amoeboid, filamentous, and colonial forms. Asexual and sexual reproduction is common. Some filamentous forms undergo conjugation.

Golden-Brown algae (Chrysophyta): Chrysophyceae have a golden-brown color because of B-carotein and xanthophyll carotenoid pigments. Most are unicellular, with one flagellum. Reproduction is predominantly by cell division.

Baccilariophyceae (diatoms): These have highly ornamented silicious cell walls.

Cryptomonads (Cryptophytes): Most cryptophytes are unicellular and motile. Cells are usually compressed with two equal length flagella. Reproduction is by longitudinal division.

Dinoflagellates (Pyrrophyta): These are unicellular, flagellated algae. Most have a thick cell wall with spines. The flagellum is usually associated with transverse and longitudinal furrows in the cell wall.

Euglenoids (Euglenophyta): Many of these organisms are not planktonic forms, but they can become planktonic when environmental conditions are right. They have no cell wall and often change shape, may have 1-3 flagella, and are photosynthetic and heterotrophic (consume pre-formed food particles).

Chara and Nitella (Charaophyta). These two forms of algae appear to be submerged vascular plants, but are actually advanced forms of algae. Chara (muskgrass) is prevalent in Arizona's hard water lakes, often precipitating carbonate on its thallus to become crusty and resistant to chemical control.

2.4.1.3 Cyanobacteria (Blue-green Algae) and Algal Toxins

Toxin-producing blue-green algae are often a concern in lakes. A number of algae species have been identified as potential toxin formers including representatives from the following genera: *Microcystis, Nodularia, Nostoc, Oscillatoria, Anabaena, Aphanizomenon, Cylindrospermum, Gloeotrichia, Phormidium, Schizothrix, Scytonema, Synechocystis, Tolypothrix*, and *Trichodesmium*. Not all species in these genera produce toxins, and in some cases, only certain strains produce the toxins and only under specific environmental conditions. In most reported cases, the toxins are associated with mortality of livestock animals that consume large numbers of the algae under bloom conditions. However, some evidence indicates the toxins may limit the growth of other algae and zooplankton. Factors affecting cyanobacteria (blue-green algae) blooms are summarized in **Table 3**.

Table 3 Factors impacting cyanobacteria algae blooms	
Environmental factor	**Impact on bloom**
Nitrogen	Low N:P ratio favors blue-greens because heterocyst-forming algae can grow in low-N conditions
Phosphorus	Typically need high concentrations; however, in collected data from Watson Lake, cyanobacteria appeared to grow in lower concentrations.
Temperature	Optimum near 35C for some species but can grow in cooler water
Light	Low light often favorable but many can migrate to preferred depth
Micronutrients	Iron and molybdenum important
pH	Tolerate high pH; many can photosynthesize with bicarbonate
Toxins	May reduce zooplankton predation
Morphometry	Shoreline coves create quiescent waters favoring blue-green growth Lakes capable of recycling nutrients from sediment favor blue-greens

The golden alga, *Prymnesium parvum*, has recently been the cause of numerous fish kills in central Arizona urban lakes. The alga, once considered to be a species found in brackish, cold waters has adapted to warmer and less saline environments. The trigger for toxin production and release is unknown. Because the toxins destroy exposed cells, they can attack the naked cells in gill tissue of fish and mollusks. When the gill cells are ruptured, oxygen cannot be absorbed and hemorrhaging, lethargy, loss of motor control, asphyxiation, and death occur within hours. P. parvum has not been reported in northern Arizona; however, it is moving north and westward and might become a concern in the future.

2.4.1.4 Management of Algae

Mitigation methods for limiting cyanobacteria formation in lakes include:

- Artificial circulation (de-stratification, hypolimnetic aeration, or layer aeration) to prevent release of nutrients from sediment
- Phosphorus precipitation or inactivation (alum or ferric chloride treatment)
- Light attenuation (application of lake dyes)
- Biomanipulation (adding herbivorous fish to change the community structure)
- Watershed management to reduce nutrient inputs (especially phosphorus) to lakes
- Algaecide application to reduce population density and lower pH
- Lake level increase or flushing

Light attenuation, algaecide applications, biological controls, and lake level and flushing are discussed below. The remaining management methods are discussed in later sections.

While unlikely to be appealing, lake dyes are an option and can be added to the water to absorb photosynthetically active radiation (PAR). Two products are currently Environmental Protection Agency (EPA) registered for use (Admiral® and Aquashade®). Products are water soluble and have no adverse effects on aquatic organisms. The dye should be applied to waters with greater than a 3-foot depth to be effective. The dye decreases PAR by about 30 percent.

While unlikely to be appealing to the City, algaecides can be applied, usually to the upper 3 feet of water, to management various algal forms. Application can be by spray, subsurface injection, prop-wash, or spreader (granular forms). In some cases such as shallow waters, algae growth occurs on the sediment surface and application by weighted hose or using a density increasing additive is required. Products contain different active ingredients and additives that impact genera and forms it may control. Some products have water use restrictions following application, such as for drinking water supplies, swimming, and irrigation. The product label should always be consulted before making any application.

A brief summary of common algaecides is presented in **Table 4**.

Table 4
Common algaecides

Algaecide	Trade names ®	Plants affected
Mixed copper ethanolamine	Cutrine Plus Clearigate Captain	Planktonic algae Filamentous algae *Chara* and *Nitella*
Mixed copper ethanolamine with surfactant	Captain XTR Cutrine Ultra	
Copper sulfate pentahydrate with aluminum sulfate	SeClear	Planktonic algae Filamentous algae
Copper citrate and gluconate	Algimycin	Planktonic algae Filamentous algae *Pithophora*
Copper sulfate pentahydrate in acid	Earthtec	Planktonic algae
Mixed copper ethanolamine with diquat dibromide	Cutrine+Reward/Tribune	Filamentous algae
Sodium peroxycarbonate	Green Clean Pro Phycomycin	Planktonic algae Filamentous algae
Endothall dimethylamine salt	Hydrothol 191	
Flumioxazin	Cutrine Plus Clearigate Captain	

<u>Herbivorous fish</u> can also be stocked in a lake to consume submerged weeds and sometimes filamentous algae, but no fish species is truly capable of filter-feeding on microscopic planktonic algae. Species regularly used include tilapia (*Tilapia spp*.) and the White Amur (*Ctenopharyngodon idella*). Tilapia can overpopulate lakes and compete with game species. They are also cold-sensitive and die at temperatures below 55 F and thus cannot be used in Watson Lake. White Amur (grass carp, **Figure 4**) are considered an exotic species. They require a license from Arizona Game and Fish Department (AZGF), must be 12-14-inch minimum size, and there must be no possibility of ingress or egress from the lake. They are thermally tolerant. Stocking densities from 10 to 50 fish per acre are typically planted.

Lake level adjustment and flushing is sometimes an option when source water is available. Flushing the lake can serve multiple purposes including removing nutrients and suspended algae from the water column and decreasing the time for algae to grow, among many others. Much of the volume in Watson Lake is displaced during winter runoff, and some volume is displaced during summer monsoon runoff in July to August.

2.4.2 Submerged, Floating, and Emergent Weeds

2.4.2.1 Forms

Floating plants include those that float on the surface and are rooted on the lake bottom. Others can be free-floating on the water surface and derive their nutrients directly from the water through cell walls or through a well-developed root system that penetrates into the water. Water lilies and duckweed are common examples.

Emergent plants are either found growing upright along the damp shoreline or anchored to the lake bottom through their root systems, but have a substantial portion of the plant body emerging out of the water. Cattail would be a typical example.

A submerged plant essentially grows under water. It can often send up flowering parts above the water for seed dissemination or have vegetative parts reach the surface in shallow reservoirs. Horned pondweed (*Zanechellia palustris*), brittle naiad (*Najas minor*), and Eurasian watermilfoil (*Ceratophyllum spicatum*) are common local examples.

2.4.2.2 Management Methods

The same list of management methods as described for algae (Section 2.4.1.4) applies to aquatic weeds, and submerged forms in particular. The described fish species will usually prefer submerged plants over filamentous algae. However, they do not consume most types of established emergent vegetation. Aquatic dyes are effective on submerged weeds but have no effect on established floating or emergent forms. Chemical herbicides for aquatic weeds contain different formulations than algaecides and are discussed below. Submerged and floating weeds may also be physically removed and these methods are also presented below.

The City of Prescott has historically been opposed to the application of herbicides in Watson Lake; however, chemical herbicides are a viable option for controlling aquatic weeds and may need to be considered depending on lake conditions. The primary chemical categories for weed control are presented below.

Copper herbicides contain copper that is either available or chelated with an organic compound to keep it in solution and prevent rapid precipitation in the water column. Copper is very effective for algae control and some submerged macrophytes as southern naiad and macroscopic algae (Chara and Nitella). Mixed with diquat (2 parts copper to 1 part diquat), it provides an effective agent against many shoreline plants including filamentous algae. However, copper can be very toxic to fish.

2,4-D works on broadleaf species. It is systemic, requiring a relatively short contact time. It is usually not effective on pondweeds, but is effective on Elodea, milfoils, coontail, and hydrilla. However, it should not be used on lakes subject to water contact or consumption because of irrigation restrictions.

Diquat is a contact herbicide that works very quickly and causes a rapid die-off. It is not effective in killing roots, rhizomes, or tubers, thus it requires repeated applications. It combines with particulates (especially clays) and dissolved organic matter which limits its effectiveness in some waters. It is tank-mixed with copper for edge treatments (see above).

Endothall is a contact herbicide which is unaffected by particulates or organic matter. It should not be used in combination with copper compounds.

Flumioxazin is a relatively new aquatic contact herbicide for selective control of tough invasive and nuisance plants such as cabomba, watermeal, Eurasian watermilfoil, water lettuce, duckweed, and giant salvinia. The chemical dissipates quickly from the water column and does not accumulate in the sediment. It is pH sensitive, working best at pH 7, and requiring maximum label rate when pH exceeds 8.0 SU.

Fluridone product trade names include Sonar® and Whitecap®. Fluridone is a slow-acting systemic herbicide used to control underwater plants. It may be applied as a pellet or as a liquid. Fluridone can show good control of submersed plants where there is little water movement and an extended time for the treatment. Its use is most applicable to whole-lake or isolated bay treatments where dilution can be minimized. It is slow-acting and may take six to twelve weeks before the dying plants fall to the sediment and decompose. Granular formulations of fluridone are proving to be effective when treating areas of higher water exchange or when applicators need to maintain low levels over long time periods. Some native aquatic plants, especially pondweeds, are minimally affected by low concentrations of fluridone.

Glyphosate is a systemic herbicide. It is only used on shoreline emergent species such as cattail.

Triclopyr-TEA: There are two formulations of triclopyr. It is the TEA formation of triclopyr that is registered for use in aquatic or riparian environments. Triclopyr, applied as a liquid, is a relatively fast-acting, systemic, selective herbicide used for the control of Eurasian watermilfoil and other broad-leaved species such as purple loosestrife. Many native aquatic species are unaffected by triclopyr.

Imazapyr: This systemic broad spectrum, slow-acting herbicide, applied as a liquid, is used to control emergent plants like spartina, reed canarygrass, and phragmites and floating- leaved plants like water lilies. Imazapyr does not work on underwater plants. Although imazapyr is a broad spectrum, non-selective herbicide, a good applicator can somewhat selectively remove targeted plants by focusing the spray only on the plants to be removed.

Imazamox: Imazamox is the common name of the active ingredient ammonium salt of imazamox pyridinecarboxylic acid. It was registered with EPA in 2008 and is currently marketed for aquatic use as Clearcast® and Imox® It is a liquid formulation that is applied to submerged vegetation by broadcast spray or underwater hose application and to emergent or floating leaf vegetation by broadcast spray or foliar application. There is also a granular version.

Penoxsulam: Penoxsulam is a liquid used for large-scale control of submerged, emergent and floating-leaf vegetation. Penoxsulam must remain in contact with plants for around 60 days. Because of this long contact period, penoxsulam is likely to be used for larger-scale or whole-lake treatments and should not be used where rapid dilution can occur such as spot treatments or moving water.

Information on the various products and their use is presented in **Table 5**.

Table 5
Herbicide information

Active ingredient	Mode of action	Environmental fate	Advantage	Disadvantage
Copper	Photosynthesis and cell growth inhibitor. Cu2+ is primary toxic form. Broad-spectrum contact herbicide	Highly water soluble with no degradation. Strong particle and DOC affinity causes rapid sediment deposition. Transport occurs between water and sediment	Cost-effective Relatively safe for applicator Moderately effective on some forms of submerged weeds	Toxic to sensitive fishes and other non-target organisms Sediment accumulation/persistence Ineffective at cold temperatures
Endothall	Inhibition of messenger RNA activity. Decreasing rate of respiration and lipid metabolism, inhibiting protein synthesis and interfering with normal cell division. Selective contact herbicide	Rapidly degraded in water. Its half-life is 4 to 7days for dipotassium endothall and about 7 days for technical endothall in surface water.	Moderately to highly effective on submersed and floating plants Limited toxicity to fish Rapid action	Non-selective Potentially toxic to aquatic fauna Water use restriction
Diquat dibromide	Causes superoxide to be generated during photosynthesis, that damages cell membranes and cytoplasm. Leads to desiccation. Non-selective contact herbicide.	Water column concentrations typically drop below detection within days to weeks after application. This results from binding to particles and sediment and retention in plant tissue.	Moderately to highly effective on submersed and floating plants Limited toxicity to fish. Rapid action.	Potentially toxic to zooplankton. Inactivated by particulates.

Table 5
Herbicide information

Active ingredient	Mode of action	Environmental fate	Advantage	Disadvantage
Fluridone	inhibits production of carotene, which enhances degradation of chlorophyll and inhibits photosynthesis Selective systemic herbicide,	Photodegrades; low K_{OW} and experiments indicated low potential to bioaccumulate or biomagnify.		
Glyphosate	Inhibits a key enzyme that plants and bacteria use to make amino acids (EPSP synthase), Systemic	Once glyphosate enters the water column, it is quickly adsorbed to soil particles. Microbial degradation begins Immediately,	Moderately to highly effective on emergent and floating plants. Rapid action and low toxicity. No time restrictions for water use.	Inactivated by suspended particulates.
Triclopyr	Mimics the plant growth hormone auxin (indole acetic acid), causes uncontrolled and disorganized plant growth that leads to plant death. Selective systemic.	Hydrolysis occurs rapidly with half-lives in water of 2.8-14.1 hours. Photolysis is the primary breakdown process in water. Microbial degradation occurs in soil with a soil half-life of 30-90 days.	Effect ion floating and submersed plants. Effective n difficult to control species Low toxicity to aquatic fauna. Fast acting.	Non-selective. Time delays for recreational use of water.
Flumioxazin	inhibition of protoporphyrinogen oxidase, an enzyme important in the synthesis of chlorophyll. Contact herbicide.	Flumioxazin degrades rapidly in water and soil. Dissipation occurs by a combination of hydrolysis and microbial oxidation.	Low use rate. Low toxicity to aquatic fauna.	Efficacy reduced in high pH waters.
Imazapyr	Imazapyr kills plants by preventing the synthesis of certain amino acids produced by plants but not animals. Non-selective systemic.	Imazapyr can be highly mobile or persistent in soils, dependent on soil characteristics. The primary form of degradation in water is photodegradation with a half- life of approximately 2 days.	Non-toxic to fish and most aquatic flora and fauna.	Non-selective. Persistent in soils.

