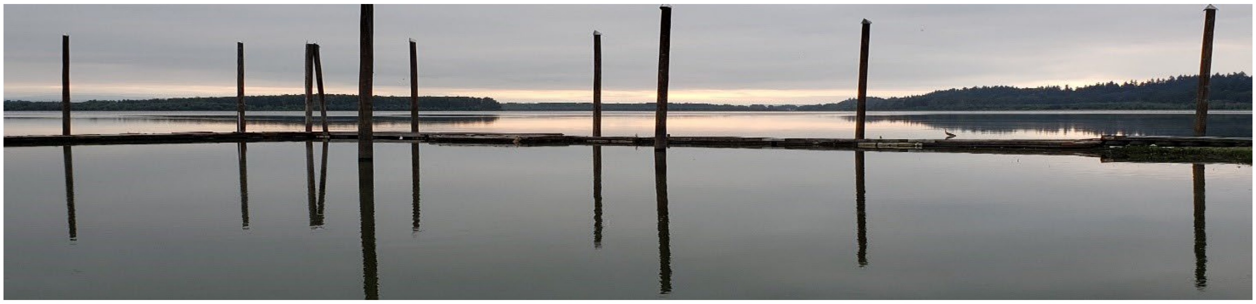
DRAFT
WORK PLAN

VANCOUVER LAKE
MANAGEMENT PLAN PROJECT



Prepared for
Clark County

Prepared by
Herrera Environmental Consultants, Inc.

HERRERA

In Association with
LimnoTech
Kearns & West
AquaTechnex

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VANCOUVER LAKE
MANAGEMENT PLAN PROJECT

Prepared for
Clark County
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DRAFT
July 29, 2022

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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 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 wildlife. Vancouver Lake falls under several governmental jurisdictions. Washington State Department of Ecology (Ecology) and Department of Natural Resources (DNR) share regulatory authority over the water and lakebed, respectively, while the lakeshore is comprised of shoreline primarily managed by Clark County under their Legacy Lands and Parks departments, with sections along the south and southwest owned by Washington State Fish and Wildlife, Columbia Land Trust, Port of Vancouver, and City of Vancouver. Several privately owned parcels are distributed along the east and northeast shoreline of the lake.

Vancouver Lake is a category five 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. It has exhibited known water quality issues, including but not limited to high water temperatures and turbidity, low dissolved oxygen, eutrophication, fecal bacteria contamination, increasingly frequent harmful algal blooms (HABs) comprised of toxin-producing algae called cyanobacteria, large infestations of aquatic invasive (noxious) weeds, and reduced summer lake depth.

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, the LMP will build on existing work and involve a variety of stakeholders to outline a management strategy and address plan development, entity responsibilities, timelines, and potential funding sources for plan implementation.

This LMP project includes development of a Work Plan for Phase 1 and preparation of the LMP for Phase 2. The goal of this Work Plan is to inform and provide a framework for the development of the Vancouver Lake Management Plan in project Phase 2. As such, this Work Plan first describes the project team, approach, and phased schedule. A summary of existing data sources and notable findings related to lake characteristics, water quality, watershed information, ecological function, and human uses will be provided as background information to demonstrate the richness of existing knowledge related to Vancouver Lake and to inform the LMP development process.

Using this information and stakeholder input, this Work Plan establishes a preliminary problem statement and outlines the goals and objectives for lake management to be further refined in Phase 2. The LMP will address problems caused by HABs and aquatic noxious weeds. Preliminary in-lake and watershed management techniques to reduce HABs are briefly evaluated in this Work Plan. Key advantages and disadvantages for each technique are considered for developing a qualitative feasibility matrix, which assesses the relative feasibility of the technique using three levels (high, medium, and low) of effectiveness, cost, and impact. The most feasible techniques selected in this Work Plan will be further evaluated and compared to identify up to six promising management techniques of varying cost and potential effectiveness for further analysis in Phase 2.

This Work Plan describes the strategy for modeling the effectiveness of potential management techniques using existing data, and a strategy for stakeholder involvement to ensure that agencies and the public support the management goals and techniques, are educated about our plan, and are otherwise engaged and invested in the success of the LMP. Overall, the Work Plan is intended to help engage stakeholders, inform modeling for the development of the LMP, and provide a sound, science-based basis for Vancouver Lake management decision-making.

This Work Plan incorporates comments on the draft Work Plan from a Technical Advisory Group. An important comment is to clearly define expectations and limitations of the LMP. The LMP will establish an adaptive management framework for controlling toxic algae and invasive plants impacting uses of Vancouver Lake based on a cost-effectiveness analysis of management techniques for meeting establish objectives. The LMP may require additional time and funds to further analyze management techniques based on available funding and stakeholder input prior implementation of the LMP. While it is expected that the LMP will also identify other issues of concern to lake users to be addressed in the future, it is beyond the scope of this project to prioritize or evaluate cost-effectiveness of other issues impacting lake users that are not related to toxic algae and invasive plants.

PROJECT DESCRIPTION

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", which resulted in the Vancouver Lake Management Plan project described herein. Funded by the appropriation, this project will accomplish the goals set by the state and consequent County expectations to design the Plan development process, and will also develop an adaptive management plan for immediate action with a structure for future development of supplemental and long-term management scenarios. Phase 1 of the project represents the project start-up period with initial Work Plan development for the design and development of the Lake Management Plan, to be completed by June 30, 2022. Phase 2 of the project will finalize and implement the Work Plan to develop the Lake Management Plan, to be completed by June 30, 2023 fiscal year. The project team, approach, and schedule are described in more detail below.

PROJECT TEAM

The consultant project team for the Vancouver Lake Management Plan project is described below, with a visualization of organization structure and table of contact information provided in Figure 1 and Table 1, respectively.

Herrera Environmental Consultants ("Herrera"), as the primary consultant firm hired by Clark County, leads the project team providing project management services, technical expertise, and limnological knowledge. Herrera is responsible for general project progress, regular communication with the client and key stakeholders, background review, and preparing the LMP and other deliverables. The Herrera team consists of Rob Zisette as project manager and lead limnologist, Joy Michaud as principal in charge and funding analysis lead, Katie Sweeney as project limnologist, Eliza Spear as aquatic plant management support, and Rebecca Dugopolski, PE as engineering support. This core Herrera team is supported by additional subconsultants as follows (Figure 1):

- LimnoTech is a water science and environmental engineering consulting firm and, guided by Herrera, will provide modeling services to evaluate lake dynamics and the efficacy of various management scenarios in achieving project objectives. The LimnoTech team is led by Steve Skripnik, PE, and Dan Rucinski, who will develop the lake water quality model and provide engineering support.

- AquaTechnex, an innovative company specializing in the development and implementation of algal bloom and invasive plant mitigation technologies will be represented on the project team by Terry McNabb, who evaluate various cyanobacteria and aquatic plant management techniques alongside Herrera scientists and provide costing information for plan implementation.
- Samantha Meysohn from Kearns & West, a facilitation, mediation, and public engagement firm, is responsible for facilitating stakeholder meetings and public engagement throughout the project.

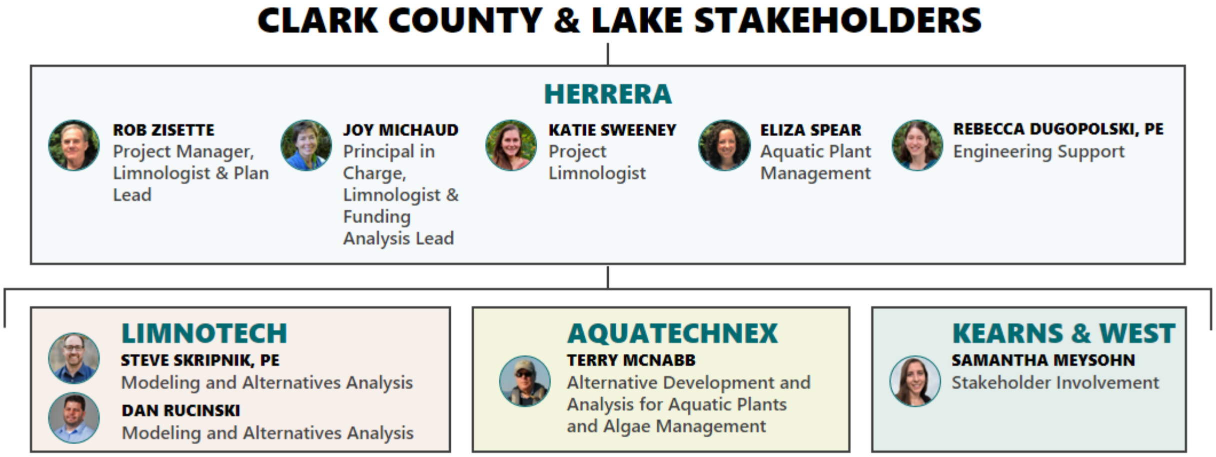


Figure 1. Project Team Key Staff Organization and Roles.

Table 1. Project Team Key Staff Contact Information.

Lindsey Hueer (Clark County)	360-605-6366	lindsey.hueer@clark.wa.gov
Rob Zisette (Herrera)	206-787-8262	rzisette@herrerainc.com
Joy Michaud (Herrera)	360-292-1221	jmichaud@herrerainc.com
Katie Sweeney (Herrera)	971-200-8877	ksweeney@herrerainc.com
Eliza Spear (Herrera)	206-787-8269	espear@herrerainc.com
Rebecca Dugopolski, PE (Herrera)	206-787-8261	rdugopolski@herrerainc.com
Steve Skripnik, PE (LimnoTech)	213-454-0390	sskripnik@limno.com
Dan Rucinski (LimnoTech)	734-821-3149	drucinski@limno.com
Terry McNabb (AquaTechnex)	855-245-5253	tmcnabb@aquatechnex.com
Samantha Meysohn (Kearns & West)	360-536-3660	smeysohn@kearnswest.com

PROJECT APPROACH

The project is divided into two main phases, where Phase 1 is 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 (present document). Phase 2 is focused on developing the Lake Management Plan by gathering input from the public and key stakeholders, analyzing historical data, creating a lake water quality model, defining potential management scenarios, and evaluating the effectiveness of those methods. Descriptions of each task under each phase are described below. A project schedule is provided in Table 2.

Phase 1–Project Work Plan

Task 1–Background Review

Herrera will perform a thorough review of previous research conducted and other documentation related to lake and watershed characteristics and past management efforts, to be used in developing the LMP and adaptive management decisions. Information from the following key sources will be reviewed and summarized in the *Background Information* section of the present document:

- Vancouver Lake Watershed Partnership (VLWP) technical foundation, research plan, algae control, management objectives, and funding strategy reports (2008-2015)
- United States Geological Survey (USGS) water and nutrient budgets for Vancouver Lake (Sheibley et al. 2014)
- Washington State University (WSU) studies of plankton and nutrient dynamics in Vancouver Lake (2007-2022)
- Vancouver Lake hydraulics and management evaluations (Jacobs 2022)
- Vancouver Lake cyanotoxin and bacteria monitoring data from Clark County Public Health (CCPH) and the Ecology's Washington State Toxic Algae Program.

Task 2–Work Plan

The present document as the Work Plan has been prepared to provide background information and strategies to inform and act as a framework for the development of the LMP.

Task 3–Stakeholder Involvement Phase 1

Herrera and Kearns & West are responsible for engaging key stakeholders and a public audience throughout the project. For Phase 1, stakeholder involvement entailed participation from a technical advisory group (TAG) for the identification of the Problem Statement, Goals and

Objectives, and initial management methods for further evaluation, as described in the Work Plan sections below.

Task 4–Project Management Phase 1 and 2

Herrera will provide contract and project management services to the County throughout Phase 1 and 2, including coordinating the technical, policy, public outreach, and administrative aspects of the LMP. Herrera will prepare monthly progress reports detailing task budgets, work completed, work pending, and project issues and associated corrective actions, and facilitate regular project update meetings virtually with the Technical Advisory Group of key stakeholders to present the project work and gather feedback.

Phase 2–Lake Management Plan

Task 5–Water Quality Modeling

LimnoTech will develop and run the water quality model for predicting effects of the priority cyanobacteria management techniques specified here in the Work Plan. The initial model specifications will be based on input from the advisory group of key stakeholders but is anticipated to be performed again in Phase 2 following the review of the initial model results and further development of alternative scenarios from public feedback. See the *Modeling Plan* section below for a detailed description.

Task 6–Lake Management Plan

Using water quality modeling results, additional research, and stakeholder feedback, up to three cyanobacteria management scenarios and three aquatic plant management scenarios will be developed to meet the project goals and objectives outlined in the Work Plan below. Planning level costs and relative uncertainty in effectiveness and costs will be developed for each scenario based on experience and literature. Funding strategies for the implementation of management scenarios will be explored as a key piece of the LMP, detailing respective advantages and constraints. A preliminary LMP will be prepared for review by the TAG and a draft LMP for presentation to the public; a final LMP will be developed in response to public input.

Task 7–Stakeholder Involvement 2

For Phase 2, Herrera will engage the TAG every second month virtually to describe project updates and invite input. Kearns & West will facilitate two public meetings aimed to educate public stakeholders about the project and garner input, as critical steps for decision-making related to the initial management scenarios modeled and to the production of the final LMP.

PROJECT SCHEDULE

The project schedule is summarized in Table 2. Project Phase 1 is set to end on June 30, 2022, with the draft Work Plan developed by that date. Phase 2 commences on July 1, 2022 and comprises the rest of the project work, with the final LMP to be delivered to Clark County by June 30, 2023.

Table 2. Project Schedule.

Task	Activity	2022										2023					
			5	**6**		**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**
1	Background Review	Phase 1	🟩	🟩	Phase 2												
2	Work Plan		🟩	**D**		🟩	**F**										
3	Stakeholder Involvement 1		🧑‍🏫	🧑‍🏫		🟩											
4	Project Management 1 and 2		🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
5	Water Quality Modeling							🟩	🟩			🟩	🟩				
6	Lake Management Plan							🟩	🟩	🟩	🟩	🟩	🟩	**D1**	**D2**		**F**
7	Stakeholder Involvement 2					👥	🧑‍🏫	🟩	🧑‍🏫	🟩	🧑‍🏫	🟩	🧑‍🏫	🟩	🧑‍🏫	👥	🧑‍🏫

D = draft deliverable; F = final deliverable.

🧑‍🏫 = TAG meeting; 👥 = public stakeholder meeting.

TECHNICAL ADVISORY GROUP

TAG members include, but are not limited to, representatives from: Clark County, the City of Vancouver, Washington Department of Ecology (Ecology), Washington Department of Fish and Wildlife (WDFW), Washington Department of Natural Resources (DNR), Port of Vancouver, Cowlitz Indian Tribe, Friends of Vancouver Lake (FOVL), Vancouver Lake Sailing Club, Vancouver Lake Rowing Club, and Washington State University (WSU). In addition, a representative from the Port of Ridgefield recently joined the TAG because they expressed an interest. Attempts to include a representative from United States Army Corps of Engineers (USACE) were made but unsuccessful. TAG member information is presented in Table 3.

Phase 2 TAG meetings will occur on the fourth Thursday every other month from 12 to 2 pm (Pacific). Tentative topics to be discussed during each meeting are outlined below, acknowledging that topics and dates are flexible to suit project needs:

1. **August 18, 2022–**Stakeholder Involvement with Samantha Meysohn/ Modeling Part 1
2. **October 27, 2022–**Plan Funding
3. **December 15, 2022–**Modeling Part 2
4. **February 23, 2023–**Lake Management Alternatives/Plan Funding
5. **April 27, 2023–**Draft LMP

6. **June 22, 2023–**Final LMP, Project Debrief, and Next Steps

Table 3. Technical Advisory Group.

Name	Organization	Title
Rob Zisette	Herrera Environmental Consultants	Senior Limnologist
Katie Sweeney	Herrera Environmental Consultants	Project Limnologist
Lindsey Hueer	Clark County, County Manager's Office	Senior Policy Analyst
Alyssa Payne	Clark County, Public Health	Environmental Health Specialist
Jeff Schnabel	Clark County, Dept. Public Works, Clean Water	Stormwater Infrastructure Manager
Dorie Sutton	City of Vancouver, Surface Water Management	Environmental Scientist, Water Quality Monitoring Program
Lizbeth Seebacher	WA Dept. of Ecology, Water Quality Program	Wetland & Aquatic Ecologist
Amaia Smith	WA Dept. of Fish and Wildlife	Clark County Habitat Biologist
James Huinker	WA Dept. of Natural Resources, Aquatic Resources Division	Rivers District, Habitat Stewardship Specialist
Kent Cash	Port of Vancouver	Chief Operations Officer (flushing channel engineer)
Rudy Salakory	Cowlitz Indian Tribe, Natural Resources Department	Habitat Restoration & Conservation Program Manager, Interim Director
Ken Imse	Friends of Vancouver Lake	Board Chairman
Philip Parshley	Vancouver Lake Sailing Club	Race Captain
Gretchen Rollwagen-Bollens	Washington State University	Associate Professor of Biology and Environmental Sciences, Plankton Ecologist
Harvey Claussen	Claussen Engineering, Inc.	Resident expert, sailing club member, former Partnership member, PE Chemical Engineer
Conor Bullis	Vancouver Lake Rowing Club	Head Coach

Comments from Kickoff Meeting

Key project concerns and suggestions identified by the TAG at the kickoff meeting on May 26, 2022 have been addressed as applicable in this Work Plan and include the following:

- The management strategy identified by this project must be sustainable, science-based, socially equitable, well-informed by public input, account for agency constraints, and adaptable beyond the next five years.
- Water quality modeling will largely inform the cyanobacteria management scenarios explored in the LMP and given its importance should occur as soon as feasible to provide time to educate the public and stakeholders about the lake and management opportunities.
- The problem statement and management scenarios explored need to include an aspect of seasonality, since impacts to water quality and beneficial lake uses are strongest and/or most abundant during the summer season.
- In wording the project objectives for the reduction of algal blooms, language related to beach notifications (i.e., “advisory”, “closure”, or “warning”) should be avoided in favor of numeric objectives, such as those outlining a maximum frequency of occurrence or toxin concentration threshold, but also should be clearly understood by public audiences.
- Distinct objectives should be determined for the reduction of each type of algal bloom, toxic and nuisance (non-toxic).
- An objective for the prevention of new noxious aquatic weed infestations is needed.
- Objectives for reducing noxious aquatic weeds should consider all emergent, floating leaved, and submerged species, but will not address control of nuisance native plants that may develop in the future.
- Goals to reduce harmful algal blooms and aquatic noxious weeds may compete in that they are each associated with separate ends of a water quality continuum (i.e., clear water state vs. turbid water state); the LMP will outline the balance we seek to achieve, determined in part by the results of the water quality model.
- Public safety and preservation of recreational opportunities must be ensured when considering management options (e.g., drowning, entrapment, or navigational access to the lake from tributaries and side-channels).
- Public outreach and education will be critical in identifying beneficial lake uses, primary lake use areas and access points, major concerns of lake users, and problematic lake management methods to consider in the development of the LMP.

