Draft Vancouver Lake Management Plan

Vancouver Lake, Clark County, Washington

Prepared for
Clark County

Prepared by
Herrera Environmental Consultants, Inc.

In Association with
LimnoTech
Kearns & West
AquaTechnex

Note:
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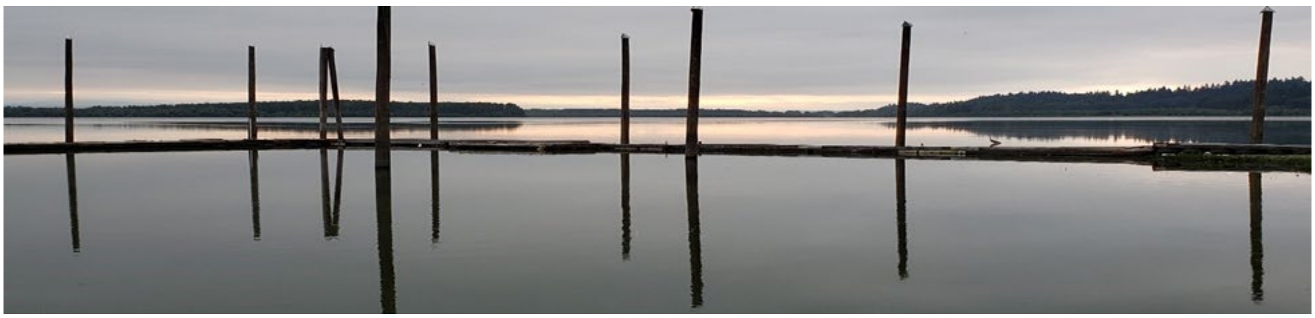

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ACKNOWLEDGEMENTS

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LAKE MANAGEMENT PLAN REVIEW AND APPROVAL

The following individuals have reviewed this Lake Management Plan and have approved its use.

Clark County	Signature	Date
Washington State Department of Ecology	Signature	Date

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EXECUTIVE SUMMARY

Vancouver Lake, located in Clark County in the southwest portion of Washington state, sits adjacent to the Columbia River and the city of Vancouver north of Portland, Oregon, and covers approximately 2,300 acres. As a large lake located within a metropolitan area, the lake is used by a multitude of recreational users and is home to a variety of fish and wildlife. Vancouver Lake has exhibited known water quality issues, including but not limited to increasingly frequent harmful algal blooms (HABs) composed of toxin-producing algae called blue-green algae or cyanobacteria, and large infestations of aquatic invasive (noxious) weeds. Prior actions have made minor and/or temporary improvements (e.g., dredging, Flushing Channel construction, aquatic weed treatment). In addition to these efforts, a comprehensive and cohesive Lake Management Plan (LMP) is necessary to ensure the long-term viability and health of Vancouver Lake.

This LMP, prepared for Clark County, is intended to serve as a guide for managing Vancouver Lake and its watershed in the next phases of the decision-making process. Decisions on which lake management methods will be used and how they will be funded have yet to be made. A lake management team needs to be identified to work directly with various stakeholder groups throughout the decision-making process to ensure consistent public engagement and consideration of concerns and aspirations, and to help build support for management outcomes. Ultimately, the lake management team will make the decisions about which strategies to pursue to restore and protect Vancouver Lake and its users.

Project Description

In 2021, a state operating budget appropriation allocating $150,000 was awarded to Clark County for the purpose of designing the process for developing a long-term plan to restore and maintain the health of Vancouver Lake, as well as designing an institutional structure to take responsibility for the plan's implementation in a financially sustainable manner. Herrera Environmental Consultants, Inc. (Herrera) was hired to prepare the Vancouver Lake Management Plan (VLMP) described herein to address lake use problems caused by HABs and aquatic noxious weeds, with a structure for future development of supplemental and long-term management scenarios to address these and other issues of concern to lake users, such as fecal bacteria contamination, insufficient public access, and other types of impacts to native fish and wildlife use of the lake. While it is beyond the scope of this project to prioritize other issues impacting lake users or to evaluate cost-effectiveness of lake management techniques that are not related to toxic algae and invasive plants, it is expected that the adaptive management approach developed for the present LMP version will be applicable to future LMP versions addressing these other issues.

The VLMP project was divided into two main phases. Phase 1 (May–June 2022), was focused on organizing the project team, initiating engagement with key stakeholders, reviewing historical data and information, and completing the comprehensive Work Plan for the project (Herrera 2022), which guided stakeholder engagement in the project and modeling approaches for the development of the LMP, and provided a sound, science-based basis for Vancouver Lake management decision making. Phase 2 (July 2022–June 2023) is focused on developing the LMP by gathering input from the public and key stakeholders, analyzing historical data, creating a lake water quality and hydraulic model, defining potential management scenarios, evaluating the effectiveness of those methods, and developing a funding plan for implementation of the management scenarios.

The Work Plan established the following problem statement:

> *Vancouver Lake is a unique and important feature of Clark County, Washington and provides invaluable ecological and community resources. A rich history of community involvement, local and state organizational collaboration, thorough research, and restorative efforts has found the lake and its uses to be impacted by a variety of known water quality issues for several decades. Beneficial lake uses are most impaired by intense summertime levels of harmful algae blooms and aquatic invasive plants, requiring the development of sustainable short-term and long-term management objectives and strategies.*

The Work Plan asserted the following three project-specific goals, which both benefit lake users and improve lake health in the short-term, along with a guiding set of objectives for each of these goals based on what is achievable and affordable:

1. **Reduce impacts of HABs** with objectives for:
    a. Concentrations of cyanotoxins produced by cyanobacteria to not exceed Washington State Department of Health (WDOH) recreational guidelines for issuing a public health advisory on more than two dates during each of 2 or more years
    b. Numerical thresholds for algae (phytoplankton) biomass measured as chlorophyll-a
    c. Numerical thresholds for concentrations of phosphorus, which limits algae biomass
    d. Numerical thresholds for water transparency measured as Secchi depth.
2. **Reduce impacts of aquatic invasive plants** with objectives for:
    a. Reducing two submersed noxious weeds in the lake (Eurasian watermilfoil and curly leaf pondweed) and two emergent noxious weeds along the shoreline (purple loosestrife and yellow flag iris)
    b. Taking measures to prevent new introductions of noxious weeds and other aquatic invasive species.
3. **Identify other specific lake uses important to public users and ecosystem function** with the objective for addressing them in future LMP versions.

In addition, the Friends of Vancouver Lake (FOVL) and Vancouver Lake Sailing Club (VLSC) developed long-term goals to be regularly reassessed and amended as part of ongoing, adaptive lake management practices identified in the VLMP, pursuant to future lake needs, input from stakeholders, and funding.

HAB Management Evaluation

HAB management techniques were evaluated for the Work Plan with ratings of their overall HAB control effectiveness, total long-term cost, environmental impact to beneficial uses and non-target organisms, and overall feasibility for implementation at Vancouver Lake with consideration of public acceptance. This assessment was slightly modified for this LMP based on additional considerations by the project team and input from the technical advisory group (TAG). A total of eight feasible HAB management techniques were further developed and evaluated that include two watershed management methods, three lake physical methods, and three lake chemical methods.

Feasible watershed management methods include:

- Wastewater Management: Study how best to reduce nutrient inputs to Vancouver Lake from septic systems and expand existing sanitary sewer extension programs by the City and County in the watershed to connect problem systems or replace them with non-polluting systems at an average annual rate of 2.5 percent over 20 years, totaling a 50 percent connection/replacement of the problem systems that are assumed to be responsible for 90 percent of the septic system phosphorus loadings to the lake.
- Stormwater Management: Expand existing stormwater treatment programs by the City and County in the watershed to significantly reduce phosphorus loading by 30 percent over a period of 20 years. This would be done by requiring phosphorus treatment of stormwater for all new development and redevelopment, retrofitting the existing stormwater conveyance systems to add phosphorus treatment where no treatment facilities exist, converting existing basic treatment facilities to phosphorus treatment facilities, and where possible, relying heavily on regional treatment facilities with high-flow and high-phosphorus removal media filter systems such as that constructed at the Park Place facility in Bellingham.

Feasible lake physical management methods include:

- Lake River Dam: Construct a dam on Lake River near the lake to reduce nutrient-rich backflow from the river back into the lake while maintaining fish and boat passage, assuming the dam crest is set at 4 or 5 meters compared to the lake level range of 2 to 6 meters and an average outflow of 5 cubic feet per second (cfs) through fish gates and boat locks.
- Flushing Channel Enlargement: Widen the flushing channel outlet structure from the existing double barrel (77-inch and 84-inch) culverts to a 100-foot-wide by 10-foot-tall box culvert to increase lake inflow from the Columbia River to Vancouver Lake by 30 times the current flow, with fish-friendly gates to restrict backflow from the lake back into the Columbia River.
- Floating Wetlands: Install floating wetland breakwaters to reduce wind wave height and the resulting sediment suspension and internal nutrient loading, and to also provide nutrient uptake by the root biofilm, assuming a total length of 4,950 meters of floating wetlands that are 3.6 meters wide for a total surface area of 17,820 square meters or 0.2 percent of the total lake surface area.

Feasible lake chemical management methods include:

- Buffered Alum Treatment: Apply buffered aluminum sulfate (alum) to the entire lake to strip 80 percent of the phosphorus out of the water column and inactivate all biologically available sediment phosphorus.
- Lanthanum Modified Bentonite Treatment: Apply lanthanum modified bentonite to strip 80 percent of the phosphorus out of the water column and inactivate all biologically available sediment phosphorus.
- Algaecide Treatment: Apply sodium carbonate peroxyhydrate (Phycomycin or PAK 27) over the entire lake in late June and again in early August to kill all algae in the lake.

Table ES-1 summarizes the eight feasible HAB management methods along with approximate cost, relative effectiveness and longevity, and recommendations by this LMP for implementation.

Lake Modeling

LimnoTech developed a linked hydrodynamic model (HEC-RAS 2D from USACE) and water quality model (WASP from EPA) for Vancouver Lake to assess effectiveness of the eight feasible management alternatives for reducing cyanobacteria blooms in the lake. The model used extensive monitoring data collected by the United States Geological Survey (USGS) in 2011–2012. Although extensive physical and biological data are available from other years, collected and provided for use in this study by Washington State University Vancouver's Aquatic Ecology lab, the availability of the nutrient and hydrological data necessary to expand the model to additional years was insufficient.

The model produced represents an advanced lower food web model capable of simulating water quality including up to three algal classes; multiple forms of phosphorus, nitrogen, and carbon; dissolved oxygen, temperature, solids; toxics; and sediment diagenesis. Ecological endpoints used to assess HAB management methods included summer average chlorophyll-a concentrations, summer maximum cyanobacteria (as chlorophyll-a), summer average Secchi depth, summer average total phosphorus, and maximum water temperature.

The greatest reductions in peak cyanobacteria chlorophyll-a were for the in-lake treatments of phosphorus inactivation by alum or lanthanum (58 percent) and algaecide (55 percent). Moderate reductions were predicted for Lake River dam (27 percent), flushing channel enlargement (27 percent), and stormwater treatment (25 percent). Low reductions were predicted for floating wetlands (9 percent) and wastewater management (7 percent).

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Table ES-1. Harmful Algal Bloom Management Actions Evaluated for the Vancouver Lake Management Plan.

Management Method	Mechanism	Conceptual Design	Average Annual Cost Over 20 Years	Expected Effectiveness and Longevity	Recommendation
Wastewater Management	Reduce phosphorus to the lake from failing or poor functioning septic systems.	Increase septic system surveillance and expand the existing sanitary sewer connection program by an average annual rate of 2.5 percent over 20 years, to reduce watershed phosphorus loading by 18 percent in 20 years.	High cost: $9.1 M for connecting 200 homes/year	Low effectiveness: 7% reduction in peak HAB in 20 years High longevity	**Recommended** to enhance existing City and County wastewater programs and budgets, with funding for a manager to promote septic system source control.
Stormwater Management	Reduce phosphorus in stormwater runoff to the lake, and enable watershed stewardship and ownership	Require stormwater phosphorus treatment for developments and expand the existing stormwater management program to reduce watershed phosphorus loading by 30 percent in 20 years.	Moderate cost: $2.0 M (plus grants)	Moderate effectiveness: 25% reduction in peak HAB in 20 years High longevity	**Recommended** to enhance existing City and County stormwater programs and budgets, with funding for a manager to promote phosphorus treatment.
Lake River Dam	Reduce nutrient-rich water in Lake River from flowing back into the lake.	Construct a dam at the head of Lake River with a dam crest set at 4 or 5 meters (1 to 3 meters higher than lake level) and allow for fish and boat passage.	Moderate cost: $2.1 M	Moderate effectiveness: 27% reduction in peak HAB forever High longevity	Not recommended due to higher cost and potential fish and boat passage impacts than Flushing Channel enlargement
Flushing Channel Enlargement	Increase lake inflow from the Columbia River to Vancouver Lake and restrict backflow from the lake back into the Columbia River to reduce HABs from lower nutrients.	Widen the flushing channel outlet structure from the existing double barrel (77-inch and 84-inch) culverts to a 100 foot-wide by 10 foot-tall box culvert with fish-friendly tide gates.	Moderate cost: $1.6 M	Moderate effectiveness: 27% reduction in peak HAB forever High longevity	**Recommended** as the primary control method
Floating Wetlands	Reduce wind wave height and resulting sediment nutrient suspension, thereby reducing internal nutrient loading and HABs.	Install floating wetland breakwaters to a total length of 4,950 meters by 3.6 meters wide for a total surface area of 17,820 square meters or 0.2 percent of the total lake surface area.	Low cost: $0.6 M	Low effectiveness: 2% reduction in peak HAB for at least 20 years Moderate longevity	Not recommended due to low effectiveness and sailing impacts.

Table ES-1. Harmful Algal Bloom Management Actions Evaluated for the Vancouver Lake Management Plan.					
Management Method	**Mechanism**	**Conceptual Design**	**Average Annual Cost Over 20 Years**	**Expected Effectiveness and Longevity**	**Recommendation**
Alum Treatment	Reduce phosphorus availability in water and sediments to reduce cyanobacteria growth and competitive advantage.	Apply buffered aluminum sulfate (alum) to the entire lake to strip phosphorus out of the water column and inactivate all biologically available sediment phosphorus.	Low cost: $0.5 M	High effectiveness: 58% in peak HAB for less than 5 years Low longevity	**Recommended** for low dose, water phosphorus stripping without buffer as needed to precede or supplement Flushing Channel enlargement.
Lanthanum Modified Bentonite Treatment	Reduce phosphorus availability in water and sediments to reduce cyanobacteria growth and competitive advantage.	Apply lanthanum modified bentonite (EutroSORB G) to the entire lake to strip phosphorus out of the water column and inactivate all biologically available sediment phosphorus.	Low cost: $0.9 M	High effectiveness: 58% reduction in peak HAB for less than 5 years Low longevity	Not recommended due to high cost.
Algaecide Treatment	Kill all algae in the lake, including cyanobacteria.	Apply sodium carbonate peroxyhydrate (Phycomycin or PAK 27) over the entire lake in late June and again in early August.	Low cost: $1.0 M	High effectiveness: 55% reduction in peak HAB for only one year Very low longevity	**Recommended** for beach treatment only as needed in response to beach closure.

HAB Management Plan

Cost-effectiveness analysis results showed that the chemical methods of alum and algaecide treatment yielded the greatest benefit in terms of chlorophyll-a and cyanobacteria reduction per dollar, followed by chemical lanthanum treatment, and next by the physical management methods of flushing channel enlargement and Lake River dam construction. Despite roughly equal cost-effectiveness of these physical methods in terms of reducing chlorophyll-a and cyanobacteria, the flushing channel enlargement alternative yielded significantly greater benefit to water clarity per dollar compared to all other alternatives.

The recommended HAB management plan and 20-year average annual cost includes:

- Flushing channel enlargement at $1.6 million/year
- Watershed management, limited to promoting enhancement of existing programs and requiring stormwater phosphorus treatment using existing City, County, and grant funding sources to be determined and supplemented with an LMP cost of $10,000/year for program promotion.
- Alum treatment using a low-dose water column stripping approach on one occasion as needed before or after flushing channel enlargement at a cost of $50,000/year.
- Beach algaecide treatment of the swimming beach area in response to cyanotoxin or *E. coli* criteria exceedances on 10 occasions as needed before or after flushing channel enlargement at a cost of $2,500/year, which could include installation of a turbidity curtain or bubble curtain to reduce treatment area and increase effectiveness.
- Monitoring lake water quality, conducting special studies, and reporting LMP activities each year at a cost of $75,000/year.
- Adding a 10 percent contingency for a total HAB management cost of $1.9 million/year.

Noxious Weed Management Plan

Noxious submersed weed management alternatives were recently evaluated in 2020 for the Integrated Aquatic Vegetation Management Plan (IAVMP) by the Clark County Noxious Weed Board. Eurasian watermilfoil (milfoil) was successfully controlled by an application of florpyrauxifen-benzyl (ProcellaCOR) to 700 infested acres of the lake in 2020. Building on this work and other noxious weed observations, the noxious weed management plan, assumptions, and 20-year average annual cost include (in order of decreasing cost and importance):

- Preparation and implementation of an aquatic invasive species (AIS) prevention plan to include public education on existing risks of new invasive plant and animal infestations, decontamination procedures for preventing their spread, early detection monitoring, and rapid response actions for an average annual cost of $12,500.

- Mapping and reporting of submersed and emergent noxious weeds before and after each treatment at an average annual cost of $10,500/year.
- Milfoil treatment with ProcellaCOR over an average of 50 acres once every 3 years or a total of seven treatments in a period of 20 years at an average annual cost of $9,188/year.
- Curly leaf pondweed treatment with penoxsulam (Galleon SC) over an average of 20 acres once every 3 years or a total of seven treatments in a period of 20 years at an average annual cost of $6,300/year.
- Purple loosestrife and yellow flag iris treatment with glyphosate using an airboat for shoreline emergent plans and an all-terrain vehicle (ATV) for upland emergent plants emergent weed control will occur an average of once every 3 years for a total of seven treatments in a period of 20 years at an average annual cost of $2,625/year.

With a 20 percent contingency ($9,123/year) the average annual total cost for the recommended noxious weed and invasive species management plan is $54,735/year.

Stakeholder Involvement Plan

The stakeholder involvement plan outlines a strategy for engaging members of the public, lake user groups, and others throughout the development and implementation of the Vancouver Lake Management Plan. This plan outlines activities and communication tools that are most critical for engaging different areas of the project and are mindful of limited resources. This plan does not capture the creative potential ways to engage the public that could build support but are more resource intensive such as festivals, arts events, etc. The plan was prepared from TAG and general public input collected during the LMP project.

The goal of the stakeholder involvement plan is to generate and build upon existing support for the VLMP with the following objectives:

- Educate the general public about the lake and the plan
- Hear the concerns and interests of the public about the lake
- Collaborate on the strategies to be used
- Shift public perception to see the lake as a clean and safe area as improvements are made
- Improve public understanding of who is responsible for lake management

Stakeholders are critical for successful implementation of this plan by being involved in decisions on which management methods are selected, lake issues to be addressed in the future, and funding sources to be sought. The plan recognizes the public support for lake protection based on previous management, outreach, and partnership efforts. Public involvement opportunities for LMP implementation include public support; outreach, communication, and education through existing citizen-led organizations like FOVL or Vancouver Lake's recreational clubs. Public involvement should include historically underserved and under-represented communities, and include elected officials for political support as was exhibited early on by funding this LMP development project. However, numerous challenges related to the LMP public involvement effort were also identified.

Guiding principles for public engagement, and specific communication principles and tools are identified for the following key audiences: Cowlitz Indian Tribe, Vancouver Lake user groups, residents, general public, and governments/ports. Note that Cowlitz Indian Tribe is a sovereign entity their engagement in this project them should honor this distinction with government-to-government communication and consideration of cultural resource implications.

The annual cost estimate for implementing the recommended stakeholder involvement plan presented is approximately $168,000.

Funding Plan

Preparation of the funding plan began with evaluating and summarizing appropriate mechanisms for funding lake management activities, including long-term and short-term (i.e., loans and grants) sources. Several options were considered for meeting long-term funding needs that included organizing a special use district, establishing an interagency coalition, and relying on the State capital budget. Three different approaches to using a special use district were presented at a TAG meeting: a Flood Control Special Use District, a Lake and Beach Maintenance and Management District, and Park District. Establishing a new Flood Control Special District was recommended as the preferred approach for the VLMP because its powers, authority, and governance best matched the diverse project needs. The key steps in establishing this district include setting district boundaries, setting rates, public outreach, public hearings, and voting, which typically takes 2 to 3 years to establish.

Several TAG members recommended that appropriations from the State capital budget was the most appropriate funding source due to the statewide significance of the lake and the anticipated challenges in approving a tax levy. The district tax levy was estimated to be $0.05/$1,000 average property value ($2.2 million/87,712 properties x $520K average property value/$1000), which represents less than a 1 percent increase in the current total levy rate of $9.33/$1,000 value for City of Vancouver properties not exempt from school taxes.

The special use district strategy is at risk of failure by the voting public who may oppose new taxes. The legislative appropriations strategy is at risk of failure due to the large amount of funds needed. A combination of both funding sources could be considered to reduce the risk of failure. In April 2023, the state legislature appropriated $330,000 for implementation of the VLMP through June 2025, which represents 7.5 percent of the $4.4 million proposed for the next two years. More work is needed to fully develop a funding strategy, particularly for large-scale investments, as the management plan further develops in the next phase of the LMP. Whatever the strategy, it is important to educate stakeholders and the general public on the value of Vancouver Lake and the importance of the LMP to increase and protect its value.

Roles and Responsibilities

The relevant entities to fulfill the required roles and responsibilities of organizing, governing, and executing the decisions of a Flood Control District, as the primary mechanism for funding and implementation of management activities for Vancouver Lake, were defined. Key roles include a governing board consisting of at least three members, who are appointed for the first year and elected thereafter, and a Lake Manager hired by the board. Many of these 14 roles would be needed to successfully implement the LMP if it were entirely funded by appropriations from the State capital budget and short-term sources (e.g., grants) that do not rely on a tax levy.

Adaptive Management

In order to further the long-term, inclusive goals of the LMP, an adaptive lake management framework was described to regularly reassess and amend LMP goals as part of ongoing, adaptive lake management, pursuant to future lake needs, stakeholder values, and funding. Adaptive management is a structured process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Under the framework of a Flood Control District, this LMP recommends the formation of a Steering Committee or otherwise defined supervisory group (e.g., the continuation of the Technical Advisory Group formed by this project) to manage a formal, science-based adaptive management program that follows the following steps for decision making:

1. Assessing the Problem
2. Designing a Solution
3. Implementation
4. Monitoring
5. Effectiveness Evaluation
6. Adjust and Repeat

Examples of current knowledge gaps and limitations of the VLMP are listed for future assessment. Future adaptations to consider were identified, including reducing public use impacts and lake closures from high fecal bacteria and expanding recreational access to the lake.

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INTRODUCTION

Vancouver Lake, located in Clark County in the southwest portion of Washington state, sits adjacent to the Columbia River and the city of Vancouver, north of Portland, Oregon. The lake covers approximately 2,300 acres (931 hectares or 3.6 square miles). As a large lake located within a metropolitan area, the lake is used by a multitude of recreational users and is home to a variety of wildlife. Vancouver Lake falls under several governmental jurisdictions. Washington State Department of Ecology (Ecology) and Washington State Department of Natural Resources (WDNR) share regulatory authority over the water and lakebed, respectively, while the lakeshore is composed of shoreline primarily managed by Clark County under their Legacy Lands and Parks departments, with sections along the south and southwest owned by the Washington Department of Fish and Wildlife (WDFW), the Columbia Land Trust, the Port of Vancouver, and the City of Vancouver. Several privately owned parcels are distributed along the east and northeast shoreline of the lake.

Vancouver Lake has exhibited known water quality issues for many years, including but not limited to increasing nutrients and algae growth (eutrophication), increasingly frequent harmful algal blooms (HABs) composed of toxin-producing algae called cyanobacteria, large infestations of aquatic invasive (noxious) weeds, high water temperatures and turbidity, fecal bacteria contamination, and reduced summer lake depth. It is a Category 5 303(d) status impaired body of water for total phosphorus, fecal coliform bacteria, and fish tissue contamination by methyl mercury, PCBs, dioxin, toxaphene, and DDE.

Prior actions have made minor and/or temporary improvements (e.g., Flushing Channel construction, aquatic weed treatment). In addition to these efforts, a comprehensive and cohesive Lake Management Plan (LMP) is necessary to ensure the long-term viability and health of Vancouver Lake. Specifically, an LMP is needed to outline a management strategy that not only describes feasible lake management techniques, but also addresses lake use concerns, adaptive plan development, stakeholder and public involvement, entity responsibilities, timelines, and potential funding sources for plan implementation.

In 2021, Friends of Vancouver Lake (FOVL) spearheaded a renewed effort to procure funding to begin restoring Vancouver Lake's beneficial uses. Teamed with Senator Annette Cleveland, they voiced concerns over Vancouver Lake's degraded conditions to the Washington State legislature. In response, a state operating budget appropriation allocating $150,000 was awarded to Clark County:

> ***"… for the purpose of designing the process for developing a long-term plan to restore and maintain the health of Vancouver Lake … as well as designing an institutional structure to take responsibility for the plan's implementation in a financially sustainable manner."***

This effort resulted in the Vancouver Lake Management Plan (VLMP) project described herein. Funded by the appropriation, this project has accomplished the goals set by the state and consequent County expectations to design the Plan development process. This project has also developed an adaptive LMP to address lake use problems caused by HABs and aquatic noxious weeds, with a structure for future development of supplemental and long-term management scenarios to address these and other issues of concern to lake users, such as fecal bacteria contamination, insufficient public access, and other types of impacts to native fish and wildlife use of the lake. While it is beyond the scope of this project to prioritize other issues impacting lake users or evaluate cost effectiveness of lake management techniques that are not related to toxic algae and invasive plants, it is expected that the adaptive management approach developed for the present LMP version will be applicable to future LMP versions addressing these other issues. As such, this LMP is intended to serve as a guide for managing Vancouver Lake and its watershed in the next phases of the decision-making process.

Phase 1 of the VLMP project represented the project start-up period, which was focused on developing a Work Plan (Herrera 2022) to guide the design and development of the LMP. Phase 2 of the project focused on finalizing and implementing the Work Plan to develop the LMP.

The present document is composed of the following sections, following Ecology's Algae and Aquatic Weed Management Plan guidelines (Ecology 2004, 2020):

- *Executive Summary*: A synopsis of key project conclusions and recommendations.
- *Background*: Details the Vancouver Lake area, hydrologic and nutrient budgets, water quality and contaminants of concern, aquatic plants, fish and wildlife, and community involvement.
- *Project Description*: Defines a problem statement, lists lake management goals and objectives, and provides an overview of the project schedule.
- *HAB Management Methods Evaluation*: Provides background and conceptual designs of eight feasible HAB management methods, presents methods and results of lake modeling to evaluated method effectiveness, compares cost effectiveness among the feasible methods, and briefly describes the rejected HAB management methods.
- *Noxious Weed Management Methods Evaluation*: Provides background and evaluates methods for managing noxious weeds in the lake and along the shoreline.
- *Additional Lake Issues*: Summarizes other lake issues not addressed by this LMP.
- *Recommended Lake Management Plan*: Establishes recommendations for immediately implementable and long-term management actions for controlling toxic algae and invasive plants in Vancouver Lake.
- *Stakeholder Involvement Plan*: Identifies goals and objectives, decisions to be made, opportunities and challenges, guiding principles, key audiences, and engagement tools for involving stakeholders for implementing the LMP.
- *Funding Plan*: Details the approaches and results of our analysis of funding options and recommends funding strategies to further evaluate and fund LMP implementation.
- *Roles and Responsibilities*: Identifies which agencies, groups, and/or individuals may be responsible for implementing the plan and monitoring progress.
- *Adaptive Management*: Presents an adaptive management framework for future management strategy development, identifies current knowledge gaps and plan limitations, and suggests future adaptations to consider.

BACKGROUND

This section summarizes existing data sources and notable findings related to lake characteristics, watershed information, water quality, ecological function, and human uses, and demonstrates the richness of existing Vancouver Lake knowledge with which the LMP was developed. Additional background information is provided in the HAB and noxious weed management evaluation sections.

Study Area

Hydrology

Vancouver Lake is a large (2,300 acres), shallow (mean depth less than 3 feet) lake located adjacent to the city of Vancouver in Clark County, Washington, and within the greater Portland, Oregon, metropolitan area (Figure 1). Vancouver Lake is part of the Willamette Valley ecoregion and one of several floodplain lakes hydrologically connected to the lower Columbia River and therefore is influenced by both tides and hydropower operations upstream. The deepest lake depths occur in the winter and the lowest depths in summer, with annual lake stage changes between 10 and 15 feet. The deepest area of the lake is the dredged area by the Flushing Channel while most of the central lake area remains shallow, particularly around Turtle Island (Figure 2).

Surface water inflows to the lake include the Columbia River via the Flushing Channel to the southwest, Burnt Bridge Creek to the east, and runoff from the surrounding lake area. Lake River is the greatest source of water to Vancouver Lake (85 percent of inflow) while the Flushing Channel provides 10 percent and Burnt Bridge Creek just 3 percent of total water inflow (Sheibley et al. 2014). Water flows out through Lake River to the north, a long flat slough, which reverses direction during high seasonal flows and tidal fluctuations during which times Lake River becomes the major inflow source including the contents of Salmon Creek (which drains into Lake River). Water inputs via precipitation and groundwater, and export via evaporation, each contributed 1 percent or less to the total water budget. Water retention time in Vancouver Lake is very short, ranging from 8 to 27 days throughout the year (Sheibley et al. 2014).

Historically, Vancouver Lake was much clearer and deeper (up to 20 feet), and water entered the lake from the Columbia River via Mulligan Slough. Construction of the Bonneville Dam in 1938 altered the natural hydrologic regime of the lower Columbia River and significantly reduced flooding and periodic inundation from heavy runoff flows in the spring. Diking and filling along the south and west shorelines from flood control measures and urban development disconnected the lake from the river, resulting in a loss of the “flushing” benefits provided by the river and subsequently increased nutrient and sediment loading.

Several years after the lake was disconnected from the Columbia River, hydraulic monitoring and the development of a water budget was done by Washington State University (WSU) researchers in 1967 (Bhagat and Orsborn 1971) to test the efficiency of various approaches for improving flow. The results of that study concluded that introducing Columbia River water to flush Vancouver Lake would significantly increase the quality of water in the lake. This study was followed by a project which included dredging Vancouver Lake and the construction of the Flushing Channel in 1983 by the Port of Vancouver. The U. S. Army Corps of Engineers (USACE) performed hydraulic modeling in 2008–2009 to evaluate effects of enlarging the Flushing Channel on flow patterns within Vancouver Lake because water quality in the lake did not improve as expected following construction of the channel (USACE 2009).

Monitoring data from various sources show the lake is well-mixed both vertically in the water column and spatially, with lake mixing and lake sediment resuspension driven by wind. From a study conducted by Ecology (1993), Vancouver Lake ranked as the shallowest lake and with the worst water clarity in Washington state. Due to this lack of clarity and the high algae and phosphorus concentrations, Vancouver Lake was determined to be eutrophic with one of the highest trophic state index (TSI) values of the lakes evaluated in Washington state.

Figure 1. Vicinity Map of Vancouver Lake, Vancouver, Washington.
Source: Sheibley et al. (2014)

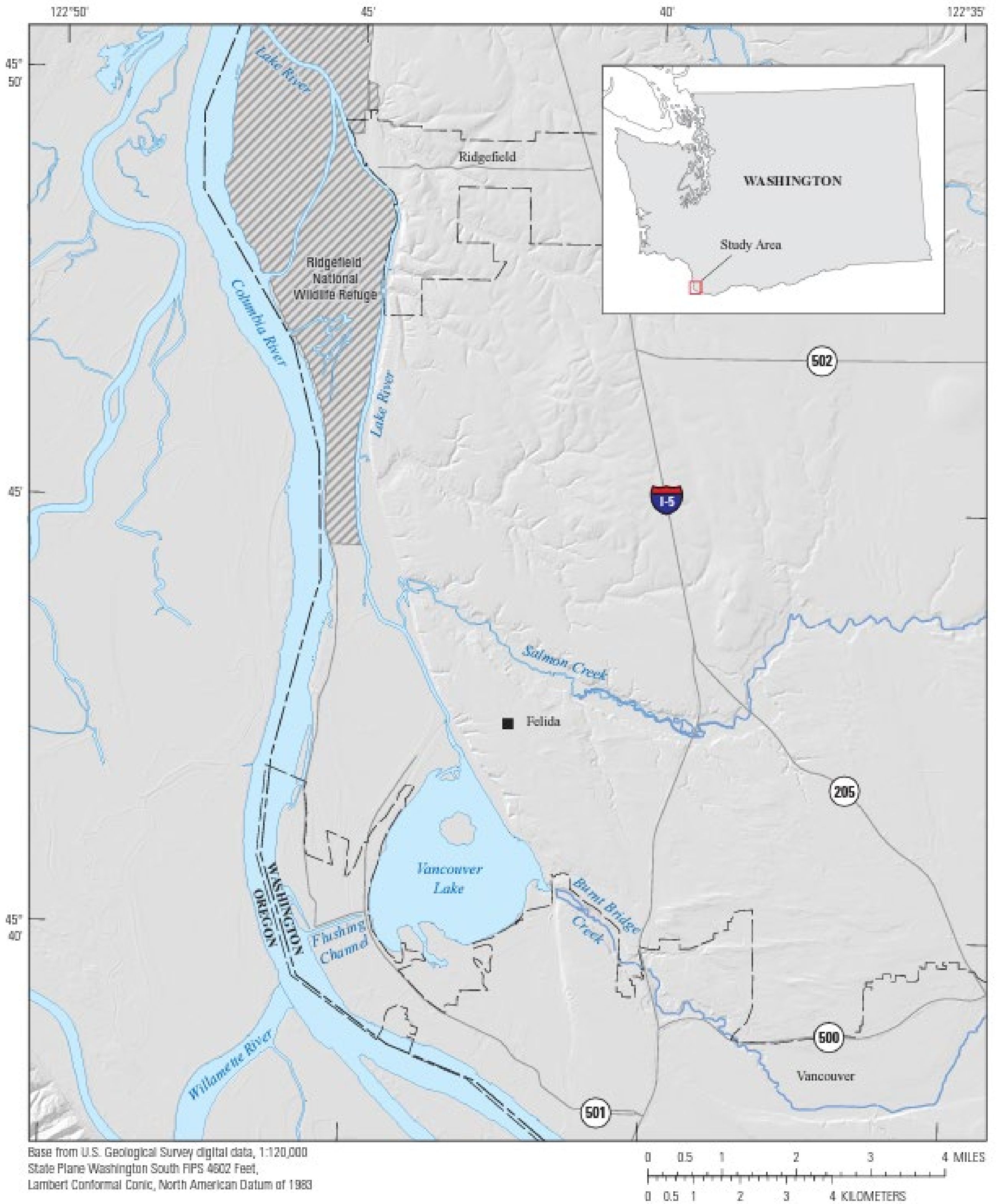
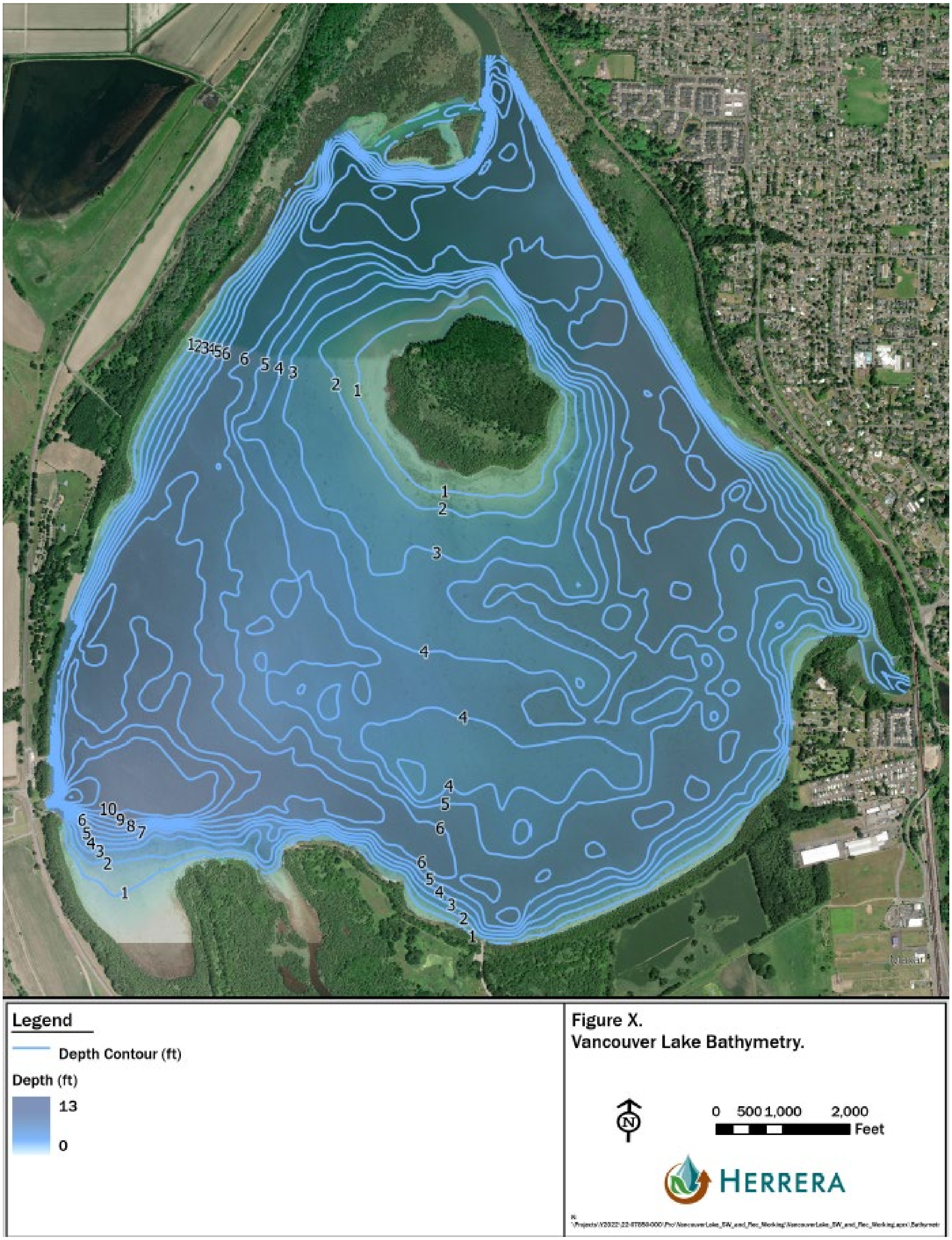


Figure 2. Bathymetry Map of Vancouver Lake (June 15, 2019).
Source: USACE (2009)



Watershed

The Vancouver Lake watershed is located within the Salmon Basin, which extends from Camas to the Port of Ridgefield and drains to the Columbia River. Figure 3 presents stormwater facilities in the various watersheds located in the Salmon Basin. Sub-watersheds draining directly to the lake include the Burnt Bridge Creek watershed to the east, Lakeshore watershed to the north, and Vancouver Lake/Lake River watershed to the south and west. Watersheds draining indirectly to Vancouver Lake via backflow during flood tides in Lake River primarily include the Salmon Creek watershed but also include Whipple Creek and Flume Creek watersheds, which are smaller and located further downstream (north) on Lake River. The Columbia Slope watershed is also located in the Salmon Basin but drains directly to the Columbia River and not to Vancouver Lake. The total lake watershed area is estimated to be approximately 125 square miles (mi^2) including Salmon Creek (90 mi^2), Burnt Bridge Creek (25 mi^2), Lakeshore (4 mi^2), and the nearshore portion of the Vancouver Lake/Lake River (3 mi^2) sub-watersheds.

In terms of land use characteristics, the Vancouver Lake watershed is highly developed beyond the immediate lake vicinity, composed largely of residential with some commercial/industrial land uses in the Burnt Bridge Creek watershed and the southern portion of the Salmon Creek watershed, as shown by the high density of stormwater facilities in Figure 3. Low-density residential, agricultural, and forested land are common in the northern portion of the Salmon Creek watershed and most of the Whipple Creek and Flume Creek watersheds. The Vancouver Lake/Lake River watershed is the floodplain area adjacent to the lake and Lake River, composed of wetland, pasture, open water, and forested areas. Finally, the Lakeshore watershed is the upland residential area just east of the lake and upper Lake River.

Development along the shoreline is low, as most of the land is publicly owned and remains open as farms, pasture, forest, and park areas. Few private residences exist on the eastern shoreline. Nearby wetlands include Buckmire Slough and Matthew Slough directly to the west of the lake, connecting Vancouver Lake Regional Park to Frenchman's Bar Regional Park, and Ridgefield National Wildlife Refuge to the north, which is fed by the lake via Lake River.

Present and planned future land uses in the watershed are described in comprehensive plans prepared by the City of Vancouver and Clark County. Washington's Growth Management Act requires the City and the County to adopt updated plans and changes to its zoning code by June 30, 2025. It is important that these updated plans align with the VLMP. The City is currently updating their plan from 2011 to guide the City's growth and development for the next 20 years, with a target year of 2045 for achieving the overall vision that is established (Vancouver 2023a). In addition, the City recently prepared a separate comprehensive plan for parks, recreation, and cultural services (Vancouver 2022a). The current Clark County Comprehensive Growth Management Plan was initially adopted in 2016 and most recently amended in 2022 (Clark County 2022). Clark County his currently preparing an update by 2025 (Clark County 2023a).

Stormwater facilities in these basins are concentrated largely in the suburban areas of Salmon Creek and Burnt Bridge Creek, and within the city of Vancouver and part of the city of Ridgefield (Figure 3). Much of the human wastewater in the city of Vancouver is connected to the municipal sewage systems but many septic systems also exist, particularly in the Salmon Creek and Whipple Creek watersheds, as shown in the watershed sewer and septic map (Figure 4).

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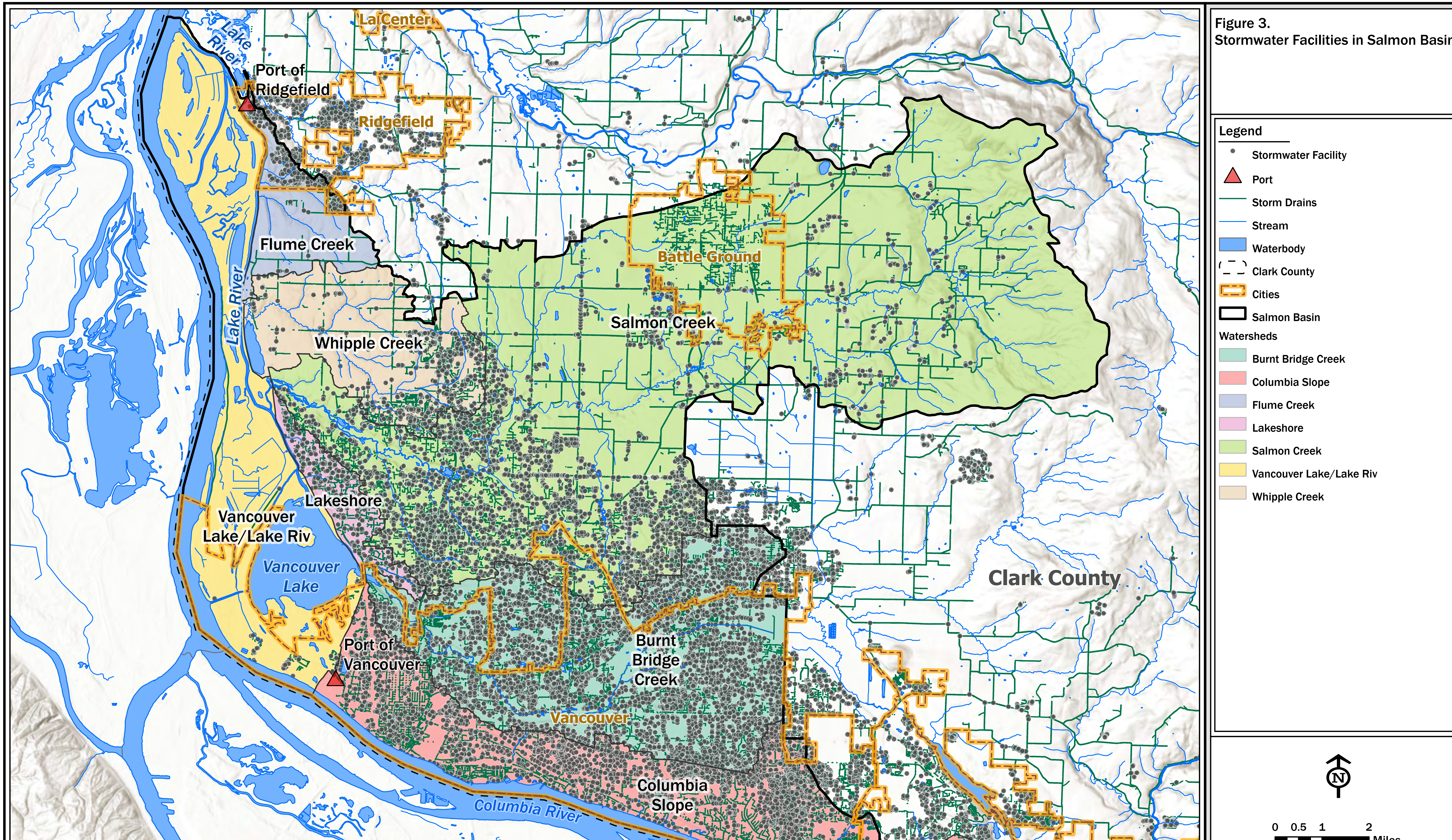
Figure 3.
Stormwater Facilities in Salmon Basin.



HERRERA

Citation: Esri, NASA, NGA, USGS, Clark County

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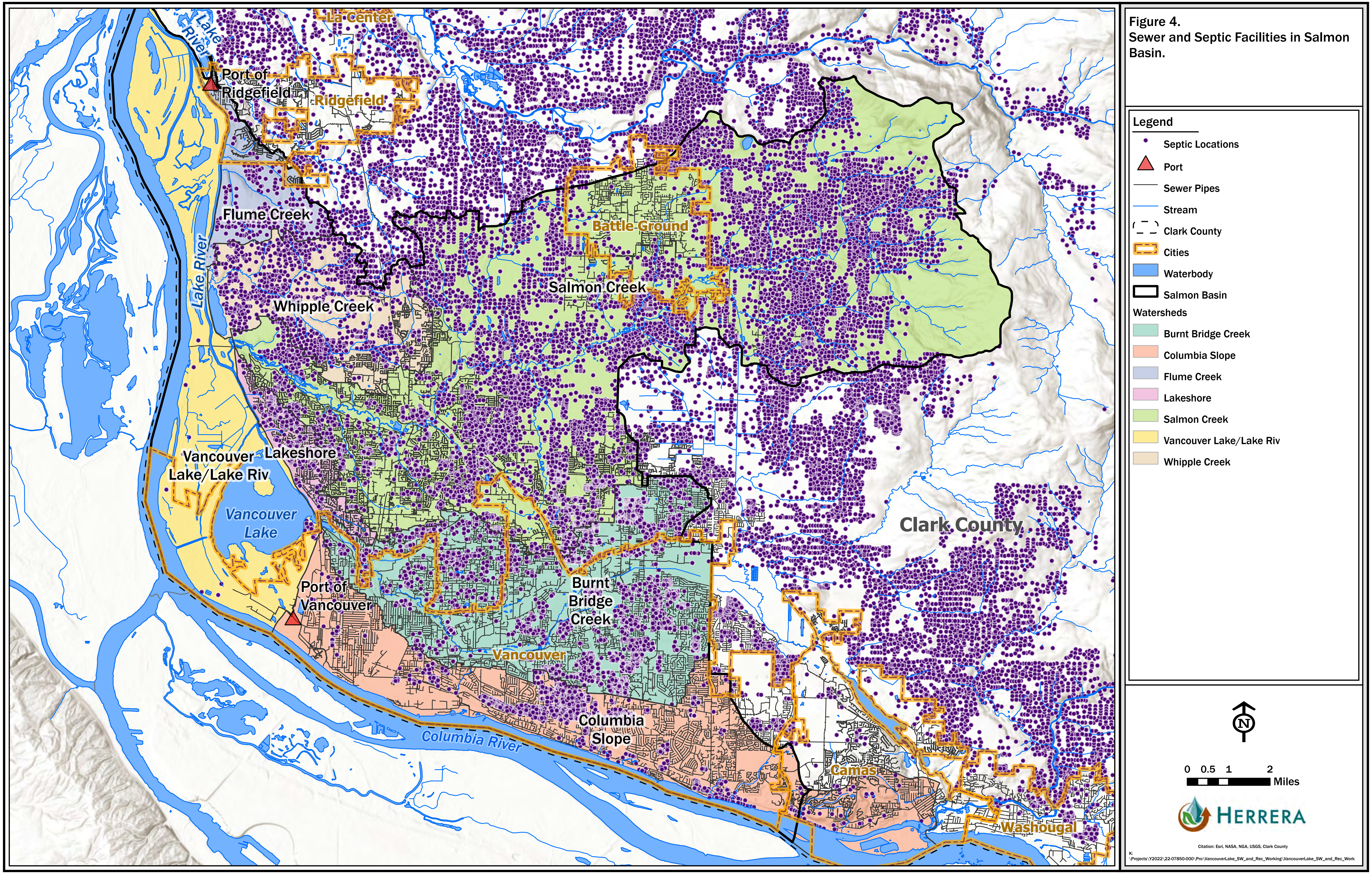

Figure 4.
Sewer and Septic Facilities in Salmon Basin.

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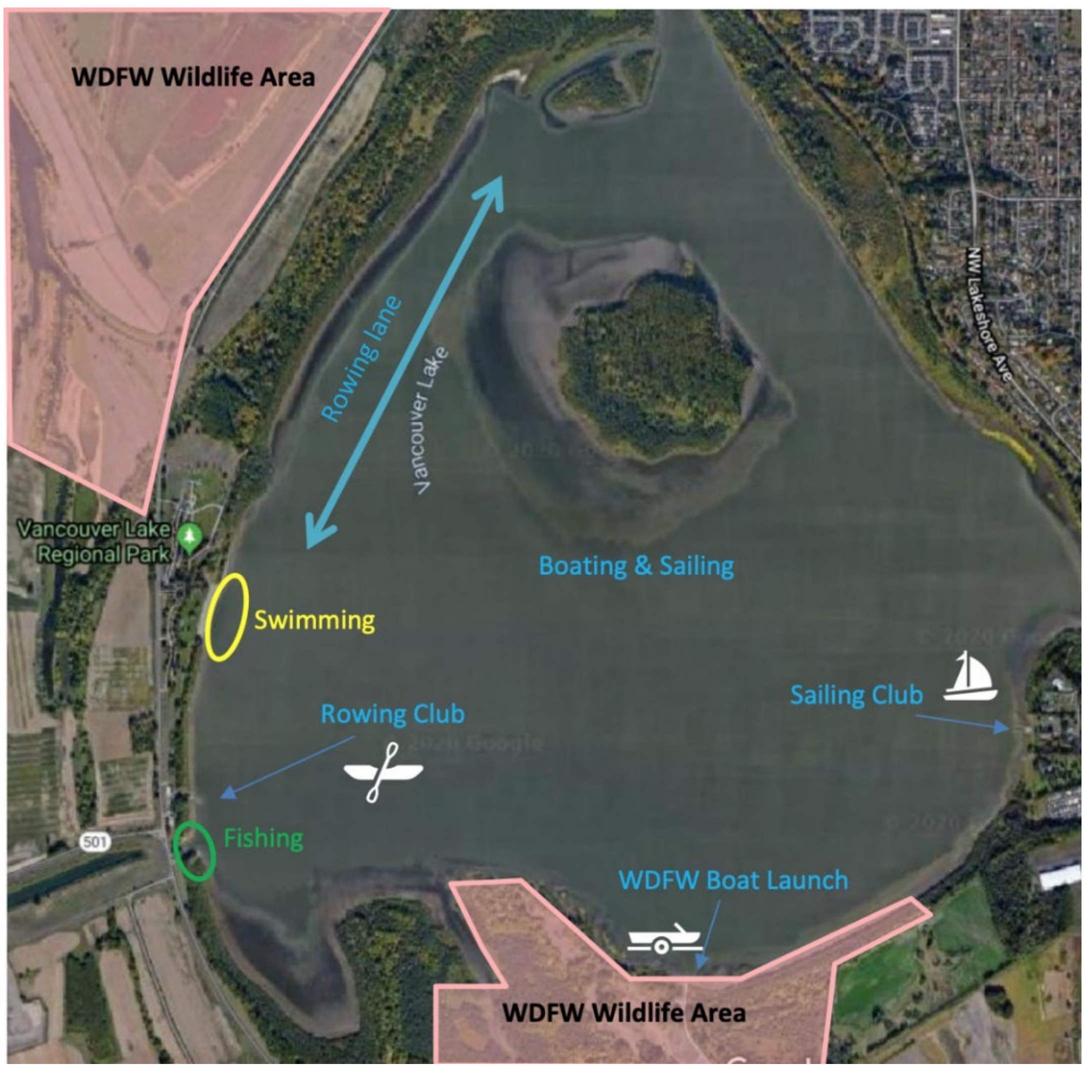
Beneficial Lake Uses

Vancouver Lake and its watershed are significant cultural and archaeological resources for understanding the rich local history of indigenous groups, early European colonists, and the development of today's communities.

Public access points allow for a wide variety of recreational uses (e.g., boating, fishing, hunting, birdwatching, swimming) and other benefits (e.g., aesthetics, public green space) (Figure 5). The lake features a park and a rowing club on the western shore, a sailing club on the eastern shore, and a public boat launch on the southern shore for non-trailered watercraft. In addition, there is a public launch for motorized watercraft at Felida Moorage located on Lake River approximately 0.5 mile north of the lake. The rowing and sailing clubs host regattas that generate significant revenue for the local business community. Sailing and rowing competitions generate $5.8 million/year in direct and indirect sending (E.D. Hovee 2020).

Figure 5. Vancouver Lake Use Map.
Source: FOVL (2021)



Herrera

The lake and Ridgefield National Wildlife Refuge, which is fed by the lake via Lake River, provide important aquatic, wetland, and forested habitat for many culturally important, sensitive, and/or endangered species of fish and wildlife.

State designated uses for Vancouver Lake include primary contact recreation, general aquatic life uses, fish harvesting, and domestic use. State designated uses for the Vancouver Lake Flushing Channel connecting the lake to the Columbia River additionally includes salmonid spawning, rearing, and migration uses. Finally, Lake River's designated uses include primary contact recreation; general aquatic life uses; salmonid spawning, rearing, and migration; harvesting; and domestic use.

Additionally, Vancouver Lake and its shoreline is used by wildlife as part of the Vancouver Lake Wildlife Area Unit, a 482-acre parcel of land located at the south end of Vancouver Lake. It is an important area for migrating waterfowl like Sandhill cranes. Likewise, the Shillapoo South Wildlife Area Unit, located in the floodplains area between Vancouver Lake and the Columbia River, provides over 1,000 acres of wetlands, pasture, and agricultural fields, which boast bald eagle nesting and Sandhill crane habitat, and opportunities for wildlife viewing, dog training, and bird hunting. Both units are components of the Shillapoo Wildlife Area (2,430 acres) managed by WDFW under the Shillapoo Wildlife Area Management Plan (WDFW 2017, 2020), which supports many restoration activities such as (but not limited to):

- Using prescribed fire to control invasive vegetation (e.g., Himalayan blackberry)
- Moist soil management to restore native wetland plant communities
- Riparian habitat enhancement at Chapman Slough and Buckmire Slough
- Oregon white oak plantings
- Columbian white-tailed deer management
- The Shillapoo Ecosystem Restoration Feature (SERF) project (under consideration)

Notably, a property to the west of Vancouver Lake and adjacent to the flushing channel, known as Crane's Landing, is owned and maintained by the Columbia Land Trust. Donated by the Port of Vancouver in 2016, this 527-acre farm is used by the Land Trust for growing crops to feed dairy cows and, upon harvest, provides a rich foraging ground for endangered sandhill cranes with protection from predators (Kosa 2020).

The Ridgefield National Wildlife Refuge, located to the north and connected to the lake via Lake River, serves as another significant area for bird habitat with around 200 species visiting annually and over 75 species utilizing the refuge for winter nesting and migration resting. The Ridgefield National Wildlife Refuge is managed by the U.S. Fish and Wildlife Service who works to restore and conserve oak woodlands, pasture, and wetland habitats for a variety of wildlife.

Water Use and Withdrawals

While Vancouver Lake is not used as a drinking water source, the Troutdale aquifer system in Clark County is a principal drinking water source (i.e., designated as a sole source aquifer [SSA]) and EPA is therefore authorized by the Safe Drinking Water Act to review federal financially assisted Vancouver Lake projects which pose risk of aquifer contamination (EPA 2006).

Additionally, according to the Department of Ecology Water Rights Map, there is one parcel (record number S2-131816CL) located near the mouth of Burnt Bridge Creek, which sources water from Vancouver Lake for domestic use via a surface water pump. Clark County Parks and Recreation (i.e., Vancouver Lake Regional Park) and shoreline homeowners are listed as using groundwater for domestic and irrigation purposes. WDFW records include groundwater and Columbia River-sourced water for nearby irrigation and storage purposes.

Hydrologic and Nutrient Budgets

USGS Study

From 2010 to 2012, the USGS conducted a study of Vancouver Lake to quantify water flows and nutrient loads for the purpose of developing monthly budgets to identify major sources and sinks. The goal of this effort was ultimately to understand the dynamics influencing the lake's cyanobacteria blooms. The final report (Sheibley et al. 2014) outlines the results of these water and nutrient budgets.

The main conclusion of the water budget study was that Lake River is the greatest source of water to Vancouver Lake (85 percent of inflow) while the Flushing Channel provides 10 percent and Burnt Bridge Creek just 3 percent of total water inflow (Figure 6). They also verified that Lake River is the sole outflow for the lake and that water inputs via precipitation and groundwater contribute less than 1 percent each to the total budget. Water retention time in Vancouver Lake ranged from 8 to 27 days throughout the year (Sheibley et al. 2014).

Similarly, the main conclusion of the nutrient budget was that Lake River was the greatest source of nutrients to the lake, contributing 88 percent of total nitrogen, 91 percent of total phosphorus, and 76 percent of orthophosphate loads into the lake, despite exhibiting relatively low concentrations of nutrients (Figure 7 and Figure 8). The next greatest sources of nutrients were from Burnt Bridge Creek and the Flushing Channel, together contributing 12 percent, 8 percent, and 21 percent of the total nitrogen, total phosphorus, and orthophosphate budgets, respectively. Nutrient budgets also revealed that major inputs of phosphorus for the lake's various inflow sources ranged from July to September, leading to peak lake phosphorus concentrations in September 2011. Finally, the field study determined that loosely bound and readily available inorganic phosphorus was 3 percent or less of the total phosphorus measured in sediments while unavailable aluminum- and calcium-bound phosphorus comprised 60 to 90 percent of the total phosphorus. Biological contributions (e.g., nutrient inputs from macrophyte decay and waterfowl excretion) were not measured and were thus represented in the budget residuals.

Figure 6. Total Water Budget for Vancouver Lake (2010–2012).

Source: Sheibley et al. (2014)

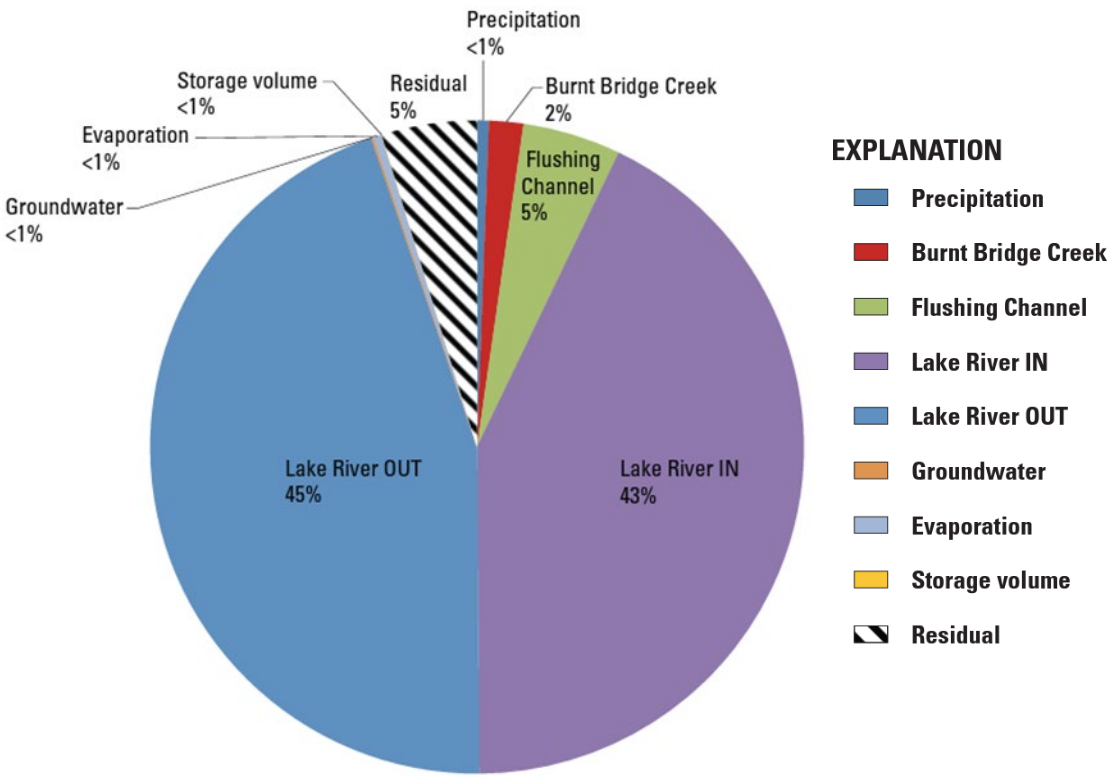


Figure 7. (A) Total Nitrogen and (B) Total Phosphorus Budgets for Vancouver Lake (2010–2012).

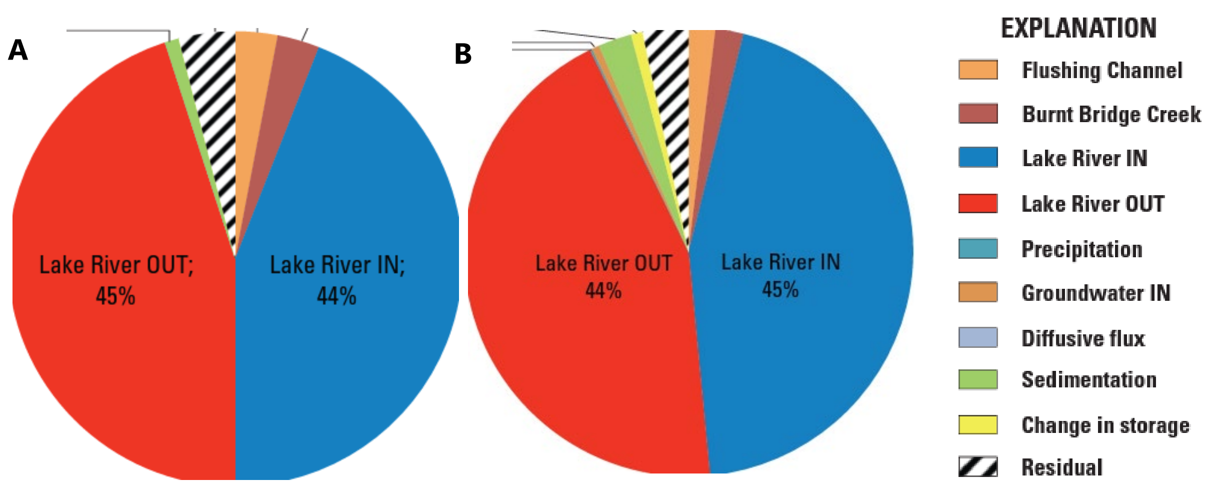
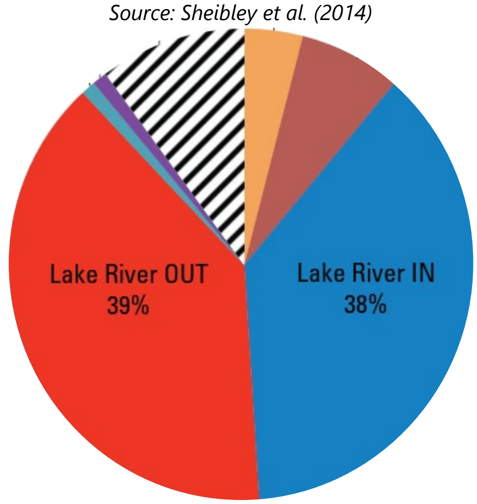


Figure 8. Orthophosphate Budget for Vancouver Lake (2010–2012).

Source: Sheibley et al. (2014)

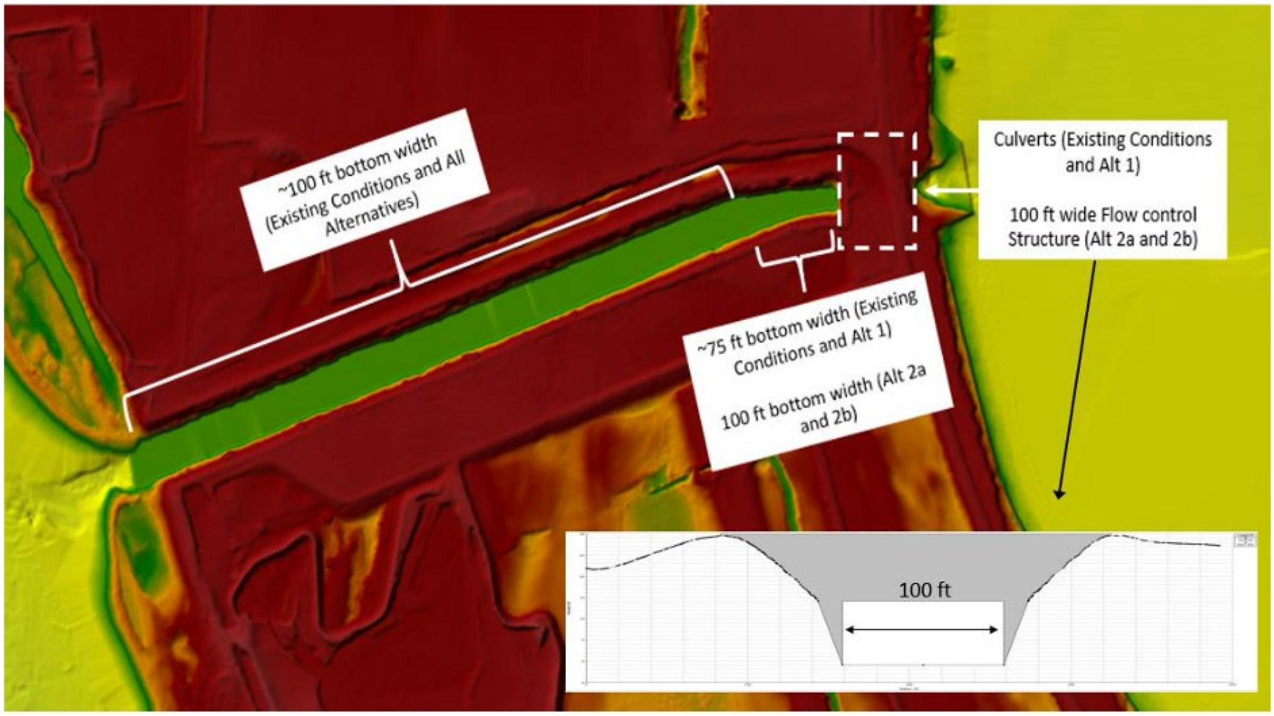


Jacobs Hydraulics Study

In 2021, FOVL hired Jacobs Engineering Group, Inc. (Jacobs) to conduct a hydraulics study on Vancouver Lake to characterize the summertime flows from the Columbia River to the lake through the Flushing Channel and evaluate potential alternative flow scenarios to reduce residence time. This study was performed to ultimately develop a model to inform and support future management and monitoring efforts. Jacobs' hydraulic model was developed using the public domain HEC-RAS software, topographic and bathymetric survey data, and channel and culvert geometry from the Tetra Tech model performed in 2020, the Federal Emergency Management Agency's (FEMA) floodplain model for Lake River, and various other hydrologic data (Jacobs 2022). Their flow results agree with those calculated by Sheibley et al. (2014) in that most of the inflow volume occurs through Lake River, with 93 percent from Lake River and 7 percent from the Flushing Channel. Using a baseline model for comparison, Jacobs developed and evaluated three alternatives for hydraulic options to increase flow rates and volumes through the Flushing Channel: Alternative 1) culvert maintenance (debris removal), Alternative 2a) culvert replacement to open channel with flap gates, and Alternative 2b) culvert replacement to open channel without flap gates (Figure 9).

They found that clearing culverts of trash (Alternative 1) increases flow through the channel but because the channel provides such low inflow volume the lake's hydrographs are unaffected. Additionally, the Port of Vancouver currently performs a robust inspection and maintenance program, including weekly debris removal and channel inspection, so debris likely has little effect on flow through the existing culverts. As channel capacity and reverse flow regulation were the most significant drivers for water volume, Alternatives 2a and 2b were found to substantially alter the flow regime in the lake. Alternative 2a would increase inflow enough to displace approximately 47 percent of the inflow from Lake River with no changes to outflow, while Alternative 2b would dramatically increase inflow from the Flushing Channel (to 28 times current values) resulting in decreased inflow from Lake River by 20 percent but also a net outflow of 120 acre-feet through the channel (i.e., the introduced volume is entirely sent back through the channel during ebb tides after mixing in the lake). Both alternatives would result in an overall reversal in the dominant inflow source (approximately 75 percent from Flushing Channel and 25 percent from Lake River).

Figure 9. Flushing Channel Geometries and Alternatives by Jacobs (2022).



Water Quality

Nutrients

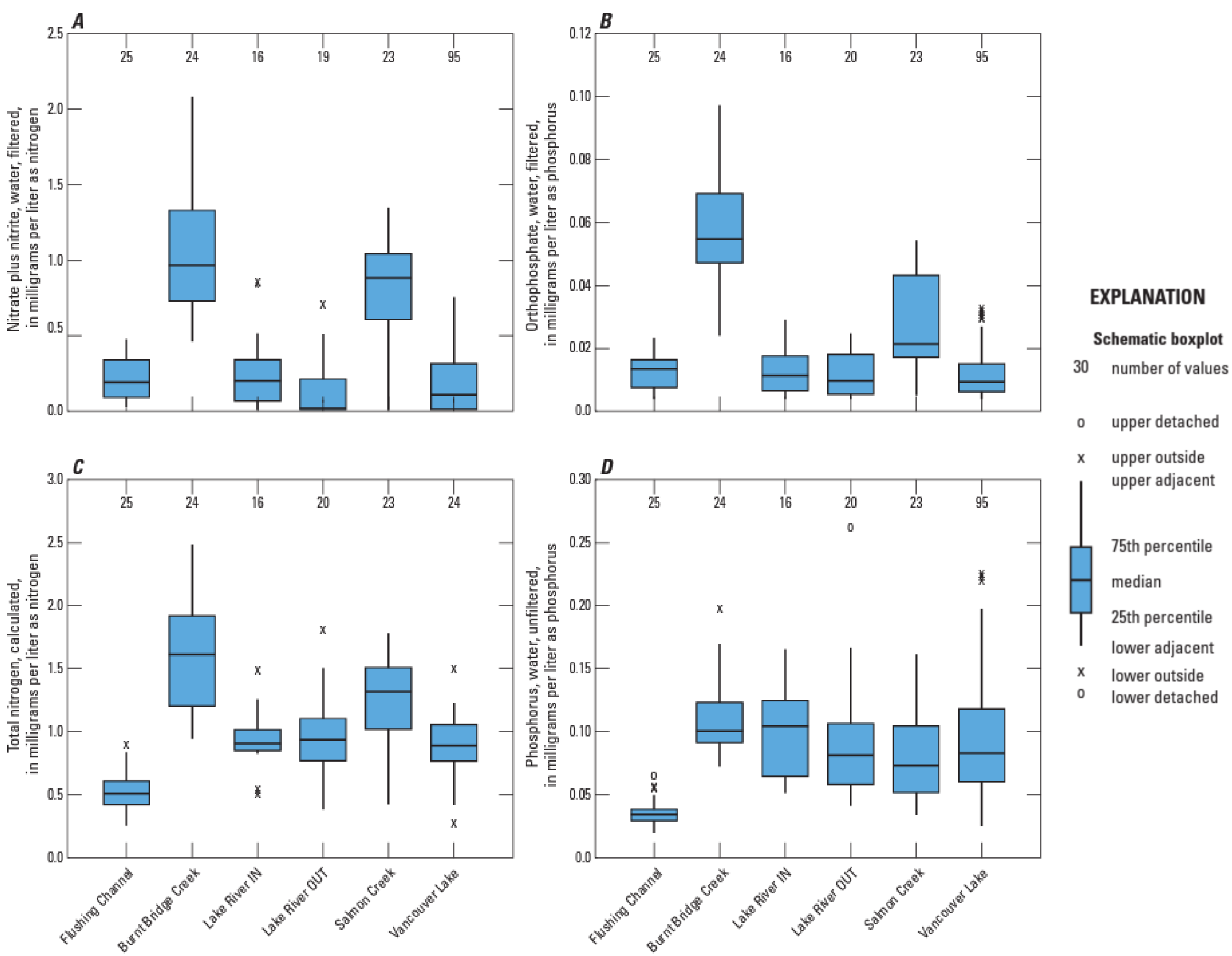
Vancouver Lake has shown signs of nutrient pollution (eutrophication) since the 1960s. Bhagat and Orsborn (1971) report "excessive" organic and inorganic nutrient concentrations, with phosphorus and nitrogen concentrations averaging 0.23 and 2.29 mg/L, respectively, and dissolved oxygen values as low as 5.7 mg/L. Compared to the same parameters measured from the Columbia River, Vancouver Lake was of "lower quality" and this led to the construction of the Flushing Channel to introduce "higher quality" water and decrease retention time in the lake. They also found that the top 6 inches of lake bottom sediments, composed of mud and sand, contained greater concentrations of nutrients than deeper layers but did not report values.

The 1990 statewide lake assessment by Ecology (1993) noted that Vancouver Lake was the shallowest and most turbid of the 73 lakes evaluated for the program, with phosphorus concentrations and Secchi depth readings leading to mean TSI values of 65 and 73, respectively. Thus, Vancouver Lake has been estimated to be one of the most eutrophic lakes monitored in Washington state.

The USGS 2010–2012 field study also quantified Vancouver Lake nutrient loads (total nitrogen, total phosphorus, and orthophosphate) and developed respective nutrient budgets to identify major nutrient sources and sinks and ultimately understand the nutrient dynamics influencing the lake's cyanobacteria blooms. The final report (Sheibley et al. 2014; see Figure 6) outlines the results of their water quality monitoring and budget analysis, the findings of which are summarized in the *Hydrologic and Nutrient Budgets* section of this LMP. Importantly, they found that Lake River was the greatest source of nutrients to the lake due to the high quantity of water inflow to the lake, loosely bound and readily available inorganic phosphorus was 3 percent or less of the total phosphorus measured in sediments, and major inputs of phosphorus July through September led to peak lake phosphorus concentrations in September. Although nutrient concentrations in Burnt Bridge Creek were higher than in other sources (Figure 6), low water inflow limited the total contribution of nutrients from this source to the lake.

Figure 10. Surface Water (A) Nitrate+Nitrite, (B) Orthophosphate, (C) Total Nitrogen, (D) Total Phosphorus in Vancouver Lake (2010–2012).

Source: Sheibley et al. (2014)



Additional nutrient data were collected and analyzed by WSU researchers in 2009–2010, finding that orthophosphate phosphorus concentrations varied from 0.001 to 0.24 mg/L (Lee et al. 2015); though far reduced from Bhagat and Orsborn's (1971) results, orthophosphate was found to influence cyanobacteria abundance during those years. From measurements taken between 2007 and 2019, WSU researchers also found that water temperature frequently exceeded 20 °C (68 °F) in the summertime and DO levels frequently fell beneath the 8 mg/L minimum guideline (Rollwagen-Bollens et al. 2018). Both pH and turbidity were greatest in late summer, concurrent with the highest temperatures and concentrations of orthophosphate and nitrate (Lee et al. 2015).

Data gaps include 1) an evaluation of nutrient inputs from sediment resuspension, and 2) a quantification of indirect nutrient inputs from Salmon Creek.