Table 5 Herbicide information				
Active ingredient	**Mode of action**	**Environmental fate**	**Advantage**	**Disadvantage**
2,4-D	Hormone that stimulates stem elongation & nucleic acid/protein synthesis, stimulating uncontrolled growth until death. Affects enzyme activity/respiration/cell division. Post emergent systemic herbicide.	Rapid hydrolysis to 2,4 D acid, then binds to sediments. 2,4 D DMA < 2,4 D BEE in sediments. Bioaccumulation not expected.	Moderately to highly effective on emergent, submerged and floating plants. Fairly fast acting.	Potential toxicity to aquatic fauna. Time delays for recreational use of water.
Imazamox	Systemic herbicide that moves throughout the plant tissue and prevents plants from producing a necessary enzyme, acetolactate synthase	Dissipation studies in lakes indicate a half-life ranging from 4 to 49 days with an average of 17 days. Herbicide breakdown doesn't occur in deep, poorly-oxygenated water where there is no light. In this part of a lake, imazamox will tend to bind to sediment rather than breaking down, with a half-life of approximately 2 years.	Fast acting Dos not harm animals. May be used immediately post-application for fishing, boating, and swimming.	Potable water use restriction. Limited data on adverse effects on desirable aquatic species.
Penoxsulam	Systemic herbicide that moves throughout the plant tissue and prevents production of a necessary enzyme, acetolactate synthase (ALS)	Very mobile. but not persistent in aquatic environment	Slow mode of action allows for whole-lake applications. No restrictions.	Slow mode of action allows for dilution in small areas

<u>Cutting and harvesting</u>: Aquatic plants can be reduced by cutting and harvesting the vegetative material by mechanical means. Some disturbance of the sediment is expected. Plants are cut, mechanically collected and placed on shore to dry prior to disposal. A wide range of techniques is available from manual to highly mechanical. For large lakes, a weed harvester, capable of cutting and collecting the material, as shown in **Figure 5**, would be applicable.

Mechanical removal provides a highly flexible control of plants. Location and timing can be selected and disruption to recreational activities minimized. Other incidental debris can also be removed simultaneously. Adverse impacts include habitat disruption for fish and benthic macroinvertebrates, possible spread of the plants by fragmentation and re-rooting, and possible increase in lake turbidity. Removal is non-selective, with any plant in the path subject to cutting and removal. Plants may also become re-established if the growing season is sufficiently long.

Drawdown or dewatering a portion of the lake supporting submerged weeds is also a physical management technique. The plant material dies and dries during solar exposure. The dried biomass may be removed mechanically or left to be incorporated into the lake sediment upon refilling. The disruption to use of the lake and aquatic fauna is significant.

2.4.3 Zooplankton

2.4.3.1 Importance and Forms

The zooplankton of lakes is composed of microscopic or nearly microscopic crustaceans, including members of the rotifers, cladocerans, copepods, and ostracods (see examples below and **Figure 6**). These organisms function as consumers of algae, bacteria, and other organic particulates and as a food source for immature fish.

Rotifers are loricate (possess a shell). They are particulate feeders, consuming algae cells, bacteria, and detritus (dead organic matter). They are easily identified by the cilia around the mouth that sweeps in particulate food.

Cladocerans, Daphnia being the most common, are indiscriminate filter feeders, and are preyed upon by the predatory zooplankton species. They consume any algae cell of a size that can be collected by the filtering apparatus. They can be identified in water samples by their large, dark eye or straight swimming motion, and eggs on back.

Copepods have three forms – cyclopoid, calanoid, and harpactacoid. These can be easily differentiated by the size of their antennae and body segments (cyclopoids-short antennae; calanoids-antennae about as long as body; harpactacoid-short antennae, extra long body). Copepods are essentially filter feeders, straining out algae cells. However, some of the larger forms can be size-selective predators; some are cannibalistic. They can be identified in a water sample by their zigzag swimming motion and females carry their eggs laterally.

Ostracods are usually a minor part of the zooplankton and usually found in shallow waters near shore. They are barely visible to the naked eye and resemble small clams (often called seed shrimp).

2.4.4 Benthos

The benthos is composed of bottom dwelling organisms. The microscopic portion of the benthic layer at the lake bottom is primarily composed of protozoa and bacteria. When it is warm enough and with sufficient oxygen present, these organisms provide the bulk of the breakdown of organic matter in the aquatic ecosystem. The larger, macroinvertebrate portion includes fly larvae, beetle larvae, dragonfly larvae, etc., that serve as a food source for bottom feeding fishes. The plant component may consist of filamentous algae and diatoms. In terms of lake management and possible manipulation, the animal portion of the benthos is most important.

2.4.5 Fish

Fish surveys at Watson Lake have found a moderate variety of game fish present within the Lake, including largemouth bass, sunfish, bluegill, crappie, catfish, and rainbow trout. The abundance of aquatic weeds provides ample protective cover for larvae and fingerlings and foraging opportunities for adults.

2.4.6 Other Organisms

2.4.6.1 Birds and Waterfowl

Birds and waterfowl are attracted to standing waterbodies. The birds are popular among bird watchers and typical lake users. The lake in turn provides food sources and nesting areas for the waterfowl. Although popular with the citizenry, birds and waterfowl can reduce water quality. The birds produce an enormous amount of fecal matter that can add nitrogen, phosphorus, and bacteria to the lake waters, soil recreational and picnic areas, and add feathers and oils to the surface waters.

2.4.6.2 Nuisance and Vector Insects

It is often impossible to prevent occurrence or totally eliminate insect populations in and around a lake. However, understanding their life histories of the organisms provides a basis for management techniques. The following sections provide information about the life cycles of these semi-aquatic organisms.

<u>Mosquitoes</u> are unlikely to breed in the lake; however, mosquitoes may breed in associated irrigated areas where water inadvertently pools or where runoff or storm water accumulates. Additionally, poorly maintained park grounds and maintenance facilities can become a breeding site for mosquitoes. Mosquitoes are not only a nuisance from their bites but pose a potential threat to public health. Many mosquito species are vectors of viruses that can impact human health.

Most mosquitoes typically breed in areas of moderate to dense vegetation and relatively stagnant waters. Both stagnant-water and flood-water forms of mosquitoes exist. Many species prefer organically rich habitats. The generalized life cycle of the mosquito has four basic stages: egg, larva, pupa, and adult (**Figures 7** and **8**).

> Egg: Most mosquitoes lay eggs singularly or in rafts on the surface of the water. The rafts can contain between 100 and 400 eggs. Other mosquitoes (flood water forms) lay eggs on rocks and vegetation in wait of submergence by rainfall or flooding. Eggs usually hatch within two to three days of being laid or submerged by water.
>
> Larvae: Upon hatching, small wiggling larvae swim to the surface of the water to begin breathing through their siphon. They feed on minute organic particulate matter and bacteria. The larvae go

through four molts (skin-shedding) to accommodate growth during the next two to 16 days, depending on species. The organism during each of these stages is called an instar.

Pupa: Following the fourth instar, the mosquito develops into a pupa. The pupa does not eat. Within the pupa the mosquito develops over the next two days. When fully developed, the pupa skin splits and the adult fly emerges.

Adult: The adult generally rests on the surface of the water until it is strong enough to fly away. The mature adult males will feed on nectar while the females will search for blood meals to nourish their eggs. Adults may fly from a few hundred yards to 15 miles in a night. Adults may live from two to nine weeks, depending upon species, and some females may produce up to three batches of eggs.

Midge flies typically encountered in Arizona are not biting insects. However, they tend to swarm, produce a nuisance buzzing, fly into eyes and mouths, congregate in eves of homes and buildings, and make a mess when large swarms die. The midge fly life cycle takes 10 to 28 days to complete depending upon species (**Figures 9** and **10**). Their larvae inhabit the bottom sediments of lakes. They tend to be more prevalent in organically rich waters with large amounts of mucky sediment. After several instars, the pupa emerges from the mud and the adult fly leaves the water. The swarms are part of the mating ritual. Females lay hundreds of eggs that are deposited on the surface of the water in a jelly-like case which later sinks to the lake bottom.

Management efforts for midge flies are similar to those for mosquitoes, but these organisms will invade a water body regardless of the degree of movement of the water column.

2.4.6.3 Bacteria

Waterfowl and birds are a source of *E. coli* bacteria. Whether added to water or shore, fecal deposits containing bacteria create a potential human health risk from incidental contact (e.g., fishing, boating, picnicking, etc.). Children, less likely to be careful where they play and how well they wash prior to eating, are at greatest risk.

2.4.6.4 Invasive Species

Aquatic invasive species present a number of different risks to both the proper and desired functioning of a waterbody. High amounts of aquatic vegetation can prevent swimming, sport fishing, and boating. Invasive fish, snails, and mussels can quickly overwhelm the natural balance of the aquatic ecosystem and have detrimental effects on the infrastructure and local aquatic species. The exclusion of aquatic invasive species can include programs to address both emergent and submerged vegetation as well as invasive aquatic fauna. Despite that Eurasian watermilfoil is considered an invasive form in other parts of the country AZGF does not currently list Watson Lake as having aquatic invasive species present.

2.5 Lake Monitoring

Monitoring the water quality of the lake is an essential component of any lake management plan. The data provide guidance on what actions are required, insight into the best management or mitigation practice, and ultimately provide the ruler for measuring success of any corrective actions.

2.5.1 Parameters

For most lakes that contain fish and at which fishing and boating are common, water quality monitoring incorporates the following general areas: (a) chemical-physical parameters, (b) nutrients, (c) algae and weed density and identification, (d) midge density, (e) bacteria density, and (f) metals. A typical list of parameters is shown below

- Temperature and oxygen profile by depth
- pH
- Secchi disk depth
- Nitrate-N
- Ammonia-N
- Total Kjeldahl N
- Total N
- Total phosphorus
- Algae identification and count
- Chlorophyll-a
- Midge larvae density (sediment grab)
- E. coli bacteria
- Metals, hardness and alkalinity (Ag, As, Be, Ba, Cd, Cr, Cu, Hg, Pb, Sb, Se. Tl, Zn)

For dendritic lakes (meaning lakes that receive drainage from many contributing drainage systems), more than a single sample location is usually required to understand variations in the water body. However, composite samples can be used as simple tracking related to compliance limits. Sampling frequency is usually monthly, except for metals that are usually checked annually.

2.5.2 Monitoring Equipment

The following is a description of recommended equipment used for lake and insect monitoring (see **Figure 11**). Other equipment may be needed based on lake conditions and measurements needed.

2.5.2.1 Water Sampling

Shallow (0.5 m) grab samples can be collected manually or using a standard water sampler such as a Van Dorn, Kemmerer, or Alpha bottle. Composite samples should include equal volume collections for each designated area that are combined in a single container.

Vertical (depth) profile sampling will require a temperature-oxygen meter with cables of sufficient length to allow releasing and maintaining the probe at all water depths. For Watson Lake this is about 15 meters.

Golden algae samples should consist of multiple surface grabs, especially in down-wind areas.

2.5.2.2 Sediment Sampling

Lake sediment should be collected with an Ekman or Ponar dredge. The Ekman dredge is spring loaded and dropped to the lake bottom. The jaws are closed by releasing a messenger (weight) that is connected to the lanyard. The Ponar dredge is for soft sediment and closes when the unit is lifted from the lake bottom.

2.5.2.3 Midge Fly Sampling

Midge larvae are collected from the lake bottom using an Ekman dredge. The standard dredge has a surface area of approximately 1/40 square meter. The sediment is hand dispersed or organisms are floated in a sugar solution. The number of midge fly larvae recovered x 40 represents the number of larvae per square meter. Typically, midge counts <400 per square meter do not result in nuisance complaints from lake visitors.

2.5.2.4 Mosquito Sampling

Mosquito larvae are sampled manually with a dipper in standing water locations around the lake or in stagnant areas of the lake itself. Five dips at a single location are considered representative of one sampling event.

Adult mosquitoes are collected using EVS (Encephalitis Vector Survey) carbon dioxide traps. The traps consist of a battery operated fan that draws mosquitoes into a collection net. The upper portion of the device holds the bait which is dry ice (carbon-dioxide attractant). Traps are set at a 6 ft height in late afternoon and collected the following morning. Mosquito counts, species identification, and encephalitis screening can be performed on collected specimens.

2.5.3 Test Methods, Data Handling, and Interpretation

Analytical methods used for examining water samples should be approved by the American Public Health Association (APHA), EPA, Water Environment Federation (WEF) or other recognized authority. Biological samples should be examined by experienced biologists or entomologists. When regulatory compliance is necessary, submitting the chemistry samples to an internal or external State-licensed laboratory that uses approved methods and has an established and accepted quality assurance program is recommended. Chain of custody, sample preservation, and holding time procedures should be followed.

Hard copies of all field notes and data, and laboratory reports should be maintained. Electronic files are suitable and usually preferred for data analysis. Chemical and biological data should be tracked on a temporal basis by spreadsheet and graphics.

Data interpretation should be made by a qualified lake manager or limnologist. The data interpretation will influence and direct any additions or changes to the lake management strategies or techniques being employed.

3.0 LAKE MANAGEMENT STRATEGIES FOR WATSON LAKE

Based on the findings of the Watson Lake modeling efforts, supplemental aeration and nutrient reduction are the major management practices recommended for Watson Lake. Other management methods related to algae and weed growth will improve pH and support the primary practices. Some additional management practices will support sustainability of the lake for recreational and aesthetic benefits.

Please note that recognition of equipment, material manufacturers, or suppliers is for example only and does not constitute endorsement of their products by Wood or the City.

3.1 Circulation and Aeration.

With typical winds in the area, horizontal circulation is not an issue at Watson Lake. Some protected coves likely exist, but for the most part, the lake appears to have sufficient horizontal flow patterns as shown by similarity between observation sites. As a monomictic reservoir, Watson Lake vertically circulates during the autumn and winter and begins to form vertical stratification in late spring and summer. The deeper water (hypolimnion) rapidly loses oxygen through decomposition of biomass and respiration in the water column above the sediment. The loss of oxygen (anoxia) causes two significant adverse effects: (1) restriction of fish, zooplankton, invertebrates and other aerobic aquatic life and (2) release of phosphorus and gases such as ammonia that can be re-circulated into the photic zone and stimulate algae growth and eventually cause an increase in pH. Adequate oxygenation is especially important to maintain a healthy fishery during the warmer months when the oxygen saturation level in the deeper waters of the lake decreases.

Mechanical vertical circulation or aeration can reduce algae growth directly by moving suspended algae in and out of the photic zone, thereby reducing its productivity. Vertical mixing also provides an aerobic zone over the sediment and limits release and redistribution of phosphorus. Aeration helps limit the release from the sediment of undesirable dissolved gases such as hydrogen sulfide and ammonia.

3.2 Types of Aeration

A number of different types of aeration systems exist with one of two functions based on their mode of action: (a) complete vertical circulation to deliver oxygen throughout the water column by destroying the thermocline and thermal stratification and (b) to deliver oxygen to the hypolimnion directly and maintaining thermal stratification. These are described below.

3.2.1 Bottom Diffuse Aeration

The term aeration is commonly used to describe submersed diffused-air aeration systems that can help oxygenate the lower depths of a waterbody that cannot be reached by floating aerators or surface fountains. These systems use an onshore compressor to pump air through subsurface tubes to submerged bubble diffusers. An air flow rate of 1.3 cu-ft/min minimum is required for each diffuser. As the bubbles rise, they carry the low-oxygen water from the bottom towards the surface, where it mixes with the oxygen-rich surface water and atmospheric oxygen before sinking back to the bottom of the water column (Figure 12). This vertical mixing, even if localized, can help to increase dissolved oxygen throughout the entire deep, low-oxygen part of the lake through lateral mixing.

Complete or partial air lift or bubble-plume diffusers would be located on the bottom in areas of the lake where the water is deep enough that there is low-oxygen hypolimnion water present during the warmer months with stratified conditions (deeper than 6 meters). Diffusers are not needed in shallow areas where only highly oxygenated water is present.

The installation and maintenance of a bottom-diffuser aeration system would only have a minor impact to routine access and recreational use of the lake. Areas of the lake would be closed to boating and fishing for one to two days while aeration tubing or piping is laid. An electrical source for compressors or blowers would be needed and the length of air conveyance tubing could be a challenge, depending on where systems were installed. However, with the lake being mixed laterally, these diffusers do not need to be installed at the very deepest point farthest from the shore; they can be installed closer to shore as long as they are below the thermal stratification. The system would require quarterly maintenance of compressors or blowers and annual maintenance on bottom diffusers, and that might result in partial closures of affected areas of the lake for a day or two.