Comments from Draft Work Plan Review

Key project concerns and suggestions obtained by TAG members and the Client during review of the draft Work Plan include:

- Gary Medvigy, Clark County District 4 Councilor, commented that the Draft Work Plan "is perfect in many ways and a great start… I believe we have just the right mix with [Herrera Environmental Consultants]."
- Patty Boyden with the Port of Vancouver raised the questions: Is there an option to allow the lake to proceed through a natural process to support fish and wildlife ecological functions? If the lake management goal was to improve fish and wildlife habitat and recreation, would we have a different list of options? Is this a Lake Management Plan (all inclusive, e.g., ecological, economical, recreation, etc.) or an invasive weed/blue-green algae management plan? The LMP will focus on HAB and invasive weed management for both recreation and habitat benefits, and potential habitat impacts from management techniques will be evaluated. The LMP also may identify other needs for managing fish and wildlife habitat to be addressed in the future as interest and funding allows.
- Jeff Schnabel with Clark County Public Works and Patty Boyden with the Port of Vancouver both raised the point that creating and communicating realistic expectations for what the LMP may be able to accomplish at a given price point and how successful management options might will be important for public and other stakeholders' understanding. Project and LMP expectations have been added as a section in this Work Plan.
- Patty Boyden with the Port of Vancouver noted that it will be important for any in-water work to consult with the National Marine Fisheries Service (NMFS). It is anticipated to the extent possible that the TAG representative from WDFW (Amaia Smith) will gather input from NMFS on concerns about in-water management techniques or needs for further analysis to be addressed in the LMP. The LMP will not include an Endangered Species Act consultation with NMFS or preparation of a Biological Assessment of a technique.
- Patty Boyden with the Port of Vancouver also commented that management techniques should be evaluated for potential climate impacts (e.g., from greenhouse gas emissions) from both construction and operation because the public will expect the plan to address climate considerations. The LMP will provide a qualitative assessment of management techniques for climate impacts and recommend quantitative analysis in the future if desired based on public input on the draft LMP.
- Jeff Schnabel with Clark County Public Works noted that the WDFW boat launch on the south shore of Vancouver Lake is an unimproved launch, which is not a functioning ramp for most trailered watercraft and primarily serves as a launch site for paddle sports. The Felida Moorage boat launch in Lake River is the nearest launch open to the public and capable of launching motorized watercraft. FOVL and VLSC also noted that a lack of boater access along the shores of Vancouver Lake is an issue, and WDFW assessments

note that improving trailered boat launches would be beneficial for anglers and for managing fish populations.

- Patty Boyden with the Port of Vancouver noted that the regulation of water level in the Columbia River related to dam operation will be an important consideration for project success. Columbia River hydraulic and water quality factors will be assessed during modeling and included as needed in subsequent management method evaluations.

- Jeff Schnabel with Clark County Public Works noted that the County's Clean Water division conducts qPCR monitoring as part of their microbial source tracking efforts and may have capacity for limited testing to better characterize bacteria sources at the swim beach. Gary Medvigy, Clark County Councilor, also inquired about DNA testing to understand point sources within the watershed. This would be a beneficial partnership and process for understanding how to reduce user impacts by *E. coli* in future implementation of the LMP.

- Alyssa Payne with Clark County Public Health provided important information about their swim beach sampling protocols and monitoring data for *E. coli* and toxins. Alyssa also clarified criteria used to determine lake advisories, which have been incorporated into the Project Objectives.

- Amaia Smith with WDFW provided important information about the Shillapoo Wildlife Area, which surrounds Vancouver Lake and encompasses a portion of its shoreline, as context for Vancouver Lake's importance to fish and wildlife and public use.

- Both FOVL and VLSC commented that they recommend broader and more inclusive goals as measures of success, with cyanobacteria and invasive weed control as just two factors. FOVL and VLSC further provided a list of recommended goals, which have been incorporated into the *Management Goals* section below.

- Jeff Schnabel with Clark County Public Works commented that the current focus on harmful algae blooms and invasive aquatic weeds is the correct course of action, and supported the idea to recognize other management issues without directly including them in the current effort.

- Patty Boyden with the Port of Vancouver and Alyssa Payne with Clark County Public Health each noted that some management objectives may act counter to and impact other objectives (e.g., using a dam to improve lake water quality could impact habitat or reduce water quality in Lake River). Potential secondary and unintended impacts from management techniques will be evaluated and described in the LMP.

- Patty Boyden with the Port of Vancouver, Alyssa Payne with Clark County Public Health, and Amaia Smith with WDFW each commented on the importance of design specifications for the following potential management options: a dam on Lake River, a flap gate in the Flushing Channel, or a water barrier at the swim beach. Designs must allow for fish and boat passage, and include specifications for boater safety (e.g., to reduce risk of drowning and entrapment). Specifications to potentially include a temporal component to minimize fish passage impacts, and all related permitting requirements should be further discussed. Modeling results will elucidate whether these methods will improve water quality and achieve the objectives without unforeseen negative impacts to fish or boat passage. If assessed as a feasible management method, conceptual designs will be developed in the LMP to minimize impacts. It is anticipated that project design, construction, and operations would be further evaluated with respect to impacts and permitting requirements during LMP implementation.

- Jeff Schnabel and Alyssa Payne with Clark County commented that the use of algae bloom scum area as a project criterion for effectiveness evaluation could be difficult to employ in the field and is not necessarily indicative of the harmful conditions impacting users since algae scums can be pushed by wind and accumulate in a limited area, potentially causing high concentrations of algae and toxins. Since toxicity of algae cannot be assessed effectively in the field, both toxic and non-toxic nuisance blooms affect lake users in the same way, so objectives must account for that limitation.
- Jeff Schnabel with Clark County Public Works noted that management objectives for emergent noxious plant species should be based on an area basis similar to the objectives for submersed aquatic species. In a related comment, Clark County Councilor Gary Medvigy noted Clark County's responsibility for shoreline management and inquired about expanding the program's role.
- Amaia Smith with WDFW noted generally that any management actions chosen will need to meet the requirements of all permitting agencies, since this Work Plan does not include a comprehensive discussion of permitting requirements nor considerations which may lead to modifications to the management methods discussed.
- Amaia Smith with WDFW also provided information about the protection of riparian areas for non-point pollutant removal and management. Alyssa Payne with Clark County Public Health similarly noted that stream and wetland restoration options could provide some level of phosphorus loading reduction without the chemical or maintenance costs related to phosphorus inactivation methods, and provide benefit towards achieving other goals (e.g., habitat restoration). Alyssa recommended including an explanation for why this management option may be preferred by stakeholders, in lieu of modeling its impacts on Vancouver Lake.
- Gary Medvigy, Clark County District 4 Councilor, commented inquiring about grant opportunities to jointly target the lake, watershed, and salmon recovery, noting the need for the City and County to work together to ensure uniform standards/efforts related to stormwater and septic/sewer management. Councilor Medvigy also commented that the Flushing Channel represents an important opportunity to correct the lake flow and further discussions regarding this potential management method should be emphasized in Phase 2.

- Jeff Schnabel with Clark County Public Works clarified that if an LMP established the need for Clark County and City of Vancouver jurisdictions to require phosphorus treatment for new development within the watershed, this would necessitate a policy decision for the County Council. Lacamas Creek is currently the only watershed in the County with a phosphorus treatment requirement.

- Clark County Councilor Gary Medvigy requested additional discussion of the dredging management option, despite the estimated high cost of implementation. Jeff Schnabel with Clark County Public Works also commented that dredging could be an effective technique for certain small-scale management objectives outside the scope of the current project (e.g., creating deeper holes for fish habitat, or excavation for boat ramp improvements). Patty Boyden with the Port of Vancouver agreed that dredging is expensive but likely easier to permit than a dam due to impacts to endangered species.

- Alyssa Payne with Clark County Public Health clarified the current funding sources and agreements for the swim beach monitoring program, and the need for additional, currently unavailable funding if increased monitoring effort is desired.

- Alyssa Payne with Clark County Public Health commented about the limitations of using historic monitoring and modeling data for current modeling purposes, citing concerns about the accuracy of historical data in representing current lake conditions. Alyssa recommended explaining why this project will not collect new data.

- Amaia Smith with WDFW commented to notify the team that there may be restoration funding opportunities available for projects which directly benefit fish passage and fish habitat, attainable for this project provided certain management solutions are chosen (e.g., increasing the size of the Flushing Channel to improve flow).

- Jeff Schnabel with Clark County Public Works noted that another state budget appropriation may be the most likely source of significant funding since FOVL has established strong connections with the state and local representatives. Jeff also commented that the Clean Water Fund is an enterprise fund required to be used for stormwater compliance. It is likely not available for internal lake management practices but could be applied to the watershed management scenarios. Funding sources from Ecology provide limited dollars for specialized projects. Jeff Schnabel and Alyssa Payne with Clark County both noted that inter-agency agreements exist to fund monitoring in Vancouver Lake, but most agencies do not have available funds to further leverage. Jeff agreed that given the complex nature of ownership related to Vancouver Lake, that a blend of strategies for meeting different needs will need to be considered, particularly for long-term management.

- Alyssa Payne with Clark County Public Health and Patty Boyden with the Port of Vancouver commented to ensure communication and outreach with the broader public, beyond regular lake user groups, will be conducted to garner interest and support for lake management and inform management and funding decisions.

BACKGROUND INFORMATION

Vancouver Lake is a large (2,300 acres), shallow (mean depth <3 feet) lake located adjacent to the City of Vancouver in Clark County, Washington, and within the greater Portland, OR metropolitan area (Figure 2). The 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 today's communities. Vancouver Lake is part of the Willamette Valley ecoregion and one of several floodplain lakes in the lower Columbia River. Its watershed and Ridgefield National Wildlife Refuge, 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.

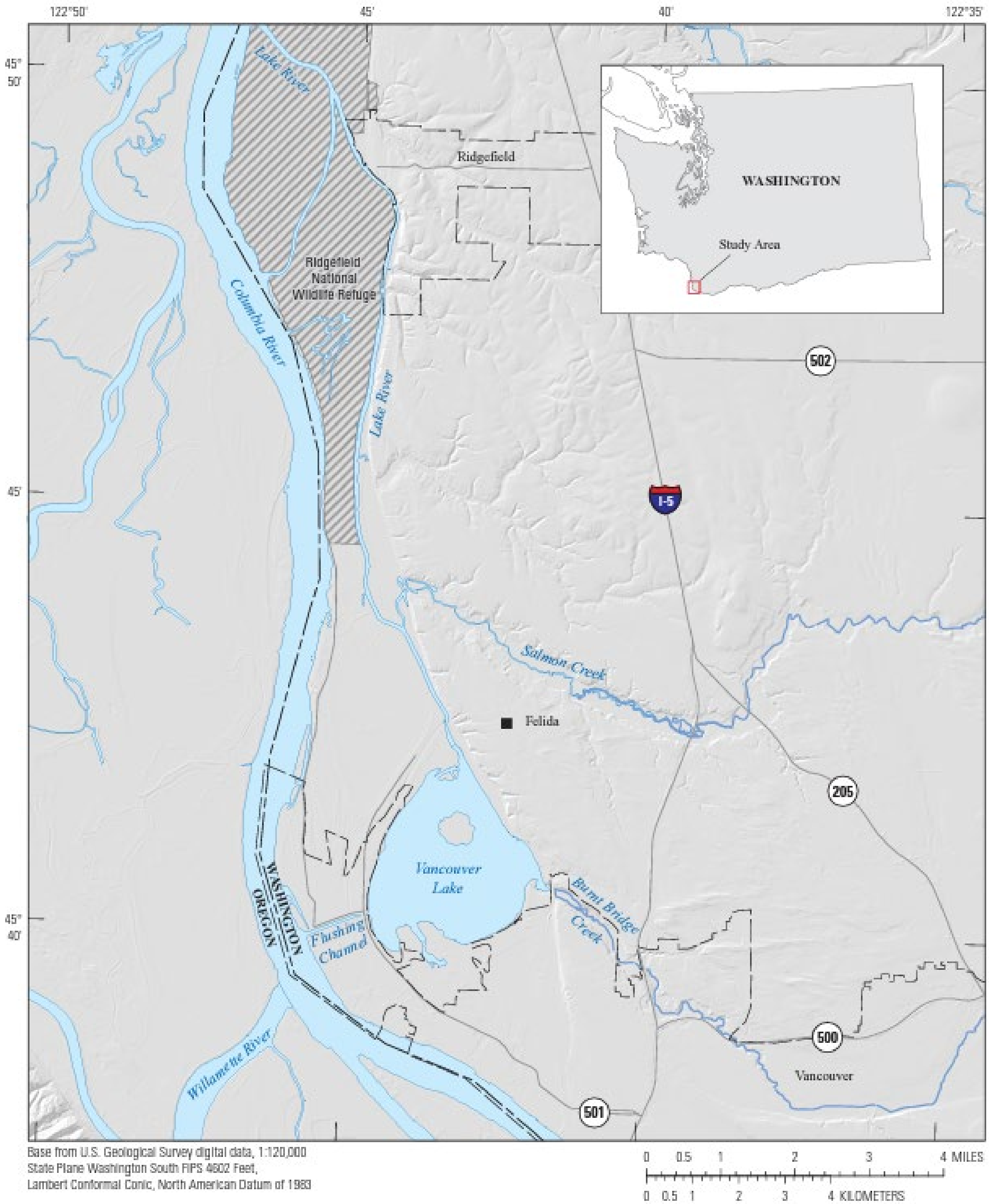
The lake features a park and a rowing club on the western shore, a sailing club on the eastern shore, and a public boat launch on the southern shore for non-trailered watercraft. In addition, there is a public launch for motorized watercraft at Felida Moorage located on Lake River approximately 0.5 miles north of the lake. The rowing and sailing clubs host regattas that generate significant revenue for the local business community. Rowing regattas have generated over $2 million USD per event. In recent years, these events have been cancelled because of lake water quality conditions.

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. These 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 3).

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. 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). In addition to tidal changes, water levels in the lake are greatly influenced by dam operations along the Columbia River.

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. Corrective actions in the 1970s and 1980s to promote flushing and to increase public desirability for recreation resulted in lake dredging and the US Army Corps of Engineers' (USACE) construction of the 4,000-foot-long

Flushing Channel in 1983, the deposits of which created an island near the center of the lake called Turtle Island. The Flushing Channel today allows water to enter the lake directly from the Columbia River but does not allow water to escape and is equipped with a trash rack upstream.



Base from U.S. Geological Survey digital data, 1:120,000
State Plane Washington South FIPS 4602 Feet,
Lambert Conformal Conic, North American Datum of 1983

Figure 2. Vicinity Map of Vancouver Lake, Vancouver, WA (Sheibley et al. 2014).