Phytoplankton and Cyanotoxins

Algae blooms in Vancouver Lake typically form in mid to late July and last 3 to 4 weeks, followed by a decline in August and often a smaller yet still substantial recurring bloom in September (Rollwagen-Bollens et al. 2018). Toxins produced by the cyanobacteria comprising these blooms ("cyanotoxins") have been regularly measured in Vancouver Lake by Clark County Public Health's (CCPHs) Swim Beach Monitoring Program since 2007 using funds from Ecology's Washington State Freshwater Algae Control Program. Sampling is performed at first signs of a bloom, weekly when harmful blooms are present, and when a scum is reported. The collected samples are tested for cyanotoxins, and the test results are recorded in the Washington State Toxic Algae Database managed by Ecology.

Cyanotoxins are not included as toxic substances in Ecology's surface water quality standards (Washington Administrative Code 173-201A), but guidelines are provided by the Washington State Department of Health (WDOH 2021) that include the following thresholds for public recreation:

- 8 µg/L of microcystin
- 1 µg/L of anatoxin-a
- 15 µg/L of cylindrospermopsin
- 75 µg/L of saxitoxin

Data show that levels of both cylindrospermopsin and saxitoxin are very low and well below state recreational criteria when measured. However, exceedances of respective toxin criteria have occurred for both anatoxin-a and microcystin, necessitating warning and danger advisories (and even lake closures) more frequently in recent years (Figure 7). Microcystin concentrations in particular frequently exceed guidelines, with some samples exceeding by more than 10 times the state guideline value at the swim beach and flushing channel sample locations.

Figure 11. Cyanotoxin Criteria Exceedances in Vancouver Lake, 2007–2022.
Source: Ecology (2023b)

Studies of water quality and plankton ecology in Vancouver Lake have been thoroughly performed by WSU Vancouver's Aquatic Ecology Laboratory since 2007. Their cyanotoxin research results agreed with measurements from CCPH in that microcystin concentrations (both intracellular and extracellular) frequently exceeded World Health Organization recreational guidelines during the study (2008 and 2009) (Lee et al. 2015). Using molecular techniques, Lee et al. (2015) identified that *Microcystis* sp. was the only microcycstin-producing cyanobacteria species in Vancouver Lake, with most of the *Microcystin* sp. population containing the toxin-producing gene (mcyE). Although *Microcystis* sp. is also observed in the lake, their relative abundance has never been recorded at greater than 1 percent of the overall cyanobacteria assemblage. Rather, the summer and fall harmful algae blooms are typically dominated by filamentous cyanobacteria species *Aphanizomenon flos-aquae* and *Dolichospermum flos-aquae* (formerly *Anabaena flos-aquae*) (Rollwagen-Bollens et al. 2018). Bhagat and Orsborn (1971) similarly found these same cyanobacteria species to represent 95 percent of all phytoplankton cells counted in samples from the late 1960s.

During annual late season algae blooms, chlorophyll-a concentrations of up to 500 to 900 µg/L can be observed (Rollwagen-Bollens et al. 2018). However, cyanotoxin concentrations do not exactly follow patterns in phytoplankton abundance or biomass. Thus, toxin production is influenced independently of the amount of cyanobacteria cells. However, cyanobacteria cell abundance, for both toxic and nontoxic species, and intracellular microcystin concentrations were all primarily influenced by orthophosphate concentrations.

Zooplankton

Research on zooplankton dynamics in the lake reveal that complex multi-level trophic cascade effects drive cyanobacteria dynamics. Both copepods and microzooplankton taxa (2 to 200 µm in size) greatly influence phytoplankton communities, though in different ways. Copepods were consistently the dominant zooplankton taxon observed in Vancouver Lake; by consuming other types of high-quality phytoplankton (e.g., diatoms and green algae) and other grazers, copepods facilitate a competitive advantage for cyanobacteria. When this advantage co-occurs with the late summer phosphate peak, the conditions result in a cyanobacteria bloom (Rollwagen-Bollens et al. 2013; Rose et al. 2017; Rollwagen-Bollens et al. 2018). Inversely, copepod grazing on these taxa typically halts in the early fall, allowing microzooplankton taxa (e.g., ciliates, rotifers, and dinoflagellates) to resume grazing. Thus, zooplankton trophic cascades and multi-tier and intra-guild trophic influences by microzooplankton, particularly rotifers, are thus responsible for the dissipation of harmful blooms in Vancouver Lake (Boyer et al. 2011; Rollwagen-Bollens et al. 2013; Sweeney et al. 2022).

Fecal Bacteria

Bhagat and Orsborn (1971) reported fecal coliform bacteria pollution (roughly 130 to 3,800 colony forming units per 100 milliliters [CFU/100 mL]) likely from untreated residential wastewater and agricultural activities within the Salmon Creek and Burnt Bridge Creek basins. Today, CCPH's Swim Beach Monitoring Program collects multiple *Escherichia coli* (*E. coli*) samples biweekly from Vancouver Lake Regional Park's swim beach to determine if there is a health hazard. CCPH uses the U.S. Environmental Protection Agency (EPA) Beach Action Value (BAV) of 235 CFU/100 mL in a single sample as the main criterion. If *E. coli* exceeds this value in one sample, a Warning is issued, and additional daily sampling is conducted until elevated levels are not detected. A beach Closure is issued with continued daily monitoring if the criterion is exceeded in more than one sample.

Since 2004, *E. coli* samples have exceeded the BAV on 15 dates with samples ranging from 235 to 2,491 CFU/100 mL, necessitating seven closure events and eight warnings. Three of the recorded lake closures, which also exhibited the maximum observed levels since 2010, are from 2022 alone. One of these 2022 closures due to elevated *E. coli* levels resulted in the cancellation of the 2022 U.S. Rowing Northwest Masters Regional Championship, an eminent event with rowing clubs participating from more than 36 cities across seven U.S. states and British Columbia, which was to be held at Vancouver Lake June 17 through 19, 2022.

Although waterfowl are suspected to be the primary sources of fecal bacteria at the Regional Park's swim beach, microbial source tracking has not been recently performed at this location to verify that human or other animal sources are not contributing to high fecal bacteria concentrations causing beach closures. The Clark County Public Works Clean Water Division conducts microbial source tracking in other water bodies and may have capacity to better characterize fecal bacteria sources at the swim beach or elsewhere in Vancouver Lake (J. Schnabel, Clark County, personal communication).

303(d) Listed Contaminants and TMDLs

The federal Clean Water Act requires states to perform a water quality assessment every 2 years to track how clean the rivers, lakes, and marine water bodies are. Using existing credible data, Ecology places assessed water bodies in one of five categories that describe the quality of the water and status of any needed cleanup (Ecology 2023a).

- Category 1: Meets tested standards for clean water
- Category 2: Water of concern
- Category 3: Insufficient Data
- Category 4: Impaired water that does not required a Total Maximum Daily Load (TMDL) because it a) has a TMDL plan, b) has another pollution control program, or c) the impairment cannot be addressed through a TMDL (e.g., low flow or invasive species).
- Category 5: Polluted water that requires a water quality improvement project.

Once the assessment is complete, Ecology provides the public a chance to review and give comments and submits the final assessment to the EPA for approval of the Category 5 listings, also called the 303(d) list. The water quality assessment helps Ecology prioritize water bodies for future clean up and preparation of a TMDL study.

A Total Maximum Daily Load is a numerical value that represents the highest amount of pollutant a surface water body can receive and still meet water quality standards. Ecology conducts the TMDL study that includes monitoring to identify sources and amounts of pollutants causing the water quality problem, and technical analysis to determine the pollution reductions each source must make to protect the water. Ecology submits the TMDL report for public review and EPA approval, and then submits a final report to the EPA that includes the TMDL, project plan, and implementation plan. The impaired assessment status is changed to Category 1 when water quality monitoring shows the water body meets water quality standards.

Vancouver Lake is listed as impaired under Category 5 on 303(d) list for the following two water parameters: total phosphorus and fecal coliform bacteria, and for fish tissue contamination for the following parameters: methyl mercury, PCBs, dioxin, toxaphene, and DDE pesticide. The lake is listed as impaired by nonnative aquatic plants under Category 4c, which is not addressed by a TMDL. Ecology has not begun preparation of a TMDL for Vancouver Lake. Table 1 presents the water quality impairments for Vancouver Lake and its tributaries, including Lake River.

Tributaries to Vancouver Lake, Burnt Bridge Creek and Salmon Creek, require TMDLs for a number of parameters. The TMDL for Burnt Bridge Creek is under development and will include plans for at least fecal coliform bacteria, dissolved oxygen, and temperature (see Ecology Publication No. 08-03-110). Salmon Creek's TMDLs (Publications No. 11-10-044 and 05-10-037) are EPA approved and include implementation plans for fecal coliform, turbidity, and temperature.

The 303(d) list presented in Table 1 is based on the 2018 water quality assessment that was approved by EPA in August 2022. Ecology is currently preparing the 2022 water quality assessment based on data submitted by September 30, 2022. They anticipate having a draft list of impaired waters for public review by early 2024 (Ecology 2023a).

For the first time, the 2022 water quality assessment will include HABs in the 303(d) list based on cyanotoxin data, which must include credible data for at least two samples collected in each of 2 years (Ecology 2023b). It is anticipated that Vancouver Lake will be listed for HABs based on cyanotoxin data submitted to the Washington State Toxic Algae database (see).

Aquatic Plants

Surveys for invasive aquatic weeds were performed first in 2007 by Ecology, finding Eurasian watermilfoil (*Myriophyllum spicatum*, "milfoil"), which was found again in 2017 and 2018 in surveys by Friends of Vancouver Lake (FOVL 2021). This infestation was found to have grown significantly, when two more surveys were conducted in 2019: one survey using drone photography and a boat-mounted differential GPS by Aquatechnex, and the other survey using a point intercept method by state and county agencies (WDFW, Ecology, and Clark County Vegetation Management). These surveys found that milfoil had covered approximately 600 acres out of the total 769 acres of shallow water (less than 4 feet) surveyed, amounting to 78 percent of milfoil's habitable area and 26 percent of the total area of Vancouver Lake (Figure 12) (FOVL 2021; Collell 2020).

Table 1. Water Impairments for Vancouver Lake and its Tributaries.		
Category	**Parameter**	**Medium**
Vancouver Lake		
4c	Nonnative aquatic plants	Habitat
5	Fecal coliform bacteria	Water
	Total phosphorus	Water
	Methyl mercury	Tissue
	Polychlorinated biphenyls (PCBs)	Tissue
	Toxaphene	Tissue
Burnt Bridge Creek		
5	Temperature	Water
	Dissolved oxygen	Water
	pH	Water
	Fecal coliform bacteria	Water
Salmon Creek		
4a	Temperature	Water
	Turbidity	Water
	Fecal coliform bacteria	Water
5	Temperature	Water
	Dissolved Oxygen	Water
Flushing Channel		
5	Temperature	Water
Lake River		
4b	Phenol	Sediment
5	Temperature	Water
	Fecal coliform bacteria	Water
	2,3,7,8-TCDD (Dioxin)	Tissue
	4,4′-DDE	Tissue
	Polychlorinated Biphenyls (PCBs)	Tissue

Additional submerged species observed included native and hybrid milfoils, water star-grass, coontail, curly leaf pondweed, common waterweed ("*Elodea*"), sago pondweed, and small pondweed (Figure 12; Table 2) (Collell 2020). Hybrid milfoil, which is a cross between Eurasian watermilfoil and native watermilfoil (*M. sibiricum*) was identified in the field and is shown in Figure 12, but genetic testing proved that it was actually Eurasian watermilfoil.

Figure 12. Aquatic Plant Populations in Vancouver Lake, June 2019.
Source: Collell (2020)

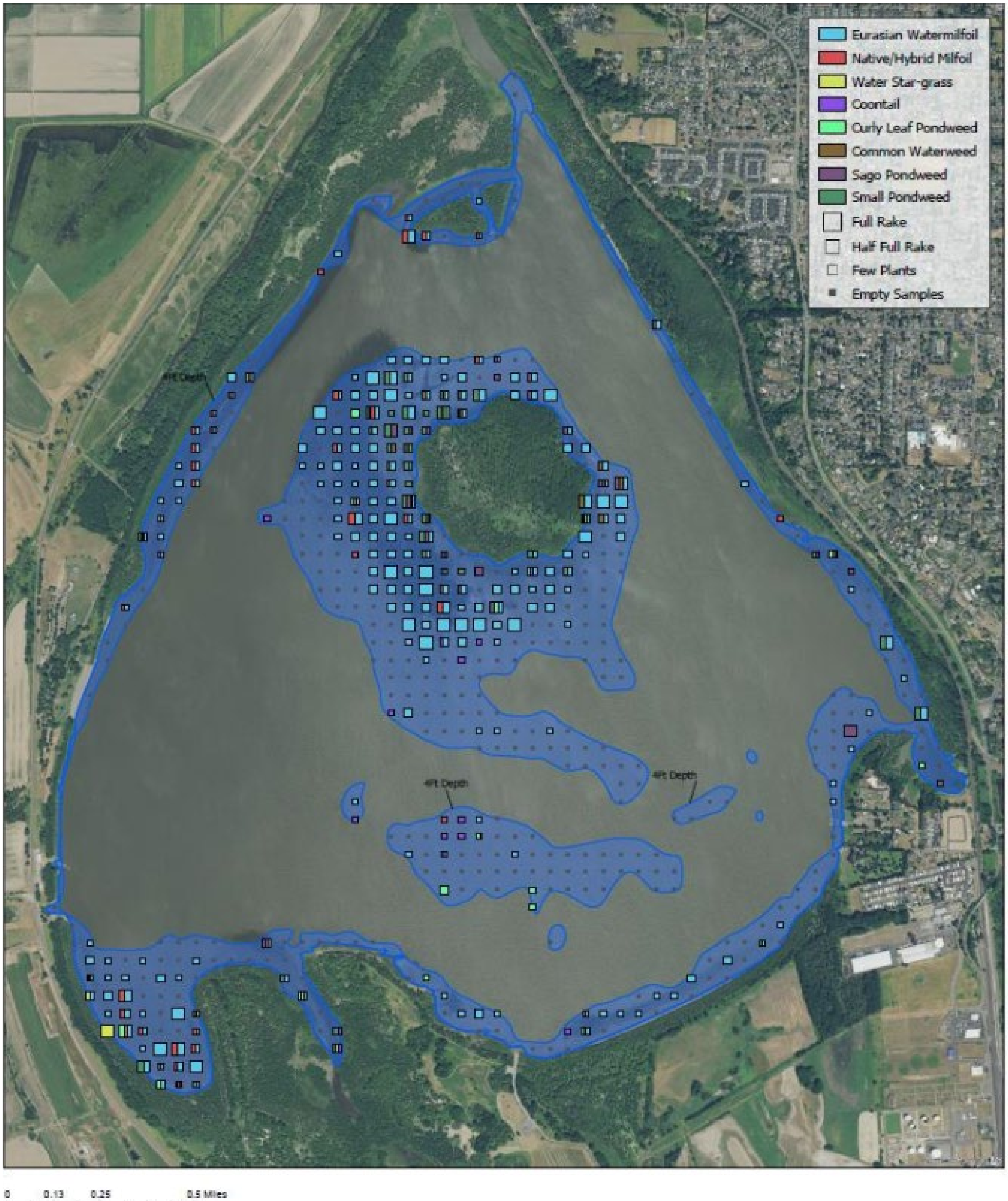


Table 2. Historically Documented Aquatic Plants at Vancouver Lake.			
Latin Name	**Common Name**	**Growth Type**	**Classification**
Myriophyllum spicatum	Eurasian watermilfoil	Submersed	Noxious Class B[a]
Potamogeton crispus	Curly leaf pondweed	Submersed	Noxious Class C
Ceratophyllum demersum	Common hornwort, coontail	Submersed	Native
Elodea spp.	Waterweed	Submersed	Native
Heteranthera dubia	Water star-grass	Submersed	Native
Potamogeton pusillus	Small pondweed	Submersed	Native
Potamogeton spp.	Pondweed species	Submersed	Native
Stuckenia pectinate	Sago pondweed	Submersed	Native
Lythrum salicaria	Purple loosestrife	Emergent	Noxious Class B[a]
Iris pseudacorus	Yellow flag iris	Emergent	Noxious Class C[a]
Phalaris arundinacea	Reed canary grass	Emergent	Noxious Class C
Lysimachia nummularia	Creeping loosestrife	Emergent	Noxious Monitor List
Carex spp.	Sedge	Emergent	Native
Cicuta douglasii	Western water hemlock	Emergent	Native
Eleocharis spp.	Spike-rush	Emergent	Native
Equisetum fluviatile	Water horsetail	Emergent	Native
Juncus spp.	Rush	Emergent	Native
Ludwigia palustris	Water-purslane	Emergent	Native
Persicaria amphibia	Water smartweed, water knotweed	Emergent	Native
Persicaria hydropiperoides	Swamp smartweed	Emergent	Native
Sagittaria latifolia	Duck potato, wapato, arrowhead	Emergent	Native
Salix spp.	Willow	Emergent	Native
Schoenoplectus	Naked-stemmed bulrush	Emergent	Native

Data Source: Collell (2020)

[a] Noxious weed on the Clark County Noxious Weed List (WSNWCB 2022) that is required to be controlled to prevent all seed production and prevent the dispersal of all propagative pars capable of forming new plants. Other listed Class B and C noxious weeds are on the Washington State Noxious Weed List but are not required to be controlled in Clark County.

In response to the milfoil infestation, the Clark County Noxious Weed Board prepared an Integrated Aquatic Vegetation Management Plan (IAVMP) in 2020 that identified aquatic plant management goals, evaluated control alternatives, and selected an integrated treatment scenario (Collell 2020). The Friends of Vancouver Lake contracted with Aquatechnex to survey milfoil cover in the lake and to treat the milfoil using ProcellaCOR herbicide. A total of 700 acres were treated on July 7, 2020, by Aquatechnex. The pre-treatment survey indicated milfoil coverage increased by roughly another 100 acres from the 600 acres mapped in 2019 (T. McNabb, Aquatechnex, personal communication). No milfoil plants were observed during similar point-intercept surveys conducted after the treatment in September 2020 and again in the summer of 2021.

Although the IAVMP only targeted milfoil, other noxious weeds were present in Vancouver Lake. Of particular concern was the presence of dense stands curly leaf pondweed (*Potamogeton crispus*) reaching the water surface in 2021 (see photo inset), which prompted consideration of another herbicide treatment. However, no treatment was conducted because the plant survey in May 2022 observed lower density and height of curly leaf pondweed than in 2021, which may have been due to unusually high lake level and cool temperatures in May 2022 (T. McNabb, Aquatechnex, personal communication).

Milfoil is a Class B weed that is required to be controlled by the Clack County Noxious Weed Board. Curly leaf pondweed is a Class C weed that is not required to be controlled. Other noxious weeds in the lake requiring control in Clark County include purple loosestrife (Class B) and yellow flag iris (Class C) (Table 2), which were reportedly found at various densities together with native plants along the entire lake shoreline (Collell 2020).

Fish and Wildlife

Fisheries

Vancouver Lake is frequently used by anglers. In 1998 and 1999, fish surveys by WDFW identified the following species present in Vancouver Lake: brown bullhead, channel catfish, white crappie, black crappie, largemouth bass, bluegill, pumpkinseed, yellow perch, goldfish, common carp, northern pike-minnow, American shad, mosquito fish, largescale sucker, unidentified sculpin, starry flounder, and white sturgeon (Caromile et al. 2000). The survey also reported fish habitat consisting of muddy flats at low tide, high turbidity, low plant growth, consistent hard sand and silt substrate, no gravel or rock bars, and few large woody structures, which WDFW considered to be poor refuge for younger fish and poor habitat for insect populations (Caromile et al. 2000). Carp were projected to represent the greatest biomass of any fish species in the lake, which is expected since the lake was also historically a commercial carp fishery (Collell 2020), but the survey showed white crappie and brown bullhead to be most abundant by numbers (Caromile et al. 2000).

Although most species observed in the lake are reflective of the warmwater conditions, Vancouver Lake likely contains many of the species that inhabit the Columbia River due to its direct connection and may use the lake as a backwater area for foraging, spawning, or resting away from the high flows of the Columbia River. These are particularly important services for the state and federally listed salmonid species that historically frequented the lake. Table 3 presents the federal- and state-listed species of fish and wildlife at Vancouver Lake. The lake uses and life stages of species present in Vancouver Lake are seasonally and temperature dependent.

Endangered/Rare Species

Vancouver Lake is also home to a variety of federal and state listed species of wildlife, providing habitat for many endangered salmonids, birds, and mammals (Table 3) among other ecologically and culturally significant species such as the Pacific lamprey, bald eagle, and peregrine falcon. The Vancouver Lake Wildlife Area Unit, a 482-acre parcel of land located at the south end of Vancouver Lake and encompassing a portion of the lake shoreline, is an important area for migrating waterfowl like Sandhill cranes. The Shillapoo South Wildlife Area Unit, located in the floodplains area between Vancouver Lake and the Columbia River, provides an additional 1,000+ acres of wetlands, pasture, and agricultural fields that boast bald eagle and Sandhill crane nesting. All units are components of the Shillapoo Wildlife Area (2,430 acres) managed by WDFW under the Shillapoo Wildlife Area Management Plan (WDFW 2017, 2020).

Table 3. Vancouver Lake Federal and State Listed Species of Fish and Wildlife.[a]

Common Name	Scientific Name	Federal Status	Washington State Status
Fish			
Snake River Sockeye	*Oncorhynchus nerka*	Endangered	Endangered
Upper Columbia Spring Chinook	*Oncorhynchus tshawytscha*	Endangered	–
Snake River Spring/Summer Chinook		Threatened	–
Lower Columbia Chinook		Threatened	–
Snake River Fall Chinook		Threatened	–
Snake River Steelhead	*Oncorhynchus mykiss*	Threatened	Candidate
Upper Columbia Steelhead		Threatened	Candidate
Mid-Columbia Steelhead		Threatened	Candidate
Lower Columbia Steelhead		Threatened	Candidate
Lower Columbia Chum Salmon	*Oncorhynchus keta*	Threatened	–
Lower Columbia Coho Salmon	*Oncorhynchus kisutch*	Threatened	–
Eulachon smelt	*Thaleichthys pacificus*	Threatened	–
Wildlife			
Common Loon	*Gavia immer*	–	Sensitive
Western Grebe	*Aechmophorus occidentalis*	–	Candidate
American White Pelican	*Pelecanus erythrorhynchos*	NA	Threatened
Northern Goshawk	*Accipiter gentilis*	–	Candidate
Sandhill Crane	*Grus canadensis*	–	Endangered
Loggerhead Shrike	*Lanius ludovicianus*	–	Candidate
Streaked Horned Lark	*Eremophila alpestris strigata*	Threatened	Endangered
Western Gray Squirrel	*Sciurus griseus*	–	Threatened
Columbian White-Tailed Deer	*Odocoileus virginianus leucurus*	Threatened	Endangered

[a] A preliminary census of species from 2007, not including insect or plant species, listed as present in the lake or in the adjacent area, including Ridgefield National Wildlife Refuge, Washington, with statuses updated according to WDFW list of threatened and endangered species (WDFW 2022).

The 527-acre farm to the west of Vancouver Lake and adjacent to the flushing channel, known as Crane's Landing, is owned and maintained by the Columbia Land Trust, the crops produced from which feed dairy cows and, upon harvest, provide a rich foraging ground for endangered sandhill cranes with protection from predators (Kosa 2020).

The Ridgefield National Wildlife Refuge, located to the north and connected to the lake via Lake River, serves as another significant area for bird habitat with around 200 species visiting annually and over 75 species utilizing the refuge for winter nesting and migration resting.

Community Involvement

Public Participation

Stakeholders for this project include but are not limited to:

General Public: Members of the public, such as local neighborhood associations, Vancouver residents, and lake and park recreators, were informed of the project and invited to participate in a public meeting that focused on 1) educating public stakeholders about the project and 2) gathering feedback on the project and draft Work Plan. Public comments on the draft Work Plan were incorporated into the final Work Plan. Members of the public were also asked to participate in a public survey to understand lake uses, public perception about the lake, and their goals for future lake quality and use, the responses of which were used to inform the goals of the Lake Management Plan. Public stakeholders are additionally invited to participate in a second public meeting focused on presenting the draft Lake Management Plan and gathering feedback on the Plan to consider and incorporate.

The Technical Advisory Group (TAG): A specific stakeholder group composed of representatives from key regulatory authorities, community leaders, and technical experts. The TAG was consulted frequently throughout the project via email and bimonthly meetings to provide data, feedback, and input on project development and key documents. TAG members included but were not limited to:

- Clark County
- The City of Vancouver
- Ecology
- WDFW
- WDNR
- Cowlitz Indian Tribe
- Port of Vancouver
- Port of Ridgefield
- Friends of Vancouver Lake
- Vancouver Lake Sailing Club
- Vancouver Lake Rowing Club
- Washington State University – Vancouver
- Watershed Alliance of Southwest Washington

TAG meetings typically occurred on the fourth Thursday every other month from 12 to 2 p.m. (Pacific). During Phase 1 of the project, the TAG was engaged to help identify the project's problem statement, goals, objectives, and initial management methods for consideration in LMP development. During

Phase 2 of the project, TAG feedback was critical to further developing feasible management alternatives, understanding the barriers to implementation of various management alternatives and coordinating solutions, identifying future LMP roles and responsibilities, and assessing potential LMP funding strategies.

Additional stakeholders include state legislators (e.g., Senator Annette Cleveland, Representative Monica Stonier, and Representative Sharon Wylie) and other agencies and organizations that operate in the Vancouver Lake watershed and were invited to participate but were not present at TAG meetings (e.g., Audubon, U.S. Army Corps of Engineers [USACE]).

Efforts to Improve Water Quality

Prior actions have made minor and/or temporary improvements to water quality, such as increased flow (decreased retention time) from the construction of the Flushing Channel by USACE in 1983. Years later, efforts to engage the public, maintain a collaborative stakeholder group, develop comprehensive management strategies, and design a long-term funding approach were undertaken by the Vancouver Lake Watershed Partnership (VLWP).

Beginning in 2004, the VLWP was an organization that brought together federal, state, and local agencies with public stakeholders and various interest groups to explore issues, share information, and strategize solutions to protect and support the lake and its uses. The VLWP was a result of efforts by the Port of Vancouver, the City of Vancouver Department of Public Works, the Vancouver-Clark Parks and Recreation, the Clark County Department of Public Works, and the Fruit Valley Neighborhood Association, and was composed of and/or attended by many of the same representatives participating in the TAG for this project.

One of the many topics the VLWP addressed was concerns regarding Vancouver Lake's toxic cyanobacteria blooms. For several years, this group led monitoring efforts, technical discussions, public outreach and involvement, and management strategy development for Vancouver Lake. VLWP achieved an impressive collaboration amongst stakeholders to spearhead a variety of managerial and outreach efforts, to share information, and to author key documents that drove VLWP activities and provided a foundation for this LMP project (see the project Work Plan [Herrera 2022] for additional details).

In recognition of local funding limitations and the need for additional feasibility studies prior to any major water quality improvement project, the Partnership in 2014 elected to discontinue meeting, and to focus the remainder of original funding on outreach and small-scale projects to enhance the use and understanding of Vancouver Lake.

In 2020, an Integrated Aquatic Vegetation Management Plan (IAVMP) was developed by Clark County under contract with WDFW, and subsequent herbicide treatment of invasive aquatic plants was conducted on behalf of FOVL. In an additional effort to improve water quality, FOVL also hired a small group of fishers to remove more than 2,000 common carp in spring 2021 to reduce sediment agitation and control algae blooms by reducing turbidity. However, WDFW noted in their 2000 report on warm water fishes in Vancouver Lake, that effective closed-system management of most fish species is not feasible due to the frequent migration of fish between the lake and the Columbia River via the Flushing

Channel, and due to difficulties related to the size of the lake. They concluded that increasing access to open water for anglers (i.e., improving boat launches) and providing education about the warm water fishes would be the most feasible management methods (Caromile et al. 2000).

In 2021, FOVL hired Jacobs Engineering Group, Inc. (Jacobs) to conduct a hydraulics study on Vancouver Lake to characterize the summertime flows from the Columbia River to the lake through the Flushing Channel and evaluate potential alternative flow scenarios to reduce residence time. This study was performed to ultimately develop a model to inform and support future management and monitoring efforts, like this Lake Management Plan project.

Public Support and Opportunities

Based on initial research and public engagement the following opportunities were identified for the public involvement effort, demonstrating evidence of wide support for LMP development and lake protection initiatives:

- The predecessor projects undertaken by the VLWP were helpful in planning for Vancouver Lake management.
- People care about the lake and want to see it improved. Even though many people recognize the water quality challenges, people see the lake as a "gem."
- Motivated groups have mobilized, such as the Friends of Vancouver Lake, who have advocated for the LMP and other clean-up efforts.
- The state provided support for the LMP planning phase, demonstrating a degree of political support for this effort.

PROJECT DESCRIPTION

Problem Statement

Vancouver Lake is a unique and important feature of Clark County, Washington, and provides invaluable ecological and community resources. A rich history of community involvement, local and state organizational collaboration, thorough research, and restorative efforts has found the lake and its uses to be impacted by a variety of known water quality issues for several decades. Beneficial lake uses are most impaired by intense summertime levels of harmful algae blooms and aquatic invasive plants, requiring the development of sustainable short-term and long-term management objectives and strategies.

Goals and Objectives for Vancouver Lake

The Work Plan asserted three project-specific goals, which both benefit lake users and improve lake health. Also outlined in the Work Plan, the guiding set of objectives for each of these goals have been refined using historical data and the results of lake modeling. The goals and finalized objectives presented below are realistic to the extent possible based on what is achievable and affordable.

The Work Plan asserted three project-specific goals:

1. Reduce impacts of HABs
2. Reduce impacts of aquatic invasive plants
3. Identify other specific lake uses important to public users and ecosystem function

1. Goal: Reduce impacts of HABs
    a. Cyanotoxin concentrations in water samples from Vancouver Lake shall not exceed Washington State methodology criteria for a Category 5 (aka 303[d] list) HAB designation (Ecology 2023c), such that:
        i. Cyanotoxin concentrations shall not exceed WDOH recreational guidelines (see the Phytoplankton and Cyanotoxins section above) for issuing a public health advisory on more than two cyanotoxin sample dates during each of 2 or more years. Years do not need to be consecutive.
        ii. Public health advisories issued by Clark County Public Health for potentially toxic cyanobacteria or HABs lasting more than 2 weeks per event shall not occur in 2 or more years. Years do not need to be consecutive.
        iii. No probable or confirmed human or animal HABs exposure events that result in illness or death shall occur.

b. Phytoplankton biomass as measured by chlorophyll-a shall not exceed:

   i. 300 µg/L in any single sample

   ii. A 30-day average concentration of 100 µg/L.

   iii. An average summer (June through October) concentration of 45 µg/L, which is representative of historical low productivity years in Vancouver Lake.

c. Total phosphorus concentrations shall not exceed:

   i. 150 µg/L in any single sample.

   ii. A summer (June through October) average concentration of 70 µg/L, which is representative of historical low productivity years in Vancouver Lake.

d. Secchi depth shall not be less than:

   i. 0.75 meter (2.5 feet) on any single sample date

   ii. A summer (June through October) average depth of 1.0 meter (3.3 feet), which equates to the upper limit of a eutrophic state (at a TSI of 50) and is representative of historical low productivity years in Vancouver Lake.

2. Goal: Reduce impacts of aquatic invasive plants

   a. The area of Eurasian watermilfoil and all other submerged noxious weeds required for control by Clark County shall not exceed 5 percent of the total lake area (i.e., 115 acres) at any given time.

   b. The area of curly leaf pondweed and all other submerged noxious weeds not required for control by Clark County, for which stem growth extends to within 1 foot of the lake surface, shall not exceed 10 percent of the total lake area (i.e., 230 acres) at any given time.

   c. The area of purple loosestrife, yellow flag iris, and all other emergent noxious species required for control by Clark County shall be reduced by at least 50 percent of the existing coverage along the lake shoreline (e.g., by an average of 2.5 percent per year over 20 years).

   d. Measures shall be taken to prevent new introductions of noxious weeds and other aquatic invasive species.

3. Goal: Identify other specific lake uses important to public users and ecosystem function

The project-specific goals and objectives described above will work towards achieving the broad purpose defined by the state appropriation funding for the VLMP project: “to restore and maintain the health of Vancouver Lake.” To drive future projects that utilize the VLMP and to ensure the goals of future projects achieve the desired long-term management outcomes, FOVL and VLSC developed the following inclusive goals:

- Keep Vancouver Lake consistently open and attractive for recreational uses (e.g., swimming, fishing, boating, sailing, hiking, picnicking), particularly spring through fall when lake use is greatest (i.e., increase lake use reliability).

- Improve general water quality and summertime lake depth to improve conditions for recreation and in-lake habitat for native fish and migratory birds.
- Restore adjacent, connected ecosystems (e.g., water, wetlands, shoreline, tidelands, forested areas, and pastures) to high quality and functioning habitat.
- Reduce excess nutrient load impacts from Lake River and other sources, such as by enhancing lake outflow through Lake River, watershed improvements, and other methods.
- Increase and enhance points of public access along the south and east shore of the lake, including improvements for motorized boating access.
- Create and maintain a long-term, adaptive plan to guide above goals and future efforts.

The above goals are purposely broad to direct current and future project-specific goals and objectives, and to define long-term measures of success. As these goals are interrelated, some may therefore inherently pose conflicts with other goals. Additionally, these goals should be regularly reassessed and amended as part of ongoing, adaptive lake management practices, pursuant to future lake needs, input from stakeholders, and funding.

Project Schedule

The VLMP project was divided into two main phases. Phase 1 (May through June 2022) was focused on organizing the project team, initiating engagement with key stakeholders, reviewing historical data and information, and completing the comprehensive Work Plan for the project (Herrera 2022). The Work Plan guided stakeholder engagement in the project to ensure that agencies and the public support the management goals and techniques, are educated about the project, and are otherwise engaged and invested in the success of the LMP. The Work Plan also described the strategy used for modeling the effectiveness of potential management techniques with existing data, to promote sound, science-based decision making for Vancouver Lake management and LMP development.

Phase 2 (July 2022 through June 2023) is focused on developing the LMP by gathering input from the public and key stakeholders, analyzing historical data, creating a lake water quality and hydraulic model, defining potential management scenarios, evaluating the effectiveness of those methods, and developing a funding plan for implementation of the management scenarios.

See the Work Plan (Herrera 2022) for further explanation of each task performed during each phase.

HAB MANAGEMENT METHODS EVALUATION

A wide variety of watershed and in-lake management techniques are available for reducing harmful algal blooms (HABs) caused by toxin-producing cyanobacteria in lakes (Cooke et al. 2005; Lake Advocates 2017). HAB management techniques were evaluated for the Work Plan and are presented in Table 4 along with ratings of their overall HAB control effectiveness, total long-term cost, environmental impact to beneficial uses and non-target organisms, and overall feasibility for implementation at Vancouver Lake with consideration of public acceptance. This assessment has been slightly modified from that prepared for the Work Plan based on additional considerations by the project team and input from the TAG. The purpose of the HAB management method assessment was to provide a framework and tool for comparing and selecting up to six promising management techniques of varying cost and potential effectiveness for modeling and educating stakeholders in Phase 2 of this project.

The following sections summarize the most feasible lake management techniques that may be used to improve the algae community and meet the water quality objectives. There are advantages and disadvantages to each, while some are more experimental in that there are fewer case studies of lake applications, and there are wide differences in initial and long-term costs. Each section briefly describes a technique considered moderately feasible in Table 4 for implementation and meeting water quality objectives at Vancouver Lake. The final section provides a brief list of in-lake management techniques that were not considered to be cost effective and the rationale for their elimination from further investigation at this time.

It is understood that any lake management technique aimed at controlling algae, if successful, is likely to impact aquatic macrophyte populations. The clearer water means more sunlight for plant growth and since most plants obtain their nutrients from the sediments rather than the water, lake nutrient reduction techniques do not impact them. Lake management needs to be focused on achieving the appropriate balance between algae and plants since too much of either can be problematic.

Individual management techniques will have different permitting requirements from various agencies. Any actions taken pursuant to the Lake Management Plan will need to meet the requirements of all permitting agencies. This Lake Management Plan does not address all the considerations that may lead to alternate management techniques outside of those listed in the following sections, or modifications thereof.

HAB management techniques may contribute to achieving multiple goals, and/or may counteract the achievement of other goals. Also, management methods are not necessarily exclusive to each other; multiple methods may be considered together to achieve lake management goals. Other lake management techniques beyond this document may be desirable for achieving other lake management objectives (e.g., *E. coli* reduction, improved public boating access, etc.) that are identified later in *Additional Lake Issues*. Comprehensive consideration is therefore important in evaluating management techniques for the current project scope and for future adaptive management strategies.

Table 4. HAB Management Method Feasibility Screening.					
Method	**HAB Control Effectiveness**	**Method Cost**	**Environmental Impact**	**Implementation Feasibility**	**Selected for Evaluation**
Watershed Methods					
Wastewater management	Moderate	High	Low	Moderate	Yes
Stormwater management	Moderate	Moderate	Low	Moderate	Yes
Stream and wetland restoration	Low	Moderate	Low	Moderate	No – not effective
Steam phosphorus inactivation	Moderate	Moderate	Moderate	Low	No – not feasible
Lake Physical Methods					
Lake River dam	High	Moderate	Moderate	Moderate	Yes
Flushing Channel enlargement	Moderate	Moderate	Low	Moderate	Yes
Floating wetland wave breaks	Low-Moderate	Low	Moderate	Low	Yes
Sonic wave control by LG Sonic	Low	Moderate	Low-Moderate	Low	No – not effective
Lake dilution	Moderate	High	Low	Low	No – high cost/benefit
Lake circulation	Low	Moderate	Low	Low	No – not effective
Nanobubble oxygenation	Low	Moderate	Low	Low	No – not effective
Shoreline modification	Low	Moderate	Moderate	Low	No – not effective
Dredging	Low-Moderate	High	Moderate	Low	No – high cost/benefit
Shading	Moderate	Moderate	High	Low	No – not feasible
Lake Chemical Methods					
Buffered alum treatment	High	Moderate	Low-Moderate	Moderate	Yes
Lanthanum bentonite treatment	High	Moderate	Low	Moderate	Yes
Iron treatment	Moderate	Low-Moderate	Low	Moderate	No – less effective
Algaecide treatment	Moderate	Low-Moderate	Low	Moderate	Yes
Lake Biological Methods					
Carp removal	Low	Moderate-High	Low-Moderate	Low	No – high cost/benefit
Zooplankton planting	Low	Moderate	Low	Low	No – not feasible
Piscivore stocking	Low	Low	Moderate	Low-none	No – not feasible
Shoreline plantings	Low	Moderate	Low	Low	No – high cost/benefit

Blue highlighted methods were selected for water quality modeling and further evaluation because they were considered to be moderately feasible for Vancouver Lake. Environmental impact is the relative adverse effect of the method on beneficial uses and non-target native species Implementation feasibility considers anticipated public acceptance in addition to all other screening elements.

Watershed Management Methods

Herrera and Pacific Groundwater Group recently conducted a watershed health assessment for the City of Vancouver, using available data, to evaluate the ecological condition of Vancouver's watersheds, to identify data gaps, and to help the City prioritize watershed management programs and activities (Herrera and PGG 2019). The watershed health assessment provides a good baseline of landscape conditions and City activities. Based on the assessment, recommendations for the City included:

- Continue to incentivize and otherwise encourage properties on septic systems to connect to sanitary sewers when appropriate.
- Partner with Clark Conservation District and other relevant entities to encourage and provide landowners financial assistance with septic inspections and maintenance.
- Expand the Greenway/Sensitive Lands and urban forestry programs that increase canopy cover.
- Continue to retrofit underground injection control devices and surface water structures that lack stormwater treatment.

This assessment of the Burnt Bridge Creek watershed likely applies to other developed areas in unincorporated Clark County that drain to Vancouver Lake and Salmon Creek. Control of nutrient inputs to Vancouver Lake by wastewater management of septic system sources and stormwater management were evaluated by the water quality model and are described herein.

Wastewater Management

Background

The Vancouver Lake watershed is located within the Salmon Basin that drains to the Columbia River from Camas to the Port of Ridgefield. Watersheds draining directly to the lake include the Burnt Bridge Creek watershed to the east, Lakeshore watershed to the north, and Vancouver Lake/Lake River watershed to the south and west. Watersheds draining indirectly to Vancouver Lake via backflow during flood tides in Lake River primarily include the Salmon Creek watershed but also include Whipple Creek and Flume Creek watersheds, which are smaller and located further downstream (north) on Lake River. The Columbia Slope watershed is also located in the Salmon Basin but drains directly to the Columbia River and not to Vancouver Lake.

In terms of land use characteristics, the Vancouver Lake watershed is highly developed beyond the immediate lake vicinity, composed largely of residential with some commercial/industrial land uses in the Burnt Bridge Creek watershed and the southern portion of the Salmon Creek watershed. Low-density residential, agricultural, and forested land are common in the northern portion of the Salmon Creek watershed and most of the Whipple Creek and Flume Creek watersheds. The Vancouver Lake/Lake River watershed is the floodplain area adjacent to the lake and Lake River, composed of wetland, pasture, open water, and forested areas. Finally, the Lakeshore watershed is the upland residential area just east of the lake and upper Lake River.

Much of the human wastewater in the city of Vancouver is connected to the municipal sewage systems but many onsite sewage systems (OSS or septic systems) also exist, particularly in the Salmon Creek and Whipple Creek watersheds, as shown in the watershed sewer and septic map (Figure 4).

The City of Vancouver watershed health assessment evaluated water quality conditions of the Burnt Bridge Creek watershed (Herrera and PGG 2019). Water quality in Burnt Bridge Creek is generally moderate and its impairments are typical of an urban creek. Analysis of recent (2011–2017) monitoring data for Burnt Bridge Creek indicate that water quality significantly improved for total suspended solids, fecal coliform, nitrate+nitrite, total nitrogen, and dissolved oxygen at some monitoring stations. However, at one or two of the eleven monitoring stations, significant water quality decline was observed for dissolved oxygen, turbidity, total suspended solids, soluble reactive phosphorus, nitrate+nitrite, and total nitrogen.

The watershed health assessment also included a spatial (GIS-based) statistical analysis to determine whether landscape conditions (such as, land use, terrain, and septic system density) and watershed management (e.g., stormwater facilities and habitat restoration) showed statistically significant correlations with water quality in the Burnt Bridge Creek watershed. Results indicate that septic systems may be increasing nitrogen and fecal bacteria concentrations and that urban development is likely increasing phosphorus concentrations in Burnt Bridge Creek. Among other actions, the watershed health assessment recommended to continue to incentivize and otherwise encourage properties on septic systems to connect to sanitary sewers when appropriate. This assessment of the Burnt Bridge Creek watershed likely applies to other developed areas in unincorporated Clark County that drain to Vancouver Lake and Salmon Creek. Therefore, control of wastewater sources of nutrients to Vancouver Lake were evaluated by the water quality model developed for the LMP.

Fecal coliform bacteria and nutrient concentrations are particularly high in Burnt Bridge Creek (Herrera and PGG 2019). A comprehensive microbial source tracking study (MST) was conducted in this stream in two phases from 1996 to 1999 and identified sources of *E. coli* bacteria using DNA analysis (ribotyping) of multiple isolates from 304 samples of stream water, stormwater, groundwater, septage, sewage, and 10 species of local animals (Samadpour et al. 1999). Human sources accounted for 20 percent of the isolates in water samples collected near the stream mouth (station BBC1). Animal sources at this site accounted for 48 percent of the isolates including 21 percent birds, 11 percent urban wildlife, and 8 percent livestock. A total of 32 percent of the water isolates at station BBC1 did not match a known source and likely originated from human or animal sources. The relatively high proportion of human sources in the stream samples suggest that a large portion of the fecal bacteria (and presumably nutrients) originate from human waste. A total of 63 of the 67 human clones seen in the water samples (94 percent) matched clones from septic tank samples. This high match of water isolates with septic tank isolates suggests that sewer lines were not contributing to *E. coli* contamination of Burnt Bridge Creek.

An extensive MST study of the Green-Duwamish Watershed in King County, which applied the same MST method to 564 water samples from five streams and four sites on the Green River, showed that human bacteria sources comprised 3.5 percent of all sources overall. Human sources were detected at all sample sites except the one stream (Springbrook Creek) that was totally sewered and without septic systems, suggesting that human sources observed at other sites primarily originated from septic systems (Herrera 2006a). Similarly, human sources accounted for less than 5 percent of all bacteria sources observed in those MST studies using the same methodology for streams draining sewered areas in the city of Blaine (Herrera 1999), the city of Renton (Herrera 2006b), the city of Seattle (Herrera 2007), and other urban streams without septic systems in King County (Herrera 2001, 2006b). One exception is that human sources comprised 6 percent in Piper's Creek in Seattle (Herrera 2011) due to an unusually high percentage of human sources during storm flow (11 percent) than during base flow (2 percent) that was attributed to sanitary sewer overflows.

A recent sanitary survey using advanced MST methodology in the small North Shore basin draining to Lake Whatcom in Bellingham identified human sources and phosphorus contamination from several of the 100 septic systems located within the basin (Herrera 2018a, 2020). This study concluded that septic systems contributed approximately 10 percent of the total phosphorus loading to the lake from the basin. Estimated costs for phosphorus removal by various BMPs were evaluated for the Lake Whatcom watershed and shown to be much lower for extending the sewer to connect all septic systems in the North Shore basin ($83,000 per pound of phosphorus removed) than stormwater treatment (ranging from $173,000/pound removed for large infiltration basins to over $6 million/pound removed for biofiltration swales and rain gardens) (Carlson 2011).

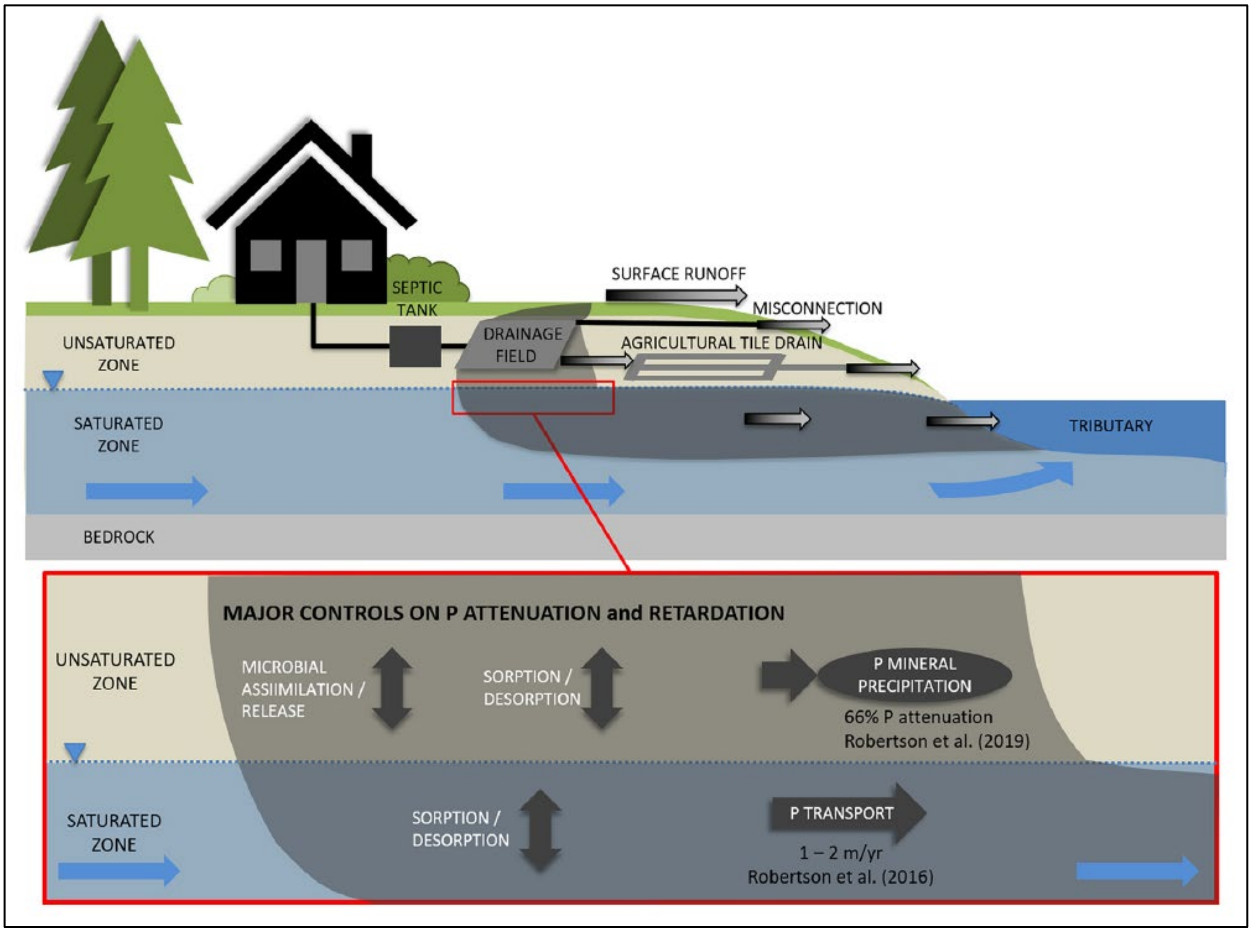
Recent modeling of P loading to Lake Erie from Canada estimated that septic systems contribute 2 to 5 percent of the total phosphorus loading from the watershed and loading rates will increase over time as slow moving (1 to 2 meters per year) septic-derived groundwater phosphorus plumes reach tributaries and if aging systems are not maintained (Oldfield et al. 2020). MST studies using the artificial sweetener acesulfame estimated 18 percent of septic effluent discharged to lake tributaries during base flow and at higher rates during storm flow. These rates were particularly high in calcareous soils with a high pH where the average retention of phosphorus from well-functioning septic systems was 66 percent compared to 90 percent in non-calcareous soils with a low pH. Shallow groundwater plumes containing soluble reactive phosphorus from functioning septic systems were observed up to 200 meters from the drain field. Septic effluent contamination of streams was higher from failing system due to poor septic system design and maintenance, overloading of the septic tank, or misconnections of septic tanks directly to tributaries or agricultural tile drains. Septic phosphorus transport and pathways are diagrammed in Figure 13.

Septic system controls may include but not be limited to:

- Sanitary surveys to identify nutrient loading of septic systems to surface waters and identify high priority areas for septic system upgrades or sewer expansion.
- Upgrading septic systems that are known from sanitary surveys to contribute to nutrient loading to surface waters.
- Upgrading septic systems that are suspected to contribute to nutrient loading to surface waters based old age, poor soils, close proximity to groundwater, close proximity to surface water, or other factors not meeting current septic system design code.
- Partner with Clark Conservation District and other relevant entities to encourage landowners and provide financial assistance to inspect septic systems and perform maintenance or repairs. See <https://poopsmartclark.org/> for more information.

- Revise current septic system design code to increase protection of surface water and groundwater by increasing restrictions on acceptable soil types and proximity to surface and groundwater and increasing inspection and maintenance requirements.
- Expanding the sanitary sewer system to connect to high priority septic system areas.
- Increasing individual property connections to the expanded sewer system through financial incentives or regulatory mandates.

Figure 13. Septic System Phosphorus Transport Pathways.
Source: Oldfield et al. 2020



Existing Conditions

The Clark Regional Wastewater District (District) operates a public wastewater system that extends more than 50 square miles and serves approximately 100,000 residents (BHC 2017). The District has a Septic Elimination Program that focuses on defined clusters of septic systems in approximately 50 to 60 neighborhoods. The District's current budget for this work is $500,000 to $1,000,000 per year (John Peterson, Clark Regional Wastewater District, personal communication). The Salmon Creek service area has 15 completed projects and 45 pending projects. The Ridgefield service area has three pending projects. The District has extended sanitary sewer service to 354 individual lots/homes and had 66 voluntary connections as of 2021 (John Peterson, Clark Regional Wastewater District, personal communication). When new sanitary sewer service is available, typically 20 to 30 percent of the homeowners in the area will voluntarily decide to connect. The wastewater district offers incentives to homeowners who decide to connect within the first year (i.e., 30 percent construction cost deferral and low-cost financing of mainline construction costs, onsite construction costs, and connection fees).

The City of Vancouver Public Works Department provides wastewater collection and treatment services to an area of approximately 56 square miles and includes customers inside and outside the city limits (Kennedy/Jenks 2011). Current projects under construction will extend sanitary sewer service to 226 individual lots/homes (Vancouver 2023b). The City's Sewer Connection Incentive Program (SCIP) provides low-interest financing for a portion of the sewer line construction costs, System Development Charge, plumber costs, and associated fees (e.g., application fee, plumbing permit fee, recording fee). The current estimated costs for a single-family property to connect to the City's sanitary sewer system are approximately $25,000 (Vancouver 2023b).

Sanitary sewer systems have a lower potential for contaminating Vancouver Lake with nutrients compared to septic systems. Sanitary sewer systems do occasionally have backups and overflows but they are typically rare, isolated events. Leaks from sanitary sewer pipes also occur but would more likely result in nutrients entering soils or groundwater.

Conceptual Design for Initial Lake Modeling

For the initial water quality modeling of Vancouver Lake, an aggressive wastewater management approach was developed to significantly reduce phosphorus (P) loading to Vancouver Lake. The conceptual design of the future wastewater management program was based on conducting a comprehensive study of cost-effective and acceptable methods to determine how best to reduce nutrient inputs to Vancouver Lake from septic systems:

- Increase the frequency of septic system surveys and improve survey methodology (e.g., microbial source tracking) to increase identification of high priority septic systems determined to be failing or with a high potential for leaching nutrients into receiving waters.
- Identify septic systems as high priority and likely to contribute to nutrient loading to surface waters based on old age, poor soils, close proximity to groundwater, close proximity to surface water, or other factors not meeting current or revised septic system design code.
- Revise current septic system design code to increase protection of surface water and groundwater by increasing restrictions on acceptable soil types and proximity to surface water and groundwater and increasing inspection and maintenance requirements.
- Increase the current rate of sanitary sewer system expansion to more areas with high priority septic system areas.
- Increasing individual property connections to the expanded sewer system through enhanced financial incentives or regulatory mandates.

- Partner with Clark Conservation District and other relevant entities to encourage and provide financial assistance to landowners for septic inspections and maintenance. See https://poopsmartclark.org/ for more information.

The conceptual design and initial modeling for the Vancouver Lake wastewater management alternative includes the following assumptions:

- Septic systems currently contribute 20 percent of the total phosphorus load in each watershed during base and storm flows. This amount is twice the 10 percent load estimated for a low density of septic systems in the North Shore basin of Lake Whatcom, and 4 to 10 times the 2 to 5 percent load estimated for the Lake Erie watershed in Canada. The higher septic proportion of the total phosphorus load for the Vancouver Lake watershed is justified by the high density of septic systems, an abundance of old systems in noncalcareous soils with low pH, high proportion of human sources observed at the mouth of Burnt Bridge Creek (20 percent positively identified plus potentially some of the 32 percent unknowns)) compared to sewered stream basins (less than 5 percent), and significant correlation of total phosphorus concentrations to septic system density in the Burnt Bridge Creek watershed.
- Septic systems will be connected to sanitary sewers or replaced with non-polluting systems at an average annual rate of 2.5 percent over 20 years, totaling a 50 percent connection/replacement of the existing systems that are responsible for 90 percent of the septic nutrient loads.
- Total phosphorus and nitrogen concentrations in groundwater, base flow, and stormwater runoff draining from each watershed will decrease 0.9 percent in each of 20 years to achieve an 18 percent reduction in total phosphorus and nitrogen concentrations and loadings in Vancouver Lake watershed.

Planning-Level Cost Estimate

Planning level costs were developed for connecting 100 homes to City/County sanitary sewer each year and for connecting 200 homes to City/County sanitary sewer each year (see Table 5). Costs were estimated based on existing County program costs for extending sanitary sewer mainlines (John Peterson, Clark Regional Wastewater District, personal communication) and City costs for connections to individual homes (Vancouver 2023b).

Stormwater Management

Background

Although most stormwater runoff in western Washington is received by waterbodies during the wet season (October–April), nutrients derived from stormwater can remain in a system available for uptake by algae and therefore facilitate summertime algae blooms, particularly in urban watersheds.

Table 5. Planning Level Costs for Wastewater Management Actions.		
Action	**Assumptions**	**Planning Level Cost**
Connect 100 homes to City/County sanitary sewer each year	• $500,000 for County to extend sanitary sewer mainlines • $500,000 for City to extend sanitary sewer mainlines • $25,000 per home for sewer line construction costs, System Development Charge, plumber costs, and associated fees • 30 percent contingency	$4,550,000 (annual cost)
Connect 200 homes to City/County sanitary sewer each year	• $1,000,000 for County to extend sanitary sewer mainlines • $1,000,000 for City to extend sanitary sewer mainlines • $25,000 per home for sewer line construction costs, System Development Charge, plumber costs, and associated fees • 30 percent contingency	$9,100,000 (annual cost)

The Vancouver Lake watershed is located within the Salmon Basin that drains to the Columbia River from Camas to the Port of Ridgefield. Figure 3 presents stormwater facilities in the various watersheds located in the Salmon Basin. Watersheds draining directly to the lake include the Burnt Bridge Creek watershed to the east, Lakeshore watershed to the north, and Vancouver Lake/Lake River watershed to the south and west. Watersheds draining indirectly to Vancouver Lake via backflow during flood tides in Lake River primarily include the Salmon Creek watershed but also include Whipple Creek and Flume Creek watersheds, which are smaller and located further downstream (north) on Lake River. The Columbia Slope watershed is also located in the Salmon Basin but drains directly to the Columbia River and not to Vancouver Lake.

In terms of land use characteristics, the Vancouver Lake watershed is highly developed beyond the immediate lake vicinity, composed largely of residential with some commercial/industrial land uses, as shown by the high density of sewer and septic facilities in Figure 4, particularly in the Burnt Bridge Creek watershed and the southern portion of the Salmon Creek watershed. Low-density residential, agricultural, and forested land are common in the northern portion of the Salmon Creek watershed and most of the Whipple Creek and Flume Creek watersheds. The Vancouver Lake/Lake River watershed is the floodplain area adjacent to the lake and Lake River, composed of wetland, pasture, open water, and forested areas. Finally, the Lakeshore watershed is the upland residential area just east of the lake and upper Lake River. Stormwater facilities in these basins are concentrated largely in the suburban areas of Salmon Creek and Burnt Bridge Creek, and within the city of Vancouver and part of the city of Ridgefield (Figure 3).

Herrera and Pacific Groundwater Group recently conducted a watershed health assessment for the City of Vancouver, using available data, to evaluate the ecological condition of the Burnt Bridge Creek watershed (Herrera and PGG 2019). Water quality in Burnt Bridge Creek is generally moderate and its impairments are typical of an urban creek. Analysis of recent (2011–2017) monitoring data for Burnt Bridge Creek indicate that water quality significantly improved for total suspended solids, fecal coliform, nitrate+nitrite, total nitrogen, and dissolved oxygen at some monitoring stations. However, at one or two monitoring stations, significant water quality decline was observed for dissolved oxygen, turbidity, total suspended solids, soluble reactive phosphorus, nitrate+nitrite, and total nitrogen.

The Vancouver watershed health assessment, which statistically and spatially analyzed whether landscape conditions and watershed management significantly correlated with water quality, indicated that urban development is likely increasing phosphorus concentrations in Burnt Bridge Creek. Among other actions, the watershed health assessment recommended continuing to retrofit underground injection control wells that lack stormwater treatment (Herrera and PGG 2019).

This assessment of the Burnt Bridge Creek watershed likely applies to other developed areas in unincorporated Clark County that drain to Vancouver Lake and Salmon Creek. Therefore, control of stormwater sources of nutrients to Vancouver Lake were evaluated by the water quality model developed for the LMP. Stormwater controls were explored by quantifying the current and planned future extent of stormwater treatment in the lake watershed and evaluating the potential effects of requiring phosphorus treatment for all new development and promoting various amounts of phosphorus treatment retrofits of existing stormwater drainage system in the lake watershed. National Pollutant Discharge Elimination System (NPDES) Municipal Stormwater permit requirements and codes currently differ for Clark County (Phase I permittee) and the City of Vancouver (Phase II permittee), but both jurisdictions can require phosphorus treatment for new development if a LMP established the need. The 303(d) listing by Ecology of Vancouver Lake as water quality impaired by total phosphorus further supports the need for phosphorus treatment of stormwater draining to Vancouver Lake.

Clark County's Phase I NPDES permit currently requires implementation of a Structural Stormwater Control (SSC) Program, which may include the construction of new treatment facilities or low-impact development best management practices (LID BMPs) for existing development that currently does not have treatment. The City of Vancouver's Phase II NPDES permit is expected to have similar SSC Program requirements for the next permit cycle, which starts in August 2024, but may not be required to be fully implemented until 2026 or 2027. However, neither permit or jurisdiction currently requires phosphorus treatment. County and City councils would need to approve a policy change and stormwater codes would need to be revised to require phosphorus treatment in the Vancouver Lake watershed. These revisions should be easily approved upon approval of this LMP by Ecology and both jurisdictions, considering the lake is listed as impaired for phosphorus while Burnt Bridge Creek and Salmon Creek are both listed as impaired for dissolved oxygen (which is mitigated by reducing phosphorus loading to the streams). Phosphorus treatment will likely be required when the Burnt Bridge Creek dissolved oxygen TMDL is implemented, but that is not anticipated for several years. Currently, Lacamas Creek is the only watershed in Clark County with a phosphorus treatment requirement.

Existing Conditions

The City of Vancouver currently implements a stormwater management program designed to meet the NPDES Phase II Municipal Stormwater Permit requirements. The City's stormwater management program addresses stormwater planning; public education and outreach; public involvement and participation; mapping and documentation; illicit discharge detection and elimination (IDDE); controlling runoff from new development, redevelopment, and construction sites; source control for existing development; operations and maintenance (O&M); compliance with TMDLs; and monitoring and assessment. In addition to the NPDES Phase II permit, the City also implements a stormwater capital improvement program with approximately $9 million in CIP projects implemented annually (Vancouver 2022b). The

City's stormwater retrofit program has leveraged grant funding to address roadway flooding and water quality issues but will be shifting to target more water quality improvement projects in the future (City of Vancouver Engineering Staff, personal communication).

Clark County currently implements a stormwater management program designed to meet the NPDES Phase I Municipal Stormwater Permit requirements. The County's stormwater management program addresses mapping and documentation; coordination; public involvement and participation; controlling runoff from new development, redevelopment, and construction sites; stormwater planning; structural stormwater controls; source control for existing development; illicit connection and illicit discharge detection and elimination; O&M; education and outreach; compliance with TMDLs; and monitoring and assessment. In addition to the NPDES Phase I permit, the County also implements a stormwater capital improvement program with $1.5 to $2 million in CIP projects implemented annually (Jeff Schnabel, Clark County, personal communication). The County uses PhosphoSorb® media, when possible, in their Contech StormFilters® since it has a higher flow rate than the ZPG media (Rod Swanson, Clark County, personal communication) and is General Use Level Designation (GULD) certified by Ecology for total suspended solids and phosphorus treatment. The capital improvement program currently focuses on the lower Salmon Creek tributaries including Cougar Creek, Suds Creek, and Tenny Creek where development occurred prior to existing stormwater regulations. The program also focuses on retrofits along linear stretches of roadway including high traffic corridors such as Highway 99.

Conceptual Design for Initial Lake Modeling

For the initial water quality modeling of Vancouver Lake, an aggressive stormwater management approach was developed to significantly reduce phosphorus (P) loading to Vancouver Lake. The conceptual design implemented in the Lake Whatcom watershed is targeting a 64 percent reduction in stormwater phosphorus loading to the lake by managing 87 percent of the currently developed area to meet the total maximum daily load (TMDL) developed by Ecology (2016).

The Lake Whatcom Management Program 2020–2024 Work Plan (Lake Whatcom ICT 2020) describes the key elements of the management program with input from the City of Bellingham, Whatcom County, and the Lake Whatcom Water and Sewer District, which comprise the Interjurisdictional Coordinating Team (ICT). The future stormwater management program was based primarily on an aggressive program with stormwater program goals focused in the following four areas:

- Capital Improvements
- Residential Stormwater Solutions
- Public Stormwater Facilities and Infrastructure
- Integrate Water Quality Improvements Across Program Areas

Targeted goals for each of the four stormwater program goals are summarized in Table 6.

The 5-year cost for implementing the stormwater program goals is $16.9 million and is broken down into staff costs ($2.68 million), capital costs ($9.4 million), and other costs (supplies, materials, equipment, consultant fees, interfund charges, taxes, bank charges, and procedural costs; $4.86 million).

Table 6. Lake Whatcom Management Program Stormwater Program Goals.

Overall Goal	Targeted Goals	TMDL Required?
2.1. Capital Improvements: Construct and retrofit capital facilities to reduce water quality and quantity impacts associated with stormwater runoff.	2.1.1. Construct capital stormwater facilities in accordance with capital improvement plans adopted by the City of Bellingham and Whatcom County as part of ongoing watershed-scale planning efforts.	Yes
	2.1.2. Complete an evaluation of the effectiveness of built stormwater treatment and flow control facilities, and an assessment of overall performance in reducing phosphorus and bacteria.	Yes
	2.1.3. Develop retrofit plans for existing facilities and program projects for design and construction in accordance with resources, budget, and need.	Yes
	2.1.4. County will complete two subwatershed master plans to identify specific strategies for target areas.	No
	2.1.5. Update capital improvement project list annually.	Yes
	2.1.6. Pursue funding opportunities, including grants, for projects identified in capital or retrofit list(s).	No
2.2. Residential Stormwater Solutions: Address unmanaged runoff and phosphorus from private properties around Lake Whatcom.	2.2.1 Provide technical and/or financial assistance for residential-scale retrofits of private property that result in phosphorus- or flow-limiting projects through the Homeowner Incentive Program (HIP) or similar programs that encourage voluntary stewardship by landowners.	No
	2.2.2 Evaluate and develop neighborhood-scale retrofit projects in public rights-of-way and community space.	No
	2.2.3. Provide inspections and/or technical assistance to owners of private stormwater facilities and document performance toward water quality improvements for properly maintained systems.	No
	2.2.4. Conduct annual private stormwater facility maintenance workshops to instruct owners about system needs and maintenance requirements.	Yes
	2.2.5. Develop and disseminate Lake Whatcom watershed-specific education and outreach messaging that encourages residents to act to protect water quality.	No
2.3. Public Stormwater Facilities and Infrastructure: Operate, inspect, and maintain all public stormwater facilities and infrastructure.	2.3.1. Conduct regular inspection and maintenance of public stormwater facilities.	Yes
	2.3.2. Conduct infrastructure maintenance activities and research and evaluate water quality benefits for activities that may include, but are not limited to, enhanced street sweeping, catch basin cleaning, and permeable pavement sweeping.	No
2.4. Integrate Water Quality Improvements Across Program Areas: Provide assistance to other program areas to achieve water quality improvement goals.	2.4.1. Provide technical assistance and consulting to other program areas and estimate water quality benefits gained through combined efforts and partnerships.	No

Stormwater-related goals are also included in other program areas including:

- Land use: $1.8 million
- Monitoring and Data: $3.4 million (includes lake and tributary monitoring, stormwater monitoring, phosphorus loading and response models, and onsite sewage system impact assessment)
- Education and Engagement: $825,000

Table 7 summarizes the metrics used to track the implementation of the stormwater program goals for Lake Whatcom along with the 2020 and 2021 progress.

Table 7. Lake Whatcom Management Program Stormwater Program Reporting Metrics.

Reporting Metric	Cumulative Value	2020 Value	2021 Value
Area treated by capital facilities	Not available	Not available	22 acres
Pounds of phosphorus (P) reduced per year through phosphorus treatment and flow control capital projects	483 pounds P/year (original methodology) 146 pounds P/year (updated methodology)	13 pounds P/year (original methodology)	16 pounds P/year (original methodology) 4 pounds P/year (updated methodology)
Pounds of P reduced per year through Homeowner Incentive Program (HIP) improvements	26.45 pounds P/year (original methodology) 9.6 pounds P/year (updated methodology)	1.51 pounds P/year (original methodology)	0.78 pound P/year (original methodology) 0.12 pound P/year (updated methodology)
Pounds of P reduced per year through land use regulations	pounds P/year (COB only; original methodology) 1.5 pounds P/year (COB only; updated methodology)	0.02 pound P/year (COB only)	0.21 pound P/year (COB only; original methodology) 0.8 pound P/year (COB only; updated methodology)
Pounds of P reduced per year through operations and maintenance activities	Not applicable	10 pounds P/year (estimate, COB only)	40 to 46 pounds P/year (estimate, COB and WC combined)
Total pounds of phosphorus reduced per year	559 pounds P/year (original methodology) 200 pounds P/year (updated methodology)	Not available	Not available
Properties with completed residential stormwater projects	209 properties since 2011	Not available	14 new properties

Source: Lake Whatcom Management Program Progress Report (Lake Whatcom ICT 2021)

COB = City of Bellingham

WC = Whatcom County

One example of a regional stormwater treatment facility in the Lake Whatcom Watershed is the Park Place Stormwater Facility (Figure 14), which was redesigned to provide phosphorus treatment with a new non-proprietary media blend. The new technology was named the Phosphorus-Optimized Stormwater Treatment (POST) system and consists of either a one- or two-chamber rectangular vault designed as a three-stage vertical filtration media bed. Stage 1 is a prefilter consisting of mulch, Stage 2 is a primary treatment media bed, and Stage 3 is a polishing media bed. The POST system received GULD approval from Ecology in 2022 (Ecology 2022a). The redesign of the Park Place Stormwater Treatment provides phosphorus treatment for approximately 180 acres of residential land use draining to Lake Whatcom. The project is designed to remove approximately 92 pounds of phosphorus per year (Herrera 2019). The mean total phosphorus reduction during the Technology Assessment Protocol – Ecology (TAPE) monitoring in Bellingham was 61.5 percent (Ecology 2022a). The construction cost for this facility was $1.7 million (Chris Webb, Herrera, personal communication).

Figure 14. Construction of the Park Place Stormwater Phosphorus Treatment Facility, Bellingham, Washington.

The conceptual design and initial modeling assumptions for the Vancouver Lake stormwater management program include the following goals and actions:

- Develop a stormwater management program to reduce stormwater P and N loading by 30 percent over a period of 20 years in each of the three primary lake watersheds (i.e., Bridge Creek, Salmon Creek, and Lakeshore).
  - Reduce total phosphorus and nitrogen concentrations in stormwater runoff from each watershed by 1.5 percent in each of 20 years to achieve a 30 percent reduction from the current conditions.
- Require phosphorus treatment of stormwater for all new development and redevelopment in the three primary lake watersheds (at no direct cost to LMP implementation).

- Phosphorus treatment for new development and redevelopment would remove 50 percent of the phosphorus from those new development and redevelopment projects.

- Retrofit the existing stormwater conveyance system to add phosphorus treatment where no treatment facilities exist and convert existing UIC or surface basic treatment facilities to phosphorus treatment facilities (e.g., adding a phosphorus removal biofilter as pre-treatment to a UIC or replacing standard biofiltration media with phosphorus biofiltration media in a surface treatment facility).
    - Where possible, rely on regional treatment facilities with high-flow and high-P removal media filters, such as that constructed at the Park Place facility in Bellingham, recognizing that a regional approach to stormwater management may not fit with the City of Vancouver's current treatment strategy (D. Sutton, City of Vancouver, personal communication).

Planning-Level Cost Estimate

Planning level costs were developed for designing and constructing regional treatment facilities throughout the watershed (see Table 8). An annual cost of $2 million could be partially funded by stormwater grants from Ecology to increase stormwater management costs by 50 percent to $3 million/year for a 20-year cost of $60 million. Using a unit cost of $10,000/acre for the POST system described above as an example, $60 million would treat 6,000 acres or 7.5 percent of the 80,000-acre watershed. Assuming a 60 percent reduction in phosphorus loading as per the POST system, the targeted 30 percent reduction would be achieved in an equivalent of 15 percent of the watershed. Thus, additional phosphorus reduction would be needed by additional funding of local and regional treatment facilities for existing and new development to meet the conceptual design of this management alternative for a 30 percent reduction in watershed phosphorus loading. In addition, operating costs of stormwater treatment facilities were not included in the planning level cost and should be included in future cost benefit analysis.

Table 8. Planning Level Costs for Stormwater Management Actions.

Action	Assumptions	Planning Level Cost
Design and construct regional treatment facilities focused on phosphorus removal (e.g., POST) each year	• $1 million for County design and construction • $1 million for City design and construction • Grant funding will be obtained from Ecology to support these projects at $50 percent.	$2 million (annual cost)

Physical Management Methods

Lake River Dam

Background

Lake River is the primary nutrient source to Vancouver Lake because Lake River flows back into the lake during flood tides that brings water and nutrients from Salmon Creek and the Columbia River. The VLWP prepared a draft report titled Conceptual Alternative Packages that proposed construction of a water control structure near Lake River's entrance to the lake as the management technique most likely to be successful at reducing nutrient input from Lake River (VLWP 2012). This structure could be a permanent dam that could be automatically adjusted to reduce backflow into the lake from Lake River during flood tides, while allowing passage for boats and all life stages of fish species currently present in the lake. The structure could also be built to raise the lake level and reduce the wind suspension of lake sediments from increased water depths.

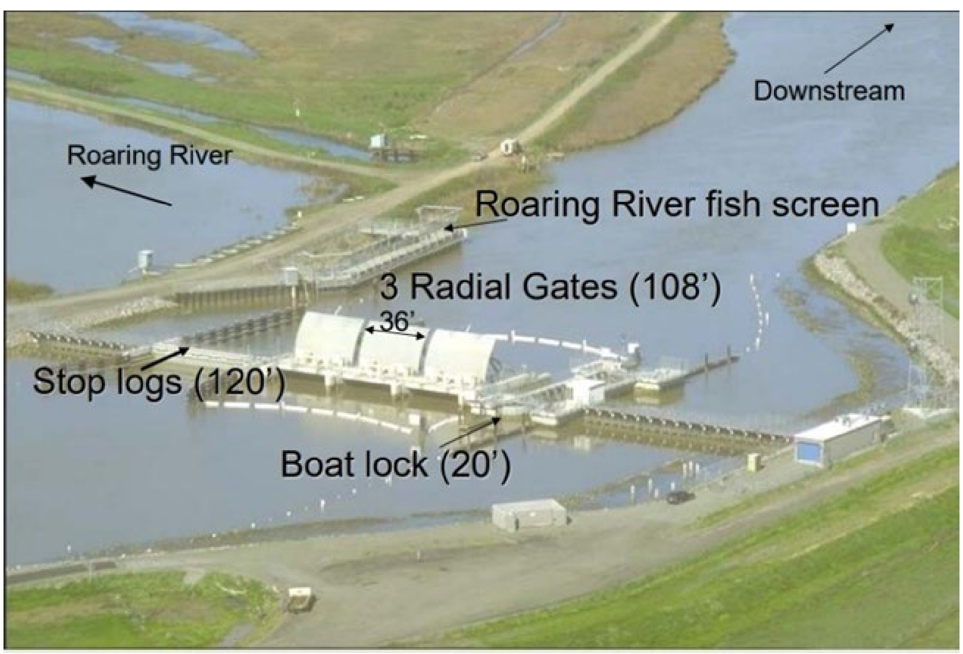
The structure could consist of an inflatable rubber dam where cylindrical rubber fabrics would be placed across the Lake River channel. The membrane is a multi-layer fabric made of synthetic fiber (usually nylon) and rubberized on one or both sides. The fabric is flexible and yet exhibits good wear-resistance characteristics. A layer of stainless-steel mesh or ceramic chips can be embedded in the surface layer to reduce or prevent vandal damage. Inflatable dams are installed in streambeds and riverbeds, generally being bolted into a concrete foundation. They are used to temporarily raise existing dams to divert water for irrigation or flood control, increasing water retention for aquifer recharge, reducing or preventing saltwater intrusion into freshwater areas, protecting low-lying coastal areas from tidal flooding, enabling fish passage past diversion works during critical migration periods by deflation, and for sewage retention/separation during flood events. Inflatable dams can be filled with water, air, or both. They typically span about 100 meters, with dam heights usually less than 5 meters. The membrane is usually deflated for large overflows, but it is common to have a small nappe over the inflated dam (Chanson 2021).

The Adam T. Bower Memorial Dam (see Figure 15) is the world's longest inflatable dam at 2,100 feet (640 meters) long. The dam is located just below the confluence of the western and main branches of the Susquehanna River in Upper Augusta Township, Pennsylvania. When it is raised in the summer, it creates the 3,000-acre (12-km^2) Lake Augusta, which is used for recreation in Shikellamy State Park. A dam across Lake River would need not be nearly as large, only requiring a length between about 200 to 700 feet, but this example is helpful in informing design and use of inflatable dams.

A more conventional and permanent dam structure could be designed to restrict lake outflow, reduce backwater inflow, and raise summer lake levels without impeding fish or boat access to the lake from Lake River. Reducing backwater inflow could be achieved by including a section of pneumatically actuated gates (Obermeyer gates) or radial gates within the dam than could be raised or lowered tidally. Boat passage could be maintained with the inclusion of a boat lock, and it is expected that a fish ladder or other fish passage feature could be designed as part of the dam to ensure fish passage during all tidal conditions. An example of this type of comprehensive water control structure is the Suisun Marsh Salinity Control Gates (see Figure 16). This structure was installed on the Montezuma Slough east of San Francisco Bay in the 1980s to reduce salinity throughout Suisun Marsh. The gates are operated tidally to be open during ebb tides when fresh water is flowing out of the delta and closed during flood tides to restrict the flow of higher salinity water into the marsh from Grizzly Bay.