Anticipated cost for initial installation of a complete aeration system using bottom diffusers, piston-driven air compressors or blowers, and weighted airline hoses is $125,000 to $250,000. Power is currently available at the south boat dock, but not at the north boat dock or dam. Additional costs would apply to provide power to the aeration system in the northern portion of the Lake. Alternatively, electrical power could be provided by solar panels where line power is not feasible.

3.2.2 Floating Vertical Water Circulators

Floating vertical water circulators (**Figure 13**) create vertical water movement by cycling deep oxygen-poor water to the water-air interface. These circulators float on the water surface and are anchored in place. They require water depths greater than 1 meter and would be anchored in water depths greater than 5 meters to be effective. Solar or shore-powered versions are available. Each unit has a footprint of approximately 16 feet in diameter. The ability to install different draft tubes could allow for water circulation from the bottom of the deepest part of the reservoir. There would be some negative impact on boating and other recreational uses in the lake because some units represent a large diameter obstruction that would need to be marked and avoided, possibly with an additional safety buffer around the unit also blocked to boating and other uses.

The vertical water circulators would float on the surface in areas of the lake where the water is deep enough that there is low-oxygen hypolimnetic water below them during the warmer months with stratified conditions. These are not needed in shallow areas where only high-oxygen epilimnion water is present.

The anticipated cost for initial installation of all four (4) floating vertical water circulators is $190,000 to $250,000. This assumes the installed units are solar powered and have no electrical requirement from land.

3.2.3 Hypolimnetic Aeration

With hypolimnetic aeration (**Figure 14**), the oxygen demand of deep water is compensated by oxygen from the atmosphere or an external oxygen supply without destroying the lake's natural stratification. Thus the deep water becomes aerobic, the phosphate dissolution is reduced significantly and the mineralization of sediments improves while stratification and habitat variations are maintained. The systems are appropriate for lakes wishing to maintain a two-tier fishery by maintaining a cold-water habitat for certain fish species.

In these systems air is blown into a diffuser at the bottom of a recirculation tube and entrains water upward through the tube. The water is re-oxygenated by contact with the air bubbles, then returns to the bottom where it discharges through radial outlets. Excess air is discharged through the top or a vent pipe.

The anticipated cost for initial installation is in the range of $100,000 to $200,000.

3.2.3.1 Speece Cone

A down-flow bubble contactor (Speece Cone) is a hypolimnetic aeration system that uses the change in water velocity that occurs in different diameter pipes to ensure complete diffusion of pure oxygen bubbles. Water flows down through a cone; as the cone widens, the water slows. At the same time, oxygen bubbles are injected into the bottom of the cone (**Figure 15**). The bubbles rise against the counter-flowing water until the point that the velocity of the down-flowing water equals the speed of the bubbles rising. At this point, the bubbles hover in the water flow as they slowly diffuse away. There is no off-gas and thus no loss of expensive oxygen. The oxygenation system is housed on land and a diffuser system is placed at the bottom of the lake. Speece Cones have been installed and are successfully operating in several California reservoirs, including those with summer algae blooms of Aphanizomenon. Reductions in nitrogen, phosphorus and algae have been reported.

Speece cones appear to be a highly effective but expensive aeration alternative. Depending on pump size, distribution locations, and use of generated or delivered oxygen, capital costs could be in excess of 1 million dollars.

3.2.4 Nanobubble Aeration

In this relatively new technology, water is pumped from the lake to an on-shore air or oxygen generator and gas diffusion system (**Figure 16**) that produces ultra-fine bubbles (nanobubbles less than 1 um diameter). Both shoreline and solar-powered floating systems are available. The oxygen infused water is returned to the lake. As a result of their small size and extremely large total surface area, nanobubbles have no natural buoyancy, follow Brownian movement, and transfer oxygen throughout the water column. This unique behavior enables nanobubbles to provide a homogenous distribution of oxygen throughout an entire body of water. They also have a strong negative charge and are attracted to organic molecules with positive surface charge. When they connect with positively charged metal ions, pollutants and dangerous cyanotoxins, nanobubbles render them inactive. Nanobubbles also remain within the water column for a longer period of time over alternative aeration methods.

Some benefits of nanobubble treatment include (a) saturation of water with over 50,000 times more oxygen than diffuse aeration, (b) helps mitigate nutrient recycling from the sediment, (c) neutralizes toxins, (d) helps sustain growth of beneficial bacteria and desirable microbes, and (e) reduces accumulation of anaerobic bottom muck and sediments.

The anticipated cost for initial installation of approximately ten (10) solar-powered nanobubble generators is $450,000 to $550,000 (for all units). This does not include electrical connections for non-solar systems.

3.3 Nutrient Reduction and Inactivation

3.3.1 Watershed Management

Only reducing the loading of nutrients into Watson Lake from Granite Creek truly treats the cause of high nutrient levels (particularly phosphorus) that support excessive growth rates of algae and weeds. The Granite Creek Watershed Pollutant Reduction Plan (developed alongside this Plan) describes ways to reduce phosphorus from the developed environment towards levels needed to limit growth of algae in the lake.

3.3.2 In-lake Methods

The successful growth and propagation of aquatic weeds and algae are dependent on adequate nutrient concentrations within the water column and sediment. Precipitation of dissolved and suspended nutrients from the water column or inactivation (immobilization) of nutrients in the bottom sediment using chemicals can reduce algae and aquatic macrophyte growth. Nitrogen is very difficult to manage because it can be replenished from the atmosphere by nitrogen fixing organisms such as cyanobacteria (also called blue-green algae); therefore, phosphorus is usually the target element. Typical forms of phosphorus in surface waterbodies include inorganic phosphates, iron-bound phosphorus and inorganic phosphorus. Nutrient inactivating chemicals can bind and capture each form of bioavailable phosphorus. Lower doses can be used to just target the water column phosphorus or higher dosages can be applied to also inactivate releases from the sediment.

The inactivating material is applied by boat throughout the water column in a series of applications spanning a few days to a few weeks depending on the treatment protocol. Water quality parameters can affect the suitability and dosage requirements of some products. Nutrient inactivation agents work through chemical precipitation; they are widely used in lakes and they are not toxic like herbicides or algaecides.

The types of products that fall into this category include aluminum sulfate (alum), buffered aluminum sulfate (Baraclear® or similar), or lanthanum-impregnated clay (Phoslock®). Liquid alum can be applied directly from a boat or barge, but is relatively expensive because of the limited solubility of alum in water and the resulting low concentration in the liquid as supplied. Dry forms are usually preferred and mixed as a suspension in lake water and applied through a manifold system from a boat or barge. The specific reaction of alum and water will also generally lower pH. For high dosage applications, addition of a buffer may be necessary to maintain a stable pH. Although there are numerous chemicals that can be used, sodium aluminate is typically added as it also contributes aluminum to the dose.

Nutrient inactivating agents have been shown to be effective in locking phosphorus in the lake sediment for five or more years between applications. Some precautions must be considered. Benefits may be short-lived when inflows contain high concentrations of phosphorus (as with Watson Lake). Although buffered alum should control cyanobacteria (blue-green algae) and some filamentous algae, it may not eliminate rooted aquatic plants that may still obtain some phosphorus from the deeper layers of lake sediment. Additionally, application of alum in the relatively shallow areas of the lake may not be effective. Effectiveness may be short-lived where area is covered with macrophytes during the summer and their decay will contribute phosphorus to the water.

Two (2) applications per year may be required to address seasonal phosphorus-laden inflows. One application would be targeted for late April or May, before the start of warm-weather algae growth, to address phosphorus that was already in the reservoir (e.g. released from bottom sediment) or in winter inflow. The second application would be applied soon after the monsoon season to help bind phosphorus washed into the reservoir. The use and application of these materials would have minimal impact on the recreational use of the lake.

Cost for a single application of alum is dosage dependent and jar testing is usually recommended to identify the optimum dosage. Costs can range from $500 to $1,000 per acre. The addition of lanthanum-impregnated clay would be the costliest, at an estimated $1,000 or more per acre. Cost is calculated based on water quality data with a total removal of 407 lb of phosphorus from the water column (or 2.45 lbs per surface acre, based on reducing phosphorus concentrations to under 3 µg/L). If applied to the entire lake, the cost would be approximately $96,000 - $192,000 per application.

3.3.3 Sediment Removal

Dredging is the process of the physical removal of sediment from the bottom of a lake or reservoir. This has the benefit of reducing a major in-lake source of nutrients (recycled phosphorus in particular), increasing the depth of the lake or reservoir, and thereby reducing the area of shallow lake water that receives sufficient light penetration to support submerged weed growth, and in some cases directly removing submerged weeds and their substrate. The benefit of dredging can be realized for 5 to 10 or more years depending on how much new sediment and nutrients wash into the lake and settle to the bottom. Selective dredging of the areas suffering from the most sedimentation may also provide benefits, particularly to reduce rooted weed growth, and would cost less than a full-scale dredging effort. Due to water rights and Active Management Area (AMA) recharge considerations, there may be limitations and significant coordination efforts required for lake draining and dredging activities to be feasible.

Because the annual inflow of water is large relative to the lake volume, dredging alone is unlikely to significantly reduce levels of phosphorus in the lake unless inflowing phosphorus is also reduced (at the watershed level) or is bound or inactivated upon entering the lake before it is used for algae growth. Lake modeling results supported this relationship. In addition, the large annual inflow means that dredging is not a once-only activity because the large inflow brings large amounts of new sediment and nutrients into the lake that settle to the bottom where they would eventually need to be re-dredged.

The spatial distribution and depth of high-phosphorus sediment deposits would need to be better quantified for an improved understanding of cost and benefit, particularly of selective dredging. Lake sediment appears to be a large potential reservoir of phosphorus, and small reductions in the sediment area in contact with the lake is unlikely to achieve large reductions in lake phosphorus; large-scale dredging might be needed.

Dredging efforts would have a major impact on the normal operation and recreational availability of the lake. Relative to other lake management techniques, dredging is one of the most disruptive alternatives in terms of aesthetics and interruption to lake operation and recreation uses. Dredging can temporarily reduce oxygen concentrations, increase turbidity, and encourage algal blooms by upwelling some of the sediment during the removal operation. It would likely require portions of the lake to be closed to boating and fishing in the vicinity of dredging activities. However, the disruption is only for the duration of the dredging, unlike some other measures that involve ongoing effects.

The depth to which the lake, or a section of the lake, is dredged is also of importance. Dredging shallow areas to a depth deeper than the photic zone (2 meters) will reduce the amount of lake bottom available for aquatic weed growth. A greater depth may need to be dredged because the lake level can vary from year to year. The Sediment Study indicates an even distribution of nutrients throughout the sediment depths. Dredging activities that do not dredge to below the bottom of the high-nutrient sediment may not reduce nutrient redistribution to the water as it will merely expose a new layer of nutrients to the sediment-water interface.

3.3.3.1 Sediment Removal Methods

The most common forms of sediment removal in large lakes include direct removal by mechanical equipment and vacuum/suction (hydraulic) dredges. Dredging involves draining the lake or a portion of the lake to the lowest level possible, targeting material dried by the drawdown, and excavating the material with conventional land equipment. Wet dredging may use a shovel-like apparatus to scoop the material from a completely filled lake and deposit the sediment in a holding bin. Hydraulic dredging uses a suction line to essentially vacuum up the material and pump it to shore. The main benefit of hydraulic dredging is the ability to retain the existing water level throughout the removal process. This avoids disruption of recreational activities and the fish community. Dredging also eliminates odors associated with exposed lake beds but there is increased lake traffic and noise associated with the activity. If the sediment slurry is not dried on site, it may be difficult to find a disposal location and relocation may require sealed transport containers to comply with Arizona Department of Transportation (ADOT) regulations.

On-site dewatering activities, when used in conjunction with dredging, may help reduce the overall cost of sediment removal and disposal. Dewatering on site may allow for disposal at a nearby facility and use of more traditional hauling equipment. Costs are reduced because the weight of the removed water is no longer included in the hauling and disposal cost. The removed liquid is redirected back to the lake or an evaporation pit.

Dewatering on site could be achieved by two different methods. First, specialized roll-off style containers that allow for the draining of bulk materials could be employed. The advantage of this option is that the dewatering container could also serve as the transport container and reduce a step and associated time between dewatering and transport. The second option is to use specially designed dewatering bags (GeoTubes). The tubes achieve a very high level of solids compaction, and are picked up, transported, and disposed at the completion of dredging operations. Dewatering presents issues including the odors while the process is undertaken and the need for a large staging area for dewatering.

A realistic cost of dredging should include costs of monitoring, dredging equipment, labor, and transport of and disposal of dredged material. Monitoring costs include pre-dredge screening of the sediment to determine quality (hazardous waste characterization), post-dredge monitoring of the lake and staging or disposal site, and in-lake monitoring to fulfill any regulatory or permit requirements.

Costs for suction dredging are estimated at $25,000 to $75,000 per acre plus approximately $25 to $50 per cubic yard. The Sediment Study revealed approximately 414 acre-feet (668,393 cubic yards) of sediment volume. Based on the cost and volume, costs for dredging the full volume are approximately $17 to $34 million. Cost is influenced by variables such as engineering and permitting, mobilization, allowable run times, transport distance, disposal, and de-watering management. A partial dredging of selected areas, especially the commonly vegetated shallows, may be advisable based on the high cost of the activity and the minimal impact on nutrient dynamics in the lake.

3.4 Submerged Weed Management

In-lake phosphorus inactivation and watershed reduction would decrease availability of a primary nutrient required for growth and propagation of aquatic weeds. Dredging in the shallow portion of the lake that supports submerged weeds would also be applicable as the process can reduce rooting substrate and simultaneously remove vegetative material with the sediment if the work is performed during the summer. Deepening the shallow portion of the lake may also decrease the portion of the lake that becomes choked with vegetation.

Other management options specifically for submerged aquatic vegetation are discussed below. The area covered by weeds during the summer is approximately 30 acres.

3.4.1 Weed Harvesting

Harvesting may be an affordable method of seasonal removal of submerged weeds. A harvester may be purchased and operated by the City or the work may be contracted out to a professional weed management provider. Based on the climate and observations made during the TMDL study, weed growth appears limited to the period of April through September. A harvesting event in June or July could remove sufficient vegetation to provide recreational and aesthetic relief until the plants begin to die back in October. Adequate shoreline exists for dumping and allowing the vegetation to dry prior to hauling and disposal. Removal of submerged weeds could make more nutrients available to algae, so this condition would require monitoring and possible initiation of other algae mitigation efforts.

Weed harvesting should be done on a trial basis. Because the species of concern tend to fragment during mechanical activities, it is possible there would be significant re-growth from those fragments. Should this occur, another means of management will be required.

Purchase cost of a weed harvester ranges from about $85,000 to $150,000. Operational, per-acre cost ranges from $500 to $3,000, including labor and disposal. Disposal costs could be reduced or eliminated if removed material were used as a fertilizer or soil amendment instead of being disposed.

3.4.2 Chemical Applications

Although the City has expressed a desire to avoid the use of chemical pesticides, herbicides, and algaecides in Watson Lake, aquatic herbicides may be safely used to reduce the density of the plants during the summer. Because the growing season at Watson Lake is relatively short, a single herbicide application or several small, area-specific applications could decrease plant density for the duration of the summer growing season and provide recreational relief to fishermen and boaters.

During lake monitoring activities, several submerged aquatic weed species were identified. They included Coontail (Ceratophyllum spicatum), Sago Pondweed (Stuckinea pectinatus), Curly-leaf Pondweed (Potamogeton crispus), and Eurasian watermilfoil (Myriophyllum spicatum). Chara, an advanced form of algae resembling an aquatic weed and often managed as one, was also present. See **Figure 17** for examples of watermilfoil and coontail weeds.

