Lake Algal Control Techniques

with Implications for Vancouver Lake

Vancouver Lake Watershed Partnership

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Purpose

The purpose of this document is to explore techniques that have been used around the United States and elsewhere to help control nuisance algal blooms. While it is likely that some combination of these techniques may be used to achieve the Vancouver Lake Watershed Partnership's goal of reducing nuisance cyanobacteria (blue-green algae) blooms in the lake, it is premature to develop conclusions before there is a good understanding of how the lake functions and the cause of the blooms. This document provides a general description of the various techniques found in the literature, provides examples of these techniques where possible, and creates linkages to Vancouver Lake by citing studies or circumstances that may help the reader consider the technique within the context of Vancouver Lake.

This document should be viewed as a primer for future decision-making after our research and studies have been completed. There has been no attempt to advocate for any specific technique type for Vancouver Lake, nor has any attempt been made to eliminate potential management methods. Clearly, not all of the techniques employed elsewhere will be applicable or feasible in Vancouver Lake due to technical, social, or fiscal reasons.

This document is focused on the reduction of cyanobacteria in Vancouver Lake. While the Vancouver Lake Watershed Partnership has identified other issues of concern in Vancouver Lake, the approach identified in the Technical Foundation uses the reduction of nuisance cyanobacteria blooms as a framework to guide research and identify future management alternatives.

Some of the other lake issues of concern (e.g., *E. coli* bacteria) may be addressed through techniques explored in this document. Such additional benefits to the lake should be explored when choosing the suite of management methods. However, techniques that would address one of these secondary concerns, but not cyanobacteria, are not included in this document.

Background

The Vancouver Lake Watershed Partnership formed in 2004, in large part due to community concerns over recurring cyanobacteria blooms. These blooms often result in the closure of the lake to contact activities due to the potential of cyanobacteria to produce harmful toxins. The blooms also may result in aesthetically unappealing surface scums and have the potential to deplete oxygen levels in the lake.

The Vancouver Lake Technical Foundation (VLWP, 2008b) outlined study areas to better understand Vancouver Lake's hydrologic processes, nutrient budget, sediment cycle, food web, and internal nutrient cycling mechanisms. Making sound management decisions is dependent on understanding the dynamics of Vancouver Lake.

Some methods, such as harvest or use of algaecides, may address the symptoms of the problem (i.e., removal of cyanobacteria while in bloom) and show immediate results. Other methods, such as using best management practices in the watershed, may address the potential causes of the cyanobacteria problem, but take a long time in which to see results. A mixture of methods that address the issue for both the short and long term may allow for accelerated restoration. There is most likely not one "silver bullet" solution, but a mix of actions will be the best management strategy for managing cyanobacteria and the overall lake quality. Choosing the appropriate management methods will be dependent on findings from studies that are being planned and implemented for Vancouver Lake.

Techniques Explored in this Document:

1. Best Management Practices
2. Water Level Drawdown
3. Lake Sediment Removal
4. Recruit/Plant Rooted Plants
5. Modify Lake Footprint
6. Dilution and Flushing
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8. Phosphorus Inactivation
9. Algaecides
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Best Management Practices

Theory

Implementing measures that prevent or reduce human inputs of nutrients and sediment into the lake could address some of the root causes of lake eutrophication. The term "best management practices" (BMPs) is broad, covering many methods of preventing, reducing, or mitigating human impacts on water quality. Implementation of such methods can range from encouraging voluntary efforts to mandating certain practices, and can include engineering solutions to reduce nutrient and sediment inputs to the lake.

Practices include:

- Minimize stormwater runoff from residential, agricultural, and commercial properties to reduce the delivery of sediment, excess fertilizers, and pollutants to water bodies.

- Retrofit existing stormwater drainage systems in residential and commercial areas to include treatment of runoff to reduce sediment and nutrient inputs to the lake and its tributaries.
- Implement agricultural BMPs to reduce sediment and nutrient inputs to the lake and its tributaries.
- Restore habitat in tributaries to enhance sediment and nutrient retention within the tributaries.
- Inspect existing septic systems to identify and fix failing systems. Construct new sewer systems to connect neighborhoods with septic tanks to neighborhood-wide sewer systems to decrease the risk of nutrient loading to the lake.
- Conduct Illicit Discharge Detection and Elimination (IDDE) monitoring of municipal stormwater conveyance systems to detect and remove illicit connections or discharges that may contribute nutrients and other pollutants to the lake.
- Conduct a phosphorus Total Maximum Daily Load (TMDL) for the lake to identify watershed sources of phosphorus and quantify the reductions in phosphorus necessary to meet lake goals.
- Develop ordinances requiring the use of Low Impact Development (LID) techniques for new residential and commercial developments.
- Reduce household phosphorus use. Local and state agencies have started education campaigns for local residents to voluntarily reduce phosphorus use/inputs to the watershed by using phosphorus-free detergents and fertilizers. Regulatory means to reduce phosphorus inputs are also underway, as the State of Washington has banned the sale of household dish detergents containing phosphorus, which will be effective throughout the state in July 2010.
- Implement education programs to encourage use of phosphorus-free fertilizers.
- Develop ordinances restricting the phosphorus content of fertilizers. This has been done in other watersheds in Washington (e.g., Lake Whatcom and Liberty Lake) and has shown to be effective in other states (e.g., Minnesota).