Figure 15. Adam T. Bower Memorial Dam on the Susquehanna River, Upper Augusta Township, Pennsylvania.

Figure 16. Suisun March Salinity Control Gates, Sacramento-San Joaquin Delta, California.



Dam concepts and operational procedures were developed for the lake model to evaluate potential effects on cyanobacteria blooms. Modeling indicated that a dam could be an effective method to achieve HAB management goals. Further consultation with appropriate stakeholders would be needed to ensure the dam design does not negatively impact flows, water quality, or users in Lake River; addresses considerations of public safety related to navigation and swimming; and would meet permitting requirements (e.g., hydraulic project approval [HPA]).

Existing Conditions

Vancouver Lake is a large (approximately 2,300 acres), shallow (mean depth 3 to 5 feet) lake located adjacent to the city of Vancouver in Clark County, Washington. Bathymetry of the lake was measured in 2007 by the USACE (2009) and most recently on June 15, 2019 (see Figure 2) (T. McNabb, personal communication, December 28, 2022). The deepest area of the lake is in the dredged area by the Flushing Channel where a small depression (200-foot-diameter) in the lake bottom reaches the maximum depth of 13 feet, compared to a range of 3 to 6 feet deep in the main body of the lake and 6 to 10 feet north of Turtle Island to Lake River.

The temporal pattern in lake elevation follows that of the Columbia River (Figure 17). The lake elevation decreases during the summer months to its lowest point in the late summer and fall (August through October), increases during the winter months (November through March), remains at its highest point in the spring months (April through June), and can fluctuate several feet in the winter and spring. Monitoring data from various sources show the lake is well mixed both vertically in the water column and spatially, with lake mixing and lake sediment resuspension driven by wind.

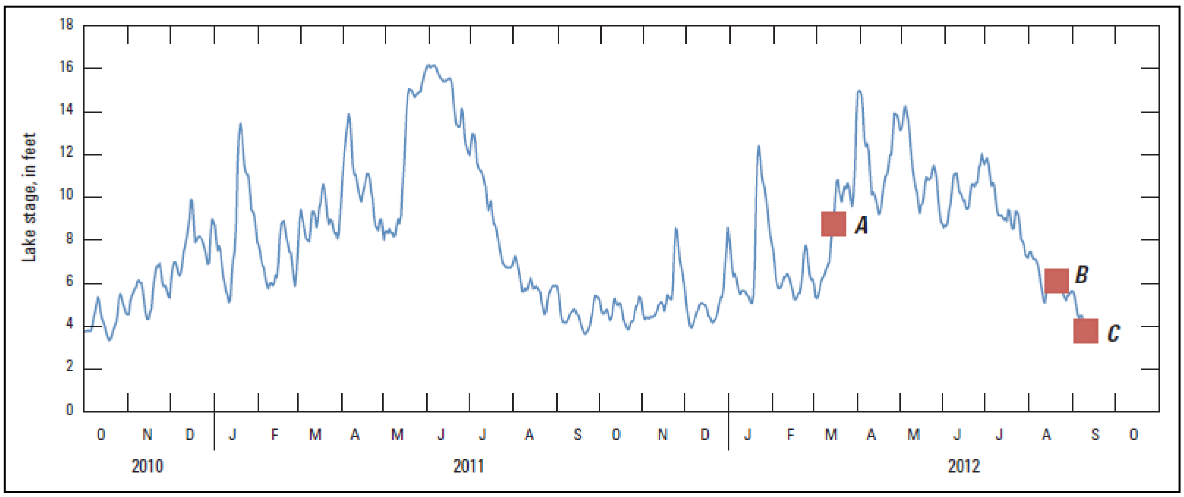
The hydraulics of Vancouver Lake are more complex than most other shallow lakes because it is connected to the Columbia River and therefore influenced by both tides and hydropower operations upstream. Initial hydraulic monitoring and the development of a water budget was done by WSU researchers in 1967 (Bhagat and Orsborn 1971), several years after the lake was disconnected from the Columbia River, to test the efficiency of various approaches for improving flow. The results of that study concluded that introducing Columbia River water to flush Vancouver Lake would significantly increase the quality of water in the lake. This study was followed by a project which included dredging Vancouver Lake and the construction of the Flushing Channel in 1983 by the Port of Vancouver. The USACE performed hydraulic modeling in 2008–2009 to evaluate effects of enlarging the Flushing Channel on flow patterns within Vancouver Lake because water quality in the lake did not improve as expected following construction of the channel (USACE 2009).

From 2010 to 2012, the USGS conducted a study of Vancouver Lake to quantify water flows and nutrient loads for the purpose of developing monthly budgets to identify major sources and sinks. The goal of this effort was ultimately to understand the dynamics influencing the lake's cyanobacteria blooms. The final report (Sheibley et al. 2014) outlines the results of these water and nutrient budgets, the main conclusion of which was that Lake River is the greatest source of water to Vancouver Lake (85 percent of inflow) (see Figure 6) while the Flushing Channel provides 10 percent and Burnt Bridge Creek just 3 percent of total water inflow. Lake inflow from the Flushing Channel was highest at 80 to 140 cubic feet per second (cfs) during the Chinook salmon rearing season from late April to late June (Figure 18).

Maximum lake inflow and outflow from Lake River was much higher at approximately 2,000 cfs during this same season and only about 1,000 cfs during the summer and fall seasons. They also verified that Lake River is the sole outflow for the lake and that water inputs via precipitation and groundwater, and export via evaporation, each contributed 1 percent or less to the total water budget (Figure 6). Water retention time in Vancouver Lake ranged from 8 to 27 days throughout the year (Sheibley et al. 2014).

Figure 17. Comparison of Vancouver Lake Stage to the Columbia River Stage at I-5 in Water Years 2011–2012.

Lake stage in upper graph in feet from the minimum lake bottom elevation (Sheibley et al. 2014) that were not converted to a standard elevation datum. Disregard the red squares labeled A, B, and C as they pertain to images in Sheibley et al. (2014) and the Work Plan but not presented in this LMP. River stage in lower graph is in feet Columbia River datum from (USGS 2022).



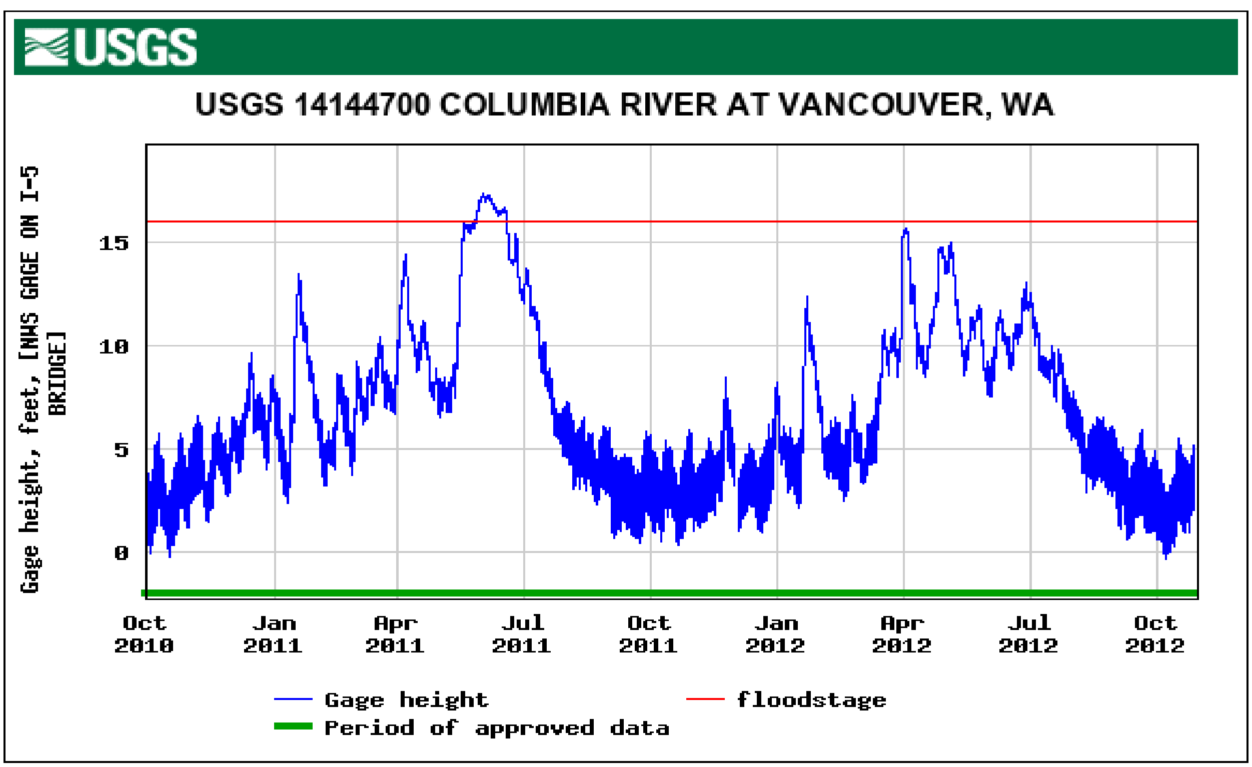
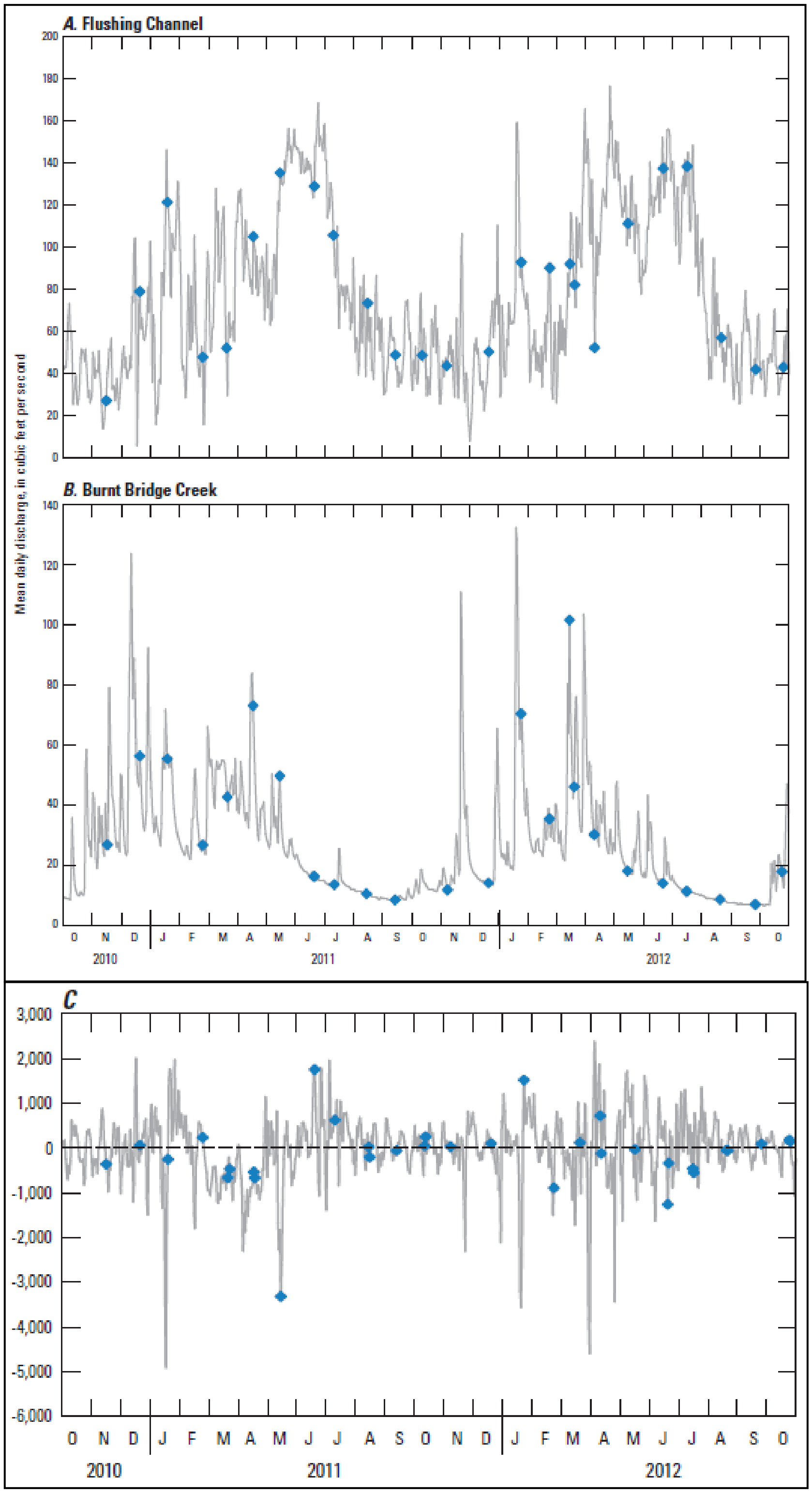


Figure 18. Comparison of Flows in Flushing Channel (A), Burnt Bridge Creek (B), and Lake River (C) in Water Years 2011–2012.



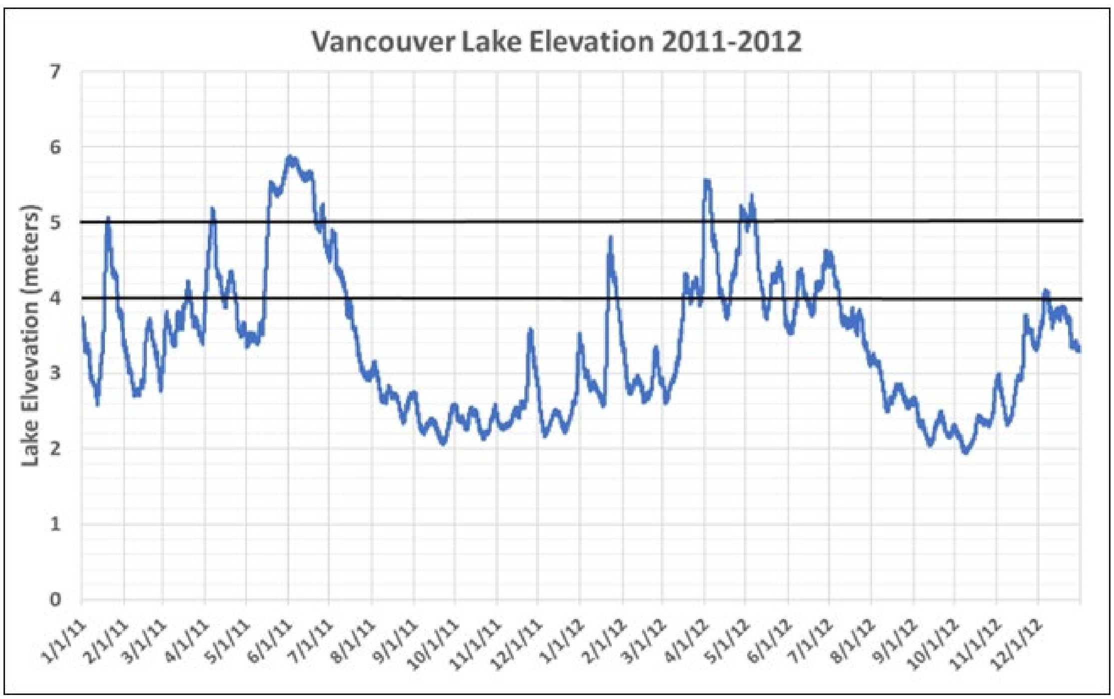
Conceptual Design for Lake Modeling

The conceptual design and initial modeling for the Lake River dam alternative includes installation of a water control structure with the following objectives:

1. Reduce backflow from Lake River to Vancouver Lake
2. Maintain fish passage
3. Maintain boat passage
4. Raise the mean water elevation of Vancouver Lake

The proposed water control structure to achieve the objectives above consists of an inflatable dam or pneumatically actuated gates (Obermeyer gates) installed in conjunction with a boat lock and fish ladder. The proposed inflatable dam or pneumatically actuated gates are assumed to have a crest elevation of either 4 or 5 meters NAVD88 (13 or 16 feet North American Datum of 1988) compared to a lake elevation range of 2 to 6 meters (6.5 to 20 feet) NAVD88. Figure 19 presents the lake elevation for 2011 and 2012 with horizontal lines added at 4 and 5 meters NAVD88.

Figure 19. Vancouver Lake Elevation in 2011–2012 Compared to Alternative Lake River Dam Crest Elevations of 4 and 5 Meters NAVD88.



These two dam crest elevations were selected to represent a high elevation of 5 meters NAVD88 corresponding to the 90th percentile and a moderate elevation of 4 meters corresponding to the 75th percentile of the lake elevations observed during the 2–year modeling period of 2011–2012. A dam crest elevation of 5 meters NAVD88 was exceeded by less than 1 meter during high water in the spring and would raise the lake level by up to 3 meters during low water in the summer/fall of each modeled year. The dam crest elevation of 4 meters NAVD88 was exceeded by up to 1.8 meters in the spring and would raise the lake level by up to 2 meters in the summer/fall of each modeled year. A lower dam crest elevation of 3 meters NAVD88 may be sufficient to significantly reduce Lake River input and algae growth during the summer/fall period, but the modeling focused on higher dams to evaluate potential maximum water quality benefits.

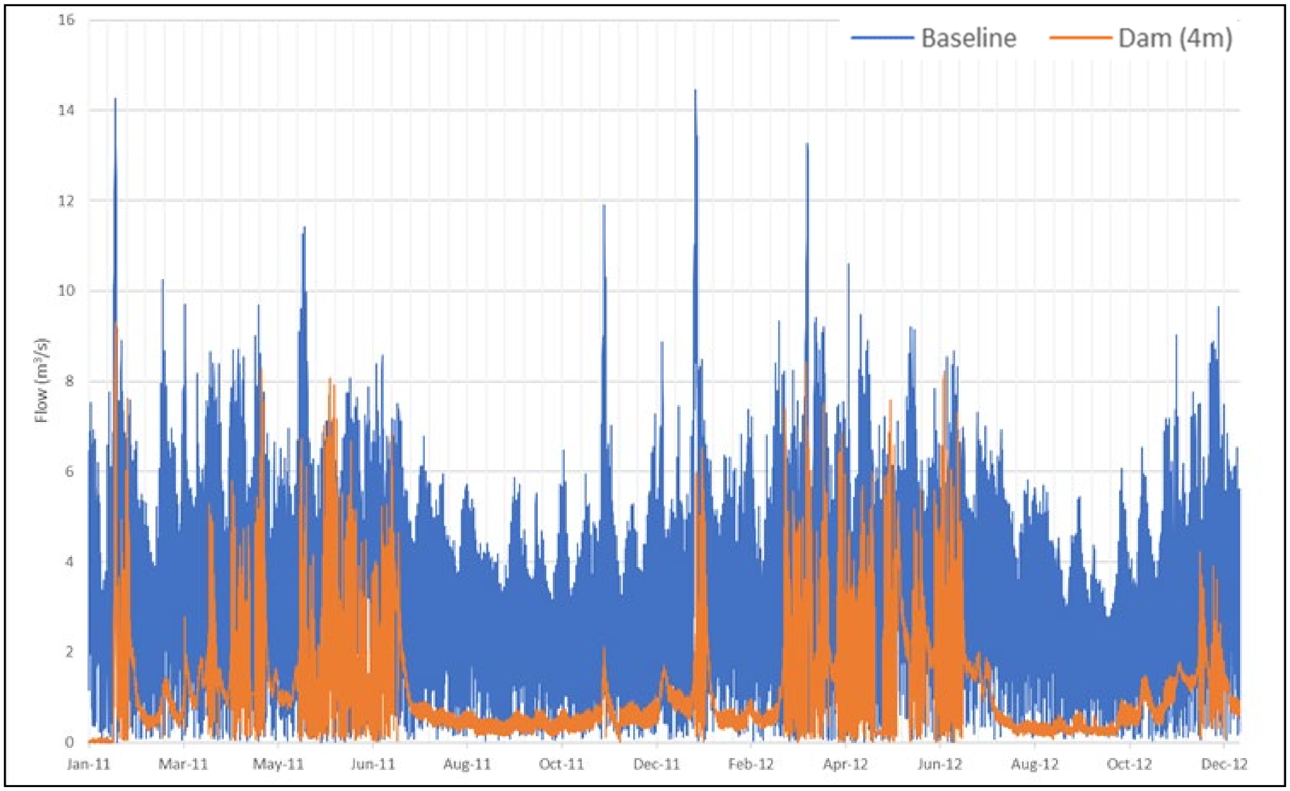
Figure 20 presents the modeled effects of the proposed structure on the backflow of Lake River into Vancouver Lake at 4- and 5-meter crest elevations, where the blue lines represent baseline Lake River flow, the orange line represents modeled Lake River flow with a 4-meter crest, and the red line represents modeled Lake River inflow with a 5-meter crest. This figure shows that under either dam scenario the lake inflow from Lake River during the summer months would be less than 5 cubic meters per second (m^3/sec) (175 cfs) and average about 3 m^3/sec (105 cfs), which is approximately 10 times greater than lake inflow from Burnt Bridge Creek (i.e., 8 to 12 cfs as shown in Figure 18).

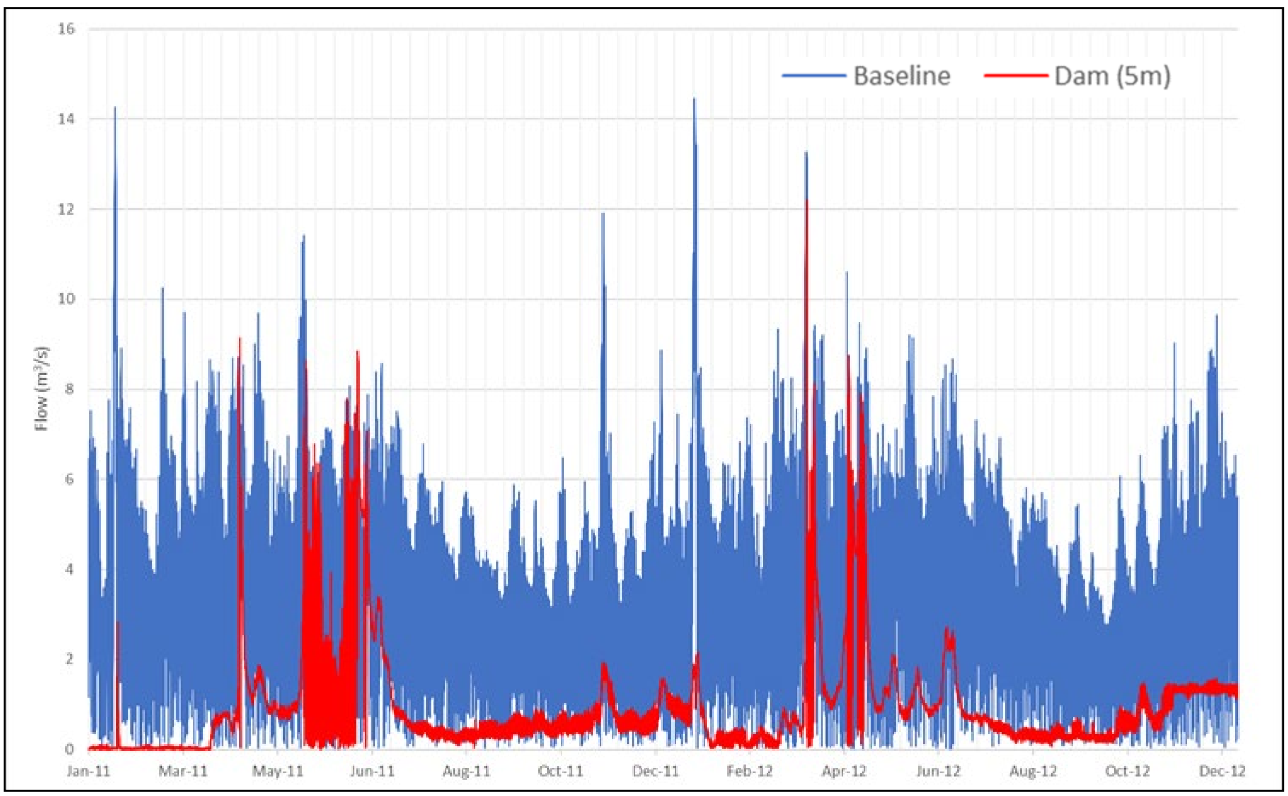
The inflatable dam or pneumatically actuated gates are anticipated to remain inflated and raised and not adjusted tidally. Flood control could be achieved by deflating the air bladders to lower the dam or gates, or by incorporating additional elements such as hydraulic radial gates in the water control structure to assist with flood control. The water control structure at the head of Lake River would reduce backflow of high nutrients into the lake all year long and reduce sediment suspension from higher summer lake levels.

The legality and requirements to allow fish passage through such a structure would need to be determined. Ideally, fish passage through the water control structure would be maintained with the installation of a fish ladder or development of a side channel for fish migration but some degree of impact from the introduction of a barrier is likely. Design for fish passage will need to consider all species within the Vancouver Lake system, including but not limited to salmonids, and is expected to be developed with guidance from applicable agencies. For the conceptual design and initial modeling, the following guidelines presented in the NOAA Fisheries West Coast Region Anadromous Salmonid Design Manual (NMFS 2022) are assumed:

- Design low flow for fishways is the average daily streamflow that is exceeded 95 percent of the time during periods when migrating fish are normally present at the site. This is determined by summarizing the previous 25 years of mean daily streamflow during the fish passage season.
- Design high flow for fishways is the average daily streamflow that is exceeded 5 percent of the time during periods when migrating fish are normally present at the site. This is determined by summarizing the previous 25 years of mean daily streamflow during the fish passage season.
- The general fishway design should have sufficient river freeboard to minimize overtopping by 50-year flood flows.
- Attraction flow from the fishway entrance should be between 5 percent and 10 percent of the fish passage high design flow.
- The fishway entrance hydraulic drop should be maintained between 1 foot and 1.5 feet and designed to operate from 0.5 foot to 2 feet of hydraulic drop.

Figure 20. Modelled Effects of the Lake River Dam on Lake River Flow into Vancouver Lake at 4 Meter (top) and 5 Meter (bottom) Crest Elevations in 2011–2012.





Boat passage through the water control structure would be maintained with the installation of a small boat lock. For the conceptual design and initial modeling, the lock chamber is assumed to be 20-feet wide and 80-feet long (see Figure 16). These fixed structures would feature an average constant outflow of 5 cfs for fish and boat passage.

Planning-Level Cost Estimate

A planning level cost estimate for the Lake River dam is presented in Table 9. This estimate totals $41.5 million that includes $30 million for construction and adds 25 percent for design, 10 percent for permitting, and 5 percent for operation and maintenance. Note that these estimated costs are based on preliminary design concepts and are subject to substantial variability as designs are better specified.

Table 9. Lake River Dam Cost Estimate.

Item Description	Quantity	Unit	Unit Cost	Total Cost	Notes
Mobilization	1	L.S.	10%	$1,921,433	
Erosion/Water Pollution Control	1	L.S.	2%	$376,752	
Site Clearing and Dewatering	1	L.S.	$54,700	$54,700	
Channel Excavation	24,000	C.Y.	$29	$696,000	a
Channel Compaction	34,520	S.F.	$24	$828,480	a
Water Control Structure (Obermeyer Gate)	300	L.F.	$3,900	$1,170,000	a
Concrete (Foundation, structure walls, stilling basin)	2,900	C.Y.	$1,100	$3,190,000	a
CMU Control House	1	L.S.	$77,300	$77,300	a
Piping, electrical controls, additional equipment	1	L.S.	$695,600	$695,600	a
Riprap	700	C.Y.	$65	$45,500	a
Fish Passage Structure	1	L.S.	$580,000	$580,000	a
Boat Lock	1	L.S.	$11,500,000	$11,500,000	b
Construction Subtotal				**$21,135,765**	
Contingency	30%			$6,340,729	
Subtotal (with +30 percent Contingency)				$27,476,494	
Tax	7.8%			$2,143,167	
Construction Total (with Contingency and Tax)				**$29,619,661**	
Design	1	L.S.	25%	$7,404,915	
Permitting	1	L.S.	10%	$2,961,966	
Operation and Maintenance	1	L.S.	5%	$1,480,983	
Total (with Design, Permitting and O&M)				**$41,467,525**	

[a] Based on 2017 San Juan Watershed Project (AECOM 2017) with 3 percent annual escalation applied to linear dam length estimated from Google Earth.

[b] Based on South Gulf Cove Parallel Locks Project (Charlotte 2023) with escalation and assuming a 20- by 125-foot concrete lock, 60- by 8-foot floating and fixed docks, and 2,800 cubic yards of dredge material.

C.Y. = cubic yards

L.S. = Lump Sum

Flushing Channel Enlargement

Background

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. 2005). It is generally recommended to exchange one lake volume at least once every 10 days (i.e., retention time less than 10 days) to overcome cyanobacteria regeneration and the added nutrients in the source water.

As part of a larger project which included dredging the lake, construction of 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 percent (Cooper Consultants 1985). Several methods of modifying the Flushing Channel have been posed with the aim of increasing flows between the Columbia River and Vancouver Lake (USACE 2009). However, the modest increase in flow has not remedied the eutrophic water conditions and nuisance cyanobacteria blooms (VLWP 2012).

Existing Conditions

As noted above, FOVL recently contracted with Jacobs Engineering Group to develop both a conceptual site model and a computer modeling tool that can be used to characterize the range of flows from the Columbia River to Vancouver Lake through the Flushing Channel under existing and possible modified conditions (Jacobs 2022). The objectives of this study included:

- To develop a system model that allows FOVL to evaluate alternative solutions to the existing water quality concerns in Vancouver Lake. The system model developed in this effort can be used beyond the scope of this study to support future efforts to improve water quality and aquatic habitat.
- To use available data and the newly developed hydraulic model to characterize the dynamic hydraulic conditions in Vancouver Lake.
- To identify and evaluate alternative flow control scenarios designed to increase inflows from the Columbia River, decrease residence time in the Lake, increase water depths, and reduce nutrient loading.

A hydraulic model was developed to characterize the existing system and evaluate the performance of alternative flow control structures. The model was developed using the public domain software HEC-RAS, developed by the USACE (2009). The model was used to characterize the existing system, creating baseline conditions for the alternatives evaluation. Results from the existing conditions model were validated against observations from 2007 and 2008, where velocities and water levels were measured through the culvert structure. Model calibration was not performed due to lack of available data to constrain the parameters (i.e., knowledge of the amount of debris present at the time of the flow study). The existing culverts and the following three alternatives were modeled:

- **Alternative 1 – Culvert Maintenance:** This alternative evaluates the changes to lake inflows and water levels due to removal of debris from both the upstream and downstream ends of the culvert.
- **Alternative 2a – Replace Culverts with an Open Channel (with flap gate):** In this alternative, the Flushing Channel culverts are replaced with a 100-foot-wide rectangular flow control structure. The section of the channel immediately upstream of the existing culverts was also widened from a 75-foot bottom to a 100-foot-wide bottom. The structure has flap gates to prevent negative flow out of the lake through the flushing channel. For water quality purposes, it is desirable to promote increased flow through Vancouver Lake. The water from the Columbia River entering the Flushing Channel is lower in nutrient concentration relative to the inflows from Lake River. Increased flow volume through the Flushing Channel will displace flow volumes from Lake River, creating a one-directional flow towards Lake River, and may overall reduce nutrient loading to Lake Vancouver. The specific type and design details of the flow control structure (e.g., to ensure fish passage and boater safety) would need to be identified in a feasibility or pre-design study.
- **Alternative 2b – Replace Culverts with an Open Channel (without flap gate):** This alternative represents the same flow control configuration without flap gates, allowing unregulated flows in and out of the Flushing Channel depending on tidal ebb and flood conditions.

The modeling analysis demonstrated that by significantly expanding the capacity of the Flushing Channel, the overall flow regime within the Flushing Channel, Vancouver Lake, and Lake River can be modified to introduce more Columbia River water, reduce Lake River inflows to the Lake, and, presumably, yield water quality benefits (Jacobs 2022). Regulating flow using weirs or flap gates produces a one-directional flow pattern that ensures that Columbia River water introduced through the Flushing Channel stays in the lake and eventually drains out through Lake River. Any such system would not be more restrictive than the current configuration and could be designed to support greater freedom of movement for fish and other wildlife between the Columbia River and the Lake system. Model results are summarized in Figure 21.

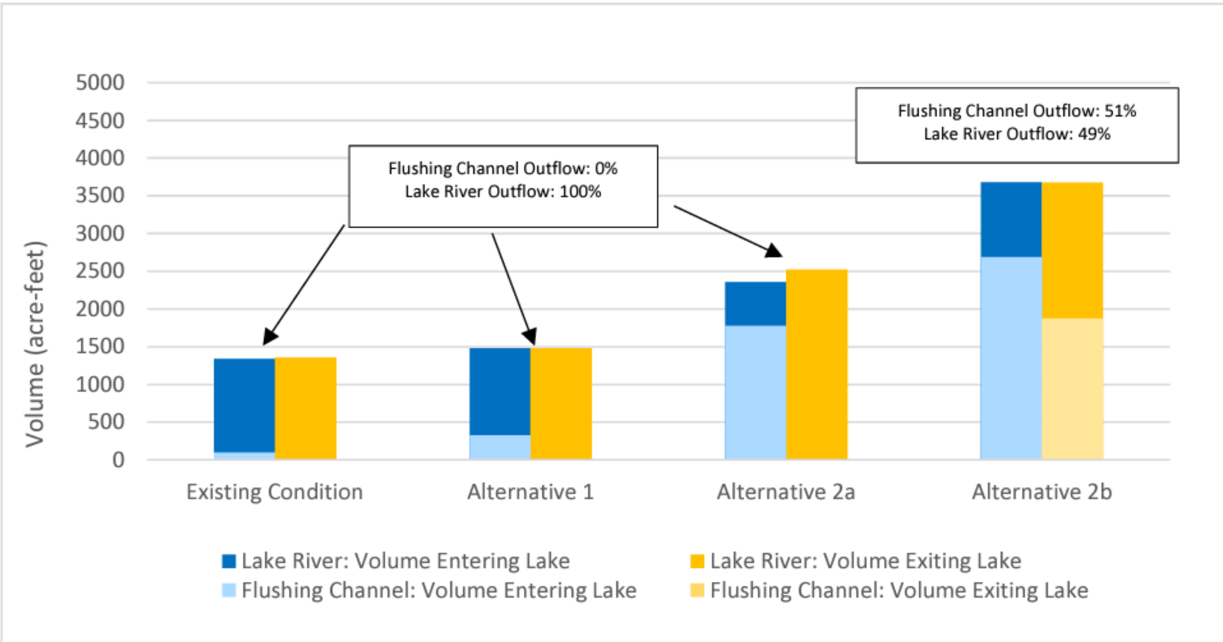
Other findings demonstrated that relatively low-cost maintenance actions, including frequent cleaning of trash rack debris on the existing control structure, would also result in more Columbia River water introduced to Vancouver Lake during critical summer low-flow periods. However, the rate and degree of debris accumulation is variable and uncertain so the benefit is not well-quantifiable, and even when effective, such increased flow is still insufficient to improve water quality and the benefits do not appear to extend to Lake River (Jacobs 2022).

Conceptual Design for Lake Modeling

The conceptual design for Flushing Channel is Alternative 2a and includes widening the channel bottom and replacing the existing culverts to achieve the following objectives:

1. Increase flow from Columbia River to Vancouver Lake
2. Prevent negative flow from Vancouver Lake to Columbia River
3. Maintain fish passage

Figure 21. Model-Predicted Vancouver Lake Inflow and Outflow Volumes Through the Flushing Channel and Lake River for Existing Conditions and All Alternatives.
Source: Jacobs 2022



The proposed Flushing Channel modifications to achieve the objectives above consists of widening the channel bottom from 75 to 100 feet and replacing the existing 6.4-foot-diameter culverts with 10-foot-tall box culverts (Figure 22). Model results indicate that summer inflow rates to the lake from the Flushing Channel would increase about 3-5 times current conditions from a daily maximum of about 175 cfs (5 cubic meters per second [m^3/sec]) to between 15 and 25 m^3/sec (530 and 880 cfs) (see Figure 22).

Fish-friendly water control features would also need to be installed to restrict backflow from Vancouver Lake to Columbia River. Temporary, partial closure and removal of Northwest Lower River Road over the Flushing Channel is likely to be required to remove and replace the existing culverts. This could be achieved by restricting traffic to one lane and planning construction in phases; full road closure would likely not be permissible by the Washington Department of Transportation. Following excavation and removal of the existing culverts, a series of 10-foot-tall box culverts could be installed across the width of the Flushing Channel (e.g., ten, 10-foot-wide box culverts). Excavated material could be backfilled over the box culverts and Northwest Lower River Road could be reconstructed to allow vehicle passage across the Flushing Channel. Additional considerations related to understanding and minimizing negative impacts from construction on endangered sandhill cranes inhabiting the adjacent Crane's Landing property should be discussed and coordinated with the Columbia Land Trust and WDFW.

Figure 22. Flushing Channel Enlargement Section Views and Modeled Lake Inflow Rate/Level Effects.
Section View Source: Jacobs 2022

Water control to prevent backflow from Vancouver Lake to Columbia River could be achieved by the installation of fish-friendly tide or flap gates (Souder and Giannico 2005, 2020). Tide or flap gates could be mounted on the Vancouver Lake side of the box culverts and installed so that they are open during conditions when flow is from Columbia River to Vancouver Lake, and then close when conditions result in backflow from Vancouver Lake to Columbia River. Tide or flap gates installed at the Flushing Channel should include a small fish door that allows fish passage when the gates are closed. The legality and requirements to allow fish passage through such a structure would need to be determined to ensure needs are met. Periodic maintenance to clear debris and installation of a trash rack or other feature to collect debris upstream of the tide or flap would likely be necessary to prevent the tide or flap gates from becoming blocked and ensure proper function.

Planning-Level Cost Estimate

A planning level cost estimate for the Flushing Channel enlargement is presented in Table 10. This estimate totals $32.7 million that includes $23 million for construction and adds 25 percent for design, 10 percent for permitting, and 5 percent for operation and maintenance. Note that these estimated costs are based on preliminary design concepts and are subject to substantial variability as the design is further developed. Also note that the operation and maintenance cost does not include maintenance dredging of the channel or lake that should be evaluated.

Table 10. Flushing Channel Enlargement Cost Estimate.

Item Description	Quantity	Unit	Unit Cost	Total Cost	Notes
Mobilization	1	L.S.	10%	$1,514,787	
Erosion/Water Pollution Control	1	L.S.	2%	$297,017	
Site Clearing and Dewatering	1	L.S.	$63,900	$63,900	
Traffic Control	1	L.S.	$50,000	$50,000	
Structure Excavation	85,715	C.Y.	$35	$3,000,024	
Removal and Disposal of Structure	980	L.F.	$25	$24,500	
Concrete Box Culverts	1	L.S.	$7,994,880	$7,994,880	
Embankment Backfill and Compaction	68,963	C.Y.	$34	$2,344,741	
Haul Excess Material Off Site	16,752	C.Y.	$29	$485,808	
Modern Tide or Flap Gates with Fish Door	1	L.S.	$887,000	$887,000	
Construction Subtotal				**$16,662,657**	
Contingency	30%			$4,998,797	
Subtotal (with +30 percent contingency)				**$21,661,454**	
Tax	7.8%			$1,689,593	
Construction Total (with contingency and tax)				**$23,351,048**	
Design	1	L.S.	25%	$5,837,762	
Permitting	1	L.S.	10%	$2,335,105	
Operation and Maintenance	1	L.S.	5%	$1,167,552	
Total (with design, permitting, and O&M)				**$32,691,467**	

C.Y. = cubic yards; L.S. = Lump Sum

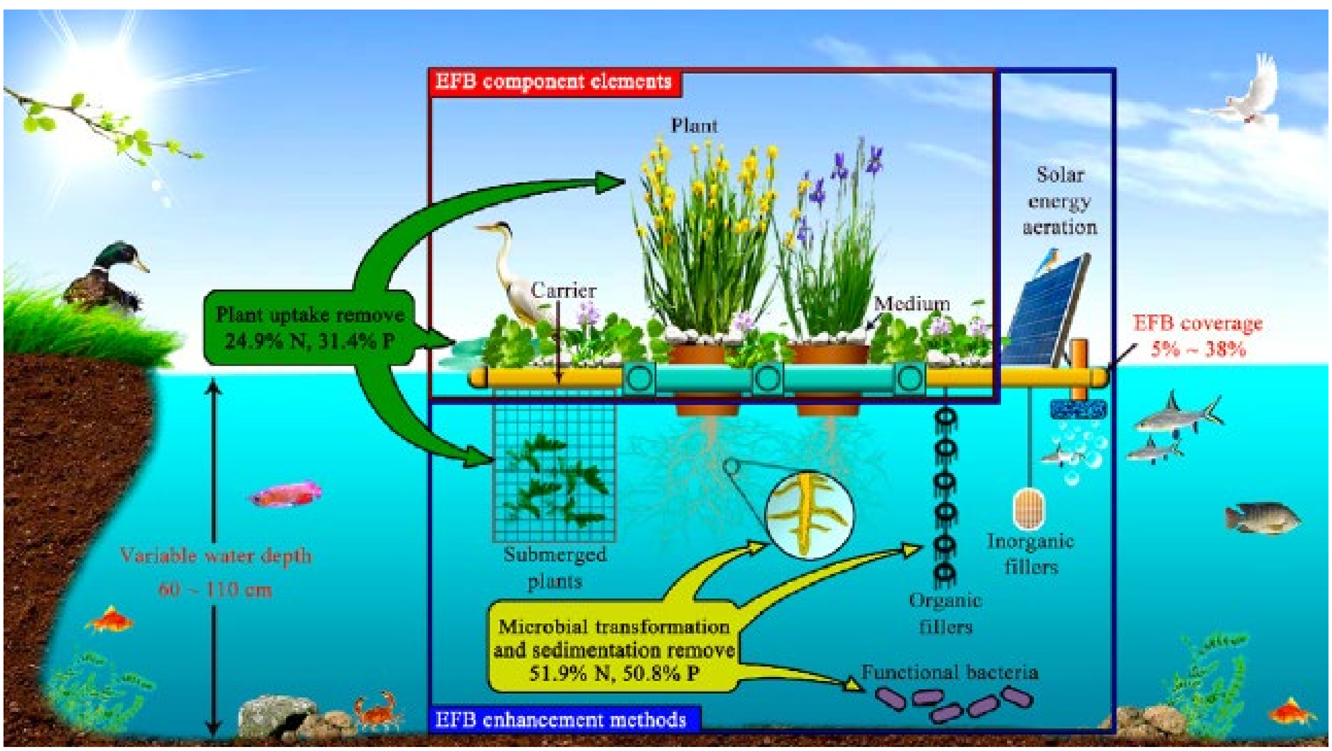
Floating Wetlands

Background

Floating wetlands improve water quality in lakes by taking nutrients from the water that otherwise would be taken up by cyanobacteria and other phytoplankton. The principal mechanism for nutrient removal is by the biofilm growing on plant roots descending into the water from the constructed floating wetland matrix. The biofilm is composed of attached algae, bacteria, and fungi within a gelatinous matrix. Dissolved nutrients are also taken up by the vascular plants themselves and the biofilm within the floating matrix. Suspended solids, metals and other particulate matter are adsorbed to biofilm on the plant roots. Nutrient uptake primarily occurs during the warm summer months and the biofilm ultimately sloughs off and becomes lake sediment.

The amount of nutrient removal is highly variable but generally increases directly with the wetland area, plant root surface area, water nutrient concentrations, water temperature, and dissolved oxygen concentrations (Pavlineri et al. 2017; Wang et al. 2019). A review of floating wetland function in stormwater ponds indicates that a 50 percent cover by floating wetlands reduces total phosphorus concentrations by about 50 percent and reductions decrease with increasing water depth and hydraulic loading rate (Pavlineri et al. 2017). A review of floating wetland function in eutrophic waters found an average phosphorus removal rate of 51 ±20 percent, and recommended designs covering 5 to 38 percent of the water at depths ranging from 2 to 4 feet (Wang et al. 2019) (Figure 23).

Figure 23. Floating Wetlands Nutrient Transformation Schematic.
Source: Wang et al. (2020)



Floating wetlands provide secondary benefits of aesthetic value and habitat for fish and wildlife. Insects graze on the biofilm; small fish feed on the insects; and the cover protects small fish from predators. Floating wetlands can be designed for waterfowl breeding habitat or can be fenced to protect new plants from waterfowl grazing.

Floating wetlands can be planted with a variety of native flowering plants, emergent plants, shrubs, and trees. Floating wetlands are easily anchored in place and should last for more than 20 years. Commercial manufacturers include Floating Islands International and Biomatrix Water, among others. Floating Islands International uses a recycled plastic (polyethylene terephthalate; PET) matrix with polyurethane for floatation. Biomatrix Water uses a natural coir fiber matrix with recycled HDPE tubes for floatation.

Floating Islands International recommends covering at least a 2 percent cover of a lake to improve water quality. Floating wetlands cost approximately $40 per square foot (G. Fulford, Biomatrix Water, personal communication) and can be planted and installed by volunteers. Two 680-square-foot floating wetland islands were installed in 1 day by 30 volunteers at Green Lake in Seattle in May 2022 (R. Zisette, Friends of Green Lake, personal communication).

Floating wetlands can be used as breakwaters to reduce shoreline or bulkhead erosion. For example, Martin Ecosystems (2022) installed a BioHaven® Floating Breakwater (see photo inset) on the Gulf Coast in 2011 that has withstood 90 mile per hour winds and a 3- to 4-foot storm surge in a C1 hurricane. In 2014, the Floating Breakwater received the endorsement of The Water Institute of the Gulf, as an innovative technology for Shoreline Protection and Bank Stabilization. Martin Ecosystems (2017) prepared a white paper describing Floating Breakwater design elements, uses, and system properties, and environmental safety and summarizing six installations in 2011–2015.

BioHaven® Floating Breakwater on Gulf Coast by Martin Ecosystems

Testing of a protype Floating Breakwater by the University of Alabama (Webb 2014) showed that a Floating Breakwater is most effective on short period waves (wind chop), higher breakwater widths, and shallower water depths. The wave transmission coefficient (ratio of transmitted wave height to incident wave height) was measured over a range of wave types and water levels in a wave basin and scaling the tests at a ratio of 1:4 for the model to a prototype with dimensions of 25 feet long, 7.5 feet wide, and 1.2 feet high. Wave transmission rates ranged from 0.44 to 0.99 among the 176 test conditions (each run in triplicate). A wave transmission rate of 0.5 reduces (attenuates) wave height by 50 percent. The wave transmission rate was shown to decrease as the ratio of breakwater width to wavelength increases and to decrease as wave steepness increases. It was recommended to use Floating Breakwaters with a width greater than 7.5 feet in water depths of 2 to 5 feet to maximize wave attenuation.

Existing Conditions

Vancouver Lake is a large (approximately 2,300 acres), shallow (mean depth 3 to 5 feet) lake located adjacent to the city of Vancouver in Clark County, Washington). Bathymetry of the lake was measured in 2007 by the USACE (2009) and most recently on June 15, 2019 (see Figure 2) (T. McNabb, personal communication, December 28, 2022). The deepest area of the lake is the dredged area by the Flushing Channel where a small depression (200 feet diameter) in the lake bottom reaches the maximum depth of 13 feet, compared to a depth range of 3 to 6 feet deep in the main body of the lake and 6 to 10 feet in the areas north of Turtle Island to Lake River.

The temporal pattern in lake elevation follows that of the Columbia River (see Figure 17). The lake elevation decreases during the summer months to its lowest point in the late summer and fall (August through October), increases during the winter months (November through March), remains at its highest point in the spring months (April through June), and can fluctuate several feet in the winter and spring. Monitoring data from various sources show the lake is well mixed both vertically in the water column and spatially, with lake mixing and lake sediment resuspension driven by wind.

Figure 24 presents a wind rose (average speed and direction) for the Vancouver Lake Sailing Club in Water Years 2011–2012 (Sheibley et al. 2014). The dominant winds at Vancouver Lake primarily came from the west where wind speeds typically ranged from 2 to 9 meters/second (5 to 20 miles/hour). Winds greater that 11 meters/second (25 miles/hour) were infrequently observed at less than 1 percent of the time.

Figure 24. Wind Speed and Direction at the Vancouver Lake Sailing Club in Water Years 2011–2012.
Source: Sheibley et al. 2014

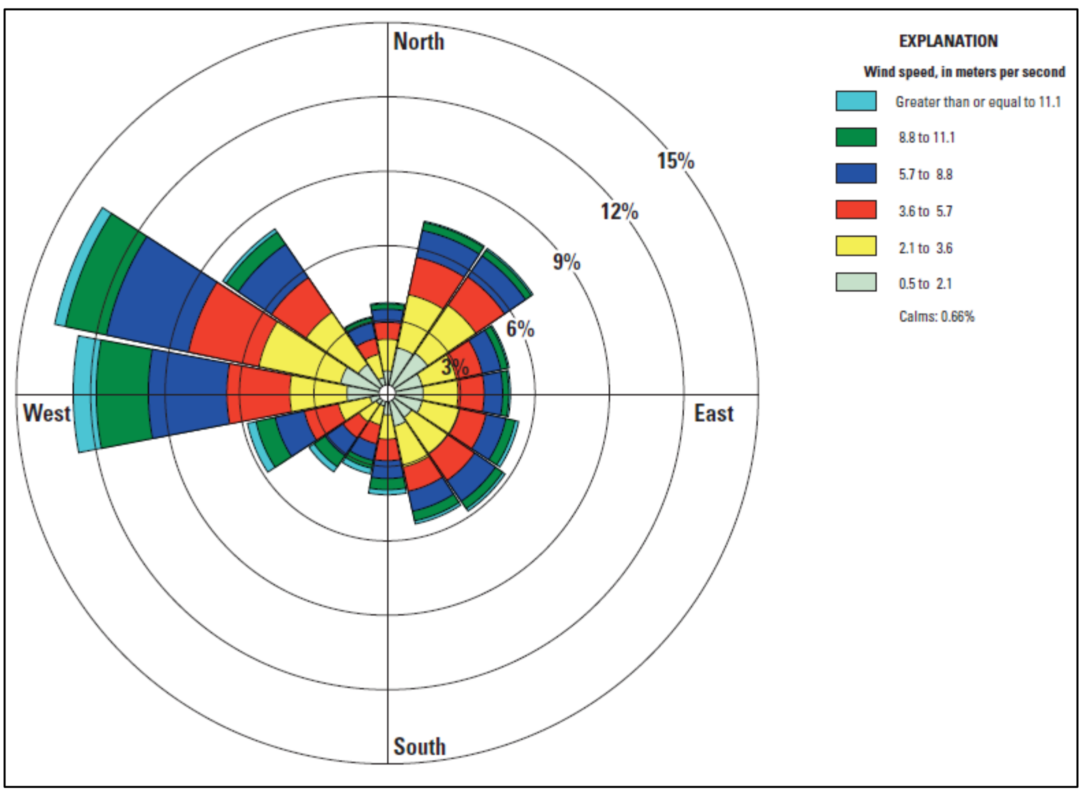


Table 11 presents mean values of key water quality parameters for the summer (May through October) of 2011 and 2012 (Sheibley et al. 2014). Summer means show that the lake has high temperature and dissolved oxygen, which are likely similar throughout the water column because the lake is too shallow to thermally stratify. Vancouver Lake is hypereutrophic (overly enriched with nutrients) with a high TSI for its high algae biomass (chlorophyll-a TSI of 66) and low water clarity (Secchi depth TSI of 67), and even higher TSI of 71 for is high total phosphorus. The similar TSI for chlorophyll-a and Secchi depth indicate that the low water clarity is primarily due to algae biomass and not suspended sediment. Total nitrogen concentrations are low in the lake in proportion to total phosphorus. The low total nitrogen to total phosphorus ratio and the low dissolved phosphorus and nitrogen concentrations indicate that algae growth is limited by both nutrients.

Table 11. Vancouver Lake Water Quality Summer Means.

Parameter	2011	2012	Mean
Depth (meters) (Site 1/2)	3.1/2.7	2.5/1.9	2.8/2.3
Temperature (°Celsius)	18.8	18.8	18.8
Dissolved oxygen (mg/L)	9.9	9.9	9.9
Secchi depth (meters)	0.8	0.4	0.6
Chlorophyll-a (µg/L)	43	26	35
Total phosphorus (µg/L)	108	103	106
Orthophosphate phosphorus (µg/L)	12	13	12.5
Dissolved orthophosphate P (µg/L)	3.8	4.3	4.1
Total nitrogen (µg/L)	843	838	841
Nitrate nitrogen (µg/L)	47	21	34
Nitrite nitrogen (µg/L)	2	1	2
Ammonia nitrogen (µg/L)	27	50	39
Dissolved inorganic nitrogen (µg/L)	77	73	75
Dissolved phosphorus (percent total)	4%	4%	4%
Dissolved inorganic nitrogen (percent total)	9%	9%	9%
DIN:DP	20	17	18
TN:TP	8	8	8

[a] Mean values for May through October. *Source: Sheibley et al. 2014*.

Conceptual Design for Initial Lake Modeling

For the initial water quality modeling of Vancouver Lake, a floating wetland design was developed to focus on floating wetland breakwaters to reduce wind wave height and the resulting sediment suspension and internal nutrient loading, but to also provide nutrient uptake by the root biofilm. Covering a significant portion of the lake to focus primarily on nutrient uptake would be much more expensive and would be difficult to avoid significant impacts on lake recreation. For example, covering 5 percent of the 2,300-acre lake for impactful nutrient uptake would require 115 acres of floating wetlands, versus just 4.4 acres of breakwater wetlands needed to reduce wave and wind impacts.

The linear wetland breakwaters would be oriented perpendicular to the predominant westerly to northwesterly wind direction. They would be at least 10 feet wide to effectively break moderately sized waves. There would be breaks of about 20 to 40 feet in each length to allow boat passage thorough the linear wetlands. Each linear section would be about 100 to 200 feet long to avoid installation difficulties with longer sections.

The initial conceptual design for floating wetland breakwaters is shown in Figure 25. This figure is a modification of FOVL's beneficial use map of the lake that also includes a proposed course for national rowing competitions that extends northeast from the swimming beach along the northwest shore (Al Mackenzie, personal communication, email to Rob Zisette on December 1, 2022).

Figure 25. Vancouver Lake Floating Wetland Conceptual Layout.

This design includes a total length of 4,950 meters (16,236 feet) of floating wetlands that are 3.6 meters (11.8 feet) wide for a total surface area of 17,820 square meters (191,715 square feet or 4.4 acres). The total area is equivalent to covering approximately 0.19 percent of the total lake surface area. In this design, one long (2,000 meters) wetland extends along the west side of the proposed rowing course and a short (500 meters) wetland extends out from shore between the swimming beach and flushing channel to break waves near the finish line of the proposed rowing course. Four moderately short (750 meters) wetlands are staggered in the main body of the lake and oriented southwest to northeast to break waves generated by the predominant westerly to northwesterly winds. Table 12 presents the design dimensions in metric and English units.

Table 12. Vancouver Lake Floating Wetland Alternative Dimensions.

Section	Length (meters)	Width (meters)	Area (m^2)	Length (feet)	Width (feet)	Area (ft^2)
Rowing Lane	2,000	3.6	7,200	6,560	11.8	77,460
Rowing Finish	500	3.6	1,800	1,640	11.8	19,365
Southwest Lake	750	3.6	2,700	2,460	11.8	29,048
Northwest Lake	750	3.6	2,700	2,460	11.8	29,048
Southeast Lake	750	3.6	2,700	2,460	11.8	29,048
Northeast Lake	750	3.6	2,700	2,460	11.8	29,048
Subtotal	**5,500**	**–**	**19,800**	**18,040**	**–**	**213,016**
Minus 10 percent gaps	-550	–	-1,980	-1,804	–	-21,302
Total	**4,950**	**–**	**17,820**	**16,236**	**–**	**191,715**
Lake Area (2,300 acres)	–	–	9,308,100	–	–	100,188,000
Percent Cover	**–**	**–**	**0.19%**	**–**	**–**	**0.19%**

ft^2 = square feet

m^2 = square meters

This design would reduce the wind fetch by about 60 percent and wave height by about 30 percent and all wind speeds. Table 13 presents the predicted wave height for those wind speeds shown in Figure 24 based on the estimated maximum and average wind fetch for a northwesterly wind under the current lake condition and wetland design, using the Sverdrup-Munk-Bretschneider model (USACE 1984). The percent reduction in wave height by a reduction in wind fetch does not vary significantly with the fetch length or wind speed.

Although wave height increases linearly with wind fetch, sediment suspension increases exponentially with wave height due to a proportionately greater effect of increasing currents and sheer stress on lake sediments. Thus, a 30 percent decrease in wave height would result in a greater decrease in sediment suspension. However, the predicted 30 percent decrease in wave height assumes that wave height is completely attenuated by each floating wetland. Modeling by Webb (2014) showed that wave attenuation by floating wetland breakwaters did not exceed 55 percent for unplanted breakwaters 7.5 feet wide, but more attenuation would occur for wider wetlands and from plant roots. It is reasonable to assume that the proposed 11.8-foot-wide floating wetlands with extensive root systems would attenuate nearly 100 percent of frequent small waves and a lessor amount for unusual large waves. Overall, it is assumed for modeling that the floating wetland design would reduce sediment suspension by 30 percent on average.

Table 13. Floating Wetland Effects on Vancouver Lake Wave Height (meters).

Condition	Wind Fetch (meters)	Wind Speed (meters/second)			
		11.1	8.8	5.7	3.6
Current Maximum	3,400	0.46	0.35	0.21	0.12
Current Average	2,400	0.40	0.31	0.18	0.11
Wetland Maximum	1,400	0.32	0.24	0.15	0.09
Wetland Average	1,000	0.28	0.21	0.13	0.08
Maximum reduction (percent)	59%	30%	31%	29%	28%
Average reduction (percent)	58%	30%	32%	28%	32%

The linear wetland breakwaters would be constructed of rectangular modules each 3.0 meters (9.9 feet) long by 1.2 meters (3.9 feet) wide with three modules forming the wetland width. It is assumed that they would be constructed of HDPE tubing, stainless steel brackets, and coir matrix by BioMatrix Water to provide high strength and longevity that far exceeds that of a traditional nonwoven polyester fiber with polyurea foam buoyancy (e.g., BioHaven®) at a similar cost. Multiple types of modules would be used to include open water, submersed, and high-buoyancy tree modules in addition to the primary floating modules. A recent example of the BioMatrix Water System is the floating wetlands installed in Green Lake in Seattle in May 2022 by the Friends of Green Lake (https://friendsofgreenlake.org/). Artificial root systems could be suspended from the floating wetland modules to increase the biofilm surface area for enhanced nutrient uptake (see Figure 23).

The wetlands would be planted on shore at the swimming beach by a team of volunteers with guidance by a consultant team with experience installing this type of floating wetlands. A planting plan would be prepared and used to plant the floating wetlands with a diverse variety of native plants known to thrive in floating wetlands. The plants would be obtained locally and consist of emergent grasses, flowering plants, herbs and shrubs, and small trees to attract a diverse aquatic animal community. Goose fencing would be installed along the perimeter of the wetlands to deter access by Canada geese but would allow access by ducks and other wildlife through small gaps at the base of the fencing.

Once planted, the floating wetlands would be assembled on shore by bolting each rectangular module together and sliding the developing length out over the water. Each wetland would be towed by boat to the desired location and securely anchored to the lake bottom. The anchoring system would be designed to withstand sustained high winds and likely require heavy (50 pound) anchors and heavy chain or metal helix anchors in firm sediment with nylon rope lines. Anchor lines would attach to the windward and leeward sides of each linear wetland and crisscross underneath to extend in opposite directions.

Floating wetlands do not require much maintenance. They would be inspected on two or more occasions each year to assess physical conditions and repair damage, and to assess plant conditions and remove invasive weeds. Maintenance could be performed by volunteers.

Planning-Level Cost Estimate

A planning level cost estimate is presented in Table 14. The total cost for covering 0.2 percent of the lake is estimated to cost $12 million based on $50 per square foot for wetland materials, anchor materials, and plants. Costs include 20 percent for design and installation assistance by a consultant along with contingency. Maintenance costs were estimated to be $10,000 per year for inspection, repair, and weeding over a 20-year project period.

Table 14. Vancouver Lake Floating Wetland Alternative Cost Estimate.

Unit Material Cost ($/square foot)	$50
Unit Design/Installation/Contingency (20 percent)	$10
Total Unit Cost ($/square foot)	$60
Wetland Area (square foot)	191,715
Total Cost Installed	$11,502,881
Maintenance Unit Cost ($/year)	$10,000
Maintenance Period (years)	20
Total Maintenance Cost	$200,000
Total Project Cost	$11,702,881

Chemical Management Methods

Buffered Alum Treatment

Background

Applications of aluminum sulfate (alum) applied in a sufficient dose to inactivate all mobile sediment phosphorus have been shown to be effective for at least 10 years in lakes with low watershed inputs (Cooke et al. 2005). When alum is added to water it forms a floc that grows in size and weight as it settles through the water column, sorbing inorganic phosphorus and incorporating particulate organic phosphorus through entrapment (Burrows 1977; Driscoll and Schecher 1990). The alum floc settles to the sediments where it continues to control phosphorus by sorbing additional phosphorus that is present in the sediments and thus forms a barrier to future phosphorus release from sediments into the water column. The resultant phosphorus that is bound to aluminum in the lake sediments is very stable and is thought to be permanently bound (Rydin and Welch 1998).

Alum treatments have been used successfully in many lakes in Washington, and several strategies have been implemented in Washington, and around the world to inactivate phosphorus in lakes, including the following:

- Whole lake alum dose
- Multiple small alum doses

- Microfloc alum injection
- Inflow stream alum injection

Multiple small alum doses typically cost more than a whole lake alum dose due to higher mobilization costs and are more appropriate for lakes with high external loading that shortens the longevity of a whole lake alum dose. Multiple small alum doses are sometimes preferred over a large long-term dose for financial reasons or to reduce potential impacts of aluminum toxicity to aquatic organisms. Multiple small alum doses can be used to strip phosphorus from the water column in addition to inactivation of sediment phosphorus. This approach may be well suited for Vancouver Lake because the USGS study did not identify a large amount of internal loading from release of sediment phosphorus (Sheibley et al. 2014).

Because of toxicity concerns, sodium aluminate is added along with alum to soft water lakes to prevent the pH from dropping below the lower end of the acceptable range (i.e., 6.0) and thereby killing fish from aluminum toxicity. The ratio typically used for alum and sodium aluminate is 2:1 by volume, and this ratio is assumed to be appropriate for Vancouver Lake.

Microfloc alum injection in a lake is more appropriate for smaller lakes with stable thermoclines, and it requires power and continued maintenance. Inflow stream alum injection is appropriate for lakes with high external loading from one primary inflow stream. Neither of these application methods would be appropriate for Vancouver Lake. Vancouver Lake does not have a stable thermocline and the shallow and large lake size would require a complicated injection system that may be prone to failure. Lake River does provide high external loading from one primary water source. However, export of alum from the lake would be prohibited by the permit and difficult to prevent due to the twice daily reverse in river flow caused by tides.

Existing Condition

Internal loading was not identified by USGS as a significant source of phosphorus in Vancouver Lake. However, modeling of the lake for this LMP clearly indicates otherwise. Therefore, an effective HAB control strategy would be to implement an initial whole lake alum dose to control (inactivate) phosphorus in shallow sediments, and occasionally treat the lake again with small alum doses to inactivate phosphorus inputs from the watershed. It is expected that each aluminum dose would be applied to the entire lake area that is accessible by boat.

USGS conducted sediment cores in 2012 from two sites (Sites 1 and 2) and analyzed phosphorus fractions in the following depth intervals: 0 to 5, 10 to 15, and 25 to 30 centimeters (cm) (Sheibley et al. 2014) (Table 15). Sediment phosphorus concentrations were similar at both sites and somewhat higher in the surface interval than either subsurface interval. The average total phosphorus concentration was highest at 1,092 mg/kg dry weight in the 0 to 5 cm surface interval compared to 784 mg/kg dry weight in the 10 to 15 cm interval and 896 mg/kg dry weight in the 25 to 30 cm interval. Most of the total phosphorus was in biologically unavailable inorganic fractions (calcium and aluminum bound totaling 60 to 90 percent of the total phosphorus). The biologically available inorganic fraction (loosely bound and iron bound) was very low, ranging from 0 to 3 percent of the total phosphorus. Organic phosphorus comprised 10 to 36 percent of the total phosphorus.

Table 15. Phosphorus Fractions in Lake Sediment Cores Collected in August 2012 from Site 1 and Site 2 in Vancouver Lake.

Sample ID	Total P (mg P/kg)	Loosely bound P (mg/kg)	Iron bound P (mg/kg)	Calcium bound P (mg/kg)	Aluminum bound P (mg/kg)	Organic P (mg/kg)	Available inorganic fraction (percent)	Unavailable inorganic fraction (percent)	Potentially available organic fraction (percent)
SITE1 0–5 cm	1,174	<2.00	37	487	224	427	3	60	36
SITE1 10–15 cm	893	<2.00	15	490	156	232	2	72	26
SITE1 25–30 cm	905	<2.00	20	528	142	215	2	74	24
SITE2 0–5 cm	1,010	<2.00	24	569	172	246	2	73	24
SITE2 10–15 cm	674	<2.00	7	433	65	169	1	74	25
SITE2 25–30 cm	886	<2.00	3	779	17	87	0	90	10

Source: Sheibley et al. (2014).

The amount (dose) of aluminum needed to inactivate sediment phosphorus is determined from the amount of mobile phosphorus in lake sediments (the source of internal loading) and the ratio of aluminum added to aluminum-bound phosphorus formed (Rydin and Welch 1998, 1999; Pilgrim et al. 2007; Huser and Pilgrim 2014). The calculated aluminum dose is then increased to account for the amount that will be used up as it moves through the water column and binds with phosphorus in the lake water.

The ratio of aluminum added to aluminum phosphorus formed has varied among lakes and researchers over time. Historically, a ratio of 20 had been successfully used in Washington lakes where the targeted amount of sediment phosphorus was based only on the mobile phosphorus concentration. More recently, a lower ratio of 8.8 parts aluminum to aluminum phosphorus formed was recommended by European limnologists when active biogenic phosphorus is included in the targeted amount of sediment phosphorus to be inactivated. For several lakes in Washington (i.e., Green Lake in Seattle, Wapato Lake in Tacoma, Heart Lake in Anacortes, and Black Lake in Olympia), Herrera used a ratio of 10 parts aluminum to targeted sediment phosphorus where the targeted phosphorus included both mobile phosphorus (labile plus iron bound phosphorus) and biogenic phosphorus, which together comprise biologically available phosphorus. Biogenic phosphorus is the easily degraded portion of organic phosphorus that can be analyzed separately but was not analyzed in the Vancouver Lake sediment samples. Other researchers use a ratio of 20 parts aluminum to one part biologically available phosphorus for alum dose calculations (J. Holz, Solitude Lake Management, personal communication).

Another important consideration for calculating an alum dose is the appropriate inactivation depth. Historically, a 4-cm inactivation depth was commonly used for dose calculations but Herrera and most other researchers currently use 10 cm. A 10-cm inactivation depth is appropriate for long-term effectiveness because the available (mobile plus biogenic) phosphorus concentrations typically decrease to near background levels below 10 cm in the sediment cores, which is the case for Vancouver Lake and suggests that background phosphorus below 10 cm is not actively releasing or being suspended into the lake (see Table 15). In addition, evaluation of alum treated lakes in Washington, showed that the aluminum bound phosphorus formed by the treatment was typically limited to the upper 10 cm of sediment in most lakes (Rydin and Welch 2000).

Another factor for calculating an alum dose is the water content of lake sediments. This is needed for converting concentrations of phosphorus in dry weight to wet weight to ultimately determine the mass of phosphorus in 10 cm of wet sediment over the application area. Percent water was not measured in the Vancouver Lake sediment cores but can be assumed to be 88 percent water (12 percent dry solids) based on other lakes (J. Holz, Solitude Lake Management, personal communication).

Average concentrations in the 0 to 5 cm samples from both Vancouver Lake cores were 30 mg/kg dry weight of mobile phosphorus and 336 mg/kg dry weight of organic phosphorus (see Table 15). Assuming 75 percent of the organic phosphorus was biogenic at 252 mg/kg dry weight and adding mobile phosphorus at 30 mg/kg dry weight, yields 282 mg/kg dry weight of biologically available phosphorus in Vancouver Lake. For comparison, biologically available phosphorus in the 0-10 cm surface interval of Lake Marcel (King County) sediments was higher at 399 mg/kg in both the shallow and deep cores, and the average measured concentration of biogenic phosphorus comprised 65 percent of the lake sediments' total organic phosphorus (Herrera 2023).

Aluminum permanently binds with phosphate and is nontoxic to all organisms in nearly all water and sediment quality conditions except extremely low or high pH (e.g., less than 6 or greater than 9). Aluminum toxicity is not a concern during an alum treatment if the acidic aluminum sulfate is properly buffered with the basic sodium aluminate. However, fish kills have been observed during buffered alum treatments because the alum was not properly buffered, or the lake pH was outside the permit-required range of 6 to 8.5 (Herrera 2018b and 2019). Some fish kills consisted of recently stocked hatchery trout and aluminum toxicity was not apparent based on fish gill examination and comparison to acute toxicity criteria recently promulgated by EPA for total aluminum, which are dependent on water hardness, pH, and dissolved organic carbon (Zisette 2022). Long-term toxicity to aquatic organisms from aluminum in treated lake sediments may occur if the sediment pH becomes acidic from decay of organic matter or if sediments are exposed or suspended in waters during high pH caused by an algae bloom. Alum treatments are prohibited in Canada and Europe due to aluminum toxicity concerns under extreme pH conditions.

Conceptual Design for Lake Modeling

For the initial water quality modeling, a whole lake alum application was assumed to include sufficient buffered alum to strip 80 percent of the phosphorus out of the water column and inactivate all biologically available sediment phosphorus. The alum treatment would occur in June before cyanobacteria blooms typically develop and after most salmon leave the lake, to maximize effectiveness and minimize aquatic biota impacts. The model assumed no biologically available phosphorus would be released from lake sediments for the remainder of the summer and entire following summer.

Planning-Level Cost Estimate

Solitude Lake Management prepared cost estimates for two alum treatment scenarios (J. Holz, Solitude Lake Management, personal communication). Assumptions, aluminum dose, and a cost estimate are listed separately for each treatment scenario:

- Scenario 1: Water Column Stripping and Sediment P Inactivation
- Scenario 2: Water Column Stripping Only
- Scenario 3: Water Column Stripping Plus 20 Percent for Supplemental P Inactivation

The total applicator cost of Scenario 1 is estimated at $8,178,310 and the total applicator cost of Scenario 2 is estimated at $730,294 in 2023 dollars that includes all treatment contractor costs (alum, sodium aluminate, labor, mobilization, demobilization, tax, incidentals, etc.), but does not include escalation or consultant planning and monitoring fees. Including consultant fees and a 10 percent applicator contingency yields total treatment costs of $9,405,056 for Scenario 1 and $949,382 for Scenario 2 in 2023 dollars. Scenario 2 assumes that sodium aluminate would not be necessary to buffer the alum because such a low dose would be applied to strip phosphorus from the water column. Because Scenario 1 is not likely to be effective for more than several years due to the high external P loading, an annual water column stripping under Scenario 2 would be more cost effective at 10 percent of the cost of Scenario 2.

Solitude Land Management then estimated costs for Scenario 3 that increased the aluminum dose by 20 percent for Scenario 2 to provide a margin of safety for annual variation in total phosphorus concentrations and lake volume, as well as inactivate some of the available sediment phosphorus over time (J. Holz, Solitude Lake Management, personal communication). The total cost of the increased aluminum dose for Scenario 3 is $830,610. Thus, the cost of Scenario 1 is approximately equivalent to the cost of 10 annual treatments with the 20 percent extra amount of alum.

These cost estimates do not include escalation, a treatment contractor contingency, or additional consultant fees for preparing a treatment plan and contractor specifications, obtaining the algae management permit, engineering oversight of the contractor, monitoring and reporting water quality conditions in accordance with permit requirements, or monitoring sediment phosphorus to adjust future dose amounts.

Alum Treatment Scenario 1: Water Column Stripping and Sediment P Inactivation

Assumptions

- Based on data presented in Sheibley et al. (2014; Table 15), 0 to 5 cm sample averages for Sites 1 and 2 are 30 mg/kg for iron bound P and 336 mg/kg for organic P.
- The average total available P was calculated as average iron bound P plus 75 percent of the average organic P, which equals 280 mg/kg rounded to two significant figures.

- Sheibley et al. (2014) does not report the percent water associated with each sample. For this planning level exercise, we assumed percent water to be 88 percent for all samples. This is a reasonable assumption based on our previous lake sediment studies.
- As requested, we assumed that the P in the upper 10 cm of sediment will be inactivated.
- Assumed the 0 to 5 cm sediment samples were representative of the entire upper 10 cm of sediment.
- Assumed aluminum to total available P ratio of 20:1.
- Assumed an application zone of 2,000 acres (~87 percent of total lake surface area).
- Assumed the total aluminum dose would be delivered by applying aluminum sulfate (alum) and 38 percent sodium aluminate at a 2:1 volumetric ratio.

Aluminum Dose

- Sediment Dose = 1,159,298 gallons (gal) alum and 579,649 gal sodium aluminate = 33.54 mg Al/L.
- Water Column Dose = 95,044 gal alum and 47,522 gal sodium aluminate = 2.75 mg Al /L (see Scenario 2 for water column dosing and assumptions).
- Total Sediment Inactivation Plus Water Column Stripping Dose = 1,254,342 gal alum and 627,171 gal sodium aluminate = 36.29 mg Al/L.

Cost Estimate

- Total Treatment Contractor Cost = $8,178,310
- Unit Costs = $2.16 per gal of alum applied and $8.72 per gal of sodium aluminate applied.
- Based on estimated chemical cost for April 2023 and does not include any potential future cost increases or contingencies.
- The total cost estimate is lump sum and includes all treatment contractor costs (alum, sodium aluminate, labor, mobilization, demobilization, tax, incidentals, etc.), but does not include consultant fees for planning and monitoring of the treatments.
- Total Cost = $9,405,056 includes 5 percent consultant cost and 10 percent contractor contingency.

Scenario 2: Water Column Stripping Only

Assumptions

- Assumed a water column total P of 55 µg/L, which is assumed to represent early June average conditions.
- Assumed a lake volume of 14,280 acre-feet. This is the average volume for the lake reported in Sheibley et al. (2014).
- Assumed aluminum to total P ratio of 50:1.

- Assumed the total aluminum dose would be delivered by applying aluminum sulfate only and a pH buffer (sodium aluminate) would not be required to maintain an acceptable pH (6.0 to 8.5) due to the low dose.

Aluminum Dose

Water Column Dose = 218,651 gal alum (2.75 mg Al/L).

Cost Estimate

- Total Treatment Contractor Cost = $730,294.
- Unit Costs = $3.34 per gal of alum applied.
- Based on estimated chemical cost for April 2023 and does not include any potential future cost increases or contingencies.
- The total cost estimate is lump sum and includes all costs (alum, labor, mobilization, demobilization, tax, incidentals, etc.), but does not include consultant fees for planning and monitoring of the treatments.
- Total Cost = $949,382 includes 20 percent consultant cost and 10 percent contractor contingency.

Scenario 3: Water Column Stripping Plus 20 Percent for Supplemental P Inactivation

Assumptions

- Same as Scenario 2 but add 20 percent more alum for safety margin and partial sediment P inactivation.
- Assumed the total aluminum dose would be delivered by applying aluminum sulfate only and a pH buffer (sodium aluminate) would not be required to maintain an acceptable pH (6.0 to 8.5) due to the low dose.
- The additional 20 percent (0.55 mg Al/L) of the water column stripping dose (2.75 mg Al/L) would inactivate additional water column total P if present in excess of 55 mg/L or partially inactivate sediment P corresponding to 2 percent of the sediment P inactivation dose (33.5 mg Al/L).

Aluminum Dose

- Water Column Dose = 262,381 gal alum (3.30 mg Al/L)

Cost Estimate

- Total Treatment Contractor Cost = $ 830,610.
- Unit Costs = $3.28 per gal of alum applied.
- Based on estimated chemical cost for April 2023 and does not include any potential future cost increases or contingencies.

- The total cost estimate is lump sum and includes all costs (alum, labor, mobilization, demobilization, tax, incidentals, etc.), but does not include consultant fees for planning and monitoring of the treatments.
- Total Cost = $1,079,793 includes 20 percent consultant cost and 10 percent contractor contingency.