Recommended herbicide choices are provided below for each of the resident species, with effectiveness indicated as good (G) or excellent (E). Liquids are usually applied by sub-surface injection using weighted hoses. Granular products are mechanically spread across the lake surface and sink to the bottom where the weeds are located and rooted. Label directions must be followed including any restrictions to use, and application should be in accordance with any ordinances, including a Pesticide General Permit. Applications must be made by a Department of Agriculture Pest Management Division licensed aquatic applicator.

Table 6
Herbicide choices

Species	Product and active ingredient.	Active ingredient	Form	Effect
Coontail	Navigate, Weedar-64	2,4-D	Liquid	G
	Cutrine Plus, Captain, Clearigate*	Copper	Liquid	G
	Reward, Tribune	Diquat dibromide	Liquid	E
	Aquathol K or Super K	Endothall	Liquid, granule	E
	Sonar	Fluridone	Liquid, granule	E
	Clipper	Flumioxazin	Granule	G
Sago pondweed	Reward, Tribune	Diquat dibromide	Liquid	E
	Cutrine Plus, Captain, Clearigate*		Liquid	G*
	Reward, Tribune		Liquid	G
	Aquathol K or Super K	Endothall	Liquid, granule	E
	Sonar	Fluridone	Liquid, granule	E
	Clipper	Flumioxazin	Granule	G
	Galleon SC	Penoxsulam	Liquid	G

Table 6 Herbicide choices				
Species	**Product and active ingredient.**	**Active ingredient**	**Form**	**Effect**
Curly-leaf Pondweed	Reward, Tribune	Diquat dibromide	Liquid	G
	Cutrine Plus, Captain, Clearigate*	Copper	Liquid	G
	Aquathol K or Super K	Endothall	Liquid, granule	E
	Sonar	Fluridone	Liquid, granule	E
	Clearcast	Imazamox	Liquid	G
	Clipper	Flumioxazin	Granule	G
Eurasian watermilfoil	Cutrine Plus, Captain, Clearigate*	Copper	Liquid	G
	Navigate, Weedar-64	2,4-D	Liquid	G
	Aquathol K or Super K	Endothall	Liquid, granule	E
	Sonar	Fluridone	Liquid, granule	G
	Reward, Tribune	Diquat dibromide	Liquid	E
	Clearcast	Imazamox	Liquid	G
	Galleon SC	Penoxsulam	Liquid	E
	Renovate	Triclopyr	Liquid	E
	Clipper	Flumioxazin	Granule	G
Chara	Cutrine Plus Granular	Copper	Granule	E
	Copper sulfate crystals	Cooper	Granule	E
	Aquathol K or Super K	Endothall	Liquid, granule	G

*can be tank mixed with diquat dibromide

If used, applications should be made to a limited area, and never more than one-third of the lake surface area at a time to avoid depletion of oxygen in the water column that results from plant decomposition. Applications are usually based on surface area for granular products and volume of treated lake water (acre-ft) for liquids. Because liquids can disperse, a sinking and/or sticking adjuvant can be added to the liquid to help keep the chemical on and around the plants. By using the adjuvants, the number of acre-feet treated can be reduced and cost minimized. Liquids are usually pumped from a boat using a weighted hose to better direct the herbicide to the weed bed.

Typical herbicide applications range in cost from $75 to 100 per labor hour plus chemical costs that range from as little as $75 to as much as $500 per acre depending on weed and product selected.

Lake dyes have been successful at reducing light penetration in lakes and reducing algae and submerged weed growth in small reservoirs. Longevity can be a month or more with no outflow. Because the entire lake must be dyed, such applications would require approximately 600 gallons of lake dye. Materials cost would be approximately $30,000 per application.

3.4.3 Biological Management of Aquatic Weeds

Stocking the lake with White Amur would be the most environmentally sound management technique for weed removal; this would involve no chemicals, no disturbance, and would offer up to 10 or more years effectiveness or until they are fished out. The City would need to negotiate with AZGF to agree upon a means to satisfy the no ingress or egress requirement. AZGF has relented most recently at Rainbow Lake where planting of White Amur has significantly reduced weed growth and distribution. An initial stocking density of 30 fish per acre is recommended.

White Amur cost $6 to $12 dollars each depending on quantity purchased. Assuming the lake would be stocked at one time, the cost would be about $35,000 - $70,000. This cost does not include the capital cost that might be required to satisfy the no ingress or egress requirement such as fish screens at or near the Lake inlet and outlet. A cost cannot be estimated until specific requirements and specifics for such measures are negotiated with AZGF. Restocking approximately 10 to 15 percent of fish per year should be anticipated.

3.5 Algae Management

Reducing the loading of nutrients into Watson Lake from Granite Creek truly addresses the cause of high nutrient levels (particularly phosphorus) that support excessive algae during the summer. The Watershed Pollutant Reduction Plan (developed alongside the Lake Management Plan) describes ways to reduce nitrogen and phosphorus from the developed environment towards levels that would be needed to inhibit algae blooms in the Lake. In-lake management efforts as aeration, phosphorus inactivation, and dredging will help reduce algae production. These practices and their benefits have been described previously.

The City has expressed a desire to avoid the use of pesticides, herbicides, and algaecides in Watson Lake. Algal densities exceeding ADEQ target ranges for total algae and cyanobacteria (blue green algae) percent composition are sometimes exceeded causing elevated pH and potential toxin formation issues. Aquatic algaecides may be judiciously used to reduce the density of nuisance and potentially harmful forms during the summer. It is simply another management tool that could be considered.

The primary problematic and high-density (biovolume) algae that have been identified in Watson Lake during the summer are listed below (see **Figure 18**):

Cyanobacteria (blue-green algae)		Others	
Oscillatoria	(filament)	*Closterium*	(green unicell)
Gloeocystis	(colony)	*Chroomonas*	(cryptophyte unicell)
Anabaena	(filament)	*Schroedria*	(green unicell)
Lyngbya	(filament)	*Fragilaria*	(diatom unicell)
Microcystis	(filament)	*Rhizoclonium*	(green filament)
Aphanizomenon	(filament)		
Coelosphaerium	(colony)		
Gloeotrichia	(colony)		

All the blue-green algae listed are represented by species that are potential toxin producers. The major pathways for human toxin exposure are by ingestion, skin contact, and inhalation. Because no swimming is allowed at Watson Lake, the major pathway, ingestion, is unlikely to occur. However, incidental contact with water and inhalation of aerosols are always possible. When concentrations of blue-green algae approach or exceed the ADEQ Targets for Lakes and Reservoirs for PBC and A&Ww (20,000 units/mL or 50 percent of total count), action may be considered. Toxin testing is recommended to determine if there is a public health concern. A few out-of-state specialty laboratories (such as Green Water Laboratories Cyanolab) are available for testing. Test strips can be used for routine monitoring; however, during blooms and peak recreational periods, using quantitative test methods (EPA method 546 ELISA or LCMS/MS) is recommended.

The major algaecides for blue-green algae management are peroxide-based algaecides and the copper-based algaecides containing a surfactant. For green algae and cryptophytes, any of the copper-based products are appropriate and cost effective. In the unlikely case of a diatom bloom, an acidic copper algaecide works well to fracture the silica cell wall of the algae and allow the copper to better penetrate the cells.

Materials should be applied to the upper three feet of the water column in the area of the algal bloom, and over an area never to exceed one-third of the total surface area of the reservoir. Application costs range from $65 to $1,000 per acre-ft, depending on the severity of the algae bloom and product choice. Labor cost for a licensed applicator usually ranges from $75 to $100 per hour.

Lake dyes have been successful at reducing light penetration in lakes and reducing algae and submerged weed growth in small reservoirs. Longevity can be a month or more with no outflow. Because the entire lake must be dyed, such applications would require approximately 600 gallons of lake dye. Materials cost would be approximately $30,000 per application.

3.6 Nuisance and Vector Insect Management

Although not directly involved with the Watson Lake TMDL, management of the lake and its immediate surrounding helps preserve its recreational benefits. The shoreline around Watson Lake provides an ample number of locations for mosquito propagation. A high level of soft sediment throughout the lake also provides good habitat for the propagation of midge flies and other aquatic-life cycle insects. These insects are part of the lake and watershed ecosystem, but at times can reach nuisance or public health concern numbers.

3.6.1 Mosquitoes

Adult mosquitoes may cause nuisances around the shoreline. Because mosquitoes are vectors of several arboviruses, elimination of breeding habitat and reduction of numbers are important. Although fogging with adulticides can be performed for immediate short-term relief, it is not recommended for Watson Lake because of public safety and environmental concerns.

Mosquitoes are not expected to breed in the lake proper. Mosquitoes prefer shallow, stagnant water with vegetative cover and absence of predatory fishes. An open-water lake does not meet these criteria. However, small isolated rocky coves at the edge of the lake and terrestrial pools in vegetated areas along the lake shoreline can serve as breeding habitats. Should such pools be identified by presence of mosquito larvae, one or more the following actions may be taken:

- Seek and identify breeding habitat if adult numbers become problematic
- Drain terrestrial pools

- Add mosquito eating fish (Gambusia) to large semi-permanent pools
- Add monomolecular film to terrestrial pools
- Apply larvicide

If monitoring of the sites is desired, traps can be placed in the late afternoon and collected the following morning, Suggested action levels for mosquitoes are >30 Culex mosquitoes per trap, >30 Aedes mosquitoes per trap, or >300 floodwater (Aedes, Anopheles, and Psorophora) mosquitoes per trap. Some laboratories can perform encephalitis screening on the collected mosquitoes, including West Nile and Dengue Viruses.

These mitigation responses pose minimal environmental or public health threat, including toxicity of management chemicals. Monomolecular films are synthetic oils that spread out and cover pools. Because the films lower the surface tension of the water, the mosquito larvae cannot hang at the surface to breathe through their siphons and essentially suffocate. Larvicides include reduced-risk bacteria-based products containing Bacillus thuringiensis and B. sphaericus endospores or spinosad (soil bacteria toxin). Methoprene, a low toxicity product, is also an excellent choice for spot applications. The products come in granular form and could be manually broadcast into standing water. The methoprene and spinosad products have formulations that can be effective for up to 150 days. Examples include Vectobac® and Aquabac® (bacteria), Natular® (spinosad), and Altosid® (methoprene).

3.6.2 Midge Flies

Midge flies will inhabit the lake sediments. They are far less likely to occur in any temporary pools on land. Algae and bacteria provide an adequate food source. Midges found in Arizona do not bite, but can be major nuisances especially at sunrise and sunset when they swarm as part of their mating routine. They tend to fly into eyes, ears, and open mouths.

As with mosquitoes, management should target the larval form. A list of possible responses to excessive midge fly populations is provided below:

- Use terrestrial traps to monitor adult numbers and dredged sediment samples to monitor larvae density
- Stock bottom-feeding fishes such as sunfish
- Apply larvicide

The methoprene and spinosad products used for mosquito management are also highly effective on midge larvae. The Bacillus products are also frequently used because they are relatively inexpensive, but their efficacy is short-term and reduced. Application of the products can vary from $60 to $350 per acre plus labor of $75 to $100 per hour for a licensed applicator.

3.6.3 Bacteria

If a need to manage bacteria in Watson Lake emerges, trying to manage bacteria density and E. coli specifically will be difficult in the large watershed and natural setting of Watson Lake. Watershed Best Management Practices will serve as the primary management strategy to prevent bacteria from washing into the lake. However, some in-lake methods are available and are listed below:

- Remove aquatic vegetation to reduce waterfowl numbers
- Remove soft anaerobic sediments that might harbor E. coli
- Maintain a strict cleanup policy for pet owners
- Redirect local runoff away from the lake wherever possible

Some copper-based algaecides are labeled for temporary reduction of bacteria concentrations in water (e.g. Earthtec) while others are oxidizing agents and will coincidentally reduce bacteria densities (e.g., Phycomycin, Green Clean). High application rates of up to six gallons product per acre-ft (~$100 per acre-ft of treated water volume) are required. Therefore, chemical applications should be considered for emergency response only. The PBC standard (575/100 CFU/100 mL) may be established as an action level.

3.7 Lake Monitoring

An ongoing lake monitoring program is recommended both to monitor water quality and compliance with TMDL goals. Ancillary monitoring of nuisance and vector insects may be part of the program as a service to recreational users of the lake in terms of quality of life and public health. The program may be operated by the City, using a contract ADHS-licensed laboratory and City personnel for field sampling and testing; or the entire monitoring program may be contracted to a suitable vendor as long as a licensed laboratory is used. A specialty lab may be required for midge and mosquito identification. Licensed laboratories employ acceptable quality assurance practices, which is needed if the data will be reviewed and used by both the City and ADEQ for decision making.

3.7.1 Monitoring Equipment

If City personnel collect samples and take field measurements, the following equipment will be required.

- Two-person boat with motor and safety equipment
- Temperature-oxygen meter with 50-ft sensor cable
- pH/ORP meter, electrodes, and calibration solutions
- Secchi disk and marked rope (at least 20 ft long)
- Sub-surface sample collection device (Alpha, Kemmerer, Van Dorn or equivalent)
- Ekman dredge
- Wisconsin plankton net (80 um)
- GPS Unit
- Sample bottles and preservatives (typically provided by laboratory)
- EVS mosquito traps, dry ice (OPTIONAL)
- Mosquito dipper (OPTIONAL)
- New Jersey Light Traps (OPTIONAL)

3.7.2 Monitoring Locations

Water samples should be collected from three to four locations on the lake. Suggested locations, using same locations as was used in past Wood and ADEQ sampling efforts. Suggestion site locations are: near dam (VRWAT-A), open deep water (VRWAT-B), cove (VRWAT-C) and shallow water (VRWAT-SO) (see **Table 7** and **Figure 19**).

Table 7 Sampling Locations			
SITE NAME	**SITE ID**	**LATITUDE Degrees**	**LONGITUDE Degrees**
Watson Lake - At Dam	VRWAT-A	34.5952778	-112.4166389
Watson Lake - Mid Lake	VRWAT-B	34.5905556	-112.4158333
Watson Lake - Mid Lake	VRWAT-C	34.5875000	-112.4191667
Watson Lake - At Boat Ramp	VRWAT-BR	34.5930833	-112.4192500
Watson Lake - South End Revised	VRWAT-SO-REV	34.584861	-112.420111

Sediment would be collected at the same locations. If optional adult midge and mosquito monitoring is performed, the two boat dock locations would be reasonable locations. Should a cyanobacteria (blue-green algae) bloom occur, toxin testing can be limited to the specific area of concern.

3.7.3 Recommended Testing

To monitor progress and adjust lake management activities when needed, on-going sampling and analysis are highly recommended. Testing should be completed monthly at each sampling location. The test frequency exceptions are the heavy metal screen that may be tested one time per year and midge and mosquito adult collections and mosquito dipping (all on shore) that may be conducted during peak season (May to August) or as needed. Weekly pH, temperature, and dissolved oxygen (surface and lake bottom) is also recommended particularly during the peak growth season (June through September). A subsurface (0.5-m deep) sample is acceptable for water samples unless otherwise stated. Midge fly, mosquito, and vertical temperature and oxygen profiles maybe limited to March through October. All testing should be in accordance with APHA, WEF, or EPA methods and all holding times should be met. Field data should be recorded in a designated water-proof field book. Chain of custody procedures should be followed.