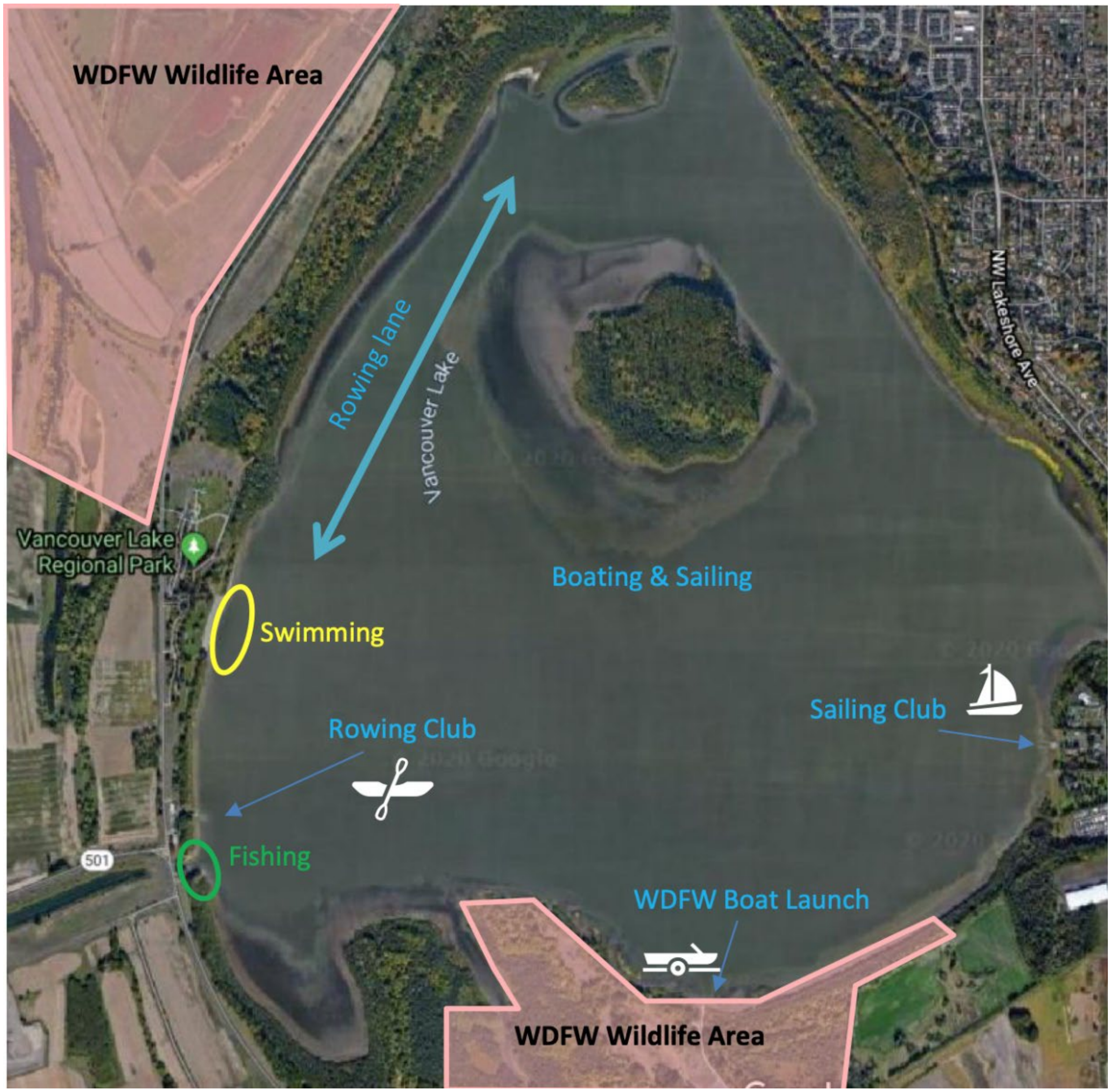


Figure 3. Vancouver Lake Use Map (FOVL 2021).

With monitoring of the lake and its tributaries dating back to 1967 (Bhagat and Orsborn 1971), data show that water quality issues in Vancouver Lake include high water temperatures and turbidity, low dissolved oxygen, reduced summer lake depth, eutrophication, fecal bacteria contamination, increasingly frequent toxic algae blooms, and large infestations of aquatic invasive weeds. Vancouver Lake is also a category five 303(d) status impaired body of water, with concerning levels of total phosphorus and fecal bacteria in water samples and polychlorinated biphenyls and pesticides in tissue samples (Ecology 2016).

The history of high-intensity hydrologic manipulation and urbanization in the Vancouver Lake watershed has been cited previously as a main contributor to the water quality issues observed, likely in addition to one or more of the following causes: untreated domestic wastewaters entering through tributaries, stormwater runoff, and pollutants carried into the lake via tidal backflow from Lake River.

Prior actions have made minor and/or temporary improvements, such as from the construction of the Flushing Channel by USACE in 1983. Other 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). In 2020, an Integrated Aquatic Vegetation Management Plan (IAVMP) was developed by Clark County under contract with Washington Department of Fish and Wildlife (WDFW), and subsequent herbicide treatment of invasive plants was conducted on behalf of Friends of Vancouver Lake (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 species is not feasible due to the frequent migration of fish between the lake and the Columbia River via the Flushing Channel, and 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).

Despite these efforts, Vancouver Lake remains afflicted by many of these concerns every summer, with toxic algal blooms and invasive aquatic weeds imposing the greatest impact to public users. To address these impacts, the LMP will utilize previously accumulated knowledge on the lake to evaluate the best management methods to pursue moving forward. The following subsections summarize key information on Vancouver Lake and its watershed, distilled from years of efforts related to water quality monitoring, watershed studies, hydraulic modeling, ecological research, and biological surveys.

VANCOUVER LAKE WATERSHED PARTNERSHIP

The VLWP was formed in October 2004, composed of various citizens, interest groups, and federal, state, and local agencies, to address community concerns regarding Vancouver Lake's toxic cyanobacteria blooms and other issues. 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 the following key documents which drove VLWP activities and provide a foundation for this LMP project:

- *Vancouver Lake Watershed Partnership Work Program (January 1, 2008–December 31, 2009)* (December 2007), which outlines a strategy to refine the Partnership's vision, goals, and objectives; identify data gaps in research; develop data gap solutions; build and maintain relationships; and garner project funding.

- *Draft Technical and Future Implementation Funding Strategy* (March 2008), which outlines a funding development pathway to support future technical work and project implementation, steering away from reliance on previous funding sources (Steering Group agencies and USACE Section 536 Feasibility Study) which are not sustainable long-term.

- *Draft Objective Continuum* (March 2008), which contains a matrix of Vancouver Lake vision statements and concerns aligned with objectives along a continuum of specific management effort and outcomes.

- *Technical Foundation for Future Management of Vancouver Lake* (November 2008), which summarized VLWP's history, technical knowledge, and data needs. This report ultimately recommended the development of water and nutrient budgets to understand lake functioning and led to the USGS work described in the next section.

- Annual Status Reports (2008–2011), which each summarized VLWP activities, key documents and data, and monitoring/management efforts for the year.

- *Lake Algal Control Techniques with Implications for Vancouver Lake* (December 2009), which described various techniques used for controlling harmful algal blooms and evaluated their use in context of reducing cyanobacteria in Vancouver Lake, as a primer for future evaluation and decision-making. From this, an *Appendix A: Annotated Bibliography of Techniques* was produced listing additional techniques and references.

- *Vancouver Lake Research Plan* (December 2009) which outlines the research objectives, costs, and timeframes for the study of six major topics for understanding Vancouver Lake processes and informing the later development of a quantitative water quality model: 1) water dynamics, 2) nutrients, 3) sediment, 4) food web interactions, 5) toxic contaminants, and 6) fish, wildlife, and habitat.

- *Vancouver Lake Outreach and Involvement Plan* (January 2011) which provides a strategy to promote public understanding of Vancouver Lake's concerns and management alternatives, including outreach goals and objectives, specific strategies, key outreach messages, audiences, a timeline, and shared duties amongst the Partnership and other project staff.

- *Vancouver Lake Partnership Planning Process and Recommendations Report* (December 2013) which summarizes overall Partnership efforts, knowledge gained, and recommendations for future considerations.

- A grant proposal (January 2015) for the Lower Columbia Estuary Partnership (LCEP) to fund a project to engage the Vancouver Lake community with the long-term goal to build a sense of ownership for the lake and create a support system for Vancouver Lake's care and value.

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.

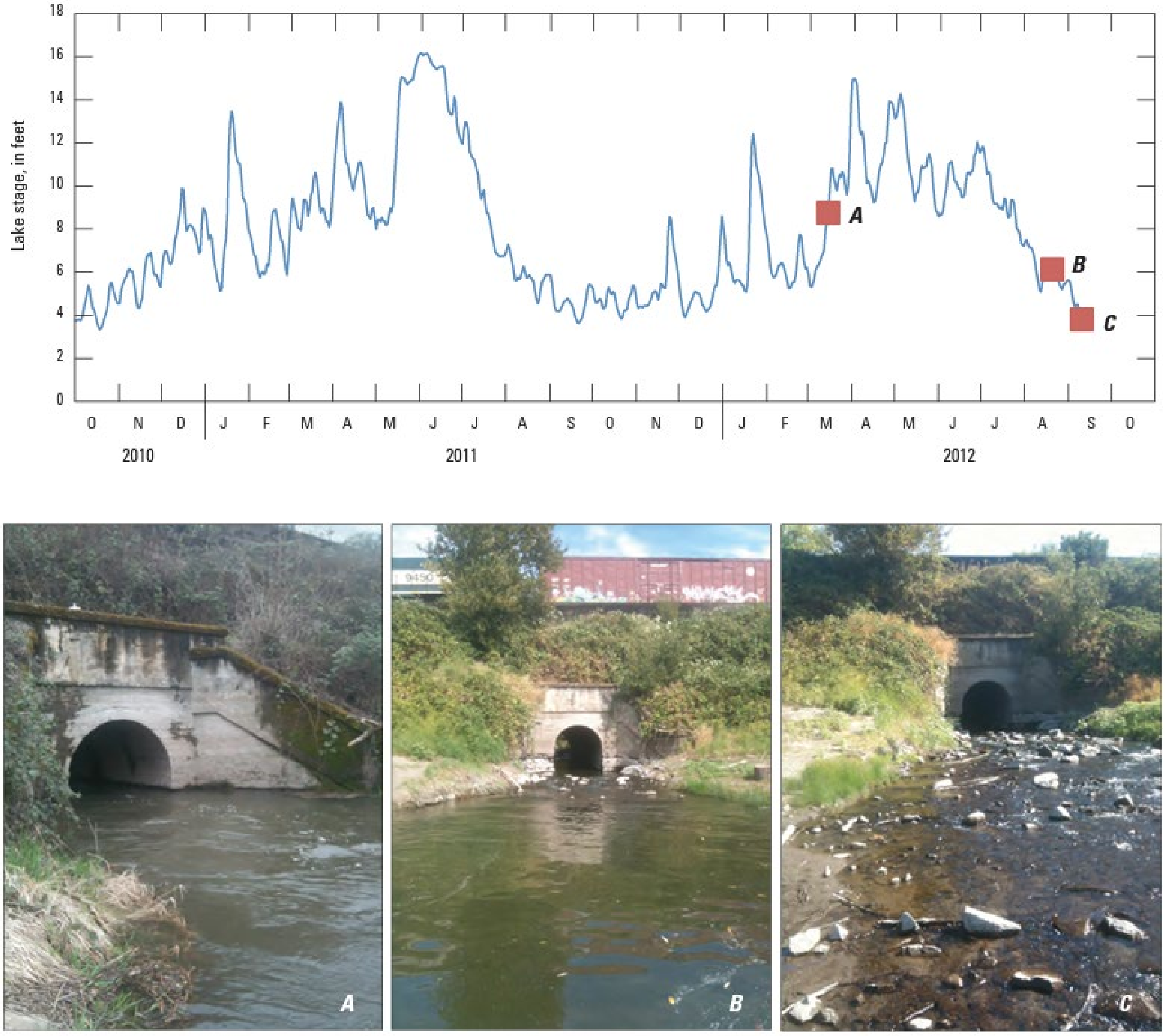
HYDROLOGY AND WATERSHED CHARACTERISTICS

The hydraulics of Vancouver Lake are more complex than many similar shallow, freshwater lakes because it is connected to the Columbia River and therefore 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 (Figure 4). The deepest area of the lake is the dredged area by the Flushing Channel while the majority of the central lake area remains shallow, particularly around Turtle Island (Figure 5).

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, leading to one of the highest trophic state index values evaluated (Figure 6).

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 the construction of the Flushing Channel in 1983 by the Port of Vancouver. The U. S. Army Corps of Engineers 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) (Figure 7) while the Flushing Channel provides 10 percent and Burnt Bridge Creek just 3 percent of total water inflow. 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 one percent or less to the total water budget. Water retention time in Vancouver Lake ranged from 8 to 27 days throughout the year (Sheibley et al. 2014).



Lake stage data provided by Dan Matlock, Pacific Groundwater Group. A lake stage of zero feet would indicate there is no water in the lake. Photographs were taken periodically during the year (shown as *A, B,* and *C* in the graph) looking towards the mouth of Burnt Bridge Creek to show how the lake level changes during the year. (Photographs taken by Rich Sheibley, US Geological Survey, 2012).

Figure 4. Lake Stage Hydrograph at the Vancouver Lake Sailing Club, October 2010 to September 2012 (Sheibley et al. 2014).

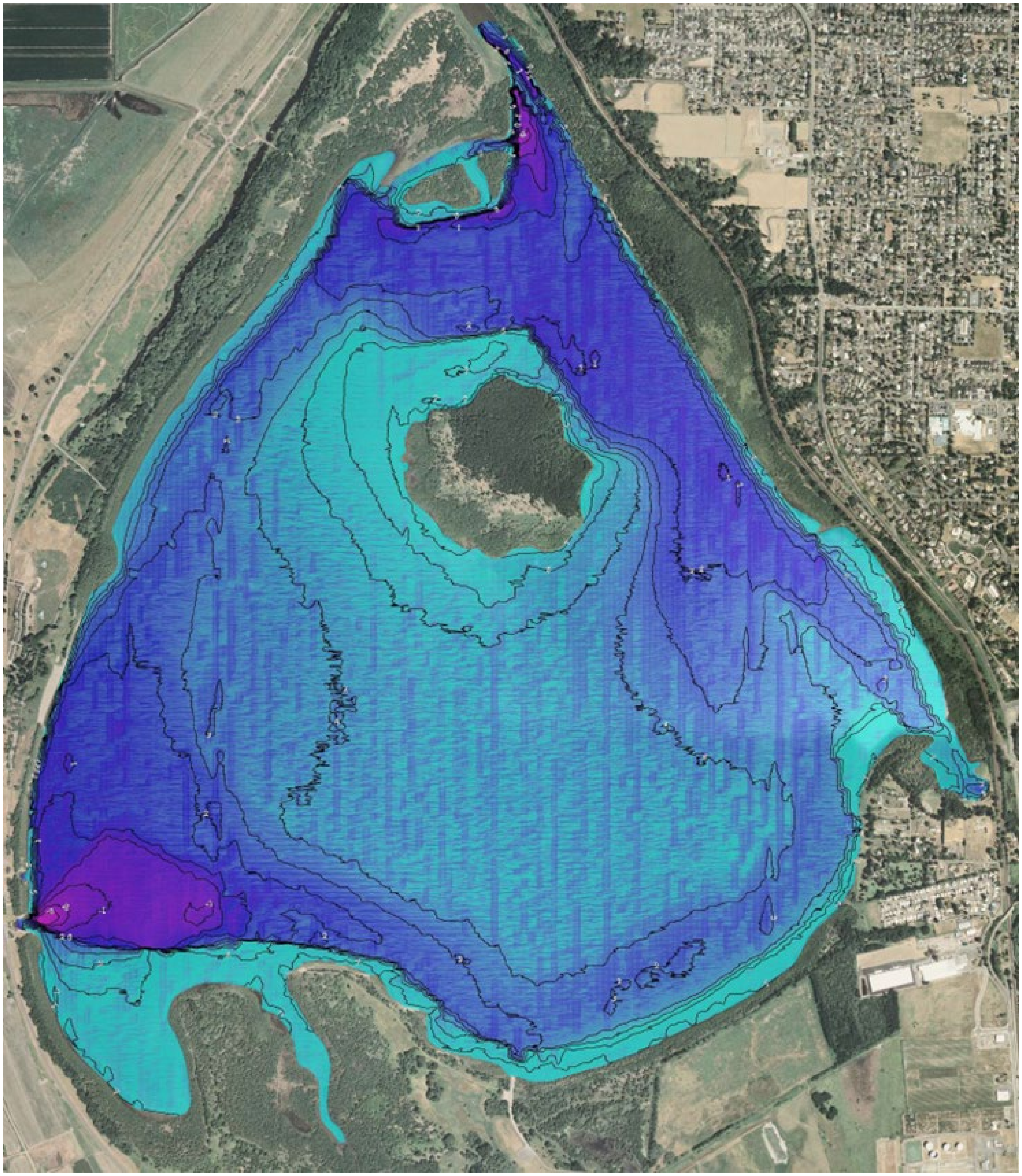


Figure 5. Bathymetry Map of Vancouver Lake (USACE 2009).

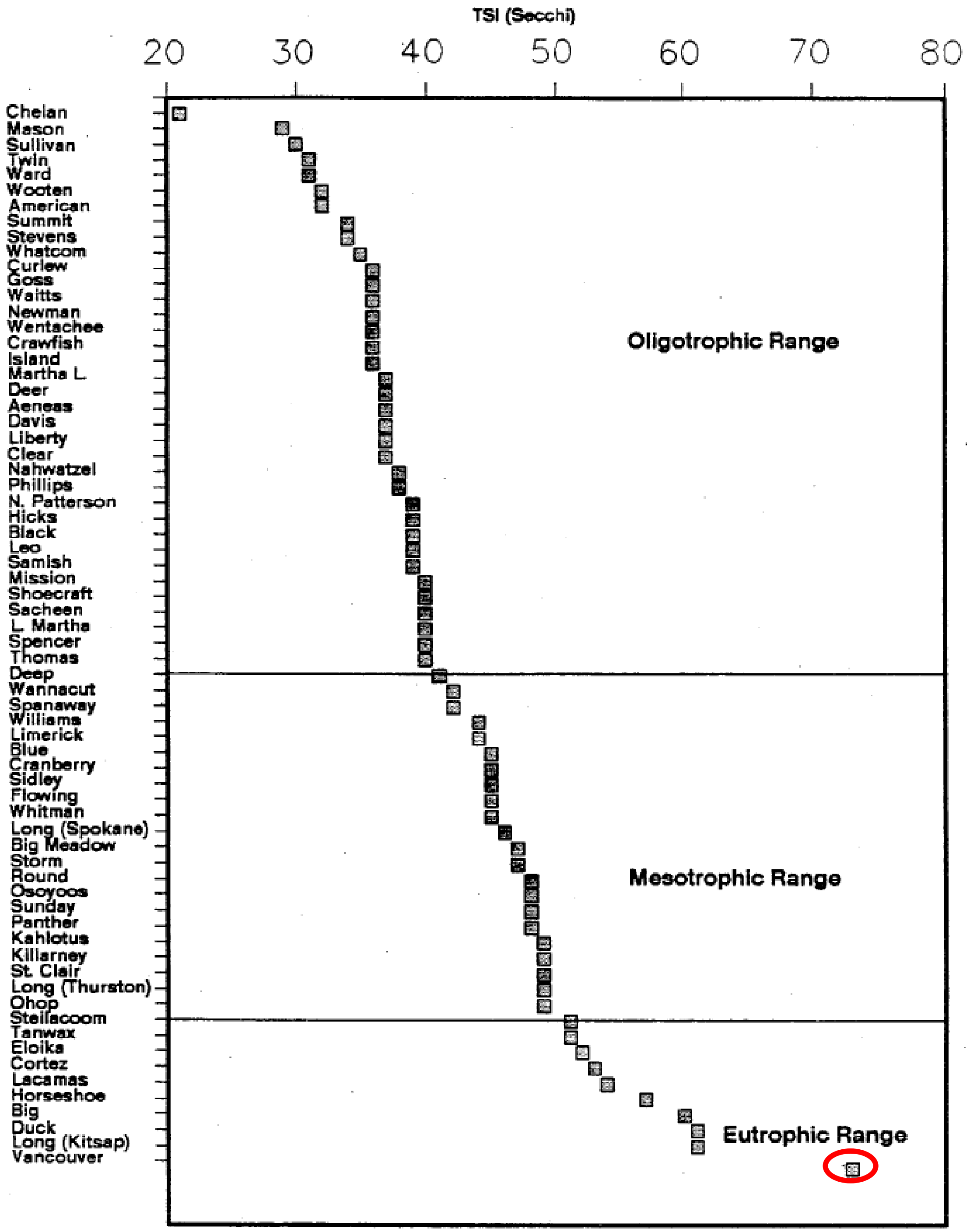


Figure 6. Washington State Lakes Ranked in Order of Increasing 1990 TSI $_{SD}$ (Ecology 1993).

