DRAFT

Technical Foundation for Future Management of Vancouver Lake

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Prepared by the

Vancouver Lake Watershed Partnership's Technical Group

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Glossary

Accretion: The accumulation of sediment deposited by natural fluid flow processes.

Algae: Primitive, primarily aquatic, one-celled or multicellular plant-like organisms that lack true stems, roots, and leaves but usually contain chlorophyll.

Algal bloom: The rapid excessive growth of algae.

Bathymetry: The science of measuring the depths of oceans, seas, or other large bodies of water.

Bluegreen algae: (see cyanobacteria)

Chlorophyll *a*: A green pigment that plants use to harness the energy in sunlight.

Chlorophyte: A green alga found mainly in fresh water.

Ciliates: Unicellular organisms having a margin or fringe of hair-like projections.

Cladoceran: Any of various small, mostly freshwater crustaceans of the order Cladocera, which includes the water fleas.

Copepod: Marine or fresh-water crustaceans usually having six pairs of limbs on the thorax; some are abundant in plankton.

Cyanobacteria (commonly known as bluegreen algae): A photosynthetic bacterium, generally blue-green in color and in some species capable of nitrogen fixation. Cyanobacteria were once thought to be algae.

DDT: Dichloro-diphenyl-trichloroethane, a synthetic insecticide used widely in the United States from 1945 to 1970. Although now banned in the United States, DDT may persist in the environment as a legacy contaminant.

Deposition: The deposit of sediments in an area through natural means, such as wave action or currents, or mechanical means.

Diatom: A unicellular organism of the kingdom Protista, characterized by a silica shell.

Dinoflagellates: A chief constituent of plankton characteristically having two flagella and a cellulose covering.

Dredging: The removal or redistribution of sediments from a watercourse.

Ecosystem: A community of organisms in a given area together with their physical environment and its characteristic climate.

Emergent vegetation: Rooted plants that can tolerate some inundation by water and that extend photosynthesis parts above the water surface for at least part of the year; emergent vegetation is intolerant of complete inundation over prolonged periods.

Estuary: A semi-enclosed coastal body of water with a free connection to the open ocean in which sea water is diluted with runoff from the land.

Eutrophication: A process whereby water bodies, such as lakes, estuaries, or slow-moving streams, receive excess nutrients that stimulate excessive plant growth.

Exotic species: A non-native plant or animal that is deliberately or accidentally introduced into a habitat.

Fill: Sand, sediment, or other earth materials that are placed, deposited, or stockpiled.

Fluvial: Involving running water; usually pertains to stream processes.

Freshet: High stream flow caused by rains or snowmelt and resulting in the sudden influx of a large volume of freshwater.

Habitat: The physical, biological, and chemical characteristics of a specific unit of the environment occupied by a specific plant or animal; the place where an organism naturally lives.

Macroinvertebrates: Invertebrates that are typically of visible size, such as clams and worms.

Macroplankton: Plankton between 200 and 2,000 micrometers (µm) in size.

Marsh: An area of soft, wet, or periodically inundated land, generally treeless and usually characterized by grasses and other low growth.

Microinvertebrate: An invertebrate of microscopic size.

Microplankton: Plankton between 20 and 200 micrometers (µm) in size.

NTU: Nephelometric turbidity unit; a measure of turbidity, using light reflection.

Phytoplankton: Tiny, free-floating, photosynthetic organisms in aquatic systems; includes diatoms, desmids, and dinoflagellates.

Plankton: Small or microscopic organisms, including algae and protozoans, that float or drift in great numbers in fresh or salt water, especially at or near the surface, and that serve as food for fish and other larger organisms

Polychlorinated biphenyls (PCBs): A group of synthetic, toxic industrial chemical compounds that are chemically inert and not biodegradable; they once were used in making paint and electrical transformers.

Polycyclic aromatic hydrocarbons (PAHs): A group of more than 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances, such as tobacco or charbroiled meat.

Rotifer: Aquatic multicellular organisms having a ciliated wheel-like organ for feeding and locomotion; constituents of freshwater plankton.

Sand: An unconsolidated mixture of inorganic soil (possibly including disintegrated shells and coral) consisting of small but easily distinguishable grains ranging in size from about 0.062 mm to 2.0 mm.

Sediment: Material in suspension in water or recently deposited from suspension; in the plural, all kinds of deposits from the waters of streams, lakes, or seas.

Submerged vegetation: Rooted plants with most of their vegetative mass below the water surface

Tidal prism: The difference in the volume of water covering an area, such as a wetland, during low tide and the volume covering it during the subsequent high tide.

Tide: The periodic rise and fall of water that results from gravitational attraction of the moon and sun acting on the rotating earth.

Tide gate: A structure placed near or at the outlet of a conduit flowing into a body of water that regulates incoming or outgoing flow from tides.

Turbidity: The cloudiness or haziness of water caused by high dissolved or suspended loads. Some causes of turbidity include the growth of phytoplankton and suspended sediment. Turbidity is often measured when testing water quality.

Zooplankton: Plankton that consists of tiny animals, such as rotifers, copepods, and krill, and of microorganisms once classified as animals, such as dinoflagellates and other protozoans.

CHAPTER 1

Introduction

Background

Vancouver Lake is a community icon treasured for its recreational, environmental, and aesthetic values. In October 2004, through a collaborative and community-driven effort, the Port of Vancouver, Vancouver-Clark Parks and Recreation, Clark County, the City of Vancouver, and the Fruit Valley Neighborhood Association became founding partners of the Vancouver Lake Watershed Partnership. The Partnership is a 22-member body that serves as a forum for consensus on the future of Vancouver Lake. The 22 members include citizens and interest groups, as well as representatives of federal, state, and local agencies.

The initial push to establish the Partnership stemmed from community concern regarding extensive reoccurring bluegreen algal blooms that render the lake a potential public health hazard during several weeks of the summer. Bluegreen algal blooms make the lake unsuitable for water contact activities because algae have the potential to produce harmful toxins. Nuisance algal blooms can have detrimental effects on lake ecosystems by depleting oxygen levels and can be aesthetically unappealing through the development of surface scums.

Although bluegreen algal blooms are a central concern at Vancouver Lake, the community also is concerned about other issues, such as the presence of toxins and pathogens, high water temperatures, excessive nutrients, and high turbidity levels. These often interrelated problems disrupt community use of the lake (when it is closed to water contact activities because of health concerns) and can be detrimental to the local ecosystem, including plants, animals, and fish.

The Partnership and its Steering Group have been meeting regularly since 2004 to create a vision for Vancouver Lake, to learn how the lake functions, and to understand potential remedies. To accomplish these tasks, the Partnership has engaged Washington State University – Vancouver (WSU) to study the algal issues and the U.S. Army Corps of Engineers – Portland District, to study lake hydraulics. These technical efforts are beginning to produce results that will help inform the Partnership's vision, its understanding of lake function, and potential future studies of the lake.

Purpose of This Document

This document is intended to organize and convey what we think we know and what we would like to know about Vancouver Lake from a technical perspective in order to address bluegreen algal blooms and other issues that are important to the Partnership. As a product of the Partnership's Technical Group, this document it is meant to serve as a technical strategy for the Partnership and is designed to prioritize and guide new technical studies that are needed to better understand how the lake functions. The document also will help identify areas where members of the Vancouver Lake Watershed Partnership agree and potentially disagree about the issues, their causes, and the information needed to help resolve those issues.

The audience for this document is the Vancouver Lake Watershed Partnership and its Steering Group as well as the many public and private interests that participate in and follow the Partnership's progress. This document is not intended to be a narrowly focused scientific paper with jargon and implied understanding. Instead, it is written for a lay audience that has interest in moving forward toward implementation of a shared vision for Vancouver Lake.

Overview of Vancouver Lake

Character of the Lake and the Larger Watershed

Vancouver Lake is relatively large, covering approximately 2,300 acres. It is the largest of the shallow lakes in the Columbia River floodplain and the largest lake in the Portland/Vancouver metropolitan area (see Figure 1-1). The water level in the lake fluctuates greatly and frequently as sources of water to the lake vary throughout the year. In general, Vancouver Lake is considered a shallow lake, with a mean depth of 3 to 5 feet. Shallow lakes are dynamic because they are easily affected by climate and weather, have a large amount of open water relative to shoreline length, and have a sizeable amount of lake bottom in contact with overlying open water.

The main water bodies that are hydrologically connected to Vancouver Lake are Salmon Creek, Burnt Bridge Creek, and Lake River. Salmon Creek drains approximately 92 square miles in Clark County and flows through or near the towns of Hazel Dell, Battle Ground, Brush Prairie, and Dollars Corner. Burnt Bridge Creek drains approximately 27 square miles and flows through the City of Vancouver. Lake River is a 12-mile slough connecting Vancouver Lake with the Columbia River. Smaller tributaries that flow into Vancouver Lake include Chicken Creek and Buckmire Slough; not much is known about them.

History of Vancouver Lake

The Lake's Formation

Hydrologically, Vancouver Lake is closely linked to the Columbia River. It is likely that Vancouver Lake was formed as a result of overbank flooding from the Columbia River, which could have been seasonal or episodic, such as with the recurring Missoula floods. This overbank flooding inundated and scoured the lowland areas, creating many small, shallow lakes and sloughs along the Columbia River floodplain in the general vicinity of Vancouver Lake.

Historically, seasonal flooding and scouring maintained the lake's depth and flow patterns. Water moved through sloughs and over low-lying banks south and west of Vancouver Lake and exited through Lake River to the north. In essence, it is likely that Vancouver Lake and other nearby floodplain lakes were side channels of the Columbia River.

Figure 1-1
Location of Vancouver Lake

Previous Restoration Efforts

Vancouver Lake has been the focus of numerous studies, plans, and restoration efforts over the past 50 years. The work has been a collaborative effort between public agencies, elected officials, and the general public. Although the Port of Vancouver often functioned as the lead agency, considerable assistance has been offered by Clark County, the City of Vancouver, Washington Department of Fish and Wildlife (WDFW), and other local, state, and federal agencies.

Beginning in the early 1960s, development plans for the lowlands were being drafted and the Port of Vancouver contracted with WSU to investigate alternatives to improve the poor water quality of the lake. In 1971, a private firm was hired by the Port to investigate the engineering and economic feasibility of several dredging and flushing alternatives recommended by WSU. The eventual recommended plan involved dredging and flushing actions to improve water quality. An environmental impact statement was completed, permits and funding were coordinated, and in the early 1980s Vancouver Lake underwent several major construction efforts (Gary Struthers Associates, Inc. 2005).

The final construction included two major components: lake dredging and creation of a flushing channel. Most in-lake dredging occurred from the mouth of Lake River to the flushing channel, with the intent of optimizing water movement through the lake. Dredged materials were placed along some areas of the lakeshore and used to create a more than 50-acre island within the lake. The flushing channel was built between 1981 and 1983 at the lake's southwest side to improve hydrologic connectivity between Vancouver Lake and the mainstem of the Columbia River (see Figure 1-2). Two 84-inch culverts with tide gate structures carry the flushing water under Lower River Road (Gary Struthers Associates, Inc. 2005).

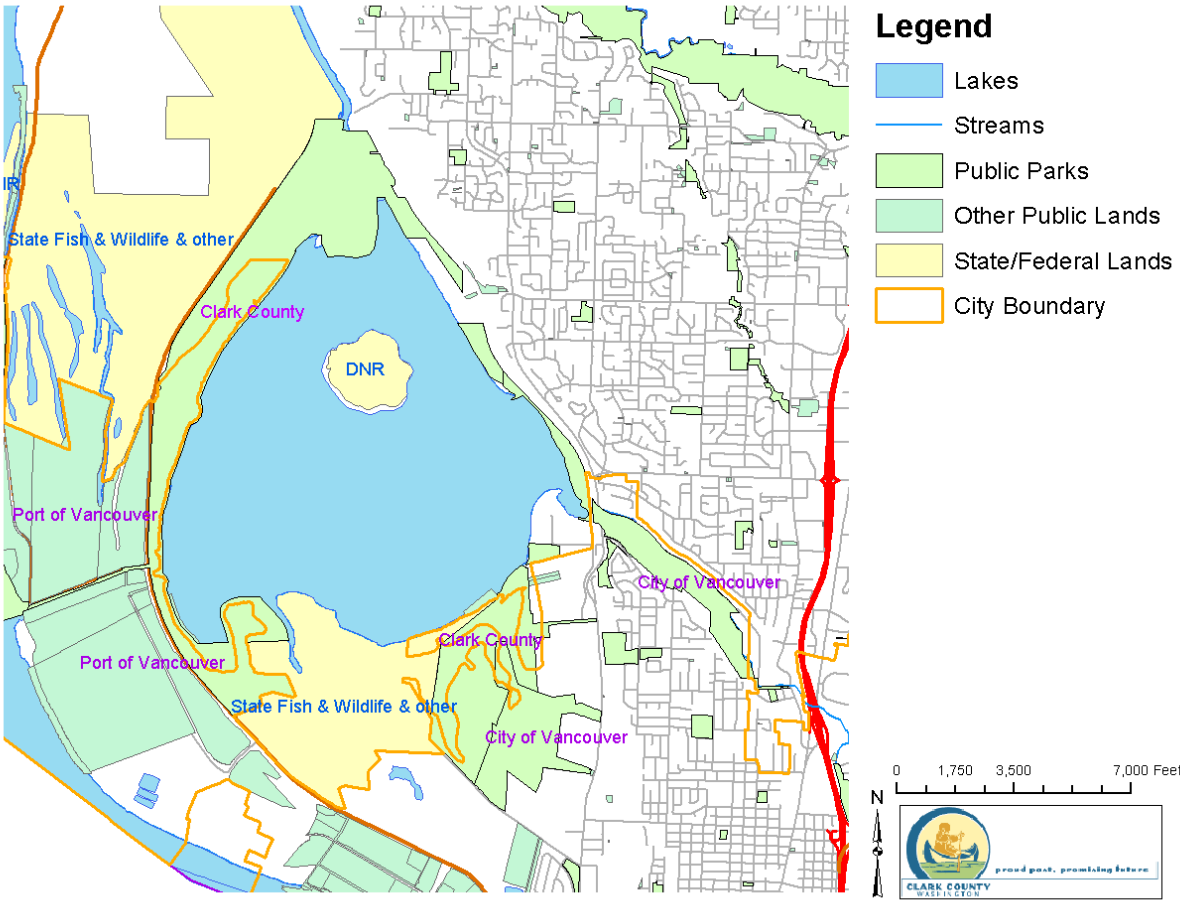
Figure 1-2
Vancouver Lake

Ownership and Surrounding Land Uses

General Ownership

Vancouver Lake's shoreline is more than 7 miles long, and much of it is publicly owned. Specific shoreline owners include Clark County, the City of Vancouver, Washington Department of Fish & Wildlife, and Washington Department of Natural Resources (see Figure 1-3). The Department of Natural Resources owns the Vancouver Lake lakebeds and tidelands.

Figure 1-3
Surrounding Ownerships



Uses of Vancouver Lake

Recreation is the primary use of Vancouver Lake. Sailing, rowing, and swimming are important activities that draw thousands of visitors annually, and a network of parks and trails adjacent to the lake provide opportunities for jogging, walking, and picnics. Wildlife watching—primarily of birds—and paddling are also recreational focuses. Many people fish the shoreline around the flushing channel and Vancouver Lake Park. Duck and goose hunters can be found in the winter months along the south and north shores, and around the island.

Annual Vancouver Lake recreation data have not been documented. However, based on a seasonal fee collection program that runs every day from Memorial Day through Labor Day and on weekends through the end of September, Vancouver-Clark Parks & Recreation estimates between 33,000 and 35,000 park visitors during the summer season, with an additional 12,000 to 15,000 visitors who come to the park during non-fee collection periods during the summer and remainder of the year (Kok 2008). [In addition, in a community survey conducted for Vancouver-Clark Parks & Recreation's most recent comprehensive plan on regional park usage, respondents listed Vancouver Lake Park as one of the four best-known parks in the City of Vancouver and Clark County. Approximately 70 percent of residents visit regional parks annually, and 50 percent of respondents reported observing wildlife at regional parks during the previous year (Vancouver-Clark Parks & Recreation 2007).

Surrounding Land Uses

The Salmon Creek and Burnt Bridge Creek watersheds have seen a significant amount of development and land use changes over the years. Major land uses include housing, industry, retail, and roads, followed by forestry and agriculture (GeoEngineers 2001). The Port of Vancouver lies to the southwest of Vancouver Lake, and a rail line travels along the northern shore.