Examples

Long Lake
Spokane County implemented the ban on phosphorus in dish detergents in July 2008. As a result, there has been a 10.7% reduction in phosphorus in the water entering the wastewater treatment plant in the first year of implementation (Brunt, 2009). The greatest impact on phosphorus inputs to the Spokane River and Long Lake is expected to be from water leaching from septic systems, as the waste-water treatment plant already removes phosphorus in treatment of all industrial and household waste water that is piped to the facility.

Lacamas Lake
Clark County addressed phosphorus reduction in Lacamas Lake through watershed BMPs and public education. The focus was on reducing agricultural phosphorus inputs; however, more stringent nutrient treatment requirements were also implemented for development in the watershed. Over a 15-year period (1985 -2000), improvements in watershed management led to an approximate 50% reduction in annual phosphorus and sediment loading to the lake. These reductions resulted in a stabilization of lake condition, but were insufficient to change the overall trophic state indicators (phosphorus, chlorophyll a, and Secchi depth). Algal and plant

growth remains extensive, and hypolimnetic dissolved oxygen depletion is an annual issue for the fishery (Schnabel, pers.com. 2009).

Minnesota
Phosphorus fertilizer laws were implemented in 2002 for the Twin Cities area of Minnesota and expanded to the entire state in 2004. These laws restrict the application of fertilizers containing phosphorus and have been shown to reduce amount of phosphorus fertilizers used and the amount of phosphorus in stormwater runoff (Barten and Johnson, 2007).

Considerations

Watershed management practices are an excellent long-term method of controlling the causes of cyanobacteria blooms because watershed inputs are typically the largest source of nutrients for cyanobacteria growth in lakes. However, a wide range of methods need to be considered and such methods will take many years to impact the amount of nutrients in Vancouver Lake. Also, with many decades of nutrient inputs to Vancouver Lake, the sediments themselves may contain enough nutrients to support cyanobacteria blooms for many years in spite of removing external inputs. This does not mean that best management practices should not be utilized, but that best management practices, on their own, may not solve the cyanobacteria problem in Vancouver Lake. In-lake management techniques on their own are often not sufficient to reduce the frequency of cyanobacteria blooms if watershed sources of nutrients inputs are not reduced (Cooke et al, 2005).

Water Level Drawdown

Theory

Drawing down the water level can dry out and consolidate sediments. Sediments may remain firm after re-filling the lake, reducing the re-suspension of sediments and nutrients. Sediment consolidation appears to have mixed results after re-flooding, so water level drawdown is best considered as a means to implement other management methods, such as dredging, planting of rooted plants, and exotic fish removal. Water level drawdown is more commonly used for controlling nuisance growth of aquatic plants by drying plants exposed during a summer drawdown period.

Examples

Long Lake, Washington
A summer water level drawdown was conducted in order to reduce macrophytes and compact sediment. The result was only a slight consolidation of sediments after re-flooding (.1 meter). Unwanted macrophytic plants were removed at time of drawdown (Jacoby et al. 1982).

Water level drawdown has been used to facilitate removal of target fish species, such as carp, in several lakes (Cooke et al. 1993).

Big Muskego Lake, Wisconsin
An 18-month water level drawdown of 50% of the lake volume allowed for a consolidation of sediments, removal of carp, and planting of desired aquatic plant communities. Water quality improvements were also significant, with trophic state indicators improving 70-80% from pre-drawdown conditions. As of 2003, improvements had persisted for 7 years, with a switch from a turbid, algae-dominated system to a clear, plant-dominated system. Management of emergent vegetation has been necessary. Active management is ongoing, with the potential for a repeated drawdown sometime in the future. Note that this project included several other management techniques including watershed BMPs, recruitment of rooted plants, modification of the lake footprint, and biomanipulation (Helsel and Zagar, 2003, Helsel, et. al., 2003).

Considerations

The timing of a water level drawdown could be important. It would be most effective when tributary input is projected to be low for a period of time. For Vancouver Lake, connections would need to be cut off to Lake River and the flushing channel to avoid tidal inflows. The tide gate at the flushing channel would facilitate this; Lake River would pose a much greater challenge. During the summer months there would be low flow from Burnt Bridge Creek, so that that source may be able to remain connected.