Lanthanum Modified Bentonite Treatment

Background

Phoslock and EutroSORB are phosphorus inactivation products that both consist of a combination of lanthanum, a natural but rare element in the earth, and bentonite clay. Because the lanthanum has a strong affinity for phosphate it can chemically inactive phosphate through precipitation and forms a mineral of extremely low solubility; thus, permanently binding the phosphorus like alum. Unlike alum it is not a coagulant and so it does not trap and remove particles in the water column. In fact, water can be more turbid in the days immediately following a Phoslock application but decrease with time, as compared to alum, which immediately clears the water. Phoslock works mainly in the sediment to bind phosphate that would normally be released to the water through decomposition or changes in sediment chemistry. It binds only to inorganic phosphate and does not address organic phosphorus. Phoslock has no known toxicity and therefore does not have the application concerns that are associated with use of alum. It is also easy to estimate dosage needed; it is based on a 100:1 ratio of Phoslock to potentially available phosphorus. While alum can be applied in frequent small doses to "strip" the water column of inorganic phosphorus, Phoslock is added to address sediment derived inorganic phosphorus and does not strip phosphorus from the water column. One of the key drawbacks to Phoslock is that there are fewer case studies of lake applications to draw from to evaluate effectiveness and duration of treatments.

Phoslock is typically applied as a slurry to the lake surface at a 100:1 ratio of Phoslock to phosphorus. Because it does not address organic phosphorus, it is best applied during winter or early spring when algae concentrations are low, and phosphorus is buried in the sediments. Re-applications would be necessary. Phoslock may be preceded by a low-dose, unbuffered alum treatment to strip phosphorus from the water column. Although there are fewer case studies of Phoslock on which to base long term effectiveness, Kitsap Lake is a recent example of a successful use of Phoslock for cyanobacteria management (Bremerton 2022).

EutroSORB entered the marketplace in 2022 and is applied as a liquid or aqueous slurry. EutroSORB WC is used for stripping phosphate out of the water column and EutroSORB G is used for inactivating sediment phosphorus. EutroSORB G has 10 times more lanthanum than Phoslock.

Lanthanum modified bentonite permanently binds with phosphate and is nontoxic to all organisms in all water and sediment quality conditions. Because aluminum can become toxic to aquatic organisms under extreme pH conditions, Phoslock and EutroSORB treatments have a lower risk to aquatic organisms than buffered alum treatments. In addition, lanthanum bound phosphorus is stable under extreme pH conditions and does not pose a risk like aluminum bound phosphorous for releasing phosphorus under acidic conditions (pH less than 6.0) or basic conditions (pH greater than 8.5).

Existing Condition

As noted for alum, modeling of the lake for this LMP clearly indicates internal loading is a significant source of phosphorus in Vancouver Lake. However, external loading is also significant and likely greater than internal loading. Therefore, an effective HAB control strategy would be to implement an initial whole lake lanthanum dose to control (inactivate) phosphorus in shallow sediments, and occasionally treat the lake again with small lanthanum doses to inactivate phosphorus inputs from the watershed. It is expected that each lanthanum dose would be applied to the entire lake area that is accessible by boat.

Like alum, lanthanum dosing for sediment inactivation is typically estimated from the amount of biologically available phosphorus in 0 to 10-cm depth interval. As noted for alum, the average concentration of potentially biologically available P in the surface interval was 363 mg/kg, which includes the small amount of available inorganic phosphorus and all the organic phosphorus. However, not all of the organic P is biologically available and the USGS analysis did not include analysis of biogenic phosphorus, which for example comprised 65 percent of the organic phosphorus in Lake Marcel sediments (Herrera 2023 in press). Applying this percentage to the organic phosphorus concentration in Vancouver Lake surface sediments yields a mean biologically available phosphorus concentration of 249 mg/L.

Conceptual Design for Lake Modeling

For the initial water quality modeling, a whole lake lanthanum modified bentonite application was assumed to include sufficient buffered alum to strip 80 percent of the phosphorus out of the water column and inactivate all biologically available sediment phosphorus. The alum treatment would occur in June before cyanobacteria blooms typically develop and after most salmon leave the lake, to maximize effectiveness and minimize aquatic biota impacts. The model assumed no biologically available phosphorus would be released from lake sediments for the remainder of the summer and entire following summer.

Since the water quality modeling of this alternative, the makers of EutroSORB were contacted and they recommended using EutroSORB G for sediment phosphorus inactivation rather than water column phosphorus inactivation by EutroSORB WC (Ryan Van Goethem, Eutrophix, personal communication). Water column stripping was not recommended because it would have such a short-term effect due to the high external phosphorus inputs from Lake River. Water column stripping and sediment inactivation using lanthanum modified bentonite would require separate applications of EutroSORB WC for water column stripping followed by either Phoslock or EutroSORB G for sediment inactivation. This conceptual design of only sediment phosphorus inactivation without water column stripping was used for cost estimating and may result in slightly lower HAB control effectiveness than predicted by the lake model.

Eutrophix also commented that lanthanum modified bentonite would be an effective sediment phosphorus binder in this shallow hypereutrophic lake, which often experiences a high pH and sediment resuspension that can release aluminum and phosphate from alum treated sediments. In addition, EutroSORB is heavier than alum and would not redistribute in the lake as readily during high wind events.

Planning-Level Cost Estimate

Planning-level cost estimates for lanthanum modified bentonite treatments of Vancouver Lake were provided by Eutrophix and SOLitude Lake Management.

Eutrophix Estimates

The EutroSORB G dose was estimated by Eutrophix based a biologically available sediment phosphorus concentration of 275 mg/kg, a bulk sediment density of 1.15 g/cm^3[1], a sediment solids content of 20 percent, and a sediment phosphorus inactivation depth of 10 cm to yield a sediment phosphorus inactivation amount of 56.43 pounds P/acre (Ryan Van Goethem, personal communication). Applying this amount to a lake area of 2,326 acres yields a total of 131,256 pounds of sediment phosphorus to inactivate. Applying EutroSORB G to inactive sediment phosphorus at the recommended ratio of 50 to 1 yields a total dose of 652,800 pounds of EutroSORB G. The cost for this EutroSORB G application was estimated to be $25 million to include planning, materials, application, and monitoring.

A reasonable application rate for EutroSORB G was estimated to be 20,000 pounds/boat-day (Ryan Van Goethem, personal communication). Thus, application of 652,800 pounds would take about 33 days or less if more than one boat was used. It would be reasonable to apply half of the 652,800-pound dose in 1 year and adjust the second dose amount and timing based on water quality and sediment monitoring results.

The longevity of this EutroSORB treatment is difficult to predict as it depends on the phosphorus loading and sedimentation and resuspension rates. Given the high external phosphorus loading rate, it is unlikely that this treatment would last more than 5 years. Assuming this treatment would be repeated every 5 years, the average annual cost would $5 million/year yield a 20-year cost of $100 million.

Solitude Lake Management Estimates

Solitude Lake Management prepared cost estimates for two lanthanum treatment scenarios (J. Holz, Solitude Lake Management, personal communication). Assumptions, aluminum dose, and a cost estimate are listed separately for each treatment scenario:

- Scenario 1: Phoslock Sediment Inactivation
- Scenario 2: EutroSORB G Sediment Inactivation

Product costs are nearly equivalent at $12,635,026 for Scenario 1 and $12,667,591 for Scenario 2. These estimates do not include contractor application costs (labor, mobilization, demobilization, tax, incidentals, etc.) or consultant fees for planning and monitoring of the treatments. Application costs were not estimated due to the much higher cost of the lanthanum products compared to buffered alum treatment products (J. Holz, Solitude Lake Management, personal communication).

[1] cm^3 = cubic meters

Scenario 1: Phoslock Sediment Inactivation

Assumptions

- Based on data presented in Sheibley et al. (2014; Table 15), 0 to 5 cm sample averages for Sites 1 and 2 are 31 mg/kg for iron bound P and 249 mg/kg for biogenic P.
- The average total available P was calculated as average iron bound P plus 75 percent of the average biogenic P, which equals 280 mg/kg.
- Sheibley et al. (2014) does not report the percent water associated with each sample. For this planning level exercise, we assumed percent water to be 88 percent for all samples. This is a reasonable assumption based on our previous lake sediment studies.
- As requested, we assumed that the P in the upper 10 cm of sediment will be inactivated.
- Assumed the 0 to 5 cm sediment samples were representative of the entire upper 10 cm of sediment.
- Assumed Phoslock to total available P ratio of 100:1 (lb:lb).
- Assumed an application zone of 2,000 acres (~87 percent of total lake surface area).
- Assumed the total lanthanum dose would be delivered by applying Phoslock.

Phoslock Dose

- Sediment Dose = 6,512,900 pounds of Phoslock.
- This dose will supply an equivalent number of P binding sites as the aluminum dose.
- Water Column Dose = not applicable. Lanthanum binds to dissolved P and dissolved P is typically low (5 to 15 percent of total P) in eutrophic lakes. Therefore, SOLitude does not recommend lanthanum-based products water column stripping because they do not strip particulate P from the water column.

Cost Estimate

- For product only = $12,635,026.
- Based on estimated chemical cost for April 2023 and does not include any potential future cost increases or contingencies.
- Given the high cost of the product compared to aluminum, application costs were not estimated by Solitude Lake Management. For budgeting purposes, application costs are estimated to be $3,000,000.
- Total Cost = $17,980,280 includes 5 percent consultant cost and 10 percent contractor contingency.

Lanthanum Application 2: EutroSORB G Sediment Inactivation

Assumptions

- Based on data presented in Sheibley et al. (2014; Table 15), 0 to 5 cm sample averages for Sites 1 and 2 are 31 mg/kg for iron bound P and 249 mg/kg for biogenic P.
- The average total available P was calculated as average iron bound P plus 75 percent of the average biogenic P, which equals 280 mg/kg.
- Sheibley et al. (2014) does not report the percent water associated with each sample. For this planning level exercise, we assumed percent water to be 88 percent for all samples. This is a reasonable assumption based on our previous lake sediment studies.
- As requested, we assumed that the P in the upper 10 cm of sediment will be inactivated.
- Assumed the 0 to 5 cm sediment samples were representative of the entire upper 10 cm of sediment.
- Assumed EutroSORB G to total available P ratio of 50:1 (lb:lb).
- Assumed an application zone of 2,000 acres (~87 percent of total lake surface area).
- Assumed the total lanthanum dose would be delivered by applying EutroSORB G.

EutroSORB G Dose

- Sediment Dose = 3,256,450 pounds of EutroSORB G.
- This does will supply an equivalent number of P binding sites as the aluminum dose.
- Water Column Dose = not applicable. Lanthanum binds to dissolved P. Dissolved P is typically low (5 to 15 percent of total P) in eutrophic lakes. Therefore, SOLitude does not recommend lanthanum-based products water column stripping.

Cost Estimate

- For product only = $12,667,591.
- Based on estimated chemical cost for April 2023 and does not include any potential future cost increases or contingencies.
- Given the high cost of the product compared to aluminum, application costs were not estimated by Solitude Lake Management. For budgeting purposes, application costs are estimated to be $3,000,000.
- Total Cost = $18,017,730 includes 5 percent consultant cost and 10 percent contractor contingency.

Algaecide Treatment

Background

Algaecides provide partial short-term algae control by killing the algae and cyanobacteria in the water column. However, all algaecides also affect other aquatic biota to varying degrees and accelerate recycling of nutrients. Algaecides are effective only while the active ingredient is in the water column and available for uptake by the algae (Cooke et al. 2005). Typically, several applications must occur within the same season to provide effective control of algae and cyanobacteria. Algaecides do not reduce phosphorus or nitrogen concentrations and do not provide long-term control. In fact, they increase recycling of phosphorus. Currently, endothall (Hydrothol 191, a mono salt formulation) and sodium carbonate peroxyhydrate (PAK 27, Phycomycin, or GreenClean) are the only algaecides that can be used in the State of Washington (Ecology 2021).

Endothall has an application timing restriction which limits applications to a treatment window of June 1 to December 31 for protection of priority fish and bird species. Priority fish include coho salmon, fall Chinook salmon, winter steelhead, and cutthroat trout. Priority birds include cavity nesting ducks and waterfowl concentrations, purple martin, great blue heron rookeries, and American white pelican. Hydrothol also has a recreational use restriction that prohibits swimming within the entire lake for 24 hours after the treatment. In addition, Hydrothol 191 must be applied at no greater than 0.2 mg/L of the active ingredient (Ecology 2021).

Sodium carbonate peroxyhydrate (PAK 27, Phycomycin, or GreenClean) has the same application restriction of a treatment window of June 1 to December 31, but this restriction is for the priority bird species and does not apply to priority fish species. These algaecides have no recreational use restrictions or treatment limitations except they are not to be applied to plants growing on the shore (Ecology 2021). If algaecides were to be used in Vancouver Lake, it would likely require a minimum of two treatments every summer.

Both algaecides rapidly kill all algae indiscriminately. Treatment frequency can be as high as weekly for small ponds or lake beach areas but should not occur more frequent than monthly in an entire lake to reduce potential impacts to fish from low dissolved oxygen concentrations caused by the decay of algae. If algaecides were used in Vancouver Lake, it would likely require a minimum of two treatments every summer for a whole-lake treatment and possibly more frequent applications if only the swimming beach was treated. A water barrier (e.g., turbidity or bubble curtain) could be deployed along the perimeter of the swimming beach to extend the effectiveness of a treatment in that area.

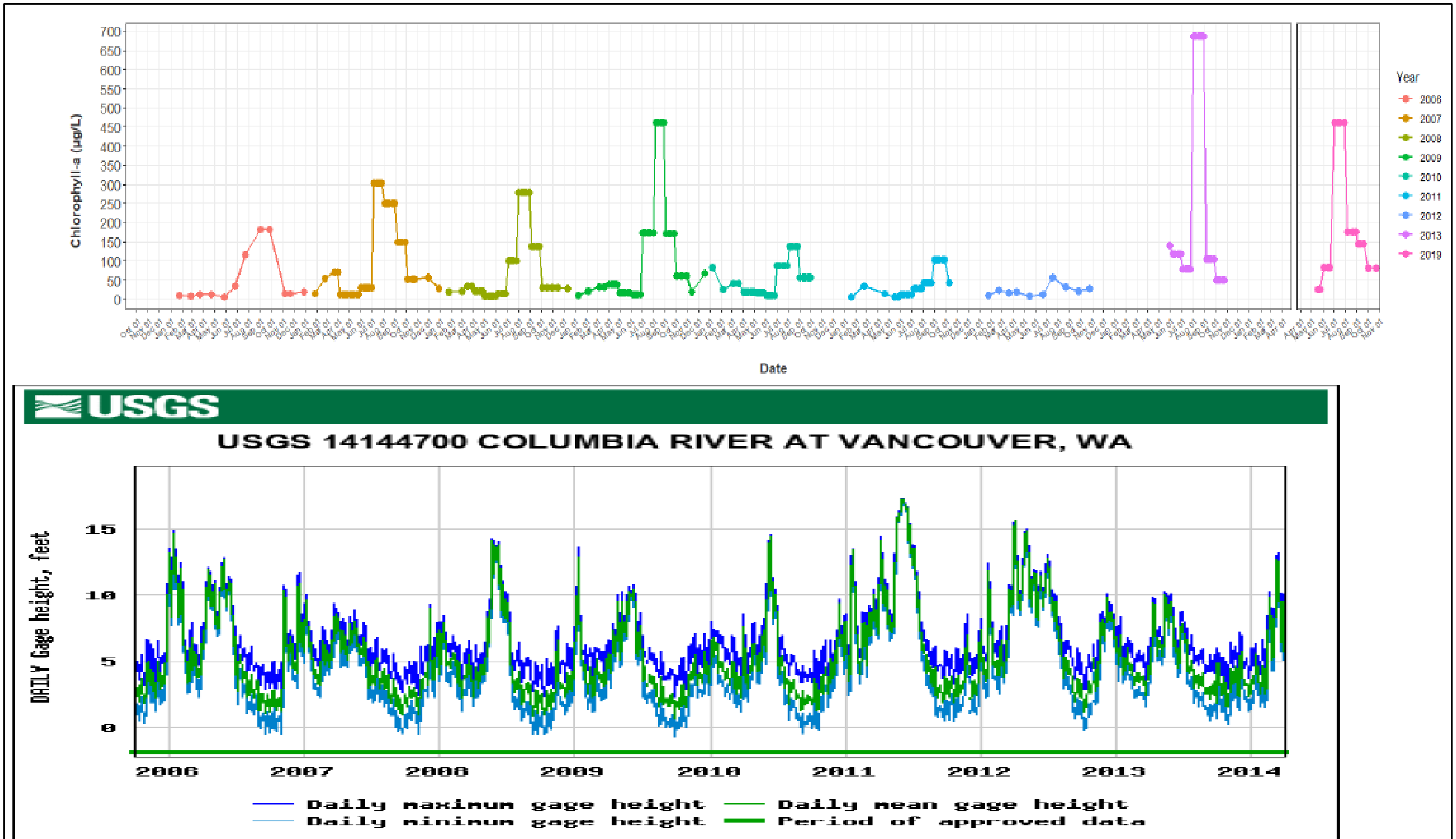
Existing Condition

Algae blooms in Vancouver Lake typically form in mid to late July and last 3 to 4 weeks, followed by a decline in August and often a smaller yet still substantial recurring bloom in September (Rollwagen-Bollens et al. 2018). During annual late season algae blooms, chlorophyll-a concentrations of up to 500 to 900 µg/L can be observed but vary widely between years and have been much less in some years. Figure 26 shows mean monthly chlorophyll-a concentrations from 2006 through 2013 where peak monthly values increased from about300 µg/L in 2010 to 450 µg/L in 2009, decreased to a low of 60 µg/L peak chlorophyll-a in 2012, and then reached a maximum peak of 690 µg/L the following year in 2013.

Figure 26 also shows water levels in the Columbia River during these years that are proportional to the amount of water flowing into the lake from the Flushing Channel. This comparison shows that the 2 years modeled for this plan (2011 and 2012) had the highest river levels, and thus also the highest flow through the Flushing Channel compared to other years. Higher lake inflows may result in lower lake temperatures from cooler river temperatures, and lower lake temperatures may have resulted in lower phytoplankton growth rates. The potential for lower phytoplankton growth rates from higher lake inflow rates is supported by lower chlorophyll-a concentrations in 2011 and 2012, which featured the smallest algae blooms compared to other years (Figure 26) and suggests that higher Flushing Channel inputs may decrease algae blooms in Vancouver Lake.

Figure 26. Chlorophyll-a Concentrations in Vancouver Lake Compared to Water Levels in the Columbia River from 2006–2013.

Top: Data from Rollwagen-Bollens et al. (2018), Sheibley et al. (2014), and Sweeney et al. (2022). Bottom figure source: USGS (2022).

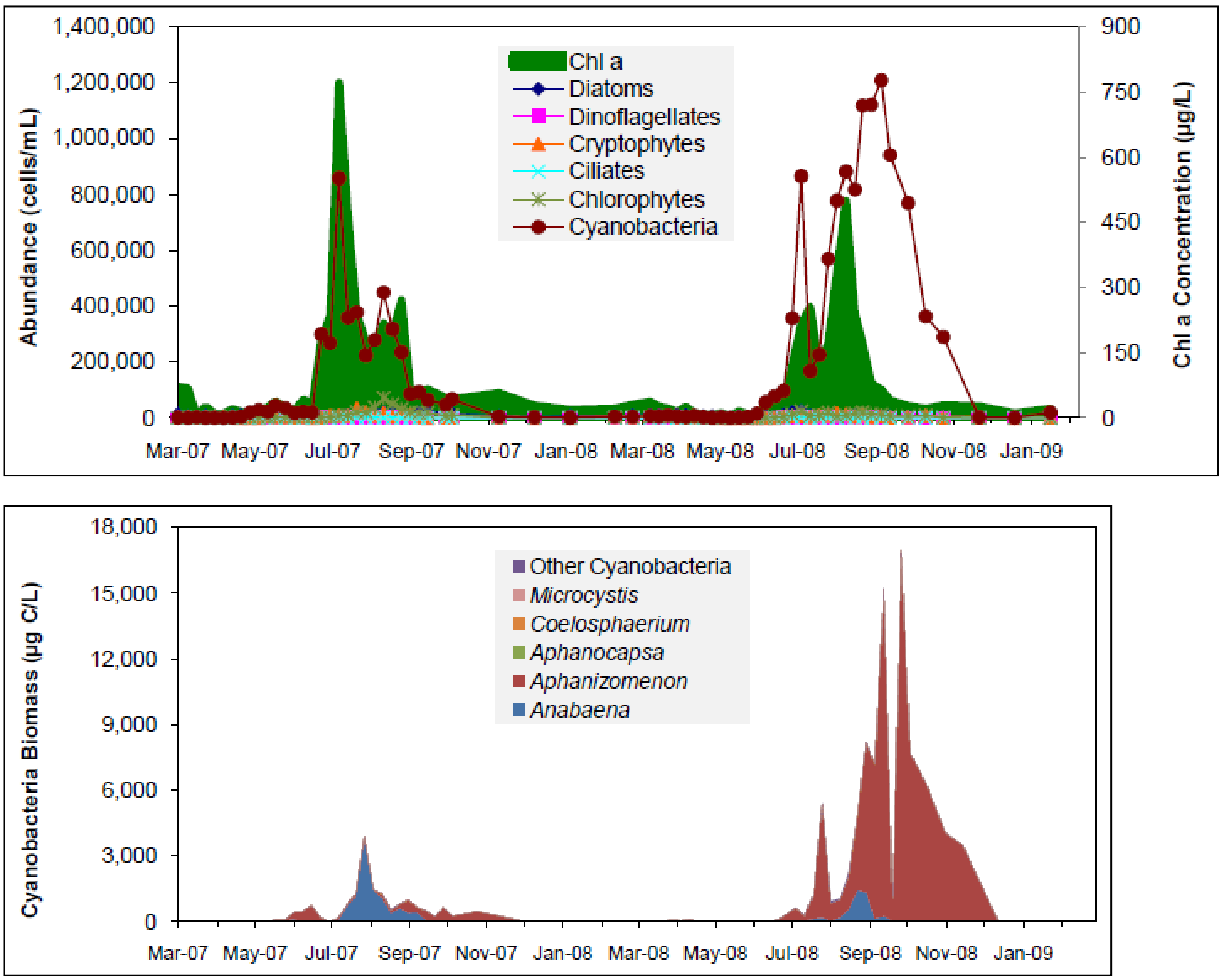


0.0 ft River Gage datum = 1.82 ft NGVD 27 datum = 5.28 ft NAVD88 datum

Algae species composition also varies widely between years in Vancouver Lake. Figure 27 shows chlorophyll-a concentrations, algae cell concentration by group, and cyanobacteria biomass concentration by species for 2007 and 2008 (Bollens and Rollwagen-Bollens 2010). Total algae biomass, as represented by chlorophyll-a, peaked at 800 µg/L in July 2007 and at 500 µg/L in August 2008, and was clearly dominated by cyanobacteria based on cell concentrations in both years. Although peak biomass and cyanobacteria dominance were similar between these years, the dominant cyanobacteria species shifted from *Dolichospermum flos-aquae* (formerly *Anabaena flos-aquae*) in 2007 to *Aphanizomenon flos-aquae* in 2008. In 2019, total algae biomass peaked to about 800 µg/L as chlorophyll-a at the end of July, where cyanobacteria (mainly *D. flos-aquae*) comprised the majority of algae but shifted to dominance by *A. flos-aquae* during the smaller, fall algae blooms (Sweeney et al. 2022).

Figure 27. Chlorophyll-a, Algae Group Composition, and Cyanobacteria Species Biomass in 2007 and 2008 in Vancouver Lake.

Source: Bollens and Rollwagen-Bollens (2010).



The historical chlorophyll-a and algae composition analysis clearly indicates that algae blooms typically occur in July and August and are dominated by cyanobacteria. Additionally, high cyanotoxin concentrations may be present at the swimming beach even though chlorophyll-a concentrations are low and cyanobacteria do not dominate the algae community. This analysis suggests that algaecide treatments, if selected, should be conducted in June of each year regardless of the amount or composition of algae in the lake to prevent toxic blooms in July and August.

Conceptual Design for Lake Modeling

The algaecide treatment design for lake modeling was to apply sodium carbonate peroxyhydrate (Phycomycin or PAK 27) over the entire lake on two occasions in the summer of each year. The algaecide would be applied at the full label rate of about 40 pounds/acre-foot over the entire lake in late June and again in early August to kill all algae, and the model assumed no algae growth in July and August.

Planning-Level Cost Estimate

It is assumed that sodium carbonate peroxyhydrate (Phycomycin or PAK 27) would be applied to 2,000 acres at a cost of $250/acre (T. McNabb, AquaTechnex, personal communication). The annual HAB management cost would be $1 million/year based on two whole-lake applications per year, or a total of $20 million for 20 years.

Hydrodynamic and Water Quality Modeling

Methods

LimnoTech has developed a linked hydraulic and water quality model for Vancouver Lake, Washington, to assess the potential relative efficacy of various management alternatives to address degraded water quality in the lake. The modeling framework allows stakeholders to assess the relative costs and benefits of several management alternatives in alleviating stressors related to eutrophication and toxigenic HABs to Vancouver Lake.

The lake management alternatives that were explored as part of this effort include:

- Reduction of external nutrient sources associated with failing septic systems
- Reduction of external nutrient sources associated with stormwater runoff in the watershed
- Construction of a dam near the outlet of the lake to Lake River
- Enlargement of the flushing channel to the west of the lake
- Construction of floating wetlands in the lake
- Sediment and water column phosphorus inactivation
- Algaecide treatment of the water column

LimnoTech was provided with an existing hybrid one-dimensional/two-dimensional HEC-RAS hydraulic model of Vancouver Lake (Jacobs 2022). The model was reconfigured to simulate the Lake River and Vancouver Lake domains using two-dimensional computational points. The core geometry files and data sources from the Jacobs model were also maintained for development of this modeling application.

Water Analysis Simulation Program (WASP; Wool et al. 2020) was linked to HEC-RAS (Hydrologic Engineering Center 2021) to add the capability of simulating water quality including up to three algal classes; multiple forms of phosphorus, nitrogen, and carbon; dissolved oxygen, temperature, solids; toxics; and sediment diagenesis. While all of the model capabilities are not used here, the configuration used represents an advanced lower food web model. A simulation period of 2011–2012 was used due to the availability of in-lake water quality data collected by USGS (Sheibley et al. 2016) for calibration. Although extensive physical and biological data are available for other years, collected and provided for use in this study by Washington State University Vancouver's Aquatic Ecology lab, and insufficient amount of nutrient and hydrological data are available to expand the model to additional years.

Ultimately, the HEC-RAS model domain consisted of approximately 13,500 computational cells and the WASP model domain consisted of 76 computational water quality cells, comprising Vancouver Lake, the flushing channel, and the entire extent of Lake River from the lake to the confluence with the Columbia River (Figure 28). Burnt Bridge Creek and Salmon Creek were included as point sources in the linked models that did not extend up either stream because watershed inputs were not evaluated on a stream subbasin level.

Only selected water quality endpoints and hydrodynamic impacts of Vancouver Lake management alternatives were evaluated for the lake in this initial phase of the LMP. The model can be used to evaluate effects of management alternatives downstream of the lake on Lake River, and for additional parameters of interest such as dissolved oxygen. The model is also capable of evaluating effects of using multiple management alternatives at the same time. It is anticipated that the linked models will be used in the future to evaluate additional water quality and hydrodynamic impacts of preferred management alternatives on Vancouver Lake and Lake River to help with the decision making process.

Additional details related to the model approach, supporting data, model development and calibration, and management alternative assumptions modeled are provided in Appendix A, Sections 2 through 5.

Results

Model results for ecological endpoints, including summer average chlorophyll-a concentrations, summer maximum cyanobacteria, summer average Secchi depth, summer average total phosphorus, and maximum water temperature are described in detail in Appendix A, Section 6.

Based on model simulations and assumptions, the in-lake treatments of algaecide and phosphorus inactivation provide the greatest benefit in reducing algal biomass (summer chlorophyll-a and cyanobacteria concentrations) (Table 16 and Table 17), although these methods do not address the underlying causes of eutrophication and only the symptoms. The physical lake management approaches, such as channel enlargement and construction of Lake River dam, do provide significant reductions in nutrients and algal biomass; although, these methods fundamentally change the hydraulic and hydrodynamic processes in the system, as demonstrated by the change in lake temperatures (Table 18) and increase in Secchi depth (Table 19). External load reduction strategies (wastewater and stormwater treatment alternatives) provide relatively modest water quality improvements while addressing some of the underlying causes of eutrophication. Note that despite most stormwater occurring during the wet season (October–April), nutrients can persist in a system; as such, the model detected minor decreases in summertime total phosphorus from stormwater treatment. Finally, floating wetlands were found to provide minor water quality improvements compared to other strategies.

Figure 28. Computational Cells for A) the Vancouver Lake Portion of the HEC-RAS 2D Domain, B) the Full Extent of the WASP Domain, and C) the Vancouver Lake Portion of the WASP Domain.

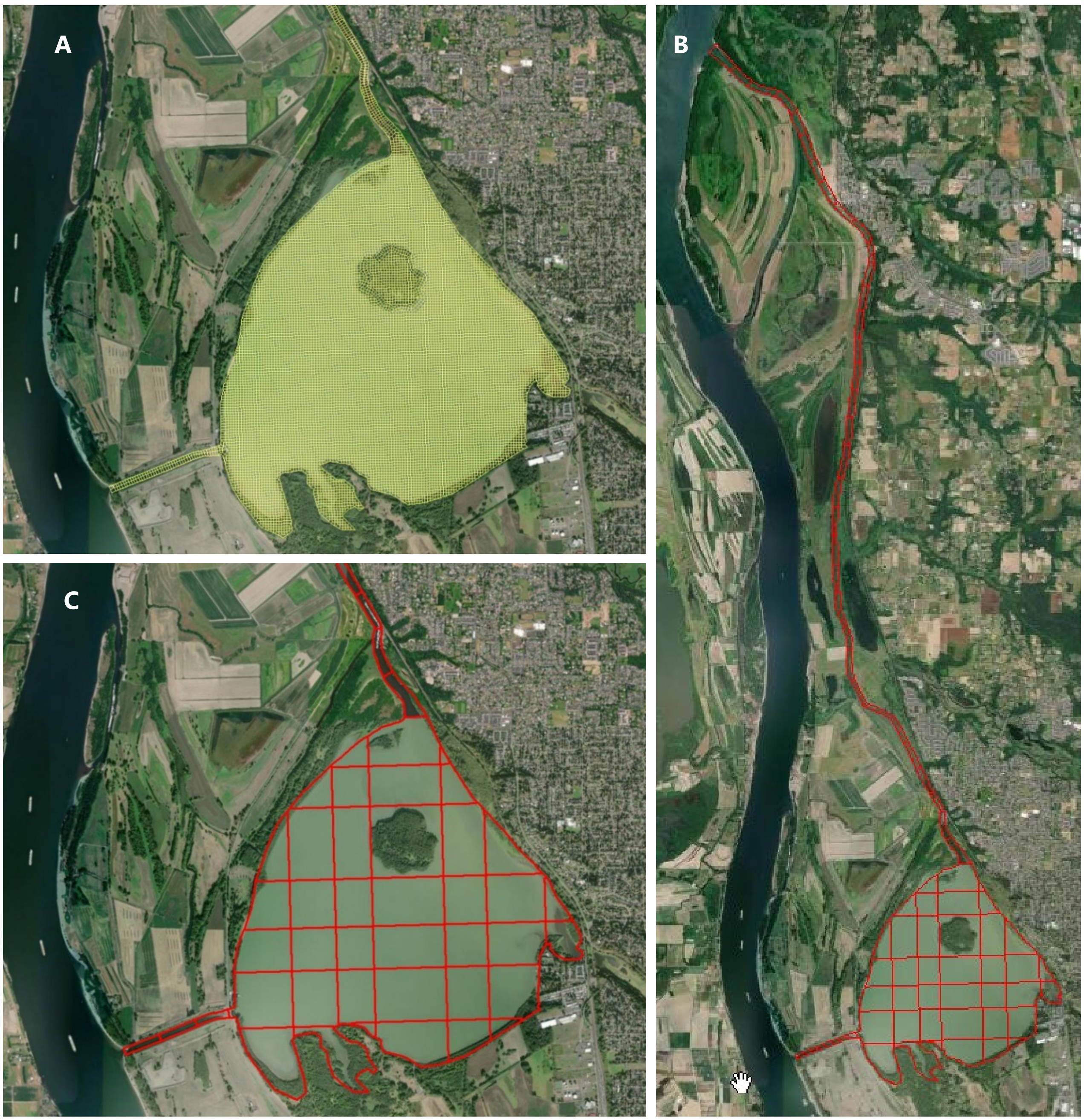


Table 16. Summer Average Chlorophyll-a Concentration and Change for Each Alternative.

Summer Average Total Chlorophyll-a (µg/L)				Percent Change		
Scenario	**2011**	**2012**	**2011–2012**	**2011**	**2012**	**2011–2012**
Calibration (baseline)	30.9	32.8	31.9	–	–	–
Wastewater Management	29.1	31.5	30.3	-6%	-4%	-5%
Stormwater Management	25.8	26.8	26.3	-16%	-18%	-17%
Lake River Dam (4 meter crest)	19.9	17.8	18.9	-35%	-46%	-41%
Lake River Dam (5 meter crest)	16.0	9.0	12.5	-48%	-73%	-61%
Flushing Channel Enlargement	16.7	22.9	19.8	-46%	-30%	-38%
Floating Wetlands	31.6	28.1	29.8	2%	-15%	-6%
Phosphorus Inactivation	13.8	14.9	14.4	-55%	-55%	-55%
Algaecide Treatment	6.5	7.9	7.2	-79%	-76%	-77%

Least Benefit Most Benefit

Table 17. Summer Maximum Cyanobacteria Concentration and Change for Each Alternative.

Summer Maximum Cyanobacteria Chlorophyll-a (mg/L)				Percent Change		
Scenario	**2011**	**2012**	**2011–2012**	**2011**	**2012**	**2011–2012**
Calibration (baseline)	51.7	56.2	56.2	–	–	–
Wastewater Management	48.9	52.3	52.3	-5%	-7%	-7%
Stormwater Management	42.1	38.0	42.1	-19%	-32%	-25%
Lake River Dam (4 meter crest)	41.3	33.8	41.3	-20%	-40%	-27%
Lake River Dam (5 meter crest)	41.1	28.6	41.1	-20%	-49%	-27%
Flushing Channel Enlargement	33.2	41.3	41.3	-36%	-27%	-27%
Floating Wetlands	51.2	49.1	51.2	-1%	-13%	-9%
Phosphorus Inactivation	23.8	21.8	23.8	-54%	-61%	-58%
Algaecide Treatment	23.1	25.3	25.3	-55%	-55%	-55%

Least Benefit Most Benefit

Table 18. Summer Maximum Temperature and Change for Each Alternative.

Summer Maximum Temperature (°C)				Percent Change		
Scenario	**2011**	**2012**	**2011–2012**	**2011**	**2012**	**2011–2012**
Calibration (Baseline)	24.8	25.6	25.6	–	–	–
Wastewater Management	24.8	25.6	25.6	0%	0%	0%
Stormwater Management	24.8	25.6	25.6	0%	0%	0%
Lake River Dam (4 meter crest)	24.0	25.0	25.0	-3%	-2%	-2%
Lake River Dam (5 meter crest)	23.7	24.8	24.8	-4%	-3%	-3%
Flushing Channel Enlargement	24.5	25.2	25.2	-1%	-2%	-2%
Floating Wetlands	24.7	25.5	25.5	0%	0%	0%
Phosphorus Inactivation	24.8	25.6	25.6	0%	0%	0%
Algaecide Treatment	24.8	25.6	25.6	0%	0%	0%

Least Benefit Most Benefit

Table 19. Summer Average Secchi Depth and Change for Each Alternative.

Summer Average Secchi Depth (meters)				Percent Change		
Scenario	**2011**	**2012**	**2011–2012**	**2011**	**2012**	**2011–2012**
Calibration (Baseline)	0.9	0.9	0.9	–	–	–
Wastewater Management	1.0	0.9	0.9	2%	2%	2%
Stormwater Management	1.0	1.0	1.0	6%	7%	7%
Lake River Dam (4 meter crest)	1.0	1.1	1.0	11%	15%	13%
Lake River Dam (5 meter crest)	1.1	1.1	1.1	15%	23%	19%
Flushing Channel Enlargement	1.4	1.3	1.4	47%	45%	46%
Floating Wetlands	1.1	1.2	1.2	21%	31%	26%
Phosphorus Inactivation	1.1	1.1	1.1	19%	22%	21%
Algaecide Treatment	1.2	1.2	1.2	25%	28%	26%

Least Benefit Most Benefit

Cost-Effectiveness Analysis

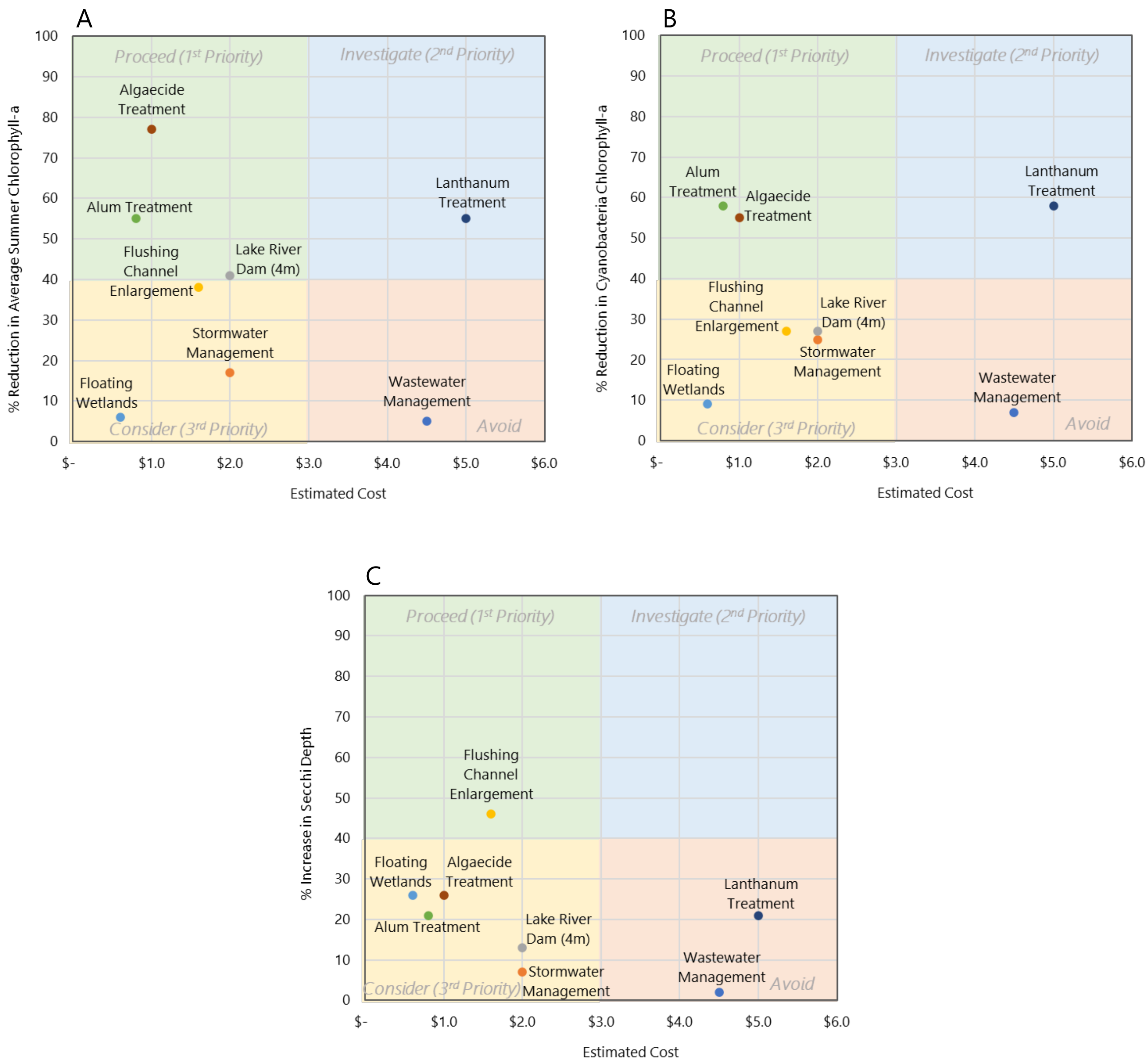
A cost-effectiveness analysis of the feasible HAB management methods was conducted by comparing the annual average cost of each method (in millions of USD) to the predicted change in three HAB benefit metrics: 1) average percent reduction in summer average chlorophyll-a concentration, 2) average percent reduction in summer maximum chlorophyll-a concentration (which represents cyanobacteria since it is the group with the greatest observed and modeled chlorophyll-a concentrations), and 3) average percent increase in average summer Secchi depth (water clarity) (Table 16, Table 17, and Table 19, respectively). The cost-benefit results are presented in panels A, B, and C of Figure 29, where:

- The most cost-efficient methods appear in the upper left quadrant (green) and represent methods that managers could *Proceed* with as a high priority management technique for the specified HAB metric.
- The second-most cost-efficient methods appear in the upper right quadrant (blue) and represent methods that should be *Investigated* for future use as a medium priority management technique for the specified HAB metric.
- The third-most cost-efficient methods appear in the lower left quadrant (yellow), and represent low risk methods that should be *Considered* for supplemental and/or future use as lower priority management techniques for the specified HAB metric.
- Inefficient methods appear in the lower-right quadrant (orange) and represent the methods that should be *Avoided* for HAB management due to high costs and low benefit.

Cost-effectiveness results show that the chemical methods of alum and algaecide treatment yield the greatest benefit in terms of chlorophyll-a and cyanobacteria reduction per dollar, followed by chemical lanthanum treatment, and next by the physical management methods of flushing channel enlargement and Lake River dam construction. Despite roughly equal cost effectiveness of these physical methods in terms of reducing chlorophyll-a and cyanobacteria, the flushing channel enlargement alternative yielded significantly greater benefit to water clarity per dollar compared to all other alternatives (Figure 29).

Due to the high costs and low benefits associated with wastewater management and lanthanum treatment for one or more HAB metrics (Figure 29), these methods are overall regarded as not cost effective. Thus, the most cost-effective HAB methods overall include alum treatment, algaecide treatment, and flushing channel enlargement.

Figure 29. A) Reduction in Summer Mean Chlorophyll-a, B) Reduction in Peak Cyanobacteria Chlorophyll-a, and C) Increase in Summer Mean Secchi Depth, per Estimated Annual Cost (in millions of USD).



Rejected HAB Management Methods

There are many other in-lake methods for controlling algae blooms that are considered inappropriate or infeasible for Vancouver Lake and were not evaluated further for this LMP. Rejected HAB management methods include but are not limited to:

- **Dredging:** Removing sediment from the lake to remove the phosphorus source and increase lake depth. Dredging is difficult to permit, prohibitively expensive particularly since hazardous substances are commonly present (approximately $200 million USD for removing an average of 2 meters of sediment over the entire lake based on a cost of $10 per cubic meter of sediment), and typically requires phosphorus inactivation or other nutrient controls to meet water quality objectives (Cooke et al. 2005; Lake Advocates 2017). Dredging occurred in Vancouver Lake in 1983 in tandem with construction of the Flushing Channel that resulted in only temporary water depth and quality improvements.

- **Dilution:** Use of a low phosphorus water supply to dilute phosphorus is likely infeasible because such a water supply does not exist or is cost prohibitive. Groundwater quality data for the watershed indicate that groundwater would not be a feasible source of dilution water due to relatively high concentrations of phosphorus.
- **Aeration or Circulation Mixing:** Installation of aerators or physical mixers (i.e., SolarBees) to mix the surface layer or entire water column to reduce cyanobacteria advantages over other algae that cannot control their buoyancy and to reduce the phosphorus supply from increased oxygen. This method is not likely to substantially reduce algae blooms in Vancouver Lake because it is very shallow and well mixed by the long wind fetch.
- **Hypolimnetic or Whole-Lake Oxygenation:** Oxygenating lake sediments to control phosphorus release from the sediments or lake waters to degrade algae cells and cyanotoxins. The lack of an anoxic hypolimnion in Vancouver Lake makes this method inappropriate and oxygenation of shallow lakes is considered experimental.
- **Hypolimnetic Withdrawal:** Withdrawing water from the hypolimnion to remove phosphorus laden water. The lack of a hypolimnion in Vancouver Lake makes this inappropriate.
- **Sonic Wave Control:** ultrasonic sound waves that create a sound barrier in the top layer of water that prevents algae from rising into the photic zone. With a maximal impact diameter of just 1,600 feet, multiple buoys would be required so application in large lakes with high recreational use is inappropriate.
- **Dye:** Coloring the lake with dye to decrease sunlight available for algae growth. Largely untested and likely very difficult to permit in natural lakes.
- **Barley Straw:** A sediment amendment that inhibits algae growth in the presence of oxygen because it favors beneficial bacteria and fungi growth over algae growth. Mechanism is poorly understood, largely untested, and difficult for a lake-wide application to a large lake.
- **Biological Methods (also known as Biomanipulation):** Manipulating the food web by adding large zooplankton to eat cyanobacteria, adding zooplankton-eating fish to decrease their predation on good algae and decrease cyanobacteria, adding fish-eating fish (piscivores) to decrease zooplankton-eating and increase cyanobacteria. Biomanipulation can also include harvesting common carp to reduce phosphorus loading from sediment disturbance and fish excrement by a dense carp population. Finally, planting aquatic macrophytes and shoreline plants is a biological method that could reduce the nutrient supply to cyanobacteria by reducing sediment disturbance and shoreline erosion. These projects are always considered experimental because of the difficulty in predicting or controlling results.

NOXIOUS WEED MANAGEMENT METHODS EVALUATION

The management of noxious weeds in Vancouver Lake was recently evaluated for preparation of the Integrated Aquatic Vegetation Management Plan (IAVMP) by Justin Collell, the Clark County Noxious Weed Board Coordinator (Collell 2020). The IAVMP is presented in Appendix B. In accordance with state guidelines (Ecology 2004), the IAVMP includes the following sections:

- Problem Statement
- Identify Management Goals
- Involve the Public
- Identify Water Body/Watershed Features
- Identify Beneficial Uses
- Map Aquatic Plants
- Characterize Aquatic Plants
- Investigate Control Alternatives
- Specify Control Areas
- Choose Integrated Treatment Scenario
- Develop Action Program.

This section of the LMP presents updates to following relevant sections of the IAVMP:

- Problem Statement and Management Goals
- Management Methods Evaluation
- Recommended Methods and Action Plan

Problem Statement and Management Goals

Noxious weed is the traditional and legal term for invasive, nonnative plants that are so aggressive they harm our local ecosystems or disrupt agricultural production. These plants crowd out the native species that fish and wildlife depend on. There are two submersed and three emergent noxious weeds known to be present in Vancouver Lake (see Table 2). The first noxious weed management goal for this LMP is to control noxious weeds in the following order of priority:

- Eurasian watermilfoil (milfoil) is a submersed aquatic plant that is the primary noxious weed of concern in the lake. Milfoil is a Class B noxious weed that is required to be controlled and it forms dense, monotypic stands that have rapidly expanded in the lake and are most impactful to lake recreation and habitat.
- Purple loosestrife is an emergent Class B noxious weed that is required to be controlled and would rapidly spread along the shoreline if not managed.
- Curly leaf pondweed is a submersed Class C noxious weed that is not as aggressive or tall as milfoil but may impact lake recreation if not managed.
- Yellow flag iris and reed canary grass are common emergent Class C noxious weeds that will spread along the shoreline without control.

The second noxious management goal is to regularly survey the lake to locate new noxious weed species in or around the lake and eradicate them before they have a chance to become established.

These goals emphasize effective ongoing control of noxious weeds and prevention, rather than eradication, to reduce risk of significant impact to ecosystem function, recreation and other lake uses. Eradication of noxious weeds, particularly in this dynamic system, is not feasible due to the high likelihood of reintroduction.

Management Methods Evaluation

The IAVMP investigated the following alternatives for controlling milfoil (in addition to a no action alternative):

1. Physical Methods:
   a. Bottom barrier
   b. Hand pulling
   c. Diver-assisted suction harvesting
   d. Mechanical harvesting
2. Biological Methods:
   a. Milfoil weevil
   b. Grass carp

3. Chemical Herbicide Methods:
    a. 2,4 D liquid
    b. Triclopyr granular and controlled release pellet
    c. ProcellaCOR liquid

Each of these alternatives were described, advantages and disadvantages were identified, costs and permitting requirements were summarized, and the appropriateness for Vancouver Lake was assessed (see Appendix B). Method descriptions and assessments are summarized in Table 20.

Other weed control methods not assessed by the IAVMP and considered inappropriate for Vancouver Lake include:

- Weed rollers: Metal rollers with tines to clear weeds within its radius as it rotates on lake bottom around a dock piling, which is rejected because there are not many docks on the lake.
- Rotovation: Vessel with submerged roller with tines to uproot plants on lake bottom, which was rejected because it creates milfoil fragments and is rarely used.
- Lake level drawdown: Lower lake level to dry out weeds exposed to air, which was rejected because drawdown of the lake is not possible and would be very impactful to aquatic biota.
- Sediment dredging: Hydraulic or clam shell sediment removal with transport to land for dewatering and disposal, which was rejected because of the high expense (as noted for HAB management).
- Shading: Adding a blue dye to water or cover with plastic balls to shade noxious weeds, which was rejected because of the aesthetic and environmental impacts.
- Planting native plants: Diver planting of native plants, which was rejected because of the high cost and limited effectiveness to prevent invasion by noxious weeds.

Table 20. Noxious Aquatic Weed Management Method Assessment.		
Method	**Description**	**Vancouver Lake Assessment**
Physical		
Bottom barrier	Permeable barrier anchored to lake bottom to prevent plant growth in up to 50 percent of shoreline. Synthetic materials must be removed every 2 years, but burlap does not require removal.	High siltation in lake promotes growth on barrier. Good for swimming beach and small portion of boat launches.
Hand pulling	Diver pulls roots and stuffs entire plant in mesh bag.	Difficult in low water clarity; best for small areas in the spring.
Diver-assisted suction dredging	Diver suctions entire plant with water pump and material is screened on a boat.	Difficult in low water clarity; best for small areas in the spring.
Mechanical harvesting	Pontoon boat with cutters down to 8 feet deep that conveys plants onto boat and then to transport trailer for composting.	Not good for milfoil due to rapid regrowth and fragment spread; also harvests insects and fish.
Chemical Herbicides		
2,4 D	Systemic herbicide effective on milfoil if sufficient contact time, selective to other broadleaf plants; fish window opens August 31; 24-hour swimming restriction in treated area.	Relatively high effectiveness but fish window restricts use until August 31 and technology replaced by triclopyr and ProcellaCOR.
Triclopyr	Systemic herbicide effective on milfoil; slow-release pellets provide needed contact time; selective to other broadleaf plants; no fish window; 12-hour swimming restriction in treated area.	Relatively high effectiveness with slow-release pellets and low impacts native species.
Florpyrauxifen-benzyl (ProcellaCOR)	Systemic herbicide effective on milfoil and requires short contact time; very selective with few other plants affected; reduced risk herbicide; no fish window; no use restrictions.	Most effective herbicide for milfoil in this lake due to short contact time.
Biological		
Milfoil weevil	Imported insects that only eat milfoil and can reproduce for a sustained low level of control.	Not allowed in Washington, due to invasive species concern.
Grass carp	Stocking of triploid (sterile) fish that eat all submersed plants.	Not possible due to lack of containment.

[a] Adapted from Vancouver Lake IAVMP (Collell 2020).

Additional herbicides not assessed by the IAVMP and considered appropriate for Vancouver Lake include fluridone, endothall, and penoxsulam. In addition to florpyrauxifen-benzyl and triclopyr, these herbicides are described as follows:

- **Florpyrauxifen-benzyl** (trade name ProcellaCOR) herbicide is a selective, systemic herbicide that is very effective when targeting milfoil. It is a broadleaf herbicide and the milfoil species are among the very few aquatic plants in the broadleaf family. As such this herbicide has no effect or impact on most native aquatic plants. It was approved by the EPA in a new category of "reduced risk" products designed to replace older technologies. ProcellaCOR can be applied without impacting most other water uses. It can be applied to potable water reservoirs without impact on delivery of drinking water. There are no swimming or fishing restrictions placed on the treated areas of a lake. There is a very short irrigation restriction if water is being drawn from the treatment area for that use. ProcellaCOR works extremely well in high water-exchange environments because of the rapid plant accumulation factor. ProcellaCOR can be used without being subject to fish timing windows.
- **Triclopyr** (trade name Renovate) herbicides are also selective, systemic herbicides with a similar mode of action to ProcelleCOR. Under the trade name Renovate, this herbicide is available as a liquid or in a controlled release pellet formulation. There is a short 12-hour swimming precaution and a short irrigation restriction. Triclopyr herbicides are not subject to a fish timing window and can be used throughout the growing season. Triclopyr herbicides also have a good fit in rotation with ProcellaCOR when annual treatment are necessary. After 2 years of ProcellaCOR application, it is recommended that a different herbicide mode of action be used to help prevent resistance in the target population.
- **Fluridone** (trade name Sonar) herbicides are very effective systemic herbicide that targets both milfoil and curly leaf pondweed. At the lower rates necessary to target these susceptible species it does not have a long-term impact on most native aquatic plant species. Fluridone has no water use restrictions, is not subject to a fish timing window, and can be used throughout the treatment season. However, Fluridone does have a long contact exposure time requirement to be effective. Target vegetation need to be subjected to 2 to 4 parts per billion for 6 to 8 weeks. This can be accomplished by treating larger blocks in a lake and using a controlled release pellet formulation with repetitive treatments. Generally, three to four applications are made at 2-week intervals. It can be cost effective when conditions are right for its use (e.g., shallow lakes with low flushing rates and multiple target species).
- **Endothall** (trade name Aquathol) herbicides. Endothall is a very effective contact herbicide with excellent activity on both milfoil and curly leaf pondweed. There is a 24-hour swimming restriction within the treatment areas and there are no irrigation restrictions. Endothall herbicides are subject to fish timing windows, which can delay their use until later in the summer. The fish timing window in Vancouver Lake is August 31 through December 31, which severely limits its usefulness. For example, curly leaf pondweed produces turions that become next year's plants. Treating after August 31 would occur after turion formation and would not impact next year's growth from the surviving turions.
- **Penoxsulam** (trade name Galleon) herbicide is another reduced risk herbicide and can be used with no water use restrictions. Galleon is not subject to a fish timing window. Galleon is extremely effective against curly leaf pondweed at low application rates. It will stop turion formation within

23 hours of application and control the plants over the course of 3 to 4 weeks. It is also systemic, killing the roots in addition to the stems and leaves. Galleon does have activity on milfoil at higher application rates. The rates used are dependent on the size of the treatment area. Larger treatment areas reduce the application rate required and the cost substantially.

Table 21 summarizes permitting requirements for the physical methods (WDFW 2015).

Chemical herbicides are permitted by separate permits for submersed and emergent weed control. Submersed weed control is covered by Ecology's Aquatic Plants and Algae Management (APAM) Permit, which is (Ecology 2022b). Emergent weed control is covered by Ecology's Aquatic Noxious Weed Management (ANWM) General Permit (Ecology 2019). Both permits are a combined federal National Pollutant Discharge Elimination System (NPDES) and State Waste Discharge General Permit. Ecology has developed and issued Environmental Impact Statements for these herbicides assessing the probable significant environmental impacts from the active ingredients conditionally authorized for use in the permits. Using these documents, associated supplements, risk assessments, and staff best professional judgement as guidance, Ecology conditioned the use of all herbicides in the permits to mitigate potential significant environmental impacts of concern noted in the environmental and human health evaluations required under the State Environmental Policy Act (SEPA). Herbicide applications are subject to WDFW's treatment timing window for fish and/or wildlife that allows application only from June 1 to December 31 for Vancouver Lake for protection of the specified sensitive species. No significant impacts to aquatic life are anticipated if the chemical herbicides are properly applied in accordance the APAM permit and treatment timing window.

Table 21. Permit Requirements for Physical Control of Aquatic Plants.

Control Method	Aquatic Noxious Weed Permit Requirement			Aquatic Beneficial Plants Permit Requirement		
	Pamphlet without Area Limitations	Pamphlet with Area Limitations	Individual HPA	Pamphlet without Area Limitations	Pamphlet with Area Limitations	Individual HPA
Removal by Hand	✔				✔	
Bottom Barriers and Screens		✔			✔	
Weed Rolling		✔				✔
Mechanical Harvesting and Cutting	✔					✔
Rotovation			✔			✔
Diver-operated Dredging	✔					✔
Other Dredging			✔			✔
Water Level Manipulation			✔			✔

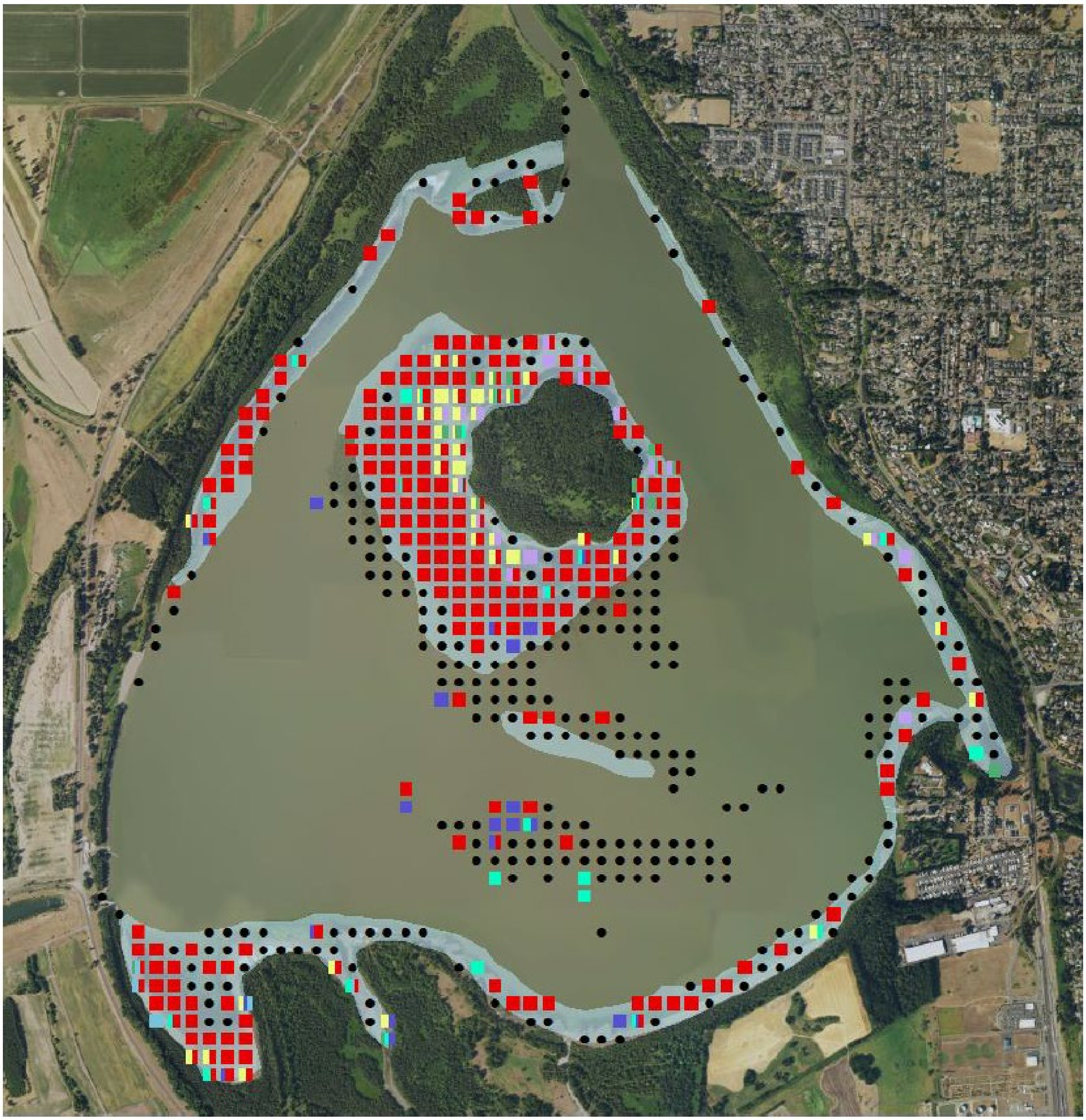
Source: WDFW 2015

HPA = Hydraulic Project Approval

The Vancouver Lake IAVMP selected an integrated treatment scenario to be implemented from June 2020 through September 2022. The treatment scenario targeted milfoil and was a follow-up to initial treatment actions by FOVL (not included in the IAVMP) in the spring of 2020 that applied the selective herbicide ProcellaCOR to approximately 700 acres of the lake. The impacted and targeted treatment area is shown in Figure 30.

Figure 30. Milfoil Impacted and Targeted Treatment Areas in Vancouver Lake.

Source: Collell 2020. Red blocks indicate milfoil was observed while small black circles indicate no plants were observed by the state and county survey. Shaded white area indicates targeted treatment area of 614 acres.



Clark County was awarded $45,000 from the Washington, Department of Ecology's Aquatic Invasive Plants Management Grants Program to help fund the initial 2-year IAVMP to include monitoring and additional treatment of milfoil. As per the IAVMP, Clark County and project partners performed follow-up plant surveys in the summers of 2021 and 2022 to prepare maps and establish the extent of control achieved. Available funding was not sufficient to support another large treatment of the lake. However, follow-up spot treatments in selected areas were planned for 2020, 2021, or 2022 based on survey results. Clark County has since pledged an additional $25,000 for milfoil treatment that has not been used to date.

According to the IAVMP, if sufficient initial control was provided by the FOVL ProcellaCOR treatment and follow-up spot treatments, the steering group would consider installation of bottom barriers in high-priority areas at or near water recreation access sites. Barrier installation would be approached as a pilot effort to evaluate effectiveness and maintenance costs.

To achieve and maintain low levels of milfoil and other aquatic noxious weeds, long-term funding was recommended by the IAVMP. A lake management district to address aquatic noxious weeds was identified as one possible funding option. IAVMP partners had raised funding from non-continuous sources (i.e., donations, grants, volunteers). Public and private stakeholders, lake users, and lakefront public/private property owners would need to evaluate the need for ongoing noxious weed control in and around Vancouver Lake and develop funding strategies accordingly (Collell 2020).

If aquatic noxious weeds do not significantly interfere with public recreation, then public recreation opportunities were considered protected by the IAVMP. Native plants will not be targeted for control regardless of recreation impacts according to the IAVMP. Since the reintroduction of milfoil from all three infested and connected water bodies (Columbia River, Lake River, and Burnt Bridge Creek) is very likely, aquatic plant management will continually need to be adjusted to find the best long-term, economical strategy that maintains recreation opportunities despite the threat of reintroduction (Collell 2020). The IAVMP identified indicators for habitat improvement using survey data that include a declining milfoil frequency and increasing native aquatic plant species diversity, which would serve as an indicator that milfoil is not outcompeting these valuable plants.

The IAVMP did not specify plans to manage other noxious weeds identified in the lake that include (see Table 2):

1. Curly leaf pondweed (*Potamogeton crispus*), a submersed Class C noxious weed <u>not required</u> for control by Clark County.
2. Purple loosestrife (*Lythrum salicaria*), an emergent Class B noxious weed <u>required</u> for control by Clark County.
3. Yellow flag iris (*Iris pseudacorus*), an emergent Class C noxious weed <u>required</u> for control by Clark County.
4. Reed canary grass (*Phalaris arundinacea*), an emergent Class C noxious weed <u>not required</u> for control by Clark County.
5. Creeping loosestrife (*Lysimachia nummularia*), an emergent noxious weed on the monitor list <u>not required</u> for control by Clark County.

Purple loosestrife and yellow flag iris are two emergent plants that grow in some areas of the shoreline and are required to be controlled by the Clark County Noxious Weed Board. Curly leaf pondweed is a submersed plant that does not require control but is a noxious weed that may interfere with recreation because it is not impacted by ProcellaCOR. FOVL contracted with Aquatechnex to survey curly leaf pondweed in the lake in 2022 and possibly treat it. However, no treatment was conducted because the plant survey in May 2022 observed lower density and height of curly leaf pondweed than in 2021, which may have been due to unusually high lake level and cool temperatures in May 2022 (T. McNabb, Aquatechnex, personal communication).

This information is used below in the Noxious Weed Management Plan where recommended actions for noxious weed control are briefly described separately for submersed and emergent noxious weeds. Monitoring and reporting associated with these control actions are summarized, and a framework for preventing aquatic invasive species infestation of the lake and involving the public is also provided.

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ADDITIONAL LAKE ISSUES

FOVL and other TAG members identified additional issues of concern to lake users that are not directly related to toxic algae or noxious weeds. These issues are identified below for analysis and management evaluation in future versions of the LMP.

Water and Sediment Quality

Water and sediment quality issues not directly addressed in this plan include:

- Fecal Bacteria. High fecal bacteria concentrations in the lake are an issue because they present a public health risk and cause beach closures. Short-term control of toxic cyanobacteria at the swimming beach using algaecides is included in the recommended HAB Management Plan below. Algaecides also kill fecal bacteria and could be used to re-open beaches that are closed due to concentrations exceeding Clark County Public Health criteria. In addition, these criteria could be revised to follow criteria that are less stringent yet still protective of public health, used by King County and others. Clark County indicated that waterfowl likely are the primary source of the fecal bacteria but further study using microbial source tracking could be performed to verify the major sources of fecal bacteria in the lake. The efficacy of waterfowl deterrent methods (e.g., lasers, noise, and decoys) and their detriments (e.g., risks to non-target organisms) could be investigated as a potential source control method. Additionally, future lake management should consider developing partnerships with Clark Conservation District and other relevant entities to encourage best practices, promote education, and provide financial assistance where applicable. See Poops Smart Clark <https://poopsmartclark.org/> for fecal bacteria control efforts and partners in Clark County.
- Suspended Sediment. Low water clarity and high turbidity caused by suspended sediment is in part is due to bioturbation from carp. Suspended sediment is an issue because in addition to being a nutrient source for toxic cyanobacteria, it can negatively impact aesthetics, safety for lake users, and some fish and wildlife uses. The relative importance of these impacts, the impacts of sustained sediment resuspension on chemical HAB management techniques, and the effects of HAB management on non-algal turbidity could be further explored.
- Toxic Substances. The presence of toxic contaminants in fish tissue has resulted in 303(d) listings of lake impairment by Ecology for methyl mercury, PCBs, and the pesticide toxaphene. Historical deposits of these chemicals and other toxic substances in the lake have accumulated in lake sediments and are biologically available to other aquatic organisms. The relative importance of these sediment contaminants and other types of lake contamination (e.g., microplastics, 6PPD-q, PFAS, etc.) and potential remedial actions could be further explored.

Fish and Wildlife Habitat

Fish and wildlife habitat issues not directly addressed in this plan include:

- **Warm Water Temperatures.** High water temperatures in the lake impact salmonid use of this system, particularly during the spring outmigration associated with the spring feshet (snowmelt). Water quality modeling results suggest that summer maximum temperatures would be reduced by less than 5 percent by the Lake River dam and Flushing Channel enlargement alternatives, and would not be affected by any other HAB management methods. The lake model could be used to evaluate potential benefits of variations in these physical management methods on water temperatures in the lake, downstream in Lake River, and during the critical spring outmigration period.
- **Invasive Animal Species.** Common European carp are abundant in Vancouver Lake and they impact fish and wildlife habitat in addition to water quality. The presence and impacts of these and other invasive aquatic animals are not well known and could be further explored. Box nets have been shown to be an effective carp removal method in Minnesota <https://www.capitolregionwd.org/carp-removal/; https://www.dnr.state.mn.us/invasives/ais/invasive-carp-modified-unified-method.html> and elsewhere and could be considered in the future
- **Ecosystem Functions.** Ecosystem functions of the lake and adjacent wetlands and floodplain are impacted by human uses. The level of impairment and effectiveness of restoration methods could be evaluated in the future. More work will be needed to restore healthy, functioning habitat for fish and wildlife, and understand effects of the proposed actions in this LMP on cultural resources, threatened and endangered species, birds, and water quality of connected water bodies prior to implementation.

Public Access and Recreation

Public access and recreation issues not directly addressed in this plan include:

- **Low Water Depths.** The lowering of lake levels as the summer progresses restricts access to a large portion of the lake due to shallow water. Impacts of low lake levels to various recreation activities, predictions of future lowering due to climate change, and methods and benefits for increasing lake levels could be evaluated for a future version of the LMP.
- **Lack of Public Access.** Public access to Vancouver Lake is very limited, especially considering the large lake area. Equitable public access needs and opportunities could be evaluated for a future version of the LMP.

Climate Change Impacts Analysis and Mitigation

The impacts of climate change on Vancouver Lake water quality, habitats, fish and wildlife, public access, and recreation have not been studied. An analysis of current and future needs with respect to mitigating negative impacts from climate change could be evaluated in future versions of the LMP, with particular attention given to the needs of historically underserved communities.

RECOMMENDED LAKE MANAGEMENT PLAN

The recommended lake management plan is presented separately for HAB management and noxious weed management. Each recommended element of these plans briefly describe:

- How this element will be implemented and the timing of implementation
- Estimated effectiveness and longevity of the element
- Potential adverse effects on zooplankton, fish, and wildlife
- Potential impacts on lake users and the downstream watershed
- Costs of implementation and maintenance

HAB Management Plan

The recommended HAB management plan includes the following elements to be further evaluated and implemented based on available funding:

- Flushing channel enlargement for long-term reductions in the frequency and magnitude of HABs.
- Ongoing wastewater and stormwater management for long-term reductions in nutrient loading to the lake.
- Annual water stripping of phosphorus using alum treatments is recommended as a short-term HAB control option for the entire lake as needed either prior to or following construction of the flushing channel.
- Beach algaecide treatments are recommended for short-term control of HABs and fecal bacteria in impacted areas of the lake as needed either prior to or following construction of the flushing channel.
- Monitoring and reporting is recommended to evaluate effectiveness of the HAB management elements, fill data gaps for improved understanding of HABs, and develop adaptive management strategies to better meet water quality objectives.
- Adaptive management methods to regularly reassess and amend the LMP as part of ongoing, adaptive lake management practices, pursuant to future lake needs, input from stakeholders, and funding.

Flushing Channel Enlargement

The flushing channel enlargement alternative is recommended for long-term HAB control for the following reasons:

- It is preferred over the more effective and less expensive algaecide and alum treatment alternatives because it is more sustainable long-term, presents a lower risk for aquatic biota impacts, and requires less ongoing management.
- It is preferred over the Lake River Dam alternative because it is expected to have a similar level of HAB control, is slightly less expensive, and is more feasible to permit and construct.
- It is expected to result in the greatest increase in water clarity (46 percent) compared to all other alternatives (2 to 26 percent).
- It was selected as the preferred alternative by many members of the TAG.
- Environmental impacts from channel construction are not expected to be significant.
- Channel operation is expected to have the greatest benefit to salmon of any alternative because of the increased connectivity with the Columbia River and greater flows from the increased river input.

Flushing channel enlargement issues to be addressed include an assessment of potential impacts; mitigation measures; public buy-in for improvements to a solution that historically underperformed because it was undersized; permitting issues associated with endangered salmon migration, endangered sandhill crane habitat, and waterfowl breeding habitat; and the potential increased risk of invasive species introductions from the Columbia River. Design and construction method alternatives should be further explored and should include an environmental assessment.

For budgeting purposes, a budget of $32.7 million (see Table 10) or $1.6 million per year over 20 years is allocated for the flushing channel enlargement.

Watershed Management

Although wastewater and stormwater management alternatives are expensive and not as cost-effective at HAB control as other alternatives because nutrient inputs are substantially less than from other sources, it is recommended to continue with ongoing septic system connection and stormwater treatment actions in the Vancouver Lake watershed. Enhancement of existing City of Vancouver and Clark County watershed management programs and budgets should be implemented to provide long-term nutrient reductions and water quality improvement, supplementary to the other HAB management actions recommended herein, and protect the efficacy of other significant HAB control investments.

Septic system connection program and budget enhancements should include:

- Improvements to the prioritization strategy for sewer system connections by enhancing ability to detect failing systems or those with a high potential for leaching nutrients into receiving waters, by:

- Increasing septic system survey frequency, which could in-part be achieved through partnerships with Clark Conservation District and others with Poops Smart Clark <https://poopsmartclark.org/>
- Improving survey methodology (e.g., microbial source tracking)
- Identifying and prioritizing high-risk systems based on old age, poor soils, close proximity to groundwater, close proximity to surface water, or other factors not meeting current or revised septic system design code

- Revisions to the current septic system design code to increase protection of surface water and groundwater, by:
  - Increasing restrictions on acceptable soil types and proximity to surface and groundwater
  - Increasing inspection and maintenance requirements
- Increasing individual property connections to the expanded sewer system through enhanced financial incentives or regulatory mandates, and/or increasing the rate of maintenance and repair of individual systems through partnerships with Clark Conservation District and others.

Stormwater treatment program enhancements and budgets should include:

- Revisions to the current City and County stormwater policy and code to require phosphorus treatment for all new development and redevelopment projects in the Vancouver Lake watershed (with costs incurred by the development projects), by:
  - Declaring the lake as a sensitive water body to phosphorus inputs
  - Getting Ecology, City, and County approval of this LMP to form the basis for the sensitive water body declaration and phosphorus treatment requirement in accordance with the Stormwater Management Manual for Western Washington (Ecology 2019).
- Prioritization of the Vancouver Lake watershed for the stormwater retrofit activities planned by the City and County to be implemented as required by their NPDES permits for constructing green stormwater infrastructure, and incorporate large, regional phosphorus treatment facilities as appropriate in those plans.

For budgeting purposes, $10,000 per year is allocated to a staff person to promote watershed management activities by Clark County and the City of Vancouver.

Alum Treatment

A low-dose alum treatment to strip the water column of phosphorus is recommended for controlling lake-wide HABs before the flushing channel enlargement is constructed, and should be considered as a backup strategy if HABs occur after the flushing channel enlargement. In accordance with Scenario 3 described in the Chemical Management Methods section above, the alum treatment should increase the dose by 20 percent from that based on 2011–2012 lake phosphorus concentrations to achieve a lake-wide average dose of 3.3 mg Al/L and inactivate higher lake phosphorus concentrations in future years. A sodium aluminate buffer should not be needed to buffer this small amount of alum, since this dose is 10 percent of the 33.5 mg Al/L dose required to inactivate sediment phosphorus in Vancouver Lake and commonly used in other western Washington lakes.

The alum should be applied in June when the entire lake is accessible at high water levels, before cyanobacteria bloom, and after the treatment timing window opens June 1 for priority wildlife species (Ecology 2021). Although alum does not trigger a treatment timing window for fish species, this is also a good time to minimize a potential risk for aluminum toxicity to salmon. It is anticipated that one treatment in June will be sufficient to suppress the cyanobacteria bloom later in the summer. Treatment timing could be adjusted in future years depending on the effects observed in the first year and would be subject to a formal SEPA review if an application is to occur outside of the existing June 1–December 31 window for Vancouver Lake.

The application must comply with permit requirements to prevent aluminum toxicity by only treating when the lake pH is between 6.0 and 8.5. Water quality monitoring shall include jar tests on site to measure pH and phosphorus effects of the alum dose prior to treatment, continuous pH monitoring during the treatment to terminate treatment if criteria are not met, and intensive water quality monitoring at multiple locations for various parameters before and after the treatment to evaluate water quality effects and aluminum toxicity. Alum application must cease when wind speed exceeds 15 mph. Additionally, the impacts of sustained sediment resuspension following the application (such as by wind or carp bioturbation) on treatment effectiveness should be considered prior to application.

A whole-lake, low-dose alum treatment is recommended over a combination water stripping and sediment inactivation because it is more cost effective. Cost for a low-dose treatment is estimated at $830,000, which is approximately 10 percent of the dose (33.5 mg Al/L) and the cost ($8.2 million) of a water stripping and sediment inactivation dose using buffered alum, which is not likely to last for more than 5 years due to the high external phosphorus loading rate.

A whole-lake, low-dose alum treatment is recommended over a whole-lake algaecide treatment because algaecide treatments present a greater risk to toxicity for some zooplankton, other invertebrates, and fish. Also, alum treatments last much longer than algaecides because they remove phosphorus from the water column, whereas algaecides release available phosphorus into the water from algae cell lysis. At least two algaecide treatments are expected to be needed in a summer. Assuming two algaecide treatments or one alum treatment in a summer, algaecide treatments are estimated to cost about 10 percent more than a low-dose alum treatment.

For budgeting purposes, it is assumed that only one low-dose alum treatment would be applied while the flushing channel is being built and would not be needed after channel construction. The proposed LMP budget includes $1 million for one treatment, based on the application cost estimate of $830,610 plus 30 percent for planning, permitting, monitoring, and reporting. LMP contingency funds could be used if additional alum treatments are needed.

Beach Algaecide Treatment

A beach algaecide treatment is recommended for controlling localized HABs before the flushing channel enlargement is constructed, and should be considered for backup if HABs occur after the flushing channel enlargement. This could be used as a lower cost and less effective alternative to the whole-lake, low-dose alum treatment described above. A beach algaecide treatment would be initiated in response to a beach closure caused by exceedance of either the cyanotoxin or fecal bacteria criteria established by the Clark County Public Health Swim Beach Program.