Although a few residences dot the lakeshore itself, the majority of land in the Vancouver Lake lowlands is held in open space as farms and pasture, wildlife habitat, and parks (see Figure 1-4). The Vancouver Lake area and some of the adjoining private farmlands are unique in that they represent the last remaining sizeable block of land in the area that is not protected from flooding by dikes (Washington Department of Fish and Wildlife 2008).

The Shillapoo and Vancouver Lake wildlife areas are located northwest and south, respectively, of Vancouver Lake and are managed by the Washington Department of Fish and Wildlife. They comprise of approximately 1,550 acres of pasture/grassland, forest, riparian areas, and wetlands (Washington Department of Fish and Wildlife 2008).

Figure 1-4
Surrounding Land Uses

CHAPTER 2

Hydrology, Vegetation, Fish and Wildlife

Lakes are unique because they can range in size and shape from little more than a pond to deep reservoirs many miles long, or to large, shallow systems like Vancouver Lake. Each of these systems is completely different from the others, having a distinct pattern of physical characteristics such as surface area, depth, and the number and size of inflows and outflows. In turn, physical factors dictate the type of fish species present in a lake, the extent of aquatic vegetation, and the distribution and abundance of algae.

Many of the problems with Vancouver Lake are related to its physical character as a turbid shallow lake. This chapter provides information on the general characteristics of such lakes, describes how Vancouver Lake fits within that context, and discusses how the lake's physical characteristics affect its vegetation, fish, and wildlife.

What Makes Shallow Lakes Different?

Shallow lakes are different from deep lakes for several reasons. One of the main reasons is that in a deep lake, water near the surface is very distinct from water near the bottom. The upper portion is frequently mixed by wind and warmed by the sun. Available light allows many different organisms to live, photosynthesize, and grow in the upper portion. But the bottom portion of a deep lake receives little or no light, and the water is much colder. The main biological and chemical activity at the bottom is decomposition, meaning the decay of dead organic matter.

In a shallow lake, conditions between the upper and bottom layers are more similar. The water is mixed by wind or some other mechanism (such as fish movement), and the lake's physical characteristics tend to vary little with depth. Vancouver Lake, for example, has a large surface area, which means that a large portion of the water is influenced by sunlight. Photosynthesis and productivity tend to be proportionately higher than in deeper lakes and occur throughout the water column.

Because of the common position of shallow lakes lower in the landscape, the ratio of drainage area to lake size typically is high, and shallow lakes in general store more nutrients. In a shallow lake, much of the lake bottom sediment is in contact with the overlying lake water, which means that the physical and chemical interactions at this interface have a greater influence on the water column. Internal nutrient loading to the water column, such as through resuspension of sediment, is often important in shallow lakes.

Two States of Shallow Lakes

Shallow lakes tend to exist in two distinct conditions: the turbid-water state or the clear-water state. They can exist for years in either state because each one can be relatively stable and a major disturbance is required to move from one state to the other.

The clear-water state is typified by clear water, abundant submerged and emergent aquatic plants, and a healthy and diverse population of fish and other aquatic organisms. Clear water is typically the result of stable bottom sediments that are protected from wind and wave action and fish disturbance by existing plant beds. Algal blooms are kept in check by nutrient and light competition as aquatic plants successfully colonize available shallow sediments. Populations of small aquatic animals (zooplankton) graze on algae and use plant beds as refuge from predation. Fish also make use of the vegetation—for habitat and as an important food source. Fish such as minnow and carp that eat zooplankton or root around in bottom sediments for food are generally fewer relative to other species.

The turbid-water state is characterized by murky water (low water clarity), unstable bottom sediments, limited emergent vegetation, little to no submerged vegetation, and a sparse fishery dominated by fish such as carp and bullheads that root around in bottom sediments for food. Vancouver Lake currently exists in this state.

Because each state is relatively stable, shallow lake restoration is challenging, as it typically involves identifying and mitigating the cause of the shift in lake state.

Hydrology of Vancouver Lake

Although Vancouver Lake is similar to other shallow, turbid, algae-dominated lakes, it is unique because it is connected to the Columbia River and is influenced by changes in river stage and tidal cycles. This relationship to the Columbia River, both historically through sloughs and currently through the flushing channel and Lake River, creates a dynamic environment for Vancouver Lake and ultimately presents challenges to understanding and management.

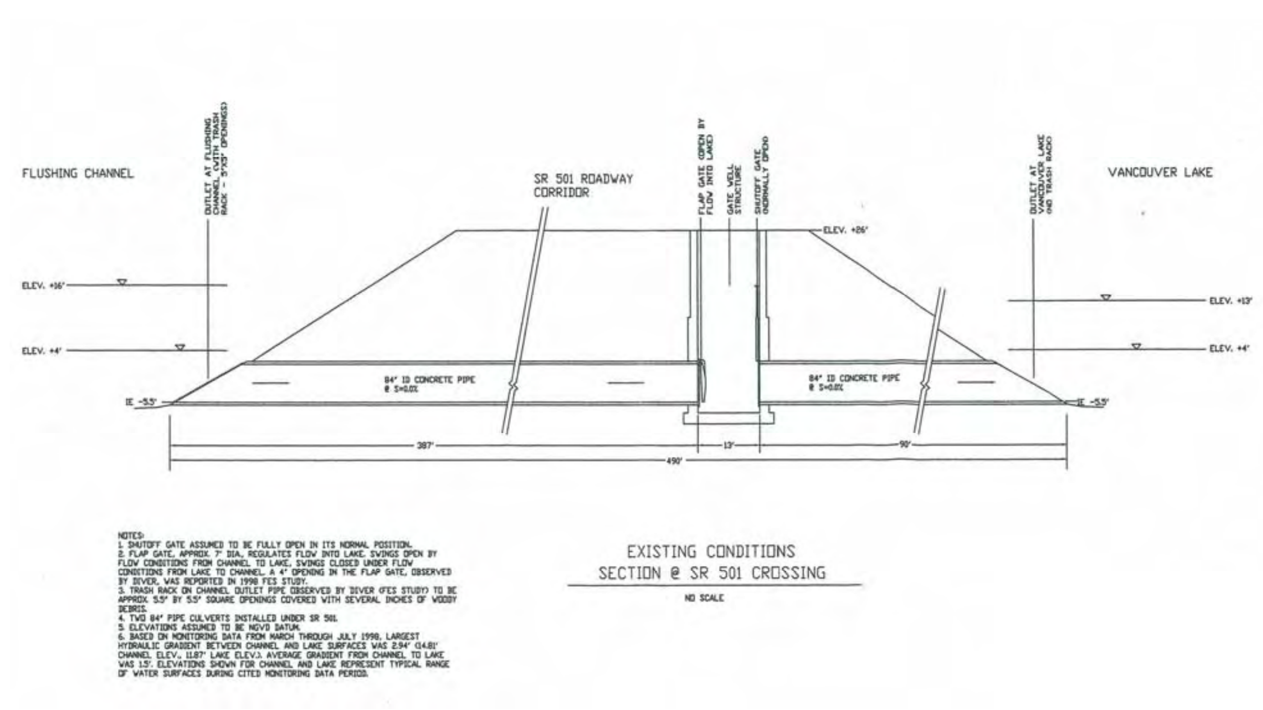
Anecdotally, Vancouver Lake is reported to have had deep, cool pockets of water, freshwater clams, and even sturgeon. Although deep pools of water may have been present in Vancouver Lake historically as spring freshets scoured the lake bottom, dam construction and subsequent regulation of Columbia River flows combined with the filling of sloughs entering the lake from the south have functionally ended spring freshets and scour flows that influenced the shape and depth of the lake bottom. The presence and extent of cool-water refuges in the lake today—if they exist—are unknown.

Columbia River, the Flushing Channel, and Lake River

The hydrology of the Columbia River is influenced by tributaries, the hydrosystem, and seasonal snowmelt in all but the lowest 30 miles of the river, where it becomes dominated by ocean tides. However, tidal effects in the river are felt as far upstream as Bonneville Dam at River Mile 140. The Columbia River affects Vancouver Lake in many ways, but in terms of basic hydrology Vancouver Lake is subject to the twice-daily high and low tides of the Columbia River. The lake also is influenced by seasonal river stage patterns like those caused by snowmelt and rainfall.

Tidal or river flows enter Vancouver Lake via the flushing channel and Lake River. Lake River is an historical slough that connects the Columbia River to the north end of Vancouver Lake. The slough is approximately 12 miles long, and its estimated annual flow rate is about 300 cubic feet per second (cfs) (Bhagat and Orsborn 1971). The flushing channel connects the Columbia River and Vancouver Lake via a 4,000-foot-long open channel constructed in the early 1980s (see Figure 2-1). On the east end of the channel are two 84-inch (7-foot) inside-diameter concrete pipes positioned side by side. Each of these culverts has a set of steel, crisscrossed reinforcing bars with 5.5-inch openings to prevent debris from flowing into the lake along with the river water (Drake & Associates 2004).

Figure 2-1
Existing Conditions and Culverts at the Flushing Channel (Drake & Associates 2004)



The gates on the culverts are constructed to allow water to pass from the flushing channel into the lake. This movement occurs when the water level in the flushing channel is higher than the lake water surface. The pressure difference that results because of this elevation difference pushes the gates open to allow water to pass from the flushing channel to Vancouver Lake (Drake & Associates 2004). However, the current configuration of the gates does not allow water to move from Vancouver Lake back to the flushing channel when the elevation gradients are reversed.

Burnt Bridge and Salmon Creek

The two largest tributaries to Vancouver Lake are Burnt Bridge Creek and Salmon Creek. The estimated average annual flow rates in Salmon Creek and Burnt Bridge Creek are about 100 cfs and 20 cfs, respectively (Bhagat and Orsborn 1971). It is likely that Salmon Creek contributes more flow to the lake than originally thought, as Salmon Creek flows directly into Lake River. The influence of Burnt Bridge and Salmon Creek flows on the water quality of Vancouver Lake is unknown. The creeks' proximity to urban areas could have significance for pollutant loading; however, pollutant loads to the lake are poorly understood at this time. Water inputs fluctuate throughout the year, and flow contributions could vary depending on season and activities occurring upstream in the watershed.

Smaller Tributaries

Several smaller tributaries, such as Chicken Creek, enter Vancouver Lake from the northeast. Although the flow volumes the smaller tributaries are relatively insignificant compared to Burnt Bridge Creek or Salmon Creek, they may be a source of nutrients, contaminants, or cooler water. Much of the flows of these smaller tributaries probably result from stormwater, and little is known about their temperature or nutrient or contaminant concentrations.

Groundwater

Groundwater that originates in shallow, underground aquifers enters Vancouver Lake through the lake bottom and nearby seeps. Recent modeling efforts by Clark Public Utilities and the Port of Vancouver substantiate groundwater input into the lake, but the extent is not yet fully understood. Initial water balancing of the model infers relatively minor groundwater inputs to the lake because of a blanket of fine sediments lining the lake; it is speculated that this sediment layer slows the movement of groundwater into the lake (Riley 2008).

Typical Water Year

The source and volume of contributing flows to Vancouver Lake vary throughout the year. When examining lake hydrology and its effects on lake dynamics, it is important to understand changes in flow from different sources. One way to become familiar with changes in flow at the lake from month to month is by looking at a typical water year at Vancouver Lake (see Figure 2-2). For scientists examining flows, a water year typically begins in October. The following paragraphs represent an interpretation of flow data by Ron Wierenga of Clark County Public Works.

In October, water levels at Vancouver Lake and their tributaries are at their lowest, and tidal fluctuations are more influential than tributary flows. As a result, the direction of flow through Lake River reverses daily, flowing into and out of Vancouver Lake at different times during the day.

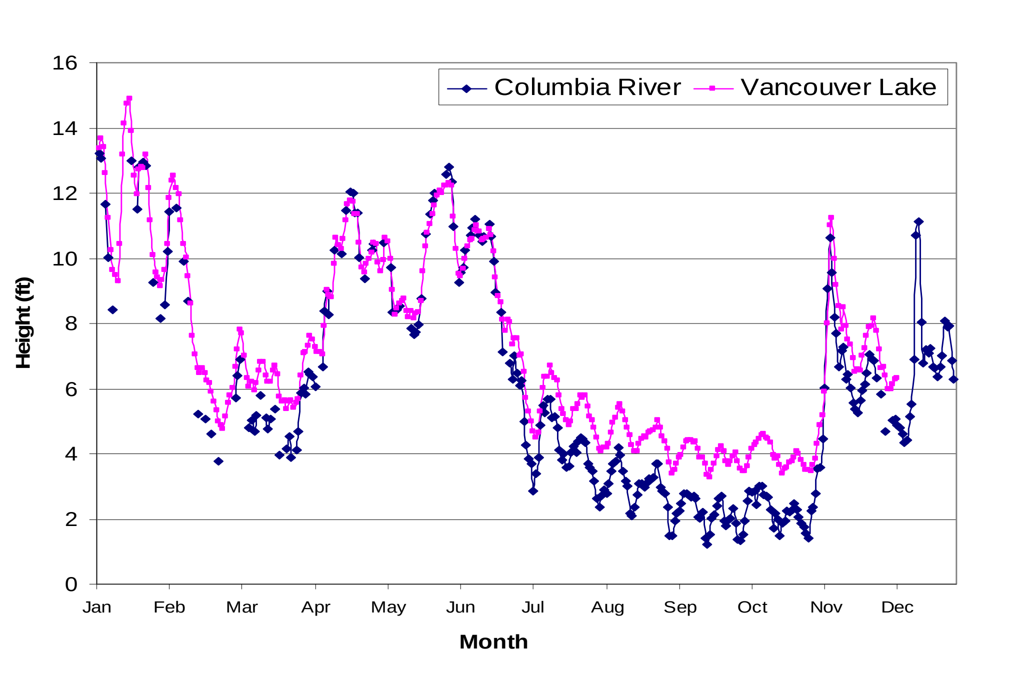
During the rainy season (November to February), the lake level rises to intermediate stages as flows from Burnt Bridge Creek and Salmon Creek increase rapidly. Lake water is dominated by flows other than the Columbia River, and during the winter it is assumed that local tributaries are the primary source of water to Vancouver Lake. Flow through Lake River reverses direction (either to or from Vancouver Lake) for days at a time, depending on runoff from local watersheds and dam operations for hydropower.

From March to June, local tributary flows decrease and inputs from the Columbia River rise as a result of springtime snowmelt and rainfall. The highest water levels at Vancouver Lake are often observed in early to mid-June. During the spring, Lake River typically flows south from the Columbia River to Vancouver Lake for long periods of time. The lake maintains high water levels, which are influenced mainly by Columbia River flows.

In June and July the lake level can drop rapidly as Columbia River stage declines. At this time Lake River typically carries water away from the lake, flowing to the north for long periods at a time.

During the last few months of the water year, from July to October, the lake remains at its lowest levels and the direction of flow in Lake River again reverse daily as a result of tidal fluctuations. During this period only water from the southern reach of Lake River is exchanged with lake water. Columbia River water continues to enter the lake through the flushing channel as a result of tidal swings and dam operation.

Figure 2-2
2006 Vancouver Lake and Columbia River Water Levels
(CPU and NOAA river gauges 2008)



Lake Bottom

The bottom of Vancouver Lake is covered with recent sediments underlain by river deposits. Borings conducted in 1972 (Shannon & Wilson Inc.) revealed that sands, silts, and clayey silts underlay the bottom to depths as great as 15.5 feet below the existing mud line. All of the soils are very loose and soft, and the distribution of soils throughout the bottom of the lake is highly erratic. Because of this irregularity it is difficult to generalize about soil type distribution around the lake; however, the investigators did note that cohesive fine-grained materials (clayey silts and clays) were more predominant in the west and south portions of the lake, while cohesionless fine-grained soils (silts, sandy silts, and fine sands) were located to the east and north. Anecdotal reports note that gravels exist on the southwest end of the lake and in pockets along the east side.

Fish, Wildlife, Invertebrates, and Aquatic Vegetation at Vancouver Lake

Fish, wildlife, invertebrates, and aquatic vegetation are important components of the Vancouver Lake ecosystem. Their web of interactions with each other influences the character of the lake and vice versa. Of all the different lake types, shallow lakes are particularly dependent on these biological interactions. Overabundant algae, for example, may occur because of a loss of vegetation or because of interactions between animals higher in the food chain, primarily zooplankton and small fish.