Timing could also be important if water level drawdown is used in conjunction with establishment of desired plants in consideration of the target plant's growing cycle.

The oxidation of sediments by exposing sediments to the air may cause nutrient release at re-flooding. For this reason, the Washington Department of Ecology warns that water level drawdown could increase algae growth. The potential release of nutrients from sediments after re-flooding the lake may be dependent on the rate of re-flooding (sediment re-suspension) and the pH of water.

Removal of non-native fish species such as common carp and brown bullhead could be conducted after water level drawdown. Impacts on non-target species must be considered as well, as drawdown is likely to increase fish predation due to loss of wetted areas.

Lake Sediment Removal

Theory

Dredging of a lake bottom can remove nutrient-rich sediments, as well as increase lake depth. An increase in depth may increase circulation rates in some lakes. In the process of removing nutrient rich-sediments there may be short term impacts from re-suspension of sediments and nutrients. Dredging after water level drawdown could minimize the re-suspension of nutrients and reduce dredging costs.

Examples

Lake Trummen, Sweden

Lake Trummen had high levels of internal nutrient cycling, with nutrients concentrated in the first meter of sediment. The removal of this top meter over two years resulted in a surface phosphorus reduction to 0.03 mg/kg from its earlier 0.78 mg/kg. The total phosphorus in the water column decreased by 90%, with a concomitant increase in water clarity and decrease in cyanobacteria concentrations. It is important to note that the external phosphorus sources were diverted a decade prior to the dredging treatment. Also, while sediment removal in Lake Trummen demonstrated great success, there are many other lakes where sediment removal did not result in the desired level of nutrient reduction (Cooke et al., 2005).

Considerations

If sediments are found to be a significant source of nutrients in the lake, the removal of the sediments and their associated nutrients could manage cyanobacteria for the short term while long term nutrient management strategies are put into place. Detailed study would be required to determine if nutrient concentrations are substantially lower in deep sediments that would remain in the lake. Sediment dredging has proved to be ineffective for reducing nutrient concentrations and primary productivity in various lakes because the remaining sediments contained high nutrient concentrations.

Dredging is typically considered to be one of the most expensive lake management techniques, primarily due to the high expense associated with sediment disposal (Cooke et al., 2005). Dredging costs can be reduced if suitable areas adjacent to the lake or in the lake are available for sediment disposal. In-lake sediment disposal could be used to modify the lake footprint (see below).

Deep water areas created by dredging might provide cooler water temperatures in the summer months, which could benefit fish and other lake organisms, in addition to expanding the area available for boating activities.

The US Army Corps of Engineers (Corps) dredged the western part of the lake during the early 1980s when the flushing channel was developed. In 2007 the Corps developed a model that included potential impacts of sediment removal on circulation rates. Their conclusion was that dredging would increase the volume of the lake, but without increasing water entering the lake, circulation and flow rate within the lake would become less dynamic (Corps, 2009).

Recruit/Plant Rooted Plants

Theory

Macrophytic vegetation can reduce wind and wave energy, thereby reducing the re-suspension of sediments (and nutrients). Rooted plants can also serve to bind nutrients to use for beneficial plant growth, making fewer nutrients available for cyanobacteria. Recent research in Klamath Lake, Oregon found the application of dried wetland plants to kill and impede the growth of cyanobacteria, supporting a theory that the loss of wetland plants in Klamath Lake was a causal factor in the increased cyanobacteria blooms in Klamath Lake (Haggard, 2008).

Examples

Pend Oreille River

Areas of the Pend Oreille River were planted with dwarf spike rush (*Eleocharis*) following removal of Eurasian watermilfoil to reduce regrowth of milfoil in those areas. The trial study showed some success but was discontinued (Pend Oreille County, 2003).

Big Muskego Lake, Wisconsin

Recruitment of emergent and submerged vegetation was facilitated through water level drawdown (Helsel and Madsen, 2003). Many management activities took place at the same time, with the establishment of native vegetation given partial credit for the stabilization of sediments and increase in water clarity.

Considerations

Emergent macrophytic vegetation could be planted in targeted areas of Vancouver Lake. Doing so may have the benefit of capturing sediments in the lake and incorporating nutrients from those sediments into the plants. Plants would also provide habitat for juvenile fish.

The establishment of macrophytic vegetation could impact the use patterns of Vancouver Lake, establishing some wetland areas while keeping other areas of the lake available for recreational activities such as swimming and boating. This could be a positive or negative contribution depending on the area(s) impacted and use patterns of the lake as well as a person's point of view.

Successful planting or recruitment of submerged aquatic plants would likely require an increase in water clarity, temporary lake drawdown, and/or stabilization of sediments in order to allow the plants to grow.