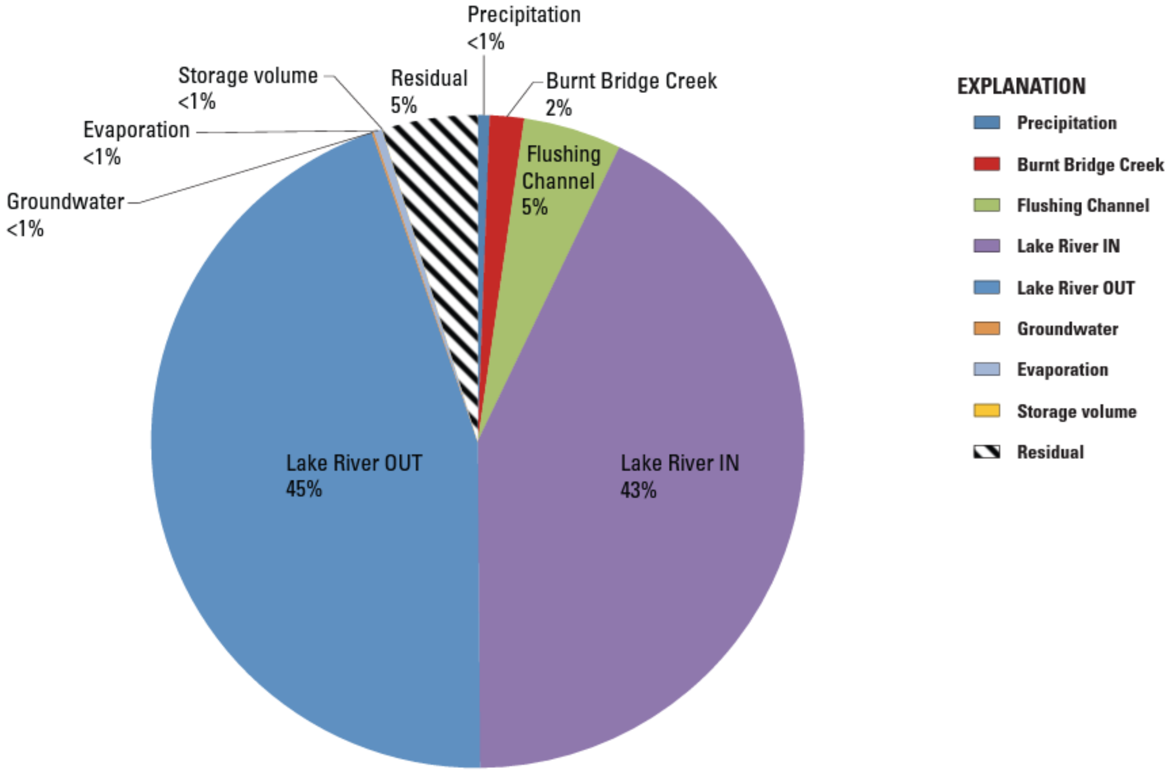


Figure 7. Total Water Budget for Vancouver Lake (2010-2012) (Sheibley et al. 2014).

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 8).

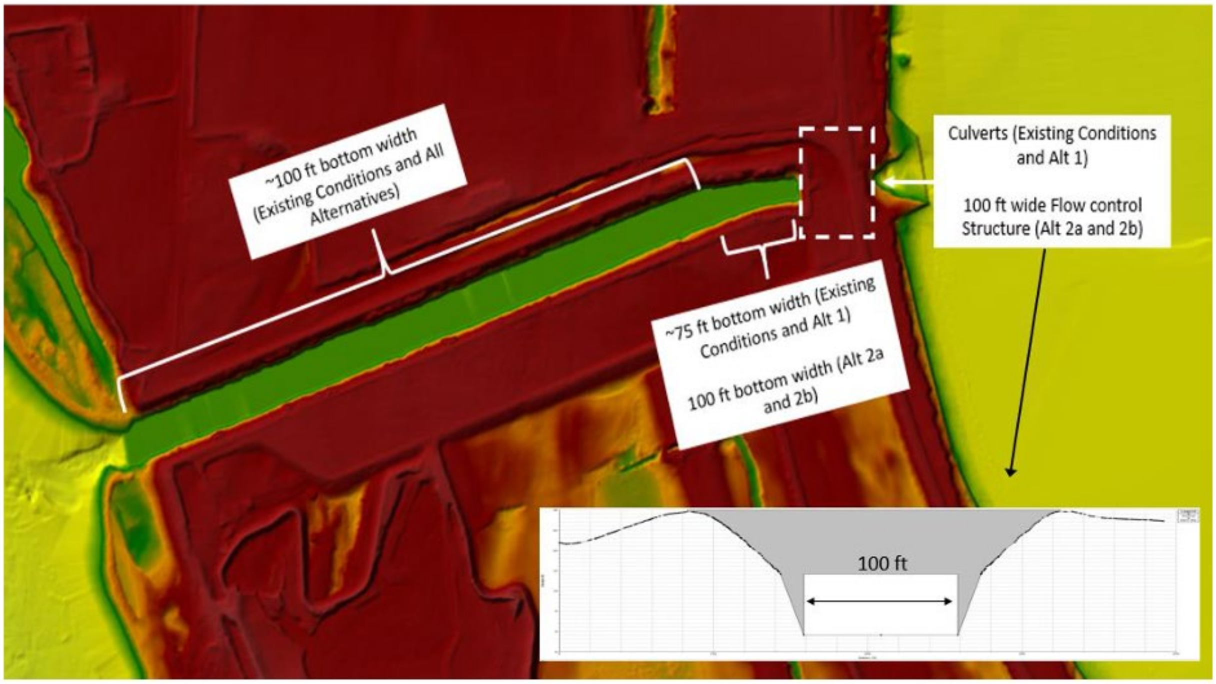


Figure 8. Flushing Channel Geometries and Alternatives (Jacobs 2022).

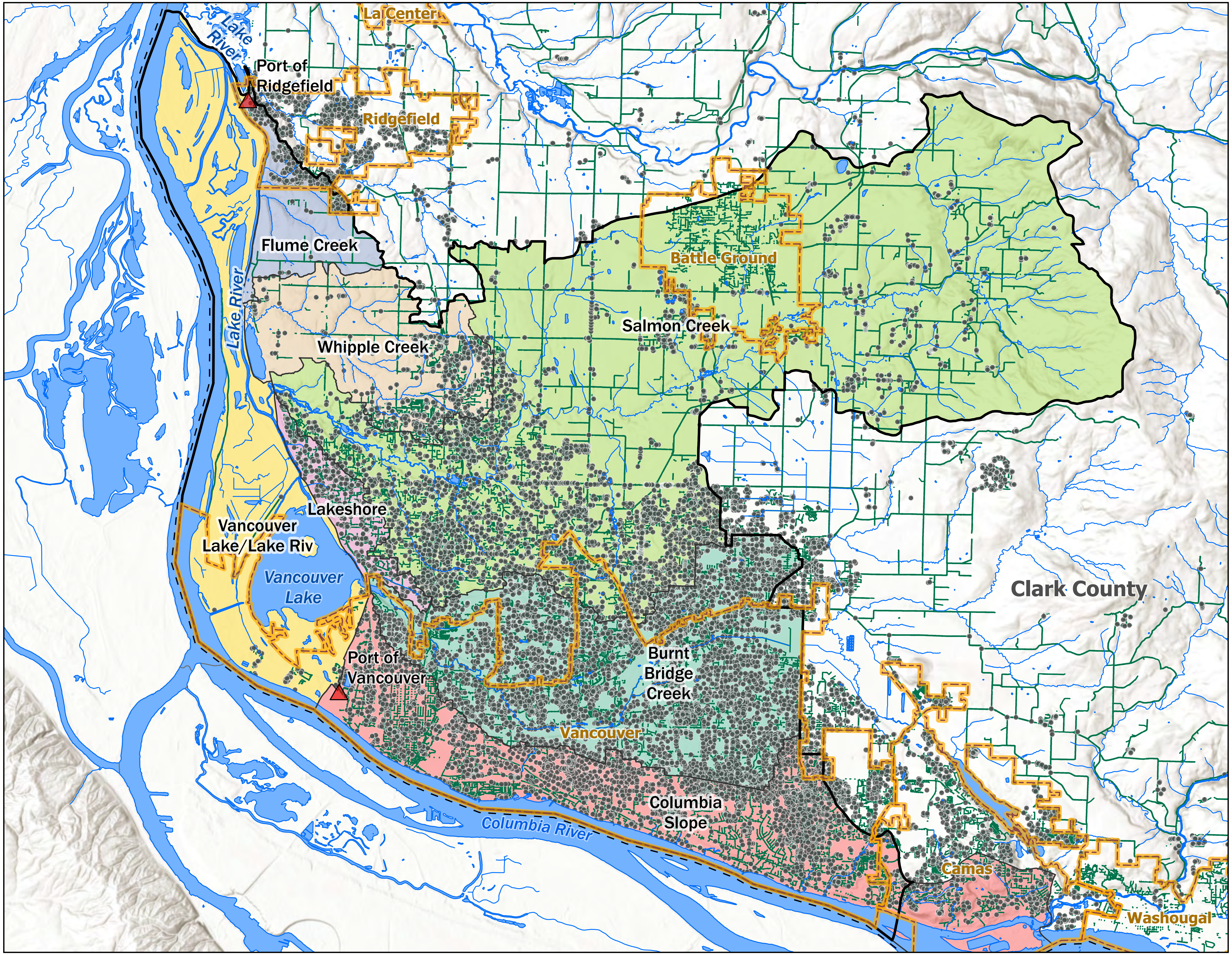
They found that clearing culverts of trash (alternative 1) increases flow through the channel but because the channel provides such low inflow volume the lake's hydrographs are unaffected. As channel capacity and reverse flow regulation were the most significant drivers for water volume, alternatives 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 28x 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).

The Vancouver Lake watershed is located within the Salmon Basin that drains to the Columbia River from Camas to the Port of Ridgefield. Figure 9 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 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 9. 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, comprised 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 9).

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 10). Herrera will quantitatively characterize Vancouver Lake's watershed characteristics as needed to inform modeling, watershed management, and monitoring options for the LMP.

Figure 9.
Stormwater Facilities in Salmon Basin.



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

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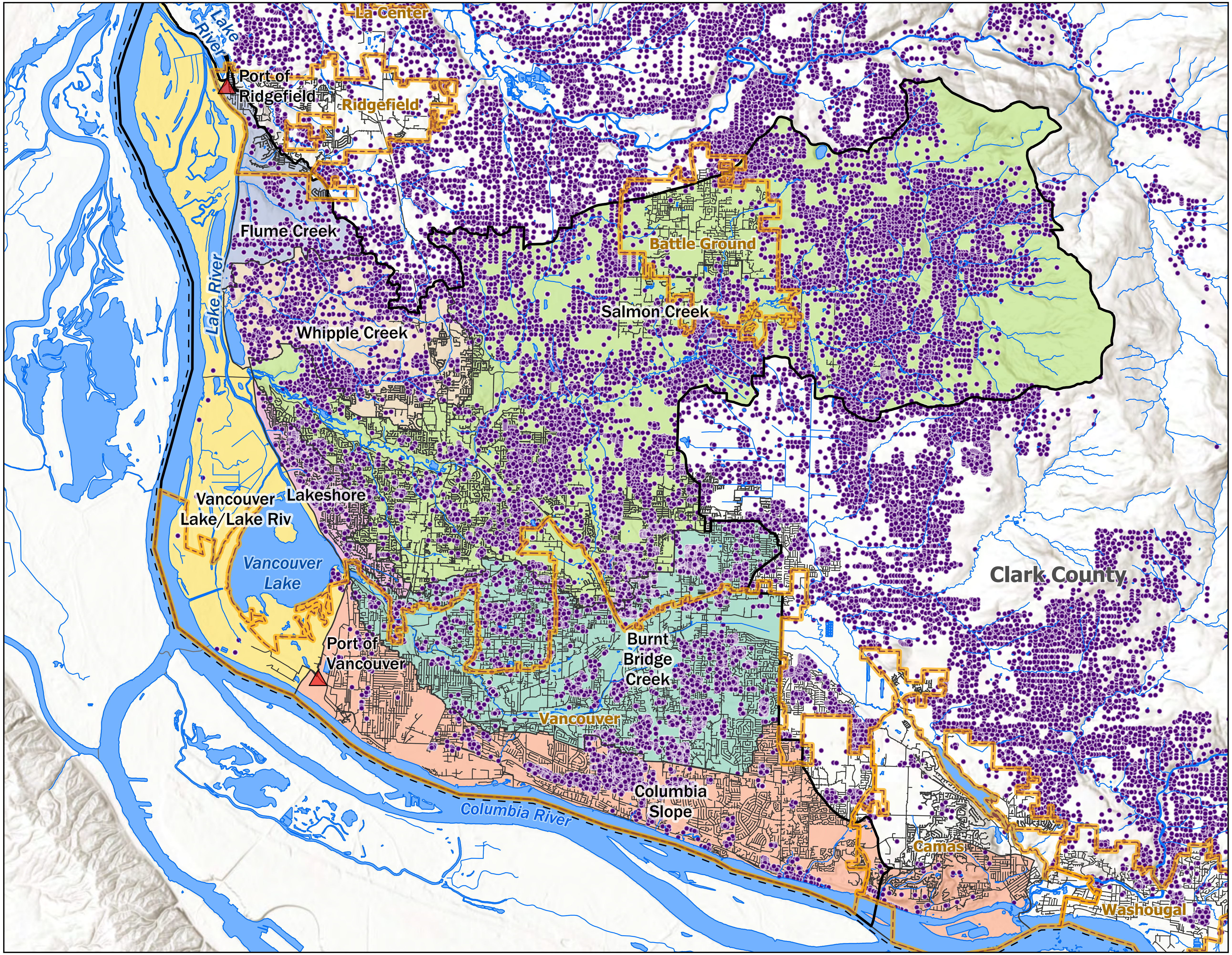
Figure 10.
Sewer and Septic Facilities in Salmon Basin.



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NUTRIENTS

Vancouver Lake has shown signs of nutrient pollution (eutrophication) since the 1960s. Phosphorus is of particular concern in freshwater because high levels can lead to accelerated plant growth, algal blooms, low dissolved oxygen, and decreases in aquatic diversity. Soluble reactive phosphorus, also known as orthophosphate, is the dissolved inorganic fraction of phosphorus and is a very unstable form of phosphate that is directly absorbed by aquatic vegetation and microbes such as algae. Nitrate+nitrite nitrogen is also a concern in freshwaters because it may contribute to an overabundant growth of algae and aquatic plants and to a decline in diversity of the biological community. These nutrients can come from natural or anthropogenic such as septic system failure, animal waste, decaying vegetation and animals, resuspension from the bottom of a lake, or fertilizer runoff.

Currently, Washington State does not have surface water quality standards for total phosphorus, orthophosphate, total nitrogen, or nitrate+nitrite in rivers and streams. The US Environmental Protection Agency (EPA) recommended a nutrient criterion of 0.040 mg/L for total phosphorus and 0.36 mg/L for total nitrogen for streams located in the Willamette Valley ecoregion (EPA 2001.

Bhagat and Orsborn (1971) first measured nutrient and other water quality parameters in Vancouver Lake, reporting “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 six inches of lake bottom sediments, comprised 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 trophic state index (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 (Figure 6).

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) outlines the results of their water quality monitoring and budget analysis, the key findings of which are summarized below:

- Lake River was the greatest source of nutrients to the lake due to the high quantity of water inflow to the lake (Figure 7). Lake River contributed 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 11).

- The next greatest source of nutrients was 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. The greatest nutrient concentrations of any inflow source were measured from Burnt Bridge Creek followed by concentrations from Salmon Creek, and generally lowest from the Flushing Channel (Figure 11).

- Loosely bound and readily available inorganic phosphorus was 3 percent or less of the total phosphorus measured in sediments and decreased with sediment depth, whereas unavailable aluminum and calcium bound phosphorus made up 60–90 percent of the total all samples analyzed.