Fish

Historically, Vancouver Lake probably was part of a larger lake complex that consisted of deep pockets, shallow-water habitats, and small braided channels that provided rearing habitat for cool-water species such as salmonids. Diking in the early 20th century altered the lake environment, disconnected side channel areas, and elevated water temperatures, making the lake more suitable to warm-water fish species. Gillnet fish surveys conducted before and after construction of the flushing channel found that fish populations in the lake were dominated by white and black crappie, yellow perch, and carp (Kincheloe 1977, Envirosphere 1984). This was confirmed by the U.S. Fish and Wildlife Service in 1998, when a warm-water fish survey found black and white crappie, carp, and brown bullhead to be the most abundant species (Caromile and others 2000). Recent anecdotal reports describe sizeable largemouth bass caught near the island in the springtime and the presence of starry flounder, sturgeon, shad, goldfish and smelt.

Wildlife

Vancouver Lake and its adjacent shoreline habitat support various wildlife populations. The most recent survey to characterize wildlife use and distribution at Vancouver Lake was conducted in 1986. The survey found that waterfowl were the most abundant users of the area. Although waterfowl were observed yearlong, they were most abundantly during wintertime (Envirosphere 1986). This study recorded more than 8,000 Canada geese and 5,000 other waterfowl wintering in the project area, along with at least 21 bald eagles and more than 110 great blue herons. The 1986 investigation also included an extensive habitat inventory and evaluation to determine baseline conditions, for use in future comparisons. Habitat quality was measured for ten bird, mammal, and amphibian species representing major habitats in the project area; no specific surveys were conducted for these organisms, but the study concluded that habitat did exist for the selected species (Envirosphere 1986).

WDFW reports that the Shilapoo and Vancouver Lake wildlife areas are home to abundant and diverse communities of waterfowl. Grasslands interspersed with emergent wetland vegetation provide good nesting and brood-rearing habitat for waterfowl and other ground-nesting species. There are two heron rookeries and at least one active bald eagle territory, with two alternate nests. Furbearers such as beaver are numerous, and the area is frequented by sandhill cranes (Washington Department of Fish and Wildlife 2008).

Invertebrates

Little is known about the extent and distribution of aquatic invertebrates at Vancouver Lake. There are anecdotal reports of historical clam and mussel beds present in Vancouver Lake bottom sediments, but whether these beds exist today is unknown.

Aquatic Vegetation

A recent informal investigation of the presence of aquatic plants in Vancouver Lake indicated that submerged aquatic plants are almost completely absent from the lake environment (Fullerton 2007). This could be the result of many factors but most likely is due to limited penetration of sunlight (Clark County Public Works 2006). However, emergent plant species are abundant near the shoreline.

Communities of submerged aquatic plants in Vancouver Lake would improve habitat for aquatic species and help remove nutrients from the water column and sediments. However, encouraging the growth of aquatic plants throughout the lake to benefit the ecosystem could present a conflict with other desired lake uses, such as sailing, rowing, and swimming. The degree of this potential conflict is unknown at this time.

CHAPTER 3

Issues at Vancouver Lake

As stated in Chapter 2, Vancouver Lake is a turbid, algae-dominated lake with few aquatic plants and unstable bottom sediments. Although there are probably several converging reasons why the Vancouver Lake Watershed Partnership formed in late 2004, few members would disagree that bluegreen algal blooms were the catalyst for the Partnership's formation and continued efforts. At the same time, bluegreen algal blooms can be thought of as a result of underlying issues at Vancouver Lake. These issues include altered hydrology, high levels of nutrients, and turbidity. Other issues such as the presence of contaminants and sedimentation remain a concern for the Vancouver Lake Watershed Partnership and increase interest in improving conditions at the lake.

This chapter highlights the various conditions that have been identified as concerns at Vancouver Lake. To aid the reader, the chapter is organized by issue, with each section describing why a particular condition is a concern, how it relates to Vancouver Lake, and its possible underlying causes or sources. Table 3-1 lists specific conditions that have been identified as concerns and associates them with potential impairments at Vancouver Lake.

Table 3-1
Issues at Vancouver Lake

Condition	Result
Excess nutrients	Proliferated algal blooms that restrict uses
Presence of cyanobacteria and pathogens	Potential health hazards such as illness, infections, and skin rashes
High water temperatures	Harmful to some fish and wildlife species
Low dissolved oxygen	Harmful to fish and other aquatic organisms
Toxic contaminants	Restricts fish consumption; can be toxic to humans and animals
Low water clarity	Reduces aesthetic values and may be indicative or cause of other water quality problems
Sedimentation/shallow water depth	Restricts boating and swimming
Exotic and invasive plant species	Compete with native/desirable species; could restrict lake uses
Lack of aquatic plants and habitat structure	Less cover for juvenile fish and no place for insects to colonize and provide food; destabilized substrate

Nuisance Algal Blooms

What Is the Concern?

Two types of nuisance algal blooms occur at Vancouver Lake: general green algal blooms (such as those caused by diatoms and chlorophytes) and cyanobacteria blooms (bluegreen algal blooms). Both types can be aesthetically unappealing and contribute to poor water quality. They can also both be responsible for reducing the available oxygen in the water when algae spike rapidly in abundance and then die off and decay. This can be hazardous for other aquatic species in the lake because oxygen at the lake bottom is depleted.

What differentiates the two types of algal blooms is that cyanobacteria blooms are capable of producing toxins that can be harmful to wildlife, domestic animals, and people. The Clark County Health Department uses World Health Organization (WHO) guidelines when analyzing water samples and considers Vancouver Lake unsafe for swimming if cyanobacteria levels in the water exceed 100,000 cells per milliliter (ml). Cyanobacteria levels have reached nearly ten times the guideline value in late July and August at Vancouver Lake and forced the closure of the beach to swimming in recent years (Wierenga 2004).

What Is the Extent at Vancouver Lake?

Studies since the late 1960s have shown that Vancouver Lake suffers from intense algal blooms that can limit lake use in the summer (Bhagat and Orsborn 1971, Cooper Consultants 1985). Measurements of chlorophyll *a*, a pigment present in algae that is used for photosynthesis, often are used to estimate how much general algae is in a lake. Eutrophic lakes typically have maximum chlorophyll *a* concentrations ranging between 20 and 200 micrograms per liter (μg/L). Vancouver Lake's average summer chlorophyll *a* concentration ranges from about 30 to 130 μg/L, with maximum values observed in the range of 300 to 400 μg/L (Clark County Public Works 2006).

WHO guidelines for cyanobacteria often are reached in late July and August. The Clark County Health Department initiated a summer monitoring program at the Vancouver Lake Park beach in 2004 after a bloom was detected by the Health Department in 2003. Each year of monitoring has shown a different situation in terms of levels of algae cells and species forming the blooms. Within one summer season, sample results have shown variable timing and duration of cyanobacteria blooms.

Currently WSU is conducting a more extensive analysis of algae at Vancouver Lake. After 1 year of data collection WSU was able to analyze the major taxonomic categories of protist plankton approximately 5 to 200 micrometers (μm) in size (operationally defined as microplankton) collected from the Vancouver Lake dock station, on the east end of the lake, between March 2007 and January 2008. The June 2007 maximum in microplankton abundance was due almost entirely to a bloom of cyanobacteria, which reached approximately 300,000 cells per milliliter. However, as cyanobacteria declined over the next 3 months, other algae groups increased in relative abundance, with chlorophytes and other algal flagellates peaking in August and/or September and diatoms peaking in October (Bollens and Rollwagen-Bollens 2008).

What Is the Likely Source?

In general, algae are supported by sunlight, excess nutrients, low volumes of water inflow, poor water circulation, and warm water temperatures. When conditions favor growth, as they typically do in early to late summer, algal populations multiply rapidly, leading to blooms. Competition for nutrients and light among major groups of algae, such as cyanobacteria and diatom algae, determines the composition of a bloom at different times of the year. How algae interact with each other and their surrounding environment is poorly understood, and the exact cause of algal blooms at Vancouver Lake is not known at this time.

Another possible influence on algae abundance is a process called grazing. This term describes the consumption relationships of plankton and the transfer of energy between organisms. Phytoplankton, which derive energy from the sun, serve as food for other planktonic organisms, including protozoans and zooplankton. WSU has begun investigating grazing relationships between cyanobacteria and other types of phytoplankton and zooplankton (such as ciliates, cladocerans, and copepods) and, after one year of research, has observed interesting relationships between cyanobacteria and its potential grazers. Although these relationships are only assumptive right now, preliminary data indicate that certain zooplankton and protozoan grazers could have an influence on blooms (Bollens and Rollwagen-Bollens 2008). To what extent is uncertain at this time.

Excess Nutrients

What Is the Concern?

Excess nutrients in a lake can be considered a problem because they result in eutrophication. Eutrophication is a process where water bodies like Vancouver Lake receive excess nutrients, such as phosphorus or nitrogen, that can stimulate excessive plant growth. This increased plant growth, often in the form of algal blooms, has the potential to reduce dissolved oxygen and accumulate on the lake bottom as organic sediments when dead plant material decomposes. Eutrophication can sometimes be described as a natural transition process for a lake if looked at over geologic time; however, in urban areas, the process is often accelerated as a result of activities upstream in the watershed.

An important aspect of nutrient levels in lakes is their availability to algae. Scientists often use the ratio of total nitrogen (TN) to total phosphorus (TP) to interpret the availability of nutrients relative to one another. Low ratios (6:1, for example) indicate an abundance of phosphorus relative to nitrogen. Higher ratios (10:1, for example) indicate a scarcity of phosphorus relative to nitrogen. The ratio in Vancouver Lake varies from month to month during the summer.

What Is the Extent at Vancouver Lake?

Vancouver Lake has high levels of nutrients and is a state 303(d) listed waterway (meaning that it is water quality impaired) for phosphorus. Impaired waters are those waters that are not meeting state water quality standards as defined by Section 303(d) of the federal Clean Water Act. The U.S. Environmental Protection Agency's (EPA) total phosphorus criterion for preventing the development of biological nuisances and to control eutrophication in lakes is 25 μg/L. Vancouver Lake often has phosphorus levels ten times higher than this criterion throughout the summer.

Total nitrogen levels are also typically high and variable. Volunteer monitoring data show that the biologically available forms of nitrogen and phosphorus typically increase sharply in late July and early August, coinciding with periods of heavy algal growth.

What Is the Source?

It is likely that Vancouver Lake acts as a sink for nutrients in the watershed. Excess nutrients can enter from agricultural areas, stormwater, urban development, fertilized yards and gardens, failing septic systems, land clearings, and municipal and industrial wastewater. Phosphorus and nitrogen may also be available in lake bed sediments or may enter through groundwater and the Columbia River.

Although current nutrient pathways to Vancouver Lake are not well defined at this time, it is likely that nutrients have accumulated in lake-bottom sediments and become suspended in the water column through wind mixing and fish activity during the summer months.

Bacteria and Pathogens

What Is the Concern?

Fecal coliforms are bacteria that typically originate in feces (though not all have a fecal origin). They are significant for water quality and human health because they are used as an indicator of the presence of other disease-carrying organisms (pathogens). E. Coli 0157 is a strain often sampled for water quality purposes. Organic matter with untreated fecal coliform can be harmful to humans by causing waterborne pathogenic diseases such as dysentery, viral and bacterial gastroenteritis, hepatitis A, and ear infections.

What Is the Extent at Vancouver Lake?

There is an increasing body of information about harmful bacteria or other pathogens in Vancouver Lake. In 2004, the Clark County Health Department initiated routine E. coli monitoring at the Vancouver Lake Park swimming beach. The Health Department uses EPA bathing water standards and considers E. coli levels in lake water samples higher than 236 bacteria/100 mL of water unsafe for swimming. The Health Department's biweekly monitoring of the Vancouver Lake Park beach has reported conditions usually suitable for swimming based on the E. coli criteria.

Vancouver Lake, Burnt Bridge Creek, Salmon Creek, and Whipple Creek are 303(d) listed waterways for fecal coliform. Limited data produced by the Southwest Washington Health District (a predecessor to the Clark County Health Department) in the 1970s showed very high fecal coliform and nutrient levels in lakeshore slope tributaries to the east of the lake.

What Is the Source?

Potential sources of fecal coliform and other pathogens in Vancouver Lake and tributaries are numerous. Runoff from roads, fields, and yards can carry animal waste to streams through drainage ditches and nearby waters. Inadequate wastewater treatment facilities and failing home septic systems can also be sources.

In the case of Vancouver Lake, birds are one possible source of fecal coliform bacteria. Waterfowl congregating and using the lakeshore habitat can elevate bacteria counts in localized areas.

Temperature and Dissolved Oxygen

What Is the Concern?

Elevated lake temperatures create conditions that may stress some fish species and be lethal to others. Temperatures also can affect physical processes in the lake, including the amount of dissolved oxygen maintained in the water column. Warmer water tends to suit particular types of algae and cyanobacteria that are capable of developing into nuisance or harmful blooms.

The dissolved oxygen levels present in the water also are governed by the amount of decomposition and decay of organic matter in the lake sediment. Oxygen depletion can occur at the lake bed as a result of decomposition of biological material that settles to the lake bottom (that is, dead algae). This decomposition can deplete oxygen and create hazardous conditions for fish and other aquatic organisms.

What Is the Extent at Vancouver Lake?

Water temperature in Vancouver Lake varies throughout the summer and is considered to be very warm, with surface temperatures sometimes reaching 77 degrees Fahrenheit (25 degrees Celsius). Vertical profiles of temperature show that the lake does not typically stratify, or separate into layers by temperature (Clark County Public Works 2006). Vancouver Lake is consistently 5 degrees warmer than the Columbia River as measured at Bonneville Dam (U.S. Army Corps of Engineers 2007b).

Vancouver Lake frequently is mixed by wind, which has the effect of distributing oxygen throughout the water column. However, during times of stagnant wind conditions, oxygen levels may vary through the water column, with supersaturated conditions near the surface as a result of algae photosynthesis and depleted levels near the lake bottom. Some segments of Burnt Bridge Creek and Salmon Creek are listed as 303(d) impaired for water temperature and dissolved oxygen.

What Is the Source?

Elevated water temperature decreases the amount of dissolved oxygen in the water column. Large shallow lakes often become warm in the summer because of their surface water to depth ratio and the amount of shoreline shading relative to the size of the lake. Vancouver Lake develops elevated water temperatures because of its large surface area. It is unlikely that warm summer low flows from tributaries such as Burnt Bridge Creek affect water temperature in the lake because the input relative to the volume of Vancouver Lake as a whole is small during those months.

Toxic Contaminants

What Is the Concern?

Toxic contaminants in water and sediment are a concern for human and ecosystem health throughout the lower Columbia River. In general, contaminants of concern in the Columbia River include dioxins and furans, heavy metals, polychlorinated biphenyls (PCBs), and organochlorine pesticides such as DDT (Lower Columbia River Estuary Partnership 2007).

PCBs are a family of synthetic organic chemicals known as chlorinated hydrocarbons. PCBs were manufactured in the United States from 1929 to 1979. Once released into the environment they can remain for long periods of time because they do not readily break down. PCBs can be toxic to humans and other organisms in varying degrees through consumption and bioaccumulation. The EPA has classified PCBs as a probable human carcinogen, with studies showing relationships between humans and cancer development. Other non-cancerous exposure effects include developmental and reproductive effects on animals, such as impaired immune function and decreased fertility.

Organochlorine pesticides such as dieldrin, lindane, chlordane, and DDT have been detected at levels in the lower Columbia River that exceed state or federal sediment quality guidelines or are considered harmful to humans and aquatic life (Lower Columbia River Estuary Partnership 2007).

What Is the Extent at Vancouver Lake?

Vancouver Lake is a 303(d) listed waterway for PCB impairment. The National Toxics Rule (NTR) human health criteria for PCB and 4,4′-DDE are 5.3 micrograms per kilogram (μg/Kg) and 31.6 μg/Kg, respectively. In 1993 and in 2002, the Washington State Department of Ecology collected a five-fish composite sample of largemouth bass at Vancouver Lake for a statewide assessment; in both years, total PCBs exceeded the NTR human health criteria. In 1993, 4,4′-DDE in fish tissue exceeded the criteria (Davis and others 1993, Seiders and Kinney 2004).

In 2005, Ecology conducted another study to further investigate levels of PCBs, chlorinated pesticides, and dioxins in sediment and fish tissue from Vancouver Lake and Lake River. Vancouver Lake sediments were found to be low in PCB and chlorinated pesticides, with only four of the 186 total analytes reported above detection limits; this result is considered to be in compliance with sediment quality guidelines. Sediment samples from Lake River did not show target compounds. Largemouth bass, common carp, and largescale sucker tissue samples were analyzed and PCB levels were elevated, exceeding the EPA's National Toxics Rule human health criteria (Coots 2007). The source of fish contamination exposure is difficult to determine because the origins and movement of the fish are unknown.