Sodium carbonate peroxyhydrate (Phycomycin or PAK 27) would be applied to the lake in the vicinity of the cyanobacteria scum and elevated cyanotoxin or fecal bacteria concentrations. The application would comply with permit requirements that include a treatment timing window from June 1 to December 31 for priority wildlife species (Ecology 2021). Sodium carbonate peroxyhydrate has no other permit restrictions and does not trigger a treatment timing window for fish species.

Algaecide treatment effectiveness will vary with the size and timing of the cyanobacteria bloom or fecal bacteria source. It is anticipated that algae and bacteria control would last for at least 2 weeks if the algae scum and fecal sources are localized and not present across the entire lake. This would allow enough time for obtaining negative test results for two consecutive weekly sampling events to open the beach in accordance with Swim Beach Program protocols. In addition, the time between testing could be shortened to obtain two negative tests shortly before any important and widely attended community events (e.g., rowing competitions). Installation of a turbidity curtain or bubble curtain around the swimming area should be considered to reduce the treatment area and extend treatment effectiveness.

For budgeting purposes, it is assumed that sodium carbonate peroxyhydrate (Phycomycin or PAK 27) would be applied to 20 acres at a cost of $250/acre on 10 occasions for a total of $50,000 over the 20-year LMP period.

Monitoring and Reporting

Establishing a routine water quality monitoring program for Vancouver Lake is essential for evaluating effects of lake management and long-term trends. At a minimum, the monitoring program should include the following elements, as performed by volunteer lake monitoring programs successfully conducted for lakes in King and Snohomish counties:

- Monitoring twice each month from May through October for a total of 12 events each year
- Multimeter profiles of temperature, dissolved oxygen, pH, conductivity, and turbidity, and measurement of Secchi depth in the field.
- Collection and laboratory analysis of water samples from 1 meter depth for chlorophyll-a and nutrients (total phosphorus, soluble reactive phosphorus, total nitrogen, and nitrate+nitrite nitrogen).

- Analysis of phytoplankton and zooplankton samples is also recommended for all or half of the monitoring events (i.e., monthly May–October) for comparison to historical plankton data collected by WSU Vancouver.

This monitoring program should occur near historically monitored sites (e.g., the "Lake 2" station located along the east shoreline or at the end of the VLSC dock) to remain comparable to historical datasets.

Additionally, we recommend a new monitoring program at the swimming beach to continuously monitor conditions where risk of human exposure and impact is typically greatest, with continuous data uploading to a web dashboard (e.g., using an AlgaeTracker [AquaRealTime 2023]). AlgaeTracker monitoring in the beach surface waters should include the following parameters:

- Chlorophyll-a
- Phycocyanin (cyanobacteria pigment)
- Turbidity
- Air and water temperature
- Ambient light
- Precipitation, wind speed/direction uploaded from a nearby weather station

AlgaeTracker

The collected data should be analyzed and reported at the end of each monitoring season. The report should include seasonal and long-term trend analysis and graphical presentation of the collected data. Water quality data should be evaluated for relationships with climate data, lake level and flushing data, and lake and watershed management actions. The report should recommend potential changes in monitoring procedures and management actions.

Special studies should be considered for improving accuracy of the lake water quality model and understanding of HAB conditions and drivers, or for investigating other lake concerns as they arise.

It is recommended that the routine lake monitoring program be conducted by WSU Vancouver, or a volunteer lake stewardship program established by Clark County. Special studies may be implemented by WSU Vancouver, Clark County, or a consultant.

For budgeting purposes, it is assumed that the routine lake monitoring program would cost $45,000 each year and special studies would cost an average of $30,000 each year for a total average annual cost of $75,000 per year.

Cost Estimate

The cost estimate for the recommended HAB management program is presented in Table 22. A budget of $39 million should be planned for a 20-year period, which equates to $2 million as an annual average.

Table 22. HAB Management Cost Estimate.		
HAB Management Element	**20-Year Cost**	**Average Annual Cost**
Flushing Channel Enlargement		
Construction	$16,660,000	$833,000
Contingency/Tax	$6,690,000	$334,500
Design/Permitting/O&M	$9,340,000	$467,000
Total	$32,690,000	$1,634,500
Watershed Management	$200,000	$10,000
Alum Treatment	$1,000,000	$50,000
Beach Algaecide Treatments	$50,000	$2,500
Monitoring and Reporting	$1,500,000	$75,000
Total Cost	**$35,440,000**	**$1,772,000**
Contingency (10 percent)	$3,544,000	$177,200
Total Budget	**$38,984,000**	**$1,949,200**

Noxious Weed Management Plan

Recommended actions for noxious weed control are briefly described separately for submersed and emergent noxious weeds. Monitoring and reporting associated with these control actions are then summarized. In addition, a framework is provided for preventing aquatic invasive species infestation of the lake and involving the public that should be further developed with stakeholders. A cost estimate concludes this recommended noxious weed management plan.

Chemical herbicides are recommended for noxious weed control because they are most cost effective and considered safe to fish, wildlife, and human health. Ecology has conditioned the use of all recommended herbicides in the APAM permit for in-water applications for submersed weed control and the ANWM permit for emergent weed control to mitigate potential significant environmental impacts of concern noted in the environmental and human health evaluations required under SEPA. The herbicide applications are subject to WDFW’s treatment timing window for fish and/or wildlife that allows application only from June 1 to December 31 for Vancouver Lake for protection of the specified sensitive species. No significant impacts to aquatic life are anticipated if the chemical herbicides are properly applied in accordance the APAM permit and treatment timing window.

Future adaptations of this LMP may consider sustainable alternatives to long-term herbicide treatment, if applicable, such as restoring the natural and dynamic processes through floodplain reconnection.

Submersed Weed Control

Eurasian Watermilfoil

Eurasian watermilfoil (*Myriophyllum spicatum*) was controlled by an application of ProcellaCOR to 700 infested acres of the lake in 2020. No milfoil plants were observed in the lake during the summer of 2021 and scattered small patches of milfoil were observed in shallow waters west of the island in 2022. It is anticipated that those small patches will rapidly expand in 2023 and subsequent years if left untreated.

A detailed survey should be performed early in the growing season (e.g., May) in first year of this plan and those acres containing milfoil plants should be targeted using ProcellaCOR in June when plant growth is active and the lake levels are still high enough to access plants in shallow areas. This pre-treatment survey should be followed by a post-treatment survey in late summer to evaluate treatment effectiveness. After that, surveys should be performed periodically and the milfoil found should be treated with ProcellaCOR, or an alternative herbicide if signs of resistance are observed. Survey methods are described below in the Monitoring and Reporting section.

It is recommended that a treatment be performed if the milfoil plants within 2 feet of the lake surface cover more than 2 acres, but treatment recommendations may vary depending on the observed conditions. For budgeting purposes, it is assumed that a ProcellaCOR treatment will be performed over an average of 50 acres once every 3 years for a total of seven treatments in a period of 20 years at an estimated cost of $525.00 per treated acre.

Curly Leaf Pondweed

Curly leaf pondweed (*Potamogeton crispus*) was observed in the lake during the summer of 2019 by Ecology and again during the milfoil treatment in 2020. In the summer of 2021, these plant beds expanded significantly. However, observations in the early summer of 2022 found no curly leaf pondweed, likely due to the high lake level as noted above.

A detailed survey should be performed early in the growing season (e.g., May) in the first year of this plan, and results shared with Clark County Noxious Weed Management. Those acres containing curly leaf pondweed should be treated with penoxsulam (Galleon SC) in June before turions have been produced and while lake levels are still high enough to access plants in shallow areas by boat. A key to long-term control of this species is to kill the plant prior to turion production in the summer. One plant can generate a significant amount of turions, which are reproductive structures that sprout into new plants the following year. In subsequent years surveys should be performed periodically, and the curly leaf pondweed found should be treated with penoxsulam (Galleon SC).

It is recommended that a treatment be performed if the pondweed plants within 2 feet of the lake surface cover more than 2 acres, but treatment recommendations may vary depending on the observed conditions. The cost of application depends on the size of the treatment areas. Galleon has a longer contact exposure time requirement so higher rates are necessary in smaller treatment plots. Herbicide costs per treated acre range from $900 when targeting less than 5 acres in one treatment plot to $400 per acre when the treatment plot is greater than 15 acres. For budgeting purposes, it is assumed that a penoxsulam (Galleon SC) treatment will be performed over an average of 20 acres once every 3 years, for a total of seven treatments in a period of 20 years, at an estimated cost of $900 per treated acre.

Other Submersed and Floating-Leaved Noxious Weeds

Milfoil and curly leaf pondweed surveys should include observation and sampling for identifying the presence of introduced species of other invasive submersed or floating-leaved plants in Vancouver Lake. Freshwater submersed and floating-leaved noxious weeds to look for include:

- Hydrilla (*Hydrilla verticillate*) (Class A)
- Variable-leaf milfoil (*Myriophyllum heterophyllum*) (Class A)
- Brazilian elodea (*Egeria densa*) (Class B)
- Parrotfeather (*Myriophyllum aquaticum*) (Class B)
- Yellow floating heart (*Nymphoides peltata*) (Class B)
- Fragrant waterlily (*Nymphaea odorata*) (Class C)

Any new noxious weed identified in the lake should be controlled as soon as possible with intent to eradicate if the population is relatively small. Herbicides and diver hand-pulling or suction harvesting should be considered for potential control methods to implement depending on the conditions and ability to employ the method within months of observation. Additional costs for control of introduced species have not been estimated or included in the noxious weed management budget because they are assumed to be relatively low, and control of small infestations could be accomplished within the milfoil and curly leaf pondweed management budget.

Emergent Weed Control

Purple Loosestrife and Yellow Flag Iris

Two emergent weeds requiring control by Clark County have been observed in Vancouver Lake include purple loosestrife (*Lythrum salica*ria) (Class B), which is primarily located near Burnt Bridge Creek, and yellow flag iris *(Iris pseudacorus*) (Class C), which is distributed throughout the lake shore. In addition, reed canarygrass (*Phalaris arundina*cea) (Class C) is also present throughout the lake shore but is not required for control and is abundant in Washington. Maps showing locations of these observed species are not available.

Emergent weed survey and control should be performed early in the growing season (e.g., May or June) in first year to map and apply herbicide to purple loosestrife and yellow flag iris plants growing along the lake shoreline. The survey should be conducted using an airboat to access the shallow waters along the shoreline when the lake level is high, and results shared with Clark County Noxious Weed Management. It is also important to control these plants early in the season before they produce seeds to spread the populations. As the boat travels along the shoreline, observed weed locations should be recorded by GPS and the plants sprayed with an approved aquatic herbicide.

These populations are generally treated effectively with a spot spray solution of 2 percent glyphosate and an aquatic surfactant. This work is conducted under a separate Ecology NPDES permit for noxious emergent weeds called the Aquatic Noxious Weed Management General Permit. This permit is less restrictive and has fewer notification requirements than the NPDES Aquatic Plant and Algae Management Permit. The Aquatic Noxious Weed Management General Permit is obtained by requesting coverage from the Washington State Department of Agriculture, which holds the general permit for this work.

Generally, emergent plant control is not priced on a per-acre basis because of the scattered nature of the infestations. There are typically only a few plants scattered along the shoreline and a spray tank with the herbicide solution will go a long way. A daily rate for herbicide, adjuvant, airboat, and treatment crew is approximately $3,500. It is likely that the entire shoreline accessible by airboat could be targeted in 1 day.

Additional control from land may be needed if purple loosestrife or yellow flag iris are observed growing upland of airboat-accessible portions of the lake shoreline. Upland infested areas should be accessed with an ATV and backpack sprayer later in the summer when the lake level is low and soils have dewatered. It is recommended to plan for up to 2 days of upland emergent weed mapping and control due to difficulties with site access. Costs for upland emergent weed control are estimated at $1,750 per day for equipment, material, and labor, and to include a mobilization fee of $500.

Post-treatment surveying of emergent noxious weeds is not recommended because most shoreline treatment areas will not be accessible by boat and the upland treatment areas will be treated late in the summer. Treatment effectiveness should be assessed in subsequent early summer surveys.

For budgeting purposes, it is assumed that emergent weed control will occur an average of once every 3 years for a total of seven treatments in a period of 20 years at a total cost of $52,500 based on $7,500 per treatment year, which includes 1 day of shoreline treatment at $3,500 and 2 days of upland treatment at $4,000.

Other Emergent Noxious Weeds

Other emergent noxious weeds should be identified and mapped during the purple loosestrife and yellow flag iris control activities. Class A and B emergent noxious weeds to look for include:

- Floating primrose-willow (*Ludwigia peploides*) (Class A)
- Flowering rush (*Butomus umbellatus*) (Class A)
- Reed Sweetgrass (*Glyceria maxima*) (Class A)
- Common reed (nonnative genotypes only) (*Phragmites australis*) (Class B)
- Garden loosestrife (*Lysimachia vulgaris*) (Class B)
- Grass-leaved arrowhead (*Sagittaria graminea*) (Class B)

- Knotweed, bohemian (*Fallopia bohemica*) (Class B)
- Knotweed, giant (*Fallopia sachalinensis*) (Class B)
- Knotweed, Himalayan (*Persicaria wallichii*) (Class B)
- Knotweed, Japanese (*Fallopia japonica*) (Class B)
- Water primrose-willow (*Ludwigia hexapetala*) (Class B)

Any new Class A or B noxious weed identified during survey and control activities should be controlled as soon as possible with intent to eradicate if the population is relatively small. Class A weeds have a higher priority than Class C weeds. Herbicides and hand removal pulling should be considered for potential control methods to implement depending on the conditions and ability to employ the method within months of observation. Additional costs for control of new emergent species have not been estimated or included in the noxious weed management budget because they are assumed to be relatively low and control of small infestations could be accomplished within the purple loosestrife and yellow flag iris management budget.

Control of reed canarygrass and other Class C weeds is not included in this LMP because control of Class C weeds is not required by law and is less important than control of the more invasive and rare Class A and B weeds. However, it is recommended that emergent weed mapping include identifying locations of all Class C weeds for consideration of future control based on their extent and impacts to native plant populations.

Monitoring and Reporting

The submersed and floating-leaved weed surveys should include collection of data to prepare aquatic plant density and weed location maps representing pre-treatment conditions early in the season, plus post-treatment conditions at the end of summer as specified. Sonar equipment should be deployed along transects up to 100 feet apart to record submersed plant height and relative biovolume. The sonar data should be processed to produce a map showing colors of relative plant biovolume occupying 0 percent (green) to 100 percent (red) of the water column in the entire lake. A second map should be prepared showing polygons of milfoil and curly leaf pondweed cover and treatment areas, and points of other noxious weed locations.

A pre-treatment and post-treatment survey of submersed weeds should be performed for every year of treatment. Pre-treatment survey observations should be immediately reported to the designated Lake Manager (see the Roles and Responsibilities section) to consult and agree on appropriate control actions. A survey and treatment report should be prepared after the post-treatment survey summarizing survey and treatment methods, presenting the prepared maps, including tables of noxious weed location and treatment areas, discussing survey or control problems, and recommending revisions to future survey and control methods.

The emergent weed surveys should include collection of GIS data to prepare weed location maps showing points of each noxious emergent species represented by different symbols. Survey and treatment observations should be immediately reported to the designated Lake Manager to consult and agree on appropriate control actions. Emergent weed survey methods and results should be included in the submersed weed report and include recommendations for future survey and control methods.

Aquatic Invasive Species Prevention

Aquatic invasive species (AIS) which have been observed in Vancouver Lake or its tributaries, or are likely to be introduced include, but are not limited to, the above aquatic invasive plant species (see Table 2), New Zealand mudsnails (*Potamopyrgus antipodarum*), Asian clams (*Corbicula fluminea*), various species of carp (nuisance), northern and/or red swamp crayfish (*Orconectes virilis, Procambarus clarkia*), invasive copepods from East Asia (*Pseudodiaptomus forbesi*), bullfrogs (*Rana catesbeiana*), and nutria (*Myocastor coypu*). Additional high-risk species that have not yet been detected but should be carefully surveyed for and introduction prevented include the Northern pike (*Esox lucius*), zebra mussels (*Dreissena polymorpha*), quagga mussels (*D. bugensis)*, and the African clawed frog (*Xenopus laevis*).

Given the variety and extent of the habitats these species may occupy, the methods by which they are introduced (e.g., ballast water, pet trade, illegal release), and ecological and economic impacts these AIS may have, preventing the introduction or spread of invasive species is the most ecologically advantageous and resource-efficient management and prevention mechanism. Therefore, a specific AIS Prevention Program for Vancouver Lake and its tributaries within the Salmon Basin should be prepared as an amendment to this LMP to prevent reintroduction or further expansion to Vancouver Lake, Lake River, and the Columbia River as applicable.

An AIS Prevention Program for Vancouver Lake and its watershed should be the product of a partnership with WDFW and Clark County Noxious Weed Management, and would incorporate and amend the existing IAVMP details as necessary. The program should otherwise consist of the following elements:

- Threat identification and risk assessment
- Pertinent regulations
- Roles, responsibilities, and coordination
- Introduction prevention methods:
  - "Clean, Drain, Dry" and other decontamination information
  - Boat inspections and boating requirements
  - Community education and engagement opportunities (e.g., AIS awareness courses)
- Early Detection and Rapid Response (ED&RR) procedures and monitoring program
- Mitigation/management actions to reduce and limit the spread of existing infestations
- AIS action prioritization
- Program evaluation and reporting

One successful example of a structured AIS plan in Washington state is the Aquatic Invasive Species Action Plan for Lake Whatcom Reservoir produced by the Lake Whatcom Management Program (2011). This plan initiated Lake Whatcom's Aquatic Invasive Species Program, which as of 2021 conducted nearly 100,000 inspections, intercepted 29 boats transporting or suspected of transporting zebra/quagga mussels, 1,366 boats transporting aquatic vegetation, and 3,579 boats that were found wet or transporting standing water (which can contain AIS). This program's management approaches were found to be particularly effective in preventing the spread of aquatic invasive species during the pandemic in 2020 and 2021 when non-motorized watercraft usage hit record highs (WAISPP 2022).

In Clark County, sightings of invasive plant species (e.g., from annual noxious weed surveys in the lake) should be reported to Clark County Noxious Weed Management (https://clark.wa.gov/public-works/noxious-weed-management) and invasive animal species to the Washington Invasive Species Council (https://invasivespecies.wa.gov/).

For budgeting purposes, it is estimated that preparation of the AIS Prevention Plan will cost $50,000 and implementation of that plan will cost an average of $10,000 per year for a 20-year cost of $250,000.

Cost Estimate

The cost estimate for the recommended noxious weed management program is presented in Table 23. A budget of $1 million should be planned for a 20-year period, which equates to $55,000 as an annual average.

Table 23. Noxious Weed Management Cost Estimate.

Activity	Unit	Unit Cost	Number of Units/ Treatment Year	Number of Treatments in 20 Years	20-Year Cost	Average Annual Cost
Milfoil treatment	acre	$525	50	7	$183,750	$9,188
Curly Leaf treatment	acre	$900	20	7	$126,000	$6,300
Shoreline emergent treatment	day	$3,500	1	7	$24,500	$1,225
Upland emergent treatment	day	$2,000	2	7	$28,000	$1,400
Noxious weed mapping	map set	$5,000	2	7	$70,000	$3,500
Pre-/Post-treatment report	report	$10,000	2	7	$140,000	$7,000
AIS prevention	year	$12,500	1	20	$250,000	$12,500
Public involvement	year	$5,000	1	20	$100,000	$5,000
Total Cost					$922,250	$46,013
Contingency (20 percent)					$182,450	$9,123
Total Budget					**$1,094,700**	**$54,735**

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STAKEHOLDER INVOLVEMENT PLAN

The stakeholder involvement plan outlines a strategy for engaging members of the public, lake user groups, and others throughout the development and implementation of the Vancouver Lake Management Plan. This plan outlines activities and communication tools that are most critical for engaging different areas of the project and are mindful of limited resources. This plan does not capture the creative potential ways to engage the public that could build support but are more resource intensive such as festivals, arts events, etc.

Inputs

This document was developed through a collaborative and iterative process. The following information sources were used:

- Interviews with key community members and leaders
- Interactive discussion with the Technical Advisory Group
- Public survey of Vancouver user groups
- Input and feedback from a public webinar

Goals and Objectives

The goal of the stakeholder involvement plan is to generate and build upon existing support (including funding, legislation, partnerships, and expertise) for the VLMP.

The stakeholder involvement plan is designed to meet the following objectives:

- Educate the general public about the lake and the plan
- Hear the concerns and interests of the public about the lake
- Collaborate on the strategies to be used
- Shift public perception to see the lake as a clean and safe area as improvements are made
- Improve public understanding of who is responsible for lake management

It is recommended that future modifications and implementation of the LMP include sufficient budget to implement the selected elements of this Stakeholder Involvement Plan.

Decisions To Be Made

The following decision points were identified for public and stakeholder involvement:

- **Management methods evaluation:** Through the development of the LMP, Herrera, along with the TAG, evaluated the effectiveness and relative costs of management methods to address the harmful algal blooms and invasive aquatic weeds. However, decisions on which methods will be used and when have yet to be decided. In addition to the TAG, various stakeholder groups and members of the public should be involved in the decision as to which methods should be used in the future. A lake management team should be identified work directly with various stakeholder groups throughout the decision-making process to ensure that public concerns and aspirations are consistently understood and considered. The public should have opportunities to weigh in on the strategies to identify which ones they support, and to identify and understand unintended consequences (if any). Ultimately, the lake management team will make the decisions about which strategies to pursue, and having the public's engagement will help to build support for the outcome.
- **Involve the public to identify future lake issues to be addressed:** As future adaptions of the LMP consider additional ways to improve water quality, the lake management team should involve key user groups and the public to understand the key interests and concerns of the public. The lake management team should share this input with key stakeholders for future effort planning and decision making.
- **Financial support for this effort:** The LMP has been supported thus far by an appropriation in the Washington State budget. The funds to implement the plan, including public involvement, have yet to be identified. The lake management team should collaborate with the public to engage their help to identify funding sources and come up with creative solutions to see this plan be implemented.

Public engagement will be important at significant milestones for the project. Table 24 indicates the nature and level of engagement.

Table 24. Engagement Mechanisms and Public Participation Goals for LMP Milestones.

Milestones	Engagement Mechanisms	Public Participation Goal	
Management scenario evaluation	TAG meetings, small group conversations	*Involve*	share information about the process, hear and address concerns, gain support
Explore funding opportunities	TAG meetings	*Involve*	share information about the process, hear and address concerns, gain support
Prioritize future water quality issues for lake management	Public meeting, TAG meeting	*Collaborate*	partner in the decision including developing alternatives and identifying preferred solutions

Table 24 (continued). Engagement Mechanisms and Public Participation Goals for LMP Milestones.			
Milestones	**Engagement Mechanisms**	**Public Participation Goal**	
Circulate draft LMP released for public input	Circulate via News, social media, mailers, Neighborhood Association Listservs; provide presentations to councils and commissioners; public meeting	*Consult*	share information about the process, hear concerns, address concerns when able, gain support
Draft revised with public input	Circulate via News, social media, mailers, Neighborhood Association Listservs; provide presentations to councils and commissioners	*Inform*	share information about the effort
Implementation of the LMP	TAG meetings, small group conversations, communication materials	*Involve*	share information about the process, hear and address concerns, gain support
Evaluation of effectiveness	TAG meetings, small group conversations, communication materials (one-pager, video, posters, etc.)	*Inform*	share information about the effort
Develop a plan for future water quality issue management	Public meetings, TAG meetings, small group conversations	*Collaborate*	partner in the decision including developing alternatives and identifying preferred solutions

Opportunities and Challenges

Public support for the LMP and general lake protection is evident from previous management, outreach, and partnership efforts. Public involvement opportunities for LMP implementation include general public support; outreach, communication, and education through existing citizen-led organizations like FOVL or Vancouver Lake's recreational clubs; and political support as was exhibited early on by funding this LMP development project.

However, the following challenges related to the LMP public involvement effort were also identified:

- Many entities have overlapping jurisdictions for the care, maintenance, and environmental health of the lake, which can cause confusing information flow and communication about the lake.
- There is high staff turnover at the City and County that affects the consistency of lake management.
- Until recently, no source of funding had been confirmed for the next phase of the LMP including clean up or public involvement, and the recent funding obtained for the next phase does not specify if funds will be available for public involvement.
- Different lake users and groups have different interests and ideas for the lake, and these visions could be compatible or could present challenges. Understanding these differing views will be important for the long-term success of the LMP.
- Concerns have been shared about the LMP demonstrating preference for some user groups over others.
- The LMP is limited in scope and there are concerns that water quality issues that impact lake uses will still be challenges, such as:

- Root causes of cyanobacteria issues
- *E. coli*, as a frequent reason for recreational closures, and
- Shallow water levels, as an impediment to boating and other recreational activities.

Guiding Principles

The following principles should guide the outreach and engagement process and apply across all audiences:

- **Public engagement needs to be done at regular intervals and at project milestones** and needs to be more than a one-time event.
- **Engagement requires time and resources to do well** from material development, planning, translation, printed materials, etc., require dedicated time and resources.
- **Outreach should consider equity and environmental justice.** Effort is needed to center frontline communities, Environmental Justice communities, and Black, Indigenous People of Color (BIPOC) to ensure historically underserved and under-represented communities are a part of the Vancouver LMP process. This also requires dedicated time, resources, and intentional outreach efforts.
- **People impacted by decisions should have a say in the decision-making process**. Since Vancouver Lake is a public resource, community input should be obtained to include the public's interests in management objectives.

Key Audiences

The following audiences were identified for outreach and engagement:

The Cowlitz Indian Tribe

Vancouver Lake is located on the traditional lands of the Cowlitz Indian Tribe (Cowlitz) and other indigenous peoples of the Columbia River Basin. Cowlitz is not a stakeholder in this process; they are a sovereign entity and engaging them should honor this distinction.

Principles

- **Communications should be done primarily government to government:** Clark County should reach out to the Tribal Councils and invite them to participate in the LMP process. Currently, Cowlitz's Interim Natural Resources Director has been engaged in the Technical Advisory Group; however, it is still important to have this communication directly with Tribal Councils. Tribal staff often cannot speak on behalf of the tribe.
- **Stay engaged with tribal leadership:** Once an invitation has been made, regularly (quarterly) provide updates about the process, timelines, and desired outcomes to tribal leadership. The Tribal Chairperson and the Tribe's Cultural and Natural Resources Departments should be provided

updates on this process. Offer to have check-in meetings about the project and continue to extend an invitation for Tribal Council leadership to participate as they see fit.

- **Continue to engage with tribal staff:** Cowlitz's Interim Director of Natural Resources and Cowlitz's Natural Resources Policy Analyst are involved in the TAG, and it is important to continue the involvement of Cowlitz's Department of Natural Resources staff.
- **Consider cultural resource implications:** Engaging directly with the Natural Resource and Cultural Resource Departments will be important to assess the cultural resource implications for proposed actions in the Vancouver Lake area. The Cultural Resource Department staff will need to review the Area of Potential Effect and can offer guidance on Cultural Resources considerations.

Communication Tools

- **Paper letters and email copies** should be used for communicating with tribal leadership.
- **One-on-one meetings** should be offered to tribal leadership and the Natural Resource Directors.
- **Inclusion on the Technical Advisory Group** should continue with tribal staff.

Additional Considerations

In addition to the Cowlitz, other Tribes consider the Vancouver Lake area as part of their ancestral lands. Future engagement work should explore ways to engage the Cayuse, Umatilla, Walla Walla, Multnomah, Confederated Tribes of Grand Ronde, Confederated Tribes of Siletz, and Yakama Nation.

Vancouver Lake User Groups

Many people enjoy the 190-acre regional park in various ways. The following recreation activities were identified (see Figure 5):

- Viewing the lake
- Swimming
- Walking
- Cycling
- Birding
- Fishing
- Hunting
- On-water recreation—sailing, rowing, kayaking, etc.

Principles

- **People who interact with the lake should have a say in lake management:** Some user groups have organizations to engage such as the Vancouver Lake Rowing Club, while others are not necessarily organized groups—such as people who swim or view the lake. When possible, the LMP should engage with organized groups, individuals, or proxies who can serve as a voice for their user group and communities. For instance, a representative from a conservation group (such as the Audubon Society) may be able to represent the interests of the birding user groups. Continuing to include these voices in the TAG is one important way that the LMP can engage these groups. The representatives on the TAG should be responsible to communicate and coordinate with their groups of interest to ensure that their group's interests are represented.

- **Uplift or incorporate traditionally under-represented groups**: Expanding the TAG to include representatives from BIPOC organizations to represent resident Latino communities would be beneficial to reaching more laker users who have been historically left out of these conversations.
- **Share information with lake visitors:** There are opportunities to share about the LMP project efforts at various parts of the lake where users access the lake such as the Vancouver Lake Regional Park, WDFW boat launch, sailing club, etc. (see Figure 5). A collaborative approach to developing this communication tool to ensure clear messaging and gain support for this communication tool. This could include incorporating indigenous storytelling and narratives. Multiple language translations and accessible formats would be recommended to increase understanding and awareness of this effort.

Communication Tools

- **Inclusion on the Technical Advisory Group** should continue with representatives from these user groups and be expanded to include representatives from BIPOC organizations.
- **Public informational posters** should be collaboratively developed and posted around the lake at access points.
- **Work to develop key messages about the LMP** with the key user groups to be included in communication materials.
- **Small group conversations** will be helpful to understand how user groups are impacted by management decisions. These meetings can help to understand the unique perspectives of the various users.

Residents

Residents around and near the lake have a close relationship with the issues of Vancouver Lake. Residents have the potential to impact the lake's water quality (positively and negatively) and are likely to be impacted by the actions of the LMP. The residents are a diverse audience including different compositions of primary languages, socioeconomic status, and primary uses of the lake area. The residents near and around the lake inhabit the following neighborhoods, with each neighborhood represented by their respective Neighborhood Association (Table 25).

Table 25. Vancouver Lake Neighborhoods.	
Location Relative to Lake	**Neighborhood**
Adjacent	Fruit Valley
Adjacent	Northwest
Adjacent	West Hazel Dell
Adjacent	Felida
Nearby	Lincoln
Nearby	Carter Park
Nearby	Hough
Nearby	Northeast Hazel Dell
Nearby	North Salmon Creek

In addition to the neighborhoods, residents include all individuals, property owners, and businesses that may contribute LMP funds in the future. This may include all those in the entire lake watershed that extends many miles from the lake and beyond the nearshore area. Residents include agricultural areas near and around the lake, as well.

Principles

- **Outreach to the residents will be important, especially when considering actions:** The residents will be impacted by the decisions, and should have opportunities to share concerns, understand proposed actions, and help to identify solutions.
- **Consider the Environmental Justice dynamics of the lake:** The residents living close to the lake may be exposed to harm from Vancouver Lake water quality issues. The need to address water quality issues will be critical to ensure the equitable distribution of environmental risks and benefits to the neighboring communities.
- **Outreach should consider equity:** Communication should offer multiple translations, accessible formatting, and different timing/resources to encourage participation (childcare, meals, and/or multiple opportunities outside of core business hours). Neighborhood associations may be able to partner to advise on the needs of the communities.

Communication Tools

- **Public meetings with presentations and opportunities for feedback** should be used to communicate with the resident groups. Another strategy should be to coordinate schedules with the Neighborhood Association Meetings, such as reaching out to the organizers to ask to be added to a scheduled meeting agenda.
- **Working with Neighborhood Associations to utilize the Associations' listservs** could be used to communicate with resident groups. Timing for circulating the messages needs to be considered since many newsletters are circulated monthly or quarterly.
- **Using NextDoor, Facebook, Twitter, The Columbian, The Oregonian, OPB, KATU Channel 2, KGW Channel 8, and KOIN Channel 6** could be effective ways to reach Vancouver Lake area residents.

- **Mailers to property owners and local businesses** in the neighborhoods near the lake could be an effective way to share about the project and engagement opportunities.
- **A one-pager/short video describing the LMP** in layperson's terms about the issues and actions for the project.
- **Inclusion on the Technical Advisory Group** could be helpful to more closely involve a representative of the resident groups. A TAG representative should be able to represent multiple neighborhoods.
- **Small group conversations** will be helpful to understand how residents are impacted. These meetings can help to understand these unique perspectives.

General Public

The general public has varying degrees of familiarity and experience with Vancouver Lake and could include people living near or far from the lake. Regardless of proximity, the public could be partners in supporting the LMP efforts. The public could include other residents of Vancouver, nearby areas, people in the entire lake watershed that extends many miles from the lake and others who may not interact directly with the lake.

Principles

- **Communications should aim to inform the public** about the lake, the issues, and the opportunities for improvement.
- **Outreach should consider equity:** communications should be accessible to members of the public with differing abilities, language needs, and access to online materials.
- **Allow for time to translate/increase accessibility in document development:** ensuring that documents can be read in multiple languages will help to reach a more diverse cross section of the public and requires time and resources.

Communication tools

- **A one-pager/short video describing the LMP** in layperson's terms about the issues and actions for the project would be useful to communicate about the project.
- **Publications and relevant project documents** should be made available on the website.
- **In-person public meetings** should be hosted to engage the interested public. This could include tabling at cultural events through Clark County to reach diverse audiences. The meetings should provide a mix of presenting information and hearing from the public. Prioritizing face-to-face communication will help build relationships and understanding. Public meetings should include multiple language interpretation, as well.
- **Engage with representative/affinity group organizations directly** to ensure BIPOC and historically under-represented voices are included in the LMP. These local organizations include but are not limited to Southwest Washington Communities United for Change, Clark County Latino Youth Conference, Comunidades, Ethnic Support Council, Hispanic Disability Support SWWA (Pasitos Gigantes), Latino Community Resource Group, NAACP Vancouver Branch 1139, Southwest

Washington League of United Latin American Citizens Council 47013, The Noble Foundation, YWCA Clark County, OneAmerica, and Pacific-Islander Community Association of Washington.

- **Articles and advertisements in The Columbian, The Oregonian, OPB, KATU Channel 2, KGW Channel 8, KOIN Channel 6, Spanish language radio, and community radio** to reach out to the public will be helpful.
- **Utilize social media to share about the project and public events** such as Facebook, Twitter, NextDoor, and other sites. Social media can allow for a greater reach of information and broader engagement.
- **Presentation to the City and County councils, commissioners to the Ports (of Ridgefield and Vancouver), and other public agencies**, many of whom have live feeds available to the public for viewing broadly by the public.

Governments/Ports

The government entities and ports include the City of Vancouver, Clark County, WDFW, Ecology, the U.S. Army Corps of Engineers, WDNR, the Port of Ridgefield, and the Port of Vancouver. With overlapping jurisdictions, communication between and among these entities must be clear.

Principles

- **Engage with the appropriate level of authority and expertise.** For instance, a biologist with the state may not be able to speak on behalf of their department about policy issues. Staff across offices can be helpful to coordinate internally and liaise between different departments to ensure the right people are engaged.
- **Overlapping jurisdictions requires clear communication about roles and responsibilities**. Not all staff have the same understanding of how other entities support Vancouver Lake Management. It is also not clear who is interfacing with the public.
- **Understanding the mandate and authority of the various entities is the first step.** It will be helpful to identify where there are opportunities and limitations to managing the lake holistically, and then work collaboratively to address any gaps.

Communication Tools

- **Develop an infographic** to help clarify the roles and responsibilities of the various entities. This graphic could also be used to communicate more broadly with other audiences.
- **Inclusion on the Technical Advisory Group** should continue with representatives from the government/ports.
- **Presentation to the City and County councils, commissioners to the Ports (of Ridgefield and Vancouver), and other public agencies** could be helpful in building support and understanding of the LMP.

- **Explore the role of a coordinator** to help with Lake Management. A dedicated point person could help to manage the complex relationships of these groups and could help to interface with the public.

Audience, Engagement Tools, and Timing

Table 26 shares the proposed communication tools associated with each audience as described above. For all audiences, continuing to host a website will be important to provide a landing page for events and information.

Table 26. Audiences, Engagement Tools, and Timing.						
Tools	**Cowlitz Indian Tribe**	**Lake User Groups**	**Residents**	**General Public**	**Governments/ Ports**	**Timing**
Website	X	X	X	X	X	Ongoing
Paper letters	X					Quarterly
One-on-one meetings	X					Quarterly
Inclusion on the TAG	X	X	X		X	Monthly
Engage with representative/affinity group organizations directly				X		At key decision points, including presentations and opportunities for input
Small group conversations		X	X			At key decision points, including presentations and opportunities for public input
Public meetings			X	X		At key decision points, including presentations and opportunities for public input
Neighborhood Association listservs			X			Utilize to share about upcoming opportunities for public involvement
Social Media			X	X		Utilize to share about upcoming opportunities for public involvement
News channels			X	X		Utilize to share about upcoming opportunities for public involvement, highlight key milestones in the project, and share outcomes of decision making
Mailers			X			Utilize to share about upcoming opportunities for public involvement, highlight key milestones in the project, and share outcomes of decision making
Infographic about the decision makers					X	In Phase 2, to clarify messaging and coordination
Informational Posters		X	X	X		In Phase 3, implementation
One-pager			X	X		In Phase 3, implementation
Short video			X	X		In Phase 3, implementation
Presentation to councils and commissioners				X	X	In Phase 3, implementation
Publications and relevant project documents				X		In Phase 3, implementation
Coordinator					X	In Phase 3, implementation

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Cost Estimate

The annual cost estimate for implementing the recommended stakeholder involvement plan presented is approximately $211,180 with consultant facilitation of future TAG meetings and community outreach events (Table 27). This annual cost estimate is based on the first year of plan implementation in 2024 by a public involvement consultant with assistance and oversight by a prime project consultant. Task activities for the first year are listed separately below the table. It is assumed that task activities would vary in following years and that a similar budget would be needed for stakeholder involvement in each of those years. A budget of $4.22 million should thus be planned for stakeholder involvement over a 20-year period.

Table 27. Stakeholder Involvement Plan Cost Estimate.

Task	Labor	Travel, Materials, and ODCS	Translation/ Interpretation	Subtotal
1, Public Meetings	$20,400	$2,200	$8,000	$30,600
2. Tribal Engagement	$14,140	-	-	$14,140
3. Small Group Meetings	$20,580	-	-	$20,580
4. Communications	$29,440	$2,000	$24,000	$55,440
5. TAG Meeting Facilitation	$65,640	-	-	$65,640
6. Community Outreach Events	$24,780	-	-	$24,780
		Annual Total		**$211,180**
	Over 20 years		**$4,223,600**	

1. Public Meetings

   - Schedule and prepare for two, 2-hour public meetings including one virtual meeting and one in-person meeting.
   - Drafting agendas, facilitating a dry-run, coordination with interpreters, and preparing other meeting materials and coordinating with members of the public.
   - Travel to, set-up/break-down, facilitation, and debrief of the public meetings.
   - Conduct follow-up tasks from the public meetings, including agreed upon action items, drafting meeting summaries, and other tasks as requested.

2. Tribal Engagement

   - Schedule and prepare for four (quarterly), 1-hour virtual meetings with the Cowlitz Indian Tribe.

- Provide logistical coordination support with Clark County and the Cowlitz Indian Tribe for government-to-government consultations.
- Support outreach and engagement of additional Tribes.
- Conduct follow-up tasks from consultations, including agreed upon action items, drafting meeting summaries, and other tasks as requested.

3. Small Group Meetings

- Prepare for up to eight, 1-hour virtual small group meetings by coordinating with Vancouver Lake user groups, BIPOC organizations, and residents.
- Scheduling and preparing for small group meetings including drafting agendas and preparing other meeting materials.
- Facilitate small group meetings
- Conduct follow-up tasks from meetings, including agreed upon action items, small group coordination, and facilitation, and other tasks as requested.

4. Communications

- Draft and finalize communications materials with review from Clark County and the Project Team
- Work with translators and ensure accessibility of materials
- Support content development for social media, newsletters, listservs, projects website, and news channels.

5. TAG Meetings

- Prepare for, schedule, and facilitate up to 12, 2-hour virtual technical advisory group meetings.
- Preparation with the Project Team and develop meeting agenda and materials.
- Provide logistical coordination with TAG members to set-up meetings.
- Conduct follow-up tasks from the TAG meetings including agreed upon action items, drafting meeting summaries, distribution of materials, and other tasks as requested.

6. Community Outreach Events

- Prepare for and attend up to six, 3-hour community outreach events including tabling, coordination with the Project Team, travel to, set-up/break-down.

FUNDING PLAN

Funding Analysis

Preparation of the funding plan began with evaluating and summarizing some of the most appropriate mechanisms for funding lake management activities, including long-term and short-term (i.e., loans and grants) sources. A number of options were considered for meeting long-term funding needs; these included organizing a special use district, establishing an interagency coalition, and relying on the State capital budget. Three different approaches to using a special use district were presented at a TAG meeting: a Flood Control Special Use District, a Lake and Beach Maintenance and Management District, and Park District. These options and their advantages and disadvantages were presented to the TAG in their meeting on October 27, 2022. In addition to describing the different types of special use districts the presentation included a summary of the steps required to establish a special use district, which can be an involved process. The key steps in their establishment require setting district boundaries, setting rates, public outreach, public hearings, and voting. Therefore, it typically takes 2 to 3 years to establish.

The presentation of long-term funding options was followed by an open discussion of the programs. A list of grant and loan programs was also developed and presented at the October 2022 TAG meeting. This list is included as Appendix C.

The following is a summary of the long-term funding options presented and their key advantages and disadvantages.

Flood Control Special Use District (Revised Code of Washington [RCW] 86.09)

Of the many different types of special use districts referenced in the States' administrative code, the powers and activities of a Flood Control Special Use District (under RCW 86.09) were most closely aligned with the varied projects and programs that have been identified for Vancouver Lake. According to the RCW, the main purpose of this type of district is protection of life and property, preservation of public health and conservation and development of natural resources. The RCW also states that the powers of RCW 86.09 also include the powers of RCW 35.61 (Lake and Beach Management District).

Among other activities, a Flood Control District can acquire, manage, improve real and personal property, enter into contracts, appoint officers and employees, and levy special assessments. A Flood Control Special Use District is governed by an elected board of commissioners and therefore has autonomy over management decisions. The boundary of such a district is set by the petitioners who request to form the district and is then voted on by all landowners within those boundaries. Thus, the petitioners should consider the appropriate district size and boundary to balance the budget needs with the ability to gain approval by the majority of constituent votes.

Lake and Beach Management District (LMD) (RCW 36.61)

Many lakes in Washington state are managed through a Lake and Beach Management District (LMD) under RCW 36.61. According to the RCW, the main purpose of an LMD is lake and beach improvement and maintenance, thus its powers and activities as defined in the RCW imply more limited powers and activities than a Flood Control District. However, perhaps the most significant difference between the two district types is that an LMD has a steering committee that makes recommendations to the lead entity but ultimately it is governed by the lead entity, typically a city or county. In practice, this means that management decisions are at least one step removed from those individuals most invested in the management of the lake which, for instance, could help streamline implementation and/or facilitate contention. As with a flood control district, the boundary of an LMD is set by the petitioners who request to form the district and is then voted on by all landowners within those boundaries, which should balance the budget needs with the ability to gain approval by the majority of constituent votes.

Existing Metropolitan Parks District (RCW 35.61)

There is an existing Metropolitan Park District organized under RCW 35.61 that covers some of the same general area in Clark County and to some extent its powers and authorities cover (or could be redefined to cover) the activities needed for Vancouver Lake. The RCW defines the main powers of a metropolitan park district as to manage, control, improve, maintain, and acquire parks, parkways, boulevards, and recreational facilities.

The possibility of expanding the powers of the existing district and slightly increasing the assessment rate is another potential mechanism for providing a long-term funding source. The main advantage to using this approach as compared to establishing a new special use district was that some of the process for establishing the district might be avoided. However, upon further consideration, this possible advantage did not seem significant since the process of redefining powers and assessments rates might likely require repeating some of the key steps to establishing a district.

Interlocal Agreement with Key Partners

Under this option the key partner agencies and large landowners, including Clark County, the City of Vancouver, the Port of Vancouver, WDFW, and possibly others would work together under the umbrella of an Interlocal Agreement (ILA). The ILA would lay out responsibilities, a decision framework, a payment schedule and other details to govern how the lake is managed and how all of the work gets done.

State Budget Appropriation

Although this funding mechanism was not presented at the February meeting of the TAG, it is the funding mechanism that has been used to date for Vancouver Lake and was recommended by some TAG members. This funding option requires that State legislators approve funding for Vancouver Lake during the development of the State capital budget every 2 years. In April 2023, the state legislature appropriated $330,000 for implementation of the VLMP through June 2025, which represents 7.5 percent of the $4.4 million proposed for the next two years.

Increase Parking Fees

Increasing parking fees at the Regional Park on the lake was also identified as a potential funding source to supplement the main funding mechanism. This potential source was intended to capture revenue from frequent lake users and the many users from outside the area. At a subsequent TAG meeting this funding mechanism was rejected due to social equity issues and it is not addressed further in this plan.

At the February 23, 2023, TAG meeting, the estimated long-term costs for implementing the Vancouver LMP were summarized for four management scenarios of increasing cost. HAB management methods and 20-year cost included: 1) phosphorus inactivation for $15 million, 2) Algaecide treatment for $20 million, 3) flushing channel enlargement for $33 million, and 4) Lake River dam for $42 million. For each scenario, routine costs were included for each management scenario to cover monitoring, public involvement, and administration at an estimated 20-year cost of $3.3 million based on an annual cost of $165,000. In addition, noxious weed management using herbicide treatments was included for each scenario at an estimated 20-year cost of $1.5 million.

Table 28 represents the average annual cost of each lake management scenario presented to the TAG. These costs were then divided equally by 87,395 parcels located in the Burnt Bridge Creek and Salmon Creek basins (which were assumed as the special use district boundaries for this simple model) to derive an average annual cost per parcel for implementing each scenario over a 20-year period, which range from $11.33 to $26.77/parcel.

$$Annual\ Cost\ per\ \$1000\ Assessed\ Property\ Value = \frac{C}{(V * P)/1000}$$

$Where$:
$C = average\ annual\ cost$
$V = average\ property\ value$
$P = number\ of\ parcels\ in\ the\ watershed$

Table 28. Funding Analysis of Four Lake Management Scenarios.

Management Scenario[a]	Average Annual Cost (millions)	Annual Cost per Parcel[b]	Annual Cost per $1,000 Assessed Property Value[c]
1 – Phosphorus Inactivation	$0.99	$11.33	$0.02
2 – Algaecide Treatment	$1.24	$14.19	$0.03
3 – Flushing Channel Enlargement	$1.89	$21.63	$0.04
4 – Lake River Dam	$2.34	$26.77	$0.05

[a] Each scenario includes weed management and routine monitoring, public involvement, and administration.

[b] Based on 87,395 parcels in the Burnt Bridge Creek and Salmon Creek basins.

[c] Based on average property value of $520,000 (Zillow 2023) for 87,395 homes in the watershed.

These assessed values for the Vancouver LMP scenarios are all much less than the $0.27/$1,000 value that voters approved in 2005 for the Greater Clark Parks District and less than the $0.14/$1,000 currently being paid for this special parks district. According to the Clark County Assessor's Office 2023 Levy Rates Report (Clark County 2023b), current levy rates for properties in the city of Vancouver are assessed at a rate of $9.33/$1,000 value (or $5.30/$1,000 value for senior/disabled exemption from school levies) that includes $2.35/$1,000 value for the City of Vancouver, $0.80/$1,000 value for Clark County, and $0.22/$1,000 value for Port of Vancouver (Clark County 2023b). Thus, a LMP levy of $0.05/$1,000 value would represent less than 1 percent of an increase in the total property tax for a property in the city of Vancouver that is not exempt from school taxes.

Cost allocation among watershed parcels can also vary, such as by distance from the lake where rates per assessed property value could be higher for tax areas closer to the lake.

Funding Strategy

Of the three approaches presented to the TAG for using a special district as a long-term revenue source, establishing a new Flood Control Special District was recommended as the preferred approach because its powers, authority, and governance best matched the diverse project needs. A bond of $5,000 may be required upon submission of a citizen petition or County resolution to form a Special Use District for the LMP. Costs paid by the bond are considered special property benefits and would be repaid through the annual district assessments.

While establishment of a Flood Control Special District was discussed at some length, several TAG members recommended that appropriations from the State capital budget was the most appropriate funding source due to the statewide significance of the lake, the anticipated challenges in approving a tax levy for special use districts, and the potential lack of available partner funding to contribute to an ILA.

Table 2929 presents the recommended LMP budget to implement the HAB management plan, noxious weed management plan, and stakeholder involvement plan. Also included in this budget is $30,000/year to administer the LMP. The 20-year cost is estimated at $44.9 million resulting in an average annual cost of approximately $2.25 million. This total average annual cost is estimated to cost LMP district taxpayers $0.05/$1,000 assessed property value.

Table 29. Vancouver Lake Management Plan Budget.

Plan Element	Estimated Total 20-Year Cost	Estimated Average Annual Cost	Annual Cost per $1,000 Assessed Property Value[a]
HAB Management Plan	$39,000,000	$1,950,000	$0.043
Noxious Weed and AIS Management Plan	$1,100,000	$55,000	$0.001
Stakeholder Involvement Plan	$4,220,000	$211,000	$0.005
Plan Administration	$600,000	$30,000	$0.001
TOTAL	**$44,920,000**	**$2,246,000**	**$0.049**

[a] Based on an average property value of $520,000 (Zillow 2023) for 87,395 homes in the watershed.

The special use district strategy is at risk of failure by the voting public who may oppose new taxes. The legislative appropriations strategy is at risk of failure due to the large amount of funds needed. A combination of both funding sources could be considered to reduce the risk of failure. In April 2023, the state legislature appropriated $330,000 for implementation of the VLMP through June 2025, which represents 7.5 percent of the $4.4 million proposed for the next two years. More work is needed to fully develop a funding strategy as the management plan further develops in the next phase of the LMP. Whatever the strategy, it is important to educate stakeholders and the general public on the value of Vancouver Lake and the importance of the LMP to increase and protect its value.

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ROLES AND RESPONSIBILITIES

The relevant entities to fulfill the required roles and responsibilities of organizing, governing, and executing the decisions of a Flood Control District, as the primary mechanism for funding and implementation of management activities for Vancouver Lake, have been defined below in Table 30. Many of these 14 roles would be needed to successfully implement the LMP even if it were entirely funded by appropriations from the State capital budget and short-term sources (e.g., grants) that do not rely on a tax levy, rather than by a Flood Control District.

Additional considerations should be granted on a project basis and pursuant to regulatory compliance, as Vancouver Lake falls under several governmental jurisdictions. Ecology and WDNR share regulatory authority over the water and lakebed, respectively, while the lakeshore is composed of shoreline primarily managed by Clark County under their Legacy Lands and Parks departments, with sections along the south and southwest owned by WDFW, the Columbia Land Trust, the Port of Vancouver, and the City of Vancouver.

Table 30. Roles and Responsibilities for Vancouver Lake Management Under a Flood Control District.

Role	Responsibilities	Entity
Flood Control District Governing Board	Members jointly have autonomy over management decisions, District affairs, expenditures, contract administration, and compliance with public laws.	Consists of at least three members, appointed for the first year and elected thereafter
Board Chair	Leads the District's governing board.	An appointed Board member
Board Secretary	Coordinates communication and collaboration between board members. Set up meetings and distribute materials like agendas and minutes.	An appointed Board member
Primary Lake Manager	Manage implementation of lake management projects and contract administration.	District staff member, hired by Board
District Legal Counsel	Provide legal services for District management and operations.	District staff member, hired by Board
District Accountant	Provide accounting services for management of District funds.	District staff member, hired by Board
District Formation – Public Support and Elections	Propose/petition and vote for formation of a Flood Control District. Elect governing board members. Vote on and pay for District assessments (taxes).	District Property Owners (public and private)

Table 30 (continued). Roles and Responsibilities for Vancouver Lake Management Under a Flood Control District.		
Role	**Responsibilities**	**Entity**
District Formation – County Support	In lieu of a public petition to form a Flood Control District, a local government may write a resolution to form the district, to then be proposed to and voted on by district property owners.	Clark County
District Formation – County Approval	Host the proposed Flood Control District public hearing and vote, and publish a resolution of findings. Appoint initial governing board of three members.	Clark County Council
District Management Support	Management of District legal notices and list of property owners. Submit Notice of Intent and performs other approved District formation aspects.	Clark County
Assessment Collection	Collects District assessments (taxes) for District use and management.	Clark County Treasurer
Public Involvement, Education, and Outreach	Learn about lake management processes, decisions, and projects. Provide Board with concerns, questions, or support. Partner in decision making, alternative development, and solution identification when relevant. (See *Stakeholder Involvement Plan*)	Cowlitz and other Indian Tribes Vancouver Lake User Groups Residents General Public Governments/Ports (See *Stakeholder Involvement Plan*)
Technical Support	Supports and advises the governing board on District and Lake issues, questions, objectives, and management actions. Provide science-based recommendations and technical information to support management decisions.	TAG/Steering Committee to include but not be limited to this project's TAG representatives. (See the Community Involvement section)
Independent Review/Support	Provide science-based recommendations and technical information to support management decisions. Project evaluation.	Third party independent reviewers (e.g., consultants)

ADAPTIVE MANAGEMENT

In order to further the long-term, inclusive goals described in the Goals and Objectives for Vancouver Lake section above, this plan includes the following adaptive lake management framework to regularly reassess and amend project and Plan goals as part of ongoing, adaptive lake management, pursuant to future lake needs, stakeholder values, and funding.

Adaptive management is a "systematic approach for improving resource management by learning from management outcomes …" (Williams et al. 2009, p. 1)

This section describes 1) the decision-making process and adaptation framework by which the VLMP shall be modified, 2) the current knowledge gaps and limitations of the current Plan, and 3) likely future Plan adaptations to begin considering.

Framework and Procedures

Adaptive management is a structured process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. This form of management can improve clarity about key Plan elements and focus decision-makers' attention on the *what*, *why*, and *how* of action implementation, and emphasizes accountability and explicitness in decision making (Williams et al. 2009). This is particularly important for resource management, which often entails multiple management objectives, constrained authorities and abilities, dynamic resource systems, and uncertainty in the responses to management actions. According to the Technical Guide for Adaptive Management Plans by the U.S. Department of the Interior (Williams et al. 2009), activities comprising this structural decision-making approach should include:

- Engaging stakeholders in the decision-making process
- Identifying the problem(s) to be addressed
- Specifying the objectives and tradeoffs that capture stakeholder values
- Characterizing assumptions about resource structures and functions
- Predicting the consequences of alternative actions
- Identifying key uncertainties
- Measuring risk tolerance for potential consequences of decisions
- Anticipating future impacts of present decisions
- Accounting for legal guidelines and constraints

Under the framework of a Flood Control District, this VLMP recommends the formation of a Steering Committee or otherwise defined supervisory group (e.g., the continuation of the Technical Advisory Group formed by this project) to manage a formal, science-based adaptive management program. This adaptive management program shall provide science-based recommendations and technical information to the managing entity (i.e., the Flood Control District Governing Board) to assist in the determination of *if* and *when* it is necessary or advisable to adjust the goals, objectives, management actions, and/or measures of evaluation set forth in previous versions of the VLMP. Additional VLMP adaptive management participants may include those staff members defined by the Board, independent reviewers, and policy makers (see the Roles and Responsibilities section).

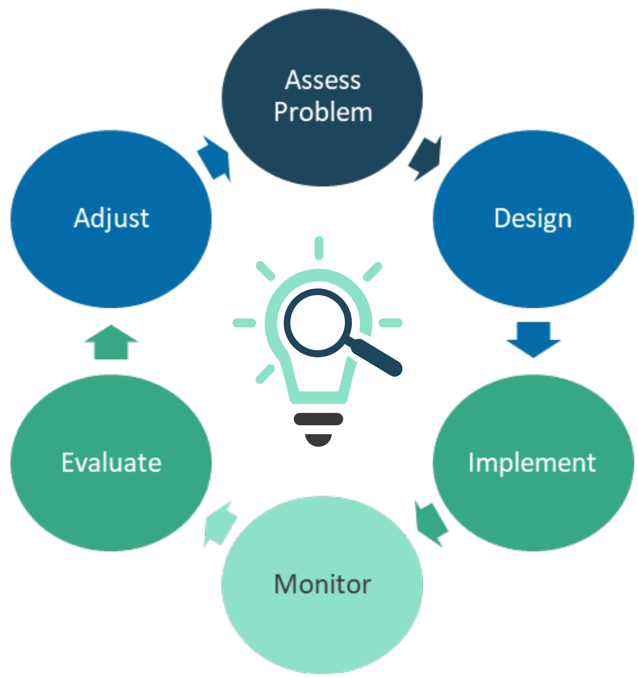
The following generalized procedure may be used for VLMP adaptive management and decision making (see inset graphic):

Assessing the Problem

Stakeholders and/or the technical advisory group shall provide observations of the system function and identify issues.

Designing a Solution

The technical advisory group and/or the Board should establish key questions, and define and prioritize resource objectives. Lake resource objectives may consist of functional objectives, which are broad statements regarding potentially affected major functions, and performance targets, which are measurable criteria defining specific and attainable conditions and processes.



Adaptive Management Cycle. Adapted from Williams et al. (2009)

Implementation

Adaptive management proposals should be submitted to the Board by the technical advisory group(s) and/or other relevant participants, or by the general public at public/board meetings. Proposals should demonstrate how future impacts will address key questions and lake resource objectives/issues. Proposal approval and prioritization will be determined by the Board. Approved projects are then implemented and/or delegated at the Board's discretion.

Monitoring

Monitoring is a key component of adaptive management. A basic monitoring program at Vancouver Lake could be conducted by trained volunteers and/or supervised by technical advisory group members or project partners, and should consist of the minimum elements described in the Climate Change

Impacts Analysis and Mitigation section. Independent scientific review may be conducted at identified points of implementation, pursuant to study goals, Board direction, and/or funding resources.

Effectiveness Evaluation

Using monitoring data and observations, project performance and management effectiveness will be evaluated. An evaluation report should outline recommended actions, data gaps, and next steps for technical advisory group and Board review. Relevant reports or petitions for rulemaking shall be shared with the public.

Adjust

Based on the recommendations established in the evaluation report and those provided by technical advisors, and the values of the general public, the Board will make all final decisions regarding VLMP adaptations/adjustments.

Current Knowledge Gaps and Plan Limitations

The following knowledge gaps and constraints identified during the development of this plan, may limit certain VLMP elements:

- Current watershed management enhancement activities are ongoing and adaptive, so specific strategies and cost estimates to include in method evaluation were not available.
- Existing data related to sewer overflow, main line breaks, and leaks were not referenced to confirm assumptions that these events are rare, which could better inform design and costing of wastewater management enhancements.
- Current watershed nutrient datasets and budgets do not include an evaluation of inputs from sediment resuspension or a quantification of indirect inputs from Salmon Creek.
- Hydrodynamic and ecological modeling constraints include but are not limited to:
    - The nature of simplifying a complex ecological system by utilizing assumptions, like those related to management alternative design, nutrient cycling, trophic dynamics and growth rates, and parameterization of all algae taxa into three main algae functional groups.
    - Using data from two consecutive low-productivity years to calibrate and validate the model, which may not be representative of the long-term average trophic state of Vancouver Lake, which tends toward a higher state of productivity.
    - Project constraints restricting the level of water quality modeling performed. With additional resources, the current design can be expanded to model additional ecological endpoints and/or additional watershed extents (i.e., Lake River).
- Additional stormwater contaminants of concern and emerging pollutants like microplastics, PFAS, and 6 PPD-quinone, which is acutely toxic to coho salmon and prevalent in urban streams and stormwater (Tian et al. 2020), have not been monitored in the watershed and may represent a gap in water quality data.

- No qualitative map or quantitative survey data representing the extent of emergent invasive weed infestations around Vancouver Lake are available with which to make better informed management recommendations at this time.
- Long-term impacts beyond the 20-year VLMP design accounting for climate change were not considered but should be addressed in subsequent VLMP adaptations.
- The feasibility of management method implementation is additionally constrained by permitting and other regulatory compliance needs like those related to public safety, navigation, and fish passage, which were mentioned in this VLMP but cannot be directly addressed until a management strategy has been selected and approved by a managing entity (e.g., Clark County, or a Flood Control District Board). Further consultation with appropriate stakeholders would be needed to ensure these considerations are addressed.
- Review, comment, and general public engagement were received from a small percentage of stakeholders, comprising a less diverse demographic than the composition of Vancouver Lake's watershed. This Plan is thus limited to the values and comments of those who participated.
- By design, this VLMP does not address the Additional Lake Issues raised by stakeholders. See Future Adaptations to Consider below.

Future Adaptations to Consider

Among other potential future concerns, VLMP adaptive management solutions should address the Additional Lake Issues raised above. Example goals and numerical objectives to consider for two such issues are outlined below.

Goal: Reduce public use impacts from *E. coli* bacteria contamination at Vancouver Lake Regional Park.

- *E. coli* concentrations shall not exceed recreational guidelines for issuing a public health advisory (>236 MPN/100 mL) on more than two sample dates during each of 2 or more years. Years do not need to be consecutive.
- Public health advisories issued by Clark County Public Health for *E. coli* lasting for more than 2 weeks per event shall not occur more than once over 2 or more years. Years do not need to be consecutive.
- No probable or confirmed human *E. coli* exposure events that result in illness or death shall occur.

Goal: Expand public recreational access to Vancouver Lake.

- By 2033, construct one additional boat ramp or improve an existing undeveloped boat ramp to include infrastructure to 1) support launch of motorized craft, 2) provide fishing access, and 3) supply invasive species decontamination equipment and education materials.

PLAN REVIEW

As lake users and managers, various stakeholder groups and members of the public were involved in the development of this LMP and should continue to be engaged in future decisions regarding management goals and methods. This LMP was reviewed in two phases. In addition to frequent consultation throughout the project via email and bimonthly meetings, a complete draft LMP was first sent to the TAG for technical review and comment. The project team reviewed comments and primarily addressed those which were mechanical, editorial, or corrective in nature, limited by available project funds. Incorporating TAG feedback, a second draft LMP was prepared to be reviewed by members of the general public. Public review of the LMP is necessary to help ensure public concerns and aspirations are understood and considered and to provide the public an opportunity to weigh in on the recommended management strategies. The following dates represent key milestones in this public review process:

- May 12, 2023– TAG comments on the first draft LMP were due to Herrera
- June 22, 2023– The second draft LMP was published for public review
- July 19, 2023– A public meeting was hosted by the Clark County Council and Herrera to provide public opportunity to hear about and comment on the draft LMP
- July 26, 2023– Public comments on the second draft LMP were due to Herrera

Suggestions for improvements to the Plan are highly valued and compiled for consideration in the next phases of Vancouver Lake management. Ultimately, the lake management team will make the decisions about which strategies to pursue, and having stakeholder and public engagement will help to build support for the outcome.

TAG Review Comments

Two-hundred and seventy-nine (279) comments were received from representatives of the following TAG organizations:

- City of Vancouver, Surface Water Management
- Clark County Public Works
- Cowlitz Indian Tribe, Natural Resources Department
- FOVL
- Port of Ridgefield
- Port of Vancouver
- Watershed Alliance of SW Washington
- WDFW
- WSU
- VLSC

Key themes identified from the comments of multiple TAG members to be addressed in the next phases, include:

- The current project to develop an LMP lacked sufficient public engagement, particularly towards the BIPOC and non-English speaking communities. There is a need for more frequent and equitable public engagement to ensure all demographics have been heard and considered, which should include but would not be limited to sufficient budget for consistent and comprehensive engagement, translational services for engagement tools, and specific engagement activities targeted toward communicating with underrepresented communities. Review of lake management goals and actions is necessary to perform through an environmental justice lens, particularly with respect to climate change considerations and equitable public access. Many state and federal funding sources additionally require these project considerations in grant proposals.
- TAG members generally agreed with Plan recommendations of management approaches, specifically that a multi-pronged strategy utilizing a combination of techniques would best achieve lake management goals. Where opinions were provided regarding HAB management decisions, TAG members generally supported the Flushing Channel enlargement alternative above all other alternatives.
- The TAG as a whole did not claim to support nor oppose the Flushing Channel enlargement alternative, as some TAG comments clarified. When asked directly during meetings, some TAG members reflected their support while other TAG members present did not indicate favor for any other HAB management alternative.
- Comments on the draft plan additionally noted that floating wetlands and algaecides as respective primary HAB management solutions should be rejected from further consideration. Floating wetlands are inadvisable due to their low cost-effectiveness and high expected negative impact to boating recreation. Algaecides may be further considered as targeted and/or supplemental solutions, as recommended in the Plan.
- There was disagreement regarding the driving goal for Vancouver Lake water quality. Some comments assert that existing objectives are not feasible and that allowing the lake to return to a "natural state" (i.e., a seasonally eutrophic system) would be more realistic and affordable than this Plan's current objectives. Other comments assert that any management objective which does not "restore" the lake to a mesotrophic state or does not prevent eutrophication "condemns the rest of this work to failure".
- Expansion and improvements of the hydrodynamic and water quality model are needed to 1) understand effects of management alternatives on Lake River, 2) include data from tributaries and the Columbia River as inflow sources to better understand watershed impacts on the lake and efficacy of management alternatives, and 3) model multiple alternatives together to understand the efficacy of a combined approach.
- Additional discussion and specification of some management alternatives is needed with respect to 1) stormwater and septic system improvements and maintenance in the watershed, 2) fish passage requirements and salmonid-specific considerations for all alternatives, and 3) structural design, timeline, and construction considerations for the flushing channel enlargement alternative.

- Floodplain ecosystem restoration as a means of both HAB management and comprehensive lake rehabilitation (e.g., including option for portions of the lake to “return to natural state” by reconnection of Vancouver Lake with the Columbia River and adjacent wetlands) was suggested to be explored, in lieu of short-term management actions and spatially-limited restoration goals. This is a large-scale, high investment alternative, for which costs and benefits should be identified, and should be considered in future LMP phases.
- Carp removal as a means of HAB management was suggested to be further described and explored in some comments. However, WDFW biologist comments suggest carp removal is expensive and often ineffective. Conversations to determine feasibility and non-target effects should be had for future LMP consideration.
- Updates, clarifications, and questions were offered regarding estimated costs of Plan components, such that some components appeared underbudgeted, some components appeared overbudgeted, and some components may not have been fully considered or included in existing estimates. Accounting for inflation in estimates for components expected to be performed over the 20-years of the Plan was also suggested.

A full repository of individual comments received, with project team responses, are provided in Appendix D.

Public Review Comments

Under development.

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APPENDIX A

Lake Modeling Report

Herrera
Science + Planning + Design

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Technical Memorandum

From:	Daniel Rucinski Steve Skripnik	**Date:**	April 14, 2023
To:	Rob Zisette – Herrera Environmental Consultants	**Project:**	Vancouver Lake Management Plan
		CC:	

SUBJECT: **Hydrodynamic and Water Quality Modeling of Vancouver Lake**

1 Executive Summary

LimnoTech has developed a linked hydraulic and water quality model for Vancouver Lake, Washington, to assess the potential relative efficacy of various management alternatives to address degraded water quality in the lake. Development of this model framework is part of the larger Vancouver Lake Management Plan, which is intended to provide guidance for mitigating water quality in the lake that has been degraded as a result of cultural eutrophication. Vancouver Lake regularly experiences nuisance and harmful algal and cyanobacteria blooms, low water clarity and recreational activity warnings. The modeling framework will allow stakeholders to assess the relative costs and benefits of several management alternatives in alleviating these stressors to the lake.

The lake management alternatives that were explored as part of this effort include:

- Reduction of external nutrient sources associated with failing septic systems;
- Reduction of external nutrient sources associated with stormwater runoff in the watershed;
- Construction of a dam near the outlet of the lake to Lake River;
- Enlargement of the flushing channel to the west of the lake;
- Construction of floating wetlands in the lake;
- Sediment and water column phosphorus inactivation;
- Algaecide treatment of the water column.

LimnoTech was provided with an existing hybrid 1-dimensional/2-dimensional HEC-RAS hydraulic model of Vancouver Lake (Jacobs 2022). The model was reconfigured to simulate the Lake River and Vancouver Lake domains using 2-dimentional computational points. The core geometry files and data sources from the Jacobs model were also maintained for development of this modeling application.

Water Analysis Simulation Program (WASP; Wool et al. 2020) was linked to HEC-RAS (Hydrologic Engineering Center, 2021) to add the capability of simulating water quality including up to three algal classes; multiple forms of phosphorus, nitrogen, and carbon; dissolved oxygen, temperature, solids; toxics; and sediment diagenesis. While all of the model capabilities are not used here, the configuration used represents an advanced lower food web model.

A simulation period of 2011-2012 was used due to the availability of in-lake water quality data for calibration. Model results for ecological endpoints, including summer average chlorophyll-a concentrations, summer maximum cyanobacteria, summer average Secchi depth, summer average total phosphorus, and maximum water temperature are described in detail in Section 6.

Based on model simulations and the assumptions stated in the report, the in-lake treatments of algaecide and phosphorus inactivation provide the greatest benefit in reducing algal biomass (summer chlorophyll-a and cyanobacteria concentrations), although these methods do not address the underlying causes of eutrophication and only the symptoms. The physical lake management approaches, such as channel enlargement and construction of Lake River dam do provide significant reductions in nutrients and algal biomass, although these methods fundamentally change the hydraulic and hydrodynamic processes in the system, as demonstrated by the change in lake temperatures. External load reduction strategies (wastewater and stormwater treatment alternatives) provide relatively modest water quality improvements, although these strategies address some of the underlying cause of eutrophication. Floating wetlands provide minor water quality improvements compared to other strategies.

2 Project Background

2.1 Site Description and Characteristics

Vancouver Lake is a shallow tidally influenced lake that is hydraulically connected to the Columbia River (Figure 1). Lake inflows include an engineered flushing channel to the west and Burnt Bridge Creek to the east (Figure 2). The lake's outlet flows north to the Columbia River via Lake River, although the tidal signal of the Columbia River periodically causes Lake River to flow south into the lake.

Vancouver Lake experiences poor water quality during the summer months when temperatures are high and water levels and inflows are low, which promotes algal growth. Nutrient inputs from Lake River, Burnt Bridge Creek and the Flushing Channel contribute external loads, while legacy nutrients stored in the lake sediments can provide internal nutrient loading. This modeling analysis focuses on simulating changes to the system to address this excess loading, via hydraulic modifications to the lake, as well as watershed and in lake treatment alternatives.

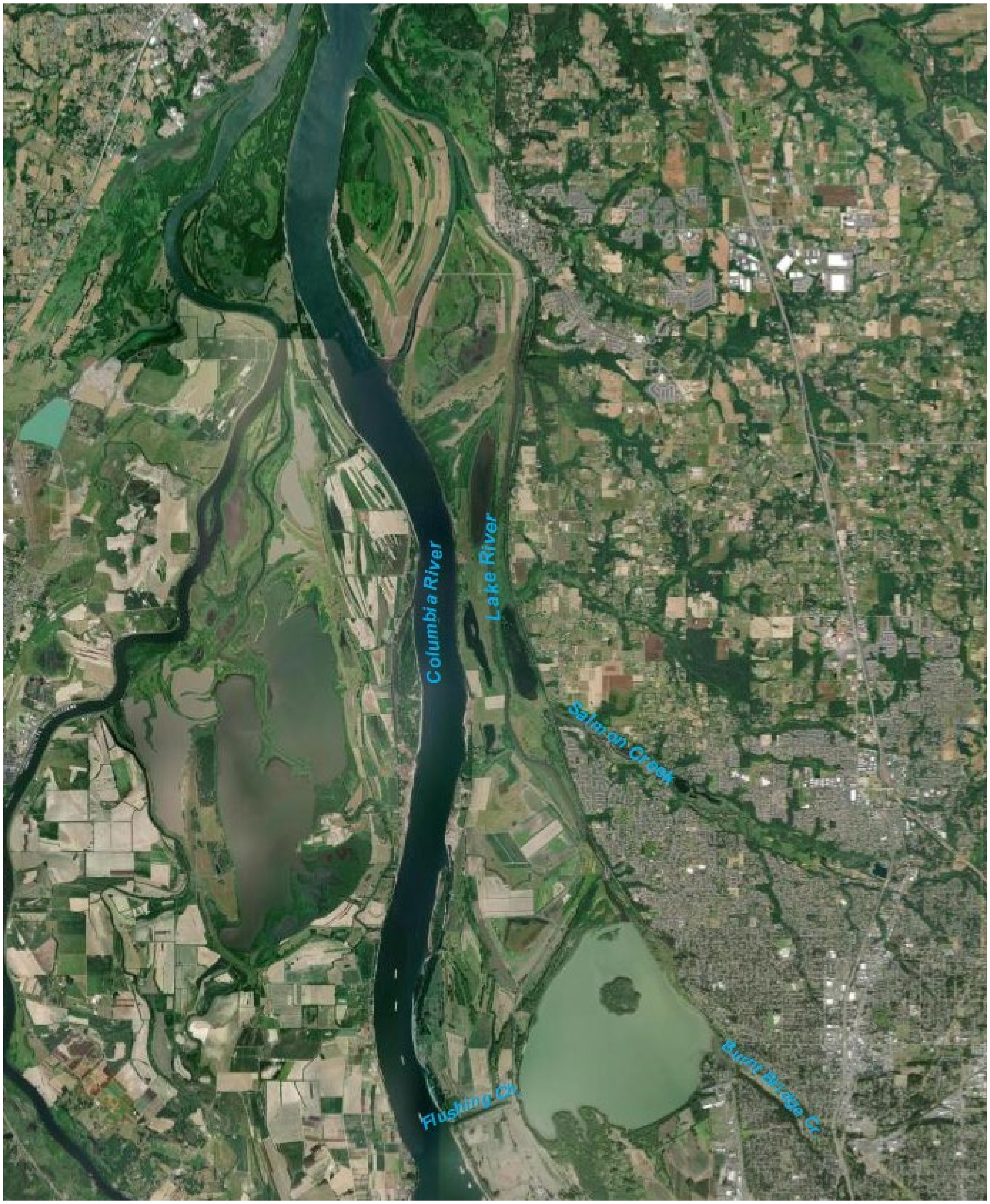


Figure 1: Vancouver Lake and Lake River system.

Figure 2: Vancouver Lake.

2.2 Modeling Objectives and Approach

For this study, a computer model simulating hydraulics, circulation, nutrient cycling, and lower food web dynamics was developed to assess the relative benefits of different lake management alternatives. This framework allows us to simulate modifications to the existing system and analyze the relative change in ecosystem responses, such as summer algal biomass or water clarity for each modification.

It is important that the existing system is well represented by the computer model before making modifications to the model. Extensive water quality observations that are required to parameterize a water quality model are not available for most years for this system. However, approximately monthly data for many nutrient species, chlorophyll-a, dissolved oxygen, and temperature at two locations in the lake and at the main tributary confluences were collected during 2011 and 2012 (Sheibley et al. 2014). While these years represented a relatively lower algal production than most summers, it was necessary to use these data and time-periods for water quality model development and calibration. As such, the full calendar years of 2011 and 2012 were simulated, while calibration was focused on total chlorophyll-a, temperature, total phosphorus, and total solids.

2.2.1 Hydraulic Model Framework

LimnoTech was provided with an existing hybrid 1-dimensional/2-dimensional HEC-RAS hydraulic model of Vancouver Lake (Jacobs 2022). This model was developed to represent periods of the summers of 2007 and 2008. While these time-periods did not coincide with our water quality calibration data, the sources of model inputs (e.g., water levels, flows) that were used in the Jacobs model were maintained in this application, with the data acquired to represent the 2011-2012 time-periods. The core geometry files and data sources from the Jacobs model were also maintained for development of this modeling application.

Additionally, because the Jacobs model was developed for hydraulic simulations only, it contained 1-dimensional portions representing Lake River and the flushing channel. While this approach works well for hydraulics, it cannot be readily transferred to a water quality model. Therefore, the HEC-RAS model domain was re-configured to include only 2-dimensional computational points throughout the lake, as well as in the channels and Lake River. Further, portions of the existing lake model covered areas that were regularly dry or wetland areas. These areas are problematic for many water quality models that cannot process time-variable flooding. For this reason, portions of the lake domain (such as the wetlands on the southwest side of the lake) were not directly simulated. Figure 3 shows the revised model domain for Vancouver Lake, which consists of approximately 13,500 computational cells. The Lake River portion of the domain extends from Vancouver Lake to the confluence of the Columbia River (Figure 1).

Figure 3. HEC-RAS 2D computational domain.

2.2.2 Water Quality Model Framework

HEC-RAS does not contain a 2-dimensional water quality submodel that is capable of simulating the algal and nutrient dynamics required for this application. Therefore, an external model must be linked to the HEC-RAS model to simulate water quality. The developers of the Water Analysis Simulation Program (WASP) model have recently linked HEC-RAS with their water quality model (Shabani et al. 2021), and their linkage code and approach was adopted here.