- Precipitation (including estimates of atmospheric nutrient deposition) and groundwater nutrient inputs each contributed one percent or less to respective budgets.

- Water temperatures and specific conductance values were greatest from groundwater inflow sources, which also exhibited lower pH and dissolved oxygen values.

- 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.

- The trophic status of Vancouver Lake varied from mesotrophic (TSI values 40 to 50) to hypereutrophic (TSI >70), with individual observations of TSI values ranging from approximately 47 to 100 (Figure 12).

- Monthly nitrogen to phosphorus (N:P) ratios were almost always greater than 7:1, revealing that phytoplankton in Vancouver Lake are likely phosphorus limited and thus management methods must reduce phosphorus concentrations to reduce algal growth.

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

Additional nutrient and other water quality data were collected and analyzed by WSU researchers between 2007 and 2019, finding that water temperature frequently exceeded 20 °C in the summertime and DO levels frequently exceed the 8 mg/L guideline. Both pH and turbidity were greatest in late summer, concurrent with the highest temperatures and concentrations of orthophosphate and nitrate (Lee et al. 2015).

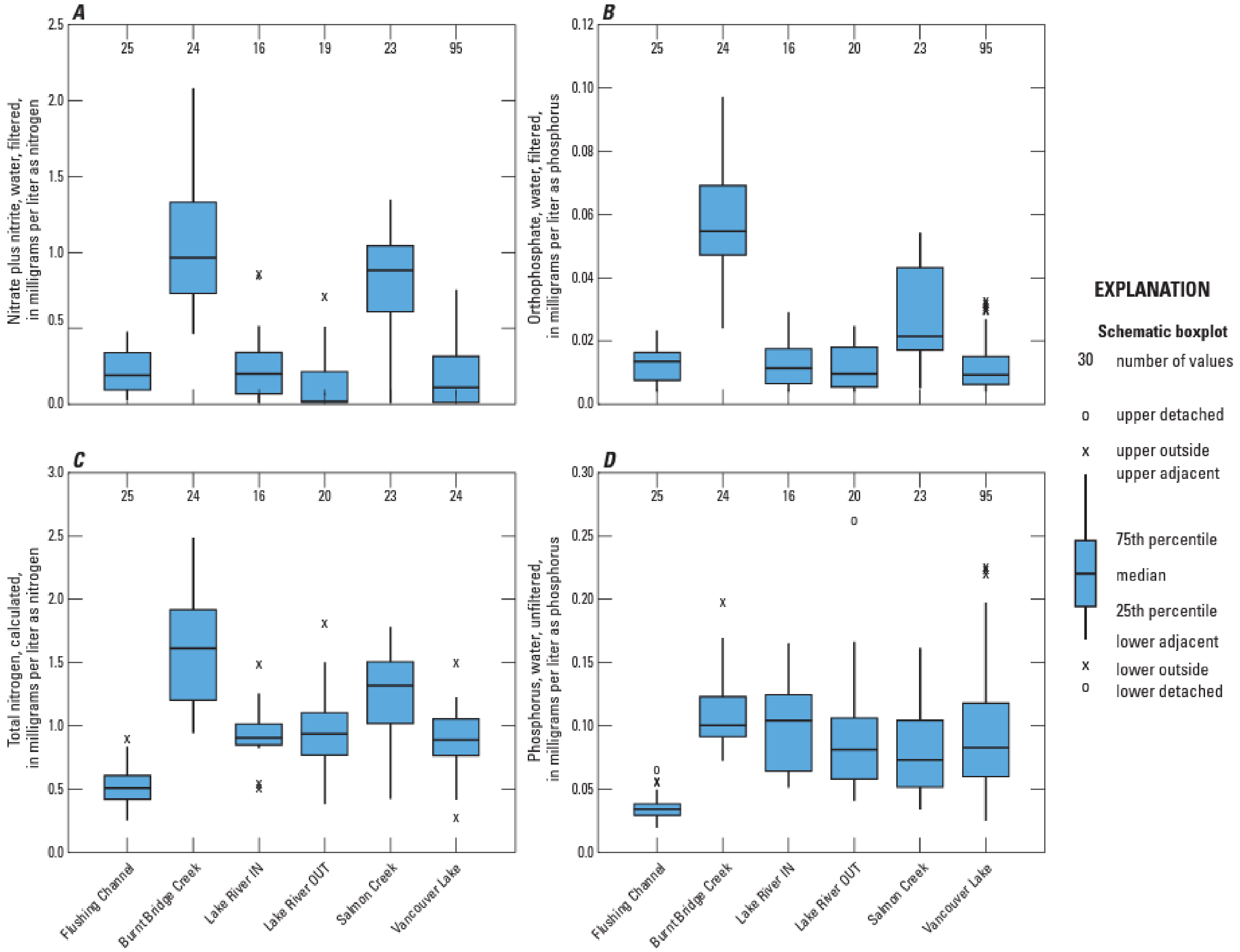


Figure 11. Comparison of (A) Nitrate Plus Nitrite, (B) Orthophosphate, (C) Total Nitrogen and (D) Total Phosphorus in Surface Water Samples Collected from Vancouver Lake, October 2010–October 2012. (Sheibley et al. 2014).

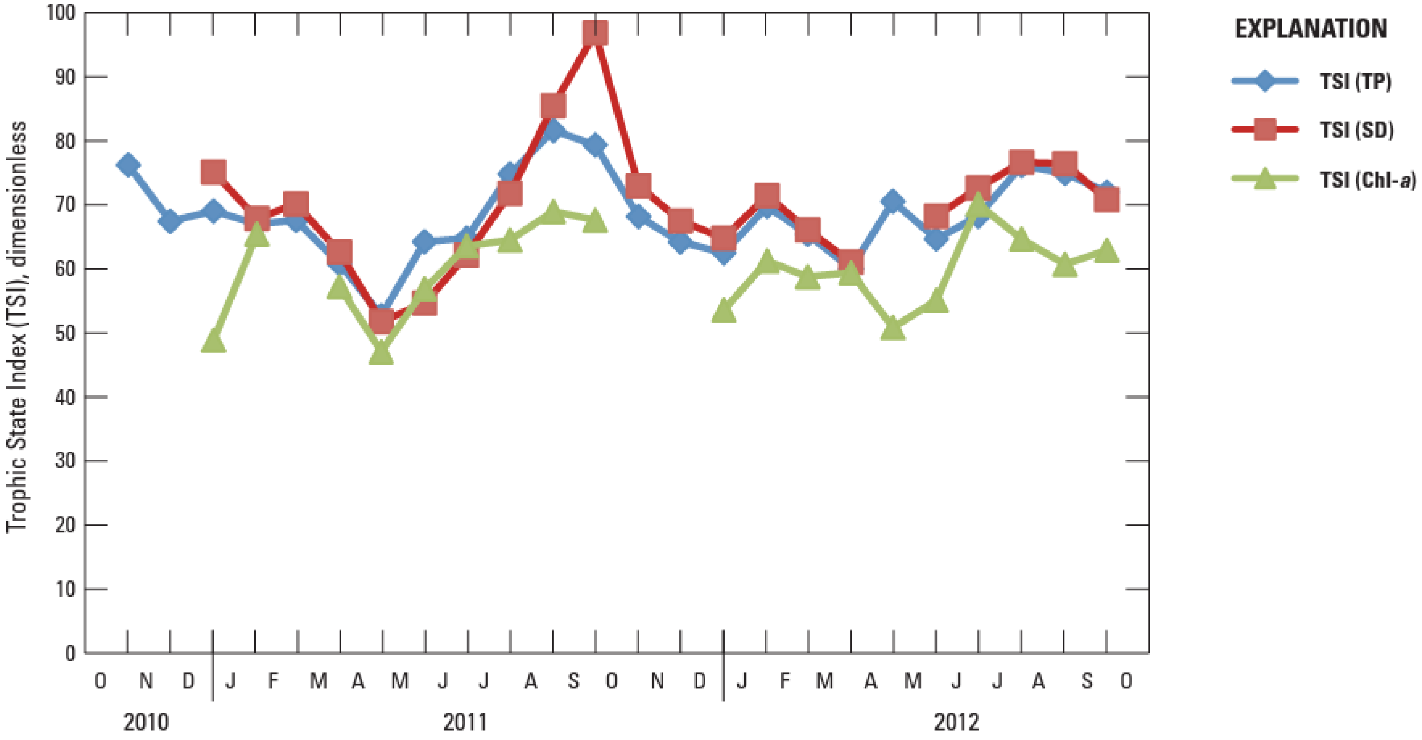


Figure 12. Trophic State Index (TSI) Determined from Total Phosphorus (TP), Secchi Depth (SD) and Chlorophyll-a (Chl-a) Measurements in Vancouver Lake (Sheibley et al. 2014).

PHYTOPLANKTON AND CYANOTOXINS

Toxins produced by cyanobacteria, which can cause illness or death in humans and wildlife if contacted or ingested, have been regularly measured in Vancouver Lake by CCPH's Swim Beach Monitoring Program since 2007 using funds from the 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 cyanobacteria toxins and the test results are recorded in the Washington State Toxic Algae Database managed by Ecology (Ecology 2022). These tests include regular analysis of microcystin and anatoxin-a with occasional testing of cylindrospermopsin and saxitoxin.

If one or more algal toxins measured from a sample are above the Washington Department of Health Recommended Guidance thresholds, CCPH will issue a Warning or Danger advisory. Warning advisories are issued when no illnesses have been reported and/or the bloom does not cover the entire lake or public access points; avoiding scums and contact with the water is recommended for all recreators and pets in addition to thorough cleaning of caught fish during warnings. A Danger advisory is issued when an illness or death is reported and/or the bloom covers the entire lake or is present at multiple public access points; all recreation is strongly discouraged, and park managers may limit access to prevent exposure during danger advisories.

Data show that levels of both cylindrospermopsin and saxitoxin are very low and well below state recreational criteria when measured (Figure 13). 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 14). Microcystin concentrations in particular frequently exceed guidelines, with some samples exceeding by more than a magnitude at the swim beach and flushing channel sample locations (see Figure 13).

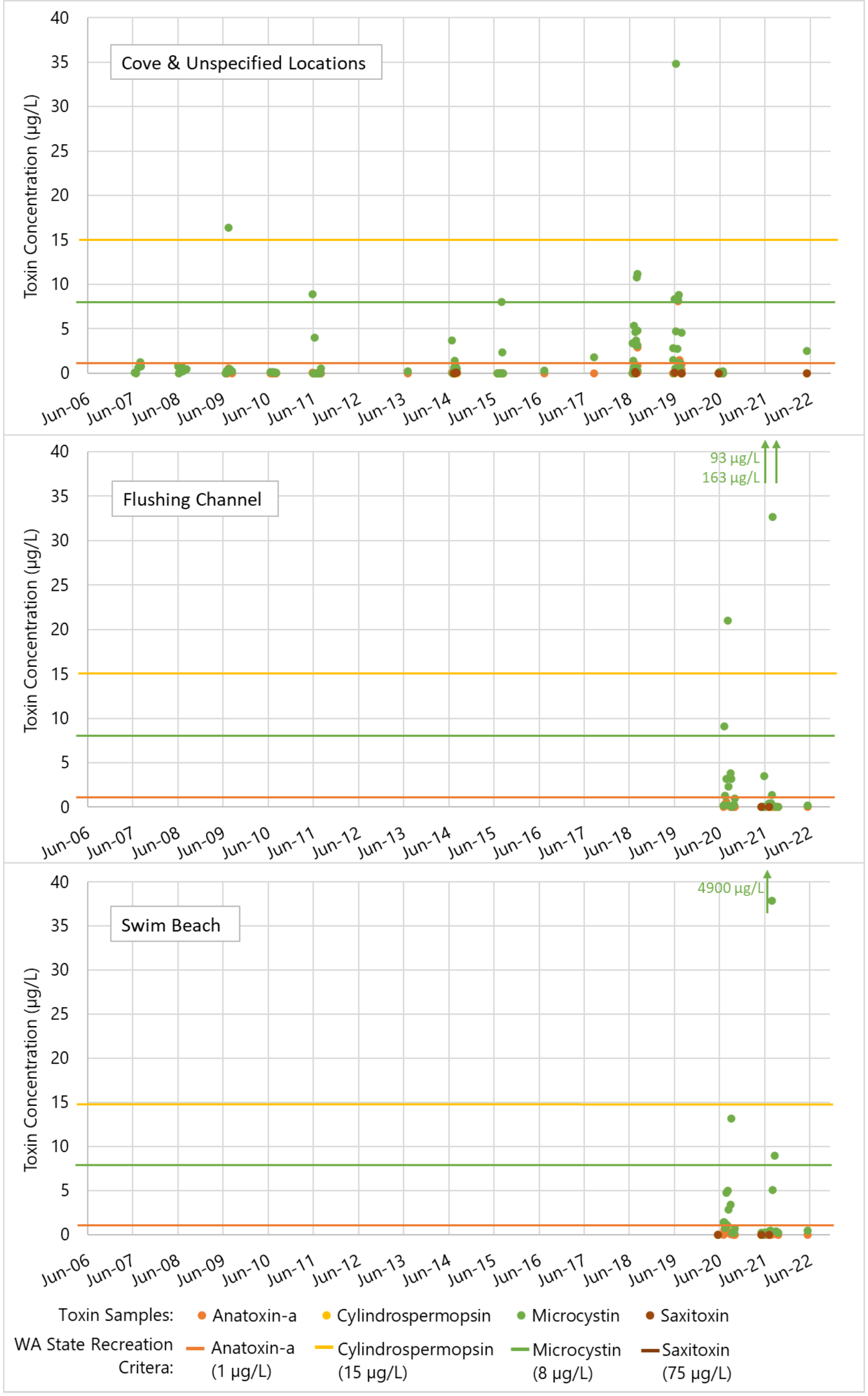


Figure 13. Vancouver Lake Cyanobacteria Toxin Concentrations 2007-2022 (Ecology 2022).

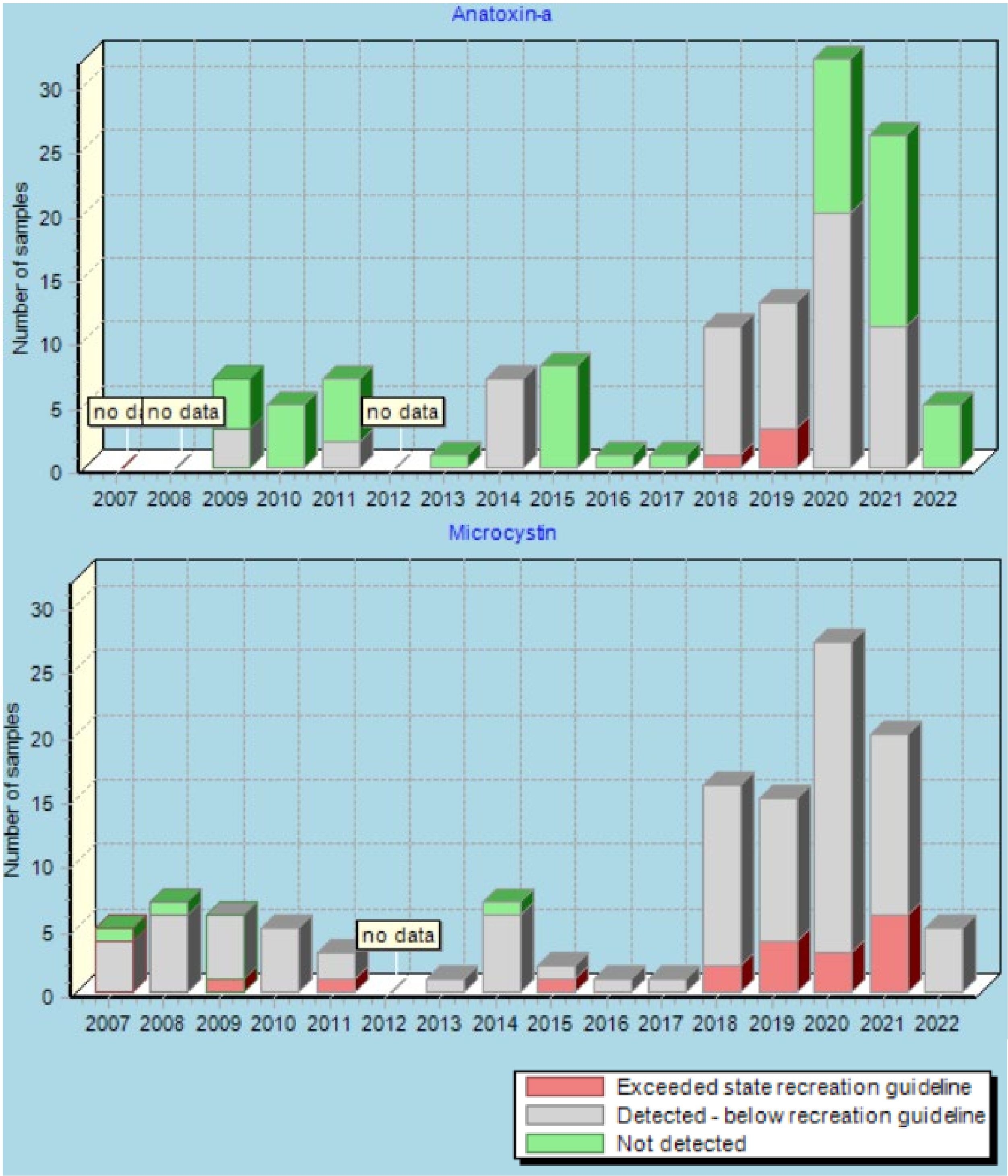


Figure 14. Annual Number of Anatoxin-a and Microcystin State Criteria Exceedances in Vancouver Lake, 2007–2022 (Ecology 2022).