What Is the Source?

The origins of PCBs and organochlorine pesticides in Vancouver Lake are unknown. However, these types of contaminants are present in Columbia River water, suspended sediments, and, to a lesser degree, coarse sediments (sand). In areas such as Vancouver Lake where suspended sediments have time to settle onto the lake bed, PCBs and organochlorine pesticides may enter the lake from local sources or as far upstream as the Yakima Valley or beyond.

Various studies on Columbia River sediments have been completed in areas near Vancouver Lake. In 2006 the Port of Vancouver conducted a sediment characterization in support of the construction of a proposed vessel approach and turning basin between River Miles 101 and 102 of the Columbia River. A total of 52 samples were collected and analyzed according to the U.S. Army Corps of Engineers dredged material evaluation framework. Sediment samples were analyzed for a variety of contaminants, including PCBs. The report concluded that sediment material underlying the proposed dredge prism did not pose a threat to aquatic and/or benthic receptors (Parametrix 2007).

Low Water Clarity

What Is the Concern?

The clarity of a lake is often used as an overall indicator of water quality because it indicates the amount of dissolved compounds and/or suspended sediments in the water column. Clarity can change throughout the year in response to seasonal variations in weather and changes in temperature, wind, and rainfall. Suspended particulates include both free-floating algae and suspended sediment. Particulates absorb and scatter sunlight and may decrease the Secchi depth value (a measure of clarity) of a lake.

Low water clarity is indicative of a eutrophic lake and can potentially point to other water quality problems. In addition, because low water clarity prevents light penetration, it can inhibit the growth of aquatic plants.

What Is the Extent at Vancouver Lake?

Throughout most of the year Vancouver Lake has very poor water clarity. Turbidity and Secchi depth readings show that light penetration is deeper in the spring and becomes shallower through the summer and early fall as water clarity deteriorates. From 2004 to 2006, the average summer Secchi depth value was 0.33 meter, with a range of 0.13 to 0.83 meter. Typical summer turbidity is 60 NTU (nephelometric turbidity units) but can range from 25 to 175 NTU (Clark County Public Works 2006).

What Is the Source?

Vancouver Lake's great size and shallow depth, coupled with the simple shoreline morphology, lead to frequent wind-induced mixing. Because the lake's bottom sediments are fine grained and unconsolidated, they are easily resuspended. Fish may disturb bottom sediments searching for food. Intense algal blooms also limit light penetration.

Sedimentation

What Is the Concern?

Sedimentation is a natural process in any lake. However, it is likely that sedimentation in Vancouver Lake has been exacerbated by human activities. Sedimentation can be considered an impairment because it can have serious implications for boating, swimming, and fishing opportunities. Sedimentation in this context means the "filling in" of lake areas through sediment movement and accumulation. Vancouver Lake is likely an accretionary lake, meaning that more material (particularly fine sediments) enters the lake than exits it. Over time (perhaps on a scale of tens or hundreds of years), if left to its current trajectory, Vancouver Lake could become even shallower and begin to form wetlands.

Another concern with sedimentation has to do with the quality and characteristics of the sediment. As discussed earlier, toxins can move and accumulate in sediment, and fine sediments are easily suspended through wind or biological activity. For this reason, sedimentation rates and sediment/water interactions are particularly important in shallow lakes.

What Is the Extent at Vancouver Lake?

The rate of sediment accumulation and movement within the Vancouver Lake system has not been quantified. However, previous bathymetry work from the 1970s does exist and might be available for comparison to a new bathymetry study performed by the U.S. Army Corps of Engineers in early 2008. How beneficial this comparison will be is not known at this time because post dredging records were not collected after dredging operations in the early 1980s.

In the summer of 2008, the U.S. Army Corps of Engineers developed a two-dimensional (2-D) hydrodynamic model of Vancouver Lake to model three representative lake stages (high, medium, and low) and to gain a better understanding of water velocities and circulation patterns within the lake. This modeling effort is important in understanding sediment movement because water is a pathway for sediment. Understanding circulation and velocity patterns will aid in understanding how sediment moves within Vancouver Lake. Although the U.S. Army Corps of Engineers' 2-D model does not investigate wind or seasonal hydrologic effects, the model results will be helpful in beginning to understand the sedimentation issue and determining what further investigation is still needed.

What Is the Source?

Vancouver Lake receives sediment from multiple sources. Major historical and current sources result from land-use changes throughout the upstream watersheds. Large amounts of sediment probably have washed downstream since initial settlement of the area began in the early 1800s. In addition, it is likely that removal of forestlands, followed by decades of farming with minimal use of sediment and erosion control measures, led to sediment washing out and accumulating in Vancouver Lake. Over the past few decades, urbanization caused by residential and commercial development represents a new source of sediment contribution.

The Columbia River also is a source of sediment entering Vancouver Lake. Seasonal flooding from the Columbia River spring freshets probably played a large role in sediment processes until the turn of the century, when construction of dams eliminated peak scouring flows. Historically these flows were approximately 1 million cfs; today's maximum flows are approximately 300,000 cfs. Fine sediments with origins as far away as the Palouse River become suspended and travel downstream until flows slow down enough for the river's load to be deposited (Tetra Tech EC 2006). Vancouver Lake is well-suited for trapping fine sediments on their journey downstream to the Pacific Ocean. Currently, it is estimated that a particle of water (possibly containing fine sediments) takes approximately 1 month to exit Vancouver Lake after entering the system. Some of these fine sediments are deposited in the lake when conditions are favorable. Later, these deposited fine sediments may become resuspended as a result of wind or other disturbances to the lake bed (such as fish activity) and are redeposited or moved out of the lake into the Columbia River.

Exotic Plant Species

What Is the Concern?

Native wildlife species have evolved over thousands of years with plant communities of the Pacific Northwest. Exotic plants are a concern because they often displace native vegetation and provide little if any habitat benefits to wildlife species. Frequently exotic plants are invasive and may outcompete native plants within years or decades of their introduction. Wildlife species often are not adapted to the exotic species and cannot keep pace with changes to their environment over the same time scale.

What Is the Extent at Vancouver Lake?

The presence of exotic plants in the Vancouver Lake system has not been systematically documented. There are anecdotal reports of exotic plants such as reed canary grass, false indigo, Canadian thistle, purple loosestrife, and milfoil in the wetland fringes of the lake. Scotch broom is present at Vancouver Lake, along with Himalayan blackberry.

What Is the Source?

The sources of exotic plant species are numerous and wide ranging. Exotic plants can be imported accidentally or deliberately, by human or natural means. Plant seeds and clippings from gardens and nurseries escape into waterways and can easily be spread by moving water and wildlife. Overgrazing, poor agricultural practices, and transportation via boat traffic are common ways that exotic species spread in lowland areas. In general, exotic plant species are opportunistic, colonize disturbed lands, and have few natural enemies.

Lack of Aquatic Habitat

What Is the Concern?

Aquatic habitat and structure are important because they provide refuge for young fish to escape predation, they supply food inputs to shallow-water lakes, and they help determine which fish and wildlife species successfully compete for scarce resources. But too much aquatic vegetation can interfere with recreational activities (for example, dense mats of floating plants may reduce opportunities for boating and swimming).

What Is the Extent at Vancouver Lake?

Previous studies have revealed a startling lack of aquatic habitat structure in the lake for fish and other aquatic wildlife. In a 1998 report by the Washington Department of Fish and Wildlife, biologists found "overall, a near complete lack of complex habitat" (Caromile and others 2000). A recent Ecology investigation on the presence of aquatic plants in Vancouver Lake indicated that submerged aquatic plants are almost completely absent from the lake environment (Fullerton 2007).

What Is the Source?

The absence of aquatic habitat in Vancouver Lake is likely due to many factors occurring over a long period of time. Vancouver Lake bottom sediments are unconsolidated and poorly suited for rooting plants (Wierenga 2004). Additionally, the lake is often too turbid to support larger rooted plants because light does not reach the lake bottom. Anecdotal information from adjacent landowners suggests that fluctuating water levels and lake circulation patterns lead to poor retention of large wood debris in the lake system. In addition, the supply of large wood entering Vancouver Lake from tributaries or the lake shore is significantly less than it was historically.

CHAPTER 4

Data Gaps

A technical understanding of Vancouver Lake is a prerequisite for identifying and initiating important changes to the lake. However, because the Vancouver Lake system is complex, technical studies are expensive, and resources are limited, the breadth of initial technical study should be directed toward those inquiries that provide a scientific foundation for the most critical management decisions.

Currently the Vancouver Lake Watershed Partnership has developed an unrestrained vision and set of values for the future of Vancouver Lake that describes the desired future condition for the lake in terms of common ideals. The vision as currently stated by the Partnership is broad and abstract, but at this stage of understanding it represents important guidance for restoration efforts and decisions about what technical information to obtain next.

Technical Questions

Technical and management questions continue to emerge from the Vancouver Lake Watershed Partnership, and until recently there has not been a clear method for organizing and addressing questions. To remedy this situation, the Partnership collected technical and management questions identified to date and organized them according to category: water/sediment quality, physical environment, and biology. The questions were subsequently reviewed and revised by a Partnership ad-hoc committee for additions and to ensure that the list was as comprehensive as possible. The questions then were evaluated and ranked for significance in terms of scientific basis, information availability, and estimated cost of a new study. Although the list of questions will continue to evolve, the Partnership's Technical Group has attempted to determine which of the current questions are more urgent to answer from a technical perspective. Individual technical questions posed by the Partnership are highlighted in Tables 4-1, 4-2, and 4-3 according to category and are listed in order of perceived urgency, as determined by the Technical Group. These tables are followed by a discussion of what information is available to help answer these questions and what information is still lacking. (A complete breakdown of Technical Group comments and scoring can be found in Appendix A.) It is important to note that the comments and rankings are the personal opinions of members of the Technical Group and are not intended to represent the views of their employing agencies.

Combining the perceived urgency of the questions with an analysis of what information is available will help guide the direction of new technical studies.

Water/Sediment Quality

As described previously, water and sediment quality are important concerns at Vancouver Lake. With cyanobacteria blooms in the summertime closing the lake to recreational uses, understanding the water quality conditions that facilitate the blooms (nutrients, temperature, etc.) is essential. The presence and extent of pathogens and toxins such as E. coli and PCBs are also very important to the community.

Table 4-1 outlines the Partnership's technical questions related to water and sediment quality. Any future management alternative that addresses these issues will need to look at water and sediment quality framed by user-driven desires, such as what the lake is used for.

TABLE 4-1
WATER/SEDIMENT QUALITY QUESTIONS

Questions	Urgency
What is the type, amount and distribution of contaminants in Vancouver Lake?	HIGH
What is the type, amount and distribution of nutrients in Vancouver Lake sediment?	↑
What is the source and quantity of contaminants entering Vancouver Lake?	
What is the type, amount and distribution of contaminants in Vancouver Lake sediment?	
Does Vancouver Lake meet water quality standards for pathogens and bacteria?	
Where does Vancouver Lake sediment come from and what is the quality of that sediment?	
How does sediment move within Vancouver Lake?	
What is rate of accumulation/disbursement of sediment in Vancouver Lake and Lake River and what is the trajectory for these rates?	
How does seasonal variation affect nutrient and contaminant concentrations?	
What is the temperature profile of Vancouver Lake and its tributaries throughout the year?	
How does sediment move within Lake River, the flushing channel, and other tributaries?	
What is the grain size distribution of Vancouver Lake sediments?	
What is the quality of groundwater entering Vancouver Lake?	↓
What is the relationship between Alcoa site contaminants and Vancouver Lake?	LOW
What is the influence of the Willamette river on Vancouver Lake water quality?	

Available Information

Currently, the most complete summertime water chemistry data for the lake come from volunteer monitoring programs run by Clark County. The data are of good quality and are useful for describing levels and temporal trends at a single lake station. WSU-Vancouver also has been sampling basic water quality parameters such as temperature since 2007— both quarterly at several distributed lake stations and more frequently at a single lake station. In 2008 WSU-Vancouver will be sampling exclusively at a single lake station.

Clark County has been tracking water quantity and quality of Vancouver Lake, Whipple Creek, and Salmon Creek for several years. Both the City of Vancouver and the Department of Ecology have collected data on Burnt Bridge Creek. Ecology compiles and manages these data in a central database called EIM. For historical data, there are the pre- and post- restoration data sets for Vancouver Lake from the 1970s and 1980s. State and federal agencies intensely monitor the Columbia River.

The Department of Ecology has conducted several studies investigating levels of PCBs, chlorinated pesticides, and dioxins in sediment and fish tissues from Vancouver Lake and Lake River (Davis and others 1993, Seiders and Kinney 2004, Coots 2007). Recently the Department of Ecology initiated a total maximum daily load (TMDL) study on Burnt Bridge Creek. This study involves intensive monitoring of ground and surface water quality parameters, including temperature, fecal coliform and dissolved oxygen. The study will provide additional understanding of the influence of Burnt Bridge Creek on Vancouver Lake’s water quality.

Data Gaps

Significant water quality data gaps exist for Vancouver Lake, Lake River, groundwater, and the small tributaries surrounding the lake. It will be important not only to collect water quality data from these sites to fill the gaps, but also to determine the annual loading of certain water quality parameters such as nutrients or suspended sediment to understand their contributions over time. Investigating contributions from other sources, like precipitation, stormwater outfalls, or aquatic animal populations, could also be helpful. Filling these gaps would help identify the most significant contributors of nutrients and other potentially harmful pollutants and improve the Partnership’s understanding of them in relation to cyanobacteria blooms and other documented water quality problems.

In terms of sediment quality, a primary data gap is the rate and mechanism of sediment movement and accumulation within the lake. Identifying and describing mechanisms of sediment resuspension and distribution will help characterize the effects of sediment on water quality. Sediment resuspension has been identified as an important driver for water quality problems in many shallow lakes, whether it is caused by wind or foraging fish.

In addition to sediment transport processes, the quality and characteristics of sediment throughout the system need to be further investigated. A few examples of sediment characteristics that need to be quantified include levels of toxins, nutrients and organic matter, particle size distribution, and sediment density.

Physical Environment (Hydrology/Hydraulics)

The physical environment category captures questions that relate to physical processes of the lake system, such as how water enters, exits, and circulates within it. Determining the primary driver of lake hydrology by looking at contributions of the upstream watershed, the Columbia River, and groundwater will be essential to any future management alternative and future studies. It will also help inform discussions about water chemistry or biology. Table 4-2 lists technical questions related to physical environment as determined by the Partnership and orders them according to urgency as determined by the Technical Group.

TABLE 4-2 PHYSICAL ENVIRONMENT QUESTIONS	
Questions	Urgency
What is the quantity and timing of flows within the flushing channel and what is its effect on lake conditions?	HIGH
What is the physical bathymetry of Vancouver Lake, the flushing channel and Lake River and its tributaries?	↑
What is the quantity and timing of flows from Lake River into and out of Vancouver Lake?	
What are the water circulation patterns within Vancouver Lake?	
How do Columbia River tidal fluctuations impact Vancouver Lake, Lake River, and its tributaries?	
How does seasonal variability impact hydrology within Vancouver Lake, Lake River, and its tributaries?	
How does groundwater influence Vancouver Lake?	
How do Columbia River dam releases impact Vancouver Lake water levels?	
What is the quantity and timing of flows from Burnt Bridge Creek into Vancouver Lake?	
What is the quantity and timing of flows from other tributaries into Vancouver Lake and/or Lake River?	↓
What is the quantity and timing of flows from Salmon Creek into Lake River?	
What effect does the island play on water circulation patterns?	LOW
What is the impact of sea level rise on Vancouver Lake?	

Available Information

In 2007 the U.S. Army Corps of Engineers developed a relatively simple one-dimensional (1-D) hydraulic model for Vancouver Lake that allowed it to describe the lake's response to gross changes in input or output capacity. Results of the 1-D modeling effort found that increasing the size of the flushing channel culverts made the greatest change in lowering the hydraulic residence time in Vancouver Lake; however, further investigation with a two-dimensional (2-D) model was necessary in order to answer questions about circulation patterns and to account for the lake's connection to the Columbia River.