WASP is a 3-dimensional water quality model that can be configured to simulate up to three algal classes; multiple forms of phosphorus, nitrogen, and carbon; dissolved oxygen, temperature, solids; toxics; and sediment diagenesis. While all of the model capabilities are not used here, the configuration used represents an advanced lower food web model (Figure 4).

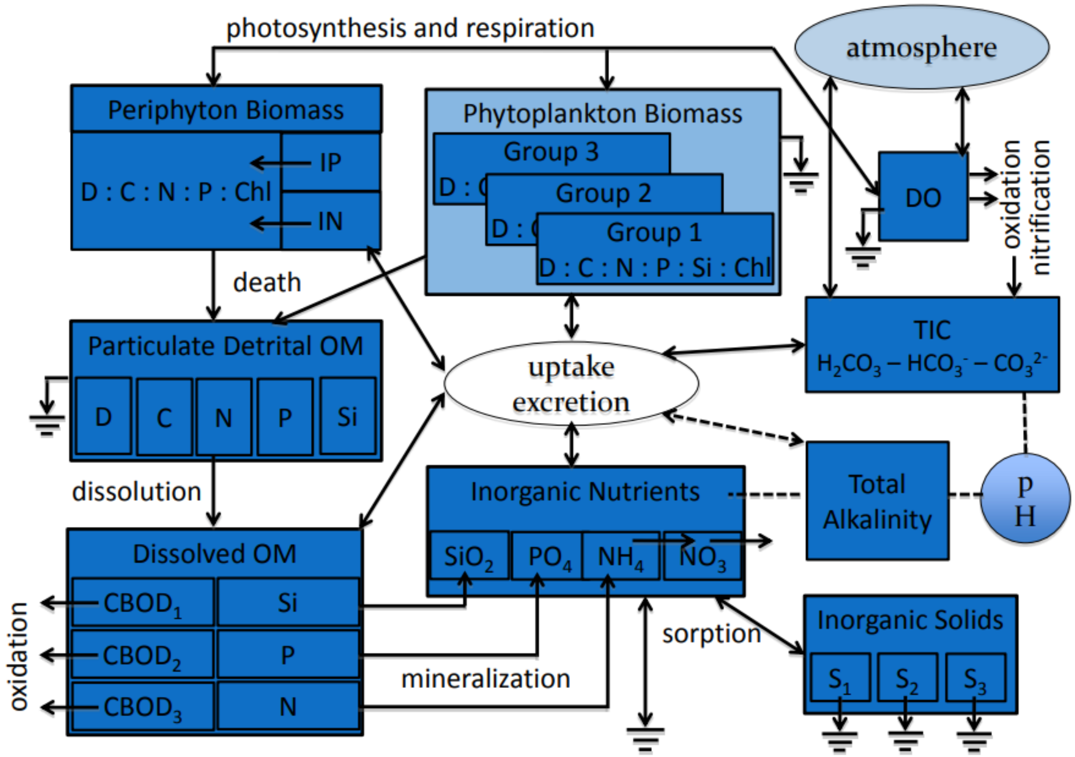


Figure 4. WASP conceptual model diagram. Periphyton, inorganic carbon and alkalinity components are not included in this study (Wool et al. 2020).

The HEC-RAS to WASP linkage code (Shabani et al. 2021) allows the user to define different computational cells for the WASP model as compared to the HEC-RAS model. As the relevant water quality end points are not expected to vary spatially as much as circulation patterns, it is appropriate to have coarser cells simulating water quality. The WASP computational cells must overlap the HEC-RAS cells, and generally conform to a 2-dimensional grid. The aggregated approach results in 76 water quality cells across Vancouver Lake and the connecting channels (Figures 5 and 6). The linkage code reads model output from HEC-RAS and aggregates the time-variable velocity, flow and depth values at the larger WASP cells.

Figure 5. WASP computational domain.

Figure 6. WASP computational domain.

3 Supporting Data

3.1 Bathymetry

HEC-RAS requires fine-scale bathymetry data in the form of digital elevation or terrain models. Generally, such data are readily available for dry land areas, although elevation data in wetted areas are less accurate. To be consistent with the Jacobs HEC-RAS model, the same digital elevation model was used for the topographic terrain (2010 Lower Columbia Digital Terrain Model; Lower Columbia Estuary Partnership, 2010), while bathymetry values under the water surface were augmented to be consistent with the Jacobs model. Specifically, we maintained the -1.2m (-3.8ft) depth adjustment in Vancouver Lake itself, and we also used the transect elevations from the 1-dimensional channels to represent the bathymetry in Lake River and the Flushing Channel.

Other morphometric and geometric data representing the system, such as culvert dimensions, flushing channel width, were defined to be consistent with the existing HEC-RAS model.

3.2 Tributary Flows

The model domain includes two boundary conditions corresponding to riverine tributaries: Burnt Bridge Creek and Salmon Creek. In HEC-RAS and WASP, these boundaries are treated as lateral inflows, with a daily variable flow rate specified at the model locations where they enter the model domain (Figure 1). Flow rates for these tributaries were obtained from USGS streamflow gages. For Burnt Bridge Creek, daily values from USGS station 14211902 (BURNT BRIDGE CREEK NEAR MOUTH AT VANCOUVER, WA) were used directly in the model. The USGS station 14213000 (SALMON CREEK NEAR VANCOUVER, WA) for Salmon Creek does not cover the period of simulation for this application (2011-2012), however, Sheibley et al. (2014) had developed a regression relationship between streamflow at this location and another monitoring location by the Clark County Department of Public Works. Sheibley et al. (2014) reported the daily flow rates for 2011-2012 using the regression relationship, which was also used in this effort.

3.3 Water Levels

Hourly water level data is specified at the boundaries representing the flushing channel and the confluence of Lake River with the Columbia River. The source of the water level data is consistent with the Jacobs HEC-RAS model, utilizing the NOAA PORTS® gages at Vancouver and Saint Helens, respectively (NOAA 2022).

Both the HEC-RAS and WASP model elevation data are specified relative to the NAVD88 vertical chart datum, while the NOAA PORTS® gages reference the Columbia River Datum (CRD). Our analysis utilized the same CRD-to-NAVD88 conversion factors reported by Jacobs (2022):

CRD to NAVDD88 at Vancouver = +1.52m (+5.15ft)
CRD to NAVDD88 at Saint Helens = +1.26m (+4.15ft)

3.4 Meteorological Forcings

The WASP water quality model requires inputs describing the time-variable atmospheric conditions above the water surface. These inputs define the thermal and wind energy at the air-water interface which influence the rates at which algae grow and other biogeochemical processes react. The heat flux sub-model in WASP requires the following inputs to calculate the heat balance: air temperature (°C), short wave radiation (Watts/m^2), cloud cover (fraction), and dew point (°C).

Data for these inputs were obtained from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Version 2 (CFSv2; Saha et al., 2011). The data from CFSv2 is available on an hourly basis.

In addition to the heat flux inputs, WASP also requires wind speed (m/s) and direction time series. Data describing the hourly wind fields were also obtained from the CFSv2 model.

3.5 Water Quality Boundary Conditions

At each of the four locations in the model domain that represent external boundaries (Figure 1; upstream Lake River, Salmon Creek, Burnt Bridge Creek, Flushing Channel), the value of each water quality state variable must be specified.

As noted previously, the availability of such data is limited in this system, and this analysis had to rely on previously observed data from the 2011-2012 period (Sheibley et al 2014). The reported values from Sheibley et al. (2014) provide approximately monthly values for the following model state variables:

- Temperature (°C)
- Dissolved oxygen (mg/L)
- Particulate carbon (mg/L)
- Ammonia (mg/L as N)
- Nitrate plus nitrite (mg/L as N)
- Orthophosphate (mg/L as P)
- Particulate nitrogen (mg/L)
- Particulate phosphorus (mg/L)
- Total dissolved phosphorus (mg/L as P)
- Total dissolved nitrogen (mg/L as N)
- Organic nitrogen, calculated (mg/L as N)
- Organic phosphorus, calculated (mg/L as P)
- Total suspended solids (mg/L)

3.6 In-lake Calibration Data

The WASP model was calibrated and confirmed using separate in-lake data (Sheibley et al. 2014) at two locations in Vancouver Lake. Both observation sites (described as "Lake 1" and "Lake 2", Figure 7) are located on the eastern side of the lake. Data from Sheibley et al. (2014) were used from these two stations to compare model simulated values, focusing primarily on total chlorophyll-a, while also comparing temperature, dissolved oxygen, and total solids.

Figure 7. Location of in-lake monitoring stations in relation to water quality model domain.

3.7 Other Model Assumptions

The WASP model framework allows for specification of time-variable forcings that represent ecological phenomena such as benthic nutrient fluxes and sediment oxygen demand. These kinetic rates and forcings are not well constrained by observed data to the system, and therefore professional judgement must be used in defining the rates and values for these inputs, where they are important to the system. A previously study of Vancouver Lake found minor flux of benthic phosphorus from the sediments to the water column, and a value for the internal phosphorus load of 1 $mg/m^2/d$ was used in this modeling study. Similarly, a sediment oxygen demand rate of 0.7 $mg/m^2/d$ was applied.

4 Model Development and Calibration

4.1 Hydraulic Model

The primary focus of this modeling effort was directed towards development, calibration, and application of the water quality model, while utilizing the already calibrated hydraulic model (Jacobs 2022) as much as possible. As described previously, some modifications to the computational domain were required to utilize the HEC-RAS model. The revised HEC-RAS model is constrained with observed water level boundary conditions at the flushing channel inlet and where Lake River meets the Columbia River. Because the main changes to the prior calibration involved extending the period of simulation and modifying the areal extent of the computations, no further validation effort was made for the hydraulic model.

4.2 Water Quality Model

The WASP model calibration was performed while comparing output to chlorophyll-a, temperature, dissolved oxygen, phosphorus, and total suspended solids at both in-lake monitoring stations, simultaneously. Effort was made to match the time-variable observed data, adjusting growth and settling rates, optimal growth parameters, nutrient cycling coefficients, and other model kinetic rates. Priority was first given to matching the seasonal algal succession, followed by nutrient and solids concentrations. All model inputs, rates, and kinetic terms were held constant throughout the two-year simulation. Additionally, the simulated growth kinetic time-series related to nutrient limitation were assessed to ensure the model was behaving as expected.

Version 8 of WASP allows the user to simulate the water heat balance based on atmospheric inputs. This is a critical aspect of WASP, as generally water temperatures are simulated directly in the hydraulic or hydrodynamic model, however this is not possible with the two-dimensional version of HEC-RAS. A reasonable representation of water temperatures is required for any biological components of the water quality model, and therefore it is important to compare the modeled water temperature with observed data. Figure 8 shows the model comparison for water temperature and observed data for both in-lake stations. The model does a good job of capturing the temporal trend in data, although the simulated values at the peak of winter are under-predicted. This is a consequence of the source of the atmospheric forcing data; however, it is assumed that the production in the lake over this period is relatively minor compared to the warmer periods.

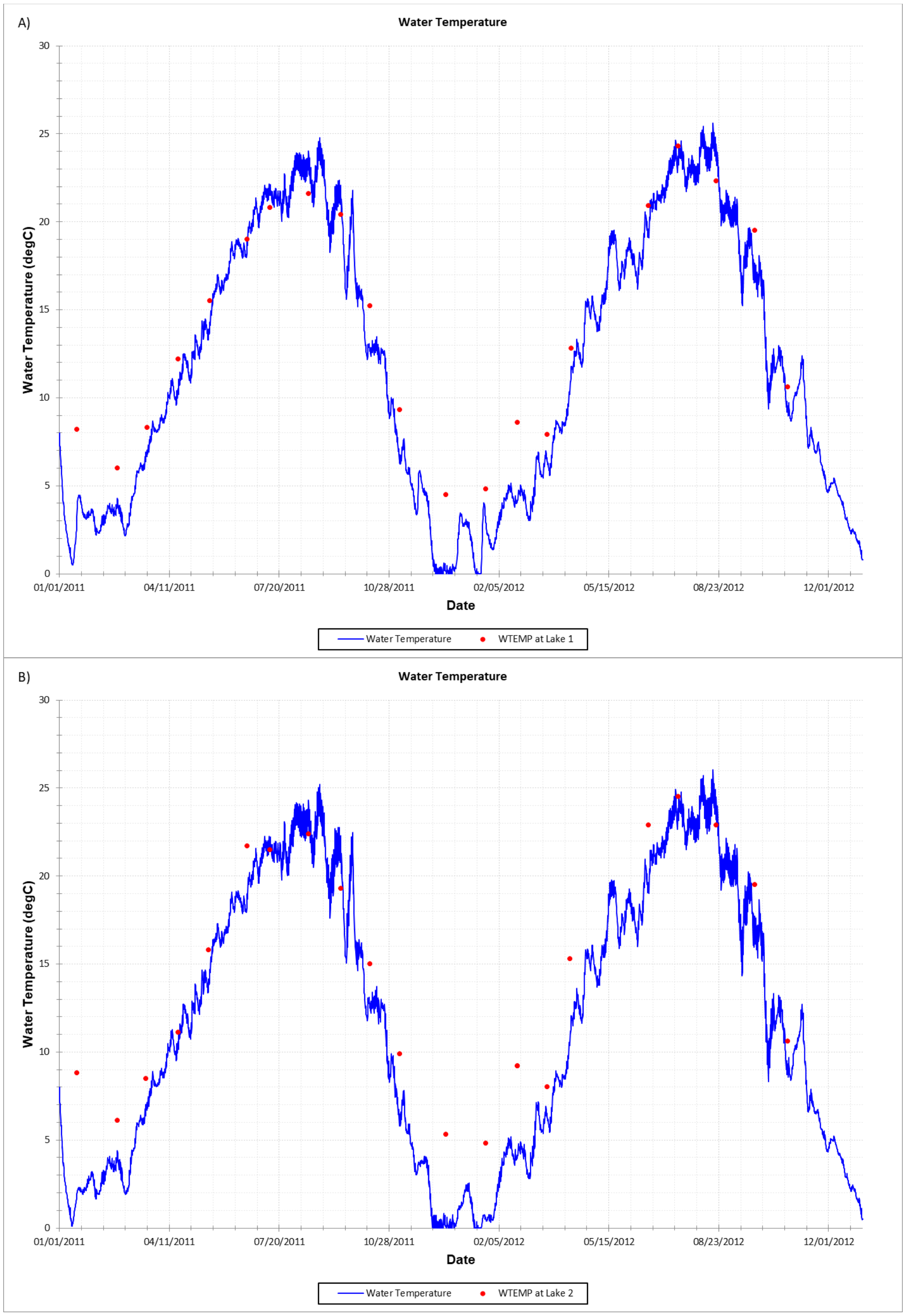


Figure 8. Model simulated water temperature. A) Lake 1 station; B) Lake 2 station.

Figure 9 shows the seasonal algal succession, in terms of chlorophyll-a concentrations; model values are shown as solid lines while observed data are shown as red points. The WASP model utilizes three individual algal functional classes, representing diatoms, green algae and cyanobacteria. These three functional groups are parameterized differently in the model to allow for different advantages and disadvantages at different times. Diatoms outperform the other groups in colder water periods and are reliant on available silica for growth, while cyanobacteria can utilize atmospheric nitrogen for growth and tend to thrive in warmer temperatures. Similarly, summer green algae grows best in temperate waters, but can be outperformed by cyanobacteria when nutrients become lower. Adjustment of these and other constraints in the model was performed to best match observed data, while holding the rates constant in space and time.

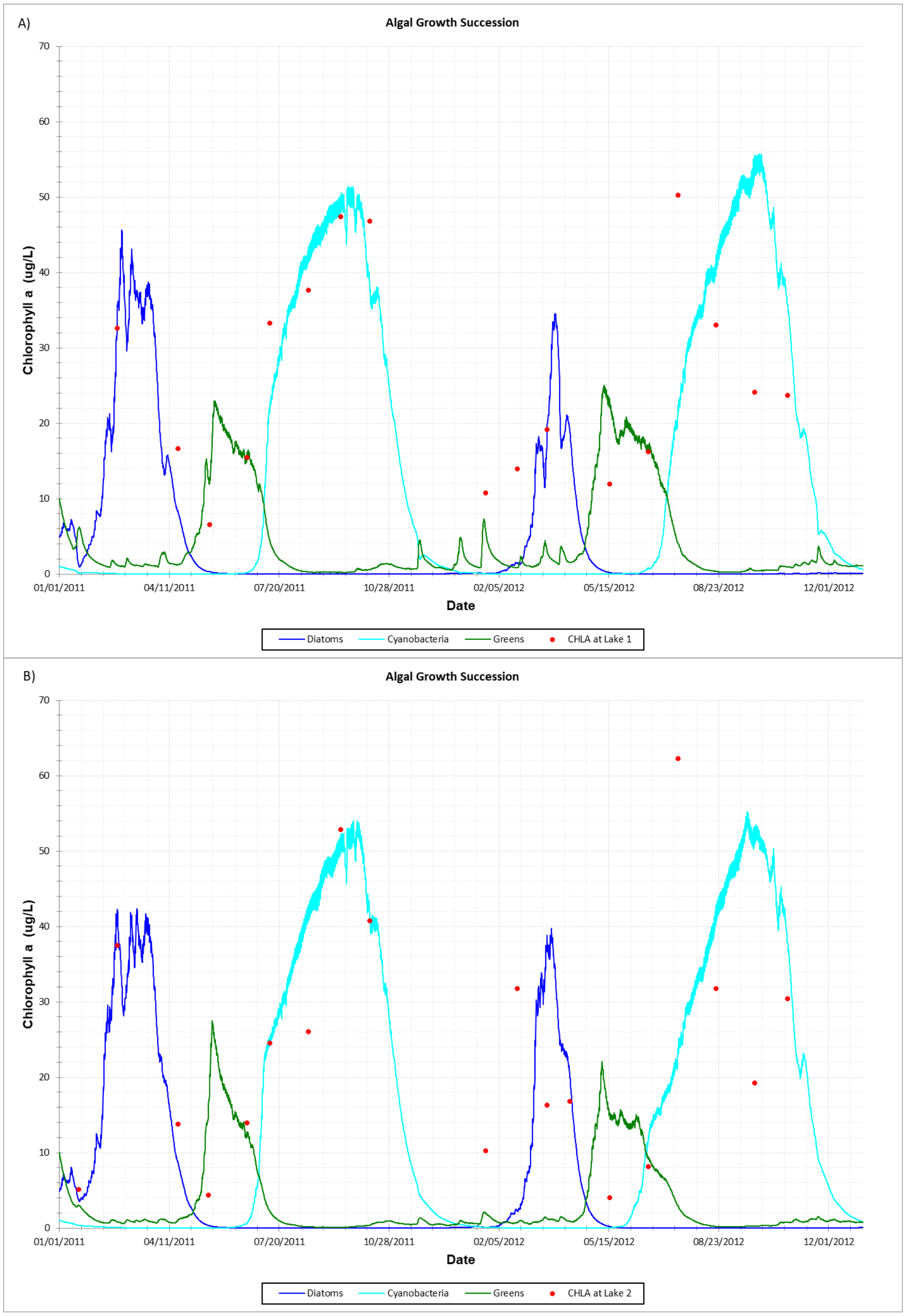
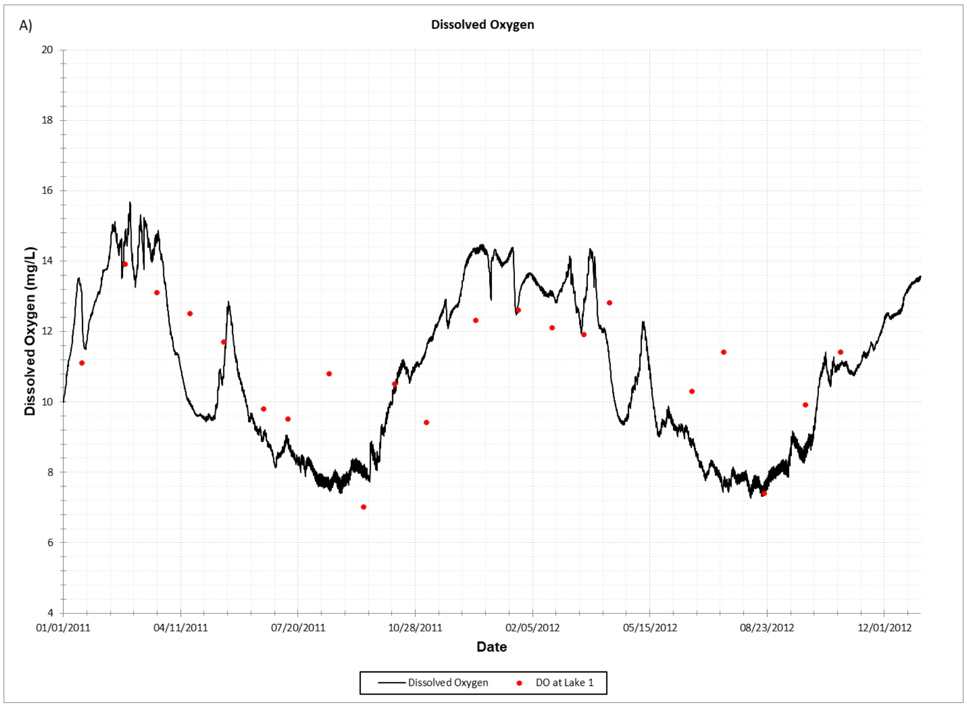


Figure 9. Model simulated algal growth succession. A) Lake 1 station; B) Lake 2 station.

The dissolved oxygen cycle in WASP includes sources from atmospheric reaeration and primary production; and sinks as a result of algal respiration and sediment oxygen demands. The algal growth and respiration rates can be adjusted in the model as part of the calibration process. Figure 10 shows the model-data comparison time-series for dissolved oxygen at both in-lake monitoring stations. Overall, the model captures the seasonal oxygen dynamics well, demonstrating the seasonal dependance on water temperature and the showing short time scale variations as a result of algal production and respiration.



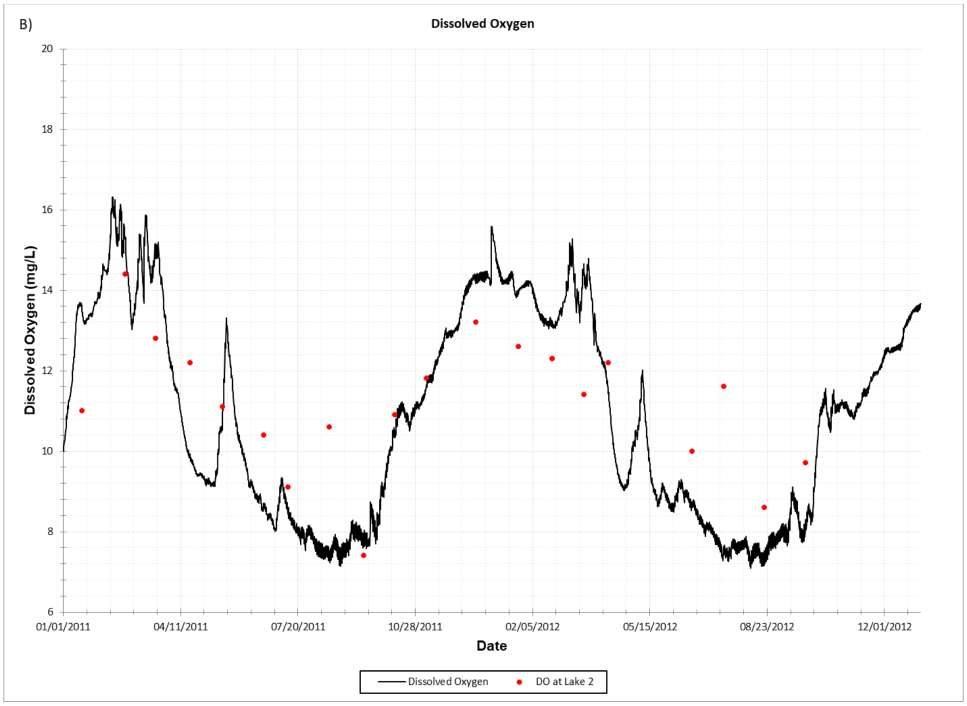


Figure 10. Model simulated dissolved oxygen. A) Lake 1 station; B) Lake 2 station.

The solids component of this model framework is relatively simple, consisting of a single solids class, which can be parameterized to settle and resuspend based on water velocities. The solids calibration was more difficult to perform as a result of the single solids class, due to the lake parameters that are adjustable. As such, the model response is heavily driven by external loads. Figure 11 shows the time-series model-data comparison at the monitoring stations. The response at Lake 2 station captures the late summer 2011 spike in solids, while the Lake 1 station does not, demonstrating the influence of Burnt Bridge Creek.

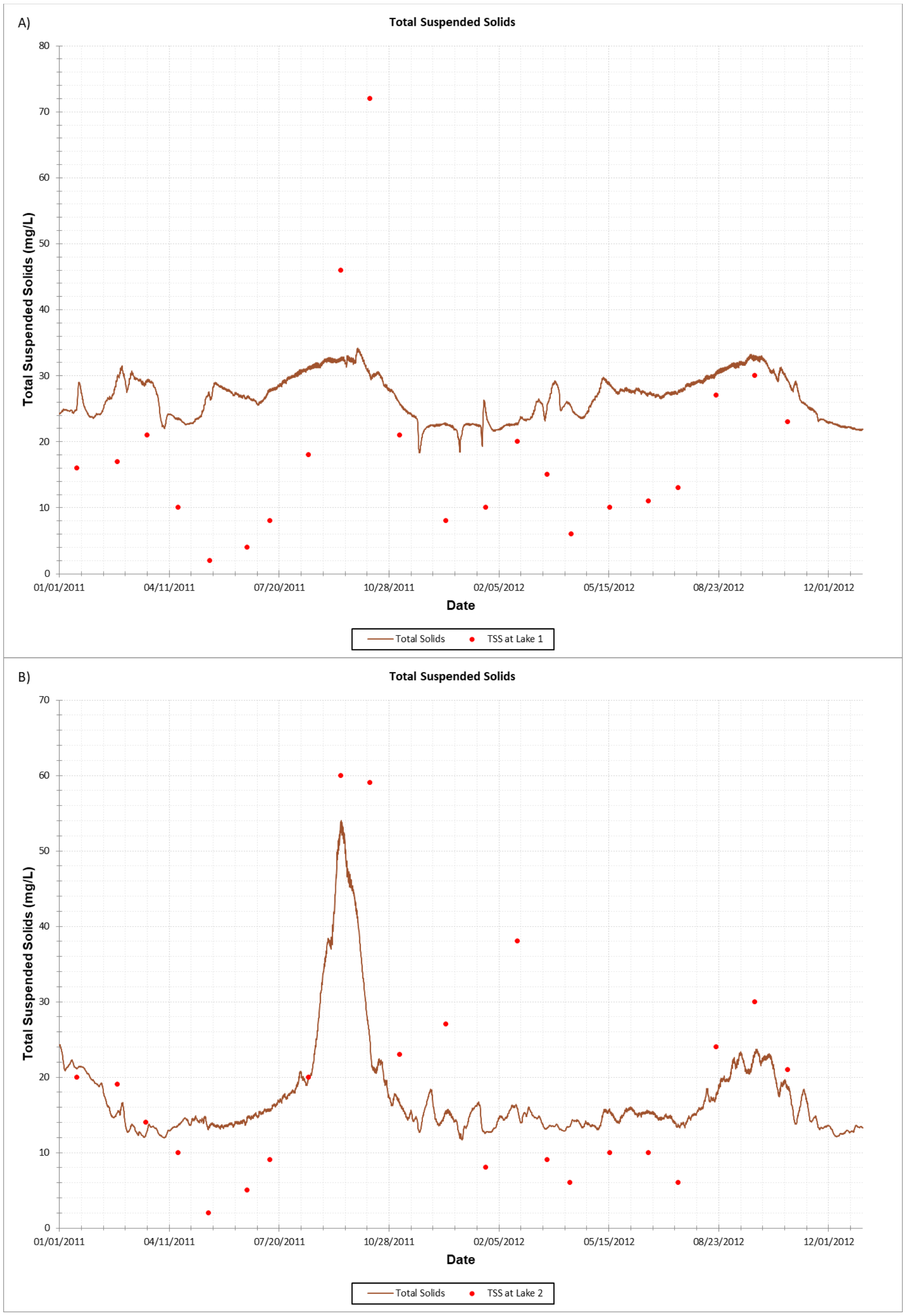


Figure 11. Model simulated total suspended solids. A) Lake 1 station; B) Lake 2 station.

The phosphorus component of WASP is highly complex and can include dozens of relevant model parameters that can be adjusted as part of the calibration process. In this analysis, rates were kept close to the default WASP values, due to the lack of local data to constrain the model. Even so, the model responds as expected with drawdowns of available phosphorus (Figure 12) in periods of high production and increases in winter when algal growth is lower. During the summer peak growing months, bioavailable phosphorus is nearly entirely depleted.

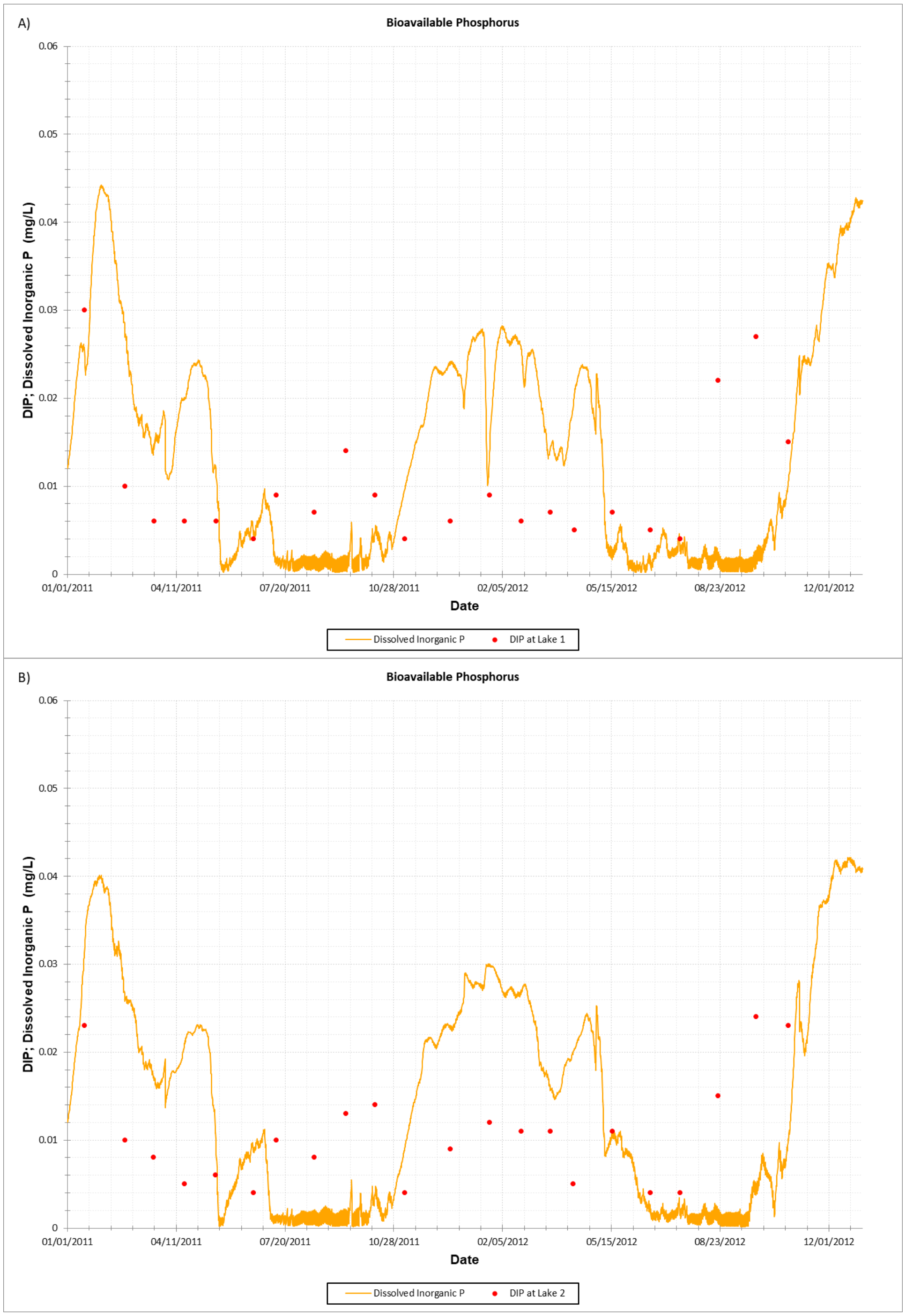


Figure 12. Model simulated bioavailable phosphorus. A) Lake 1 station; B) Lake 2 station.

In addition to comparing the model output to observed values for state variables in the model, part of the calibration exercise involves assessing the model estimate rates of kinetic processes. It is important to determine if the algal groups are responding as expected to the forces that can stimulate or limit their growth. Figure 13 shows the estimate algal growth rates as they vary over the seasons. These output variables represent the effective growth rate in the model, taking into account the availability of light, nutrients and the influence of temperature. The figure shows that diatoms can thrive in the winter months, but eventually give way to greens and cyanobacteria, which can grow at warmer temperatures. Cyanobacteria can thrive when greens have depleted much of the nitrogen, and as such dominate during the summer.

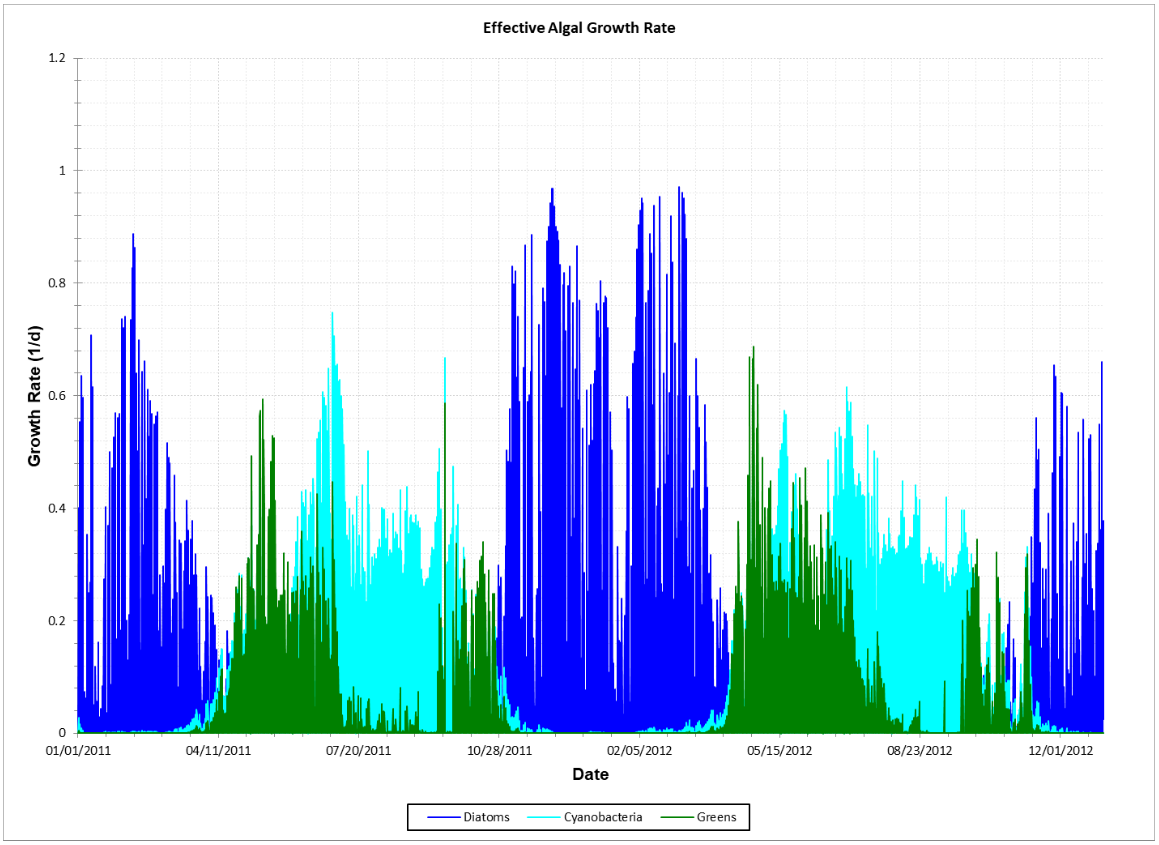


Figure 13. Model simulated effective growth rates for the three algal functional groups.

Similarly Figure 14 shows the time-variable limit that nutrients can have on algal growth. This figure takes into account the aggregate limitation of all nutrients in the model. A value of 1 represents no limitation on algal growth, while a value of 0 indicates that algae cannot reproduce as a result of nutrient availability. Both greens and diatoms are limited by nutrient availability in the summer.

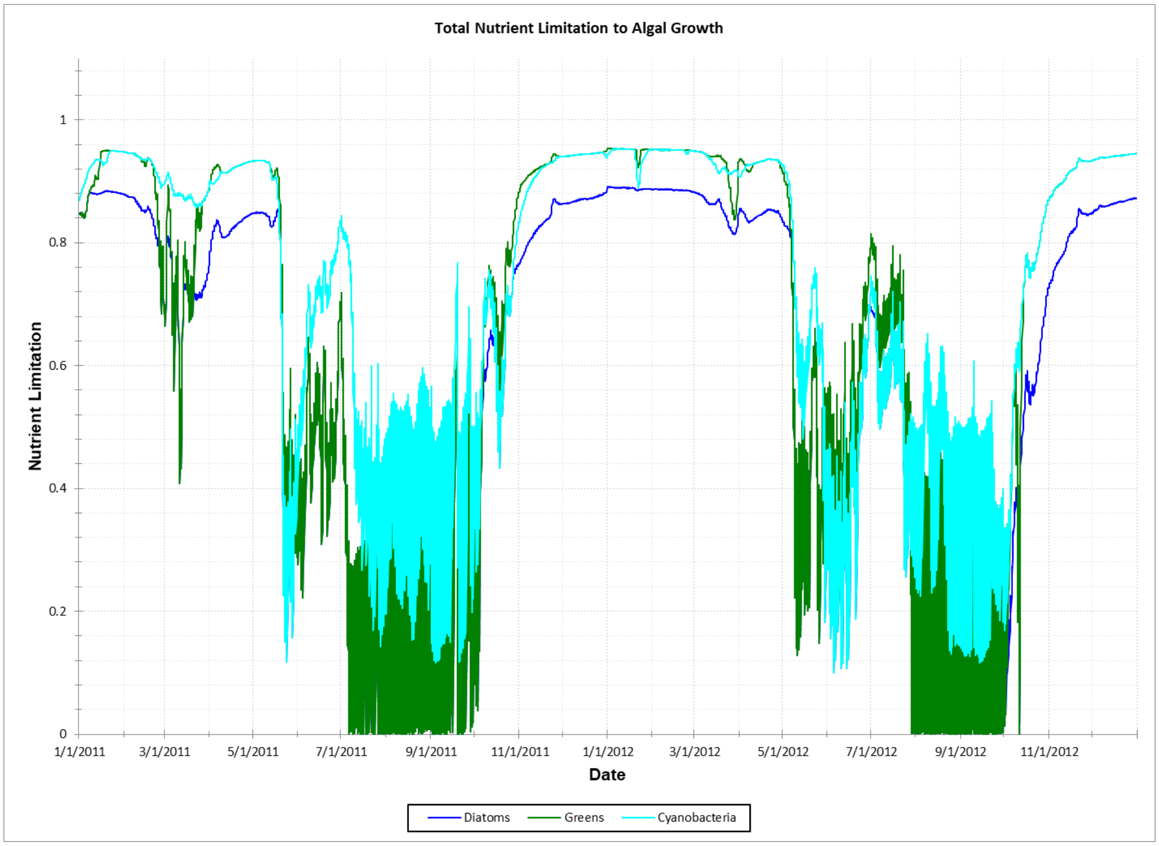


Figure 14. Model simulated nutrient limitation for the three algal functional groups.

The final WASP model parameter set is shown in Table 1.

Table 1. WASP model input values, after calibration.

Category	Description	State Variable	Value
Water Temperature	Heat exchange option	Water Temperature	full heat balance
Inorganic Nutrient Kinetics	Nitrification Rate Constant @20 degree C (1/day)	NH3	0.12
Inorganic Nutrient Kinetics	Denitrification Rate Constant @20 degree C (1/day)	NO3	0.2
Inorganic Nutrient Kinetics	Nitrification Temperature Coefficient	NH3	1.08
Inorganic Nutrient Kinetics	Denitrification Temperature Coefficient	NO3	1.045
Inorganic Nutrient Kinetics	Half Saturation Constant for Nitrification Oxygen Limit (mg O2/L)	NH3	1.5
Inorganic Nutrient Kinetics	Half Saturation Constant for Denitrification Oxygen Limit (mg O2/L)	NO3	2
Organic Nutrients	Detritus Dissolution Rate (1/day)	POC	0.4
Organic Nutrients	Dissolved Organic Nitrogen Mineralization Rate Constant @20 C (1/day)	DON	0.075
Organic Nutrients	Dissolved Organic Phosphorus Mineralization Rate Constant @20 C (1/day)	DOP	0.2
Organic Nutrients	Temperature Correction for detritus dissolution	POC	1.03
Organic Nutrients	Dissolved Organic Nitrogen Mineralization Temperature Coefficient	DON	1.08
Organic Nutrients	Dissolved Organic Phosphorus Mineralization Temperature Coefficient	DOP	1.08
CBOD	CBOD Decay Rate Constant @20 C (1/day)	Biotic BOD	0.05
CBOD	CBOD Decay Rate Temperature Correction Coefficient	Biotic BOD	1.047
CBOD	CBOD Half Saturation Oxygen Limit (mg O2/L)	Biotic BOD	0.2
CBOD	Fraction of CBOD Carbon Source for Denitrification	Biotic BOD	0.9
Dissolved Oxygen	Reaeration Option	DO	Covar
Dissolved Oxygen	Reaeration Option (Sums Wind and Hydraulic Ka)	DO	1
Dissolved Oxygen	Oxygen to Carbon Stoichiometric Ratio	DO	2.667
Dissolved Oxygen	Theta -- Reaeration Temperature Correction	DO	1.024
Dissolved Oxygen	Theta -- SOD Temperature Correction	DO	1.024

Table 1. WASP model input values, after calibration (continued).

Category	Description	State Variable	Value
Phytoplankton	Phytoplankton Maximum Growth Rate Constant @20 C (1/day)	Green Algae	2.2
Phytoplankton	Phytoplankton Maximum Growth Rate Constant @20 C (1/day)	Blue-Green Algae	2
Phytoplankton	Phytoplankton Maximum Growth Rate Constant @20 C (1/day)	Diatoms	1.6
Phytoplankton	Phytoplankton Carbon to Chlorophyll Ratio (mg C/mg Chl)	Green Algae	75
Phytoplankton	Phytoplankton Carbon to Chlorophyll Ratio (mg C/mg Chl)	Blue-Green Algae	50
Phytoplankton	Phytoplankton Carbon to Chlorophyll Ratio (mg C/mg Chl)	Diatoms	50
Phytoplankton	Nitrogen fixation option (0 no- 1=yes)	Blue-Green Algae	1
Phytoplankton	Phytoplankton Respiration Rate Constant @20 C (1/day)	Green Algae	0.1
Phytoplankton	Phytoplankton Respiration Rate Constant @20 C (1/day)	Blue-Green Algae	0.1
Phytoplankton	Phytoplankton Respiration Rate Constant @20 C (1/day)	Diatoms	0.12
Phytoplankton	Phytoplankton Death Rate Constant (Non-Zoo Predation) (1/day)	Green Algae	0.01
Phytoplankton	Phytoplankton Death Rate Constant (Non-Zoo Predation) (1/day)	Blue-Green Algae	0.01
Phytoplankton	Optimal Temperature for Growth (C)	Green Algae	17
Phytoplankton	Optimal Temperature for Growth (C)	Blue-Green Algae	20
Phytoplankton	Optimal Temperature for Growth (C)	Diatoms	5
Phytoplankton	Shape parameter for below optimal temperatures	Green Algae	0.05
Phytoplankton	Shape parameter for below optimal temperatures	Blue-Green Algae	0.02
Phytoplankton	Shape parameter for below optimal temperatures	Diatoms	0.005
Phytoplankton	Shape parameter for above optimal temperatures	Green Algae	0.05
Phytoplankton	Shape parameter for above optimal temperatures	Blue-Green Algae	0.03
Phytoplankton	Shape parameter for above optimal temperatures	Diatoms	0.06
Phytoplankton	Phytoplankton Optimal Light Saturation as PAR (watts/m2)	Green Algae	150
Phytoplankton	Phytoplankton Optimal Light Saturation as PAR (watts/m2)	Blue-Green Algae	100
Phytoplankton	Phytoplankton Optimal Light Saturation as PAR (watts/m2)	Diatoms	100
Phytoplankton	Phytoplankton Respiration Temperature Coefficient	Green Algae	1.07
Phytoplankton	Phytoplankton Respiration Temperature Coefficient	Blue-Green Algae	1.07
Phytoplankton	Phytoplankton Respiration Temperature Coefficient	Diatoms	1.07
Phytoplankton	Phytoplankton Half-Saturation Constant for N Uptake (mg N/L)	Green Algae	0.02
Phytoplankton	Phytoplankton Half-Saturation Constant for N Uptake (mg N/L)	Blue-Green Algae	0.01
Phytoplankton	Phytoplankton Half-Saturation Constant for N Uptake (mg N/L)	Diatoms	0.02
Phytoplankton	Phytoplankton Half-Saturation Constant for P Uptake (mg P/L)	Green Algae	0.002
Phytoplankton	Phytoplankton Half-Saturation Constant for P Uptake (mg P/L)	Blue-Green Algae	0.003
Phytoplankton	Phytoplankton Half-Saturation Constant for P Uptake (mg P/L)	Diatoms	0.003
Phytoplankton	Phytoplankton Half-Saturation Constant for Si Uptake (mg Si/L)	Diatoms	0.1
Phytoplankton	Fraction of Phytoplankton Respiration Recycled to Organic N	Green Algae	0.8
Phytoplankton	Fraction of Phytoplankton Respiration Recycled to Organic N	Blue-Green Algae	0.8
Phytoplankton	Fraction of Phytoplankton Respiration Recycled to Organic N	Diatoms	0.8
Phytoplankton	Fraction of Phytoplankton Respiration Recycled to Organic P	Green Algae	0.8
Phytoplankton	Fraction of Phytoplankton Respiration Recycled to Organic P	Blue-Green Algae	0.8
Phytoplankton	Fraction of Phytoplankton Respiration Recycled to Organic Si	Diatoms	0.2
Phytoplankton	Phytoplankton Nitrogen to Carbon Ratio (mg N/mg C)	Green Algae	0.18
Phytoplankton	Phytoplankton Nitrogen to Carbon Ratio (mg N/mg C)	Blue-Green Algae	0.18
Phytoplankton	Phytoplankton Nitrogen to Carbon Ratio (mg N/mg C)	Diatoms	0.18
Phytoplankton	Phytoplankton Phosphorus to Carbon Ratio (mg P/mg C)	Green Algae	0.025
Phytoplankton	Phytoplankton Phosphorus to Carbon Ratio (mg P/mg C)	Blue-Green Algae	0.025
Phytoplankton	Phytoplankton Phosphorus to Carbon Ratio (mg P/mg C)	Diatoms	0.01
Phytoplankton	Phytoplankton Silica to Carbon Ratio (mg Si/mg C)	Green Algae	0.125
Phytoplankton	Phytoplankton Silica to Carbon Ratio (mg Si/mg C)	Blue-Green Algae	0.125
Phytoplankton	Phytoplankton Silica to Carbon Ratio (mg Si/mg C)	Diatoms	0.125

Table 1. WASP model input values, after calibration (continued).

Category	Description	State Variable	Value
Light	Light Option		input diel light
Light	Fraction of Light that is PAR (Photosynthetically Active Radiation)		0.464
Light	Fraction of Light that is Infrared		0.5
Light	Fraction of Light that is Ultraviolet		0.036
Light	Include Algal Self Shading Light Extinction in Steele		Yes
Light	Multiplier for Self Shading (Mult * TCHLA^Exp)		0.001
Light	Exponent for Self Shading (Mult * TCHLA^Exp)		1.75
Light	Background Light Extinction Coefficient (1/m)		0.3
Light	Detritus & Solids Light Extinction Multiplier 1/m/(mg/L)		0.05
Solids Transport	Solids option	TSS	calculated
Solids Transport	Particle diameter for Solid- mm	TSS	0.04
Solids Transport	Critical cohesive sediment fraction- above which bed acts cohesively		0.6
Solids Transport	Critical shear stress for erosion of cohesive bed- N/m2		1
Solids Transport	Shear stress multiplier for cohesive resuspension- g/m2/sec		1
Solids Transport	Shear stress exponent for cohesive resuspension		2
Solids Transport	Critical shear stress multiplier for noncohesive resuspension		0.5
Solids Transport	Shear stress exponent for noncohesive resuspension		1.5
Solids Transport	Shear stress multiplier for noncohesive resuspension		1
Solids Transport	Noncohesive bed load multiplier		1
Solids Transport	Lower critical shear stress for Solid- N/m2; below TAUcd1- deposition is max	TSS	0
Solids Transport	Upper critical shear stress for Solid- N/m2; above TAUcd2- deposition is 0	TSS	0.2
Solids Transport	Shear stress exponent for Solid deposition	TSS	1

5 Management Alternatives

Table 2 lists the seven lake management alternatives that were including in this modeling analysis. The model frameworks do not include explicit methods to simulate these management methods directly, and therefore, modifications to the model were made to best represent them. Core model results and a brief description of the implementation process for each alternative will be listed in the following sections.

Table 2. Summary Table of Simulated Management Alternatives.

Management Alternative	Method Objective
Wastewater Management	Expand sanitary sewer collection areas and reduce nutrient loading from septic systems
Stormwater Management	Reduce nutrient loading from stormwater runoff
Lake River Dam	Install structure to reduce backflow into the lake and raise the lake surface elevation
Flushing Channel Enlargement	Enlarge the Flushing Channel to increase flow into the lake and reduce nutrient loading from Lake River
Floating Wetlands	Install floating wetlands to serve as breakwater to reduce sediment nutrient suspension and induce nutrient uptake
Phosphorus Inactivation	Apply alum or Phoslock®/EutroSORB® to strip water column phosphorus and inactivate sediment phosphorus
Algaecide Treatment	Two summer applications of algaecide each year

5.1 Wastewater Management

This management approach is intended to address the nutrient contribution to the lake that results from failing septic systems. Septic systems currently contribute approximately 20 percent of the total phosphorus and nitrogen loads in the watershed. The objective is to significantly increase connection of septic systems to sewers by increased investigation, age and condition restrictions, design code rigor, and financial incentives. It is assumed that over a 20-year investment period, the total nutrient load caused by failing septic systems could be reduced by 75%.

Septic and sanitary sewer systems are not directly included in the model, and all external loads to the model domain are represented in the tributary boundary conditions outlined previously. Therefore, implementation of this management method simply requires adjusting the external nutrient concentrations. A 75% reduction in septic load corresponds to an overall 15% reduction in phosphorus and nitrogen loads from the watershed, which was applied to the external boundary conditions for this model simulation.

A relative comparison plot of the seasonal algal succession (expressed as chlorophyll-a at Lake 1 station) is shown in Figure 15, demonstrating the impact of the 15% reduction in external load. The baseline (calibration) response is shown as dashed lines. As expected, the results show a slight global decrease in the growth of each functional group.

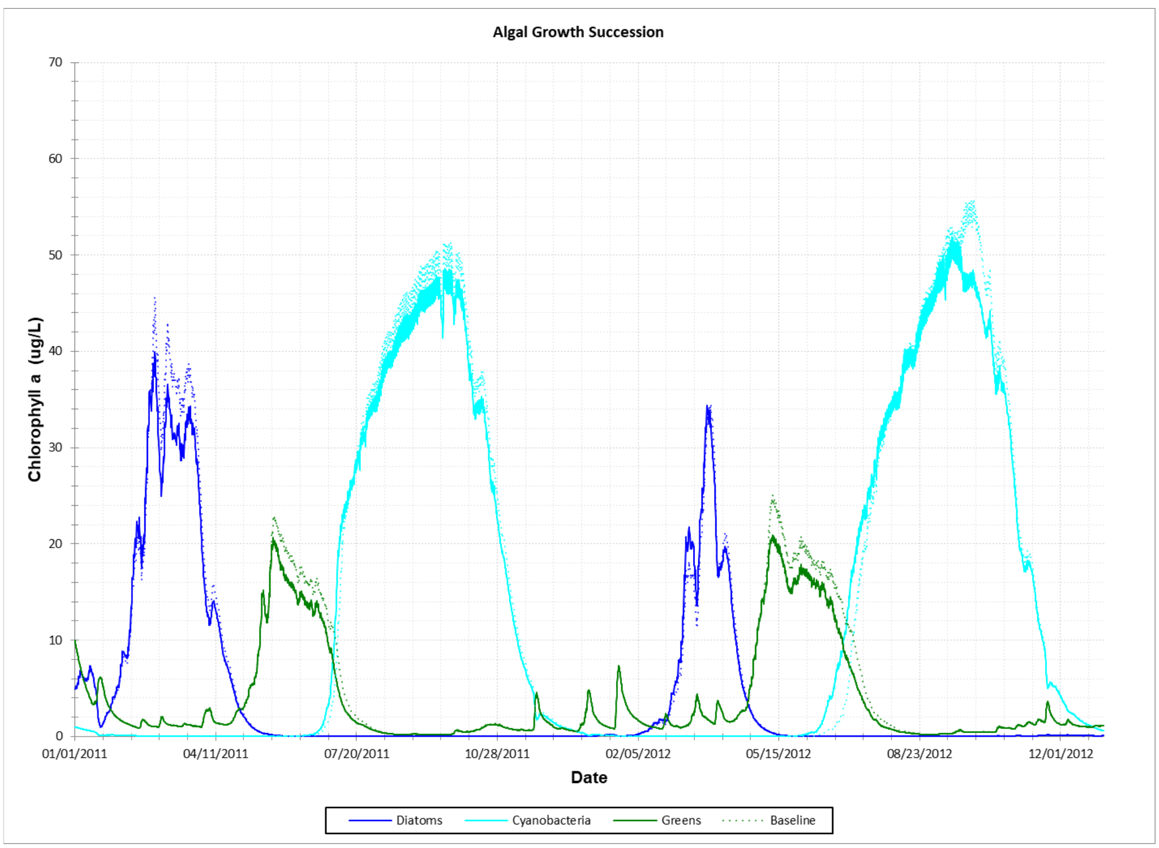


Figure 15. Model simulated algal growth succession for wastewater reduction alternative.

5.2 Stormwater Management

Stormwater runoff plays a significant part of the loading distribution from the watershed. This method intends to significantly increase stormwater treatment by requiring phosphorus treatment for new development and increasing retrofit of stormwater in untreated and basic treatment areas, relying heavily on high P removal and high flow regional media filter systems.

The assumption in this model scenario is that 60% of the stormwater runoff in the watershed will be subjected to a 50% reduction in total phosphorus over a 20-year period. Therefore, a 30% reduction in the total phosphorus from runoff is applied in the model.

A relative comparison plot of the seasonal algal is shown in Figure 16. The baseline (calibration) response is shown as dashed lines. Similar to the wastewater management scenario, the model response is fairly linear, with an expected global reduction when algae are thriving.

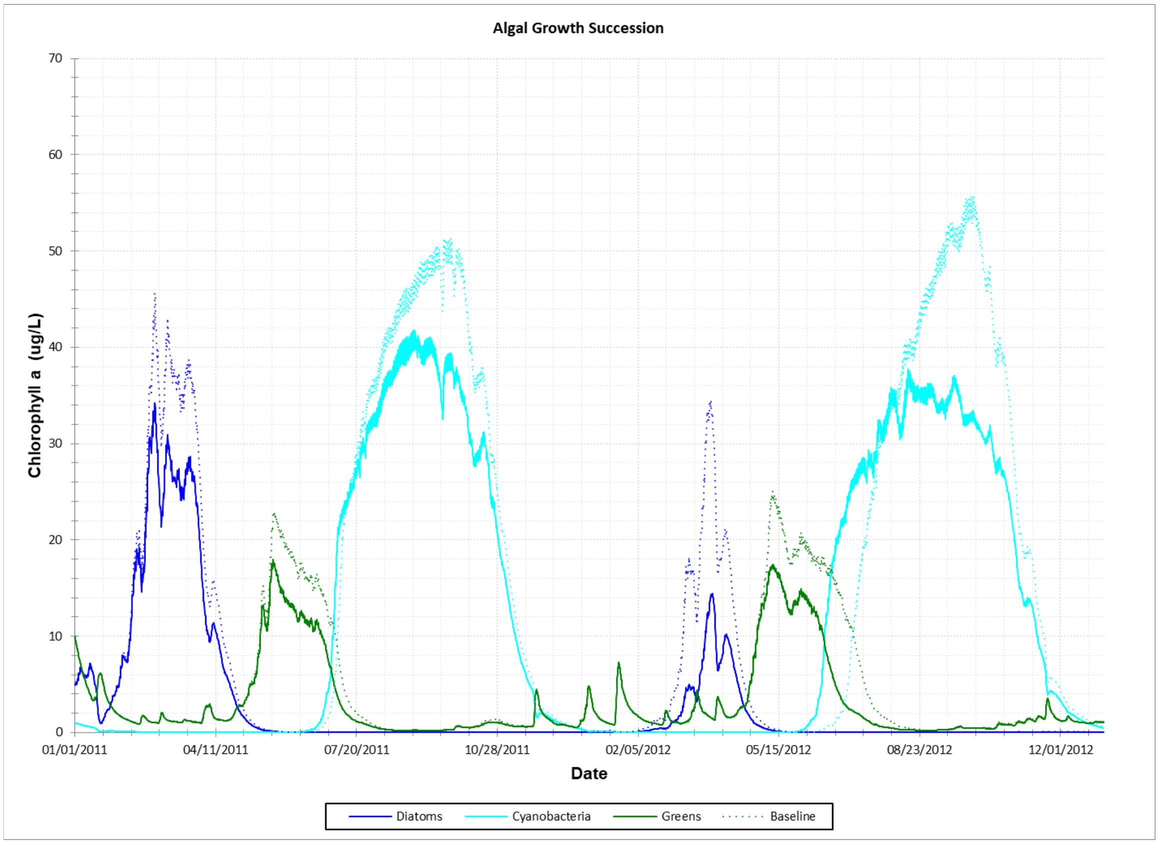


Figure 16. Model simulated algal growth succession for stormwater reduction alternative.

5.3 Lake River Dam

Because this system is tidally influenced, water can flow from Lake River into Vancouver Lake, bringing elevated nutrient loads from watershed inputs and the Columbia River. This management technique consists of installing a water control structure at the head of Lake River to reduce backflow into the lake and also reduce sediment resuspension from higher summer lake levels. This alternative modifies the structure of the system, and therefore requires modifying the HEC-RAS hydraulic model, as opposed to modifying the WASP water quality model.

The HEC-RAS model was modified to include a simple crested weir at the outlet of Vancouver Lake to Lake River. To investigate the sensitivity of the crest elevation, two such scenarios were applied: a 4m and 5m weir crest elevation corresponding to the 75th and 90th percentile lake levels. The hydraulic model was then re-run for the entire 2011-2012 simulation period before the transport variables are linked to WASP. No other changes were made to the water quality model or inputs for this management alternative.

As a result of significantly different transport regimes and circulation patterns in the lake, the water quality response is fairly complex. The dam allows for lake levels to rise as well as an overall reduction in outflow from the lake. Figures 17 and 18 show the model simulated algal growth responses for the two dam elevation scenarios. Both results show a shift in timing of the growth peaks, but also an overall reduction in cyanobacteria biomass. This timing shift may be attributable to a changing distribution of algal groups, as the timing of diatoms and greens blooms also changes and alters the timing of the available nutrient pools. Similarly, the overall reduction in cyanobacteria biomass can be attributed to both the altered nutrient pool and also the prevention of backflow from Lake River.

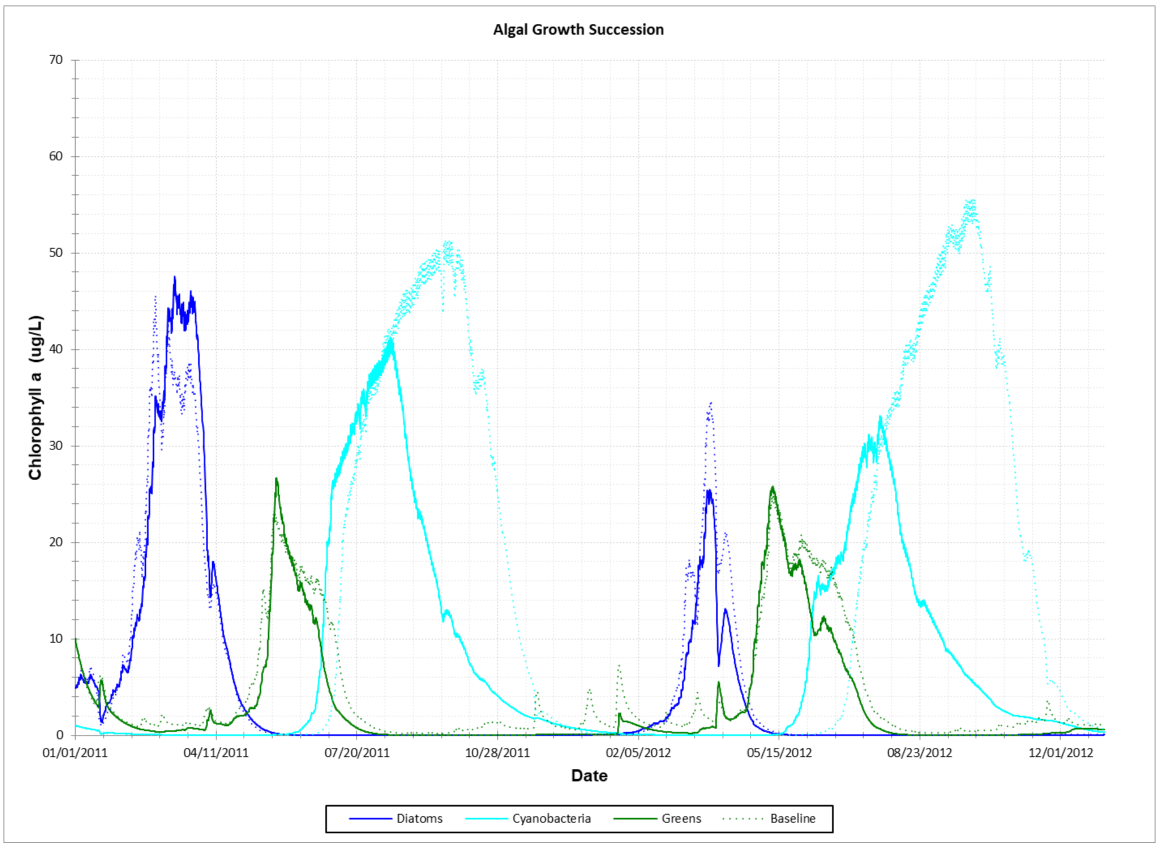


Figure 17. Model simulated algal growth succession for dam on Lake River with a crest elevation of 4m.

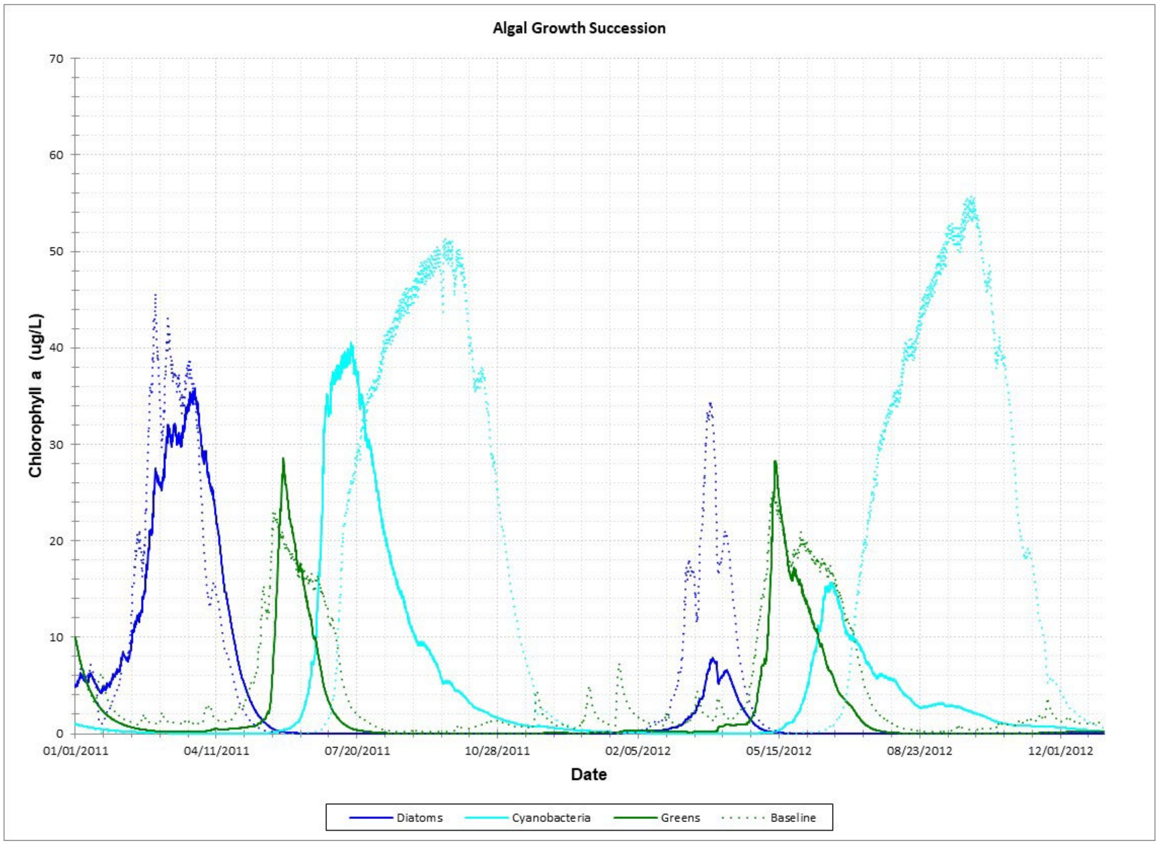


Figure 18. Model simulated algal growth succession for dam on Lake River with a crest elevation of 5m.

5.4 Flushing Channel Enlargement

An additional approach to altering the flow dynamics to the lake is to enlarge the existing flushing channel to increase conveyance of flow into the lake and thus prevent some of the backflow of high nutrient Lake River water. The existing flushing channel includes two culverts, which currently contain debris and restrict flow. The enlarged channel would replace the smaller culverts with a significantly larger box culvert, while maintaining a flap gate to prevent lake water from flowing back through the channel. The HEC-RAS model was altered to remove the two small culverts and replace with a 100 ft wide by 10 ft (3m) high box culvert and flap gate to prevent negative flows. No other changes were made to the WASP water quality model.

Figure 19 shows the algal response to this scenario, which is also complex response in comparison to the baseline conditions. The enlarged channel significantly increases the flow (Figure 20) into the lake and can significantly flush nutrients from the lake. The flap gate simulated in the model effectively prevents water from flowing from Vancouver Lake back into the flushing channel, which can result in lake water levels being higher than levels in the flushing channel when the water elevation in the channel is below the gate opening. This is demonstrated in Figure 21, showing water surface elevations lower in the channel during periods that fall below the gate opening.

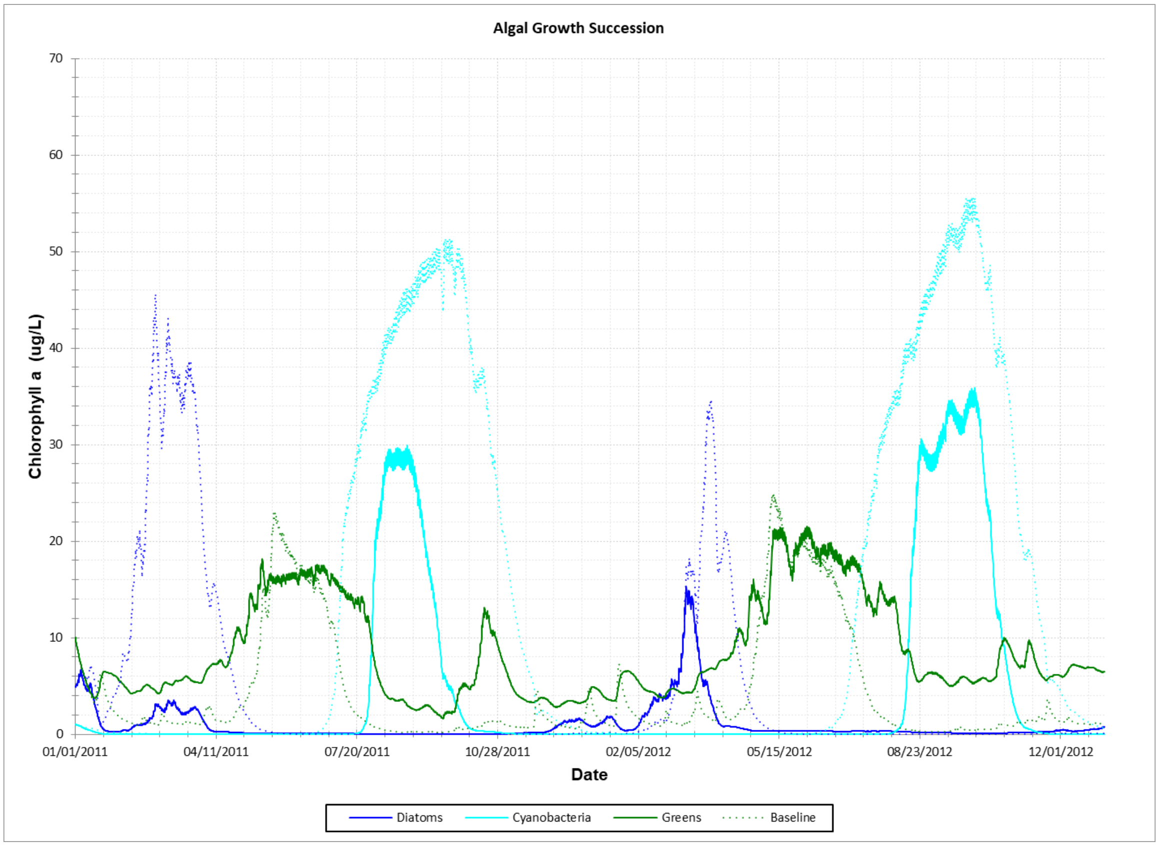


Figure 19. Model simulated algal growth succession for scenario with an enlarged flushing channel.

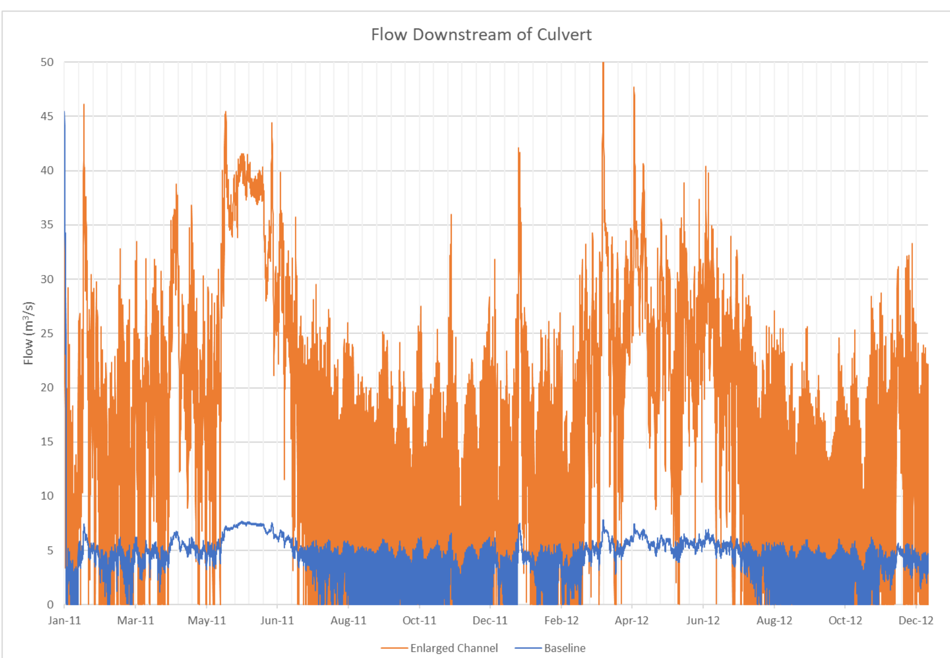


Figure 20. Model simulated flow rate into Vancouver Lake from the flushing channel.

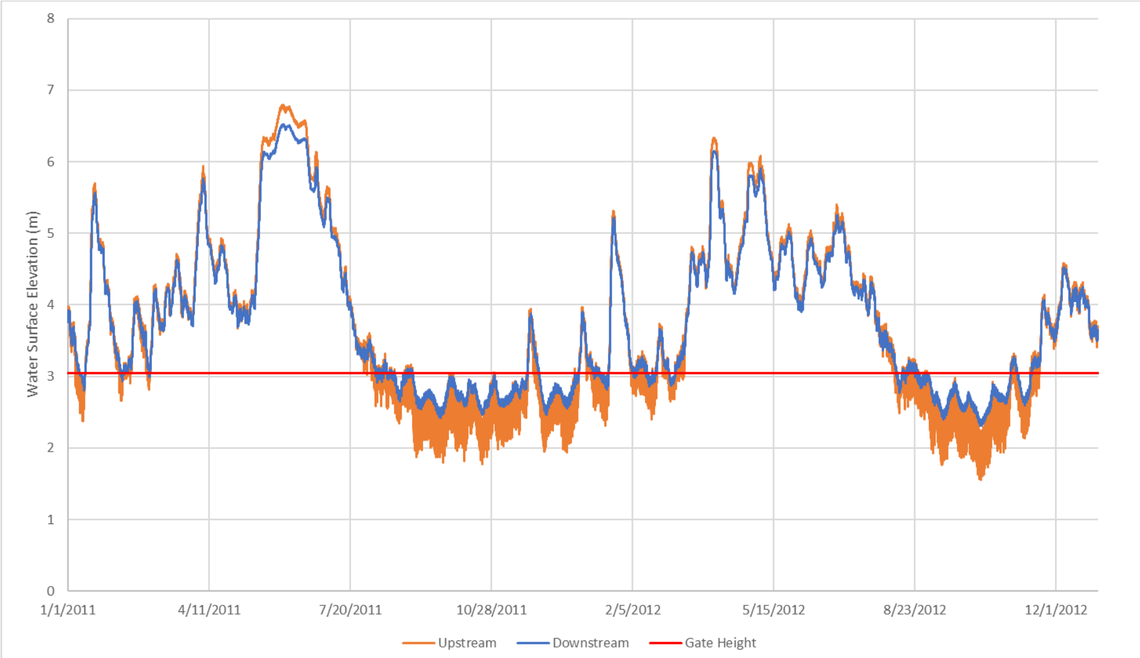


Figure 21. Model simulated water surface elevations upstream (orange) and downstream (blue) of the enlarged box culvert in the flushing channel.

5.5 Floating Wetlands

Resuspension of nutrients and solids can play an important role in water quality of this system. One approach to reducing resuspension is to create small floating wetlands throughout the lake, to reduce the wind fetch. These wetlands can also have the added benefit of taking up nutrients for plant growth.

Because the wetlands would have a very minor aerial extent, here we ignore the influence of nutrient uptake within the model and simulate a 30% reduction in resuspension rate. This adjustment is applied globally in WASP. A relative comparison plot of the seasonal algal is shown in Figure 22. This scenario shows a minor reduction in algal growth.