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). This study notably revealed that the abundance of both toxic and non-toxic cyanobacteria and the concentrations of intracellular microcystin were all primarily influenced by orthophosphate concentrations, but also strongly positively associated with silicate and turbidity and strongly negatively associated with total lake depth and Secchi depth (Lee et al. 2015). Although toxin concentrations are generally elevated at the same time as peaks in phytoplankton are observed and when green mats/streaking are visible atop the water, cyanotoxin concentrations do not exactly follow patterns in phytoplankton abundance or biomass. This disparity indicates that other forces must also influence toxin production independent of the amount of cyanobacteria cells (Lee et al. 2015).

WSU research additionally shows that the phytoplankton community peaks in late summer and fall with chlorophyll-a concentrations of 500–900 µg/L, during which time it is dominated by the filamentous cyanobacteria species *Aphanizomenon flos-aquae* and *Dolichospermum flos-aquae* (formerly *Anabaena flos-aquae*), which are responsible for much of the observed harmful algae bloom biomass. This finding is consistent with observations from Bhagat and Orsborn (1971) which found these same cyanobacteria species to represent 95 percent of all phytoplankton cells counted. Blooms in Vancouver Lake typically form in mid to late July and last three to four weeks, followed by a decline in August and often a smaller recurring bloom in September. Although *Microcystis* sp. is also observed in the lake, their relative abundance has never been recorded at greater than one percent of the overall cyanobacteria assemblage. 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 (*mcy*E).

ZOOPLANKTON

Research on zooplankton dynamics in the lake reveal that complex multi-level trophic cascade effects drive cyanobacteria dynamics. Both copepods and microzooplankton taxa (2–200 µm in size) greatly influence phytoplankton communities, though in different ways. Copepods were consistently the dominant zooplankton taxon observed; through experimental manipulation, WSU researchers discovered that by consuming other types of high-quality phytoplankton (e.g., diatoms and green algae) and other grazers, copepods facilitate a condition where cyanobacteria are at a competitive advantage and when this 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, which once again allows grazing by microzooplankton taxa (e.g., ciliates and dinoflagellates) (Rollwagen-Bollens et al. 2013), which are largely responsible for the dissipation of a harmful bloom in addition to multi-tier and intra-guild trophic influences by rotifers (Boyer et al. 2011, Sweeney et al. 2022). The results of these plankton studies elucidate that management efforts should ideally require strategies which address both biotic (trophic cascade) and abiotic controls (nutrients).

FECAL BACTERIA

Another major public health concern in Vancouver Lake is the occurrence of high concentrations of *Escherichia coli* (*E. coli*). Bhagat and Orsborn (1971) reported fecal coliform bacteria pollution (roughly 130 to 3800 CFU/100 mL) from untreated residential wastewater and agricultural activities within the Salmon Creek and Burnt Bridge Creek basins. Today, fecal bacteria pollution in Vancouver Lake is considered to be largely from waterfowl but is still excessive and often necessitates beach closures.

CCPH's Swim Beach Monitoring Program collects multiple *E. coli* samples bi-weekly from waist deep water six inches below the water surface at Vancouver Lake Regional Park's swim beach (Figure 15) to determine if there is a health hazard. CCPH uses the US 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 (Figure 16), necessitating seven closure events and eight warnings. Three of the recorded lake closures, which also exhibited the maximum observed levels since 2010, are from just earlier this year (2022) just as this LMP project began. One of these 2022 closures due to elevated E.coli levels resulted in the cancellation of the 2022 US Rowing Northwest Masters Regional Championship, an eminent event with rowing clubs participating from more than 36 cities across seven US states and British Columbia, which was to be held at Vancouver Lake June 17–19, 2022.

Although waterfowl are suspected to be the primary sources of fecal bacteria at the Lake 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).

This map was generated by Clark County's "Maps Online" website. Clark County does not warrant the accuracy, reliability or timeliness of any information on this map, and shall not be held liable for losses caused by using this information.

Figure 15. Vancouver Lake CCPH Swim Beach Monitoring Program Locations (CCPH 2021).

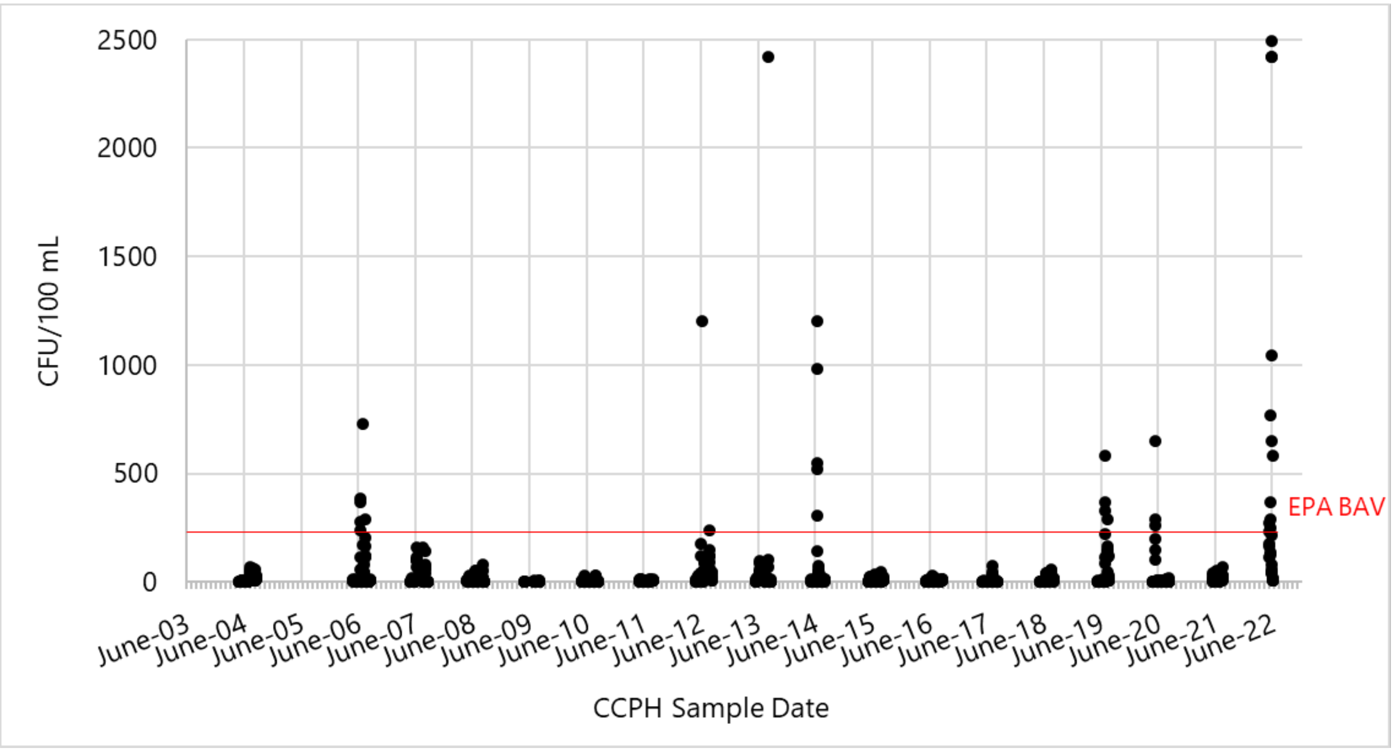


Figure 16. Vancouver Lake Regional Park Swim Beach *E. coli* Concentrations (CCPH 2022).

AQUATIC PLANTS

Surveys for invasive aquatic weeds were performed first in 2007 by the Washington Department of Ecology, finding Eurasian watermilfoil (*Myriophyllum spicatum,* "milfoil"), which was found again in 2017 and 2018 in surveys by Friends of Vancouver Lake (Figure 17) (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 (<4 feet) surveyed, amounting to 78 percent of milfoil's habitable area and 26 percent of the total area of Vancouver Lake (Figure 18) (FOVL 2021, Collell 2020). A survey in 2020 indicated milfoil coverage increased by roughly another 100 acres (T. McNabb, Aquatechnex, personal communication).

Additional submerged species observed included native and hybrid milfoils, water star-grass, coontail, curly leaf pondweed, common waterweed (*Elodea canadensis.*), sago pondweed, and small pondweed (Figure 18, Table 4) (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 18, but genetic testing proved that it was actually Eurasian watermilfoil.

Figure 17. Eurasian Watermilfoil Infestation Areas Found in FOVL Surveys in 2017 and 2018 (Collell 2020).

In response to the milfoil infestation, Clark County and Friends of Vancouver Lake teamed to create an Integrated Aquatic Vegetation Management Plan (IAVMP) to survey and treat aquatic plants long-term (Collell 2020), which led to the subsequent treatment of milfoil using ProcellaCOR herbicide, applied on July 7, 2020 by Aquatechnex (see *Noxious Weed Management Techniques*). No milfoil plants were observed during similar point-intercept surveys conducted after the treatment in September 2020 and again in the summer of 2021.

With the success of the herbicide treatment in effectively reducing milfoil, reports from 2021 and 2022 note increased densities of curly leaf pondweed, which is currently being evaluated by FOVL for potential herbicide treatment. 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 by the Clack County Noxious Weed Board. Other noxious weeds in the lake requiring control in Clark County include purple loosestrife (Class B), and yellow flag iris (Class C) (see Table 4).

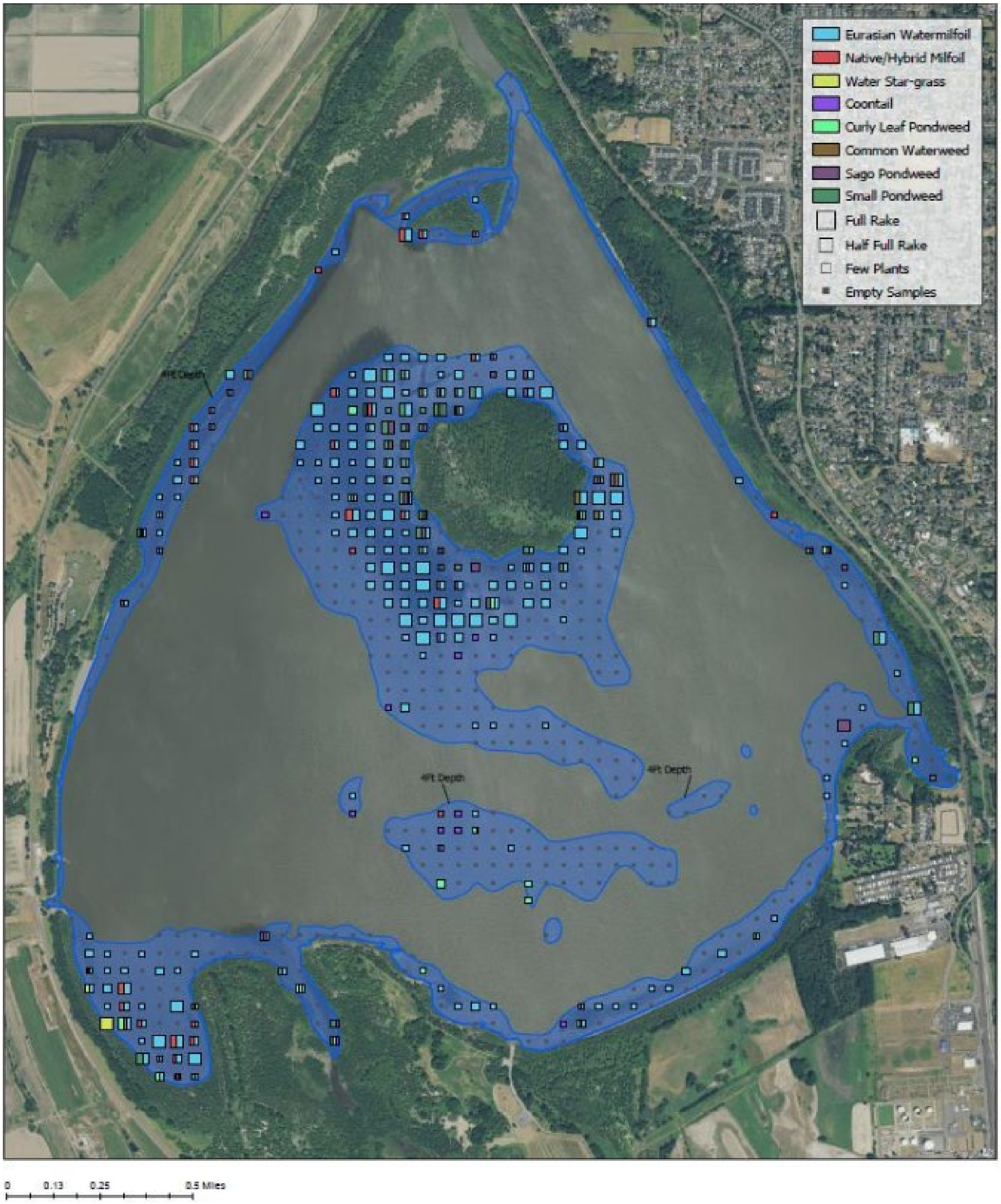


Figure 18. Aquatic plant populations by state and county surveyors, June 18–20, 2019 (Collell 2020).

Table 4. Plants Historically Documented at Vancouver Lake (Collell 2020).

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

[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.

WILDLIFE

Vancouver Lake is also home to a variety of federal and state listed species of wildlife, providing habitat for many endangered salmonids, birds, and the western pond turtle (Table 5) 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. 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 and Sandhill crane nesting, 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., purple loosestrife)
- Moist Soil Management to Restore Native Wetland Plant Communities
- The Shillapoo Ecosystem Restoration Feature (SERF) project
- The South Unit Buckmire Slough (SUBS) restoration project to reconnect the area to the Columbia River
- Oregon oak and riparian habitat enhancement at Chapman Slough and Buckmire Slough
- Columbian White-tailed Deer Management

Similarly, the Ridgefield National Wildlife Refuge is located to the north and connected to the lake via Lake River, serves as another significant winter nesting and migration resting area for over 75 species of birds, and is managed by the US Fish and Wildlife Service who works to restore and conserve oak woodlands, pasture, and wetland habitats for a variety of 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 which historically frequented the lake. Table 5 presents the federal- and state-listed species of fish and wildlife at Vancouver Lake.

Table 5. Vancouver Lake Federal and State Listed Species of Fish and Wildlife.[a]

Common Name	Scientific Name	Federal Status	WA 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
Western Pond Turtle	*Actinemys marmorata*	–	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, WA, with statuses updated according to WDFW list of threatened and endangered species (WDFW 2022).

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.

MANAGEMENT GOALS FOR VANCOUVER LAKE

PROJECT GOALS AND OBJECTIVES

This Work Plan asserts three Project-specific goals, which may both benefit lake users and improve lake health in the short-term, to include: 1) reduce impacts caused by harmful algae blooms, 2) reduce impacts caused by aquatic invasive plants, and 3) identify other specific lake uses important to public users and ecosystem function. It is assumed that these goals can be met through lake and watershed management without significantly adversely impacting fish, wildlife, and recreational uses of Vancouver Lake.

The guiding set of objectives for each goal described below are preliminary, based on estimates of diagnostic conditions. Objectives will be further refined and specified during modeling and LMP development, as more data are obtained and analyzed. The final objectives presented in the LMP will be realistic to the extent possible based on what is achievable and affordable.

1. Goal: Reduce impacts of harmful algae blooms

   - Cyanotoxin concentrations in water samples from Vancouver Lake shall not exceed Washington state and EPA guidelines for toxin concentrations (8 µg/L microcystin, 1 µg/L anatoxin-a 15 µg/L cylindrospermopsin, or 75 µg/L saxitoxin) more than once in a 10-day period. Multiple exceedances in a 10-day period (known as an 'excursion' event), shall not occur more than three times per season. Seasons with three or more excursion events shall not reoccur in consecutive years (EPA 2019).

   - Phytoplankton biomass as measured by chlorophyll-a shall not exceed a summer (June through September) average concentration of 7.2 µg/L, which equates to the lower limit of a eutrophic state at a TSI of 40. This criterion will be modified based on historical data analysis that includes evaluating long-term trends and relationships of phytoplankton biomass with cyanotoxin concentrations.

   - Total phosphorus concentrations shall not exceed a summer (June through September) average concentration of 24 µg/L, which equates to the lower limit of a eutrophic state at a TSI of 40. This criterion will be modified based on historical data analysis that includes evaluating long-term trends and relationships of total phosphorus with phytoplankton biomass.

   - Secchi depth shall exceed a summer (June through September) average value of 1 meter, which equates to the upper limit of a eutrophic state at a TSI of 50. This criterion will be modified based on historical data analysis that includes evaluating long-term trends and relationships of Secchi depth with phytoplankton biomass.

2. Goal: Reduce impacts of aquatic invasive plants
    - The area of Eurasian watermilfoil and all other submerged noxious weeds <u>required</u> for control by Clark County shall not exceed 5 percent of the total lake area.
    - The area curly leaf pondweed and all other submerged noxious weeds <u>not required</u> for control by Clark County that is within 1 foot of the lake surface shall not exceed 10 percent of the total lake area.
    - The area of purple loosestrife, yellow flag iris, and all other emergent noxious species <u>required</u> for control by Clark County shall be reduced by at least 50 percent of the existing coverage along the lake shoreline and shall not increase from managed levels.
    - Measures shall be taken to prevent introductions of noxious weeds.
3. Goal: Identify other specific lake uses important to public users and ecosystem function.

The *HAB Management Techniques* and *Noxious Weed Management Techniques* sections below briefly summarize potential management methods we will evaluate for achieving the project goals and objectives.