In the summer of 2008, the U.S. Army Corps of Engineers developed a 2-D hydraulic model of Vancouver Lake to build off of the 1-D model results and to further investigate circulation patterns within the lake. As an initial step to this more complex modeling effort, a bathymetric (lake depth) and topographic survey of the lake, surrounding shoreline, and cross-sections of Lake River were conducted. The main objective for the 2-D modeling effort was to establish flow patterns within the lake as is, but also to model the effects on flows of various modifications to the lake. Three representative lake stages (high, medium and low) were modeled under four scenarios: (1) leaving the system as is, (2) increasing the flushing channel culverts to 11 feet, (3) increasing the flushing channel culverts to 11 feet and removing tide gates, and (4) leaving the existing culverts but dredging within the lake (U.S. Army Corps of Engineers 2008).

From this modeling effort several important conclusions could be drawn. It was found that velocities in Vancouver Lake were low under all the modeled conditions. Lake dynamics as a whole were tidally dominated, with higher velocities near the connection with Lake River.

Enlarging the flushing channel culverts increased velocities within the lake, specifically along the western and northern shore, and removing the tide gates had a negligible effect on hydrodynamics (U.S. Army Corps of Engineers 2008). This modeling effort helps address a data gap the Partnership has previously identified. However, given the limited boundary conditions and short representative time frames modeled, questions remain about additional water inputs, seasonal changes, and wind effects.

In addition to the U.S. Army Corps of Engineer's valuable contribution, groundwater modeling of the Vancouver lowlands is under way by the Port of Vancouver and Clark Public Utilities (CPU). As part of this larger effort, CPU and the Port are monitoring the water surface elevation and groundwater levels of the lake at the sailing club dock (on the east end of the lake) and at multiple groundwater wells throughout the lowlands. To date their efforts have not been specifically geared toward answering Partnership groundwater questions. However, as the Partnership identifies specific questions to ask the model, it could potentially be queried to provide information regarding groundwater flow and inputs into the lake. Ideally, groundwater knowledge could be gained in this way and additional groundwater modeling outside of this joint Port/CPU effort would not be necessary to answer Partnership questions.

In October 2006 the Port of Vancouver began conducting a flow monitoring study of the flushing channel that is currently ongoing. The investigation includes continuous measurements of flow through flushing channel culverts and water level measurements in the channel and at Vancouver Lake.

Data Gaps

A basic water balance of Vancouver Lake is lacking. How much water enters, exits, and circulates within the system is poorly understood. The influence of groundwater and tributaries is unknown, as are seasonal effects and typical flow paths within the lake. Being able to describe the total annual volume of water entering and exiting the system from various sources and the timing of these flows is fundamental for future management considerations. Furthermore, understanding the sources and timing of water delivered to the system draws attention to potential sources of pollution, toxins, pathogens, or nutrients.

Biology

Partnership biology questions relate to the many different biological aspects of a lake system. They are wide ranging and cover topics from algae to wildlife. Questions about algae in Vancouver Lake are especially important to answer because nuisance blooms have frequently reduced opportunities for water contact recreation during the summer months and are aesthetically unappealing. Fishing and wildlife viewing also are important activities at Vancouver Lake, and improving environmental conditions for larger biota such as birds and fish is a goal of management efforts.

Understanding lake biology is important not only for maintaining overall ecosystem health, but also for its potential use as a management tool. A technique known as biomanipulation can help improve water quality by managing plankton grazing and food chain interactions. As the Partnership moves forward in determining management alternatives, this tool will be further described and explored. Table 4-3 outlines the Partnerships biological questions and orders them according to urgency as determined by the Technical Group.

TABLE 4-3
BIOLOGY QUESTIONS

Questions	Urgency
What is the type, amount and distribution of algae in Vancouver Lake?	HIGH
What conditions facilitate algae blooms?	↑
What is the type, amount and distribution of bluegreen algae in Vancouver Lake?	
What is the type, amount and distribution of plankton in Vancouver Lake?	
What is the type, amount and distribution of fish in Vancouver Lake?	
What is the type, amount and distribution of plants in and around Vancouver Lake?	
What is the type, amount and distribution of invertebrates in Vancouver Lake?	
What is the type, amount and distribution of habitats around Vancouver Lake?	
Are there any federal or state listed species in or around Vancouver Lake?	↓
What is the type, amount and distribution of exotic plant and animal species in and around Vancouver Lake?	LOW
How do fish, plant and animal distributions change through time?	
What is the type, amount and distribution of wildlife in and around Vancouver Lake?	

Available Information

Available information about aquatic plant and animal species at Vancouver Lake is limited. The most extensive biological work took place in the late 1970s and 1980s, when the flushing channel was being evaluated and constructed (Miller 1977 and Envirosphere 1986). More recent research efforts within the past few years are being conducted by Clark County and WSU and have focused on free-floating algae.

First-year results from WSU showed little spatial variability in phytoplankton and zooplankton abundance across the distributed lake sampling stations. This is a helpful result because it indicates that a sample taken from the sailing club dock is a good representation of what is present in the lake as a whole. This will simplify sampling strategies in the future.

From the more intense sampling regime at the sailing club dock, WSU observed several interesting relationships between the various phytoplankton and zooplankton species. WSU observed that in summer 2007 cyanobacteria had an extended summer bloom with extremely high abundance. Protist grazers (such as ciliates and dinoflagellates) may be influencing cyanobacteria blooms, and mesozooplankton grazers (cladocerans, copepods, and rotifers) may also be influencing cyanobacteria blooms. However, without further study, these relationships are not definitive and it is impossible to state the specific cause or causes of blooms.

Clark County also monitors chlorophyll concentrations throughout the summer, and some information about fish is available from previous investigations and from a recent U.S. Army Corps of Engineers review (U.S. Army Corps of Engineers 2007). The latest Washington Department of Fish and Wildlife warm-water fishery report indicated that the most common species present in Vancouver Lake were brown bullhead, crappie, and common carp (Caromile and others 2000). The report also noted a startling lack of habitat for fish.

An informal aquatic plant survey was conducted last year by the Washington State Department of Ecology; this survey indicated an overall absence of submerged aquatic plants and the presence of several exotic species (Fullerton 2007).

In 2002, Fishman Environmental Services, LLC, conducted a preliminary investigation of habitat conditions in the flushing channel and discussed its adequacy for juvenile salmonid rearing (Fishman Environmental Services 2002). During the survey Fishman Environmental observed many non-native plant species on the banks of the channel and in the in-water substrate, which consisted of riprap, silt, and alluvial sand deposits. Several dozen 30- to 60-mm salmonids, several 50- to 60-mm juvenile pikeminnow, a stickleback, and unidentified juvenile cyprinid were observed during a low-tide snorkel survey. Macroinvertbrates were sampled, and species eaten by juvenile salmonids, such as gammarid amphipods ("scuds"), cladocera ("water fleas"), spiders, aquatic worms, and chironimid (midge) larvae were found.

Fishman Environmental concluded that current habitat conditions do not preclude the use of the flushing channel by salmonids, with habitat suitability being seasonally dependent on water quality conditions and river levels. There were no clear indicators of adverse effects of the flushing channel gates during the survey. However, it was noted that debris on the trash rack may decrease the size of openings to a point where passage by adult salmonids is impeded (Fishman Environmental Services 2002).

Data Gaps

Gaps in biological information at Vancouver Lake are numerous. In addition to outdated data, several baseline questions still remain about the type, amount, and distribution of species. A baseline assessment of lake biology is needed at Vancouver Lake. Such an assessment could include an evaluation of aquatic plants and fish and descriptions of shoreline, near-shore, and open-water habitat structure. Little is known about the extent of endangered or exotic species in the lake, and this information would be useful when considering management options and their effects on such species.

One subject the Partnership is becoming more knowledgeable about but still lacks a great deal of information on is grazing and food web interactions among organisms. Understanding the connections between trophic levels will contribute to a deeper understanding of the lake ecosystem and possible management scenarios. WSU is continuing to monitor plankton over a second annual cycle and will begin to investigate rate processes of cyanobacteria (that is, the growth and death rates).

Two recent summary reports identify data gaps after site visits and review of existing information. Fishman Environmental Services, LLC (2002) listed several gaps, including: (1) the extent of current salmonid use of the channel and lake, (2) data on water quality in the lake, and (3) water quality conditions during low-flow periods in the flushing channel. The U.S. Army Corps of Engineers identified data gaps in its 2007 *Review of Biological Research on Juvenile and Adult Salmonids and Survival at Vancouver Lake* (2007a). These gaps include: (1) high-quality, detailed, and scientifically sound salmonid use information to support assumptions made about fish behavior, (2) detailed temperature and thermocline information, (3) information on use and survival of salmonids entering the lake and their fates, (4) impacts of structures to fish passing via the flushing channel and culvert system, (5) detailed assessment of predator fish and abundance at Vancouver Lake, and (6) detailed quality assessment of available riparian habitats and their use by salmonids.

CHAPTER 5

Technical Strategy

This chapter describes a strategy for learning what we need to know about Vancouver Lake in order to effectively manage it in a way that accomplishes the vision of the Vancouver Lake Watershed Partnership. The strategy outlined in this chapter builds on Chapter 4, which identifies gaps in our knowledge given the questions previously identified by the Partnership.

Several important assumptions underlie the strategy proposed in the following pages. First, the Partnership's financial resources are limited; the strategy will need to accommodate the likelihood that larger studies may need to be broken down into discrete elements that are financially feasible. Second, there are many possible ways to learn what we need to know about Vancouver Lake; the strategy outlined in this chapter is one solution out of many.

Strategy Overview

Developing a strategy implies an organized approach to resolving an issue. One of the confounding problems at Vancouver Lake is that there are many highly interrelated issues. This is important to strategy development because it suggests that an approach to learning what we need to know about Vancouver Lake can be achieved through several different avenues.

The approach suggested here is to use nuisance algal blooms as a "point of entry" to guide our learning about Vancouver Lake. This is not to say that nuisance algal blooms are our only concern. Rather, organizing our discovery process around learning about the underlying causes of the blooms allows us to learn about the lake as a system. This approach helps the Partnership focus on a specific issue that brought the group together. At the same time, the research needed to understand algal blooms also will help explain how the lake functions, which is fundamental to addressing other issues. For example, to address algal issues, it is necessary to understand how water enters, circulates around, and exits Vancouver Lake. This is base-level information that relates to such factors as water temperatures, nutrients, and dissolved oxygen. In other words, an initial focus on algal blooms will help us understand other problems at Vancouver Lake.

Studies

An investigation of algal blooms can take two distinct approaches: bottom-up or top-down. A bottom-up approach involves examining the growth factors that may cause algal blooms (nutrient availability, temperature, light, etc.), while a top-down approach looks at factors that may control the bloom once it has formed (grazing/predation by animal plankton and fish). The studies highlighted in the remainder of this chapter, in one way or another, would address either the top-down or bottom-up approach. They have been identified by the Technical Group as critical areas of inquiry for establishing a baseline understanding of Vancouver Lake necessary for management of the lake. They are organized into six major study areas: water dynamics, nutrients, sediment, food web interactions, toxics, and fish, wildlife and habitat,. Tables 5-1 through Table 5-6 describe these studies in more detail. Partnership questions outlined in Chapter 4 have been carried over into this chapter and posted under the study that could help answer them. Questions that did not fall under a potential research category are addressed separately at the end of the chapter in Table 5-7.

Table 5-1 Water Balance Assessment	
Description	A water balance characterizes the climatic, surface, and groundwater components of a system on a seasonal basis. It can characterize the volumes and timing of the various inputs and outputs of water and helps describe the fundamental hydrology of the system.
Purpose	A seasonal water balance is important to understanding the factors that cause nuisance algal blooms because water inputs and outputs are primary pathways for nutrients entering, exiting, or remaining in the system. A water balance also provides important information about circulation patterns in a system and can be an indicator of other water quality issues. Understanding the water balance at Vancouver Lake is particularly important because of the lake's complex connectivity to tidal influences and the larger watershed.
Study Elements	**Task 1: Enhance the U.S. Army Corp of Engineer's 2-D Hydraulic Model**. The hydraulic model developed by the Corps for Vancouver Lake requires enhancements to meet the larger goals of the Partnership. Specifically, the model needs additional inputs to serve the larger Partnership mission of understanding algal blooms. Enhancing the model might require more specific data inputs for Burnt Bridge Creek, Salmon Creek, Lake River, minor tributaries, and groundwater. **Task 2: Develop a New Hydraulic Model.** In the course of evaluating the Corp's 2-D hydraulic model, it may not be feasible or desirable to enhance the existing model to accommodate additional conditions or refine the model to exhibit the necessary sensitivity required for Partnership needs. If that is the case, a new model would need to be developed. **Task 3: Identify and Acquire Additional Data.** **Task 4: Run the Model.** After an appropriate model is developed, run a series of potential hydrologic changes to help inform management decisions. **Task 5: Develop recommendations for the lake based on model outcomes.**
Partnership Questions Potentially Addressed by Study	• What is the quantity and timing of flows from Lake River into and out of Vancouver Lake? • What is the physical bathymetry of Vancouver Lake, the flushing channel and Lake River and its tributaries? • What are the water circulation patterns within Vancouver Lake? • How do Columbia River tidal fluctuations impact Vancouver Lake, Lake River, and its tributaries? • How does seasonal variability impact hydrology within Vancouver Lake, Lake River and its tributaries? • What is the quantity and timing of flows within the flushing channel? • What is the quantity and timing of flows from Burnt Bridge Creek into Vancouver Lake? • What is the quantity and timing of flows from other tributaries into Vancouver Lake and/or Lake River? • What is the quantity and timing of flows from Salmon Creek into Lake River? • What affect does the island play on water circulation patterns? • Does the flushing channel affect Lake conditions? • How does groundwater influence Vancouver Lake? • What is the quality of groundwater entering Vancouver Lake? • What is the temperature profile of Vancouver Lake and its tributaries throughout the year?

Table 5-2 Nutrient Budget	
Description	The availability of nutrients such as nitrogen and phosphorus is an important factor for algal growth and proliferation. Developing a nutrient budget is important in characterizing the various pathways, quantities, and loads of nutrient inputs and outputs of a system such as tributaries, groundwater, or in-lake loading via sediment resuspension. Understanding the various sources and sinks of major nutrients in the Vancouver Lake system will be an important step in developing a management strategy to potentially reduce nutrient availability to algae.
Purpose	Previous studies have observed large and rapid increases in nitrogen and phosphorus concurrent with increases in algal abundance and often cyanobacteria blooms. Along with testing relationships between algal growth and nutrient availability, it would be helpful to develop a nutrient budget that investigates the various nutrient-loading pathways in the lake system. Measurements of nutrient loading per area of lake (per meter or acre, for example) would provide baseline data for performance measures of management strategies to reduce nutrient loading. For example, the analysis might indicate whether in-lake or watershed controls would be more effective at controlling algal growth and governing algal bloom occurrence.
Study Elements	**Task 1:** Compile and review existing data. With assistance from Partnership agencies, compile all available nutrient data, including sources such as groundwater chemistry information from the Port of Vancouver and Clark Public Utilities and tributary nutrient and flow information from the Port, the City of Vancouver, and Clark County. These data would be compiled into Clark County's data management system, and a data gap assessment to inform new data collection would be conducted. **Task 2:** Data Collection. Collect hydrologic and water chemistry data at major inputs and outputs to the system for at least one water year. Work with existing gages and set up new hydrologic stations (on Lake River, for example) for monthly data collection (with biweekly collection at certain stations during the summer months). Samples would be analyzed for total phosphorus, orthophosphorus, nitrate-nitrite nitrogen, ammonia-nitrogen and total nitrogen, turbidity, total suspended solids (TSS), total solids (TS), alkalinity, total and dissolved organic carbon, biological oxygen demand (BOD), and chlorophyll *a*. While collecting grab samples in the field, pH, water temperature, dissolved oxygen (DO), and conductivity would also be measured. Meteorologic information from an appropriate climate data source (such as Vancouver airport) would be used for atmospheric inputs. **Task 3:** Data Analysis and Recommendations. Develop a nutrient budget based on collected data. Analyze data to identify primary sources of nutrients to the lake and determine internal and external loading. Describe in-lake recycling of nutrients (net retention and internal loading) and related water quality parameters (chorlophyll *a*, water clarity, oxygen, etc.). Describe relationships between lake chemistry and tributary chemistry and develop recommendations for next steps in nutrient management in relation to algae control. Various water quality models are available for balancing nutrient inputs, exports, and storage. Data analysis would establish a basis from which to assess water quality models such as the existing U.S. Army Corps of Engineers 2-dimensional model or those used by Ecology for TMDL development.