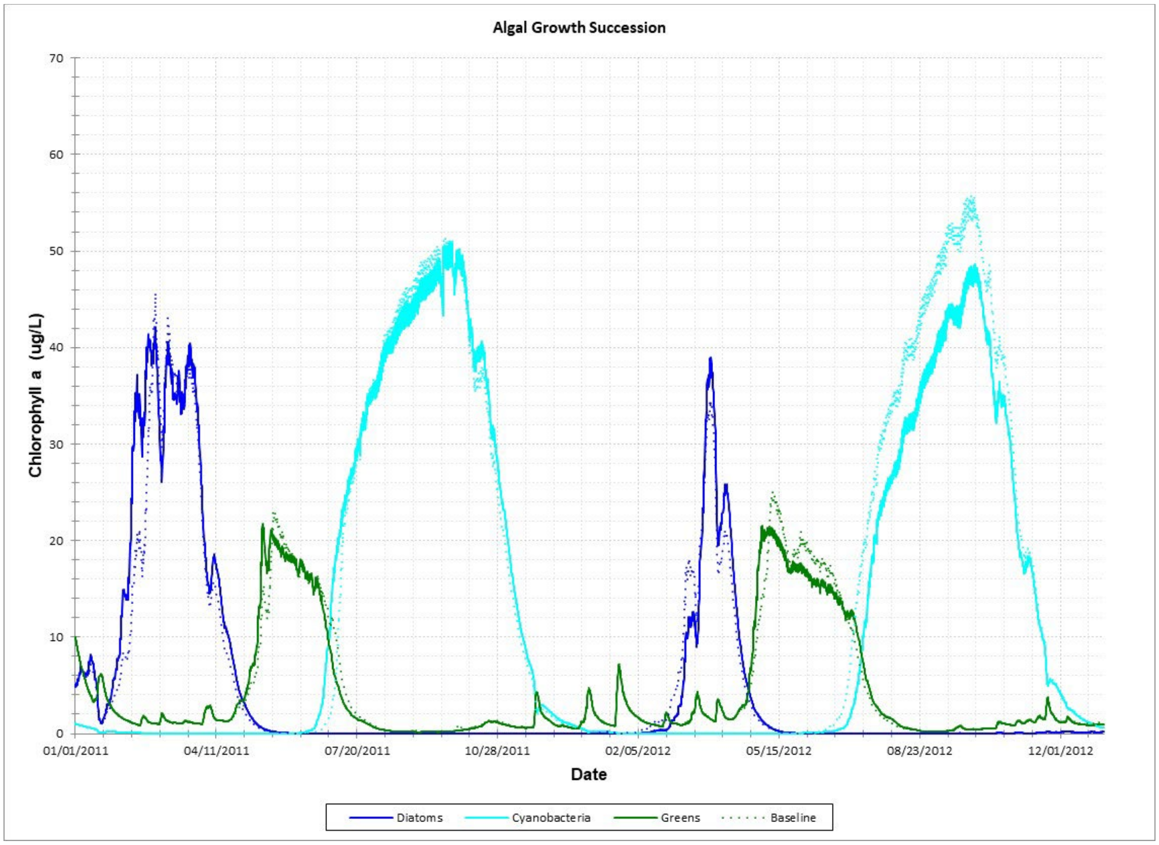


Figure 22. Model simulated algal growth succession with constructed floating wetlands.

5.6 Phosphorus Inactivation

Many lakes of comparable size experience regular eutrophication related issues and are periodically treated with an agent to flocculate and remove phosphorus from the system, thereby reducing its availability for algal update. This approach does not address the core cause of eutrophication and repeated treatments may be necessary, but it can be highly effective in improving water quality.

A phosphorus inactivation treatment is incorporated in the WASP model to settle 80% of algae, phosphorus, and nitrogen in the entire water column with a treatment in early June of every second year, while also permanently preventing a benthic flux from the sediments.

Figure 23 shows the algal growth response to this management method. By removing nutrients and algae from the water column and sediments in the summer, cyanobacteria have significantly lower available nutrients and growth is limited.

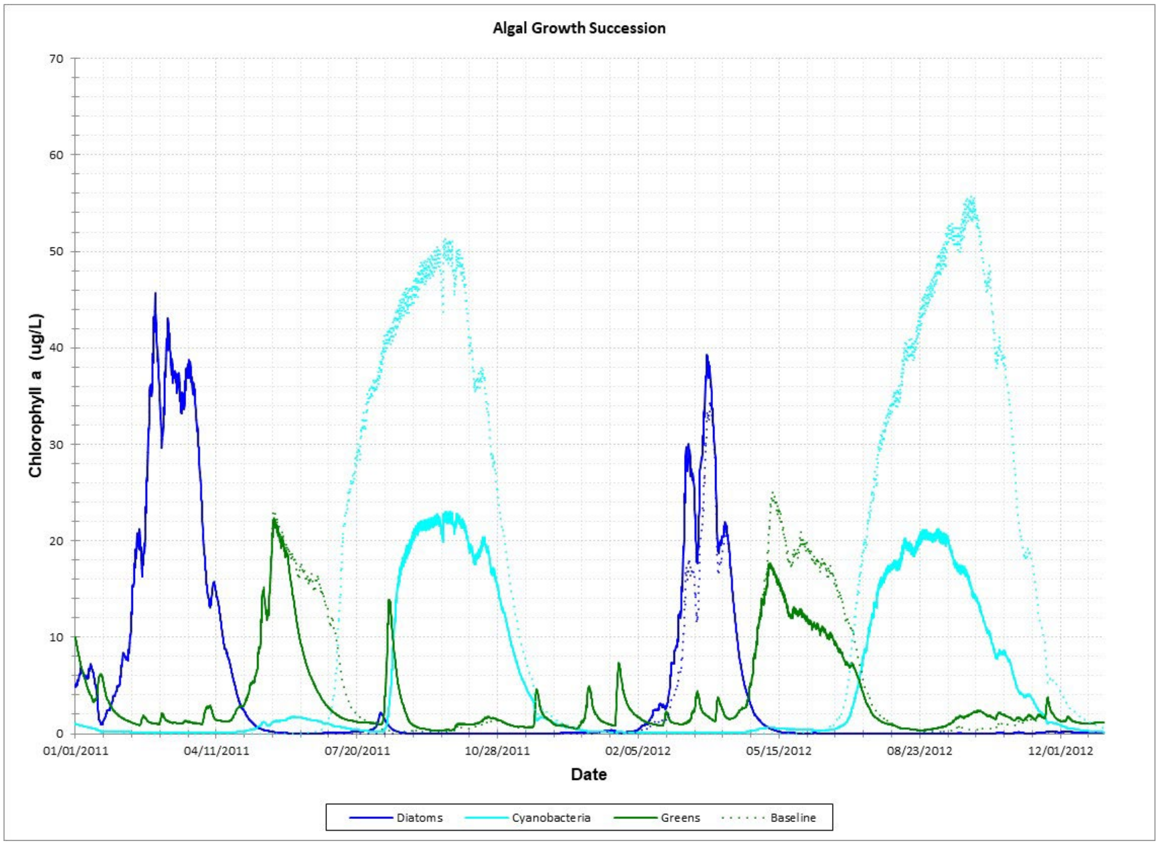


Figure 23. Model simulated algal growth succession with phosphorus inactivation.

5.7 Algaecide Treatment

Similar to the alum-based phosphorus inactivation method, many eutrophic lakes are periodically treated with an algaecide to kill water column phytoplankton. For this model scenario, we apply a death function from July 1 to August 15 to reduce algal biomass. Figure 24 shows this response in chlorophyll-a concentrations, with the expected result of significantly lower production in the summer. As with phosphorus inactivation, this management method does not treat the underlying causes of eutrophication and requires repeated applications, but it is highly effective.

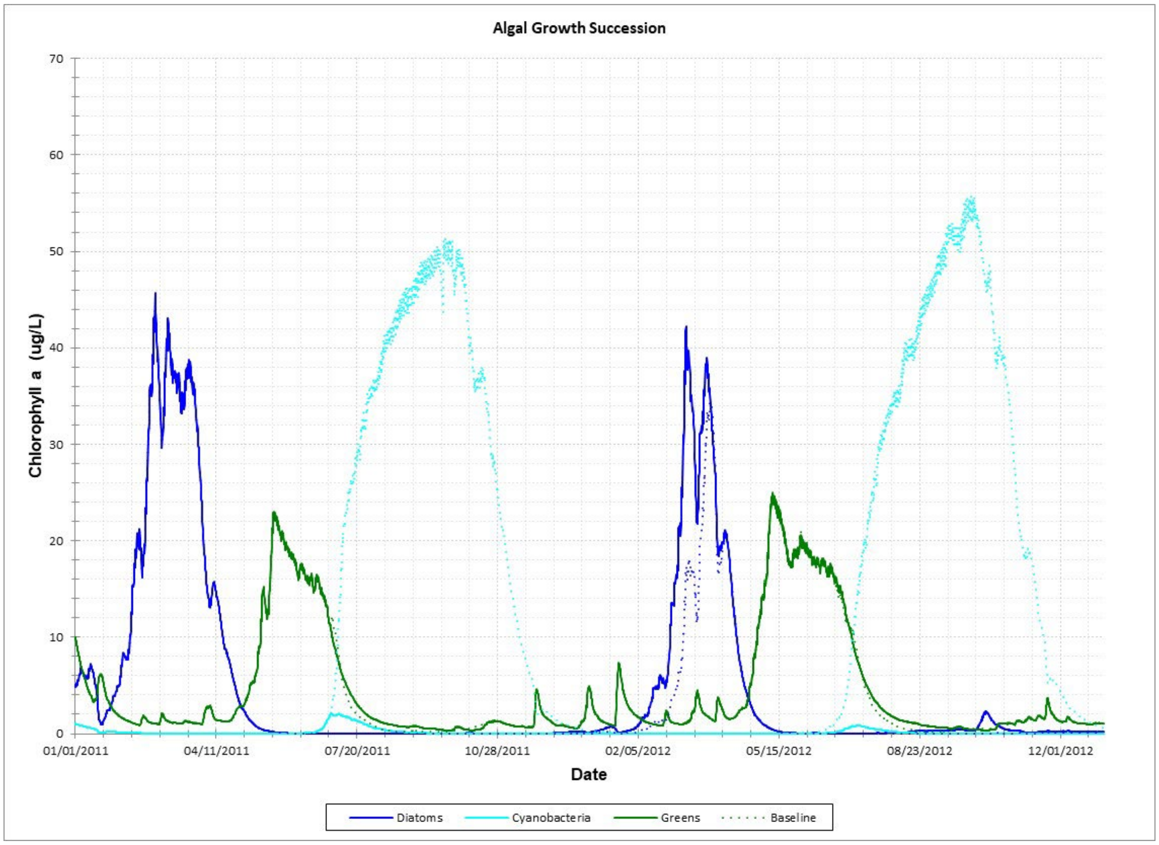


Figure 24. Model simulated algal growth succession with algaecide treatment.

6 Discussion and Summary of Model Results

A linked hydraulic and water quality model framework was developed for this effort to explore the effectiveness of management actions intended to mitigate nuisance algal blooms and water quality issues in Vancouver Lake. The framework builds on a prior hydraulic HEC-RAS model by adding a sophisticated WASP8 based water quality model. Seven different lake management alternatives were simulated with this tool, as described in Table 2 and related text. Figures 15-24 show the model simulated response time-series for each of the alternatives, focusing on the algal succession (in the form of chlorophyll-a) profiles.

Model results for other ecological endpoints, including summer average chlorophyll-a concentrations (Table 3), summer maximum cyanobacteria (Table 4), summer average Secchi depth (Table 5), summer average total phosphorus (Table 6), and maximum water temperature (Table 7) are summarized below.

Based on model simulations and the assumptions stated in the report, the in-lake treatments of algaecide and phosphorus inactivation provide the greatest benefit in reducing algal biomass (summer chlorophyll-a and cyanobacteria concentrations), although these methods do not address the underlying causes of eutrophication and only the symptoms. The physical lake management approaches, such as channel enlargement and construction of Lake River dam do provide significant reductions in nutrients and algal biomass, although these methods fundamentally change the hydraulic and hydrodynamic processes in the system, as demonstrated by the change in lake temperatures (Table 7). External load reduction strategies (wastewater and stormwater treatment alternatives) provide relatively modest water quality improvements, although these strategies address some of the underlying cause of eutrophication. Floating wetlands provide minor water quality improvements compared to other strategies.

Table 3. Summer Average Chlorophyll-a Concentration and Change for Each Alternative.

Summer Average Total Chlorophyll-a (µg/L)				Percent Change		
Scenario	2011	2012	2011-2012	2011	2012	2011-2012
Calibration (Baseline)	30.9	32.8	31.9	-	-	-
Wastewater Management	29.1	31.5	30.3	-6%	-4%	-5%
Stormwater Management	25.8	26.8	26.3	-16%	-18%	-17%
Lake River Dam (4m crest)	19.9	17.8	18.9	-35%	-46%	-41%
Lake River Dam (5m crest)	16.0	9.0	12.5	-48%	-73%	-61%
Flushing Channel Enlargement	16.7	22.9	19.8	-46%	-30%	-38%
Floating Wetlands	31.6	28.1	29.8	2%	-15%	-6%
Phosphorus Inactivation	13.8	14.9	14.4	-55%	-55%	-55%
Algaecide Treatment	6.5	7.9	7.2	-79%	-76%	-77%

Table 4. Summer Maximum Cyanobacteria Concentration and Change for Each Alternative.

Summer Maximum Cyanobacteria Chlorophyll-a (µg/L)				Percent Change		
Scenario	2011	2012	2011-2012	2011	2012	2011-2012
Calibration (Baseline)	51.7	56.2	56.2	-	-	-
Wastewater Management	48.9	52.3	52.3	-5%	-7%	-7%
Stormwater Management	42.1	38.0	42.1	-19%	-32%	-25%
Lake River Dam (4m crest)	41.3	33.8	41.3	-20%	-40%	-27%
Lake River Dam (5m crest)	41.1	28.6	41.1	-20%	-49%	-27%
Flushing Channel Enlargement	33.2	41.3	41.3	-36%	-27%	-27%
Floating Wetlands	51.2	49.1	51.2	-1%	-13%	-9%
Phosphorus Inactivation	23.8	21.8	23.8	-54%	-61%	-58%
Algaecide Treatment	23.1	25.3	25.3	-55%	-55%	-55%

Table 5. Summer Average Secchi Depth and Change for Each Alternative.

Summer Average Secchi Depth (m)				Percent Change		
Scenario	2011	2012	2011-2012	2011	2012	2011-2012
Calibration (Baseline)	0.9	0.9	0.9	-	-	-
Wastewater Management	1.0	0.9	0.9	2%	2%	2%
Stormwater Management	1.0	1.0	1.0	6%	7%	7%
Lake River Dam (4m crest)	1.0	1.1	1.0	11%	15%	13%
Lake River Dam (5m crest)	1.1	1.1	1.1	15%	23%	19%
Flushing Channel Enlargement	1.4	1.3	1.4	47%	45%	46%
Floating Wetlands	1.1	1.2	1.2	21%	31%	26%
Phosphorus Inactivation	1.1	1.1	1.1	19%	22%	21%
Algaecide Treatment	1.2	1.2	1.2	25%	28%	26%

Table 6. Summer Average Total Phosphorus Concentration and Change for Each Alternative.

Summer Average Total Phosphorus (mg/L)				Percent Change		
Scenario	2011	2012	2011-2012	2011	2012	2011-2012
Calibration (Baseline)	0.07	0.07	0.07	-	-	-
Wastewater Management	0.07	0.07	0.07	-7%	-3%	-5%
Stormwater Management	0.06	0.07	0.07	-13%	-4%	-8%
Lake River Dam (4m crest)	0.06	0.07	0.06	-10%	-11%	-10%
Lake River Dam (5m crest)	0.06	0.07	0.06	-15%	-11%	-16%
Flushing Channel Enlargement	0.05	0.07	0.06	-28%	-10%	-19%
Floating Wetlands	0.07	0.06	0.07	-2%	-16%	-9%
Phosphorus Inactivation	0.05	0.04	0.04	-27%	-51%	-39%
Algaecide Treatment	0.07	0.07	0.07	0%	1%	0%

Table 7. Summer Maximum Temperature and Change for Each Alternative.

Summer Maximum Temperature (degC)				Percent Change		
Scenario	2011	2012	2011-2012	2011	2012	2011-2012
Calibration (Baseline)	24.8	25.6	25.6	-	-	-
Wastewater Management	24.8	25.6	25.6	0%	0%	0%
Stormwater Management	24.8	25.6	25.6	0%	0%	0%
Lake River Dam (4m crest)	24.0	25.0	25.0	-3%	-2%	-2%
Lake River Dam (5m crest)	23.7	24.8	24.8	-4%	-3%	-3%
Flushing Channel Enlargement	24.5	25.2	25.2	-1%	-2%	-2%
Floating Wetlands	24.7	25.5	25.5	0%	0%	0%
Phosphorus Inactivation	24.8	25.6	25.6	0%	0%	0%
Algaecide Treatment	24.8	25.6	25.6	0%	0%	0%

LimnoTech
Water Environment | Scientists Engineers

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APPENDIX B

IAVMP

HERRERA
Science + Planning + Design

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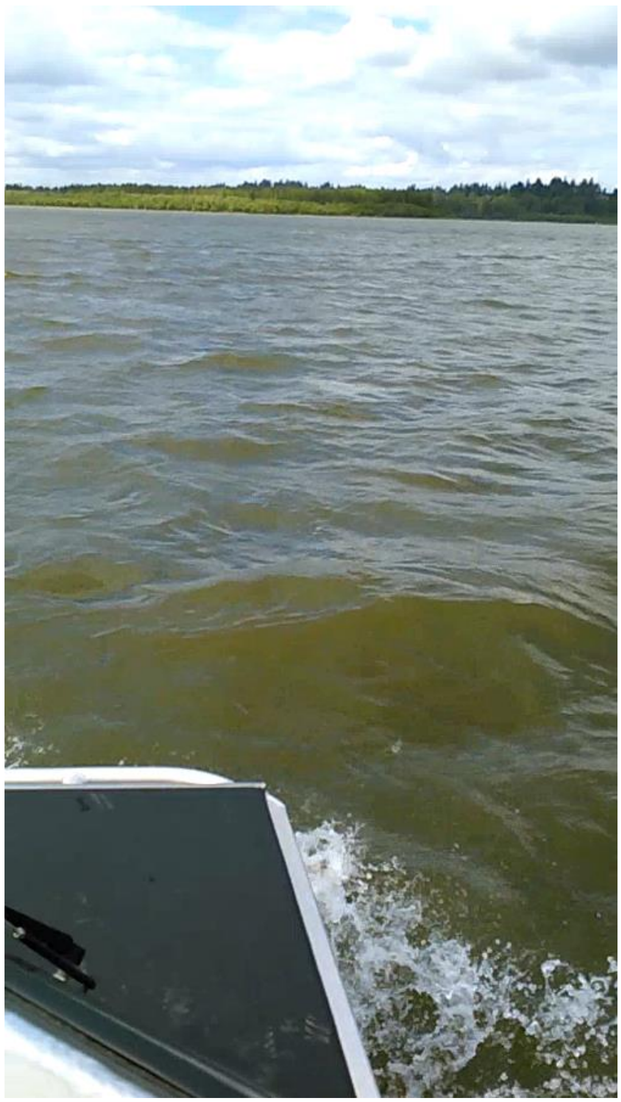
Vancouver Lake
Integrated Aquatic Vegetation Management Plan (IAVMP)



Prepared by Justin Collell,
Clark County Noxious Weed Board Coordinator

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Problem Statement

In 2017, Friends of Vancouver Lake (a volunteer 501 (c3) organization) observed widespread *Myriophyllum spicatum*, (also known as Eurasian watermilfoil, milfoil, or EWM) in Vancouver Lake for the first time. Washington Department of Ecology, (Ecology) also noted EWM in Vancouver Lake in 2007. Since that time the infestation in Vancouver Lake has grown exponentially. In 2019, two separate surveys with different methods were used to assess the level of lake acreage affected. A survey by Aquatechnex used drone photography and boat mounted DGPS (differential geographic positioning system) to draw boundaries around milfoil beds. The other survey, by state and county agencies, used a point intercept method. Both surveys produced similar results and were complimentary, (Figure 10). The area infested by milfoil based on the surveys is thought to not be less than 614 acres. The infestation is primarily concentrated in the center of the lake, around Turtle Island in water less than four-feet deep. Milfoil is also concentrated at the southwest corner of the lake, near the flushing channel, and around the edges of the lake. These other noxious weeds are also present in Vancouver Lake: *Lythrum salicaria,* (purple loosestrife); *Phalaris arundinacea,* (reed canarygrass); *Iris pseudacorus,* (yellow flag iris); *Potamogeton crispus,* (curly leaf pondweed).

Of these species, EWM has spread the most since first detection and is illustrated by comparing Figure 1, Figure 2, and Figure 10. Milfoil causes recreational, economic and ecological damage by changing how residents, visitors, and wildlife use and enjoy infested lakes. It overtakes habitat and outcompetes native aquatic plants, lowering plant species diversity (Madsen et al., 1991). Dense mats of EWM at the water's surface inhibit all water recreationists such as swimmers, rowers, sailors, paddlers, anglers, and hunters. Across Washington, the total direct impacts to boating from EWM are estimated at $5,140,000 (Cohen et al., 2017). Hunters using the WDFW wildlife area at the southern end of the lake have expressed fear of their dogs getting entangled in milfoil, or having difficulty walking through it themselves. The WDFW wildlife area at the end of La Frambois road is shown in Figure 5 along with the other beneficial use areas at Vancouver Lake.

Figure 1. 2017 Survey for Eurasian watermilfoil by Friends of Vancouver Lake. Map points were drawn from many observations over the summer months.

Figure 2. 2018 Survey for Eurasian watermilfoil by Friends of Vancouver Lake. Map points were drawn from many observations over the summer months.

The wildlife habitat of Vancouver Lake could possibly be negatively impacted by milfoil, if it outcompetes native plants that provide better shelter, food, and nesting habitat for fish and waterfowl. However, waterfowl do eat EWM (Goecker et al., 2006). According to Washington Department of Fish and Wildlife, these fish species have been found in Vancouver Lake:
American shad, bluegill, black bullhead, black crappie, brown bullhead, channel catfish, chinook, coho, common carp, eulachon (smelt), goldfish, killifish, largemouth bass, mosquitofish (*Gambusia*), northern pikeminnow, pumpkinseed, sculpin, starry flounder, steelhead, sucker, white crappie, white sturgeon, and yellow perch (Caromile et al., 2000).

There is potential for milfoil to harm these fish as dense stands of milfoil can decrease the water quality by reducing dissolved oxygen levels and may not contribute to a fishery food web as well as native aquatic plants (Kovalenko and Dibble 2014).

The dense canopy often formed by Eurasian milfoil colonies reduces light penetration and can affect pH and temperature in the water column. Dissolved oxygen levels can be lowered significantly by milfoil due to attenuation of light to algae and other aquatic plants, restriction of water mixing coupled with biochemical oxygen demand caused by decomposing vegetation in the fall (Honnell et al. 1993, sources in Getsinger et al. 2002a, Unmuth et al. 2000). By extracting nutrients (especially phosphorus) from the sediments and releasing them into the water column during fragmentation and fall senescence, Eurasian milfoil can also contribute significantly to eutrophication (nutrient enrichment) of lakes and ponds (Carpenter 1980b, Smith and Adams 1986). It should be noted that Vancouver lake's water quality will remain poor with or without the milfoil as it has been for decades. This is because milfoil, other aquatic plants, and algae sequester and release phosphorus into the water as they grow and decompose.

If milfoil is left unchecked, its spread throughout Vancouver Lake could negatively impact swimming, sailing, and rowing, and cause important events to the community to be cancelled. To illustrate possible impacts of EWM on recreation, past closures that were due to other causes may be used for reference. The lake has been closed several times in 2018 and 2019 because of harmful blue-green algal blooms and elevated E. coli bacteria. Several events were cancelled, costing the local economy hundreds of thousands of dollars. Future cancellation of multiple state, regional, and national rowing, sailing and paddling events would produce potential economic impacts over $1 million. With or without controlling EWM, Vancouver Lake will likely to continue to be closed due to harmful cyanobacteria blooms and elevated E. coli bacteria unless these issues are mitigated.

One local event, the Northwest Regional High School Rowing Regatta, brings in about 1,800 competitors. According to the consultant hired by Visit Vancouver USA, for every female competitor, about 3.4 family members attend. For every male competitor, it is 0.9 family members. Assuming half of the rowers are male and the other half female, it is estimated that an additional 3,870 family members and coaches attend. Similarly, the Northwest Masters Rowing Regatta brought in 1,160 entries from all over the country including Canada.

For comparison, this past year the US Masters Regatta in Grand Rapids, Michigan had 2,124 entries and the estimated contribution to the local economy was $1.8 million. By this estimate, the Northwest Masters Rowing Regatta contributes about $0.9 to $1 million while the Junior Regional Championships contributes about $1.5 million to the economy. Vancouver Lake has been suggested as the venue for this national championship event (US Masters Regatta). However, Vancouver Lake was passed over because the event is held in early August, when harmful blue-green algal blooms are a concern.

In addition to potentially losing these large events, if EWM's growth is unchecked, local rowing, sailing, and paddling clubs could lose revenue from lessons, camps, and membership as beneficial use of lake waters for recreation diminishes. The Vancouver Lake Regional Park has a beach for swimming in the lake, and 19,348 parking permits were issued in 2019. Of those, 1,437 parking permits were for regattas. There isn't a nearby lake that is similar to Vancouver Lake. This is one of the very few low-cost swimming areas for Portland and Vancouver. Washington Department of Fish and Wildlife (WDFW) estimates that the Vancouver Lake Unit, which has a public boat ramp at the end of La Frambois Rd, receives an average of 110 vehicle visits per day, with seasonal variation showing less visits in winter months. WDFW vehicle visit data for this site is available for less than half of the months from 2015-2019.

Further complicating the milfoil problem, Vancouver Lake is not a closed system. Milfoil and other noxious weeds will likely be perpetually reintroduced from all three connected water bodies; Lake River, Burnt Bridge Creek, and the Columbia River are all infested with milfoil. Therefore, control strategies must be sustainable over the long-term and in line with the management goals, while reducing impacts to the environment.

Identify Management Goals

Goals have been developed for the Vancouver Lake Integrated Aquatic Plant Management Plan by a steering committee composed of several stakeholder groups and input from the public.

- Manage Eurasian watermilfoil and other state-listed noxious weeds in Vancouver Lake at a level that ensures safety and opportunity for aquatic recreational activities and does not negatively impact wildlife habitat.
- Plan and implement management efforts carefully to ensure treatments are efficacious while minimizing negative impacts to the extent practicable.
- Educate the public about how to avoid spreading Eurasian watermilfoil and other aquatic invasive species.
- Monitor the extent of milfoil and other noxious weeds on a regular basis to inform adaptive management decisions and help prevent the movement of milfoil from Vancouver Lake to other water bodies.
- Prevent the reinfestation of Vancouver Lake by managing adjacent weed sources (e.g. flushing channel, Lake River, etc.).

Involve the Public

During development of this IAVMP, input and help from the public was received in several ways. On Jan. 30, 2020, a public open house was conducted to solicit input on the effort to develop the Vancouver Lake IAVMP. 30 people attended this open house. A first, rough draft of the IAVMP was released on February 6, 2020 for the steering committee and other technical experts to review.

The public was represented by several stakeholder groups in the steering committee of the IAVMP. The steering committee included these partners:
Watershed Alliance
The Vancouver Rowing Club
The Vancouver Sailing Club
Washington Department of Natural Resources
Washington Department of Fish and Wildlife
Clark County Parks Advisory Board
Clark County Legacy Lands
Clark County Noxious Weed Control Services
Clark County Clean Water
Clark County Noxious Weed Control Board
Friends of Vancouver Lake (FoVL)

A first draft was prepared for the steering committee to review, and after incorporating this feedback, a second draft was prepared.

Public Comment Period
The second draft of this IAVMP was released for public comment, and these comments influenced the production of the final IAVMP.

The SEPA Comment period for this IAVMP was March 18th through April 2nd, 2020.

Social Media
Nextdoor, Facebook, Instagram, and Twitter were also utilized to educate the public about aquatic noxious weeds and the importance of cleaning boats to stop the spread of invasive species.

To keep the public up to date on issues surrounding Vancouver Lake, FoVL agreed to start a listserv and Clark County agreed to contribute any Vancouver Lake noxious weed related updates.

Clark County has agreed to host a workshop to train resident-scientists to use WA Invasives, an app that allows users to report noxious weeds and view current distribution maps. Once they've taken the training, members of the public will be equipped to train others to use the app, multiplying the effectiveness of the outreach effort. This will enable initial reports for milfoil and other noxious weeds to be recorded by volunteer labor, which controls costs somewhat.

Identify Water Body/Watershed Features

Vancouver Lake is situated in the Columbia River floodplain in southwest Clark County, west of the city of Vancouver, Washington. The lake and surrounding watersheds are positioned at the base of the foothills of the Cascade Range to the east and the Pacific Coast Range to the west. The lake is part of the Willamette Valley ecoregion, which extends south into Oregon (Clark County, 2004).

Vancouver Lake is one of several large, shallow lakes in the lower Columbia River floodplain and may have been formed by a series of Missoula Floods coursing through the Columbia River channel, and then further worked by the river itself with seasonal inundation. Historically, the lake was connected to the Columbia River through Mulligan Slough to the south and Lake River to the north. Diking and filling along the south and west lake shoreline and along the Columbia River shoreline led to the eventual separation of the lake and the river (Clark County, 2004). As part of a project to dredge the lake and create the flushing channel in the 1980's, Turtle Island was created towards the north end of the lake. Vancouver Lake is part of Water Resource Inventory Area (WRIA) 28, see Figure 3.

Figure 3. Water Resource Inventory Area 28 boundaries (Map credit: Salmon-Washougal and Lewis Watershed Management Plan, Lower Columbia Fish Recovery Board)

Figure 4. Vancouver Lake's relative water depth contours in feet based on GPS and depthfinder data collected by Spenser Vines as part of his Eagle Scout project work (October 11, 2004). Water flows into the lake from Burnt Bridge Creek (Point C), and sometimes from Lake River (Point A), and the flushing channel (Point B). Water only flows out via Lake River (Point A).

Vancouver Lake has a surface area of about 2,300 acres and a maximum width of over two miles. Its depth is highly variable, but the lake is considered to be very shallow with a mean depth of less than three feet and a maximum depth of about twelve feet near the dredged area at the mouth of the flushing channel (Figure 4). The lake's deepest parts are located along the east and west shorelines, in channels along the margins of the lake, leaving the majority of open water near the middle of the lake less than four feet deep throughout much of the year.

The lake's shoreline is over seven miles long and is very uniform with very few backwater bays or inlets. Development of the shoreline is minimal because much of the land is in public ownership. A few residences dot the eastern shore, but most of the shoreline land is held in open space as farms and pasture, wildlife habitat, and a park.

There are two drainages that continually supply water to the lake: Burnt Bridge Creek and the land surrounding the lake, which includes the adjacent flood plain and the hills to the east known as the Lakeshore area. Burnt Bridge Creek drains a 28-square-mile watershed that contains mostly urban areas (Clark County, 2004). An extensive database exists for the creek that shows its health to be poor, with high levels of nutrients (Sheibley et al. 2014).

The lands adjacent to the lake itself, including the Lakeshore area, are located primarily within the Columbia River floodplain. Although most of the Vancouver Lake and Lake River area is a wildlife refuge and farmland, many of the streams in these areas flow through a mix of urban, suburban, and rural zones (Clark County, 2004). The primary outlet of the lake is a slow, flat slough of the Columbia River called Lake River. Numerous streams, including Salmon, Whipple, and Flume Creeks flow into Lake River along its eleven-mile length (Clark County, 2004). Seasonally high flows and tidal fluctuations in the Columbia River affect the flow direction of Lake River, often reversing its flow for long periods of time. Land uses range from rural to urban in the watershed of Lake River, and the creeks are generally poor in health due to extensive development. Lake River contributes the vast majority of the nutrient load to Vancouver Lake (Sheibley et al. 2014).

Lastly, the flushing channel located on the southwest shore allows water from the Columbia River to intermittently enter the lake, but not to escape. Water from the Columbia River originates from a vast area extending hundreds of miles inland. The water quality of the flushing channel has not been extensively studied, although monitoring stations located in the Columbia River indicate the quality of water to be very good (Clark County, 2004).

Studies going back to the late 1960s show that Vancouver Lake has poor water quality (Bhagat and Orsborn, 1971; Cooper Consultants Inc, 1985). Extremely high levels of phosphorus and nitrogen, high water temperature, and high turbidity levels have contributed to nuisance algal blooms. Since the late 1960s, lake uses have sometimes been limited in the late summer due to intense algae blooms. Water quality monitoring by Clark County volunteers in 2003 and 2004 supported previous conclusions regarding the poor condition of the lake, and it was documented again in 2010-2012 by USGS (Sheibley et al. 2014).

Phosphorus levels in Vancouver Lake are typically much higher than EPA's aquatic life criteria recommended to avoid nuisance algal blooms. The open-lake water is shallow, warm, and turbid from algae and sediment suspended during wind-induced mixing. Oxygen levels are typically super-saturated due to photosynthesis and air to water interface, but levels decrease during calm weather conditions (Clark County, 2004). The lake's pH levels are above state water quality standards during the periods of heavy algal growth. Light penetration is typically very low, with Secchi disc depth readings ranging from 0.1 to 0.5 meters in the summer. Water clarity in the spring is improved (Clark County, 2004). Vancouver Lake was given the 'Impaired water body' – Category 5 designation by Washington Department of Ecology in 2004.

Vancouver Lake is very warm and does not currently exhibit widespread oxygen depletion. Vertical profiles of oxygen and temperature show that the lake does not typically stratify or separate into layers by temperature. Water temperature was variable throughout the summer and is considered to be very warm, with surface temperatures reaching 25 degrees Celsius, about 77 degrees Fahrenheit (Clark County, 2004). The warm water suits species of cyanobacteria that are capable of developing into harmful cyanobacterial blooms capable of producing toxins harmful to humans and animals. The lake is frequently mixed by wind, distributing oxygen throughout the water column. Oxygen levels varied widely, from supersaturated conditions near the surface as a result of algae photosynthesis, to somewhat depleted levels near the bottom during times of stagnant wind conditions (Clark County, 2004). Oxygen depletion (also called an oxygen demand) results from the decomposition of biological material that settles to the lake bottom. This demand often uses up the oxygen in the bottom layers of eutrophic lakes.

Identify Beneficial Uses

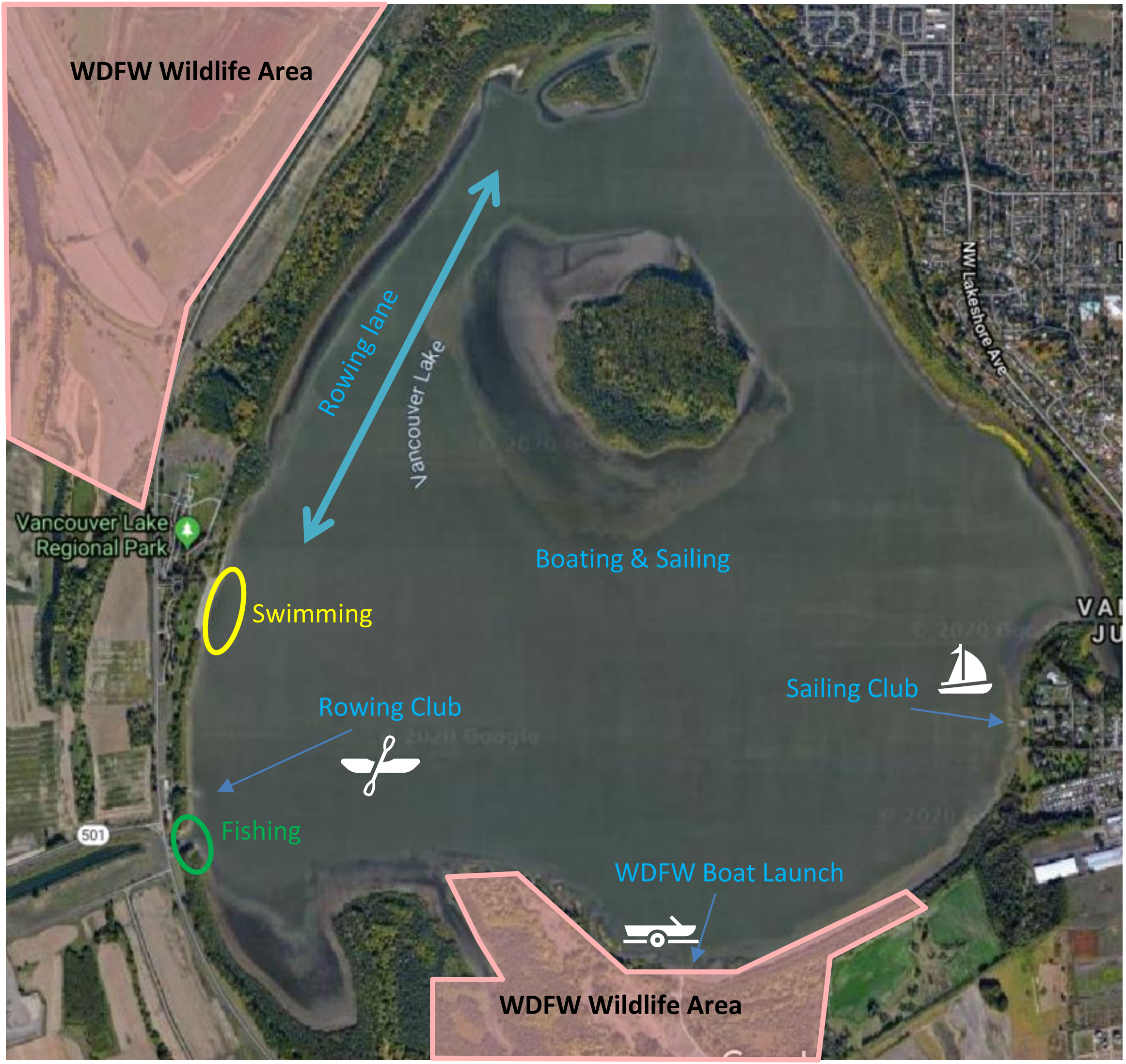

Figure 5. Public and recreational areas of interest for Vancouver Lake, showing three boat launches. The WDFW Wildlife areas are also used for hunting.

In addition to its use by swimmers, rowers, sailors, paddlers, anglers, and hunters (Figure 5), Vancouver Lake also sees use by a commercial carp fishery operation. This business operates mostly at certain times of the year, providing common carp to those in their community who eat it when they celebrate certain religious holidays such as Christmas, Easter, and 60 different Saints days (Caromile et al., 2000).

Map Aquatic Plants

This map on page 16 (Figure 6) is the result of a collaborative effort led by WDFW, Ecology and Clark County Vegetation Management.

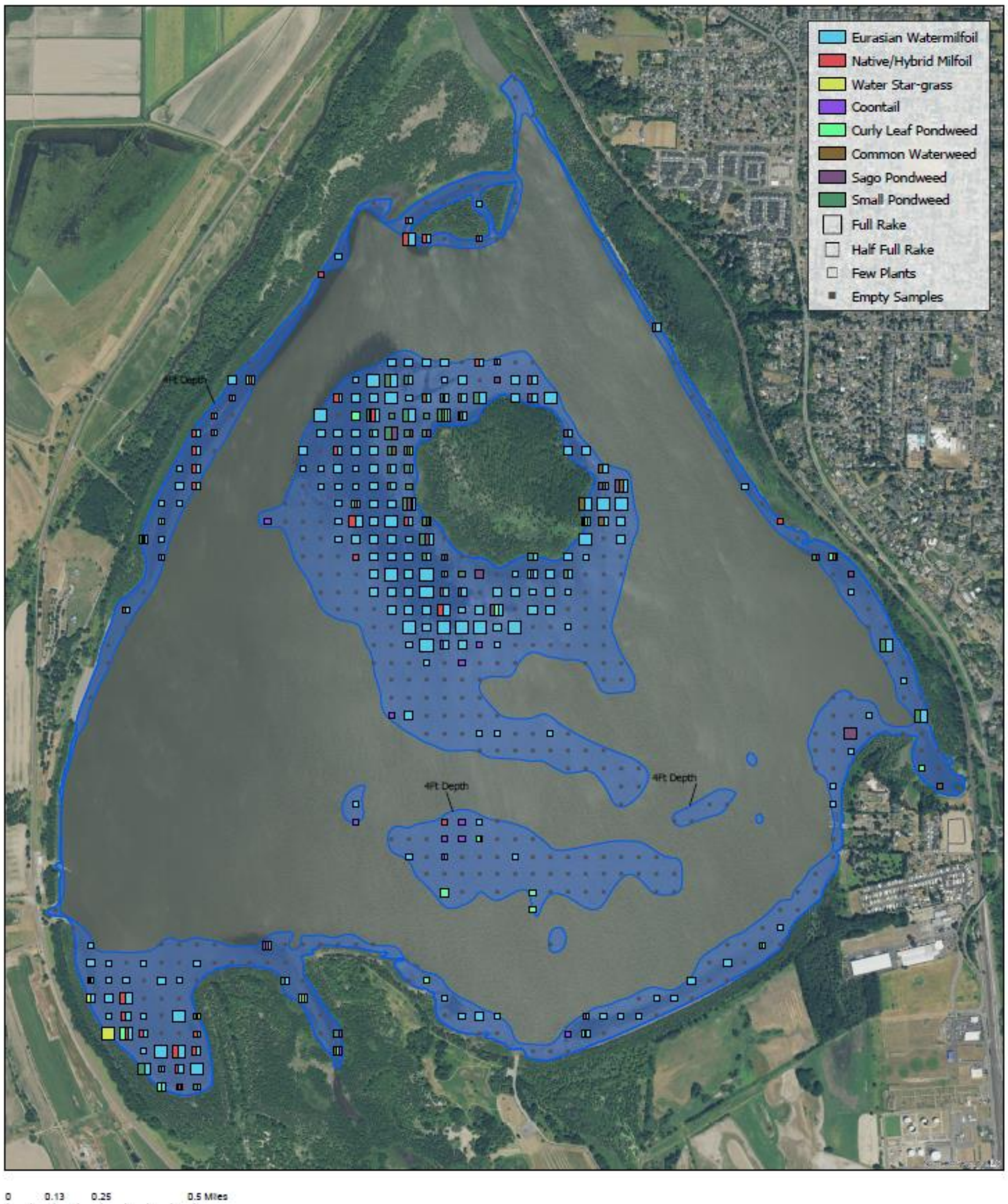

Figure 6. State and county survey for aquatic plants conducted from June 18-20, 2019. The dark blue shading shows the 4' or shallower area of the lake. The small dots show locations where no plants were found.

Survey points were loaded onto GPS units by WDFW. The points were 250 feet apart in a square grid, and included all areas of the lake 4 feet deep or shallower. This would account for a 769 acre portion of the lake where milfoil was expected. Milfoil was identified in 224 of these samples. Two boats and staff to pilot them were supplied by WDFW. A sampling rake was deployed overboard and retrieved. The total amount of plant material collected by the rake (i.e. the fullness) during a toss was given a subjective fullness ranking of between 0 (empty) and 3 (full) to describe the overall relative abundance of plants at a sampling point. The aquatic plants in the sample were then separated by species and ranked, with 1 being the most dominant and other being ranked as 2, 3, etc. in descending abundance.

Characterize Aquatic Plants

The 2019 state and county survey of the lake found that the most abundant and widely distributed submerged species in the surveyed area was Eurasian watermilfoil. According to the identification key used during the survey, hybrid watermilfoil was present, but when genetic testing was performed on a sample, it was Eurasian watermilfoil. EWM was found most concentrated at depths less than four feet, like the lake's perimeter and Turtle Island's shores. This survey accounted for approximately 769 acres of the lake, and 42% of the samples contained EWM. After milfoil, the most abundant aquatic plants found were small pondweed, (*Potamogeton pusillus*), and curly leaf pondweed, (*Potamogeton crispus*). Around the entire shoreline of the lake, the emergent plants are a mix of native plants and some noxious weeds. Purple loosestrife is among the emergent species found around the lake, growing sparsely in some areas near the mouth of Burnt Bridge Creek. Yellow flag iris is widely scattered around the lake.

Table 7. Table of Plants Historically Documented at Vancouver Lake

Latin Name	Common Name	Growth Habit
Myriophyllum spicatum	Eurasian watermilfoil	Submerged
M. spicatum x *M. sibiricum*	hybrid watermilfoil (not confirmed)	Submerged
Sagittaria spp.	arrowhead	Emergent
Heteranthera dubia	water star-grass	Submerged
Eleocharis spp.	spike-rush	Emergent
Potamogeton spp.	pondweed	Submerged
Ceratophyllum demersum	common hornwort, coon's tail, coontail	Submerged
Potamogeton crispus	curly leaf (curly-leaved) pondweed	Submerged
Carex spp.	sedge	Emergent
Cicuta douglasii	western water-hemlock	Emergent
Iris pseudacorus	yellow flag iris	Emergent
Phalaris arundinacea	reed canary grass	Emergent
Salix spp.	willow	Emergent
Persicaria amphibia	water smartweed, water knotweed	Emergent
Persicaria hydropiperoides	swamp smartweed	Emergent
Sagittaria latifolia	broadleaf arrowhead, Wapato	Emergent
Schoenoplectus	naked-stemmed bulrush	Emergent
Lysimachia nummularia	creeping loosestrife	Emergent
Elodea spp.	waterweed	Submerged
Equisetum fluviatile	water horsetail	Emergent
Juncus spp.	rush	Emergent
Ludwigia palustris	water-purslane	Emergent
Lythrum salicaria	purple loosestrife	Emergent
Stuckenia pectinata	Sago pondweed	Submerged

Investigate Control Alternatives

No Action Alternative
One option is to choose to take no action. This alternative leaves in place all the negative impacts caused by this noxious aquatic weed infestation. While this option doesn't have direct costs for management, costs to the community can include depressed property values, reduced tax collections, losing multimillion-dollar events such as the Junior Regatta, degradation of wildlife habitat and native plants, potential for large-scale fish harm from direct and indirect impacts, and potential loss of human life.

At this point up to 614 acres of Vancouver Lake may be affected by milfoil. Delaying action to target and control this growth may result in the whole lake becoming infested, since the whole lake is shallow enough for milfoil to grow, hyper-eutrophic and only limited by sunlight. The impact of no action at this point would be an immediate savings of $419,000. However, based on current control costs, if the milfoil infestation expands and the entire lake must be treated the cost would be $1,840,000.00, which is a 439% cost increase.

Bottom Barrier
A bottom screen or benthic barrier covers the sediment like a blanket, compressing aquatic plants while reducing or blocking light. An ideal bottom screen should be durable, heavier than water, reduce or block light, prevent plants from growing into and under the fabric, be easy to install and maintain, and should readily allow gases produced by rotting weeds to escape without "ballooning" the fabric upwards. Even the most porous materials, such as window screen, will billow due to gas buildup. Therefore, it is best to remove as much plant material as possible (such as via suction harvesting) to reduce the gassing of the decomposing plants. Materials such as burlap, plastics and woven synthetics can all be used for bottom screens. It is important to anchor the bottom barrier securely to the bottom to keep wave action or ballooning from dislodging the barriers. Unsecured screens can create navigation hazards and are dangerous to swimmers. Anchors must be effective at keeping the material down and must be regularly checked. Natural materials such as rocks or sandbags are preferred as anchors.

The duration of weed control depends on the rate that weeds can grow through or on top of the bottom screen, the rate that new sediment is deposited on the barrier, and the durability and longevity of the material. For example, burlap left in place may rot and tear within two years and in one season plants can grow through window screening material, or on top of felt-like fabric. Regular maintenance is essential to extend the life of most bottom barriers. Barriers should be removed annually at the end of the growing season so the accumulated substrate on top of the barriers does not become new rooting habitat for unwanted plants, (Figure 8).

In addition to controlling nuisance weeds around docks and in swimming beaches, bottom screening has become an important tool to help eradicate and contain early or small infestations of noxious weeds. Divers should re-check screens every few weeks to make sure that all targeted plants remain covered and that no new fragments have taken root nearby.

Figure 8. Workers using bottom barriers

Advantages

- Not toxic.
- Installation of a bottom screen creates an immediate open area of water.
- Bottom screens are easily installed around docks and in swimming areas.
- Properly installed bottom screens can control up to 100% of aquatic plants.
- Screen materials are readily available and can be installed by divers.
- Barriers can be moved, removed, cleaned and used in other water bodies or used repeatedly in one location for many years.

Disadvantages

- Because bottom screens reduce habitat by covering the sediment, they are suitable only for very localized control.
- For safety and performance reasons, bottom screens must be regularly inspected and maintained, adding to initial cost.
- Boat anchors, fishing gear, or paddles may damage or dislodge bottom screens.
- Improperly anchored bottom screens may create safety hazards for boaters and swimmers.
- Some bottom screens are difficult to anchor on deep muck sediments.
- Bottom screens can interfere with fish spawning and bottom-dwelling animals.
- Without regular maintenance, aquatic plants may quickly colonize bottom screens.

- Bottom barriers are not selective and impact native plants as well as invasive plants.

Costs of Bottom Barriers:

- $0.50 to $1.00 per square foot for geotextile or burlap material
- $0.35 to $0.60 per square foot for labor to install barriers
- $0.30 to $0.50 per square foot for removal costs

Permitting:
This control measure requires a Hydraulic Project Approval (HPA).

Appropriateness for Vancouver Lake:
Vancouver Lake is highly mixed. This may present an especially poor outlook for using bottom barriers, due to silt deposition on top of the barrier, allowing plants to grow on top of the barrier. The swimming area near Vancouver Lake Regional Park is a good candidate for a bottom barrier, as the firm sandy bottom there may provide a stable anchoring substrate. Boat launches may also benefit from this method, but total area covered would be relatively small. This method cannot provide widespread control.

Mechanical Methods: Hand-Pulling and Harvesting
The Washington State Noxious Weed Control Board's website advises:
"Mechanical control is not advised [for milfoil] unless the area is entirely invaded by plants. Otherwise, mechanical methods may increase the infestation. Hand pulling may be employed, but the entire plant must be removed, or it will re-sprout."

Hand-Pulling and Diver-Assisted Suction Harvesting (DASH)

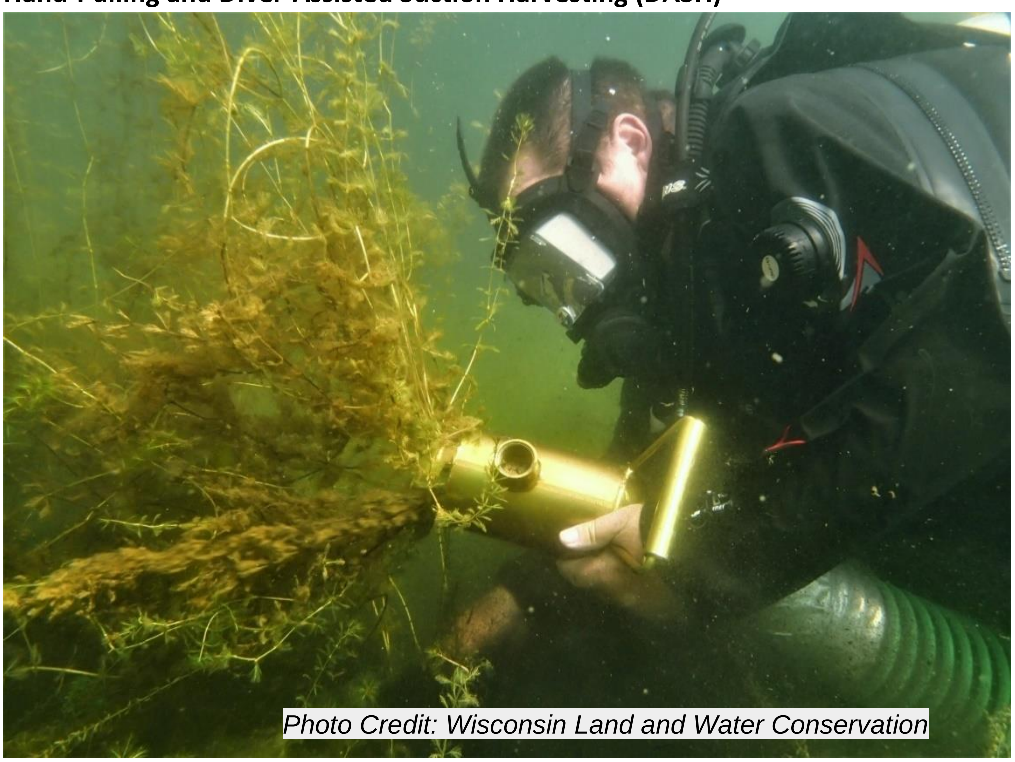

Figure 9. DASH removing Eurasian watermilfoil

Diver-Assisted Suction Harvesting is distinguished from hand-pulling using a suction hose that pulls plant material to the surface where it is captured by a boat. Hand-pulling and Diver-Assisted Suction Harvesting (DASH) use divers to visually identify and manually dislodge invasive aquatic plants (Figure 9) and requires a support team including a boat for weed removal and safety. When divers can see the weeds that they are targeting, hand pulling and DASH can be effective, but expensive.

One example comes from New York State, where the hand-pulling-only campaign was successful against EWM (Kelting & Laxson 2010):

- The lake's littoral zone (the area where light can penetrate to promote aquatic plant growth) was 1,193 acres
- The cost per acre (in 2008) was $294.61
- Maintenance cost to continue hand-pulling is estimated at $120,000 in perpetuity

A second example of Hand-Pulling is closer to Vancouver Lake, and more recent:
The cost estimated by the American Lake IAVMP in 2019 was $800-$1,600 per day for two divers with a support boat and operator, and the typical coverage ranges from 400 to 2,000 square feet per day.

According to the American Lake IAVMP, the cost of DASH is $1,500 a day for two divers and support boat, and they can cover 0.25 to 1.0 acres per day depending on plant density.

Permitting:
This control measure requires a Hydraulic Project Approval (HPA).

Appropriateness for Vancouver Lake:
Since Vancouver Lake suffers from high turbidity, visibility for workers to locate EWM root crowns may be a limiting factor for this method. Without locating all the plants and removing all the root crowns, EWM will re-grow and re-populate. With the current cost for local hand-pulling crews, this method may only be practical for small areas, specifically in the spring when the lake is clearer.

Harvesting
Conventional aquatic harvesting machines have a cutter head that cuts and captures most of the aquatic plant growth during a pass. Then the plant mass moves onto the deck of the harvester. When the harvester storage area is filled, the machine travels to a shore and offloads the aquatic plant biomass. The shore team then disposes of the aquatic plant growth, generally at a landfill or composting facility.

The key to an effective aquatic plant harvesting operation is having the right mix of equipment and minimizing the transport distances to shoreline unloading sites. All aquatic plant harvesting programs have two components. First, the harvester(s) work on the water to cut and collect target vegetation. Second, a shoreline site needs to receive the harvester(s), unload the cut weed growth and transport it to a disposal site. Developed lakes often have very limited shoreline access for this type of activity forcing the harvesters to travel some distances. While they are moving back and forth to unload, no harvesting occurs. Generally, one mid-sized aquatic plant harvesting system can clear from 0.25 to 0.50 acres per day in open water when working within a quarter mile of the shore unloading site.

If harvesting were to be selected, there are two ways to proceed. An entity like a city or county can purchase and operate this equipment, or a contractor can be hired.

Equipment purchase for a mid-sized aquatic plant harvester, a trailer, and a shore conveyor are currently in the $175,000-$200,000 price range. One such system has the capacity to harvest between 0.25 and 0.5 acres per day. The capital cost of the system would have to be considered and factored into a cost per acre assumption. In addition, a large truck is required to support the transport of cut vegetation on the shore side of the operation. Other costs associated with operation are daily labor costs for at least three persons: a shore side driver to transport vegetation for disposal, an assistance to support docking and transfer of cut vegetation, and the harvester operator. Storage of the equipment on the water (marina dock space), fuel, plant disposal fees and other associated costs also have to be considered.

The second option is contract harvesting. There are a handful of companies that do this work in the western United States. They generally bill on a daily rate model with $1,500 per day being a recent average cost. This cost can go higher depending on the size of equipment and the cost of disposal of cut vegetation. The production limitations of shore access affect them as well and production costs would probably be in the same range as quoted above. At a 0.25 acre per day production rate and $1,500 per day cost, a per acre estimate might be $6,000.

Lastly, harvesting operations do not kill the plant, they mow the top 5 feet off. As the harvester moves on to the next area, the milfoil will start to grow again. Areas which are harvested can still produce dense mats of EWM at the surface again in 5 to 6 weeks, due to regrowth from the intact roots.

Permitting:
This control measure requires a Hydraulic Project Approval (HPA).

Appropriateness for Vancouver Lake:
Merely cutting the milfoil is not an efficient use of resources, as the plants will certainly come back quickly, and any missed fragments are capable of producing whole new plants, which could make the problem worse. There are very shallow areas of Vancouver Lake (less than one-foot deep) currently infested by EWM and these areas cannot support the draft of some models of conventional harvester. There are few small harvesters that are available that can work in such shallow areas. One such harvester is available to purchase for under $100,000 and it is capable of pulling weeds instead of cutting them. This harvester might not be able to pull up the entire plant if it breaks and would result in regrowth from the roots and fragments. If the roots are pulled out of the lakebed, it could stir up sediment. By removing the vegetation from the lake, harvesting and pulling would remove some of the excess nutrients from the lake system. Using a harvester is not selective, so native plants and associated organisms would be removed with the milfoil.

In addition, while aquatic plant harvesting is generally thought to be compatible with the environment, studies have documented severe negative impacts on fisheries and invertebrate communities from aquatic weed harvesting operations.

Sandy Engel with the Wisconsin DNR studied harvesting operations on lakes with invasive aquatic species present. He concluded that:

"Harvesting both removed and dislodged plant dwelling macroinvertebrates. Patches of displaced snails, caddisfly larva and chironomids drifted about the lake and onto shorelines after harvesting. Each harvest in 1980 removed about 3 million macroinvertebrates amounting to 22% in June and 11% in July

of all plant dwelling macroinvertebrates in the lake. Insects alone accounted for one half of all macroinvertebrates harvested"

Furthermore:
"Harvesting removed about 21,000 fish in 1980 and 31,000 in 1981. This constituted about one fourth of all fry in the lake based on electrofishing data. Over 90 percent were young of the year."

Biological Control
Releasing an animal or a disease that negatively impacts EWM is another control strategy that has been researched extensively in the past. Certain species of weevils and grass carp do have significant effects on EWM, when their populations are high enough. *Euhrychiopsis lecontei* is a species of weevil that has shown some potential to control EWM, but there is no local source to purchase this species at this time. Grass carp prefer to eat other vegetation before milfoil. Therefore, grass carp are not selective and would harm native plants.

Permitting:
This control measure requires a Hydraulic Project Approval (HPA).

Appropriateness for Vancouver Lake:
While it is known that the weevil *Euhrychiopsis lecontei* can reduce the level of milfoil biomass somewhat, it cannot guarantee consistent and reliable management of the milfoil immediately, which is what is needed as per the management goals of this document. Weevils are subject to predation and may or may not be able to sustain a population sufficient to control milfoil after their release. Without the ability to purchase a number of weevils significant enough to control the milfoil in Vancouver Lake, this method is not likely to meet the management goals immediately and consistently.

Stocking triploid grass carp is not an appropriate control method for Vancouver Lake because they cannot be contained in Vancouver Lake. In addition, EWM is not their preferred food.

Herbicide
Aquatic herbicides are an effective method of aquatic plant control. These products are reviewed by the US Environmental Protection Agency (EPA) and if they meet the Agency's requirement for efficacy and protection of the environment, they are approved for use nationally. Each state can then address any additional concerns they may have about products.

In Washington State the Department of Agriculture (WSDA) has regulatory authority to register aquatic herbicides for use and license applicators. The WSDA has the ability to classify products as general use and restricted use. Restricted use herbicides can only be sold to and applied by applicators licensed by the department in the category (e.g. Aquatic, Agricultural, etc.) that the applicator is licensed in. WSDA has classified all aquatic herbicides as restricted use in Washington State.

Additional regulatory oversight for use of these aquatic herbicides comes from Ecology. This agency regulates applications to "waters of the State" through a general National Pollution Discharge Elimination System (NPDES) Permit . The Ecology Aquatic Plants and Algae Management NPDES Permit is supported by a number of risk assessments they have performed or commissioned on each herbicide that is available under their permit.

There are several ‘synthetic auxin’ herbicides on the market that can selectively kill EWM. One such herbicide, triclopyr, is systemic meaning it moves through the plant all the way to the roots for successful control of the whole plant. It is also selective, meaning when it is used according to the label for aquatic areas, it will harm fewer types of plants than non-selective herbicides.

A new product called ProcellaCOR has a unique mode of action which disrupts each node of milfoil, causing it to shatter. It is used at very low rates, and it is extremely effective at controlling EWM selectively. It does kill native milfoils such as *Myriophyllum sibericum*, but it does not kill many other native plants such as the pondweeds. ProcellaCOR is classified by the EPA as a “Reduced Risk” pesticide. It is categorized as “practically non-toxic” to animals and humans.

Permitting:
This control measure does not require an HPA, it is regulated by the NPDES.

Appropriateness for Vancouver Lake:
Controlling weeds with herbicide does not remove nutrients from the lake, as some other control methods can, but the reduced environmental impacts and selective nature of modern herbicide applications make this a viable option for Vancouver Lake.

There are several steps and costs associated with herbicide treatment activities. The Washington Department of Ecology Permit application is the first step needed to move this forward.

There is a requirement to publish two legal notices in a local paper and deliver notification to shoreline property owners. The mailing to shoreline residents is dependent on number of homes and includes development, printing and postage. The total permitting process could cost between $1,000-$2,000.00 depending on legal notice and mailing costs.

There are also some public notice requirements just prior to treatment. All lakeshore properties must receive notification 10 days prior to any treatment work performed. On the day of treatment, there is also a posting requirement where shoreline properties receive signage so that people know the work is going to occur that day. This should be inexpensive since Vancouver Lake has relatively few private landowners on the shore.

The final cost to be considered is the application. For budgetary purposes, here are some estimated costs for various products, (in cost per acre, applied by a contractor):

- 2,4-D liquid herbicide, $295.00 per acre.
- Triclopyr granular, controlled release pellet, $504.00-$1,100.00 per treated acre.
- ProcellaCOR, costs should range from $500.00 to $800.00 per acre based on water depth and plant densities.

Specify Control Areas

Near Vancouver Lake's center island (Turtle Island), especially the south and west sides of the island, large masses of Eurasian watermilfoil form acres of dense mats. The southwest shallow area of the lake also has a large infestation, and in general, the edges of the lake show some scattered infestations of EWM. These treatment areas are shaded white in Figure 10, to show that control efforts will focus there. However, EWM will be treated wherever it is found.

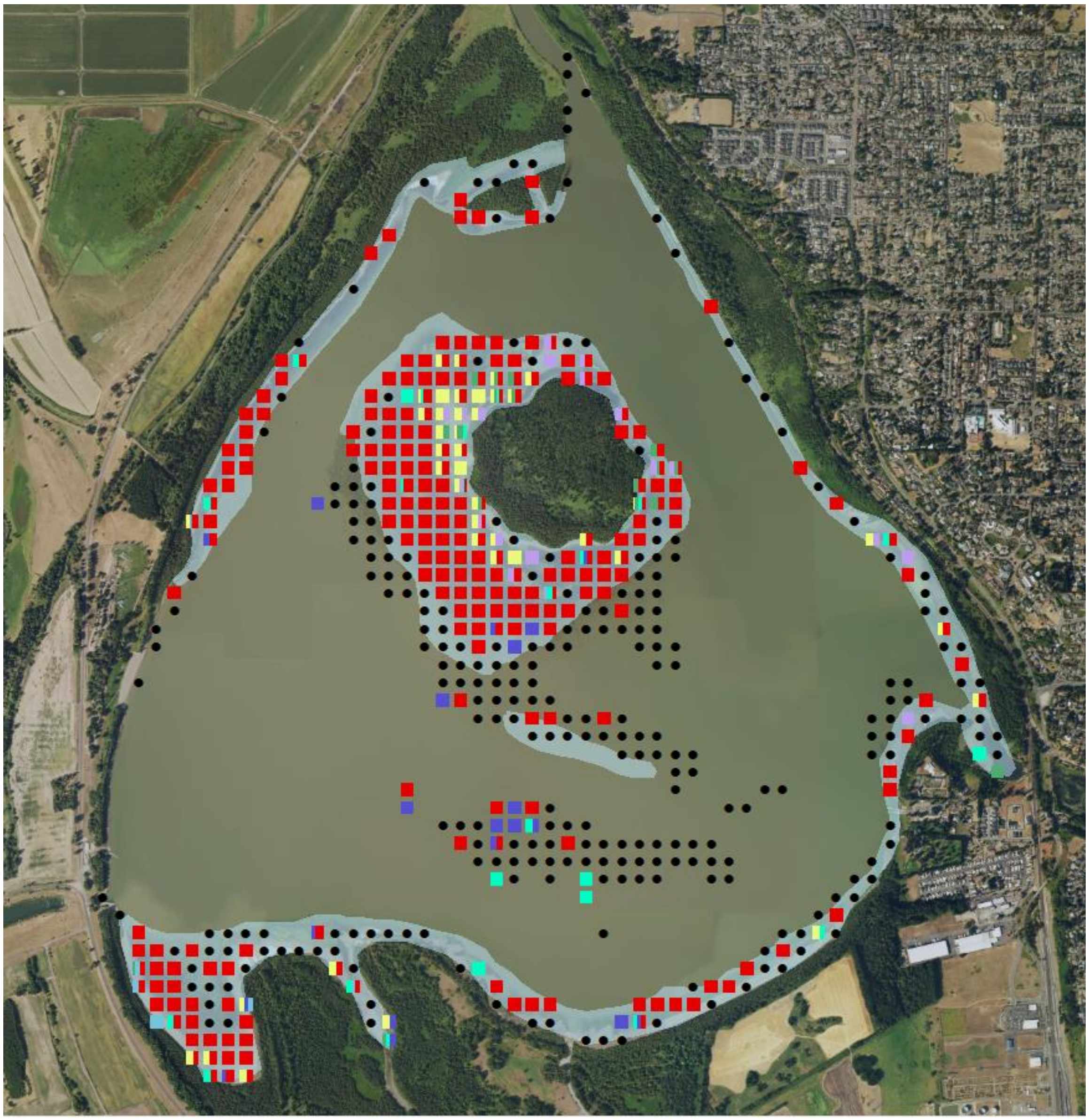

Figure 10. Area affected by some level of milfoil in Vancouver Lake as estimated by two independent surveys. The small black circles indicate no plants were found by the state and county survey. The any red block indicates EWM present, as does the treatment area shaded white which is 614 acres.

Need for Special Action
EWM in Vancouver Lake is widely distributed but confined to the shallower (less than four feet) areas of the lake, probably due to limited light levels. Turbidity fluctuates seasonally, with spring being the clearest season. If water clarity improved, milfoil could spread throughout the lake with the increased light levels. EWM is a class B, state-designated noxious weed that poses threats to wildlife habitat and recreation opportunities. Therefore, actions to control it are merited.

Choose Integrated Treatment Scenario

Vancouver Lake is not a closed system, and milfoil and other noxious weeds will likely be perpetually reintroduced from all three connected water bodies; Lake River, Burnt Bridge Creek, and the Columbia River are all infested with milfoil. Therefore, control strategies must be sustainable over the long-term and in line with the management goals, while reducing impacts to the environment. Native plants, which are a keystone in the food web, must be allowed to grow in the lake.

Milfoil is a class B noxious weed, is designated for control, competes with native plants, and is a hindrance to recreational lake uses and a hazard to swimmers. The infestation in Vancouver Lake also poses a risk to the health of other lakes via boats fouled with milfoil. EWM must be immediately reduced in Vancouver Lake to meet the IAVMP management goals. Other noxious weeds should be monitored to protect against these same risks. It is not feasible to start control efforts with the least potentially effective methods and eliminate their prospective viability. The situation requires decisive action to stop the spread of milfoil.

To immediately reduce the level of EWM in Vancouver Lake, treating EWM with selective herbicide wherever it is found throughout the lake is prudent. These areas are shown in Figure 10. Using an herbicide that has highest activity on milfoils, and much less destructive effect on other native plants, will ensure the least harm to any native plants growing alongside the milfoil. After the initial treatment, follow up monitoring and retreatments will be necessary to prevent the infestation from returning to the current level. Bottom barriers could be installed in small areas where all vegetation should be excluded such as swimming areas and boat docks, if budget allows, but this should be a second choice as the maintenance is cost-prohibitive as the barriers must be reinstalled every year.

Develop Action Program

This IAVMP has an effective period of June 2020 – June 2022. During this period, the short-term Action Program below will be implemented to begin addressing the management goals defined in the section "Identify Management Goals". Long-term action plans are dependent on future funding and continued community support. The IAVMP management goals are as follows:

- Manage Eurasian watermilfoil and other state-listed noxious weeds in Vancouver Lake at a level that ensures safety and opportunity for aquatic recreational activities and does not negatively impact wildlife habitat.
- Plan and implement management efforts carefully to ensure treatments are efficacious while minimizing negative impacts to the extent practicable.
- Educate the public about how to avoid spreading Eurasian watermilfoil and other aquatic invasive species.
- Monitor the extent of milfoil and other noxious weeds on a regular basis to inform adaptive management decisions and help prevent the movement of milfoil from Vancouver Lake to other water bodies.
- Prevent the reinfestation of Vancouver Lake by managing adjacent weed sources (e.g. flushing channel, Lake River, etc.).

Initial results will be evaluated at the end of the two-year implementation period. At that time, the resulting information can be used to adjust the management efforts. Future funding will have a tremendous impact on possible management actions. Vancouver Lake is changing, turbidity is decreasing. Because of the known and unidentified uncertainty involved, an Adaptive Management approach is recommended for long-term decision-making.

Short-term Action Program (June 2020 – June 2022)
Initial treatment actions planned by the Friends of Vancouver Lake in early 2020 are not included in this IAVMP. However, this action program anticipates FoVL will treat approximately 600 acres with ProcellaCOR (shaded area of Figure 10) and builds off this significant upcoming action.

Clark County has applied for and been awarded $45,000 from the Washington Department of Ecology's Aquatic Invasive Plants Management Grants Program to help fund the initial two-year IAVMP. Treatments with these funds could occur Spring 2021.

Effectiveness monitoring
Following FoVL-sponsored ProcellaCOR treatment in spring 2020, Clark County and project partners will perform follow-up plant surveys to establish the extent of control achieved. Methodology will be the same as recent surveys for consistency. Surveys may also be repeated in summer 2021 and 2022. Updated maps of the EWM infestation will be created for comparison.

Follow-up Treatment
Available funding is not sufficient to support another large treatment; however, follow-up spot treatments may be performed in 2020, 2021, or 2022 in selected areas based on survey results.

If sufficient initial control is provided by the FoVL ProcellaCOR treatment and follow-up spot treatment, the steering group may consider installation of bottom barriers in high-priority areas at or near water recreation access sites. Barrier installation would be approached as a pilot effort to evaluate effectiveness and maintenance costs.

Public Outreach

Workshops

Clark County will host a workshop to train citizen-scientists to use WA Invasives, an app that allows users to report noxious weeds and view current distribution maps, and how to avoid spreading aquatic invasive species. Once they've taken the training, the citizen-scientists will be equipped to train other members of the public to use the app, multiplying the effectiveness of the outreach effort. This will enable initial reports for milfoil and other noxious weeds to be recorded by volunteer labor, which can reduce management costs. This training will also protect Vancouver Lake from new invasions and prevent invasive species such as milfoil from infesting other water bodies.

Signage

- Signs will be posted at all boat launches and public water access areas
- News releases and social media updates will be issued regarding planned treatments

Planning

The Steering Group and stakeholders will continue to meet quarterly to discuss long-term funding and actions during the initial 2-year implementation.

Long-term Action Program (post- June 2022)

To achieve and maintain lower levels of EWM and guard against other aquatic noxious weeds, long-term funding is recommended. A lake management district to address aquatic noxious weeds is one possible option.

Currently, partners of this IAVMP have raised funding from non-continuous sources (i.e. donations, grants, volunteers). Public and private stakeholders, lake users, and lakefront public/private property owners will need to evaluate the need for ongoing noxious weed control in and around Vancouver Lake and develop funding strategies accordingly.

If aquatic noxious weeds do not significantly interfere with public recreation, then public recreation opportunities can be considered protected, however native plants will not be targeted for control. Since the continual reintroduction of milfoil from all three infested, connected water bodies is very likely, lake management will continually need to be adjusted to find the best long-term, economical strategy that maintains recreation opportunities despite the threat of reintroduction.

Indicators for habitat improvement could include resurveying and vegetation analyses that indicate milfoil frequency is declining. Increasing native aquatic plant species diversity could indicate milfoil is not outcompeting these valuable plants.