The following parameters are recommended for routine testing:

- Temperature and DO profile by depth (field measurement)
- Secchi disk depth (field)
- pH
- Alkalinity
- Hardness
- Turbidity
- Oxidation-reduction potential (water above and below thermocline and superficial sediment)
- Nitrate+nitrite-N
- Ammonia-N
- Total Kjeldahl N
- Total N
- Total phosphorus
- Dissolved phosphorus
- Dissolved Silica
- Dissolved in inorganic carbon
- Algae identification (to genus) and individual counts

- Chlorophyll-a
- *E. coli* bacteria
- Metals (Ag, As, Be, Ba, Cd, Cr, Cu, Hg, Pb, Sb, Se, Tl, Zn)
- Adult midges, total
- Midge larvae density (sediment grab, OPTIONAL)
- Adult mosquitoes, total and species counts; encephalitis screens as appropriate (OPTIONAL)
- Algal toxin testing (OPTIONAL)

3.8 Integrated Management Approach

Based on the information above, it is clear that no single management technique will result in achieving the TMDL limitations for nutrients, pH, and dissolved oxygen, and there are other important factors and conditions that need to be managed that go beyond the TMDL. Therefore, an integrated management plan should be used that combines a number of techniques to achieve success. An integrated plan also allows for staging of activities and initiation of some activities while delays might occur for funding, construction, or installation.

The integrated approach for managing water quality at Watson Lake should incorporate most of the suggested activities in this document. All have a purpose and can assist in achieving TMDL goals as well as improving the lake for recreational uses. An example of how an integrated management approach may work for Watson Lake is provided below.

- Immediately initiate the Lake Monitoring Program
- Apply phosphorus inactivation chemicals in late April (after winter inflows) through late June. Depending on Lake response, additional application after summer monsoons in late August to early September (before lake turn-over) may also be suggested.
- Select and install hypolimnetic aeration system
- Harvest submerged weeds in mid-June to early July as an interim, trial measure
- Because re-growth may occur and the method deemed unreliable, contracting the service would be advisable during this trial period before purchasing a harvester
- Determine cost specifics for dredging the shallow portions of the lake where weed growth occurs
- Negotiate with AZGF for use of White Amur for aquatic vegetation management
- Install fish barriers or other mechanisms of ingress and egress protection if White Amur are approved
- Implement dredging if use of White Amur is rejected
- Apply algaecides sparingly and herbicides as an interim activity to manage excess plant growths during the summer, especially to reduce cyanobacteria (blue-green algae) that produce toxin
- Monitor midges and mosquitos for quality of life maintenance and public health protection

4.0 FIELD REFERENCE GUIDE FOR WATSON LAKE

This Field Reference Guide, contained in **Appendix A,** is a stand-alone document designed for use by lake operators during their day to day activities. It includes a trouble shooting guide that refers to common lake management problems, lists items to check and verify, and offers appropriate corrective action choices. The Field Reference Guide also includes photographs of common resident plant and animal species of Watson Lake, so organisms can be readily identified. The following Field Reference Guide for Watson Lake is provided for interim use and should be considered a living document. Because management strategies laid out in this LMP have not yet been implemented, the contents of the Field Reference Guide could change considerably. As management methods are accepted and implemented, the Field Reference Guide should be modified to address applicable procedures relative to them.

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FIGURES

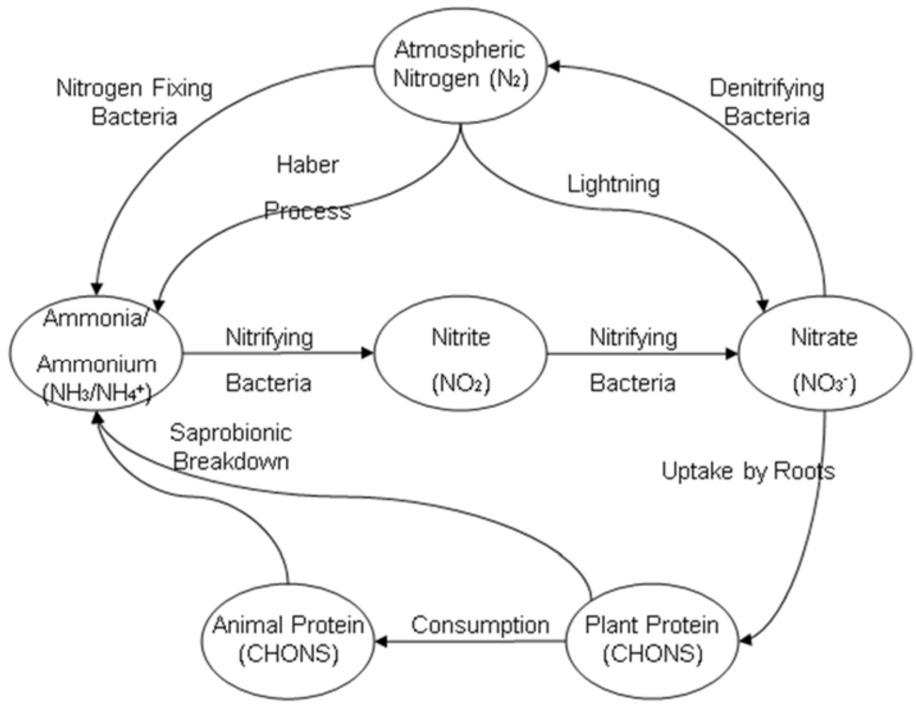

Figure 1 Aquatic nitrogen cycle

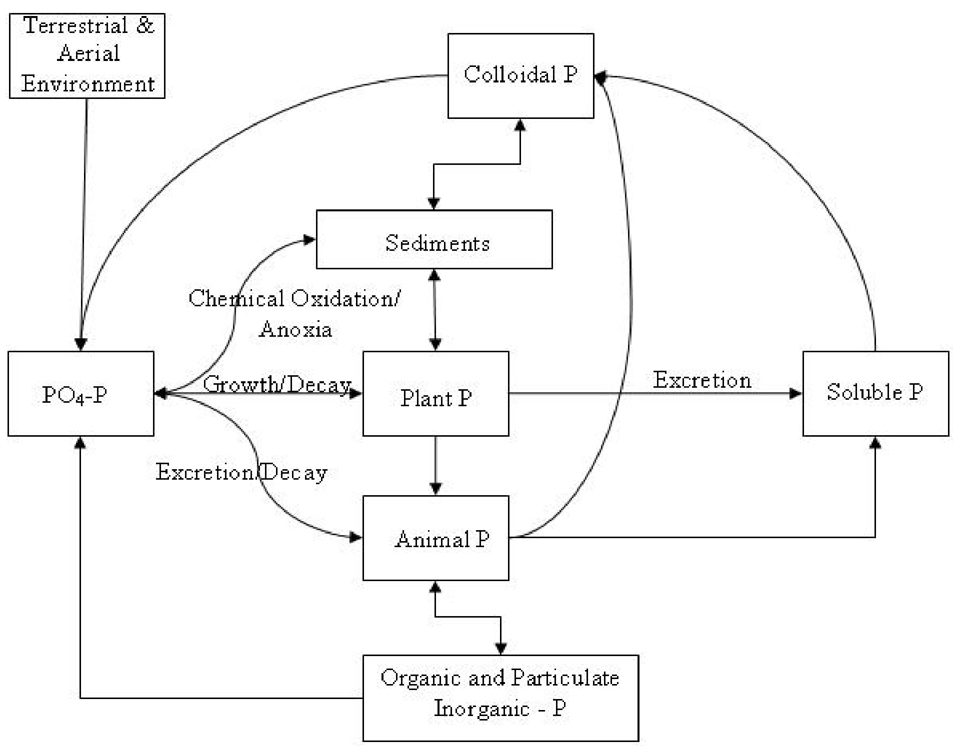

Figure 2 Aquatic phosphorus cycle

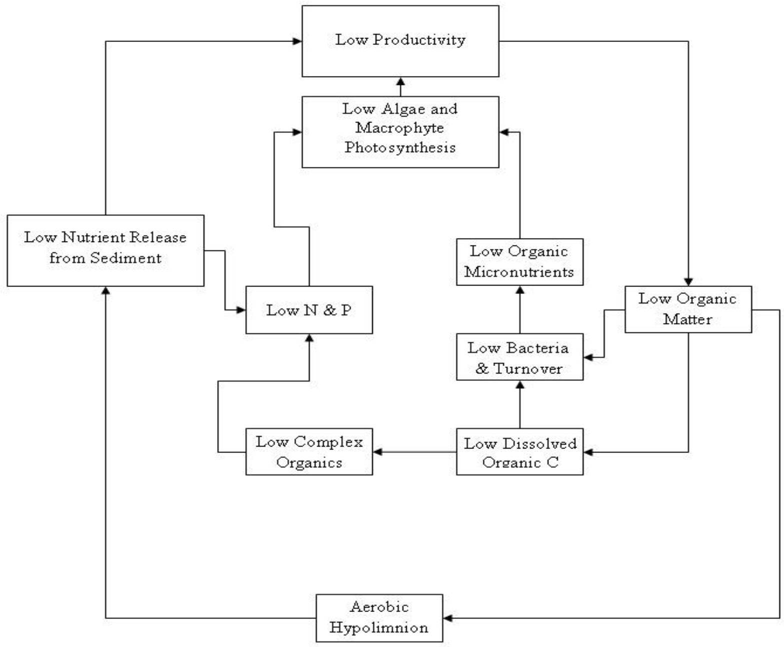

Figure 3A Oligotrophic lake nutrient dynamics

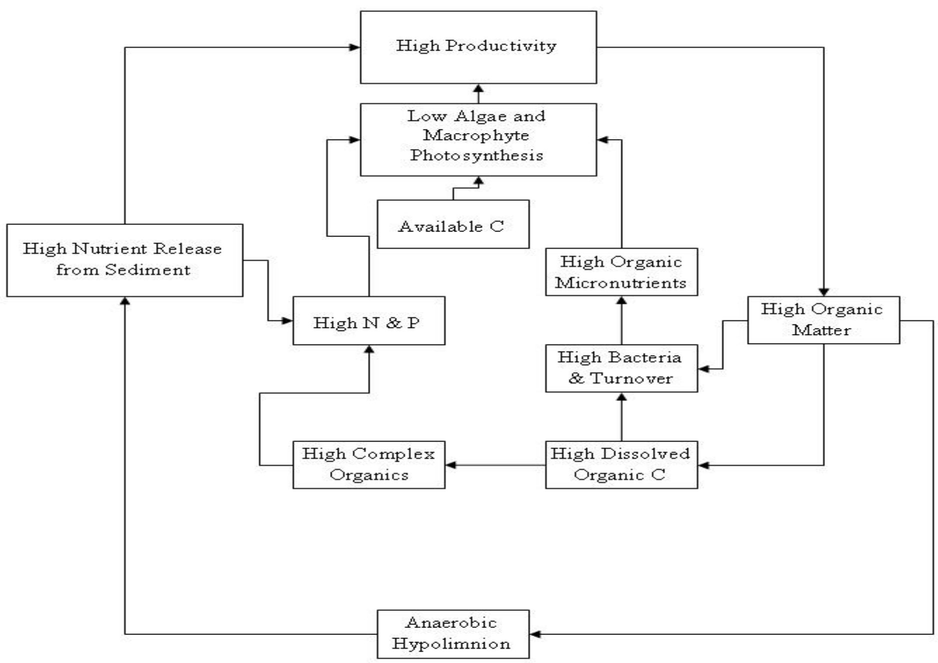

Figure 3B Eutrophic lake nutrient dynamics

Figure 4 White Amur

Figure 5 Weed harvester

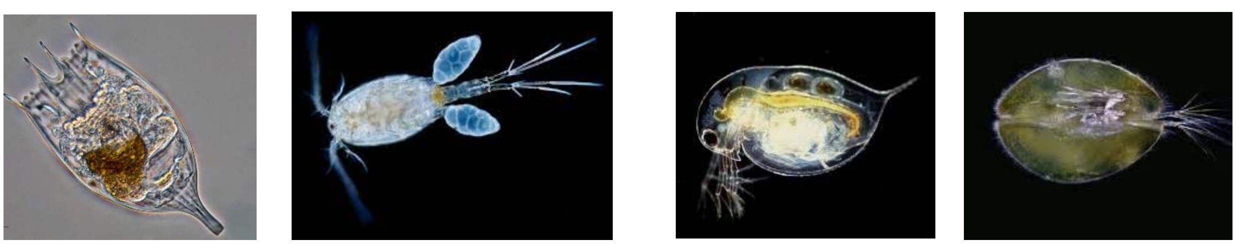

Figure 6 Zooplankton forms (left to right: rotifer, cladoceran, copepod, and ostracod)

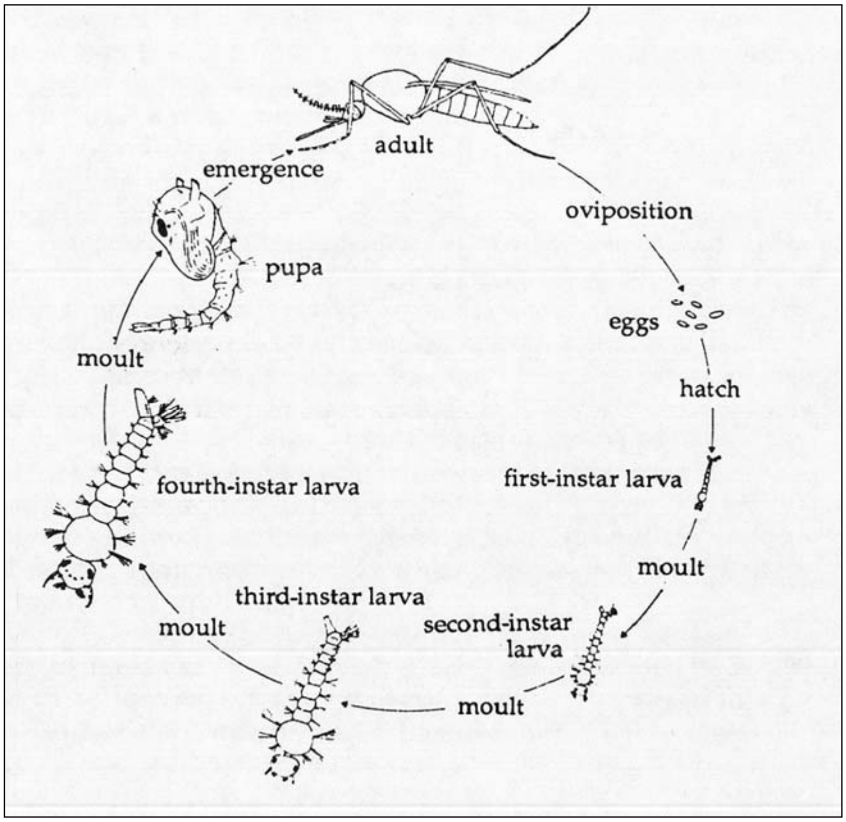

Figure 7 **Mosquito life cycle**

Figure 8 **Mosquito life forms (left to right: larva, pupa, adult)**

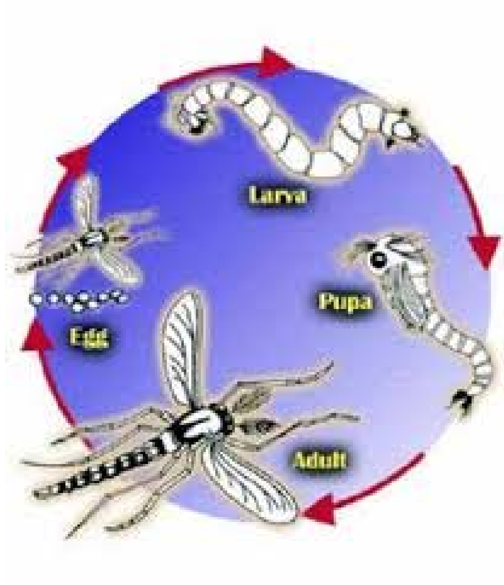

Figure 9 Aquatic midge life cycle

Figure 10 Midge life forms (left to right: larva and adult)

Figure 11 Lake sampling equipment
(left to right: Van Dorn bottle, Kemmerer bottle, Ekman dredge, Ponar dredge, EVS trap, New Jersey light trap)