Table 5-2 Nutrient Budget	
Partnership Questions Potentially Addressed by Study	• What are the type, amount and distribution of nutrients in Vancouver Lake? • What is the source and quantity of contaminants entering Vancouver Lake? • What conditions facilitate algal blooms? • What is the type, amount and distribution of nutrients in Vancouver Lake sediment? • How does seasonal variation affect nutrient and contaminant concentrations?

Table 5-3 Sediment Investigation	
Purpose	Investigating sediment movement and quality at Vancouver Lake is important in understanding the deeper processes at play at Vancouver Lake. Nutrients, toxics, and organic matter travel with sediment, and how sediment moves and acts while in the lake and tributaries could help identify where nutrient loads are coming from, or where toxins are settling out of suspension. Sediment resuspension (from the lake bottom) has been identified as a potentially important driver for water quality problems in Vancouver Lake. Whether sediment resuspension is caused by wind or foraging fish, understanding this process would help fill an important data gap.
Description	Rates and mechanisms of sediment movement and accumulation within the lake are unknown. Developing a sediment budget to understand sediment transport processes and how sediment moves into, out of, and within the system would be part of the sediment investigation. Another would be to take a deeper look at sediment quality and characteristics throughout the lake, such as levels of toxins, nutrients and organic matter, particle size distribution, and sediment density.
Study Elements	**Task 1:** Compile and review existing data. **Task 2:** Conduct a sediment analysis to develop a more complete understanding of historical conditions at Vancouver Lake and determine the degree to which water quality has changed over time. Collect cores to submit for analysis of lead (210Pb), nitrogen (15N and N), phosphorus (P), carbon (C), titanium (Ti), aluminum (Al), diatoms, and cyanobacterial akinetes. Dating of the cores would be determined by the 210Pb analysis; 15N, N, P and C would describe nutrients in the lake and eutrophication; diatoms would act as water quality indicators; akinetes describe cyanobacteria; and metals Ti and Al describe watershed contributions, sedimentation rates, and atmospheric inputs. By analyzing material preserved in the sediment, the Partnership would be able to determine how water quality and algae composition has changed over the past century, gain a better understanding of changes in sediment chemistry related to changes upstream in the watershed, and define sediment accumulation rates. **Task 3:** Investigate sediment resuspension mechanisms (fish and wind mixing). **Task 4:** Develop recommendations to positively manage sediment issues.

Table 5-3 Sediment Investigation	
Partnership Questions Potentially Addressed by Study	• What is the type, amount and distribution of contaminants in Vancouver Lake sediment? • What is the type, amount and distribution of nutrients in Vancouver Lake sediment? • Where does Vancouver Lake sediment come from and what is the quality of that sediment? • How does sediment move within Vancouver Lake? • What is rate of accumulation/disbursement of sediment in Vancouver Lake and Lake River and what is the trajectory for these rates? • How does sediment move within Lake River, the flushing channel, and other tributaries? • What is the grain size distribution of Vancouver Lake sediments? • How much sediment has accumulated since dredging in the 1980's? Since development of the Columbia River hydrosystem?

Table 5-4 **Food Web Interactions**	
Purpose	Intense bluegreen algal blooms often occur at Vancouver Lake during the summer. During some years the blooms persist throughout the summer months, while during others the blooms are intermittent and recurrent. It is not known whether plankton grazing is influencing the observed cycling of the algal community because very little data for plankton abundance and composition are available. Valuable information about bloom-forming factors could be gained by investigating growth and death rates, trophic interactions between grazer populations, and factors that influence grazing. Several lake management techniques are available for balancing biological communities to favor diverse ecological interactions that could enhance plankton-grazing pressure. Preliminary grazing studies would help to support or eliminate this management technique from consideration.
Description	WSU has nearly completed a 1-year biological assessment focused on three specific objectives: (1) to determine the abundance, distribution, and taxonomic composition of cyanobacteria, algae, and zooplankton in Vancouver Lake over a full annual cycle, (2) to initiate some preliminary investigations of the biotic factors (grazers, for example) and abiotic factors (such as temperature and mixing) that influence these blooms, and (3) to analyze the extant data on cyanobacteria blooms in Vancouver Lake for spatial and temporal patterns and trends in abundance, as well as provide a literature review. Continuing this assessment would involve building on this work and initiating a plankton grazing study that would include a combination of continued abundance and composition data collection and specific grazing-rate experiments. The plankton community data would tell us about the "what" and "where," and the grazing experiments would help us understand the "how." This work could be conducted concurrently with fish community studies to help explain what we may see in the plankton community data.
Study Elements	**Task 1:** Continue abundance and composition data collection over a second annual cycle. **Task 2:** Determine rate processes—the growth and death rates of cyanobacteria—through nutrient manipulation experiments in the laboratory. **Task 3:** Integrate plankton work into broader food web dynamics and other important species in the ecosystem, such as salmonids. **Task 4:** Develop recommendations for potentially managing food web interactions in a way that could favorably influence bluegreen algal blooms.
Partnership Questions Potentially Addressed by Study	• What is the type, amount and distribution of algae in Vancouver Lake? • What conditions facilitate algal blooms? • What is the type, amount and distribution of bluegreen algae in Vancouver Lake? • What is the type, amount and distribution of plankton in Vancouver Lake?

Table 5-5
Fish, Wildlife, and Habitat Investigation

Purpose	Very few data exist on current in-water and upland habitat and the species that use these habitats. It is unknown whether fish use the lake year round or only for specific life stages, for both migratory and resident fish species alike. Previous fish studies have noted very little in-water habitat (meaning cover) for fish-eating fish such as crappie, perch, and bass. Recently conducted aquatic plant surveys noted practically no submerged aquatic plant beds that would provide habitat suitable for fish or plankton. It is possible that habitat and water quality may not allow for the diverse fish communities that normally would be expected in a shallow lake. This lack of diversity might favor fish species that feed heavily on certain plankton populations, such that the plankton's role in controlling the formation of algal blooms is disrupted. Several lake management strategies are available for manipulating fish communities to increase algae grazing by plankton. Initial abundance and composition surveys for fish, coupled with habitat evaluations, might support these management strategies and allow for further research or perhaps pilot studies.
Description	Techniques common for fisheries management would be used to sample fish and make inferences about the greater fish community in the lake and tributaries. Fish collection techniques suitable for the physical conditions of the lake (its water clarity and depth) would be used to collect fish and record information such as species, count, weight, and length. Data would be used to determine indices that assess the "health" of the lake's fish community. These indices could include such factors as fish condition, growth rates, and catch per unit of effort. Classifying fish into functional groups for feeding would allow inferences about interactions between fish and other plants and animals in the lake.
Study Elements	**Task 1:** Compile and review existing data. With assistance from Partnership agencies, compile all available wildlife and habitat data, including sources such as past habitat and wildlife studies and information and data from the Port's current wetland and songbird habitat investigations. **Task 2:** Conduct a habitat survey. **Task 3:** Conduct a fish community study. The study would sample fish at different times of the year using techniques such as boat-electrofishing and experimental gill nets. The number of locations and the duration of the study would be based on the anticipated geographic and temporal variability and available budget. Data would be analyzed to determine metrics that would be useful for describing the relative health of the fish community, both ecologically and recreationally. Interactions within the fish community and between other plants and animals in the lake could be identified and further explored for studies or managment plans. **Task 4:** Develop recommendations to improve habitat for fish and wildlife.

Table 5-5 Fish, Wildlife, and Habitat Investigation	
Partnership Questions Potentially Addressed by Study	• What are the type, amount and distribution of fish in Vancouver Lake? • Are there any federal or state listed species in or around Vancouver Lake? • What is the type, amount and distribution of wildlife in and around Vancouver Lake? • What are the type, amount and distribution of plants in and around Vancouver Lake? • What are the type, amount and distribution of habitats around Vancouver Lake? • What are the type, amount and distribution of exotic plant and animal species in and around Vancouver Lake? • What is the type, amount and distribution of invertebrates in Vancouver Lake? • How do changes in certain water quality parameters (e.g., temperature, nutrient levels, fecal coliform levels, contaminant levels, turbidity, dissolved oxygen concentrations) influence species abundance and distribution? • How do fish, plant and animal distributions change through time? • What is the effect of the flushing channel on fish passage (if any)?

Table 5-6 Toxic Contaminants	
Purpose	Toxic contaminants in water and sediment are a concern for human and ecosystem health. Contaminants of concern in the lower Columbia River include dioxins and furans, heavy metals, PCBs, and organochlorine pesticides such as DDT. Many of these toxins remain in the environment for long periods of time because they do not readily break down. They can be toxic to humans in varying degrees through consumption and bioaccumulation.
Description	The extent and origin of PCBs and organochlorine pesticides such as DDT in Vancouver Lake are unknown. A study of toxic contaminants would further investigate the source and quantity of contaminants entering and remaining in the sediment, water, fish, and wildlife of Vancouver Lake.
Study Elements	**Task 1:** Build on existing toxics studies by sampling water, sediment, and fish tissue for toxins. **Task 2:** Investigate the pathways and origins of toxic contaminants in Vancouver Lake. **Task 3:** Develop recommendations to manage toxic contaminants in the lake.
Partnership Questions Potentially Addressed by Study	• What is the source and quantity of contaminants entering Vancouver Lake? • How does seasonal variation affect nutrient and contaminant concentrations? • What is the relationship between ALCOA site contaminants and Vancouver Lake?

Additional Technical Questions

The Partnership has identified a diverse set of technical questions whose answers would help inform future management of Vancouver Lake (see Chapter 4). The Technical Group proposes to answer these questions through studies that will maximize resources and address the most urgent questions. Unfortunately, not all of the Partnership's questions fall under one of the previous study categories. Table 5-7 outlines Partnership technical questions that were not covered in the previous tables and provides a brief explanation for why they are not being addressed at this time.

Table 5-7 **Technical Questions Not Addressed By a Suggested Study at This Time**	
1.	What is the impact of sea level rise on Vancouver Lake?
	Although sea level rise is an important concern for the environment, the Technical Group did not see this as an urgent technical issue for the Vancouver Lake Watershed Partnership at this time. Sea level rise is an issue best dealt with on a regional level that takes into account the long-term impacts of the sea level rise on multiple scales.
2.	Does Vancouver Lake meet water quality standards for pathogens and bacteria?
	Fecal coliforms are significant for water quality and human health because they indicate the presence of other disease-carrying organisms. The Technical Group believes that the Clark County Health Department is addressing this issue by sampling the Vancouver Lake Park swimming beach every 2 weeks throughout the summer for the presence of E. coli and cyanobacteria. Using EPA bathing water standards, conditions at the lake are usually suitable for swimming based on these criteria. The lake is considered no longer safe for swimming when E. coli samples exceed 236 cells per 100 milliliter and when cyanobacteria tests exceed 100,000 cells per milliliter.
3.	What is the influence of the Willamette River on water quality at Vancouver Lake?
	The influence of the Willamette River on Lake water quality is unknown. Given the available resources and other urgent technical questions of the Partnership, the Technical Group felt that this question did not warrant additional study at this time.

Research Strategy

Tables 5-1 through 5-6 show the six topical study areas for Vancouver Lake. At its August 7, 2008, meeting, the Technical Group discussed priorities for addressing the study needs. After a lengthy discussion, it was agreed that all six study areas are important for Vancouver Lake and that a strategic approach to initiating studies would likely require expertise not currently available to the Technical Group. The approach suggested by the group is to contract with one or more lake experts to define discrete tasks within the six study areas given what we know already, potential interdependencies among studies, and opportunities for cost-effectiveness. Implementing this approach would involve using the Partnership's funds to contract with one or more lake experts.

The Technical Group discussion also touched on an important factor related to research funding. Although the Partnership has its own resources generated from contributions from the City of Vancouver, Clark County, and the Port of Vancouver, a significant portion of the research needs identified in Tables 5-1 through 5-6 will require state or federal assistance, or both. The implication of using grant funds or legislative appropriations for Vancouver Lake is that funding requests need to be tailored to the funding source. This means that priorities to fill data gaps at Vancouver Lake would be driven in part by the available funding source and in part by the critical path of research. For example, the Centennial Clean Water Program administered by the Washington State Department of Ecology would be a suitable grant program for research pathways related to water quality, such as nutrients or fecal coliform. But it would not be the appropriate program for investigations of fish, wildlife, and habitat.

Given these considerations, the initial Vancouver Lake Technical strategy is two-pronged:

1. Work with a limnologist or other lake specialist to help refine the six study areas defined by the Technical Group. The contractor would review the Technical Foundation document and the proposed studies and provide discrete tasks for a scope of work in a future Request for Proposals. The contractor will advise the Technical Group on tasks that could span the six study areas if this makes sense in terms of the critical path or cost effectiveness.

2. Evaluate potential funding sources relative to the scope of work defined by the contractor to identify opportunities to fund specific tasks. This will be done by the Partnership's Steering Group. Specific opportunities will be evaluated to ensure that the identified research makes sense from a critical path perspective. Smaller tasks could be funded directly by Steering Group members if adequate funds are available. Funding for larger tasks will be sought from grant programs, from the Legislature, or through congressional appropriation.

CHAPTER 6

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Appendix A

Vancouver Lake Watershed Partnership Questions Matrix

Vancouver Lake Watershed Partnership Questions Matrix **A = J. Polston Barnes, B = J. Schnabel, C = T. Cummings, D = J. Belston, E = R. Wierenga, F = T. McConathy, G = M. McGinn, H = P. Trask, I = S. Litton, J = D. Sutton**

Table 1. Biological Questions - Technical Group Scores

Type	Vancouver Lake Biological Questions	Significance To Biological Basis 1-5 Scale (1 = highest, 5 = lowest)											Info Availability 1-5 Scale (1 = highest, 5 = lowest)											Is it answered by current studies? 1-5 Scale (1 = highest, 5 = lowest)										
		A	B	C	D	E	F	G	H	I	J	AVG.	A	B	C	D	E	F	G	H	I	J	AVG.	A	B	C	D	E	F	G	H	I	J	AVG.
Bio-2	What is the type, amount and distribution of algae in Vancouver Lake?	1	1	1	1	1	1	1	1	1	1	**1.0**	2	5	3	4	3	5	3	3	3		**3.4**	2	2	2	3	3	5	3	1	3		**2.7**
Bio-11	What conditions facilitate algae blooms?	1	1	1	1	2	1	1	1	1	1	**1.1**	3	3	3	2	2	5	3	3	3		**3.0**	3	3	2	2	2	5	3	3	3		**2.9**
Bio-3	What is the type, amount and distribution of bluegreen algae in Vancouver Lake?	2	1	1	1	1	1	1	1	1	1	**1.1**	2	4	3	4	3	5	3	3	3		**3.3**	2	2	2	3	3	5	3	1	2		**2.6**
Bio-7	What is the type, amount and distribution of plankton in Vancouver Lake?	2	1	3	1	1	1	2	1	2	1	**1.5**	3	5	3	4	3	5	3	3	3		**3.6**	3	2	3	3	3	3	3	1	3		**2.7**
Bio-5	What is the type, amount and distribution of fish in Vancouver Lake?	2	1	3	1	1	1	2	3	1	1	**1.6**	3	4	3	2	2	5	3	3	4		**3.2**	3	5	3	3	2	5	3	3	5		**3.6**
Bio-4	What is the type, amount and distribution of plants in and around Vancouver Lake?	1	1	3	2	1	1	3	2	2	2	**1.8**	1	2	2	5	4	3	3	2	3		**2.8**	1	5	3	unk	3	5	3	2	4		**3.3**
Bio-13	Are there any federal or state listed species in or around Vancouver Lake?	1	2	2	1	2	1	2	4	2	1	**1.8**	1	1	4	2	2	3	2	1	1		**1.9**	3	5	4	2	2		3	1	1		**2.6**
Bio-10	What is the type, amount and distribution of habitats around Vancouver Lake?	1	4	4	1	3	1	3	2	1	3	**2.3**	1	3	3	2	2	5	3	4	3		**2.9**	3	5	4	2	2	5	4	4	3		**3.6**
Bio-9	What is the type, amount and distribution of exotic plant and animal species in and around Vancouver Lake?	2	2	4	1	4	1	4	3	3	1	**2.5**	3	3	3	2	2	5	3	3	3		**3.0**	3	5	4	2	1	5	3	4			**3.4**
Bio-8	What is the type, amount and distribution of invertebrates in Vancouver Lake?	3	4	3	1	3	1	3	2	2	4	**2.6**	1	5	3	4	2	5	3	5	4		**3.6**	1	5	3	3	3	5	4	5	5		**3.8**
Bio-12	How do fish, plant and animal distributions change through time?	5	5	2	2	3	1	2	3	3	1	**2.7**	3	5	5	unk	2	5	4	4	4		**4.0**	3	5	5	unk	2	5	4	5	4		**4.1**
Bio-1	Is Vancouver Lake swimmable and safe for human contact?	4	5	1	1	5	1	1	3	4	4	**2.9**	2	3	3	2	4	3	2	3	3		**2.8**	2	3	2	2	4	5	2	1			**2.6**
Bio-6	What is the type, amount and distribution of wildlife in and around Vancouver Lake?	2	3	5	3	4	1	3	3	2	4	**3.0**	3	2	3	5	2	3	4	2	4		**3.1**	3	5	3	unk	2	5	4	4	5		**3.9**