Steps would need to be taken to avoid the recruitment of invasive macrophytic vegetation such as purple loosestrife (*Lythrum salicaria*), reed canarygrass (Phalaris arundinacea), fragrant water lily (Nymphaea odorata), and Eurasian watermilfoil (*Myriophyllum spicatum*).

Modify Lake Footprint

Theory

Modifying the shape of a lake may address cyanobacteria blooms in several ways. Depositing soils in the lake in slower flowing areas along the lake edge could facilitate the development of emergent wetland areas. These emergent wetland areas could serve as wind fetch spurs, reducing wind fetch impacts on the lake and potentially reducing re-suspension of nutrients. Plants could benefit the lake as discussed in the previous section.

A smaller lake footprint could result in a greater ratio of inflow per acre foot of lake, bringing about improved water circulation and retention time.

Similarly, the lake could be modified strictly within the lake bed without emerging wetland areas with the deposition of soils. Such areas could be located in a way to alter in-lake water flow patterns.

Examples

Vancouver Lake
At the time of the construction of the flushing channel, the western portion of the lake was dredged and dredge material was used to form the island located near the north end of the lake. This island was not contoured for emergent plant growth, but is an example of use of the dredge material within the lake.

Considerations

Soil sources could be the lake itself, faster flowing areas of the lake could be dredged, forming deeper, cooler water areas with potentially faster flow patterns. The combination of deeper, cooler water areas with shallow habitat areas with associated shade and cover would allow the lake to serve as better habitat for native fish.

As discussed with in the macrophytic plant section, modifying the footprint of the lake could impact the use patterns of Vancouver Lake.

Dilution and Flushing

Theory

Dilution can improve water quality by reducing the concentration of limiting nutrients (such as nitrogen or phosphorus) in a water body. Adding low-nutrient dilution water to the system can reduce the concentration of the limiting nutrient. Dilution can be effective with small volumes of water if the dilution water has a much lower concentration of the limiting nutrient than that of the lake and the lake's regular water sources. Adding a large volume of dilution water would also result in flushing of the water body by increasing the water exchange rate, thereby increasing the rate of removal of plankton from the lake (Cooke et al., 1993).

Flushing is the use of a large volume of water of any nutrient concentration, such that algal cells are washed out of the lake. For flushing to be successful without dilution, the rate of flushing must be near the rate of regeneration of cyanobacteria cells in order to flush lake water out before new cyanobacteria can be established (Cooke et al., 1993; Horne and Goldman, 1994).

Dilution and/or flushing could be achieved by piping in water from some water source, or alternately, for Vancouver Lake, several methods of modifying the flushing channel have been posed with the aim of increasing flows between the Columbia River and Vancouver Lake. Potential modifications are:

- Divert water from the Port of Vancouver's groundwater cleanup efforts that is currently being put into the Columbia River into Vancouver Lake (approximate volume of 8-14 cubic feet per second)
- Increase the size of the flushing channel and/or or remove the tide gate from the flushing channel
- Modify the orientation of the flushing channel (or replace it with a new one) to mimic the historical connection to the Columbia River.

Examples

Green Lake in Seattle

The municipal water supply was used to dilute eutrophic Green Lake from 1962 to the mid 1970s. At first a large volume of low-nutrient water was used, reducing water residence time from 14 months to 3 months (Horne and Goldman, 1994). This reduced the level of nitrates in the lake but made only a minor drop in the lake's phosphate levels. As the input of dilution water to Green Lake was diminished, the lake water quality worsened. Green Lake was later treated with alum that dramatically reduced the phosphate levels and cyanobacteria growth (see Inactivate Phosphorus section below).

Moses Lake, Washington

Columbia River water was pumped into Moses Lake intermittently from spring through summer starting in 1977 in order to dilute the level of phosphorus in lake water. This annual dilution was considered successful in reducing phosphorus levels and increasing lake visibility (Cooke et al., 1993).

Vancouver Lake

The Vancouver Lake flushing channel was completed in 1983. Construction was for the purpose of increasing water flow and improving water quality. Flow into the lake was increased by approximately 2% (Cooper Consultants, 1985). However, it has not remedied the eutrophic water conditions and nuisance cyanobacteria blooms.

Considerations

Using dilution as a management tool depends on the availability of a feasible and appropriate source of low-nutrient water. Groundwater can contain high nutrient concentrations, as was found at Blue Lake in Multnomah County Oregon. (Pfauth and Systma, 2004)

Results of the Corps' 1 and 2-D modeling indicate that modifying the size of the flushing channel (from 7 to 11 feet) would increases velocities in the lake, specifically along the western and northern shores and adjacent to dredge disposal island, but overall flow would still remain relatively low (Corps, 2009).

Removal of the tide gate from the flushing channel had negligible effect on hydrodynamics in most hydrologic conditions in the Corps' model (Corps, 2009).