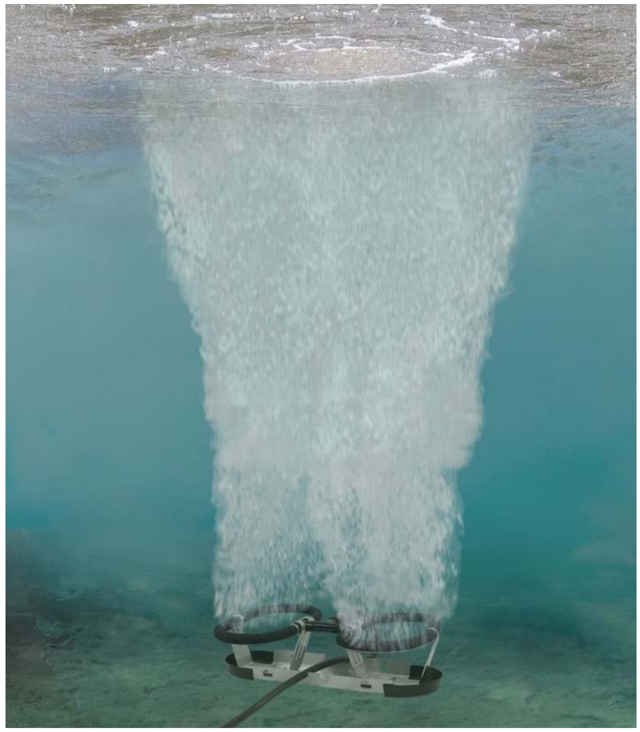

Figure 12 Bottom diffuse aeration (Kasco)

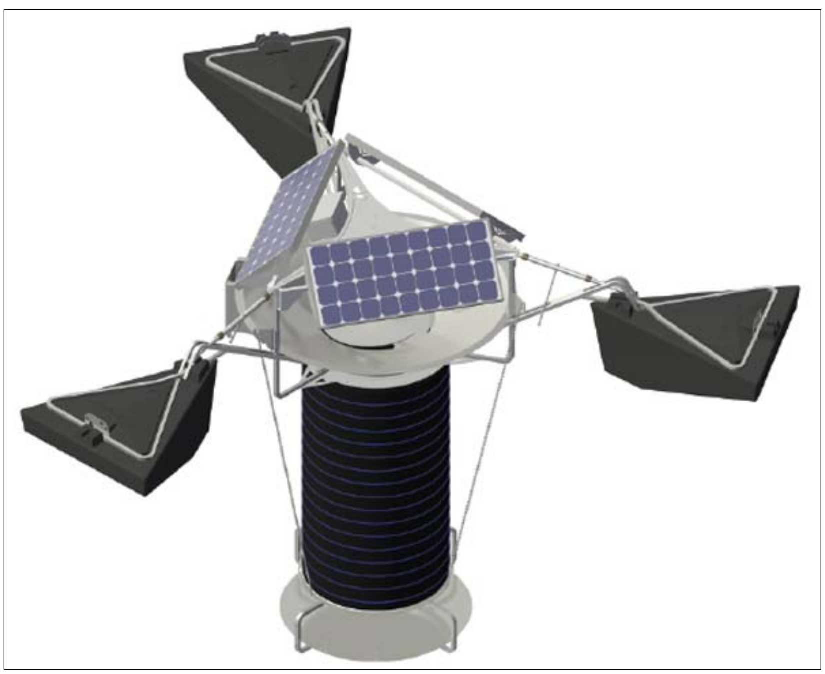

Figure 13 Floating aerator (Solarbee)

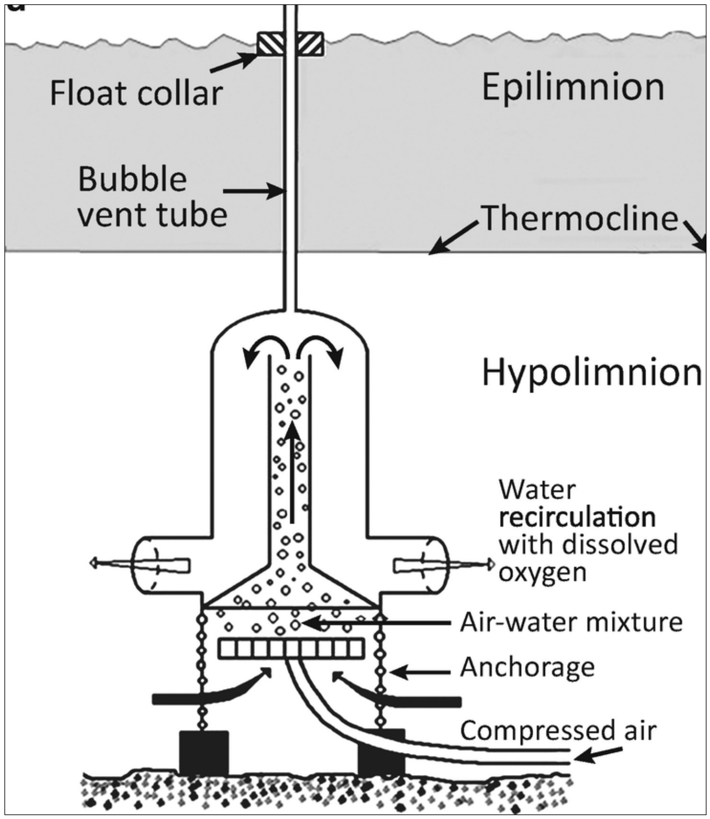

Figure 14 Hypolimnetic aeration (from McAliley, HDR Inc.)

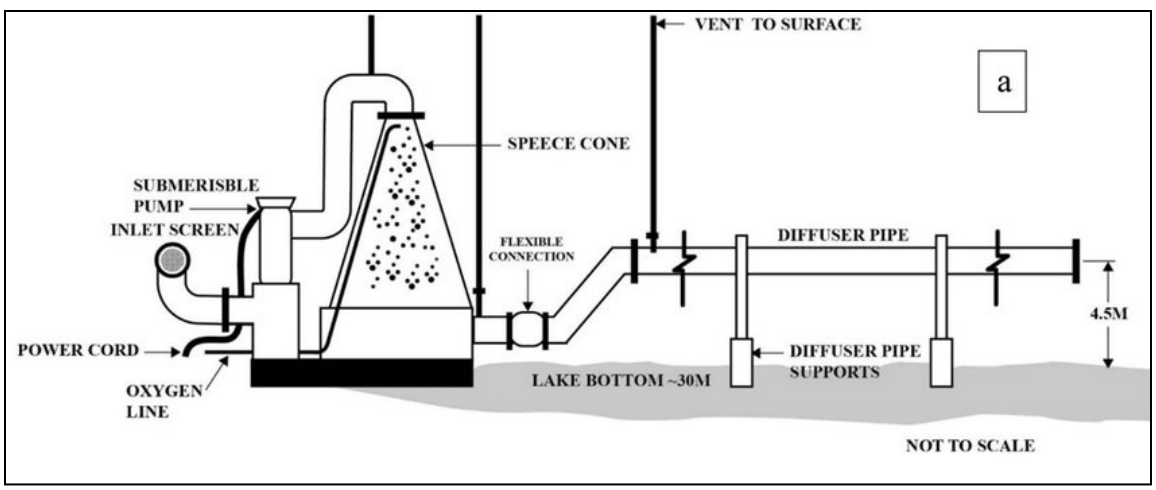

Figure 15 Hypolimnetic aerator-Speece Cone

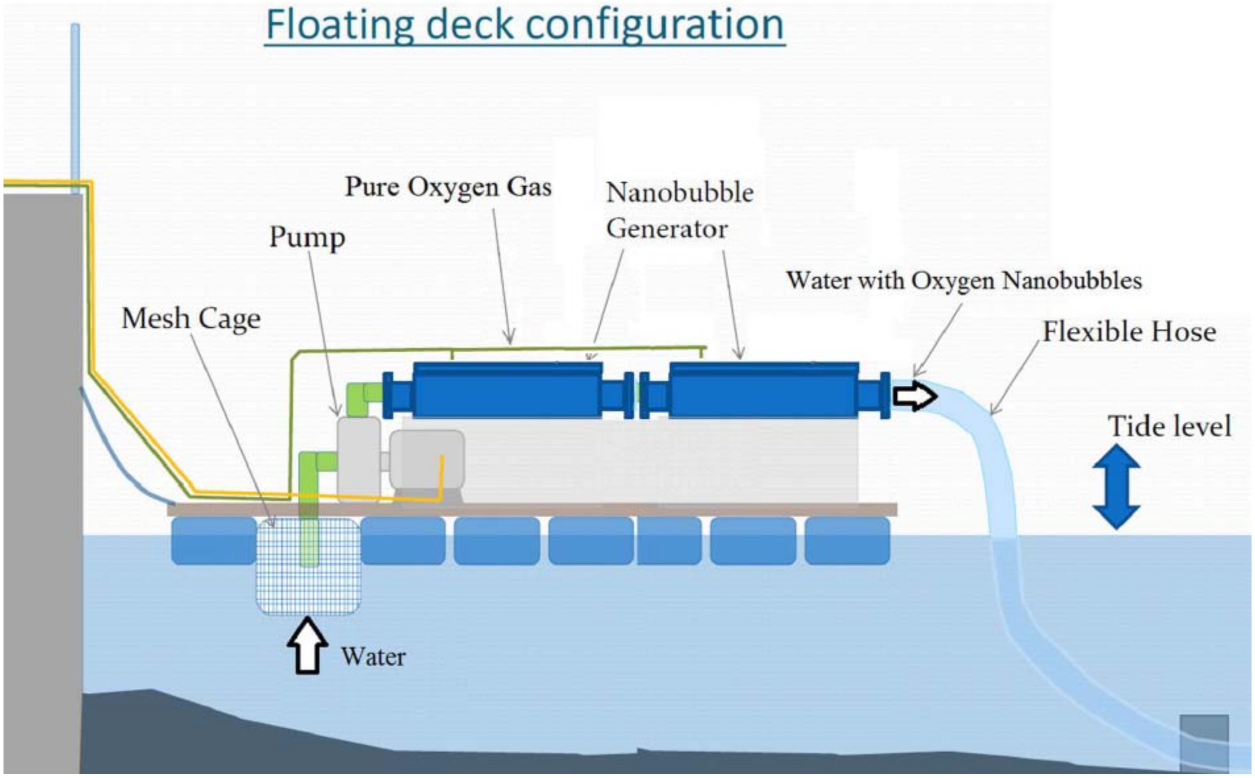

Figure 16 Nanobubble aeration configuration

Figure 17 Watermilfoil (left) and coontail (right)

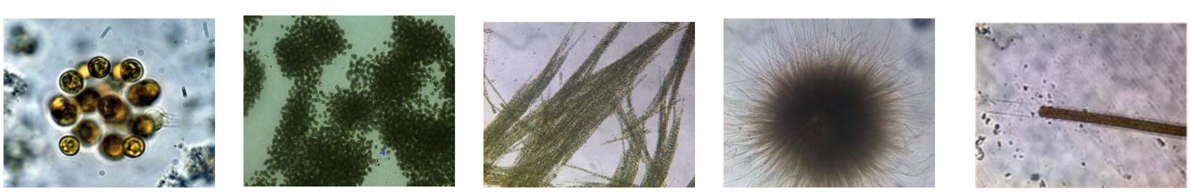

Figure 18 Common blue-green algae of Watson Lake (left to right: Gloeocystis, Microcystis, Aphanizomenon, Gloeotrichia, Lyngbya.)

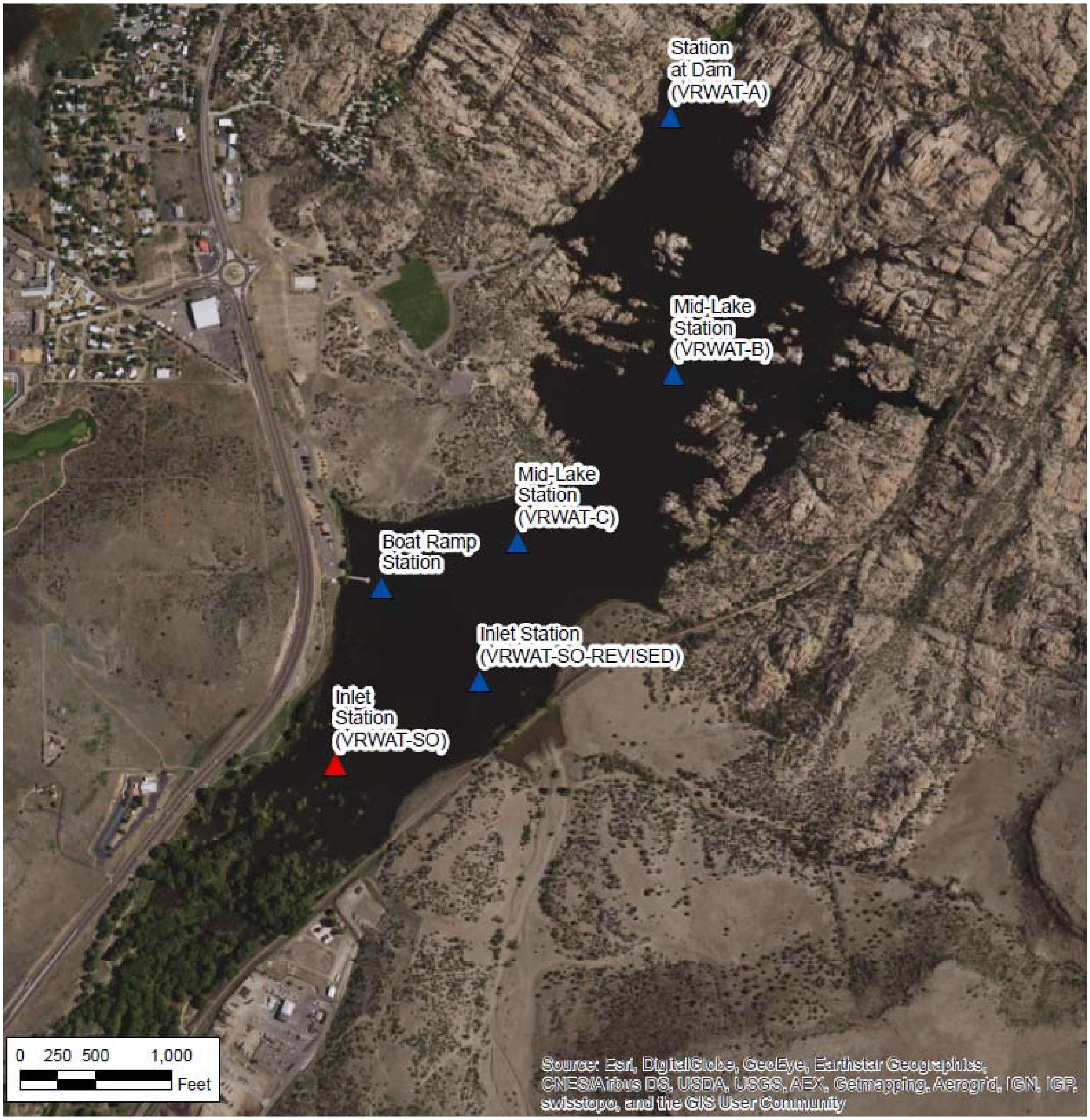

Figure 19 Sampling Locations

APPENDIX A
FIELD REFERENCE GUIDE

FIELD REFERENCE GUIDE FOR WATSON LAKE

TABLE OF CONTENTS

Part 1: MONITORING PROGRAM

Locations

Sampling Locations			
SITE NAME	SITE ID	LATITUDE Degrees	LONGITUDE Degrees
Watson Lake - At Dam	VRWAT-A	34.5952778	-112.4166389
Watson Lake - Mid Lake	VRWAT-B	34.5905556	-112.4158333
Watson Lake - Mid Lake	VRWAT-C	34.5875000	-112.4191667
Watson Lake - At Boat Ramp	VRWAT-BR	34.5930833	-112.4192500
Watson Lake - South End Revised	VRWAT-SO-REV	34.584861	-112.420111