Vancouver Lake Watershed Partnership Questions Matrix A = J. Polston Barnes, B = J. Schnabel, C = T. Cummings, D = J. Belston, E = R. Wierenga, F = T. McConathy, G = M. McGinn, H = P. Trask, I = S. Litton, J = D. Sutton

Table 1. Biological Questions - Technical Group Comments

Type	Vancouver Lake Biological Questions	Comments									
		A	B	C	D	E	F	G	H	I	J
Bio-2	What is the type, amount and distribution of algae in Vancouver Lake?	Important to evaulate if blooms are out of norm or natural process of lake.	combine with Bio-3-- Bollens/WSU study addresses much of this	Directly tied to human contact question; WSU study will provide critical info	directly relates to Ques 1?	Cost-wise combining 2,3,7,11 would be lower	Info availability I have marked low due to the limited periods of observation and the current studies as low as we have only a two years period of study one in the late 70's and one this last year.		WSU		Bio-2,3,7 would be one study.
Bio-11	What conditions facilitate algae blooms?	Seems important to evaluate.	this is very broadly stated, but understanding the dynamics between sediment, water column, nutrients, and algae is critical	WSU study will provide some info	coordination w/ Dept of Health		Info availability on what allows or causes a particular alga to dominate over all others is only poorly understood. This is not the focus of any of the current studies. We should do a lit search on this to see if others are working on this and to possibl	vital info. Existing data points to depth and phosphorus most important		WSU thinking about this. Will they be able to answer?	Understanding the conditions that support algal blooms in VL is necessary to develop management practices.
Bio-3	What is the type, amount and distribution of bluegreen algae in Vancouver Lake?	See Bio-2	combine with Bio-2	Believe this is a component of Bio-2 question	see above	Algae data collected by ClarkCo volunteers and WSU-V; 4 years Health Department data; 2006 Ecology Bac-t data; Health Department Closure record;	It is my understanding that alga populations are fairly uniform throughout the lake. is this also true with the Blue greens? B11 and B3 seem to be a logical linking for a future study	very variable but often predictable		Clark Couty has data and WSU is working on this. Important for Vancouver Lake	Bio-2,3,7 would be one study.
Bio-7	What is the type, amount and distribution of plankton in Vancouver Lake?		am I correct that the Bollens/WSU study covers this?	WSU study will provide some info	indicator of overall lake ecological health	~ $65-100K; post-construction data and WSU-V data;	Info availability I have marked as low as we have only one year of observations and we have not seen that report, the current studies I have so marked for the same considerations.			WSU working on this	Bio-2,3,7 would be one study.
Bio-5	What is the type, amount and distribution of fish in Vancouver Lake?	Significant to food web and ecology of lake system. Little info avail. Need enough to evaluate level of importance.		Value for "answered by current studies" would go up to 4 if ACE gets funding for fish survey	high priority for VLWP	Cost-wise combining 5, 12, 13 would be lower; post-construction surveys; WDFW Caromile and others report;	This question should be expanded to movement in and out of the lake system and include both adults and juveniles. This is a key to many future funding sources.		important, but if we improve habitat and water quality first, communities will improve	No recent work done. Still many questions.	Required to determine existence of listed fish species for special protection. Distribution may raise concerns about levels of contaminants in specific fish tissues.
Bio-4	What is the type, amount and distribution of plants in and around Vancouver Lake?	The types and amount of vegetation that surrounds the lake can have a significant impact on the aqautic environment.	July 2007 Ecology inventory may be sufficient. Easily expanded if necessary.			Ecology qualitative survey report (Ron W has)	Botanist with Bio 4, 9, 12 ,13			DOE informal plant survey. Still have lots left to learn	Bio-4,9,10 would be one study.
Bio-13	Are there any federal or state listed species in or around Vancouver Lake?		the list we already have should be sufficient	Seems to be pretty good info for birds and mammals but little info on fish	several area studies have looked at this	anecdotal (Limiting Factors Analysis for WRIA 28, Salmon Recovery Plan);	This should be grouped with Bio 5		listed species known in the region		Listed species will impact management decisions, important to survey and document.
Bio-10	What is the type, amount and distribution of habitats around Vancouver Lake?		ranked based on "around", not "in"		several area studies have looked at this		Fish and wildlife with bio 6, 12, 13			Older studies discuss this. Plant survey could help?	Necessary to determine existing and desired habitat for restoration purposes.
Bio-9	What is the type, amount and distribution of exotic plant and animal species in and around Vancouver Lake?	Seems important only for those species that are known to significantly negetivley or positivley influence aqautic systems.	2007 plant survey indicates several aggressive exotic species. Some management strategies could allow them to expand		several area studies have looked at this		important to the developing of a management plan.			Not sure how extensive knowledge is in this area	Split Bio-9 so it is specific to either plant or animal species. Control of certain invasive species can be critical to ecosystem health.
Bio-8	What is the type, amount and distribution of invertebrates in Vancouver Lake?	Depends on the purpose of information. Can impact water quality or food web . With current info, not sure how it applies to VL.			indicator of overall lake ecological health	<$50K; WSU-V data	Macro should include Fresh water mussels				Invertebrate populations will improve with water quality improvements. Distribution can help direct restoration activities.
Bio-12	How do fish, plant and animal distributions change through time?	Seems more approriate to decide which "time" is being preserved for lake mamagement decisions. Info would help if trying to restore something to past conditions.	Not sure what this means. If long-term trends, then outside current info needs. If seasonal distribution, then relatively unimportant	(Overall survey comment: I interpreted "info Available" as pertaining to past studies/data and "is it answered by current studies" as pertaining to ongoing studies/data collection). Health Dept. data show answer is "not always". May not be most important issue from a strictly ecological perspective, but given high societal value of human recreation in lake, ranked significance as 5		WSU-V data;	Link with Fish and Wildlife study as per Bio 10 This is an important consideration in the developing of future management plans.				Not a condition for ecosystem health but must meet use criteria and management goals (1).
Bio-1	Is Vancouver Lake swimmable and safe for human contact?	A lake can be unpleasent or unswimable but not reflect the bio or eco state of the system.	suggest eliminating: this is an abstract concept better addressed through WQ-8		coordination with Dept of Health	We may want a different type for Public Health	What about fecal Coliform Crypto- sporidea issues? !!!!!!!!!	direct correlation between public health/ecology. CWA of 1972 authorized "swimmable" waters	Safe and swimmable is an end goal; if we do our job elsewhere, this will occur	Not necissarily related to scientific basis.	These types of surveys can be important to monitor the effectiveness of BMPs and restoration efforts.
Bio-6	What is the type, amount and distribution of wildlife in and around Vancouver Lake?	For those species that play a significant role in lake ecology.				~ $50K, pre-construction surveys; Audubon or WDFW surveys?;	This is an important consideration as to the developing of a management plan.			Not familiar with any recent wildlife studies	Link to habitat availability for restoration goals.

Table 2. Physical Environment Questions - Technical Group Scores

Type	Vancouver Lake Physical Environment Questions	Significance To Biological Basis 1-5 Scale (1 = highest, 5 = lowest)											Info Availability 1-5 Scale (1 = highest, 5 = lowest)											Is it answered by current studies? 1-5 Scale (1 = highest, 5 = lowest)										
		A	B	C	D	E	F	G	H	I	J	AVG.	A	B	C	D	E	F	G	H	I	J	AVG.	A	B	C	D	E	F	G	H	I	J	AVG.
Phy-2	What is the quantity and timing of flows within the flushing channel?	1	1	1	1	1	1	1	1	1	1	**1.0**	3	3	4	2	3	3	3	2	3		**2.9**	3	2	2.5	2	3	3	3	2	4		**2.7**
Phy-9	What is the physical bathymetry of Vancouver Lake, the flushing channel and Lake River and its tributaries?	1	1	1	1	1	1	1	1	1	1	**1.0**	2	3	2	3	3	3	3	4	1		**2.7**	2	1	4	3	3	in progress	2	1	2		**2.3**
Phy-3	What is the quantity and timing of flows from Lake River into and out of Vancouver Lake?	1	1	1	2	1	1	1	1	1	1	**1.1**	3	5	5	3	4	5	2	4	5		**4.0**	3	2	2.5	3	4	5	2	2	5		**3.2**
Phy-1	What are the water circulation patterns within Vancouver Lake?	2	2	1	2	1	1	1	1	1	1	**1.3**	2	4	5	4	3	5	3	3	3		**3.6**	2	4	2.5	4	4	?	4	2	4		**3.3**
Phy-14	How much sediment has accumulated since dredging in the 1980's? Since development of the Columbia River hydrosystem?	1	3	1	2	2	1	1	2	3	1	**1.7**	1	3	5	3	4	5	4	3	4		**3.6**	1	4	5	3	4	5	4	3	5		**3.8**
Phy-11	How do Columbia River tidal fluctuations impact Vancouver Lake, Lake River, and its tributaries?	3	1	3	1		1	1	2	2	2	**1.8**	3	4	2	3		4	3	1	3		**2.9**	3	2	4	2		1	3	1	4		**2.5**
Phy-15	Does the flushing channel affect lake conditions?	1	5		1	3	1	1	2	2	1	**1.9**	1	2		2	2	5	4	3			**2.7**	1	2		2	2	5	5	2	5		**3.0**
Phy-12	How does seasonal variability impact hydrology within Vancouver Lake, Lake River, and its tributaries?	3	1	2	3	2	1	1	2	2	2	**1.9**	3	3	4	3	3	5	3	1	4		**3.2**	3	5	5	4	4	3	3	1	4		**3.6**
Phy-7	How does groundwater influence Vancouver Lake?	2	2	4	3	3	2	2	2	2	3	**2.5**	5	5	2.5	2	3	?	3	2	3		**3.2**	5	2	2.5	2	4	5	3	2	2		**3.1**
Phy-10	How do Columbia River dam releases impact Vancouver Lake water levels?	3	4	3	2	2	1	2	2	4	4	**2.7**	3	5	2	2	3	3	3	1			**2.8**	3	5	4	3	3	3	3	1	5		**3.3**
Phy-4	What is the quantity and timing of flows from Burnt Bridge Creek into Vancouver Lake?	3	3	3	2	3	1	4	3	3	4	**2.9**	3	3	4	2	3	3	4	2			**3.0**	3	2	2	3	3	3	3	2			**2.6**
Phy-6	What is the quantity and timing of flows from other tributaries into Vancouver Lake and/or Lake River?	1	4	5	3	3	2	3	3	3	4	**3.1**	1	4	4	4	4	5	4	5			**3.9**	1	5	2	4	4	5	4	4			**3.6**
Phy-5	What is the quantity and timing of flows from Salmon Creek into Lake River?	3	4	4	2	3	1	4	3	3	4	**3.1**	3	2	4	3	3	5	4	2			**3.3**	3	3	2	3	3	5	4	2			**3.1**
Phy-8	What affect does the island play on water circulation patterns?	4	5	5	4		1	4	3	4	5	**3.9**	3	5	5	4			5	5			**4.5**	3	4	5	4			5	3	4		**4.0**
Phy-13	What is the impact of sea level rise on Vancouver Lake?	3	5	4	3	4	1	5	5	4	5	**3.9**	3	5	5	5	5		5	5			**4.7**	3	5	5	5	5	4	5	5			**4.6**

Vancouver Lake Watershed Partnership Questions Matrix A = J. Polston Barnes, B = J. Schnabel, C = T. Cummings, D = J. Belston, E = R. Wierenga, F = T. McConathy, G = M. McGinn, H = P. Trask, I = S. Litton, J = D. Sutton

Table 2. Physical Environment Questions - Technical Group Comments

Type	Vancouver Lake Physical Environment Questions	Comments									
		A	B	C	D	E	F	G	H	I	
Phy-2	What is the quantity and timing of flows within the flushing channel?		Phy-2 -6 plus Phy 10-12 could all be combined--- much of this is covered by the current Corps modeling effort or could be covered by expanding that effort	Unclear if ACE survey and modeling will provide some info relative to this; Component of Phy-1	Port data summary	Port gaging data needs analysis and summary;	Corps and Port We have one years of monitoring We need to widen the scope of	quantity is vital but apparently not enough to impact lake	Port of Vancouver gauge and USACE model	port taking recent data right?	Need information.
Phy-9	What is the physical bathymetry of Vancouver Lake, the flushing channel and Lake River and its tributaries?		Corps bathymetric study should be sufficient	ACE study will provide important info		on the way; Lake River coverage unknown;	we don't know the nature or quality of this yet	if lake was deeper groundwater inflow would be greater	USACE bathymetry	corps providing. Don't have for tribs other than Lake River	
Phy-3	What is the quantity and timing of flows from Lake River into and out of Vancouver Lake?			Unclear if ACE survey and modeling will provide some info relative to this; Component of Phy-1		very little info; probably most important;	Corps We do not have flow measuring equipment in place. The Corps seems to be concentrating on low flow	Lake River is more or less just an arm of the Lake	USACE hydraulic model	not familiar with data adressing this	Not well understood.
Phy-1	What are the water circulation patterns within Vancouver Lake?		dye study	Unclear if ACE survey and modeling will provide some info relative to this		not sure whee corps work will get us;	Corps It is unclear whether the Corps will model this under year round conditions. The presentation that we were given earlier was only under low flow.		USACE getting to this question	crucial	
Phy-14	How much sediment has accumulated since dredging in the 1980's? Since development of the Columbia River hydrosystem?	Can flow from tributaries help answer this question?	move to SQ , combine w/ SQ-7			move to SQ section;	No as built assessment was made but perhaps the Corps or its contractor might have logs that might be useful		still need core sample analysis to test rates		Question would be posed within a sediment study SQ-7.
Phy-11	How do Columbia River tidal fluctuations impact Vancouver Lake, Lake River, and its tributaries?	Important but hasn't this been answered to some extent?				combine with Phy-10;	This should be postulated alternatively with active management of the flushing gates.		USACE hydraulic model	GW report shed some light on these relationships	Should be part of hydrological system study.
Phy-15	Does the flushing channel affect lake conditions?	After ACOE and Gourndwater analysis it seems the flushing channel may be a key element of lake ecology.	suggest eliminating-- many other questions address elements of this question more specifically	Question needs to be clarified--not sure what it means. If it has to do with flow, is redundant with Phy-2	Pare down question-if addressing flow, Phy 2 can answer		Nutrient loading algal and bacteria and the synergetic effect of combining with lake waters needs to be known before expansion of this can be considered. Active verses passive operation of the flushing gates need to also be considered. Perhaps reword as how dose the flushing channel effect lake water quality/temp/quantity		USACE hydraulic model	related to Phy-2	Would need to be determined after quantity and timing of flow study. Important to understand for implementing changes to system.
Phy-12	How does seasonal variability impact hydrology within Vancouver Lake, Lake River, and its tributaries?	As relates to seasonal change in lake. Is there a corralation?				should be answered by other questions;	This would include lake size and height. This dose change year to year . A permanent flow and water height gage and recording station should be put in place for the confluence of BBC, Lake River and the flushing channel..		USACE hydraulic model		Would be determined after answering Phy 2-6. Useful to understand in evaluating management strategies.
Phy-7	How does groundwater influence Vancouver Lake?	Important to consider. Recent data seems suffcient.	Vancouver Lake lowlands groundwater model appears to address this	According to Vancouver Lake groundwater model, groundwater influence is insignificant; would be nice to do additional data collection to verify model results	Prelim info from Port/CPU model-more study needed	Port/CPU model	When I submitted this I framed it with how groundwater might effect water temperature to create microhabitats similar to what occurs with Bull trout on the Lewis. This was not intended as a circulation question. The Ground water report given to us by the Port and CPU did not deal with the ground water contributions to the Lake. In looking at the report I did not see test wells at the foot of the Hazeldell-Falida Ridge that would define this contribution. .	could bring in phosphorus from the sediment		can start to answer this with port/cpu model	
Phy-10	How do Columbia River dam releases impact Vancouver Lake water levels?	Couldn't this be seen in flow or seasonal data?	suggest eliminating-- covered by Phy-2 and Phy-3		Combine with Phys-11?	How do water levels (tide or flow) impact VanLake and Lake R?	We have not monitored this long enough to completely dismiss this as the corps has . The Corps is concentrating on low season flows.		USACE hydraulic model		
Phy-4	What is the quantity and timing of flows from Burnt Bridge Creek into Vancouver Lake?	I thoughtthe groundwater study showed this is the one natural spring that has a significant flow into the lake. If so important as relates to groundwater info.		Suspect impact from BBC is less important than that from flushing channel and Lake River; can't recall if Vancouver Lake groundwater study provides info relevant to this question; info could be gained at same time as for Phy-1		historic USGS gage data (Clark County may have copies)	We need a permanent flow and temp gage and recording station	quantity of BBC is insignificant particularly in summer	Stream guages	not up to date on trib gauge data availability	Phy 2-6 and Phy 10-12 would be combined into a system study. Can build on existing data for tributary contributions.
Phy-6	What is the quantity and timing of flows from other tributaries into Vancouver Lake and/or Lake River?	As relates to loading issues such as sediment, nutrients, contaminants, etc		Suspect impact from other tribs is less important than that from flushing channel and Lake River; can't recall if Vancouver Lake groundwater study provides info relevant to this question; info could be gained at same time as for Phy-1	combine with Phys-3	ClarkCo 1997 draft Salmon Cr watershed play may estimate;	This may be unimportant as far as quantity but these may be major sources of water quality issues. Carl Addey recorded Chicken creek as a problem with this regard and if we look at the 99 and Bendrosean outfalls I am sure we will find major sources of water quality concerns		Port and CPU groundwater model	not up to date on trib gauge data availability	Phy 2-6 and Phy 10-12 would be combined into a system study. Can build on existing data for tributary contributions.
Phy-5	What is the quantity and timing of flows from Salmon Creek into Lake River?	Seems import if Lake River flows deemed significatn		Suspect impact from Salmon Creek is less important than that from flushing channel and Lake River; can't recall if Vancouver Lake groundwater study provides info relevant to this question; info could be gained at same time as for Phy-1		ClarkCo gage data;	We need perm monitoring stations for at least flow and temperature.	also insignificant impact on the lake in summer	Stream guages	not up to date on trib gauge data availability	Phy 2-6 and Phy 10-12 would be combined into a system study. Can build on existing data for tributary contributions.
Phy-8	What affect does the island play on water circulation patterns?	Seems important if plan to alter island or create a second island.	suggest eliminating-- included in Phy-1	Don't know why this matters unless one management option is to remove the island	eliminate or combine w/ Phys-1	combine with Phy-9	I would hope that the Corps study might help with this.		Port and CPU model, USACE model somewhat	would be answered if phy-1 was addressed	Covered in Phy-1.
Phy-13	What is the impact of sea level rise on Vancouver Lake?	Should be discussed to determine if important.	suggest eliminating-- many other questions are more pressing	Believe question best addressed on a regional level	too broad a question global issue	long-term seal level rise?					Big picture, long term issues. Possible impacts should be considered in management decisions.