The findings of the upcoming water balance study would inform the consideration of water volume needed for effective dilution or flushing of Vancouver Lake.

The Corps' modeling did not look at modifying the orientation of the flushing channel. However, the modeling did show that the energy component of the water does not extend far into the lake after exiting the culvert. Based on this, the Corps' modeler reasons that it is not likely that changing the orientation of the flushing channel would have an influence on flows (VLWP, 2008a).

One of the intents of modifying the flushing channel is to mimic historical flows and scouring from high spring flows. However, the hydrosystem on the Columbia River dampens high spring river flows; higher flows on the Columbia River would be needed to induce historical scouring flows in Vancouver Lake.

Biomanipulation

Theory

Cyanobacteria may be controlled through manipulation of the species present in a lake. This may be through the introduction or removal of aquatic species to manipulate the food web and/or the removal of species causing resuspension of sediments and nutrients, or the introduction of a cyanophage (a cyanobacteria virus).

Methods of biomanipulation that target the level of nutrients in the water column include:

- Control of the number of geese on a lake if waterfowl are determined to be a significant source of animal waste and nutrients.
- Removal of bottom feeding fish such as common carp and brown bullhead to reduce nutrients in the water column by reducing the resuspension of sediments and nutrients in the water column.

Methods of biomanipulation that target removal of cyanobacteria include:

- Removal of planktivorous fish to allow for an increase in zooplankton populations. The resultant increase in zooplankton would reduce phytoplankton and cyanobacteria populations by predation.
- Introduction of piscivorous fish that target planktivorous fish to allow for an increase in zooplankton populations.
- Propagation (artificial) of filter feeding invertebrates such as clams and mussels native to Vancouver Lake to reduce phytoplankton and cyanobacteria concentrations.
- Introduction of cyanophages to infect and control the cyanobacteria bloom. Cyanophages are cyanobacteria viruses that are found naturally in marine and fresh water. A marine study found an estimated daily removal rate of 3% of the species under study (Suttle, 2000). Cyanophages have been found in lab experiments to significantly control freshwater cyanobacteria populations (Denge and Hayes, 2008).

The removal of either bottom feeding or planktivorous fish species could be achieved through direct methods, such as electroshocking or chemical treatment (e.g., Rotenone), or they could be removed by the introduction of a fish species that preys on the target species.

Examples

Tiger muskies

Tiger muskies (muskellunge bred with northern pike) were introduced as a top predator to several Washington lakes and reservoirs, including Curlew Lake and Merwin Reservoir. Studies note that northern pikeminnow is the preferred food of the tiger muskie (WDFW, 2006). As northern pikeminnow are another piscivorous fish, the result may be more of a substitution of top predators, with minimal impact on zooplankton and phytoplankton.

Silver carp
Silver carp (*Hypophthalmichthys molitrix*) is one fish species sometimes used for control of planktonic algae (Kolar et al., 2007). Conversely, Wu et al (1997) found that by decreasing silver carp density phytoplankton concentrations decreased due to an increase in zooplankton.

Big headed carp
Big headed carp (*Hypophthalmichthys nobilis*) are sometimes introduced for management of phytoplankton and filamentous blue-green algae. However, they may be opportunistic feeders, shifting from phytoplankton to zooplankton depending on food source abundance (USGS, 2005).

Mosquito fish
Mosquito fish (*Gambusia*) removal may allow for an increase in algae-eating zooplankton populations (e.g., *Daphnia*), thereby decreasing algae blooms in the water (Margaritora et al., 2001). Mosquito fish are also known to outcompete native fish. Mosquito fish are very aggressive, and tend to attack other fish and nip their fins, leading to infection or death (Moore, 2002).

Big Muskego Lake, Wisconsin
In Big Muskego Lake, 160 tons of carp were removed during water level drawdown after chemical treatment with Rotenone. Electronic carp barriers have been used to successfully limit re-population. Stocking is used to help maintain the desired mix of predator/prey species within the lake. The lake supports a fishery for largemouth bass, northern pike, crappie, and bluegill. Size-limits imposed on the fishery were used to increase the population of large predator fish and control populations of planktivorous fish. (Helsel and Zagar, 2003)

Considerations

If a fish species is to be introduced with the aim of removing another species, the preferred diet of the fish to be introduced will need to be closely examined along with other potential impacts of such an introduction.

There is no barrier to recruitment of new fish entering lake from the Columbia River, Burnt Bridge Creek or Lake River, so non-native species targeted for removal (such as common carp) can return to the lake unless measures are taken to limit re-entry. A desire to allow anadromous fish migration may make installing carp barriers challenging.

The current populations of clams and mussels in Vancouver Lake may be limited due to the high level of sediments in the water column, which can suffocate filter feeders.