Parameters

	0.5 m grab	Vertical profile	2X Month	Monthly	Annually
Temperature		X*	X		
Oxygen		X*	X		
Temperature and Oxygen profile at 1.0 m intervals		X	Mar to Oct		
pH	X			X	
Transparency	Secchi disk			X	
Alkalinity	X			X	
Total hardness	X			X	
Turbidity	X			X	
Ammonia-N	X			X	
Nitrate+nitrite-N	X			X	
TKN	X			X	
Phosphorus, total	X			X	
Phosphorus, dissolved	X			X	
Chlorophyll-a	X			X	
Pheophytin-a	X			X	
Algae Identification	X			X	
Algae count by genus	X			X	
Zooplankton count		X		X	
Aquatic macrophyte inspection	Bottom survey			X	
Midge density (sediment)	Bottom survey			Mar to Oct	
E. coli	X			Mar to Oct	
Waterfowl count/ID	Visual			X	
Metals (13 priority pollutants)					X
Mosquito (adults) (OPTIONAL)	Shore				
Midge flies(adult) (OPTIONAL)	Shore				

*0.5 m and above sediment

Field Survey Form

Date ______________ ....**Analysts** ______________________

Sampling Locations			
SITE NAME	**SITE ID**	**LATITUDE Degrees**	**LONGITUDE Degrees**
Watson Lake - At Dam	VRWAT-A	34.5952778	-112.4166389
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Watson Lake - At Boat Ramp	VRWAT-BR	34.5930833	-112.4192500
Watson Lake - South End Revised	VRWAT-SO-REV	34.584861	-112.420111

Field Measurements

Constituent	Unit	VRWAT-A	VRWAT-B	VRWAT-C	VRWAT-BR	VRWAT-SO-REV
Temperature	C					
Dissolved oxygen	mg/L					
pH	SU					
ORP	mV					
Secchi disk depth	m					

Vertical Profiles

	VRWAT-A		VRWAT-B		VRWAT-C		VRWAT-BR		VRWAT-SO-REV	
Depth (m)	T	DO	T	DO	T	DO	T	DO	T	DO
0.0										
1.0										
2.0										
3.0										
4.0										
5.0										
6.0										
7.0										
8.0										
9.0										
10.0										
11.0										
12.0										
13.0										
14.0										

Vegetation location, density, species: ____

<u>Sample Collection</u>

☐	Inorganics	☐	Bacteria
☐	Metals	☐	Bacteria
☐	Nutrients	☐	Midges
☐	Chlorophyll	☐	Other

Part 2: TROUBLE SHOOTING

Common Problems and Causes

Problem	Possible causes	Possible corrective actions
pH too high	Too much algae	• Add fresh water • Apply algaecide or dye • Reduce nutrients • Check aeration system operation
Odor present	Stagnant areas	• Check aeration system operation • Add permanganate or calcium nitrate
	Dead fish	• Check aeration system operation
	Low dissolved oxygen	• Check aeration system operation
Turbidity, transparency, or suspended solids too high	Planktonic algae	• Apply algaecide • Check nutrient levels • Add alum, nutrient inactivation
	Storm water/runoff	• Wait for settling of non-biological solids
Low dissolved oxygen	Aeration system malfunction	• Check aeration system operation • Increase system run time • Increase number of diffusers
	Algae population crash	• Improve algae management • Increase algaecide application frequency with decreased dosage.
	Organic accumulation at lake bottom	• Check for runoff entry points and eliminate • Improve algae management Dredge lake bottom
Phosphorus concentration too high	Runoff or fertilizer inputs	• Add alum; nutrient inactivation • Check with Watershed Pollutant Reduction Plan
	Recycling from sediment	• Check aeration system operation • Add alum; nutrient inactivation • Dredge lake bottom
	Aeration system malfunction	• Check aeration system operation

Problem	Possible causes	Possible corrective actions
Fish kill	Oxygen depletion	• Check aeration system operation
	Ammonia toxicity	• Check aeration system operation • Reduce algae density • Add nitrifying bacteria • Investigate nutrient load from watershed
	Metals toxicity	• Check for change in metals levels and water hardness in source waters (especially copper) • Increase alkalinity or hardness • Eliminate corroding materials in distribution system • Check for runoff entry points and eliminate
	Fish disease	• Analyze fish and use antibiotic foods • Remove infected fish population
Submerged aquatic macrophytes too dense	Nutrient levels too high	• Check for runoff entry points and eliminate • Change fertilizer application and irrigation protocol
	Transparency too great	• Apply dyes • Apply herbicide
Emergent aquatic vegetation present	Nutrient levels too high	• Check for runoff entry points and eliminate • Change fertilizer application and irrigation protocol • Apply alum for phosphorus inactivation
	Bank erosion	• Stabilize shoreline and remove sediment
	Contamination or transplantation	• Educate citizens • Apply herbicide
	Too much transparency	• Consider adding lake dye
Mosquitoes present	Stagnant water	• Identify species, locate breeding site, apply larvicide • Stock with top and bottom, larvae-eating fish

Problem	Possible causes	Possible corrective actions
Algae mats at water surface	High nutrient levels	• Check for and eliminate runoff entry points • Change fertilizer application and irrigation protocol • Apply alum for phosphorus inactivation
	Bottom growths surfacing	• Apply algaecide or dye
Too many birds	Migration	• Wait/cannot remove migratory waterfowl • Limit nesting areas • Install decoys • Apply repellents • Remove food sources
	Feeding with human food	• Educate public • Relocate waterfowl
Bacteria levels too high	Storm water runoff	• Check for and eliminate runoff entry points
	Irrigation runoff	• Change irrigation protocol
	Bird feces	• Limit waterfowl
	Animal feces	• Require bagging of dog wastes or restrict pets near lake
Lake depth loss/sedimentation	Erosion	• Stabilize shoreline and remove deposits • Check for and eliminate runoff entry points
	Excess algae growth	• Reduce growth rate with algaecides or dyes
Midge flies becoming a nuisance	Organic sediments	• Increase appropriate fish stocks • Apply larvicide • Dredge sediments
Chlorophyll-a or algae density too high	Nutrient levels too high	• Check for runoff entry points and eliminate • Change fertilizer application and irrigation protocols • Apply alum for phosphorus inactivation • Apply algaecides or dyes

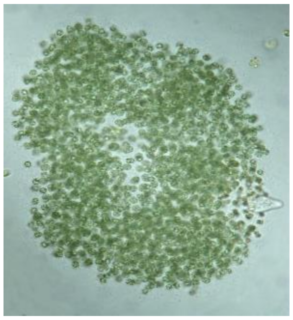
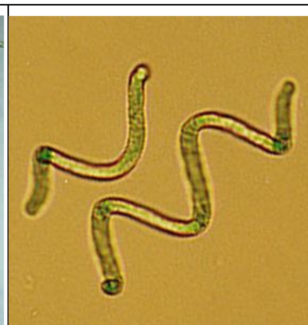
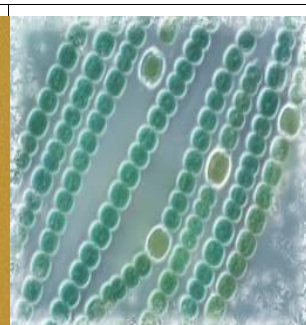
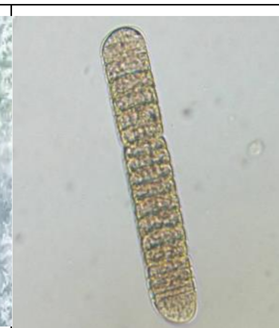
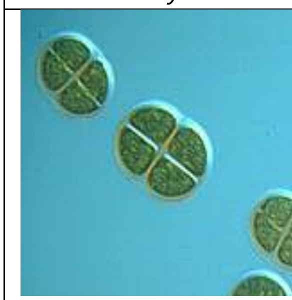
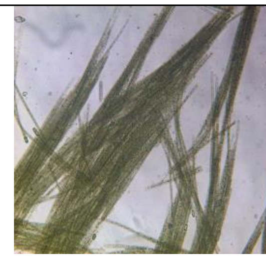
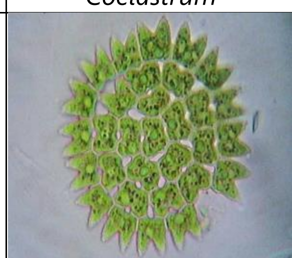
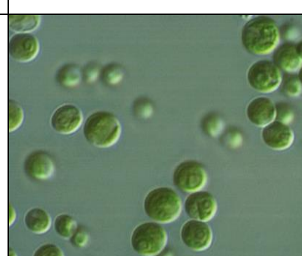
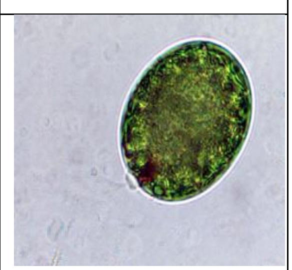
Water Quality

Action Levels and Responses

Parameter	Trigger	Importance	Possible actions
Dissolved oxygen	<6 mg/L @ 1m <2 mg/L @ bottom	TMDL limits Fish kills Nutrient cycling	• Increase aeration system run time
pH	9.0 SU or higher	TMDL Ammonia toxicity	• Apply algaecide to reduce algae
Transparency	<12 inches	Aesthetics	• Apply algaecide to reduce algae • Apply light reducing dye • Flocculate solids with aluminum sulfate
Ammonia	>0.5 mg/L and pH>9 and temp >28 C	Ammonia toxicity	• Increase aeration system run time • Add nitrifying bacteria
Chlorophyll-a	>10 ug/L	TMDL Aesthetics	• Apply algaecide to reduce algae • Inactivate nutrients • Consider light reducing dye addition
Algae Count	>5 x 10^6 cells/mL	Aesthetics	• Apply algaecide to reduce algae • Inactivate nutrients • Consider light reducing dye addition
Golden algae	Present	Fish kills	• Apply potassium permanganate to oxidize toxin • Apply algaecide to reduce algae • Consider light reducing dye addition
Midge fly density	>500/m^2 in sediment	Public nuisance	• Stock additional bottom feeding fish • Apply larvicide
E. coli bacteria	>575 per 100 mL	Public health	• Apply bactericide

Part 3: AQUATIC PLANT IDENTIFICATION AND CONTROLS

Common phytoplankton and algae (40x-1000x magnification)

 *Microcystis*	 *Spirulina*	 *Anabaena*	 *Oscillatoria*
 *Chroococcus*	 *Coelastrum*	 *Chlamydomonas*	 *Aphanizomenon*
 *Selenastrum*	 *Pediastrum*	 *Scenedesmus*	 *Carteria*
 *Golenkinia*	 *Chlorella*	 *Euglena*	 *Trachelomonas*


Chroomonas

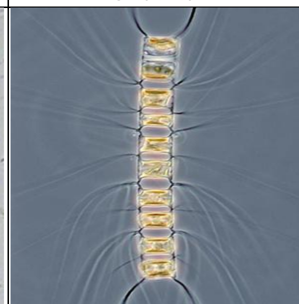

Cryptomonas


Peridinium


Glenodinium


Diatoma

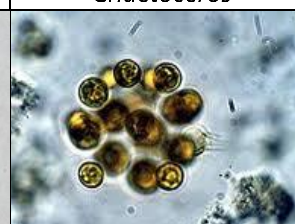

Synedra

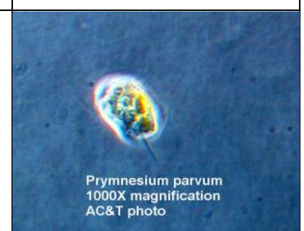

Chaetoceros


Cyclotella


Navicula (type 1)


Navicula (type 2)


Gleocystis



Prymnesium

Common Weeds- Floating Macrophytes


Duckweed (*Lemna* sp.)


Water lily (*Nymphia* sp.)


Pennywort (*Hydrocotyle* sp.)

Common Weeds-Emergents

 Bulrush (*Scirpus* sp.)	 Bulrush (*Eleocharis* sp.)	 Cattail (*Typha* sp.)

Common Weeds-Submerged Macrophytes

 Sago Pondweed (*Stuckenia pectinatus*)	 Eurasian watermilfoil (*Myriophyllum spicatum*)	 Horned pondweed (*Zannichellia palustris*)
 Brittle naiad (*Najas minor*)	 Coontail (*Ceratophyllum* sp.)	 *Chara* sp.
 Widgeon grass (*Ruppia maritima*)	 Curly-leaf pondweed *Potomogeton crispus*	

Herbicide Information

Chemical	Exposure required	Advantages	Disadvantage	Best uses	Plants controlled and response time	Relative Persistence in Environment	Bio-accumulation Risk
Copper, chelated	18-72 hr	inexpensive, rapid action	non-degradable, but inactive in sediment	Algae and macrophytes in lakes and ponds	broad spectrum; 7-10 days	Low, rate of sediment accumulation outpaces rate of copper accumulation	Low
2,4-D	18-72 hr	inexpensive; systemic	perceived as toxin	lakes; watermilfoils	broad-leaf; 5-7 days	Low	Low
Diquat	12-36 hr	rapid; little drift	does not affect underground plant parts	Shorelines and localized areas; submersed and marginal plants	broad spectrum; 7 days	Low, absorbs into sediment and is inactivated	Low
Endothall	12-36 hr	rapid; little drift	does not affect underground plant parts	Shorelines and localized areas; submersed plants; algae (Hydrothol)	broad spectrum; 7-14 days	Moderate, present 30-60 days in environment before microbial degradation	Low
Flumioxazin	20 hr	low dosage; few restrictions	Works poorly at higher pH	small lakes; submersed or floating plants	broad spectrum 1-3 weeks	Low, quick microbial degradation	Low
Fluridone	30-60 days	low dosage; few restrictions	long contact time required	small lakes; submersed plants	broad spectrum; 30-90 days	Moderate to High, present 50-75 days	Low, EPA tolerance level set at 0.5 ppm in fish tissue

Chemical	Exposure required	Advantages	Disadvantage	Best uses	Plants controlled and response time	Relative Persistence in Environment	Bio-accumulation Risk
Glyphosate	n/a	systemic	slow; does not control submersed plants	emergent and floating plants only	broad spectrum; 7-10 days	Moderate to High, environmental persistence is currently under strong debate	Moderate, metabolites persist in new plant material after initial treatment
Sodium peroxycarbonate	30 min	Contact, extremely fast-acting	No residual	Suspended and filamentous (string) algae	broad spectrum; 1 hr	Very low, degraded in less than 30 minutes	Very low

Common Aquatic Plant Control Product Dosages (refer to label before using)

Chemical	Trade names	Manufacturers	Max. application rate	Max. water conc.	Application notes
Copper, chelated	Cutrine Plus Cutrine Ultra	Applied Biochemists/Arch	0.6-3.0 gal/acre-ft Some also available as granular	1.0 mg/L	algaecide and herbicide
	Komeen Nautique	Applied Biochemists/Arch			
	Earthtec	Earth Science Laboratories			
	Clearigate	Applied Biochemists/Arch			
	K-Tea	SePro.			
	Captain	SePro.			
2,4-D	Navigate	Applied Biochemists/Arch	100-200 lb/A	2.0 mg/L	systemic; excellent on milfoils
	Aqua-Kleen	Cerexagri	0.5 gal/acre		
Diquat	Reward	Syngenta	2 gal/acre	2.0 mg/L	contact herbicide
	Weed Plex Pro	Sanco Industries			
	Harvester	Applied Biochemists/Arch			
Endothall	Aquathol K Aquathol Super K Hydrothol 191	UPI	1.3 gal/acre	5.0 mg/L	binds with particulates and loses effectiveness
Flumioxazin	Clipper	Valent	6-12 oz/A	100-400 ppb	pH sensitive
Fluridone	Sonar	SePRO	13 gal/acre	5.0 mg/L	fish may be sensitive
Glyphosate	AquaMaster	Monsanto	2 gal/acre	0.2 mg/L	Emergents and floating plants only
	AquaPro	SePRO			
Peroxy-carbonate	Alimycin Green Clean Pro	Applied Biochemists Biosafe Systems	200 lb/Aft	n/a	Algae