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APPENDIX C

Grant and Loan Programs

HERRERA
Science + Planning + Design

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Table C-1. Vancouver Lake Management Plan – Potential Short-Term or Supplementary Funding Options.							
Name	**Funder or Administrative Agency**	**Award Range**	**Target Purpose**	**Required Applicants or Lead Entities**	**Match Requirement**	**Notes**	**Resource URL**
I-5 Bridge Replacement Project Mitigation	WDFW and others	TBD	Habitat improvement projects to serve as off-site mitigation to offset habitat impairment associated with construction for the I-5 bridge replacement project	TBD	TBD	Discussions for potential areas for habitat mitigation for the project are still underway, but the Flushing Channel (and Vancouver Lake?) is one of the sites being considered. Proposed mitigation sites are expected to be announced in early 2023 and funding availability is TBD next year.	Amaia Smith (WDFW) is involved with the I-5 bridge replacement project and is a point of contact.
State Budget Appropriation	WA State Legislature	Set by legislature	Set by legislature based on request	Can be championed by many individuals and organizations, but Clark County would be the awardee and managing entity	None	Previously awarded to Clark County to fund the LMP development, in the amount of $150K.	
National Estuary Program's Coastal Watersheds Grant Program	Restore America's Estuaries, U.S. EPA	$75K–$250K	Protect/restore water quality or ecological integrity coastal or estuarine habitat	Public agencies (federal, state, tribal, intertribal, regional water pollution control, etc.), non-profits, local governments, academic institutions, for-profit organizations	33% (25% total cost), but ability to request full or partial waiver	Projects within specific geographic areas (including Lower Columbia River and floodplains) following Congressionally set priorities (see list online; includes recurring HABs). Awarded annually to 3 to 10 awardees.	https://estuaries.org/coastal-watershed-grants/
Freshwater Algae Control Grants Program	WA Ecology	$50K	Management of toxic algae blooms (cyanobacteria)	State agencies, counties, cities, special purpose districts, Tribes	25%	Used by Clark County Public Health for toxin monitoring; awarded annually.	https://ecology.wa.gov/About-us/Payments-contracts-grants/Grants-loans/Find-a-grant-or-loan/Freshwater-algae-program-grants
Aquatic Invasive Plants Management Grants	WA Ecology	Depends on project: up to $30K–$75K	Aquatic invasive plants management activities (e.g., mapping/inventory, IAVMP development, public education, plant control activities, pilot projects, evaluation of implementation, and follow-up monitoring)	State agencies, counties, cities, special purpose districts, Tribes	25%, or 12.5% if early infestation grant	Already awarded to Clark County for Vancouver Lake in 2020. Funds originate from boat trailer registration fees. Lower match percent and higher grant total for early Infestation grants.	https://ecology.wa.gov/About-us/Payments-contracts-grants/Grants-loans/Find-a-grant-or-loan/Aquatic-Invasive-Plants-Management-Grants
Stormwater Capacity Grants Program	WA Ecology	Set biennially based on state budget	Stormwater projects	Phase I and Phase II NPDES municipal permittees	None	Noncompetitive; activities and equipment necessary for permit installation.	https://ecology.wa.gov/About-us/Payments-contracts-grants/Grants-loans/Find-a-grant-or-loan/Stormwater-capacity-grants
Stormwater Grants of Regional or Statewide Significance (GROSS)	WA Ecology	≤$300K	Stormwater projects	Phase I and Phase II NPDES municipal permittees	None	Competitive; assist permittees in completing projects that will benefit multiple permittees.	https://ecology.wa.gov/About-us/Payments-contracts-grants/Grants-loans/Find-a-grant-or-loan/Grants-of-regional-or-statewide-significance
Water Quality Combined Funding Program	WA Ecology	Varies	Single-application process for all funding sources at once- eligible projects benefit water quality	Varies	Varies	Funds from: CWA Section 319 grants, Centennial Clean Water Program grants, CWA state revolving fund (CWSRF), stormwater financial assistance program (SFAP).	https://ecology.wa.gov/About-us/Payments-contracts-grants/Grants-loans/Find-a-grant-or-loan/Water-Quality-grants-and-loans
Salmon Recovery Funding Program	WA State Conservation Commission, funded by state legislature	Unclear	Protect/restore riparian habitats and streams for salmon while maintaining agricultural viability	Conservation districts (can be partnered with other entities, and/or landowners for cost-share)	NA	New in 2022, encourages incentive programs with landowners' involvement in riparian restoration projects; projects must be in riparian areas, instream projects must support riparian projects.	https://www.scc.wa.gov/salmon-recovery-program

Table C-1 (continued). Vancouver Lake Management Plan – Potential Short-Term or Supplementary Funding Options.							
Name	**Funder or Administrative Agency**	**Award Range**	**Target Purpose**	**Required Applicants or Lead Entities**	**Match Requirement**	**Notes**	**Resource URL**
Land and Water Conservation Fund-State Program	WA Recreation and Conservation Office	$200K–$2M	Develop outdoor recreation resources (parks, trails, wildlife lands)—available to all communities	Local agencies, special purpose districts, Tribes, state agencies	50%	Eligible projects: certain types of land acquisition, development/renovation of parks; applicants MUST have a comprehensive recreation or conservation plan.	https://rco.wa.gov/grant/land-and-water-conservation-fund/
Land and Water Conservation Fund-Legacy Program	WA Recreation and Conservation Office	$300K–$9.85M	For urban communities to buy/develop land for parks/recreation; priority to disadvantaged areas	Local agencies, special purpose districts, Tribes, state agencies	50%	Eligible projects: certain types of land acquisition, development/renovation of parks; applicants MUST have a comprehensive recreation or conservation plan.	https://rco.wa.gov/grant/land-and-water-conservation-fund/
Salmon Recovery & Puget Sound Acquisition and Restoration Grants	WA Recreation and Conservation Office	No maximum	Restore degraded salmon habitat and protect existing, high-quality habitat (including actual habitat used by salmon and land/water supporting salmon processes)	Local agencies, special purpose districts (port, park, conservation, school), Tribes, state agencies, private landowners, nonprofits, regional fisheries enhancement groups	15%	The grant program for both salmon recovery and PSAR grants are run together and generally have the same requirements. PSAR program is to help implement habitat protection/restoration in the Puget Sound only, co-managed by the Partnership.	https://rco.wa.gov/grant/salmon-recovery/
Pacific Coastal Salmon Recovery Fund	NOAA	≤$25M	Salmon recovery	Western U.S. states, federally recognized Tribes of the Columbia River and Pacific Coast	Yes (amount unclear)	Funds many other grants.	https://www.fisheries.noaa.gov/grant/pacific-coastal-salmon-recovery-fund
Aquatic Lands Enhancement Account	WA Recreation and Conservation Office	≤$1M	Aquatic lands improvement	Washington agencies or Tribes may apply	50%	Usually awarded at $500K for acquisition, improvement, or protection of aquatic lands for public purposes; or to provide or improve public access to the waterfront.	https://rco.wa.gov/grant/aquatic-lands-enhancement-account/
WWRP – Farmland Preservation	WA Recreation and Conservation Office	No maximum (*but see note)	To buy development rights on farmlands to ensure they remain available for farming, and restore natural functions to improve land's viability for farming	Cities, counties, nonprofit nature conservancies, State Conservation Commission	50%	*Stewardship plans not to exceed $10K; restoration elements may not exceed half of total land acquisition costs.	https://rco.wa.gov/grant/washington-wildlife-and-recreation-program-farmland-preservation/
WWRP – Forestland Preservation	WA Recreation and Conservation Office	≤$500K	Conserve land for timber, wildlife, public access. Used to lease or buy voluntary land preservation/conservation agreements to restore forests and/or ensure they remain available for timber production in the future	Cities, counties, nonprofit nature conservancies, State Conservation Commission	50%	Commonly used with conservation easement/lease to restore stream corridors to support clean water/fish habitat. Eligible forests: industrial, private, community, tribal, publicly owned forests of contiguous 5+ Acres devoted primarily to timber production and enrolled in a county's open space or forestland property tax program.	https://rco.wa.gov/grant/washington-wildlife-and-recreation-program-forestland-preservation/
WWRP – Habitat Conservation (includes 3 categories)	WA Recreation and Conservation Office	Varies by category (e.g., no cap, ≥$25K request, and/or ≤$1M)	Conserve natural areas/wildlife habitat, improve/acquire recreation areas	Cities, counties, towns, Tribes, nonprofit nature conservancies, special purpose districts, port districts (and other political subdivisions), state agencies	50%	For a broad range of land conservation efforts, from conserving natural areas near big cities to protecting the most pristine and unique collections of plants in the state. Typically used to buy land to conserve wildlife habitat and to restore state lands	https://rco.wa.gov/grant/washington-wildlife-and-recreation-program-habitat/
WWRP – Recreation Projects	WA Recreation and Conservation Office	Varies by category (e.g., no cap, ≥$25K request, and/or ≤$1M)	Land protection and outdoor recreation (parks, trails, water access)	Cities, counties, towns, Tribes, nonprofit nature conservancies, special purpose districts, port districts (and other political subdivisions), state agencies	Varies by applicant	For a broad range of land protection and outdoor recreation including for local and state parks, trails, water access, and the conservation and restoration of state land. Typically used to buy land for a park, building athletic facilities, building/renovating parks, developing regional trails, developing state lands. Applicants must have a comprehensive recreation or conservation plan.	https://rco.wa.gov/grant/washington-wildlife-and-recreation-program-recreation/

Table C-2. Vancouver Lake Management Plan – Other Potentially Useful Programs.					
Name	**Funder or Administrative Agency**	**Target Purpose**	**Required Applicants or Lead Entities**	**Notes**	**Resource URL**
Forest Legacy Program	U.S. Forest Service	Encourage the protection of privately owned forest lands through conservation easements or land purchases.	States and Tribes		https://www.fs.usda.gov/managing-land/private-land/forest-legacy
Family Forest Fish Passage Program	WA DNR	Assist private forestland owners in activities to improve fish passage to upstream habitat (e.g., removing culverts, stream crossing structures, and replacement of other eligible barriers with new structures).	Private or small forest landowner (timber harvest restrictions) with fish-bearing stream		https://www.dnr.wa.gov/fffpp
Healthy Forests Reserve Program	USDA NRCS	Protect and restore forest on private land with 10-year restoration agreements and 30-year or permanent easements for specific conservation actions.	Private owners, or owned by Tribes	For acreage owned by an American Indian Tribe, there is an additional enrollment option of a 30-year contract. Some landowners may avoid regulatory restrictions under the Endangered Species Act by restoring or improving habitat on their land for a specified period of time.	https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/easements/forests/
Rivers and Habitat Open Space Program (WAC 222-23)	WA DNR	Easement to protect forestland with at-risk species (critical habitat), or CMZ river habitat.	Washington landowners of forestland, free of hazardous substances or other jeopardizing conditions to conservation	Program is funded by a grant and requires submission of an application.	https://www.dnr.wa.gov/programs-and-services/forest-practices/small-forest-landowners/rivers-and-habitat-open-space
Forestry Riparian Easement Program	WA DNR	Easement to protect fish habitat.	Landowners with >20 acres of contiguous forest, or >80 acres forest in Washington, with other timber harvest specs	Reimburses landowners for the value of the trees they are required to leave to protect fish habitat. The program provides compensation for a minimum of 50 percent of the timber value and applies to trees adjacent to streams, wetlands, seeps, or unstable slopes.	https://www.dnr.wa.gov/programs-and-services/forest-practices/small-forest-landowners/forestry-riparian-easement-program
Clark Public Utilities Watershed Restoration Programs	Clark County Public Utilities	Protect high quality drinking water, by maintaining and improving both the quality and quantity of our water resources (e.g., Salmon Creek) and reducing stormwater contaminants.	NA	Funded by state and federal grants, projects through this program are carried out by Clark Public Utilities.	https://www.clarkpublicutilities.com/community-environment/environmental-stewardship-programs/watershed-restoration-programs/grant-funded-projects/
Clark County Clean Water Projects	Clark County Public Works	Develop new stormwater facilities and implements updates to older facilities that collect and treat polluted storm runoff (e.g., installing rain gardens or wetlands for improved water quality treatment, expanding water storage, modifying inlets and outlets, and repairing or replacing aging facilities).	NA	Funded by state and federal grants, projects through this program are carried out by Clark Public Works Clean Water Division.	https://clark.wa.gov/public-works/clean-water-projects
On-site Sewage Systems program	WA Ecology, DOH, local counties and health departments	Set up low-interest loan programs for property owners to repair/replace failing OSS systems.	Local governments	Regional On-Site Sewage System Loan Program provides financing through Craft3, a non-profit third-party lender; focus may be on Puget Sound.	https://ecology.wa.gov/About-us/Payments-contracts-grants/Grants-loans/Find-a-grant-or-loan/Water-Quality-grants-and-loans/On-site-sewage-projects
Conservation Reserve Enhancement Program (CREP)	WA State Conservation Commission, Farm Service Agency, local conservation districts	Restore streams along farmland by planting native vegetation.	Farmers/landowners	Farmers are paid directly by program for planting native vegetation as a buffer, project costs/maintenance for 5 years covered by program, landowners paid rent for acreage restored and receive enrollment bonus, renewable for 10 to 15-year contracts.	https://www.scc.wa.gov/conservation-reserve-enhancement-program

Note that Tables C-1 and C-2 are non-exhaustive lists that can and should be continuously updated by managing entities as project needs and program options change.

APPENDIX D

Comments on the Draft Vancouver Lake Management Plan

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Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
schnabel et al	1	ix	Misc	Executive Summary would benefit from a clear and concise table summarizing the methods evaluated, costs and beneffits, and whether they are being recommended	added table
Amaia Smith	1	ix	1	As a large lake located within a metropolitan area, the lake is used by a multitude of recreational users and is home to a variety of **fish and** wildlife.	addressed
schnabel et al	2	x	3 and 4	Consider identifying items within these goals with separate bullets or identifier (e.g., a., b.)	addressed
Kent Cash	1	xi	4	Flushing Channel Enlargement. The ES indicates "twin 6-foot culverts". I believe the field survey indicated an 84-inch diameter culvert and a 77-inch diameter culvert.	addressed
Kent Cash	2	xi	4	This section indicates that the flushing channel culverts will be replaced with a "100-foot-wide by 10-foot-tall box culvert wih fish friendly gates". It would have been more appropriate to indicate “widening the flushing channel outlet structure to increase flow from the Columbia River to Vancouver Lake." It would be important to note increased flows through the flushing channel but the "how" will include much more evaluation, study, and engineering.	addressed
schnabel et al	3	xi	5 thru 7	Chemical Management Methods - do these treatments take into account ongoing negating effects of sediment disturbance by carp?	addressed
Sutton	1	xi	1	Stormwater Management: …"relying heavily on regional treatment facilities … such as that constructed at the Park Place facility in Bellingham." The City of Vancouver relies on dispersed and decentralized stormwater management due to our high infiltration capacity through most of the city. Although requiring phosphorus treatment in new and redevelopment is possible, we do not have any regional facilities similar to Park Place available for conversion.	addressed by noting "where possible"
Amaia Smith	2	xii	4	If the recommended HAB treatments are not in a particular order, it would be easier to read if the treatments were listed in order of cost/year (lowest to highest or vice versa) Keeping the contingency last makes sense.	retained order evaluated and listed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com- ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Rollwagen-Bollens	1	xii	1	Please explicitly acknowledge the extensive monitoring and contribution of data by the Aquatic Ecology Lab at WSU Vancouver in the lake modeling summary	addressed
schnabel et al	4	xii	4	2nd bullet - Watershed management for stormwater phosphorus - cost should reflect true cost beyond just the LMP, e.g. the assumed cost to county and city	clarified use of existing funds to be determined
schnabel et al	5	xii	4	4th bullet - How will algicide application in swimming beach area benefit if there is mixing of lake waters from areas beyond beach area? Consider a suspended barrior to minimize mixing of the main lake waters with swimming beach area waters.	addressed
Amaia Smith	3	xiii	2	Similar comment as above for noxious weed treatment order	addressed
Fry/Donehower	1	xiii	Stakeholder Involvement Plan	We recommend calling out Tribes separately from "stakeholders" given their unique cultural and legal status. We appreciate statements at the end of the draft (p. 126) that acknowledge this distinction and urge the authors to make that important clarification throughout this document.	addressed
schnabel et al	6	xiii	1	suggest adding a contingency and providing the total annual cost of noxious weed plan as was done for HAB	addressed
schnabel et al	7	xiv	5	Agree the Flood Control district would be at risk of failure in a vote of the public. State appropriations seems like the most feasible source for large-scale investment.	acknowledged
Amaia Smith	4	1	1	Since Lake River is identified as a major contributor of nutrients into Vancouver Lake, should land ownership around Lake River be included somewhere in the introduction? *Follow-up: I saw land ownership discussed later in document	acknowledged
Sutton/Olinger	1	2		format - bullets 7 and 8 have a comma following vs a period on the others	addressed
Patty Boyden	1	4	1	Construction of flushing channel was only one piece of a much larger project that included dredging of the lake. Please mention the Vancouver Lake dredging element - this is general comment throughout the report. Not mentioning the dredging element is missing a key previous action for the lake.	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Patty Boyden	2	4 and 18	2 and 2	Vancouver Lake was determined to be…one of highest trophic state index in WA state and most eutrophic lake in WA state. Therefore, The plan should consider an <u>option that allows portions of the lake to return to a natural state</u>. This would be more realistic, affordable and implentable. We could actually make a difference and improve the lake. Creating a clean lake from the worst trophic state index in Washington is not realistic nor achievable.	Goals were lowered to reflect the natural eutrophic state of the lake and are for modest and realistic reduction in toxic algae
Amaia Smith	5	7		*I recommend incorporating a paragraph about land designation under the City of Vancouver and Clark County's Comprehensive Plan. Including this will bring conversation to long range planning about future land use around Vancouver Lake. Clark County is starting their 2025 Comprehensive Plan periodic update and the City is scheduled to begin their Comprehensive Plan update some time this year. By referencing the Comprehensive Plans in the VLMP, local governments can work to align land use designation with management recommendations for the lake. https://www.cityofvancouver.us/sites/default/files/fileattachments/community_and_economic_development/page/874/vancouver_comprehensive_plan_2011-2030_august_2021_update.pdf https://clark.wa.gov/sites/default/files/media/document/2023-01/2015-2035%20Comprehensive%20Plan-ORD.%202022-07-01%20AR_Dockets.pdf	addressed
Rollwagen-Bollens	2	7	1	I was unaware that the region from Camas to Ridgefield was called the Salmon Basin. I've never seen that. Since you use this name throughout, I guess you have more info. But I initially tagged it, since I thought you had left out "Creek" :)	acknowledged
Amaia Smith	6	14	2	*Sandhill cranes are not known to nest at Shillapoo, but there is appropriate habitat available	addressed
Sutton/Olinger	2	13	2	last sentence - is there a reference or documentation for the $2 million per event? Or is this attributed to an estimate from the Rowing Club?	addressed
Amaia Smith	7	14	2	*Using Prescribed Fire to Control Invasive Vegetation (e.g., ~~purple loosestrife~~ blackberry)	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Amaia Smith	8	14	2	*Shillapoo Ecosystem Restoration Feature (SERF)- no current plans to complete this project, still interested in performing it	addressed
Amaia Smith	9	14	2	*South Unit Buckmire Slough (SUBS) - project currently not being considered.	addressed
Amaia Smith	10	14	2	*Oregon white oak and riparian habitat enhancement at Chapman and Buckmire - Sloughs have riparian plantings but oak is not a component at either sites. Oregon white oaks plantings occur at 3 other locations within wildlife area	addressed
Amaia Smith	11	14	3	*Paragraph about Ridgefield NWR - refuge also provides waterfowl hunting opportunities. The 75 species identified in this paragraph might be the number of wintering species. The total number is likely closer to 200. Update or clarify	addressed
Patty Boyden	3	14	2	Include the 527 acre Crane's Landing (sandhill cranes) adjacent to west side of flushing channel owned by Columbia Land Trust. Especially important given proposed flushing channel revisions. https://www.columbialandtrust.org/project/clark-county/	addressed
Patty Boyden	4	14	4	While VL is not used as a drinkingwater source it is within the EPA listed sole-source Troutdale Aquifer for Vancouver. https://www.federalregister.gov/documents/2006/09/06/E6-14710/sole-source-aquifer-designation-of-the-troutdale-aquifer-system-clark-county-wa	addressed
Sutton/Olinger	3	14	1	first sentence - is the harvesting specific to fish?	addressed
Patty Boyden	5	15	2	The inflow data figures do not match Figure 6 which is the total water budget. Therefore, the reference is confusing e.g. flushing channel says 10% in text but 5% in diagram	acknowledged
Sutton/Olinger	4	15	2	The main conclusion of the water budget study was that Lake River … They also verified that Lake River...and that water inputs via precipitation and groundwater are less than 1% each. ~~and determined~~ Water retention time in Vancouver Lake ranged….throughout the year of the study.	addressed
schnabel et al	8	16	1	Was nutrient exchange / turn-over from macrophyte senescence / decay evaluated since often this can be a large source of recycled nutrients to the lake water column?	No it was not included in the USGS study.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sutton/Olinger	5	16	1	sentence 2 - various inflow sources ~~ranged~~ increased from July to September	addressed
Kent Cash	3	17	1	The Jacobs report indicates that one alternative for increased flow would be "culvert maintenance (debris removal)...". The Port has a robust inspection and maintenance program for the flushing channel including weekly inspection of the channel and debris structure that includes raking the grates, a monthy preventative maintenance site visit, and quarterly, yearly, and every five year activities that are scheduled for inspection and maintenance as necessary. Some floating debris will have little to no effect on the flow through the submerged culverts and debris rack.	addressed
Sutton	2	18	3	Trophic State Index (TSI) - spell out as not shown until page 68	spelled out on page 4
Sutton	3	18	4	Please add a sentence to explain that although the concentration of nutrients is higher in Burnt Bridge Creek than other sources (as shown in Figure 10), the low volume of flow limits the amount of nutrients (load) flowing into the lake from the stream.	addressed
Sutton/Olinger	6	18	5	...frequently exceeded 20^0 C (68^0 F) just for those more familiar with that scale	addressed
Rollwagen-Bollens	3	20	2	last sentence of paragraph 2 (after the bulleted list): "...with some samples exceeding by a magnitude..." should say: "...with some samples kmore than 10 times what the guidelines require." Some readers may not know what an order of magnitude means. Or just add "an order" before magnitude, but I think the sentence is confusing that way.	addressed
Sutton/Olinger	7	20	1	... that include the following thresholds to protect human health: (or use for public recreation if that is more accurate)	addressed
Amaia Smith	12	28	2	*This paragraph expands the discussion to potential listed species that could be found in the lake. This section is specific to fisheries, but should it be more encompassing to include out-migrating salmonids that pass through Vancouver Lake from Burnt Bridge Creek? Or should there be a new paragraph? Salmonid use within the lake is largely temperature/time of year driven	addressed
Amaia Smith	13	29	Table 4	*West Pond Turtles are likely no longer in the area.	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Amaia Smith	14	29	1	*West Pond Turtles are likely no longer in the area.	addressed
Amaia Smith	15	29	1	*"The Shillapoo South Wildlife Area Unit, located in the floodplains area between Vancouver Lake and the Columbia River, provides an additional 1,000+ acres of wetlands, pasture, and agricultural fields that boast bald eagle and Sandhill crane nesting. ~~Both~~ All units are components of the Shillapoo Wildlife Area (2,430 acres) managed by WDFW under the Shillapoo Wildlife Area Management Plan (WDFW 2017, 2020)." - There are 3 units with the Shillapoo Wildlife Area (North Unit, South Unit, Vancouver Lake Unit). Is this reference just for Shillapoo North and South? It can be expanded to discuss all three.	addressed
Patty Boyden	6	29	2	General comment for report: Include the 527 acre Cranes Landing (sandhill cranes) refuge adjacnet to west side of flushing channel owned by Columbia Land Trust. Especially important given proposed flushing channel revisions,	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Patty Boyden	7	30	1	Social equity considerations for this report including engagment to multiple groups e.g. BIPOC, English as a second-language,, lower economic groups etc. was minimal. Though, appreciate that it is mentioned a goal for future public process. The focus has been recreational users who have the means /time to sail and row. Focus of report needs to be expanded to include broader community and other users of the lake including fish and wildlife. E.g. what if a goal was to increase use and species diversity for salmonid and migratory/resident bird etc?	Yes, more needs to be done to engage non-recreational users and broaden the concept of the public. Targeting historically marginalized groups is needed for this effort and will require investment in the public outreach to engage these groups. Addressed to expand "General Public" and acknowledge the work that was done to engage Vancouver residents broadly. Expanding the Focus of the Report to other users of the lake including fish and wildlife seems like this could be addressed in other areas of the approach.
schnabel et al	9	33	7.i and ii	wording and intent in i. and ii. is unclear and appears difficult to measure or enforce.	addressed
Sutton/Olinger	8	33-34		Numbering the goals 7-9 is confusing	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
schnabel et al	10	34	8.a.c	i and ii seem out of scale with each other, also ii needs a time definition -- at any time? at the end of 20 years? Also 50 percent of the community over more than 30% of shoreline sounds like a much larger infestation than we have currently, which would conflict with iii.	addressed
Philip Parshley	5	35		"Improve general water quality and summertime lake depth to improve conditions for recreation and in-lake habitat for native fish and migratory birds." I agree with this statement that greater Summer time depths should be a primary objective; and the target should be six feet more than current summer depths, not just another foot or two. There are many advantages for greater depth, one is certainly better recreation value, but also its impact on summer time water temperatures.	acknowledged
schnabel et al	11	35	bullet 5	improved access for motorized boating is likely in direct conflict with nutrient control efforts -- the lake is shallow enough that motorized boats easily disrupt the sediment layer unless depth is increased significantly.	addressed
Sutton/Olinger	9	35		First paragraph under Project Schedule - the sentences are really long which makes it a challenge to read	addressed
Sutton/Olinger	10	37	2	Last sentence - …and the rational for their elimination from further investigation at this time.	addressed
Sutton/Olinger	11	37	5	last sentence - for the current project scope and for future~~,~~ adaptive management strategies.	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Philip Parshley	1b	38	Table 5	Why are "Floating Wetlands" listed as a "Yes" for "Selected for Evaluation" on Table 5? It's clear the current TAG group was not in favor of it, and the Technical Committee of the Vancouver Lake Watershed Partnership also rejected this concept over 10 years ago. It has a "Low Effectiveness and Feasibility" in Table 5. My own research and outreach indicates that Floating Wetlands are a very poor choice for shallow lakes, are high maintenance, and their uptake impact is extremely limited beyond the perimeter of the plant area. Most importantly, it fundamentally poses an existential threat to sailing on the lake, an established community activity for more than a half-century. I can guarantee that future consideration of floating wetlands will lead directly to legal challenges. It would be most sensible to give this up now, and save the headaches that will come if it remains on this list for consideration. I realize Floating Wetlands are a favorite of Rob's, but its time to take this off the table for Vancouver Lake.	It was retained in the Work Plan because it was not clear to us that the TAG rejected it at that time, but it did become clear that it is unacceptable after it was evaluated and it was not recommended to pursue.
Ted Gathe/FOVL	1	38	Table 5	Carp removal has been shown to be effective in other lakes with similar water quality issues- should continue to be studied in the next phase of the LMP.	Good comment that needs to be addressed in future phases.
Amaia Smith	16	39	1	bullet points - Clark CD has experience applying for grant funding for old septic systems with their Poop Smart program. The first bullet point focuses on incentivizing, what about expanding the bullet point to include partnerships? If not here, maybe this could be incorporated elsewhere in the plan	addressed
Olinger	1	39	3	Figure 3 presents stormwater facilities. Recommend to refer to Figure 4 (sewer and septic facilities) as it is more relevant to this section.	addressed
Olinger	2	39	4	Figure 3 presents stormwater facilities. Recommend to refer to Figure 4 (sewer and septic facilities) as it is more relevant to this section.	addressed
Sutton	4	39	2	Did this evaluation only cover underground injection control for stormwater management or was stormwater discharges to surface water included as well? Bullet 3 only mentions UIC retrofits.	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sutton	5	40	4	In early MST studies such as this one, with 36% isolates not matched across watershed stream sites, percentages should be interpreted broadly.	addressed
Sutton/Olinger	12	40	2	However, at one or two of the eleven monitoring stations (just gives some perspective)	addressed
Sutton/Olinger	13	40	3	Results indicate that septic systems ~~are~~ may be increasing nitrogen ...and that urban development is likely increasing phosphorus concentrations in Burnt Bridge Creek	addressed
Ted Gathe/FOVL	2	40	2	There are methods of in situ treatment of phosphates in Burnt Bridge Creek. Those methods should be further examined.	Good comment that needs to be addressed in future phases.
Rollwagen-Bollens	4	42	1	First line: "...operates of public..." should be "operates a public..."	addressed
Sutton/Olinger	14	42	1	Clark Regional Wastewater District (District) operates ~~of~~ a public wastewater	addressed
Sutton/Olinger	15	42	1	The Salmon Creek service area has 15 completed projects	addressed
Ted Gathe/FOVL	3	43	1	The term 'regulatory mandates' needs to be expanded on with regard to septic systems and sewers. The County/Health Department currently has minimal regulatory requirements for septic systems. There should be a requirement that septic systems be inspected on a regular basis depending on the age of the system; failure to inspect should result in a fine; failing systems should be required to be repaired or replaced with a specific time line; state funding for repair/replacement should be investigated. Clark Regional should be encouraged to be more aggressive in requiring septic system owners to hook up to sewer when sewer is available; low or no cost funding such as Vancouver's SCIP program should be provided.	Good comment that needs to be addressed in future phases.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sutton	6	44	1	..."high proportion of human sources observed in Burnt Bridge Creek (20percent)" This is the same concern with identifying 20% at one site, vs overall human source isolates identified at 12.7% from different sites across the watershed, quite variable between monitoring sites and a large percentage not matched. Though 20% was used as an assumption in the model it is likely high.	The one site used is the BBC1 at the mouth which is most relevant to lake input and was higher human than upstream locations. Clarified that it does not include any of the 32 percent unkonw which could make human >20%.
Sutton/Olinger	16	44	2	the existing systems that are responsible for 90 percent of the septic nutrient loads. (for some reason this sounds like 90% of all nutrient loads to the lake)	addressed
Ted Gathe/FOVL	4	44	Table 6	Cost of new mainline sewer construction would be the responsibility of Clark Regional not the County. Encourage City and County/Clark Regional to set a goal of 200 new hookups per year at a minimum.	Acknowledged. Existing details were provided by Clark Regional Wastewater District.
Olinger	3	45	1	Figure 4 should be Figure 3	addressed
Sutton/Olinger	17	45	3 and 4	a repeat from page 40	addressed
Olinger	4	46	2	Delete sentence: (Note: An assumption of $5 million per year for Stormwater Financial Assistance Program [SFAP] grant funding was included in the 2022–2027 CIP program starting in 2024. $5 million is the maximum funding allotted to a specific jurisdiction, so this full amount of funding may not be received by the City on an annual basis.)	addressed
Olinger	5	46	2	The City's stormwater retrofit program has leveraged grant funding to address roadway flooding and water quality issues but will be shifting to target more water quality improvement projects in the future. ~~since most of the roadway flooding issues have been addressed~~	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Olinger	6	46	2	Prefer to have the reference changed to: Vancouver Engineering staff instead of a personal communications	addressed
Patty Boyden	8	46	1	Industrial stormwater general permit NPDES testing requirement for phosphorus is based on the users NAICS code which is appropriate (i.e. treat based on use). A blanket requirement for all NPDES permits is impractical and does not get at the source. i.e. why create a requirement for a user that does not contribute phosphorus. Will be difficult to implement and is not equitable among permit holders. i.e. should focus on the actual source.	This paragraph describes municipal NPDES permits. Requiring phosphorus treatment for the industrial permits was not addressed or proposed .
Sutton	7	46	1	first line at the top of page "of Vancouver Lake ~~and Burnt Bridge Creek~~ as water quality impaired by total phosphorus..." BBC is not on the 303 (d) list for TP.	addressed
Rollwagen-Bollens	5	47	1	Should "Teney" Creek be "Tenney" Creek?	"Tenny". Addressed.
Rollwagen-Bollens	6	47	2	"The conceptual design **IS** being implemented…"	addressed
Sutton	8	47	5	Remove first sentence referring to Table 6. Including information on costs associated with their program goals ok.	Added paragraph break to separate table of goals and costs of the program
Sutton/Olinger	18	47	2	"The conceptual design ~~of~~ being implemented in the Lake Watcom watershed ~~that~~ is targeting a 64 percent..."	addressed
Sutton	9	48-50	all	Remove Table 7 and Table 8. A basic list of overall goals related to the Park Place vacility should suffice. Vancouver and Clark County will work within their own programs and types of existing facilities for appropriate strategies to reduce nutrients. Clark County may comment on the inclusion of the Park Place facility redesign section, but it is not relevant to the current infrastructure utilized in our stormwater utility system in the City of Vancouver.	Retained tables for future reference and planning pruposes

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com- ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Bob Chapman/FOVL	1	50-51	last several/ first several	One prinicipal approach of the draft LMP is to minimize 2HAB growth in Vancouver Lake during the summer months. Please address and provide some quantification as to what extent stormwater phosphorus treatment would reduce the P concentrations in the Lake during those months when there is very little rainfall.	Nutrients derived from stormwater can remain in a system, available for uptake by algae, and therefore can facilitate summertime algae blooms, particularly in urban watersheds. The model found that stormwater management could decrease summertime total phosphorus by about 8 percent.
Bob Chapman/FOVL	2	51	Table 9	There are no operating costs included in the estimate, and such costs could be very substantial. If the bullet that states grant funding will be obtain from Ecology "top support these projects" infers that operating costs would be covered by grants from Ecology, such costs should still be included.	Good comment that was noted and needs to be addressed in future phases.
Fry/Donehower	2	51	Lake River Dam	If the Lake River dam alternative receives further consideration, we would like to see an in-depth assessment of fish passage criteria and water quality effects (including effects on connected water bodies). Further evaluation would be critical to undertanding impacts and making informed decisions.	Good comment that needs to be addressed in future phases.
schnabel et al	12	51	table 9	The proposed level of investment seems unlikely to provide a 30 percent reduction. $2 million per regional facility to treat 180 acres; $1M/year county gets you 10 facilities over 20 years, treating 1800 acres (2.8 square miles). The target watersheds cover many times more square miles, much of which is untreated or undertreated.	Good comment that was noted needs more work in future phases.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sutton	10	51	3	Sub-bullet - "Rely heavily on regional treatment facilities with high-flow and high-P removal media filters such as that constructed at the Park Place facility in Bellingham." This is too specific and not a useful recommendation for Vancouver due to current stormwater managment strategies used within the city.	Clarified to use where possible and does not fit with current City dtrategy.
Ted Gathe/FOVL	5	51	last bullet point	Does retrofitting existing stormwater facilities including retrofitting underground injection control wells for phosphorous treatment?	Yes, such as adding a P removal biofilter before discharge into the UIC.
Bob Chapman/FOVL	5	52	Bower Dam example	The Adam T. Bower dam us uncluded as a a good example of an inflatable dam. It is noted that the world's longest inflatable dam at 2100 feet creates a 3,000 acre lake. To help readers better visualize a Vancouver Lake application, I suggest that a comparison be included along the lines that an application across the channel of Lake River would likely require a lenth of less than 200 feet (? or whatever you visualize) for a simlar sized lake.	addressed
Bob Chapman/FOVL	3	52-53	Suisun Marsh dam example. Fig 16	Although this example has a similarity in that it manages tidal driven water levels and flows, the magnitude of that project and image could be very misleading. I recommend including an example that is more representative, or at least elaborating on the significant differences (design flows, water level differentials, etc). The basis for much of the cost estimate in Table 10 is a 2017 San Jan Watershed Project...would a visual graphic of that project be a better choice?	good comment that could be addressed in the future if a dam is pursued.
Kent Cash	4	55	Figure 17	Lake stage should be referenced to an NGVD elevation benchmark or Columbia River Datum (CRD) and not the "lake bottom eleveation (?)". The graph on page 55 does not provide reference to the reader what the red A, B, and C are for. I believe they are a reference to Figure 18 on the following page.	Clarified that red squares on upper graph are for photo points in source and defined lake depth noting it was not converted to a standard elevation datum in this figure by authors.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Kent Cash	5	55-57	Figure 17 and 19	One graph references feet and inches and the other uses meters. In the US, the standard is the Imperial System (feet, inches, etc. to measure length). Shouldn't mix systems.	acknowledged; clarity added
Bob Chapman/FOVL	4	56	2	The basis for setting a crest elevation at 4 or 5 meters is not discussed. Make it very clear that the only way to increase the level of the lake without pumping water into it is by capturing water in the lake drung high water levels in the Spring. Per the data on Fig 19, 5 meters is about the max possilbe elvation in those years, so one assumes that is one key basis. One could assume that 4 meters was selected as that could nearly prevent any backflow from Lake River during the recreational season. One could argue that a crest of 3 meters would largely push back Lake River during this season, and might be prove to be a cost-effective solution given further optimization studies.	Added basis for 4 and 5 meters
Bob Chapman/FOVL	6	56	2 an Fig 20	Clearly point out that the only source of water flow through the Lake during the recreational season will be flow from BBC, which gets down to about 10 cfs (.3 cu meters/sec)in the summer. Also suggest adding a conversion factor in the text and on Figures to convert from cfs to cu meters/sec, for example	Noted that most of summer inflow would be from Flushing Channel not BBC . Unit conversion was added to text to clarify that point and unit conversion could be added in the figures in the future.
Bob Chapman/FOVL	7	56	Fig 19	While crest elevation is important to reduce backflow, water depth is another important benefit of raising the level. Suggest showing the range of lake bottom elevations in the areas with the greatest potential for various forms of boating. Then also highlight the resultant range in water depths. In the associated text include comparative information about the desired water depths for crew racing, for sailing, etc.	Good comment that should to be addressed in future phases.
Bob Chapman/FOVL	8	56	Fig 19	Add a parrallel scale one of the ordinates that would provide the elevations in feet referenced to the same datum as the the bathometric data on Figure 2	Good comment that needs to be addressed in future phases.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Rollwagen-Bollens	7	58		Figures 20 and 21: You need to better explain to the readers how to interpret these graphs. Fig 19 is clear in that it shows water depth over tme. But Fig 20/21 show flow rate over time, and I can't quite figure out how to translate low flow rate to water depth. I doubt anyone except hydrologists could derive the importance of Figs 20 and 21 for lake height.	Good comment that should be addressed in the future by also presenting model results for lake elevation and for comparisons of average daily lake level to inflow rates from each source including Lake River, Columbia River, BBC, drains, and direct precipitation.
Amaia Smith	17	59		Somewhere in this section, clarify that a fish passage system will consider all species within the system, not just salmonids.	addressed
Bob Chapman/FOVL	14	59	1	"Flood Control" is not the best terminology. State that the gates would be fully open, or bladders fully deflated, except during the summer recreational season. This will allow unrestricted flow, fish passage, boat passage.	No, the dam should only be lowered during a severe winter flood and not be lowered at other times to minimize nutrient inputs all year. Unrestricted flow defeats the dam purpose.
Bob Chapman/FOVL	15	59	3	Re description of "small boat lock", a 20 foot wide by 80 foot long lock chamber appears to be way more than needed to accommodate kayaks, canoes, small fishing boats. See related comment re Table 10. (Small, manually operated locks used for boats and barges on the canals in England might be a more applicable vision.)	Good comment that needs to be addressed in future phases.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Kent Cash	6	59	2	In the second sentence, the portion of the sentence that reads, "...but no impact from the introduction of a barrier is unlikely." This makes no sense.	addressed
Rollwagen-Bollens	8	59	2	"...but no impact from the introduction of a barrier is unlikely." Awkward wording. Maybe something like: "...but there is no barrier that will not somehow impact fish passage to some degree."	addressed
Sutton/Olinger	19	59	2	"...but no impact from introduction of a barrier is unlikely." Although a "no-impact" determination is the reference point, it would read clearer "...but impacts from introduction of a barrier are likely."	addressed
Sutton/Olinger	20	59	3	bullet 1 - during periods ~~with~~ when migrating fish are normally present at the site	addressed
Amaia Smith	18	60	Table 10	Table 10 doesn't account for compensatory mitigation that could be a required for the construction of this structure, provided it could be implemented and meet legal requirements.	Good comment that needs to be addressed in future phases.
Amaia Smith	19	60	Table 10	Table 10 - I recognize that this would be more for review phase, but there would need to be a decommissioning plan and that cost is also not accounted for.	Good comment that needs to be addressed in future phases.
Bob Chapman/FOVL	16	60	Table 10	Suggest that it be acknowledged that estimating costs on a basis of very preliminary concepts is very difficult and subject a large number of variables. Consider adding a statement from tradiional cost estimating guidelines that the accuracy of such estimates could range from " -x% to +y%" (Maybe this is covered generically elsewhere in the plan.)	addressed
Bob Chapman/FOVL	17	60	Table 10	The estimate for the Boat Lock should in particular be re-evaluated. At $11,500,000, it represents about 55% of the total estimated construction subtotal. In footnote b, this estimate is based on a projet with a 20-foot by 125-foot concrfete lock with 60-foot by 8-foot floating an fixed docks.	Good comment that needs to be addressed in future phases.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Kent Cash	7	61	3	The last sentence reads, "The existing culverts and three alternatives were modeled to asess potential hydraulic options that would increase flow rates and volumes through the Flushing Channel, increase water depths in the Lake, and reduce nutrient loading to the Lake." None of the three options will increase the lake level without an outlet control structure (a dam) on Lake River.	Revised sentence to delete the modeling objectives partially repeated from above list.
Kent Cash	8	61	3	Alternative 1. I presume that upstream of the culvert is on the Lake side of the culverts. There are large rocks and riprap that are being investigated by a diver for the Port of Vancouver beginning after June 1. The downstream side of the culverts are regularly maintained as is noted above in our comments.	acknowledged
Kent Cash	9	61	3	Alternative 2a. Replace Culverts with an Open Channel (with flap gate). We have not determined the purpose of the flap gates. When the flap gates are closed, water is discharged natuarally out Lake River anyway and water is not retained in the lake.	addressed
Sutton/Olinger	21	61	1	However, the modest increase in flow ~~it~~ has not remedied the eutrophic water conditions	addressed
Bob Chapman/FOVL	10	62	last para	I suggest this paragraph be deleted as the degree of debris accumulation is variable and uncertain, and the potential relative benefits are minimal relative to the current LMP evaluations	addressed
schnabel et al	13	62	figure 21	Flushing channel enlargement appears to be the most promising Physical management method for the cost. However the estimate seems surprisingly low and an O&M cost of 5% seems optimistic. Does the estimate include any plan to mitigate sedimentation in the channel?	Good comment that should be addressed in the futrure, and noted that cost does not include maintenance dredging of the channel or lake.
Bob Chapman/FOVL	12	63	2nd para	Alternative 2A n the Jacobs report is the compaprable option	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Bob Chapman/FOVL	13	63	last para	Where is the data in the plan or Limnotech report from which the estimate of a 30 times flow increase is determined?	That proportion was taken from Limnotechs meeting presentation and was confused by the use of different flow units. A flow chart was added and the proportion was corrected to increase only 3-5 times.
Kent Cash	10	63	2	There would be no "Temporary closure" of Lower River Road. Lower River Road may be restricted to a single lane with construction taking place in phases, but not closed. This would not be allowed by WSDOT.	addressed
Kent Cash	11	63	2	"Four 26-foot-wide culverts are anticipated to span across the width of the Flushing Channel." The concept of a box culvert, or culverts, is OK to discuss, but a description of "26-foot-wide culvert" and "are anticipated" are far too preliminary for discussion or presentation. A 26-foot-wide culvert would be a very difficult section of culvert to have precast. I would anticpate a series of culverts, say 10-foot by 10-foot in sectional area, that are 8-feet in width, and are post tensioned or grouted together in series for the necessary length. Culverts could then be placed side by side to obtain the necessary sectional area e.g. a group of 10 culverts that are 10-foot by 10-foot would provide a sectional open area of 1,000 square feet.	addressed
Kent Cash	12	63	3	The Obermeyer gates would not provide an increase inflow of 30 times current conditions. The open sectional area of the culverts would provide the increased inflow. The Obermeyer gates would restrict flow.	addressed
schnabel et al	14	63	1	typo: the conceptual design should read "Alternative 2A", not 2B.	addressed
Kent Cash	13	64	Table 11.	I believe the $32.7 million dollar estimate is far too high.	acknowledged

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Rollwagen-Bollens	9	67	1	"The deepset area ofo the lake **IS** in the dredged…"	addressed
Sutton/Olinger	22	67	1	measured in 2007 by the USACE (2009) and most recently ~~during an~~ on June 15, 2019…. The deepest area of the lake is in the dredged area by the Flushing Channel,	addressed
Sutton/Olinger	23	69	1	would require 115 acres of floating wetlands verses 4.4 acres needed for breakwater wetlands to reduce wind and wave impacts.	addressed
Rollwagen-Bollens	10	71	2	first line after Table 14: remove "varies" from the sentence.	addressed
Bob Chapman/FOVL	11	74	4th para	The statement that inflow stream alum injection is not appropriate because the lake does not have one primary inflow stream seems questionable. Both flow and nutrient loadings are very predominantly associated with backflow from Lake River. The flow into an out of Lake River twice a day is quite large compared to the volume of the lake. This would seem to make a single treatment with alum early in the year questionable as to lasting efficacy, and possibly favor periodic treament of Lake River inflow, at least as an option to periodic whole-lake treatment.	Clarified that Lake River injection is not feasible because alum is not allowed to be discharged from lakes.
Rollwagen-Bollens	11	74	5	add units after "1,092"	addressed
Rollwagen-Bollens	12	75	2	remove comma after Washington in "…used in Washington, lakes…"	addressed
Rollwagen-Bollens	13	75	2	Is the O in Solitude supposed to be capitalized? I guess since it is like this in multiple places it's correct…	Yes it is correct.
Rollwagen-Bollens	14	75	3	Change "commonly" to "common" in line 2	addressed
Sutton/Olinger	24	75	2	Historically, a ratio of 20 had been successfully used in Washington~~,~~ lakes where the targeted	addressed
Sutton/Olinger	25	75	3	Historically, a 4-cm inactivation depth was commonly used for dose calculations,	addressed
Rollwagen-Bollens	15	76	1	First sentence of this paragraph doesn't make any sense. Please clarify and simplify.	addressed

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Rollwagen-Bollens	16	76	2	Remove "was biogenic" and end that sentence after "phosphorus"; Capitalize "biologically" and remove "for example"	Edited text for clarity and corrected values
schnabel et al	15	77	4	agree the water column stripping seems the better choice for alum. However there are a lot of additional costs listed for which no estimate is given - can we develop a general estimate for these?	Additional consultant costs were added
Sutton/Olinger	26	77	2	bullet 3 - Water Column Stripping Plus 20 Percent with Partial Sediment P Inactivation (just a bit more explanatory)	It is for either more water P or minor amount of sediment P so simply added for Supplemental P Inactivation
Sutton/Olinger	27	77	3	Thus, the cost of Scenario 1 is approximately equivalent to the cost of 10	addressed
schnabel et al	16	79	bullet 3	general comment: is there a way to incorporate an inflation factor in the costs for items that cover the entire 20 year implementation period	A 10% contractor contingency was added that could include inflation, but inflation is better addressed for refining costs of the recommended alternatives
Rollwagen-Bollens	17	80	3	Remove "is" after EutroSORB in first line.	addressed
schnabel et al	17	80	1	Seems like the first two words are intended to be "While alum", not "While Phoslock".	addressed
Sutton/Olinger	28	80	3	EutroSORB ~~is~~ entered the marketplace	addressed
Rollwagen-Bollens	18	81	3	change "...which is used water column phosphorus..." to "...which uses water column phosphorus..."	addressed
Rollwagen-Bollens	19	81	6	First sentence of this paragraph should read: "The EutroSORG does was estimated by Eutrophix..." (remove extra "was estimated" and add capital T at the start)	addressed

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sutton/Olinger	29	81	3	line 6 bentonite would require separate applications of ~~would require application of~~	addressed
Sutton/Olinger	30	81	5	Planning-level cost estimates for lanthanum ... were provided by Eutrophix (also missing a T (he) under Eutrophix Estimates first line)	addressed
Rollwagen-Bollens	20	84	3	"These algaecides have NO recreation use... not to be applied to PLANTS growing on the shore..."	addressed
Rollwagen-Bollens	21	84	3	remove space between us and ed in last sentence.	addressed
schnabel et al	18	84	4	Hydrothol 191 sounds like a no-go for the public based on the potential impacts and restrictions	acknowledged
Sutton/Olinger	31	84	4	Endothall has an application timing restriction ~~the~~ that limits applications	addressed
Sutton/Olinger	32	84	5	These algaecides have no~~t~~ recreation use restrictions or treatment limitations except they are not to be applied to plants growing on the shore. If algaecides were to be used in...	addressed
Rollwagen-Bollens	22	85	2	You should probably note in the paragraph that high flows are typically characterized by lower temperatures, which also contribute to low phytoplankton growth.	addressed
Rollwagen-Bollens	22	85	4	***You need to remove all references and discussion of Rollwagen-Bollens et al. 2022!! These results are from the mainstem Columbia River sampled from the Vancouver City Dock and NOT VANCOUVER LAKE. There is only minimal correspondence between conditions in the River and Vancouver Lake, and certainly shouldn't be compared directly - especially comparing chl levels in the river with toxin levels in the lake.	addressed
Sutton	11	85	1	reduce potential impacts to fish from low dissolved oxygen concentrations caused by decay of algae.	addressed
Sutton/Olinger	33	86	1	analysis clearly indicates ... This analysis suggests that ~~A~~algaecide treatments should be conducted in June ~~or~~ of each year	addressed
Rollwagen-Bollens	23	89		Remove Figure 28	addressed

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sutton	12	90	4	"water quality cells, comprising Vancouver Lake, the flushing channel, and the entire extent of Lake River" add a note on why Burnt Bridge Creek was not included.	addressed
Philip Parshley	1	92		Pg 92: "Floating wetlands provide minor water quality improvements compared to other strategies."	acknowledged
Rollwagen-Bollens	24	92		Please provide a legend so readers can easily understand what the colors mean in Table 17-20	addressed
Sutton	13	92-94	1	update table numbers	addressed
Bob Chapman/FOVL	21	96	1st bullet	In the first sentence, suggest you delete "and increase lake depth". The remaining characterization of dredging as a means of HAB control appears generally appropriate. The point is that in all alternatives except building a dam, at least some targeted dredging may be necessary to achieve/maintain desrable boating recreational benfits. Even though evaluation of such benefits are not included in this current LMP, they may well be in future planning.	left that text in because it would be a secondary benefit just as the dam is.
Bob Chapman/FOVL	22	96	last bullet	The negative effect that carp can have on contributing to the P loading on the lake was noted, and harvesting carp was discounted as a means of reducing this impact. I don't disagree with discounting harvesting. However, I have heard some individuals statements that carp in the lake is a huge water quality issue. It would seem that this issue should be more fully addressed in the LMP	Good comment that should be addressed in future phases.
Rollwagen-Bollens	25	96	2	Bullet 2 Dilution: remove "both"	addressed
Fry/Donehower	3	99	Problem Statement and Management Goals	It would be helpful to emphasize in this section that effective control, not eradication, is the primary goal for most noxious weeds in Vancouver Lake. The aim is to reduce them to a point that they are no longer having significant impacts on ecosystem function, recreation, and other desired lake uses. Given likelihood of reintroduction from connected water bodies, eradication is probably not feasible. For example, p. 107 states that "reintroduction of milfoil from all three infested and connected water bodies (Columbia River, Lake River, and Burnt Bridge Creek) is very likely."	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sutton/Olinger	34	99	1	The management of noxious weeds in Vancouver Lake ~~were~~ was recently evaluated … The IAVMP is presented in Appendix B.	addressed
Amaia Smith	20	104	1	Table 21….Chemical herbicides are permitted by Ecology…..and subject to WDFW's treatment timing windows.	addressed
Amaia Smith	21	105	3	Barrier installation and a pilot effort - bottom barriers or screen are recommended for early infection of noxious weed and are best used in small, confined areas (per 2015 Aquatic Plants and Fish Pamphlet HPA). While I am not opposed to a pilot effort in Vancouver Lake, I recommend additional planning to select areas if this proceeds.	Good comment that needs to be addressed in future phases.
Ted Gathe/FOVL	6	105	2	County pledged an additional $25,000 for Milfoil followup treatment. Those funds have not been expended to date.	addressed
Amaia Smith	22	109	3	Fish and Wildlife Habitat - Warm Water Temperatures: salmonids are not likely to use the lake during warm summer days. They are most likely to be present during spring outmigration (in line with historic spring freshet). My recommendations is to remove language on "hot summer day" and expand it to "high temperatures when salmonids are expected to use this system" or something along that line.	addressed
Bob Chapman/FOVL	18	109	last bullet	This comment ties to the comment on p. 112. The impacts of warm water on salmonoids hardly seems to need any further study. It probably should be noted that none of the lake management alternatives studied had any meaningul impact on the lake maximum water temperatures.	addressed
Fry/Donehower	4	109	Water and Sediment Quality	Waterfowl deterrent methods such as lasers and noise are mentioned as a possible source control method for fecal bacteria. These methods are generally non-selective and could disturb many waterbirds and other wildlife. Given the importance of the Vancouver Lake area to both resident and migratory waterbirds, we urge a precautionary approach and recommend further study of fecal bacteria-waterfowl dynamics.	Clarified in document. Good comment that needs to be addressed in future phases.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Fry/Donehower	5	109	Additional Lake Issues	We agree that there are additional issues not addressed in this LMP and that the proposed project will not address the full suite of ecological impediments affecting Vancouver Lake. Much more work will be needed to restore healthy, functioning habitat for fish and wildlife. It will also be important to better understand effects of the proposed actions in this LMP on Cultural Resources, threatened and endangered species, birds, and water quality of connected water bodies prior to implementation.	Good comment that needs to be addressed in future phases.
Amaia Smith	23	110	1	Invasive Animal Species: per communication with one of our fish biologists, carp control is expensive and often times ineffective for improving conditions. This is a bit outside my purview, but additional conversations are needed to determine the feasibility of carp removal to achieve goals	Good comment that needs to be addressed in future phases.
Amaia Smith	24	110	2	Ecosystem Functions: including funciton of floodplain habitat. As a side note, The Dept of Ecology funds restoration projects through their Floodplain by design grant, provided it also reduces flood risk. I wonder what the flood risk is around Vancouver Lake and if this could be a potential funding opportunity for restoration? https://ecology.wa.gov/Water-Shorelines/Shoreline-coastal-management/Hazards/Floods-floodplain-planning/Floodplains-by-design#:~:text=Floodplains%20by%20Design%20%28FbD%29%20is%20an%20ambitious%20public-private,and%20restore%20habitat%20along%20Washington%27s%20major%20river%20corridors.	Good comment that needs to be addressed in future phases.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Bob Chapman/FOVL	20	110	Last paragraphs	Public access and recreation. From my perspective, this "plan for a lake management plan" merited much greater consideration of these aspects. Consider emphasizing why these aspects are likely to be extremely important as part of any investment of millions of dollars going forward. Is there solid rational, and will there be public support for solutions aimed at improving the safety and water quality of the whole of Vancouver Lake when only a small fraction of the shorline is accessible even by trails, public boat launching is extremely limited, and some types of boating are substantially constrainted by shallow waters? Also, I would change "mehonds for increasing lake levels" to. "....increasing the water depth". I suspect that target dredging in certain areas of the lake may be a supportable from a cost-to-benefit perspective.	Good comment that needs to be addressed in future phases.
Ted Gathe/FOVL	7	110	last bullet point	There are existing pilings- apparently meant for dock construction- at the beach area of the Park. If a dock was constructed, it would improve and increase public access via boat use to the Lake.	Good comment that needs to be addressed in future phases.
Fry/Donehower	6	111	HAB Management Plan	From the information presented to date, we concur with the consultant team's recommendation to advance Alternative 2B (flushing channel enlargement) for further evaluation as part of the HAB management plan. If tide or flap gates will be considered, we recommend an in-depth assessment of fish passage criteria and water quality effects.	Acknowledged.
Amaia Smith	25	112	1	Flushing channel enlargement....preferred over Lake River Dam alternative: reduces uncertainty over long term and this option does not require decomissioning. Since alternative 2b for flushing channel is being considered, fish passage is easier to meet.	Acknowledged.
Amaia Smith	26	112	6	Maybe include reference to partnerships (such as Clark CD) for grant funding opportunities to fix septic systems?	addressed
Bob Chapman/FOVL	23	112	4th bullet	The statement that the flushing channel enlargement was selected by the TAG does not appear to be supportable. If not, this bullet should be removed	See other comments, herein.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Bob Chapman/FOVL	24	112	last bullet	Part of this statement is that the enlargedd channel would benefic salmon because of lower water temperatures from incrased river input. Table 19 data indicates the maximum water temperature would slightly increase.	addressed
Bob Chapman/FOVL	26	112	2nd from bottom	This paragraph in part states stormwater management alternatives are not recommended because they are expensive and not very effective at HAB control. This conclusion is supported by the data in this report, if the assumptions on P removal are correct. This conflicts with reommendations on p. 113	No conflict present. Text clarified. Stormwater management is effective but not as cost-effective as other methods. Stormwater management is recommended for ongoing watershed P reduction to protect in-lake investments and efficacy.
Kent Cash	14	112	1	I don't recall that the TAG "selected" the Flushing Channel Enlargement as the "preferred alternative."	Clarified. Also see other comments, herein.
schnabel et al	19	112	bullet 6	is there an expectation that salmonids will migrate through the channel to Salmon Creek, BBC, etc? Likely a very limited benefit, especially given lake temperatures and the limited likelihood any of the proposed actions would result in temperature reduction.	Acknowledged.
schnabel et al	20	112	ws mgmt 1st sentence	sentence and section is worded in a confusing way -- the chapter is Recommended Lake Management Plan, but the statement leads with these measures being not recommended. Then the section recommends doing them anyway.	Addressed.
Ted Gathe/FOVL	8	112	1	An expanded LMP- the next version- that provides more detail with regard to project feasability, alternatives analysis and purpose and need could be the springboard to start the process for a federal infrastructure funding request.	Good comment that needs to be addressed in future phases.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Bob Chapman/FOVL	9	113	stormwater treatement section	This states that stormwater treatement enhancements should include requirements for P removal. But this conflicts with p. 112, and the costs are not included in the overall costs of the recommended plan. Suggest this paragraph be removed or re-written.	No conflict present. It is recommended to enhance exisiting city and county stormwater management programs and axxociated budgets in the watershed without direct cost to the VLMP other than a part-time advocate.
Sutton	14	113		Black bullet 4 - incorporate large, regional phosphorus treatment facilities as appropriate in those plans	addressed
Ted Gathe/FOVL	9	113	bullet point 3	Doesn't Ecology's approval of this LMP form the basis for a sensitive water body declaration? Why do City and County need to approve as well?	City and County must make declaration as specified in the Stormwater Management Manual for Western Washington prepared by Ecology and Ecology approval of this plan helps support the local determination.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Amaia Smith	27	114	1	Adjust to treatment window needs to go through a formal process if it occurs outside the existing June 1 - Dec 31 window. I believe SEPA is required to adjust this window but only needs to be completed once. I think there are ongoing conversations about the treatment window for Vancouver Lake, sharing as an FYI	Addressed. The treatment window only applies to wildlife and not fish for alum and algaecide and unlikely for a need to treat before June 1.
Bob Chapman/FOVL	25	114	Beach Algaecide paragraphs	In the second sentence of first paragraph, it is stated this is an alternate to whole-lake alum dosing. It is not. It should be recommended on it's considerable potential benefit of minimizing feal bacteria as well as cyanotoxins.	Modified sentence to identify it as a potential lower cost and less effective alternative to alum.
Sutton/Olinger	35	114	3	Also, alum treatments last much longer than algaecides because they remove phosphorus from ~~settling out of~~ the water column, whereas …. ~~Thus, a~~At least two	addressed
Bob Chapman/FOVL	27	115	Monitoring and Reporting bullets	This secition is confusing because the 2nd paragraph refers to Lake 2 station, but the fourth bullet does not apply to that station. Emphasize that you are recommending a new continuous water water quality monitoring instrument near the beach. Consider recommending that an additinal sampling station be established in the area of the beach to collect information similar to that for stations 2. Lake closures predominantly effect swimming and rowing activitiues which only occur in this area of the. lake and it makes sense that water quality monitoring in this area is particularly important.	Clarified. Further considerations to be addressed in future phases.
Sutton/Olinger	36	116	last	A cost estimate is ~~then~~ presented.	addressed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Patty Boyden	9	116 and 122		The plans over reliance on chemicals to address HAB and noxious weeds is very concerning. The short and long-term impact to fish, wildlife and human health/community needs to be thoroughly understood. Some limited chemical treatment may be necessary but the plan make little reference to fish, wildlife and human health. The plan is overly focused on recreation vs fish, wildlife and human health. Some chemical treatment may be advantageous but should be minimal.	Added information to management alternatives about how herbicide treatments are not expected to impact aquatic life if applice according to permit requirements that are based on SEPA review.
Sutton/Olinger	37	117	2	a post-treatment survey in late summer to evaluate~~d~~ treatment effectiveness.	addressed
Sutton/Olinger	38	117	4	summer of 2022 found no curly leaf ~~plants~~ pondweed,	addressed
Sutton/Olinger	39	117	5	(e.g., May) in the first year of this plan. Those acres containing … (Galleon SC) in June,	addressed
Sutton/Olinger	40	118	1	top of page - will be performed over an average of 20 acres once every 3 years, for a total of seven treatments in a period of 20 years, at an estimated cost…	addressed
Sutton/Olinger	41	118	3	Two emergent weeds requiring control … observed in Vancouver Lake ~~that~~ include	addressed
Sutton/Olinger	42	119	4	Treatment effectiveness should be assessed ~~is~~ in subsequent early summer surveys.	addressed
Sutton/Olinger	43	120	2	Control of reed canarygrass … because control of Class C weeds ~~it~~ is not required by law	addressed
Amaia Smith	28	121	2	"Given the variety and extent….methods bs that they are introduced…" Not sure if this is a typo?	Yes typo. Addressed

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Amaia Smith	29	121	4	Out of curiosity, was there WDFW partnership with the referenced AIS process? I can reach out internally to see if there is training or other support our program can offer, but I'm not familiar with Whatcom County's AIS Program and how it was established.	I'm not sure how involved WDFW was in the example program, but WDFW partnership would benefit a Vancouver AIS plan greatly. Good comment that needs to be addressed in future phases.
Rollwagen-Bollens	26	121	2	First line of paragraph: replace "...bs that..." with "...by which..."	addressed
Sutton/Olinger	44	121	2	Given the variety … occupy, methods ~~bs that~~ by which they are introduced (e.g., ballast water, …	addressed
Amaia Smith	30	122	2	Pg 118 paragraph 5 mentions that emergent weed surveys should be performed in early growing season. To connect the two sections, maybe the language on pg 118-119 can be expanded to include how reported noxious weeds surveys will be incorporated into this monitoring process.	addressed
Kent Cash	15	123	2	The last bullet reads "Improve public understanding of who is responsible for lake management." I think this is a critical question that neither the state or local agencies, community agencies, TAG, nor the consultant have determined. This should be one of the first goals of the projet PRIOR to trying to explain to the public.	Good comment that needs to be better addressed in future phases.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Patty Boyden	10	123		The plan says a goal of stakeholder involvment plan is to shift public perception to see the lake as a clean and safe area. This is an unattainable/unrealistic goal. The lake is not clean (see water quality and trophic level discussion on page 4 and 18). The goal should be that the community has realistic expectations on what the lake can become. This goal distracts and therefore can derail realistic improvments.	Acknowledged - I'm hesitant to change this goal because this is what we heard from the engagement work that we did through this effort. I've added a caveat "as improvements are made" to capture that the ability to speak to the cleanliness and safety of the lake will be increased as the lake improves.

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sunrise O'Mahoney	5	123-131		Not entirely clear on the budget and scope for the public involvment sections. I think it was different in the TAG draft plan presentation. Basing my comments are primarily from page 131 primarily. $30,000 a year to do the level of outreach to the public is not enough to fulfill the proposed work. The Power Point had $10,000 each year but limited details on what that would cover. Moving forward outreach is a key piece of moving this forward. There is a general perception of the lake and process, as we all know, and this is not something that can be done with this amount. I run an environmental nonprofit and as a nonprofit our rates are typically lower than governmental rates. For us to run a full outreach campaign (here are some elements of this goal: create outreach plan, tabling, door to door, printed materials, social media, electronic communications with places like NextDoor and neighborhood associations) I would budget for at least $40,000/yr range. If, however, a nonprofit with extensive experience is not used and instead it goes through a municipality the amount would probably be higher. In the end I am very unclear by what the outreach proposal is. Once it is clearer, I may increase or decrease the amount. I understand this is an estimate but outreach when done well is a comprehensive plan that takes time to do.	Acknowledged during TAG meeting. Agree that this temporary value was underestimated. See updated values in revised document.
Amaia Smith	31	124	1	Management evaluation measure: Is the messaging clear in the beginning that this LMP is to provide the framework for the next step and that no final decision has been made? I think it is essential to make that clarification earlier in the document if it is not already.	addressed
Amaia Smith	32	124	2	"Future lake issued to be addressed": This bold title doesn't *quite* align with description. Maybe reword to additional stakeholder involvement and/or outline other issues that we have yet to explore?	Addressed - "Involve the public to identify future water quality improvements"
Ted Gathe/FOVL	10	125	bullet point 3	The State Operating Budget provides for and additional $320,000 for lake management planning over the next two years. This bullet point should be omitted or corrected.	Addressed

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Fry/Donehower	7	126	The Cowlitz Indian Tribe	"Currently, Rudy Salakory, Interim Natural Resource Director, has been engaged in the Technical Advisory Group (...)." Rudy Salakory previously participated in the TAG. He moved on from employment with the Cowlitz Indian Tribe in fall 2022. Dalton Fry is the current Interim Director of Natural Resources.	addressed
Fry/Donehower	8	126	The Cowlitz Indian Tribe	Please notify the Cowlitz Tribal Chairperson as well as the Tribe's Natural and Cultural Resources Departments of updates on this process/project. Natural Resources Department staff are participating in the TAG, but it will be important to involve Cultural Resources Department staff in assessing "cultural resource implications for proposed actions in the Vancouver Lake area" as this work advances; they will need to review the Area of Potential Effect and can offer guidance on Cultural Resources considerations. Dalton Fry and Christina Donehower can provide Tribal contact information and further guidance on communications.	Added in Cultural Resources Department, and included Chairperson and Cultural/Natural Resource Departments
Kent Cash	16	126	1	Suggestion on the final bullet. "People impacted by decisions should have a say in the decision-making process. ~~and since~~ Since Vancouver Lake is a public ~~good~~ resource, ~~public involvement~~ community input should be obtained for including the publics interests ~~seek to incorporate the interests of the public~~ into the management objectives."	addressed
Kent Cash	17	126	3	The third bullet under Principles. The report should not include specific individual names, people change jobs and move on, while the content of the report should live on. It would be simply easy to say, "It is important to continue the involvement of the Department of Natural Resources staff." This also may be confusing with respect to the State's DNR staff.	addressed
Patty Boyden	11	126	1st bullet	Sugggest not including people's names "Rudy Salakory..." Can become outdated. CIA has others on the TAG. i.e. better to use a title vs a name.	addressed

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Reviewer Name	Com- ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Patty Boyden	12	126		Key audiences needs to include a broader list of tribes or acknowldege need to reach out to other tribes.	Addressed and the language has been modified to be applicable to these other tribes - I'll note that navigating Tribal involvement requires sensitivity. We spoke with Cowlitz about this topic of reaching out to other Tribes, and while it is good practice to be inclusive, Cowlitz have the closest tie to this land in present day divisions of land, and may see that expanding the engagement may have some consequences
Rollwagen-Bollens	27	126	2	Bullet 3 Outreach should…: replace "…to engage…" with "…toward engaging…"; and remove "effort" at end of bullet - this is redundant.	addressed
Amaia Smith	33	130	4	first bullet point under Government/Port: I appreciate that you included this, but want to acknowledge that even if you engage with an employee who is not at the appropriate level, we can often connect you with the right policy person within our agency and act as a sort of unofficial liason	Addressed - "Staff across offices can be helpful to coordinate internally and liaise between different departments to ensure the right people are engaged."

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sutton/Olinger	45	130	3	Engage with the appropriate level~~,~~ of authority~~,~~ and expertise.	addressed
Sunrise O'Mahoney	6	131		I would like to see a list made of BIPOC organizations included in the plan	addressed
Amaia Smith	34	133		Funding analysis: disadvantages of each funding options are unclear for some proposed funding options. For example, the interlocal agreement is not clear on the disadvantage, which includes but is not limited to, identifying state funding to contribute towards this plan and/or supplemental legislative funding request. This funding source is not the preferred option by the TAG, but outlining the disadvantage for this proposal (and others) helps tell the story.	Good comment that is partially addressed here and needs further clarification in future phases.
Kent Cash	18	134	1	I am unable to discern the intent and purpose of the last sentatance of the paragraph which reads, "In practice this means that management decisions are at least one step removed from those most involved in management of the lake." Is this a good thing or a negative thing.	clarified
Amaia Smith	35	136	3	This is a clear outline of the disadvantages the potential funding sources have (relevant to above comment)	Acknowledged.
Ted Gathe/FOVL	11	137		References in the text to the tables don't match up.	Comment unclear. Clarified some text.
Ted Gathe/FOVL	12	137		It's not clear in the discussion of the Flood Control District Model where it's jurisdiction boundaries are- whether they include some but not all of the City of Vancouver and the County urban area. Maybe that will be expanded upon in the next verion of the LMP.	Addressed.
schnabel et al	21	138	Table 32	replace "Clark County Commissioners" with "Clark County Council"	(Table 29). Addressed.
Sutton/Olinger	46	139	2	… and adaptation framework by which the VLMP shall be ~~adapted~~ modified, 2) …	addressed
Sutton/Olinger	47	141	3	4th black bullet 1st open bullet - The nature of simplifying a complex ecological system by utilizing	addressed
Amaia Smith	36	142	3	is salmonid use synonymous with fish passage here? While salmonid use is a consideration, fish passage requirements are not exclusive to anadramous species	Addressed

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Amaia Smith	37	142		Future Adaptations: include bullet point on other natural processes to restore not identified within this plan?	Addressed in "Additional Lake Issues" section.
Rollwagen-Bollens	28	143		Please provide the DOI for all references that may be accessed this way (e.g. all WSU Vancouver publications)	Good idea but not our standard practice and will try to include them in the future.
Rollwagen-Bollens	29	147		Remove Rollwagen-Bollens et al 2022 from reference list	removed
Amaia Smith	38	Misc		To clarify the intent of this LMP, the messaging that this document is to serve as a guide for the next phase of the decision making process should be clear at the beginning of this document.	addressed
Amaia Smith	39	Misc		I recognize that herbicide treatments are often a requirement to manage infested waters, but I think there should be an emphasis on restoring natural processes as a sustainable solution for future iterations of this plan. I am interested in learning if restoration actions on Lake River could improve water quality. Per comment 24 above, if the restoration action improves floodplain connectivity and reduces flood risk, Floodplain by Design through the Dept of ECY should be looked into	addressed
Amaia Smith	*	Misc		Based on communication with wildlife area manager. Let me know if you need sources	Thank you.

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Bob Chapman/FOVL	28	Misc	General Comment	Lake River Water Quality. It is unfortunate that water quality in Lake River was not extracted and presented, apparently being outside the scope and budget for this project. It is my understanding that both the hydraulic and water quality models included Lake River. With the exception of the Dam alternative, it seems reasonable to assume that any of the alternatives that improved Vancouver Lake would to some degree improve water quality in Lake River. In the case of the Dam alternative, the impacts on Lake River flows to and from the Columbia, and the water quality impacts, are not easy to visualize, at least not for me. WQ could be better or worse. How much calendar time, and what would be the cost of extracting the water qualiy data for the dam and the enlarged flushing channel alternative?	addressed in Hydrodynamic and Water Quality Modeling section
Bob Chapman/FOVL	29	Misc	General Comment	The modeling was based on available data from 2011 and 2012. Some people believe that the water quality of the Columbia River has declined since then, particularly with respect to nutrient content. Is relevant recent Columbia River water quality data (especially temperature and phosphorus data available? If so, was it reviewed and compared to the 2011/12 data?	Columbia River water quality was not considered in the model but see Rollwagen-Bollens (2022; linked here) for recent (2018) data. Direct nutrient comparisons are difficult due to low sample sizes for each nutrient type at each time point.
Harvey L Claussen, PE	1	Misc		While the technology findings need adjustment, many necessary new management ideas are introduced.	acknowledged
Harvey L Claussen, PE	1.1	Misc		The order of magnitude of the capital budget should be adequate to manage tha lake successfully.	acknowledged
Harvey L Claussen, PE	1.2	Misc		Establishing an operating budget is an excellent plan.	acknowledged
Harvey L Claussen, PE	1.3	Misc		The recommendation that a lake management team be put in place is long overdue.	agreed

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Harvey L Claussen, PE	2	Misc		The starting premise that Vancouver Lake will be eutrophic forever condemns the rest of this work to failure.	disagree, eutrophic lakes are sucessfully managed to reduce HABs
Harvey L Claussen, PE	2.1	Misc		The very goal of successful lake management should be to prevent eutrophication.	good comment that should be addressed in the future with respect to prevent increased watershed nutrient loading
Harvey L Claussen, PE	2.2	Misc		Selecting lake management criteria that assure eutrophication creates a future of mediocrity.	Proposed criteria target reducing trophic state condiions which in essence woutl reduce eutrophication
Harvey L Claussen, PE	3	Misc		Isolating each management technique from all of the others eliminates virtually any chance of success.	disagree but future adaptations and modeling should consider multiple techniques together
Harvey L Claussen, PE	3.1	Misc		Treatment alone is likely to be a total failure unless the tidal flows are at least temporarily halted with a dam	modeling did not indicate that
Harvey L Claussen, PE	3.2	Misc		Capture and hold (dam) technology is greatly enhanced by treatment upon capture.	acknowledged
Harvey L Claussen, PE	3.3	Misc		Capture and hold (dam) technology is also enhanced by introducing a reliable flow of clean(ed) water.	acknowledged
Harvey L Claussen, PE	3.4	Misc		Pumping through the existing flushing tubes should provide a reliable flow of water without an open channel.	possible alterantive worth considering
Harvey L Claussen, PE	3.5	Misc		Increasing Columbia River water flow through the lake would require treatment to prevent eutrophication.	modeling did not indicate that
Harvey L Claussen, PE	3.6	Misc		Floating wetlands are difficult to culture, obstruct navigation and quickly root to the bottom in shallow lakes	acknowledged

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Harvey L Claussen, PE	3.7	Misc		Any design should add depth to minimize summer temperatures and enhance deep keel sailing.	acknowledged
Harvey L Claussen, PE	4	Misc		The stated technique of starting with a 2D model and jury-rigging it into a 3D model invites flaws.	Good comment that needs to be addressed in future phases.
Harvey L Claussen, PE	4.1	Misc		An expert in 3D modeling should be engaged to carefully double check any and all findings.	
Philip Parshley	2	Misc		One short-fall of the current evaluations is it seems each potential action was considered and modeled in isolation, but there was little effort to evaluation and/or model combinations of some of the potential actions; which I think is more likely than not how things may unfold going forward. I can see on obvious example: improvements in the flushing channel combined with a flow control structure might well show significant impact on the ability to manage the hydraulics in the lake, significantly more control than either action on its own. I realize Herrera had limited time and resources, but I think this approach would in the long run result in a better plan for the lake.	acknowledged in Modeling section
Philip Parshley	3	Misc		Much of the discussion around water quality includes references to "increased flow" thru the lake – but that phrase is insufficient and mis-leading, as it may not be necessary or even advisable to have constant flow all the time; but more likely increased flow may be required at different periods of the year, but not necessarily for all 365 days.	Good comment that needs to be addressed in future phases.

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Philip Parshley	4	Misc		The stated rationale for a significant expansion of the flushing channel into the lake is to provide more flow, and specifically push back against Lake River, and the modeling does indicate this may work. One period where the lake likely needs flow the most would be during the summer months when both the Columbia River and the lake are currently at their lowest levels. Perhaps an alternative might be the addition of hydraulic pumps into the existing culverts which might provide sufficient amounts of water into the lake during the periods its needed, but with a much lower capital cost compared to the expense of a significant change to the existing channel and culverts. Solar panels on the North side of the channel would likely offset the required annual power to run the pumps during the periods when more water from the Columbia is needed.	Good comment that needs to be addressed in future phases.
Randy Mueller, CEO, Port of Ridgefield	1	Misc	Misc	The Port of Ridgefield appreciates the work that has been done on this project to date. There is still additional work to be done before a true plan for the management of the Vancouver Lake/Lake River watershed can be developed. Most notably, the data collected and modeled does not sufficiently examine impacts to Lake River and the Ridgefield Waterfront. Any future work must examine impacts to the entire watershed and not just the lake body.	acknowledged in Modeling section
Rollwagen-Bollens	Misc	Misc	Misc	Overall I think the report is a good description of the work you've done, and the modeling results. I tend to agree that expanding the flushing channel, combined with phosphorus removal treatment (NOT algaecides), is the best way to go. I'd prefer not to see a dam across the outlet to Lake River for a lot of reasons.	acknowledged
schnabel et al	22	Misc	Misc	Clean Water did not review for typo's, word-smithing, etc. However, we did note the need for both prior to final draft.	acknowledged
schnabel et al	23	Misc	Misc	The floating wetlands are an intriguing idea and it is disappointing to see this method did not perform as well in the model at a whole-lake scale. However, could smaller scale installations near stream inflows (BBC, Chicken Creek, storm outfalls along Lakeshore, etc) provide benefit?	acknowledged and Lake River is a particularly good location for them

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
schnabel et al	24	Misc	Misc	Staff opinions reflected something that would likely be a hurdle with the public as well, namely: if the flushing channel never worked, why spend more money on it? Perhaps additional explanation tying the new proposal back to why the original channel underperformed would be helpful.	addressed in ES and HAB management plan sections.
schnabel et al	25	Misc	Misc	in general, a multi-pronged approach such as the proposed plan seems like the best path forward. The plan recognizes there is no single silver bullet and proposes a range of activities including physical, chemical, and watershed based.	acknowledged. Thanks!
schnabel et al	26	Misc	Misc	Need to reflect more of the true costs throughout the doc, specifically listing the proposed costs to agencies in the executive summary, etc.	Good comment that needs to be addressed in future phases.
schnabel et al	27	Misc	Misc	the overall plan is quite ambitious, which is good. However, more thought needs to be given to whether it is realistic, and to true up the cost estimates -- they seem universally low.	acknowledged. Some cost estimates have been increased using updated information
schnabel et al	28	Misc	Misc	the cost-effectiveness section would benefit from further expansion and development	acknowledged
schnabel et al	29	Misc	Misc	the stormwater costs assigned to achieve a 30% P reduction are much too low -- overall it would be nice if the plan contemplated a larger investment in watershed practices to accompany the in-lake actions	Good comment that needs to be addressed in future phases.
schnabel et al	30	Misc	Misc	were the P loading data from county's High-Density-Residential site in Lakeshore accounted for in the model and projections? We saw 4.7 lbs/year of P loading from 256 acres in our study.	Yes the model included the lakeshore basin and it would be good to compare the model loadings to study loadings

Table D1. Technical Advisory Group Comments and Responses on the Draft Vancouver Lake Managment Plan.

Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
schnabel et al	31	Misc	Misc	has the timing of flow peaks and minimums through the channel been accounted for in the model and recommendations? Is there enough flow at low river levels during summer to achieve the desired flushing rates?	Added flow charts to the text from model that address this but more detailed analysis is warrented
schnabel et al	32	Misc	Misc	Is a partition still being considered for the swimming beach? Curtain, bubble-barrier, etc.	added that it could be added and needs more evaluation

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sunrise O'Mahoney	1	Misc	Misc	I am seriously concerned by the lack of involvement with the BIPOC community. There is no language in the plan that addresses this. I know I was told it is too late now, but think it is imperative to do outreach with the BIPOC community about the draft and give time for them to respond. I believe it is too late now but want it on the record saying that this should have happened and unfortunately it did not. A large demographic that utilizes the beach are non-English speakers and Hispanic families. Yet, in the process there was no engagement with the BIPOC (Hispanic) community. The TAG ended up being what it has historically been-a non-diverse group of people/organizations. I see limited wording on pg. 128 where the NA's are mentioned but this is not looking at the BIPOC and I am still not seeing any direct wording about reaching out to the BIPOC and Hispanic communities.	Acknowledged and Addressed - The NA's were the primary means to engage with resident hispanic communities, and you're right more needed to be done to engage BIPOC community. With the limited budget we had for developing this plan we did not have adequate resources to do best practices. I am hopeful that the implementation will include more substantial resources for reaching BIPOC communities. I've added in more direct mention of BIPOC, frontline, and EJ communties.

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Reviewer Name	Com- ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sunrise O'Mahoney	2	Misc	Misc	Connected to the above comment. All the information given to the public needs to be in other languages. One grant from Ecology required that we translate any materials into the languages used over a certain percentage. This would be good at a minimum. I know the comment when I asked about this before was the money was not put into the contract with Herrera and so there is no additional funding now, but it is ok the general public (non-English speakers) can always comment on the final plan. As I pointed out this is leaving a large demographic in our community out of the draft stage, which is not acceptable. Who is the managing entity that contracted with Herrera?	See emphasis on translation in the relevant audience sections. The public survey was available in Spanish and no one completed the survey in Spanish. We asked about any accessibility needs during registration for the first Public Meeting and were prepared to provide Spanish interpretation, but no one requested this service. More needs to be done to increase involvement of BIPOC groups. Translation and interpretation is a cost that wasn't originally budgeted for with Kearns & West support.
Sunrise O'Mahoney	3	Misc	Misc	Climate change impacts and studies in relation to Vancouver Lake's present and future needs to be incorporated	addressed

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Reviewer Name	Com-ment No.	Page No.	Paragraph No.	Reviewer Comment	Herrera Response
Sunrise O'Mahoney	4	Misc	Misc	Environmental Justice (EJ) lens needs to be included in the plan and is not. When looking for future funding this will be a requirement for funding and by leaving it out it leaves the plan not complete enough to use moving forward.	Acknowledged - I added in a little language around EJ but that certainly was not the predominant lens of the plan