While cyanophages exist in nature and likely play a role in cyanobacteria population dynamics, total control of cyanobacteria populations in open systems seems unlikely thus far due to variation in population composition and genetic mutations (of both the cyanobacteria and cyanophages) in natural systems (Denge and Hayes, 2008; Suttle, 2000).

Phosphorus Inactivation

Theory

Inactivating phosphorus in a lake with the addition of alum or another substance can render the phosphorus unavailable for cyanobacteria use, thus limiting growth. This works only if phosphorus (not nitrogen) is the limiting nutrient in algal growth. Cyanobacteria can fix nitrogen, so most often phosphorus is the limiting nutrient (Cooke et al., 1993). Some methods of inactivation, such as the addition of iron or calcium hydroxide may also require oxidation to avoid the re-release of phosphorus from the binding agent.

Phosphorus inactivation can be accomplished in some cases for several years with one treatment. Results may be effective for up to twelve years. Inactivation is only successful when the lake bottom is the major source of phosphorus, not the tributaries (Cooke et al., 1993). A lake can be treated regularly (every year or two) using smaller amounts of alum to inactivate phosphorus in the water column in addition to lake sediments. Alum can also be injected into tributary waters to inactivate those phosphorus inputs.

Examples

Alum

Alum has been used for phosphorus inactivation in Green Lake, in Seattle on two occasions. Alum was applied in March of 2004, with water clarity quickly increasing. The treatment has been effective for six years, and is expected to last for a total of 10 or more years (Zisette, pers. com., 2009). An earlier treatment, in 1991, lasted for only three years, and was considered an underdose for the lake (Herrera, 2003; Zisette, pers.com., 2009).

Calcium hydroxide

Calcium hydroxide was added to Frisken Lake, British Columbia in 1983 to bind phosphorus in a calcium carbonate floc. Phosphorus was bound by the method, but only temporarily, as all of the precipitate dissolved into the water column each summer, so the treatment was not effective over the long-term in this hard water lake (Cooke et al., 1993).

Iron chloride

Iron chloride has been used in several lakes, including Vadnais Lake in Minnesota in conjunction with an aerator. Most cases were only effective over the short term (Cooke et al., 1993).

Considerations

Aluminum sulfate (alum)

Nutrient inactivation by alum is only appropriate where internal loading is a significant phosphorus source. If most phosphorus is coming from external sources, this method would not be effective in reducing the nutrient source for cyanobacteria.

When an aluminum salt enters the water the aluminum salt dissociates and then combines with phosphorus to form a flocculent of aluminum phosphate and aluminum hydroxide. After the floc settles to the bottom it continues to adsorb phosphorus for approximately a decade. The possibility of the floc layer interfering with fish reproduction and with beneficial bacteria and insects that feed on lake sediments would need to be explored.

Alum treatment is only appropriate if a lake is "well-buffered" in order to avoid very low pH and high concentrations of toxic aluminum. Soft-water lakes such as Vancouver Lake would require the addition of sodium aluminate (a base) to prevent impacts from low pH due to the acidic nature of aluminum sulfate.

Calcium hydroxide and ferric chloride
The addition of calcium hydroxide or ferric chloride to phosphorus-rich water will form a floc as with alum, but if aerobic conditions are kept, it can be less toxic to other aquatic organisms than alum. Solubility of the resultant floc from either of these substances is more sensitive to pH and oxidation and reduction than aluminum hydroxide floc. There may be a diurnal issue where dissolved oxygen is low near sediments/releasing phosphorus at night. Iron or calcium salts would require aeration of the lake to avoid anoxia and subsequent re-release of phosphorus.

The use of aluminum sulfate is considered a more permanent solution for phosphorus than other salts, because it is not as affected by changes in oxidation levels and pH. However, Cooke et al. (1993) pose the possibility that shallow lakes may be better served by frequent applications of calcium hydroxide, with alum being more appropriate for deeper lakes.

A phosphorus inactivation treatment in Vancouver Lake may have a shorter time period of success than other lakes due to the amount of sediment re-suspension in Vancouver Lake from wind and bottom feeding fish, which would also disturb the floc layer, allowing the release of phosphorus.

Algaecides

Theory

Algaecides work by killing existing algae. There are several different types that have been used in other areas. Potential algaecides permitted for use in Washington State include sodium carbonate peroxyhydrate, endothall-amine salt products, and diquat. Endothall-amine salt products are broad-spectrum water soluble contact algaecides. There are several endothall-amine salts which have varying toxicities to blue-green algae and other aquatic organisms (WDOE, 2001). Sodium carbonate peroxyhydrate kills algae by the formation of hydrogen peroxide (WDOE, 2009). Diquat is a water soluble, broad spectrum contact herbicide to which cyanobacteria are reported to be highly sensitive (Peterson et al., 1997). Copper sulfate can control blue-green algae by affecting cell membranes and preventing photosynthesis. However, copper sulfate is classified as highly toxic to other aquatic organisms and has been prohibited for use in Washington.