PLANT SUSCEPTIBILITY TO VARIOUS AQUATIC HERBICIDES

Plant	Endothall (Aquathol)	Copper	Diquat	Endothall (Hydrothol)	Fluridone	Glyphosate	Flumioxazin	2,4-D	Sodium peroxycarbonate
Algae									
Filamentous algae		X	X	X			X		X
Suspended algae		X							X
Chara		X		X					
Submersed macrophytes									
Elodea			X	X	X				
Bladderwort			X		X			X	
Brittle naiad	X		X	X	X				
Coontail	X		X	X	X		X		
Curlyleaf pondweed	X		X	X	X		X		
Eurasian watermilfoil	X		X	X	X		X		
Horned pondweed	X			X	X		X		
Sago pondweed	X		X	X	X		X		
Southern naiad	X		X	X	X				
Waterstargrass	X							X	
Free-floating macrophytes									
Duckweed			X		X		X		
Watermeal					X				

Plant	Endothall (Aquathol)	Copper	Diquat	Endothall (Hydrothol)	Fluridone	Glyphosate	Flumioxazin	2,4-D	Sodium peroxycarbonate
Rooted floating macrophytes									
American pondweed	X		X	X	X		X		
Spatterdock					X	X		X	
Water lily					X			X	
Emergent plants									
Arrowhead								X	
Bulrush						X		X	
Cattail			X		X	X			
Spikerush					X				
Water smartweed					X	X			

Water Use Restrictions (in days after herbicide application)

Chemical	Drinking	Swimming	Fish consumption	Animal drinking	Irrigation
Copper	0	0	0	0	0
Diquat	1-3	0	0	1	1-5
Endothall	7-25	0	3	7-25	7-25
Fluridone	0	0	0	0	7-30
Glyphosate	0	0	0	0	0
Flumioxazin	0	0	0	0	5
2,4-D	1	0	0	1	1

Part 4: AQUATIC INSECT MANAGEMENT

Larva and Adult Midges and Mosquitos

Midge larva

Mosquito larva

Adult midge

Adult mosquito

Mosquito and Midge Management Products

Product	Active ingredient (A.I.)	Category	Target organism	Typical application rate
Acrobe®	*Bacillus thuringiensis*	biological	Mosquito & midge larva	5-10 lb/SA
Agnique®	Monomolecular film	film	mosquito larvae	0.5G/SA
Altosid®	methoprene	growth regulator	mosquito & midge larvae	5-10 lb/SA
Bactimos briquets®	*Bacillus thuringiensis*	biological	mosquito and midge larvae	1 per 100 lin ft
Bonide®	oil	film	mosquito larvae	0.5G/SA
Teknar HP-D or G®	*Bacillus thuringiensis*	biological	mosquito & midge larvae	0.25-1 pt/SA
Vectobac 12AS®	*Bacillus thuringiensis*	biological	mosquito & midge fly larvae	0.25-1 pt/SA
Vectobac G®	*Bacillus thuringiensis*	biological	Midge & mosquito larvae	5-20 lb/SA

Product	Active ingredient (A.I.)	Category	Target organism	Typical application rate
Vectolex G®	*Bacillus sphaericus*	biological	Midge and mosquito larvae	10-20 lb/A

Applying larvicide is advantageous because adult mosquitoes can fly over great distances and are difficult to locate and control. An application of larvicide during the larval or pupa stage can control many more mosquitoes as compared to waiting until they emerge as adults. The duration of control is dependent upon the choice of product, site conditions, and rate of application. The table below provides typical residual ranges for common aquatic larvicides.

Larvacide Residual Duration

Product type	Form	Residual duration
Bti	Liquid	12-24 hr
Bti	Granules	1-7 days
Bti	Briquet	Up to 30 days
Oil	liquid	1-5 days
monomolecular film	liquid	5-15 days
Methoprene	liquid	1-7 days
Methoprene	granule	5-15 days
Methoprene	pellet	5-20 days
Methoprene	briquet	30-150 days

Part 5: FISHERY

Overall fishery management can be enhanced by accomplishing the following tasks:

- Controlling algae growth
- Applying herbicides and pesticides according to label instructions to avoid fish toxicity
- Limiting external nutrient supplies to the lake
- Providing mechanical aeration as appropriate
- Identifying fish kill causes
- Installing and/or maintaining fish habitat
- Recording fish mortality to determine if additional stocking is required
- Tracking occurrence of adult and larvae midge flies to determine if stocking densities of larvae-eating fish need to be increased
- Tracking occurrence of submerged weeds to determine if stocking densities of weed-eating fish need to be increased

Possible Species Present

Channel catfish (*Ictalurus punctatus*): The fish has spines in the dorsal and pectoral fins, an adipose fin, and large barbels around the mouth. Young fish are silver with black spots, while older fish are blue-black with white bellies. They are bottom foragers and primarily consume insect larvae. They can be an important part of a biological midge fly control program. They spawn in spring and early summer.

Gila Longfin Dace: (*Agoisa chrysogaster chrysogaster*) The Longfin Dace is an endangered species native to Arizona. The body of the Dace is typically 3.0 – 3.5 inches in length and spindle shaped. The fish is typically silver/grey and has a single black spot at the base of the caudal fin. Longfin Dace are opportunistic omnivores and typically feed on wetland detritus and aquatic invertebrates

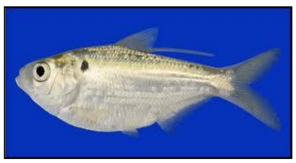
Rainbow trout (*Oncorhynchus mykiss*): The fish has a silvery body that is dark olive to black on top and silvery to white on the belly. Both body and fins are spotted and its sides often have a horizontal pink streak. Trout are a cold water fish and do not survive the warm Arizona summer urban lake temperatures such as Watson Lake.
Sunfish: Sunfish include bluegill, redear sunfish, green sunfish, and hybrid sunfish. These fish all have compressed or flat bodies; color varies with species. Although they may reach up to 3 pounds, most sunfish are only 4 to 8 inches in length.

Bluegill (*Lepomis macrochirus*): The bluegill sunfish has a blue coloring on the chin, with a black opercle flap, and a dark spot and the rear of the dorsal fin. It has a small mouth, compressed body, and five to none dark vertical bands on its sides. It consumes zooplankton and insects throughout their life. They usually mature within two years and spawn in the spring.

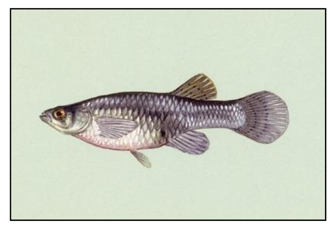
Largemouth bass (*Micropterus salmoides*): This fish is dark green on top and white on the belly, has a wide mottled band along each side, and a deep notch in the dorsal fin. Its upper jaw extends beyond the rear margin of the eye. It feeds almost exclusively on other fish.

Black Crappie (*Poxomis nigromaculatus*): The color of this fish is silvery white with dark speckling across its sides and fins. The body is flat with large dorsal and anal fins. The crappie's mouth is larger and head is longer than most other sunfish. It feeds primarily on other small fish, small crustaceans, and insect larvae. The fish prefers cool, clear lakes with little vegetation. It is often adversely affected by fluctuating water levels.

Carp (*Cyprinus carpio*): The fish is brassy to yellow-colored and has large scales and two small barbels on each side of the mouth. It has a large saw-toothed spine at the front of the long, single dorsal fin and anal fin. Carp are scavengers and bottom feeders. It is an important biological control mechanism for midge flies.



Threadfin shad (*Dorosoma pretenense*): The fish is dark slate gray to blue-black on top, and silvery on sides and bottom. The dorsal fin has a long filament that extends to the rear of the fish when deflected. It is often a forage fish for predacious species. It feeds on plankton and organic detritus at the lake bottom. They have a high reproductive rate.



Mosquitofish (*Gambusia affinis*): This fish is small; about 30-50 mm long. It is present in most warm water habitats. It consumes insect larvae and newborn young of other fish. It is a live-breeder with a high reproductive rate.

Fathead minnow (*Pimephales promelas*): Fathead minnow feeds on detritus and algae on the bottom of lakes. It consumes insects and larvae, including those of mosquitoes and midges, near the water surface. Fathead minnows are food for most predacious fish. Nesting habits involve the eggs being attached to the underside of an object that is situated somewhere above the lake bottom.

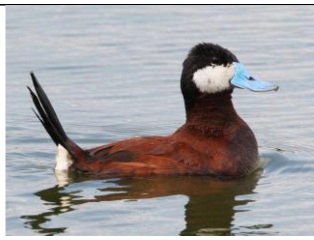
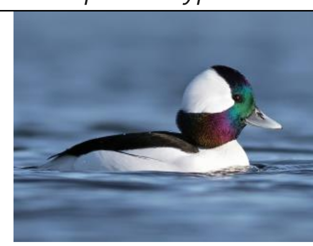
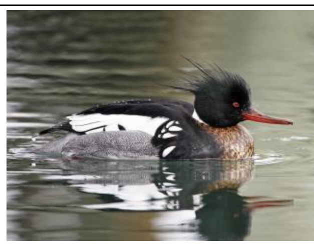
Problem Identification

Condition	Possible cause
Piping (gulping for air)	Low dissolved oxygen Golden algae toxin Disease or parasites
Lethargy	Golden algae toxin Disease or parasites
Nighttime mortality	Low dissolved oxygen
Daytime mortality	Ammonia toxicity

In the event of a fish kill

1. Remove dead fish as soon as possible.
2. Freeze at least one intact (freshest) specimen for necropsy.
3. Measure water temperature, oxygen, and pH.
4. Collect sample for ammonia, hardness, heavy metals, and algae identification

Part 6: WATERFOWL IDENTIFICATION

 Ruddy duck *Oxyura jamaicensis*	 American coot *Fulica americanas*	 Mallard *Anas platyrhynchos*
 Canada goose *Branta canadensis*	 Northern pintail *Anas acuta*	 Northern shoveler *Spatula clypeata*
 Gadwall *Mareca strepera*	 American avocet *Recurvirostra americana*	 Bufflehead *Bucephala albeola*
 Red-breasted merganser *Mergus serrator*	 Green-winged teal *Anas crecca*	 Cinnamon teal *Spatula cyanoptera*
 Lesser scaup *Aythya affinis*	 Double-crested cormorant *Phalacrocorax auritus*	 White-winged scoter *Melanitta deglandi*

Part 7: MAINTENANCE

This section can be completed when aeration, weed harvesting, or chemical application equipment is acquired and installed. The following is provided for example only.

Main Fountain/Aerator Maintenance

The following presents the basic maintenance schedule for City staff. A qualified professional contractor should be used for specific scheduled maintenance and major repairs.

Task	Frequency
Leak check	Daily
Pump operation	Daily
Loose nuts or bolts	Daily
Grease fittings	Monthly
Pump rotation	Weekly

If maintenance requires the fountain/aerator to be shut down for an extended period of time, proper notifications should be made to necessary City personnel.

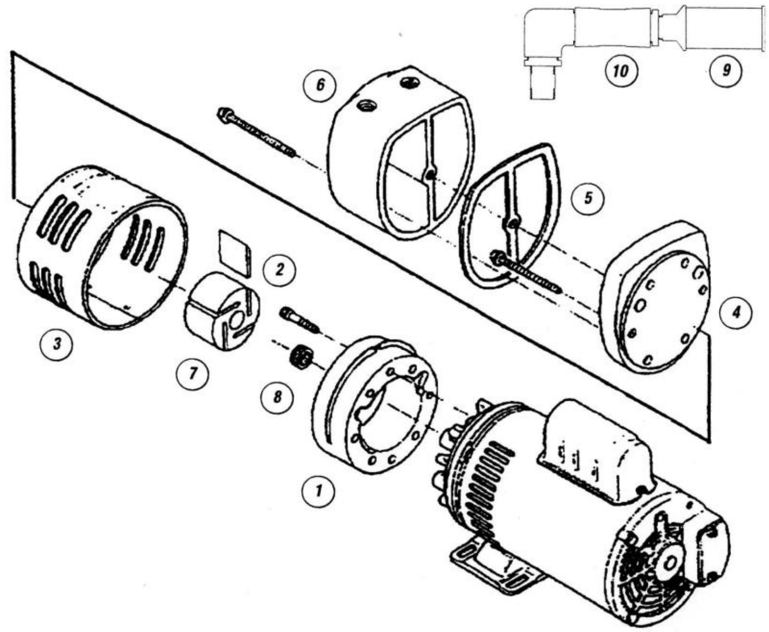
Ancillary Diffuser System Maintenance

Always reference the supplied manuals for specific operation and maintenance procedures. The following are basic monthly maintenance steps:

1. Verify system is depressurized. Remove endplate and filters.
2. Inspect filters for rips tears, cuts, or brittleness, and excessive foreign matter.
3. Clean satisfactory filters with compressed air.
4. Check filter/muffler for compacted debris. If debris is present, flush or replace filter/muffler.
5. Check o-ring for softness and flexibility. Replace hardened or brittle o-rings.
6. Remove, inspect and clean muffler box. Check and replace worn gaskets.
7. Replace muffler box and reinstall cleaned or replacement filters.

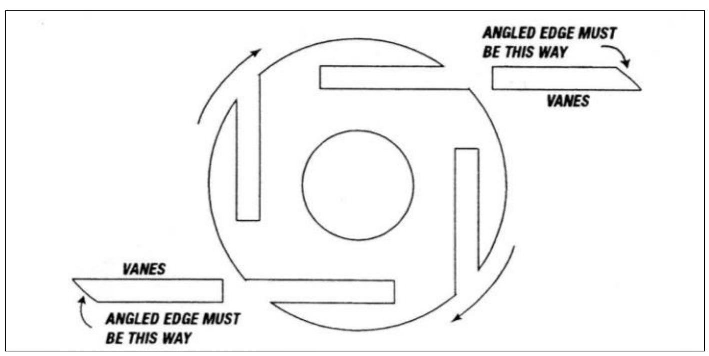
Flushing the muffler assembly will remove dirt, particles, excess moisture, and oil that will cause the vanes to act sluggishly. Use only flushing solvent.

Ref	Description
1	Body
2	Vane
3	Shroud
4	End Plate
5	Gasket
6	Muffler Box
7	Rotor
8	Crush Ring
9	Muffler
10	Inlet Check Valve



Vane Replacement

Vanes should be replaced every 9 to 12 months. Replacement steps follow.



1. Remove two end caps from front of muffler box.
2. Tap and loosen muffler box.
3. Remove six bolts holding end plate to body.
4. Remove end plate. Do not remove rotor or loosen motor.
5. Check vanes for free movement in and out of slots. Replace any vane with more than 50% extending past the vane slot.
6. Remove vanes and clean both side with emery cloth. Clean end caps in same manner.
7. Flush vanes, body, rotor, and end plat with cleaning solvent.
8. Remove any solvent residue.
9. Check all parts for scoring. Replace parts as necessary.
10. Re-assemble.

Troubleshooting Chart

Troubleshooting Chart

Low Pressure	High Pressure	Compressor Overheat	Motor Overload	Problem Cause and Solution
X		X	X	Filter dirty. Clean or replace.
X	At Compressor	X	X	Plugged or collapsed pressure line. Inspect and repair.
X				Vanes sticking. Clean or replace.
X				Vanes worn. Replace.
X				Shaft seal worn. Replace.
X		X	X	Debris in compressor. Inspect and clean.
X		X	X	Motor not wired correctly. Check wiring diagram and line voltage.

Diffuser Heads and Air Distribution

Diffusers should be removed each year and cleaned in a dilute alkaline solution to remove biofilm, followed by cleaning in a dilute hydrochloric acid solution to remove scale. Airlines (distribution) can be inspected during each lake monitoring trip by simply paying attention to the presence of any superfluous air bubbles rising in the water column where no diffuser head in stationed. These bubbles indicate a break or tear in the air line has occurred.