INCLUSIVE LONG-TERM GOALS

The Project-specific goals and objectives described above will work towards achieving the broad purpose underlying the state appropriation funding for the Vancouver Lake Management Plan project: “to restore and maintain the health of Vancouver Lake”. To drive future projects which utilize the Vancouver Lake Management Plan 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 interrelated and purposely broad to direct current and future project-specific goals and objectives, and to define long-term measures of success. These inclusive, long-term 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.

HAB MANAGEMENT TECHNIQUES

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 (Cook et al. 2005 and Lake Advocates 2017). HAB management techniques are presented in Table 6 along with a preliminary rating of their overall effectiveness, total long-term cost, impact to beneficial uses, and feasibility for implementation at Vancouver Lake. This preliminary assessment will be further developed for the LMP based on input from the project team and TAG. The purpose of the HAB management method assessment is 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 6 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.

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 Work Plan and subsequent Lake Management Plan does not address all the considerations which 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.). Comprehensive consideration is therefore important in evaluating management techniques for the current project scope and for future, adaptive management.

Table 6. Cyanobacteria Management Method Feasibility Initial Screening Example.

Method	Effectiveness	Cost	Impact	Feasibility
Watershed Methods				
Septic system upgrades and sewer connection	Moderate	High	Low	Moderate
Stormwater management	Moderate	Moderate	Low	Moderate
Stream and wetland restoration	Low	Moderate	Low	Low
Steam phosphorus inactivation by alum injection	Moderate	Moderate	Moderate	Low
Steam phosphorus inactivation by Eutrosorb	Moderate	Moderate	Moderate	Low
Lake Physical Methods				
Lake River Dam to reduce backflow into lake	High	Moderate	Moderate	Moderate
Flushing	Moderate	Moderate	Low	Moderate
Floating wetland wave breaks	Low-Moderate	Low	Moderate	Moderate
Sonic wave control by LG Sonic	Low-Moderate	Moderate	Low	Moderate
Dilution	Moderate	High	Low	Low
Lake circulation by aeration or mechanical devices (SolarBee)	Low	Moderate	Low	Low
Nanobubble oxygenation	Low-Moderate	Moderate	Low	Low
Shoreline modification	Low	Moderate	Moderate	Low
Dredging	Low-Moderate	High	Moderate	Low
Shading	Moderate	Moderate	High	Low
Lake Chemical Methods				
Phosphorus inactivation by alum	High	Moderate	Low-Moderate	Moderate
Phosphorus inactivation by Phoslock	High	Moderate	Low	Moderate
Phosphorus inactivation by iron	Moderate	Low-Moderate	Low	Low
Algaecide Hydrothol 191	Moderate	Low-Moderate	Low	Moderate
Algaecide PAK 27	Moderate	Low-Moderate	Low	Moderate
Lake Biological Methods				
Carp removal	Low	Moderate-High	Low-Moderate	Low
Zooplankton planting	Low	Moderate	Low	Low
Piscivore stocking	Low	Low	Moderate	Low-none
Shoreline plantings	Low	Moderate	Low	Low

WATERSHED 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). Vancouver includes land within five main watersheds, but the Burnt Bridge Creek watershed and, to a lesser extent, the Columbia Slope watersheds, represent the core area of the City's watershed management and, therefore, were selected as the study area for the watershed health assessment.

Water quality in Burnt Bridge Creek is generally moderate. 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 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 are increasing nitrogen and fecal bacteria concentrations and that urban development is increasing phosphorus concentrations in Burnt Bridge Creek. Riparian canopy cover showed a positive water quality effect by increasing dissolved oxygen concentrations and pH, which are considered improvements because some areas of the creek occasionally have a low pH. However, the correlation analysis of riparian canopy cover showed unexpected negative relationships with increasing temperature and turbidity in stream waters. Because riparian buffers should reduce stream temperatures and turbidity, other upstream factors are likely increasing stream temperatures and turbidity.

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
- Expand the Greenway/Sensitive Lands and urban forestry programs that increase canopy cover
- Continue to retrofit underground injection control devices 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. Therefore, control of septic system and stormwater sources of nutrients to Vancouver Lake will be evaluated by the water quality model developed for the LMP.

Septic system controls will be explored that may include but not be limited to sanitary surveys to identify nutrient loading of septic systems, upgrading systems known or suspected to contribute to nutrient loading to the lake, and expanding the sanitary sewer system to connect to high priority septic systems.

Stormwater controls will be explored by quantifying the current and planned future amounts 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. Stormwater permit requirements and codes currently differ for Clark County and City of Vancouver, but both jurisdictions can require phosphorus treatment for new development if an LMP established the need. The listing by Ecology of Vancouver Lake and Burnt Bridge Creek as water quality impaired by total phosphorus further supports the need for phosphorus treatment of stormwater polluting Vancouver Lake.

Clark County's Phase I National Pollutant Discharge Elimination System Municipal Stormwater permit (Phase I NPDES permit) currently requires implementation of a Structural Stormwater Control 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 and can be required to include phosphorus treatment rather that basic treatment of suspended solids. The City of Vancouver's Phase II NPDES permit is expected to have similar Structural Stormwater Control 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. County and City councils would need to approve a policy change and stormwater codes would need to be revised. Currently, Lacamas Creek is the only watershed in Clark County with a phosphorus treatment requirement.

Stream and wetland restoration will not be modeled for the LMP because this watershed method is not expected to result in substantial nutrient control. Stream and wetland restoration can reduce phosphorus loadings to lakes by trapping suspended solids in watersheds with erosive soils and high runoff, but source controls through stormwater management to reduce suspended solids loadings to the stream and sediment suspension in the stream by stormwater detention (which can include constructed wetlands) is generally considered to more effective than stream restoration. However, it is recognized that long-term maintenance of low nutrient levels in the lake and achievement of additional lake management goals (e.g., improve habitat for fish and wildlife) benefit from stream and wetland restoration in the Vancouver Lake watershed.

Phosphorus inactivation of stream flows in either the Burnt Bridge Creek or Salmon Creek will not be modeled for the LMP because phosphorus inactivation of lake sediments is likely more cost-effective and feasible than phosphorus inactivation of lake inflow waters.

FEASIBLE IN-LAKE METHODS

Feasible in-lake cyanobacteria control methods include the following techniques tentatively identified as having moderate feasibility (see Table 6) of meeting cyanobacteria management objectives at a reasonable cost:

- Lake River Dam
- Flushing

- Floating Wetlands
- Sonic Wave Control
- Phosphorus Inactivation
- Algaecide Treatment

Lake River Dam

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 is a water control structure (VLWP 2012). This structure could be a permanent dam and can 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).

Adam T. Bower Memorial Dam in Pennsylvania

The Adam T. Bower Memorial Dam (see photo inset) 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 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. It may be possible for the dam to support different types of boat passage different water level (e.g., motorboat passage during high tides and whitewater kayaking during low tides) and ensure fish passage during all tidal conditions.

Various dam concepts and operational procedures will be developed for the LMP and modeled to evaluate potential effects on cyanobacteria blooms. Upon determination that a dam would be effective technique to achieve these goals and does not negatively impact flows or users in Lake River, further consultation with appropriate stakeholders will occur to ensure dam design concepts include considerations of public safety related to navigation and swimming, and will meet permitting requirements (e.g., HPA).

Flushing

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.

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, it has not remedied the eutrophic water conditions and nuisance cyanobacteria blooms (VLWP 2012).

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 three alternatives were modeled to assess 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. The three alternatives include:

- **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-ft bottom to a 100-ft wide bottom. The structure has flap gates to prevent negative flow out of the lake. 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 1-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 19.

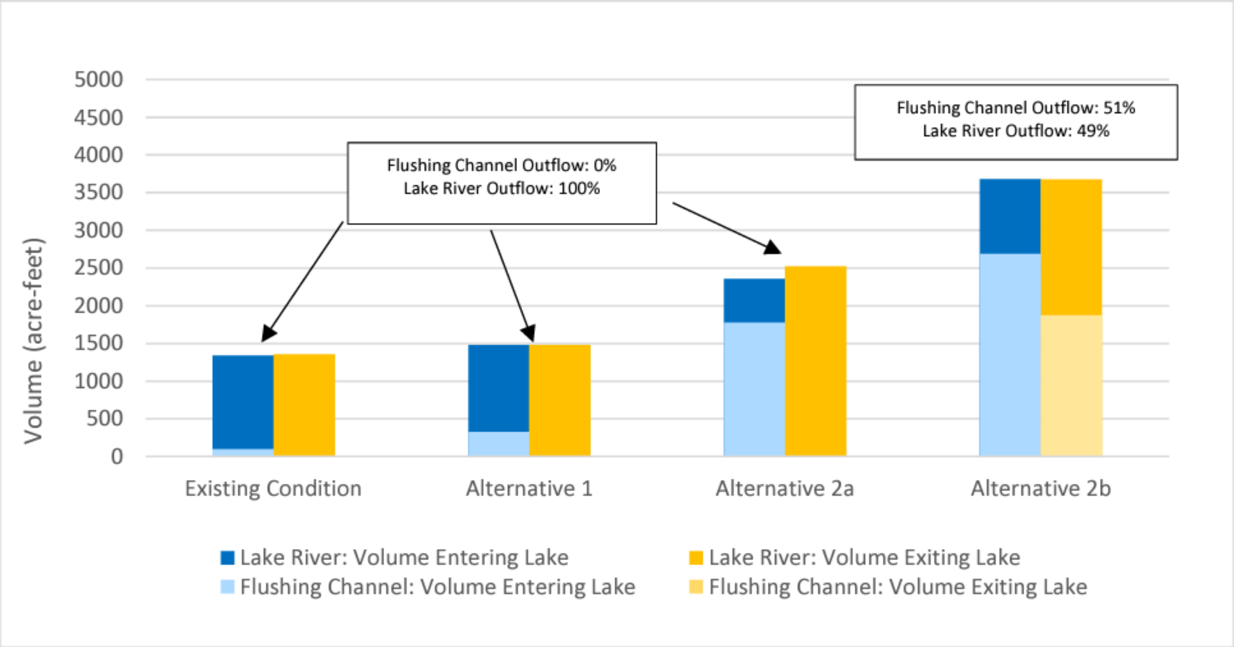


Figure 19. Model-Predicted Vancouver Lake Inflow and Outflow Volumes Through the Flushing Channel and Lake River for Existing Conditions and All Alternatives (Jacobs 2022).

Other findings demonstrated that relatively low-cost maintenance actions, especially more 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, such increased flow is still insufficient to improve water quality and the benefits do not appear to extend to Lake River (Jacobs 2022).

Floating Wetlands

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. In addition to dissolved nutrient uptake by the biofilm microbes, dissolved nutrients are taken up by the vascular plants themselves and the biofilm within the floating matrix, and suspended solids 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).

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 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 one 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 mph winds and a 3- to 4-foot storm surge in a C1 hurricane. Testing by the University of Alabama showed that it is most effective on short period waves (wind chop) and an installation depth of 4 0.5 feet is most effective for reducing shore erosion from waves.

Biohaven Floating Breakwater on Gulf Coast by Martin Ecosystems

Phosphorus Inactivation

Feasible phosphorus inactivation methods include treatment with aluminum sulfate (alum) or Phoslock®.

Alum Treatment

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).

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.

Internal loading was not identified by USGS as a significant source of phosphorus in Vancouver Lake. If modeling of the lake for the LMP indicates otherwise, then a potentially effective 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 excluding shallow areas less than 5 feet deep to avoid nearshore obstructions and sediment disturbance, but additional sediment phosphorus analysis may reveal areas of greater need for treatment than others.

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.

Phoslock Treatment

Phoslock® is the tradename for a product that is a combination of Lanthanum, a natural but rare element in the earth, and bentonite. Because the lanthanum has a strong affinity for phosphate it is able to chemically inactive phosphate through precipitation and forms a mineral of extremely low solubility; thus, permanently binding the phosphorus. 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 an 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 Phoslock can be applied in frequent small does to ‘strip’ the water column of inorganic phosphorus, Phoslock can be added to address sediment derived inorganic phosphorus. 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).

Algaecide Treatment

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) and sodium carbonate peroxyhydrate (PAK 27) are the only algaecides that can be used in the State of Washington.

Hydrothol has some use restrictions related to drinking water and toxicity to fish. PAK 27 has no fishing, drinking, or irrigation use restrictions but Ecology does require a 12-hour closure to swimming. If algaecides were to be used in Vancouver Lake, it would likely require a minimum of two treatments every summer.

INFEASIBLE IN-LAKE METHODS

There are many other in-lake methods for controlling algae that are considered inappropriate or infeasible for Vancouver Lake and will not be evaluated further for this purpose (but may be evaluated for other future management goals):

- 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]).

- Dilution: Use of a low phosphorus water supply to both 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.

- Hypolimnetic Oxygenation: Oxygenating the sediments to control phosphorus release from the sediments. The lack of a hypolimnion in Vancouver Lake makes this inappropriate.

- 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.

EVALUATION OF ENVIRONMENTAL HEALTH PROTOCOLS

Algal toxin and *E. coli* monitoring procedures and beach closure/opening protocols currently employed by Clark County Public Health generally follow US EPA and Washington State Department of Health guidance. These protocols will be evaluated for the LMP to determine if they should be modified to reduce health risks or impacts to lake users. For example, impacts to beneficial uses of the lake may be reduced by increasing the monitoring frequency, increasing the number of monitoring locations, or decreasing data turnaround time for these water quality parameters. In addition, advisory protocols could be adapted to address different risks of different uses (e.g., swimming versus boating) and locations (nearshore versus open water).

Procedures and protocols used by other jurisdictions will be investigated through interviews. Potential mitigation measures to employ for prevention of or in response to criteria exceedance will be considered, such as goose deterrence, chemical treatment, or water barriers at the swimming beach.

Currently, *E.coli* monitoring is only performed for designated swimming areas where primary contact recreation by children is encouraged. Results are compared to US EPA beach criteria and the sample testing is paid by Clark County Parks through interlocal agreement. *E.coli* monitoring for beaches began in 2001 and little has changed to the testing procedures and advisory process. This program began after an *E.coli* outbreak at Battle Ground Lake resulted in 36 illnesses mostly among children, with several hospitalized that sustained life altering injuries due to Shiga toxin-producing *E. coli* (STEC) infection. Clark County Public Health adopted EPA protocols at that time because Ecology fecal bacteria standards (based on fecal coliform bacteria) conflicted with EPA recommendations to use *E. coli* as the best fecal contamination indicator in freshwater environments. Washington State regulations for bathing beaches (WAC 246-260-180) gives local health officer authority to maintain and operate “bathing beaches” to ensure they do not create a hazard.

Monitoring freshwater beaches for fecal bacteria contamination is voluntary and not required by Washington State regulations. King County has the most extensive beach monitoring program for fecal bacteria contamination in Washington, where currently 27 beaches are monitored on a weekly basis from Memorial Day to Labor Day. King County (2022) beach closure protocols are quite different and use much higher action levels (daily average value for 3 samples of *E. coli* greater than 1,000 CFU/100 mL or the geometric mean of the most recent 3 days greater than 200 CFU/100 mL) than those used at Vancouver Lake (one or more of five samples of *E. coli* exceeding 235 CFU/100 mL).

HABs are monitored and advisories issued following US EPA and WDOH guidance, and sample testing is paid by the Washington State Toxic Algae Program. Any increase in testing frequency or locations would require additional funding not currently available. In 2020, Clark County Public Health worked with King County, Tacoma-Pierce County, and Thurston County health departments in conjunction with WDOH and EPA to develop the current HAB monitoring and protocols.

NOXIOUS WEED MANAGEMENT TECHNIQUES

Noxious weed problems in Vancouver Lake have recently been evaluated and described in the Vancouver Lake Integrated Aquatic Vegetation Management Plan (IAVMP) (Collell 2020). As summarized above in Background Information, Eurasian watermilfoil (milfoil) is a submersed aquatic plant that is the primary noxious weed 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.

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

- Physical Methods:
  - Bottom barrier
  - Hand pulling
  - Diver-assisted suction harvesting
  - Mechanical harvesting
- Biological Methods:
  - Milfoil weevil
  - Grass carp
- Chemical Herbicide Methods:
  - 2,4 D liquid
  - Triclopyr granular and controlled release pellet
  - 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. Method descriptions and assessments are summarized in Table 7. Other plant control methods not assessed by the IAVMP include weed rollers, rotovation, lake level drawdown, sediment dredging, water circulation, shading, and planting native plants.

Table 7. Invasive Aquatic Plant Management Method Assessment (Collell 2020).

Method	Description	Vancouver Lake Assessment
Physical		
Bottom barrier	Permeable barrier anchored to lake bottom to prevent plant growth in up to 50 % 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, but also kills many native plants	Relatively low effectiveness due to high dilution and impacts native species.
Triclopyr	Systemic herbicide effective on milfoil; slow-release pellets provide needed contact time; much more selective than 2, 4 D with only a few native plants affected	Relatively high effectiveness with slow-release pellets and low impacts native species.
ProcellaCOR	Systemic herbicide effective on milfoil and requires short contact time; very selective with no other plants affected.	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.

Table 8 summarizes permitting requirements for the physical methods (WDFW 2015). Chemical herbicides are permitted by Ecology's Aquatic Plants and Algae Management Permit, which is a combined federal National Pollutant Discharge Elimination System (NPDES) and State Waste Discharge General Permit (Ecology 2022b).

Table 8. Permit Requirements for Physical Control of Aquatic Plants.