Examples

Case studies on the use of herbicides without other algal or cyanobacteria control methods are limited.

Considerations

The use of an algaecide may address the aesthetic and potential health issues related to large cyanobacteria blooms but would not address the root causes of cyanobacteria blooms. If algaecides kill a large volume of algae, the decomposing algae may tie up oxygen and cause anoxic conditions in the lake. The decomposing algae may also release cyanotoxins, thereby not immediately addressing the toxin concern. The use of algaecides early in the bloom cycle could minimize both of these potential negative side effects.

Each of the algaecides outlined are non-specific to blue-green algae and can be toxic to desired algae, bacteria, plants and animals at certain concentrations. Considerations specific to each type of algaecide are as follows:

Endothall-amine salt products break down relatively rapidly (half life of 7 days) and do not accumulate in sediments (EXTOXNET, 1995). Washington State allows these salts at very low concentrations for blue-green algae control due to toxicities to fish. When used at the allowable level this may serve as more of an algaestat than an algaecide (see algaestat section below). Treatment may need to be repeated several times over a season to control algae (WADOE, 2001).

After the application of sodium carbonate peroxyhydrate, the resultant hydrogen peroxide breaks down quickly so that long term toxicity is not a concern. However, non-target plants and insects (such as honey bees) may also be harmed by use of this algaecide (USEPA, 2002).

Diquat can be toxic to non-target plankton and aquatic organisms at levels below traditional detection limits (Peterson et al., 1997).

Algaestats

Theory

Algaestatic compounds work by impeding the growth of algae. The benefit of applying an algaestat instead of an algaecide is that preventing the growth of cyanobacteria avoids the potential reduction of oxygen levels in the water from decomposing cyanobacteria. Some algaecides, when applied at low dosages, work more as an algaestat than an algaecide. Other products may work as algaestats are dried vascular plants and microbial products. Microbial treatment products have anecdotal success, but scientific reports show little effectiveness (WDOE, 2009).

Examples

Klamath Lake, Oregon

The application of dried barley straw has been touted for algae control in the United Kingdom, and to a lesser extent, the United States. A study in Upper Klamath Lake found dried barley straw and dried wetland plants to be equally effective at suppressing and killing cyanobacteria (Haggard, 2008). The mechanism of control appears to be the decomposition of the dried plant material and the release of colored dissolved organic matter, which in decomposition produces several chemicals that are toxic to the cyanobacteria. The Klamath Lake study appears to support the theory that wetlands that are no longer present on Klamath Lake may have served as cyanobacteria control in the past (Haggard, 2008).

Considerations

Barley straw would need to be applied at a significant level: 225 pounds (or 5 bales) per acre of water is the recommended level. If the whole of Vancouver Lake was to be treated in this manner, approximately 11,500 bales would be required.

Decomposing barley straw could deplete water oxygen levels just as decomposing cyanobacteria would.

The Klamath Lake study indicates that control of cyanobacteria may not only be achieved by the application of dried plants to the lake, but that re-establishment of functioning wetlands may allow for sustained control of cyanobacteria in Vancouver Lake.

Artificial Circulation

Theory

Water circulation can reduce cyanobacteria growth by various physical and chemical mechanisms. Cyanobacteria have a competitive advantage over other types of phytoplankton (e.g., diatoms and other algae) because they have gas vacuoles used to control their buoyancy. As such, cyanobacteria remain suspended longer and form surface scums in nutrient-rich lakes. Artificial circulation of relatively stagnant lake waters can be used to promote the growth of beneficial algae over cyanobacteria by reducing the algae settling rate, and can reduce phytoplankton biomass by increasing the mixing depth and limiting growth in deeper waters. Artificial circulation can also increase dissolved oxygen concentrations in the lake, which in turn reduces internal inputs of phosphorus from lake sediment and reduces the amount of algae growth. Artificial circulation can also reduce cyanobacteria dominance by decreasing the pH, which increases carbon dioxide concentrations and favors algae growth, and a shift to algae dominance can increase zooplankton populations and further reduce phytoplankton biomass.

Aeration is the most common method of artificial circulation, and there are a variety of aeration devices that are available and commonly used for small and large lakes. Typically, compressed air is introduced to bottom waters of the lake through a diffuser or perforated pipe, and the rising plume of air bubbles creates vertical circulation of the lake water column.

Water circulation can also be achieved by water pumps and other mechanical methods. The “SolarBee” is an example of a water circulation device that uses solar power to rotate paddles and pull bottom waters up and away from the remotely anchored device.

Examples

Aeration

Artificial circulation is the most frequently used technique to improve lake water quality (Cooke et al., 2005). Artificial circulation has been used on several large shallow lakes. Examples include Waco Lake in Texas (7,270 acre area and 10.7 feet mean depth) and Clear Lake in California (3,000 acre area and 10.2 feet mean depth). Effects of artificial circulation on cyanobacteria have generally have been mixed. Although the proportion of cyanobacteria in the phytoplankton community has typically been reduced, artificial circulation did not reduce the total cyanobacteria or phytoplankton biomass in most lakes studies summarized by Cooke et al. (2005).

Water circulation devices

Three SolarBee water circulation units were installed in Blue Lake, Oregon in 2007 to address water quality issues including large cyanobacteria blooms and low water clarity. Water quality studies before and after the installation found an increase in water clarity. However, a significant impact on algae biomass did not result (Temple, 2009). Mixing of the water column by the SolarBees may have added to the intensity of the fall turnover of the lake and resultant release of phosphorus to the water column (Temple, 2009). Due to the increased summer water clarity, continued use of the SolarBees was recommended until fall of each year. Three SolarBee units were also installed in T. Albans Bay, Vermont, with studies by the Vermont Agency of Natural Resources indicating that the area treated by SolarBees showed no significant improvement in water clarity compared to untreated areas of the bay (Smeltzer et al., 2008).

Considerations

Artificial circulation is typically used to destratify a lake during the summer by mixing cool bottom waters with warm surface waters. Vancouver Lake is considered a shallow, highly mixed, and turbid lake that does not stratify during the summer. Further mixing of the system may not provide any of the potential benefits described above. However, there may be selected areas of the lake where circulation would reduce the accumulation of cyanobacteria scums during stagnant summer periods.

At 2,300 acres, Vancouver Lake would require approximately 100 water circulation devices like the SolarBee, as Blue Lake, at 65 acres requires three circulators.

Mechanical Removal

Theory

Cyanobacteria could be collected from a barge and the algae/water mixture later separated. Alternately, electronic "weeders" can be used to kill cyanobacteria with an ultrasonic signal. The ultrasonic weeding unit floats just below the water's surface and kills algae by producing a frequency of ultrasonic waves that disrupts and destroys the cellular functioning and structure.

Examples

Barges collect cyanobacteria on Klamath Lake for commercial purposes. The harvesting barge is able to vary its depth of harvest below the water's surface to effectively target the cyanobacteria bloom. Collection takes place between September and November, and after harvest, the collected cyanobacteria are de-watered (Klamath Blue Green, 2009).

Manufacturers of weeder systems offer testimonials of success on their websites.

Considerations

Harvest or weeding of the cyanobacteria would address the aesthetic and potential health issues related to large cyanobacteria blooms, but would not address the root causes of cyanobacteria blooms. Either method of cyanobacteria removal would need to be done on a frequent basis as the conditions allowing for cyanobacteria growth remain in the lake.

The ultrasonic weeders would leave dead cyanobacteria in the lake, which could result in the release of cyanotoxins from the dead cyanobacteria. If there is a large amount of dead cyanobacteria then anoxic conditions could result. The ultrasonic approach would also require consideration of potential side effects of ultrasonic waves.

One weeder on the market (SonicSolutions®) addresses 3 acres per unit (Weeders Digest, 2009). For Vancouver Lake, the number of weeders needed to address the entire lake would be impractical. However, enclosures could be set up around areas of heavy bloom to use a smaller number of weeders.

Shading

Theory

Shading by the use of dyes reduces the amount of sunlight that reaches phytoplankton in the water column thereby limiting growth. Surface algae would not be shaded out by the dye.

Examples

Dye manufacturers give several examples for small private lakes and ponds.

Considerations

Many dyes are not effective in water less than 2 feet deep or on the algae that is floating on the water surface. Use of dyes is most effective when used prior to the growing season to retard initial growth (Lynch, 2009). Dye would need to be re-applied after time to maintain shading. As cyanobacteria self-regulate their location in the water column, the potential effectiveness of shading in controlling cyanobacteria is uncertain.

Washington Department of Ecology does not permit the use of dyes in waters that discharge to surface waters. There may be allowances for use of dyes if physically dividing the lake in some manner and applying dye only in a contained area. In this manner one or more management techniques could be explored in smaller cross sections of the lake.

As water clarity in Vancouver Lake is already low the effectiveness of further reducing clarity by addition of dyes is questionable.

Summary

The many techniques described above are outlined from experiences from restoration of other lakes with nuisance algal or cyanobacteria blooms. The brief discussion of each strategy is to serve as an informed starting point for a dialogue of potential strategies for Vancouver Lake.

As described in the purpose section above, no strategy is being advocated for or against within this document. Choosing the appropriate technique(s) will be dependent on the findings of research into the Vancouver Lake system. The needed research studies, some of which have begun, are outlined in the Research Plan for Vancouver Lake (VLWP, 2009).

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