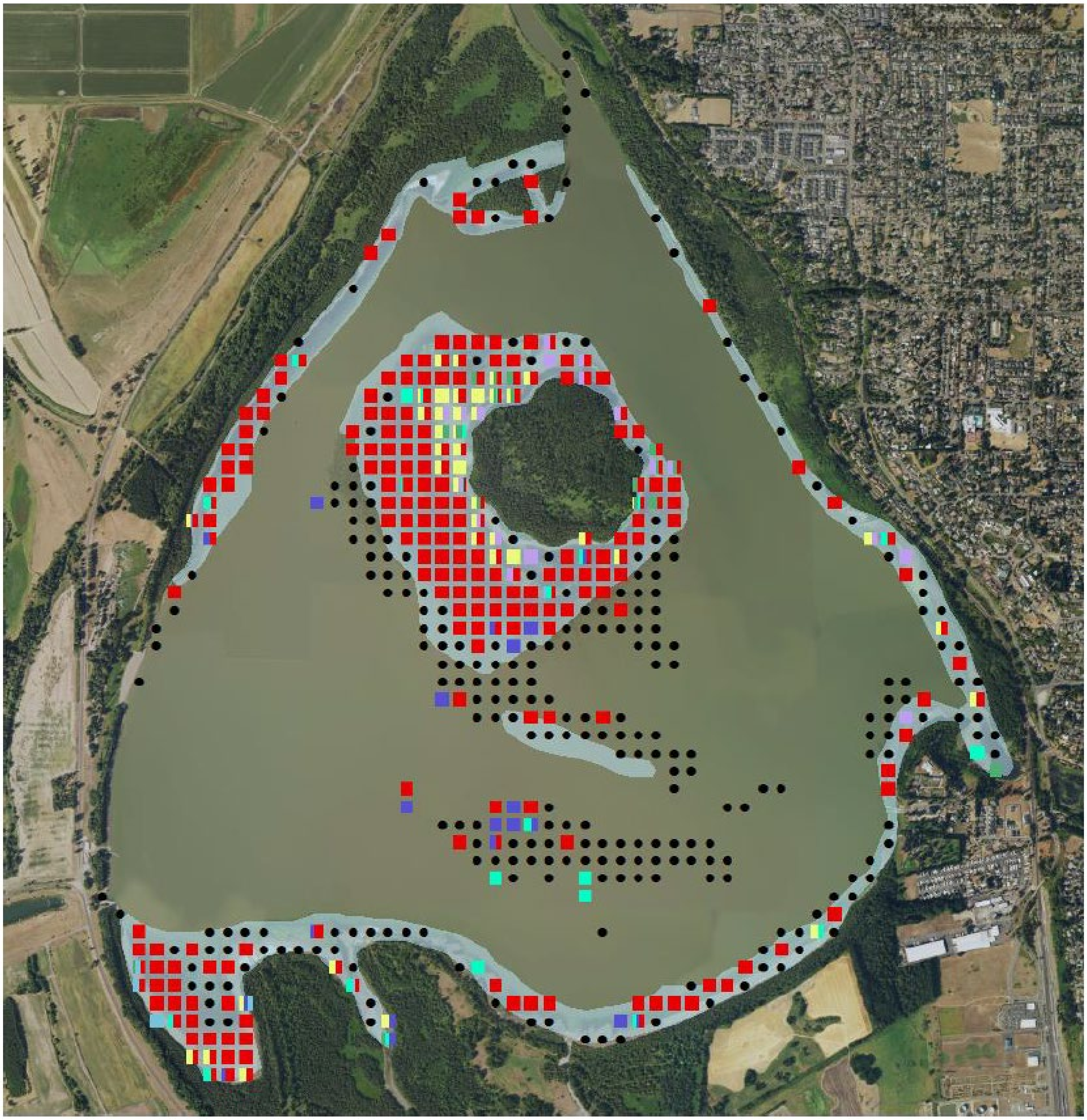
Control Method	Aquatic Noxious Weed Permit Requirement			Aquatic Beneficial Plants Permit Requirement		
	Pamphlet without Area Limitations	Pamphlet with Area Limitations	Individual HPA	Pamphlet without Area Limitations	Pamphlet with Area Limitations	Individual HPA
Removal by Hand	✓				✓	
Bottom Barriers 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 July 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 600 acres of the lake. The impacted and targeted treatment area is shown in Figure 20.

Clark County was awarded $45,000 from the Washington Department of Ecology's Aquatic Invasive Plants Management Grants Program to help fund the initial two-year IAVMP to include monitoring and additional treatment of milfoil. As per the IAVMP, Clark County and project partners performed a follow-up plant survey in summer 2021 and will perform a second survey in summer 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.

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.



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.

Figure 20. Milfoil Impacted and Targeted Treatment Areas in Vancouver Lake.

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 4):

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

The LMP will include updated information from Clark County and FOVL about aquatic plant surveys and treatments performed in 2020, 2021, and 2022. The LMP will further evaluate control methods and develop aquatic plant management scenarios for milfoil, curly leaf pondweed, purple loosestrife, and yellow flag iris starting in 2023 using the IAVMP information, survey results, treatment effectiveness data, additional technical analysis, and stakeholder input.

The LMP also will identify methods for preventing infestation of the lake from aquatic invasive plants and animals. Methods will be based on education, inspection, and decontamination procedures and lessons learned by the Whatcom Aquatic Invasive Species (AIS) Program in Whatcom County, where boats and equipment are inspected at four checkpoints before entering Lake Whatcom and Lake Samish to ensure they are clean, drained, and dry and are not transporting aquatic invasive species (WAISP 2022). Boats are decontaminated at a checkpoint if they are deemed to be an AIS threat, which has been performed on less than 10 percent of the inspected boats. The main AIS of interest in Whatcom County lakes are the zebra mussel (*Dreissena polymorpha*) and quagga mussel (*D. bugensis*), but the program also includes the New Zealand mudsnail, Asian clams, Eurasian watermilfoil, and other invasive plants.

Monitoring by WDFW has shown that this program has been effective in preventing the introduction of zebra or quagga mussels to Whatcom County as no species have been found in the lakes since the program began 10 years ago. To date, the program has conducted almost 100,000 inspections and has intercepted 29 boats transporting or suspected of transporting zebra or quagga mussels, 1,366 boats transporting vegetation, and another 3,579 boats that were either wet or found to be transporting standing water. In 2018, the program detected New Zealand mudsnails in Lake Padden and has since detected them in nearby streams. No mudsnails have been detected in Lake Whatcom, Lake Samish, or at any of the four checkpoints. Non-motorized watercraft usage hit record highs during the pandemic in 2020 and 2021 and the similar management approaches have been effective in preventing the spread of aquatic invasive species (WAISP 2022).

New Zealand mudsnails and curly leaf pondweed are present in Burnt Bridge Creek. Therefore, aquatic invasive species management and prevention in the watershed will also be considered to prevent reintroduction or further expansion to Vancouver Lake.

MODELING PLAN

LimnoTech is tasked with developing an ecosystem model for the system to help guide development of the Vancouver Lake Management Plan. The model will be capable of simulating ecological responses in the lake to several potential management options. Given that the lake management objectives focus on cyanobacteria control, the model must be able to adequately represent this algal functional group, as well as the nutrient cycling and lower food web interactions associated with cyanobacteria. The model will be able to predict effects of management options on fish and wildlife habitat with respect to water temperature, dissolved oxygen, and water clarity, but will not predict effects on fish and wildlife populations. Aquatic plant impacts will not be predicted by the model but can be inferred from the effects on water clarity.

Development of a model simulating cyanobacteria may not be appropriate based on the limited amount of data available for accurately predicting cyanobacteria abundance. LimnoTech will assess the potential to model basic eutrophication responses with correlations to toxicity and cyanobacteria growth to meet the goals and requirements of evaluating the management alternatives.

Additionally, as Vancouver Lake is a dynamic floodplain-based system, the model must also capture the appropriate spatial resolution. Given these primary criteria, LimnoTech will assess several modeling packages and software and determine the most appropriate approach to develop the model.

Table 9 presents the parameters (used for calibration and validation of the water quality model. Detailed lake and watershed data are available for water years 2011 and 2012, which will be targeted as the time period for development of the model. Boundary conditions for the HEC-RAS model including upstream flow inputs and tidal boundary conditions will be extended to cover the 2011-2012 period.

Table 9. Water Quality Calibration Parameters.

Observed Parameter	Priority
Chlorophyll-a	Critical
Total phosphorus	Critical
Orthophosphate phosphorus	Beneficial
Total Nitrogen	Critical
Dissolved Inorganic Nitrogen (nitrate=nitrite and ammonia)	Beneficial
Dissolved oxygen	Critical
Temperature	Critical
Sediment oxygen demand	Beneficial

Table 9 (continued). Water Quality Calibration Parameters.

Observed Parameter	Priority
Algal functional group distribution	Beneficial
Zooplankton biomass	Low/medium
Growth rate kinetics	Low

LimnoTech will leverage the existing 2-dimensional HEC-RAS model of the system to the extent possible. The simplified water quality module that is contained within HEC-RAS is not fully operational for 2-dimensional applications and cannot reliably simulate cyanobacteria and other water quality parameters. Therefore, an alternative water quality model will be required. An attempt will be made to link the output from the existing HEC-RAS model to the selected water quality model to represent the hydraulics and hydrodynamics. Based on a limited initial assessment, it may be appropriate to link the HEC-RAS hydrodynamic model to a WASP water quality model, following the approach of Shabani et al. (2021). However, it may be necessary to use an alternative hydraulic and hydrodynamic model if this linkage is not feasible.

While assessing potential ecosystem model options, LimnoTech will consider the following criteria and options:

- Evaluation of existing HEC-RAS model
- Number of algal functional groups and succession complexity
- Phosphorus speciation and cycling
- Nitrogen speciation and cycling
- Sediment-water interactions
- Spatial resolution/dimensionality
- Lower food web components (e.g., zooplankton)
- Ability to simulate (explicitly or implicitly) management options such as alum treatment, flow diversions, etc.

Once the ecosystem model framework is chosen, the model will be set up to operate in a linked fashion, isolating the hydraulics and hydrodynamics from the water quality components. This will allow management options to focus on one aspect and the relative impacts of each option can be properly assessed.

Model development will proceed with the following plan:

1. Existing model review

   LimnoTech will review the existing HEC-RAS model and evaluate its ability to either be extended to include water quality components or used alongside a separate water quality model to create an ecosystem modeling tool that meets the needs of the project.

2. Data acquisition and assessment

   Water quality, hydraulic, and biological data for Vancouver Lake are abundant (see *Background* section for summary) and general assessments indicate lake conditions have not changed substantially throughout the data availability period. In addition, extensive water quality monitoring data are available for Burnt Bridge Creek, Salmon Creek, and the Lakeshore watershed. Thus, new data collection is not necessary for this project.

   LimnoTech and project partners will aggregate any relevant hydrodynamic and water quality data to use for model development and calibration. These data can consist of in-situ, remote or other observational data, as well as existing model output that may be of use. Recent flow data in Lake River will also be compiled to account for potential changes in flow from previous models due to recent water quality improvement projects (e.g., dredging) by the Port of Ridgefield. Herrera will provide LimnoTech the compiled existing hydrodynamic and water quality data specified above in spreadsheet formats for use in model input and calibration/validation.

3. Hydrodynamic model development and application

   The hydrodynamic model acts as a driver for flows and mixing in the system. As noted above, LimnoTech will attempt to leverage the existing HEC-RAS model to the extent possible. If an alternate hydraulic/hydrodynamic model is required, the model outputs will be compared to both observed data and the existing model to ensure adequate representation of the system.

   The hydrodynamic model will be run to simulate flows and meteorological conditions over a typical growing season and water year, as well as cases corresponding to particularly high nuisance algal growth for management purposes. Any management alternatives related to flow diversions, mixing augmentation will be simulated to the extent possible with the chosen hydrodynamic model.

4. Water quality model development and application

   The outputs (velocity fields, mixing, temperature) from the hydrodynamic model will be externally linked to the water quality model. This decoupling allows for more efficient computer resources management, as well as independent assessment of physical and biological management alternatives.

Other main forcings for the water quality model include meteorology and nutrient loads (both external and potentially internal). The nutrient loads will be the main mechanism for management alternatives related to algal blooms and other eutrophication processes. The model will be used to implement nutrient reduction strategies by scaling the time-series of external loads to the lake, as well as potentially mitigating internal nutrient sources from the sediments.

The water quality model will simulate the same time periods as the hydrodynamic model and represent the same conditions of each hydrodynamic run. Because the models are decoupled, several nutrient reduction simulations can be performed with the water quality model for each individual hydrodynamic simulation. LimnoTech will provide results from model scenarios to the project team for incorporation into project deliverables, stakeholder meetings, and TAG meetings.

FUNDING PLAN

Initial development of the funding plan will begin with development of a comparative matrix of funding options. The list of funding sources we will consider includes:

- Lake management district (which was researched by the VLWP)
- Special purpose district
- State budget appropriation (which was used to fund the LMP)
- Clark County clean water project (which is an enterprise fund required to be used for stormwater compliance and could be used to fund stormwater management in the lake watershed)
- Lake management fee
- Inter-agency agreements (assuming agencies have funds available for lake management)
- Ecology Water Quality Combined Funding Program (annual budget of $100 to $200 million)
- Ecology Algae Control Program (annual budget of $100,000 to $200,000)
- Ecology Aquatic Invasive Plant Grant Program (annual budget of $350,000)
- National Estuary Program Grants
- Other local and federal grants for activities that directly benefit fish passage and fish habitat (such as increasing the size of the flushing channel)

We will also collect information from states with strong lake management programs (e.g., Minnesota, Wisconsin, and Florida) to inquire about their funding approaches. This will be a small effort in terms of hours but may generate new ideas as well as more information on benefits and constraints of different programs.

The comparative matrix will include components such as:

- Whether the funding source is appropriate for long-term or short-term needs
- The expected limits on the fund source in terms of revenue generated

- Complexity of establishing the funding source
- Reliability of the funding source
- Likely managing entity and their responsibilities

The matrix will be shared with TAG members at one of the TAG meetings and be used to launch initial discussions about long term funding needs and the most likely paths to consider for funding. Based on those discussions additional work will be done to further refine the approach and potential revenue associated with, for example, establishing a special use district.

When the planning level costs have been defined for the different management scenarios, we will identify which components may be appropriately treated as a one-time cost and those that will be long-term costs and link these to potential funding sources. We will then develop up to three potential funding plans that will likely rely on multiple funding sources to lay out a plan for funding lake management activities over a 10-year period.

STAKEHOLDER INVOLVEMENT PLAN

Stakeholder involvement will entail frequent participation from a technical advisory group (TAG) and occasional engagement with the general public. Herrera and Clark County identified key project stakeholders for the TAG based on past and present interest in the review of project documents and attendance at virtual project meetings (see *Technical Advisory Group* section above). Rob Zisette will regularly (e.g., every second month) meet with the TAG for virtual project updates and input.

Samantha Meysohn will lead additional stakeholder involvement and strategy development tasks (Table 10), starting with interviews of representative stakeholders to better understand the diversity of opinions on Vancouver Lake and how best to engage the public. Samantha will engage with the TAG to understand their role as key stakeholders. Based on these discussions, she will draft a survey and circulate it to the public. Samantha will analyze results and present these to the public at the first Public Webinar. She will incorporate feedback and utilize the input to draft an annotated outline for a stakeholder involvement strategy, which will identify how key stakeholders will implement the LMP and make adaptive management decisions. It will also outline procedures for educating the public and gathering feedback from the general public about lake management issues. This Stakeholder Involvement Plan will be included in the LMP for simultaneous and complementary implementation.

All project documents will be made available for email distribution and posting on a website.

Table 10. Stakeholder Involvement Tasks and Timing.

Task	Timing
Interview 3-5 representative stakeholders	End of July 2022
Develop a public survey	July 2022
Administer the survey and receive feedback	July–August 2022
Meet with TAG to discuss stakeholder involvement	August 2022
Analyze survey results	
Present the present document (Draft Work Plan) and survey results at a Public Webinar	
Develop a Draft Stakeholder Involvement Plan	September 2022
Review the Stakeholder Involvement Plan	November 2022
Present the Draft Lake Management Plan and hear input from the public at a Public Webinar	May 2023

LAKE MANAGEMENT PLAN

The Herrera Team will use water quality modeling results, additional research, and stakeholder feedback to further develop up to three cyanobacteria management scenarios and three aquatic plant management scenarios for meeting the management goals. Planning level costs will be developed for each scenario that may be modified based on the initial model results. The relative uncertainty in effectiveness and cost will be assessed for each scenario based on experience and literature.

The Herrera Team will work with the TAG to identify various funding strategies and their advantages. Given the nature of land ownership in the watershed coupled with Vancouver Lake's importance as a regional recreational asset, some of the more traditional mechanisms for funding lake management activities (e.g., a lake management district) may not be as appropriate. The funding plan may need to reflect a blend of strategies for meeting different needs. Funding constraints will be identified and may restrict or delay the implementation of more costly long-term management scenarios.

The Lake Management Plan will be clearly written and formatted, concise but detailed, and will be based on the best available lake and watershed science. We will prepare a preliminary draft LMP for review by the TAG, a draft LMP for presentation to the public, and a final LMP responding to public input.

The LMP will include the following sections:

- Introduction
- Lake and Watershed Characteristics
    - Watershed Features
    - Lake Hydrology and Hydraulics
    - Trophic State and Water Quality
    - Phosphorus Budget
    - Harmful Algae Blooms
    - Aquatic Invasive Weeds
- Lake Management Goals
    - Project Goals and Objectives
    - Inclusive Long-term Goals

- HAB Management
    - Alternative Scenario Development
    - Modeling Methods and Results
    - Short-term Actions
    - Long-term Actions
- Aquatic Invasive Weed Management
    - Alternative Scenario Development
    - Short-term Actions
    - Long-term Actions
- Additional Lake Management Issues
    - Fecal Bacteria
    - Fish and Wildlife
- Evaluation of Lake Management Activities
- Adaptive Management
- Funding Analysis and Plan
- Stakeholder Involvement
    - Initial Strategy
    - Project Activities
    - Implementation Plan
- Knowledge Gaps and Plan Limitations
- References

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