Table 3. Water and Sediment Quality Questions - Technical Group Scores

Significance To Biological Basis (1-5 Scale, (1 = highest, 5 = lowest))

Type	Vancouver Lake Water and Sediment Quality Questions	A	B	C	D	E	F	G	H	I	J	AVG.
WQ-3	What is the source and quantity of nutrients entering Vancouver Lake?	1	1	2	1	1	1	1	1	1	1	**1.1**
WQ-1	What is the type, amount and distribution of nutrients (i.e. phosphorus) in Vancouver Lake?	1	1	1	2	1	1	1	1	1	1	**1.1**
WQ-2	What is the type, amount and distribution of contaminants in Vancouver Lake?	1	1	2	1	3	1	1	1	1	1	**1.3**
SQ-4	What is the type, amount and distribution of nutrients in Vancouver Lake sediment?	1	1	2	2	1	1	2	1	1	1	**1.3**
WQ-4	What is the source and quantity of contaminants entering Vancouver Lake?	1	2	3	1	2	1	1	1	1	1	**1.4**
SQ-5	What is the type, amount and distribution of contaminants in Vancouver Lake sediment?	1	1	3	2	2	1	2	1	1	1	**1.5**
WQ-8	Does Vancouver Lake meet water quality standards for pathogens and bacteria?	1	1	1	1	2	1	3	2	2	1	**1.5**
SQ-1	Where does Vancouver Lake sediment come from and what is the quality of that sediment?	2	1	3	2	1	1	2	1	2	1	**1.6**
SQ-2	How does sediment move within Vancouver Lake?	3	1	2	2	1	1	2	2	2	1	**1.7**
SQ-7	What is current rate of accumulation/disbursement of sediment in Vancouver Lake and Lake River and what is the trajectory for these rates?	1	1	2	2	3	1	2	2	2	1	**1.7**
WQ-10	How does seasonal variation affect nutrient and contaminant concentrations?	3	1	2	2	2	1	1	2	3	2	**1.9**
WQ-5	What is the temperature profile of Vancouver Lake and its tributaries throughout the year?	3	3	2	1	3	1	4	1	1	1	**2.0**
SQ-3	How does sediment move within Lake River, the flushing channel, and other tributaries?	2	2	3	2	2	1	3	2	3	1	**2.1**
SQ-6	What is the grain size distribution of Vancouver Lake sediments?	4	2		3	3	1	3	2	3	1	**2.4**
WQ-9	What is the quality of groundwater entering Vancouver Lake?	5	4	5	2	3	1	3	2	2		**3.0**
WQ-7	What is the relationship between Alcoa site contaminants and Vancouver Lake?	3	4	4	3	4	1	3	3	3	3	**3.1**
WQ-6	What is the influence of the Willamette river on Vancouver Lake water quality?	4	4	4	4	5	1	4	4	4	4	**3.8**

Info Availability (1-5 Scale, (1 = highest, 5 = lowest))

Type	Vancouver Lake Water and Sediment Quality Questions	A	B	C	D	E	F	G	H	I	J	AVG.
WQ-3	What is the source and quantity of nutrients entering Vancouver Lake?	1	3	4	3	4	5	4	4	4		**3.6**
WQ-1	What is the type, amount and distribution of nutrients (i.e. phosphorus) in Vancouver Lake?	1	3	4	3	3	5	4	2	3		**3.1**
WQ-2	What is the type, amount and distribution of contaminants in Vancouver Lake?	1	4	3	4	3	5	3	3	3		**3.2**
SQ-4	What is the type, amount and distribution of nutrients in Vancouver Lake sediment?	3	5	5	5	4	5	1	4	4		**4.0**
WQ-4	What is the source and quantity of contaminants entering Vancouver Lake?	1	4	3	4	3	5	4	4	4		**3.6**
SQ-5	What is the type, amount and distribution of contaminants in Vancouver Lake sediment?	1	4	4	4	3	5	2	4	3		**3.3**
WQ-8	Does Vancouver Lake meet water quality standards for pathogens and bacteria?	1	2	2	2	2	5	2	3	2		**2.3**
SQ-1	Where does Vancouver Lake sediment come from and what is the quality of that sediment?	3	3	5	4	4	5	2	4	3		**3.7**
SQ-2	How does sediment move within Vancouver Lake?	3	5	5	4	4	5	2	4	5		**4.1**
SQ-7	What is current rate of accumulation/disbursement of sediment in Vancouver Lake and Lake River and what is the trajectory for these rates?	1	5	4	5	4	5	4	3	3		**3.8**
WQ-10	How does seasonal variation affect nutrient and contaminant concentrations?	4	4	3	3	4	5	4	3	4		**3.8**
WQ-5	What is the temperature profile of Vancouver Lake and its tributaries throughout the year?	3	2	5	3	3	3	2	3	4		**3.1**
SQ-3	How does sediment move within Lake River, the flushing channel, and other tributaries?	1	3	5	5	4	5	2	4	5		**3.8**
SQ-6	What is the grain size distribution of Vancouver Lake sediments?	4	5		4	4	5	1	2	3		**3.5**
WQ-9	What is the quality of groundwater entering Vancouver Lake?	5	2	3	4	3	4	4	3	3		**3.4**
WQ-7	What is the relationship between Alcoa site contaminants and Vancouver Lake?	3	3	1	4	3		3	2	2		**2.6**
WQ-6	What is the influence of the Willamette river on Vancouver Lake water quality?	3	4	5	3	3		3	4	4		**3.6**

Is it answered by current studies? (1-5 Scale, (1 = highest, 5 = lowest))

Type	Vancouver Lake Water and Sediment Quality Questions	A	B	C	D	E	F	G	H	I	J	AVG.
WQ-3	What is the source and quantity of nutrients entering Vancouver Lake?	1	3	4	3	3	5	4	4	4		**3.4**
WQ-1	What is the type, amount and distribution of nutrients (i.e. phosphorus) in Vancouver Lake?	1	3	5	3	2	5	4	3	4		**3.3**
WQ-2	What is the type, amount and distribution of contaminants in Vancouver Lake?	1	5	5	4	3	5	4	3	4		**3.8**
SQ-4	What is the type, amount and distribution of nutrients in Vancouver Lake sediment?	3	5	5	5	4	5	1	4	3		**3.9**
WQ-4	What is the source and quantity of contaminants entering Vancouver Lake?	1	5	5	4	3	5	4	4	3		**3.8**
SQ-5	What is the type, amount and distribution of contaminants in Vancouver Lake sediment?	1	5	5	4	2	5	2	4	4		**3.6**
WQ-8	Does Vancouver Lake meet water quality standards for pathogens and bacteria?	1	3	2	2	2	5	2	3	3		**2.6**
SQ-1	Where does Vancouver Lake sediment come from and what is the quality of that sediment?	3	4	5	4	4	5	3	4	4		**4.0**
SQ-2	How does sediment move within Vancouver Lake?	3	5	5	4	4	5	3	4	4		**4.1**
SQ-7	What is current rate of accumulation/disbursement of sediment in Vancouver Lake and Lake River and what is the trajectory for these rates?	1	5	5	5	4	5	5	4	5		**4.3**
WQ-10	How does seasonal variation affect nutrient and contaminant concentrations?	4	3	2	3	4	5	4	3	4		**3.6**
WQ-5	What is the temperature profile of Vancouver Lake and its tributaries throughout the year?	3	2	5	3	3	5	1	2	3		**3.0**
SQ-3	How does sediment move within Lake River, the flushing channel, and other tributaries?	1	4	5	5	4	5	3	4	4		**3.9**
SQ-6	What is the grain size distribution of Vancouver Lake sediments?	4	5		4	3	5	1	3	4		**3.6**
WQ-9	What is the quality of groundwater entering Vancouver Lake?	5	5	5	4	3	5	4	3	3		**4.1**
WQ-7	What is the relationship between Alcoa site contaminants and Vancouver Lake?	3	3	5	3	3	5	4	3			**3.6**
WQ-6	What is the influence of the Willamette river on Vancouver Lake water quality?	3	3	5	3	4	5	1	4			**3.5**

Vancouver Lake Watershed Partnership Questions Matrix A = J. Polston Barnes, B = J. Schnabel, C = T. Cummings, D = J. Belston, E = R. Wierenga, F = T. McConathy, G = M. McGinn, H = P. Trask, I = S. Litton, J = D. Sutton

Table 3. Water and Sediment Quality Questions - Technical Group Comments

Type	Vancouver Lake Water and Sediment Quality Questions	Comments									
		A	B	C	D	E	F	G	H	I	
WQ-3	What is the source and quantity of nutrients entering Vancouver Lake?		combine with WQ-1 and WQ-10			ClarkCo/City/River chemistry data; needs analysis;	I do not see this as being addressed in current studies.				Distribution study should include sediments. Release from sediments can be impacted by changes in physical/chemical lake conditions.
WQ-1	What is the type, amount and distribution of nutrients (i.e. phosphorus) in Vancouver Lake?		combine with WQ-3 and WQ-10 as part of overall nutrient budget study			ClarkCo and WSU-V data;	dito			nutrient questions relate to Bio - algae questions	Combine with WQ-1
WQ-2	What is the type, amount and distribution of contaminants in Vancouver Lake?			Would be helpful to define contaminants, e.g., all water pollutants, toxic compounds only, etc.		Ecology toxics studies (several)	Dito				Combine WQ-2, SQ-5, WQ-4
SQ-4	What is the type, amount and distribution of nutrients in Vancouver Lake sediment?					Simple core analysis will cover this.	Dito				Distribution study should include sediments. Changes to physical/chemical water conditions would impact release from sediments.
WQ-4	What is the source and quantity of contaminants entering Vancouver Lake?		this is a followup project, only necessary if WQ-2 indicates an issue			various studies; Col R summaries (LCREP?);	Dito				Combine WQ-2, SQ-5, WQ-4
SQ-5	What is the type, amount and distribution of contaminants in Vancouver Lake sediment?					Ecology study 2006;	Why not expand SQ 3 to include this issue. EPA will be looking at the Alcoa impacts.			Ecology toxic study	Move to bio section. Question is vital to meet use criteria. Real question is how do we meet the standards consistently.
WQ-8	Does Vancouver Lake meet water quality standards for pathogens and bacteria?			Health Dept. data indicates current answer is "not always". Seems redundnat with Bio-1.	coordination w/ Dept of Health	Public Health issue;	This is not adequately monitored for to determine this at this time.	meets guidelines most of time. Shore birds appear to have most impact	Some sampling;need more sites and frequency		SQ 1,2,3,6,7 and Psy-14 under 1 sediment study.
SQ-1	Where does Vancouver Lake sediment come from and what is the quality of that sediment?	See above.	may be covered under SQ-2, 4, and 5			combined 1-3 less costly but over $100K;					SQ 1,2,3,6,7 and Psy-14 under 1 sediment study.
SQ-2	How does sediment move within Vancouver Lake?	Important if sedimentation found to play a large role in blooms or other neg attribtes to lake ecology.	suggest expanding this question to include "to and within"			This is critical. Tells us where sediment is coming from, where to to trap it, where to stabilize it.	This is important to any future management planning.				Rate of accumulation will influence management choices.
SQ-7	What is current rate of accumulation/disbursement of sediment in Vancouver Lake and Lake River and what is the trajectory for these rates?	Could impact planning decisions.				combine w/ SQ-2	it is important to know at least for base line and to make future management plans.				Critical season studies would be most useful to assist in management strategies. Break out into separate questions for nutrients and contaminants.
WQ-10	How does seasonal variation affect nutrient and contaminant concentrations?	Important if certain nutrients or contaminants need further investigation	combine with WQ-1 and WQ-3	Ongoing Health Dept data collection may help answer this question	don't understand question- suggest eliminating	variation in what?	This is important for the making of future management plans			Would be answered through WQ-1-4	Impacts biological and chemical processes.
WQ-5	What is the temperature profile of Vancouver Lake and its tributaries throughout the year?		could probably remove tributaries from this study since summertime inflow is relatively insignificant	I think focus should be on summer temperatures; Clark County, City of Vancouver and Ecology collecting temp data in tribs		ClarkCo/WSU-V data	Need for perm monitoring/recording stations	we have summer data		some temp data exists. Need more	SQ 1,2,3,6,7 and Psy114 under 1 sediment study.
SQ-3	How does sediment move within Lake River, the flushing channel, and other tributaries?	See above.	combine with SQ-2				This is important to making future management plans				SQ 1,2,3,6,7 and Psy-14 under 1 sediment study. Grain size is important in contaminant studies.
SQ-6	What is the grain size distribution of Vancouver Lake sediments?	Could be answered in sediment flow SQ-1,3,7 due to grain size playing a large role in deposition patterns		Don't know enough about the relevance of grain size to Vancouver Lake issues to rank this question		combine w/ SQ-5; general sediment characteristics will be determined;	This is important to any management plan.			past studies of VL sediment exist. How much change has occurred since then?	Groundwater inputs would need to be determined to quantify impacts from nutrient or contaminants.
WQ-9	What is the quality of groundwater entering Vancouver Lake?	Doesn't seem as significant after Groundwater analysis.	changed to low significance based on results of current model	According to Vancouver Lake groundwater study, impact on lake from groundwater is minimal.	Port/CPU data	contaminants or nutrients?; Port/CPU well data for modelling?:	This could form micro habitat areas vital to fish survival as occurs with bull trout on the Lewis.		Port and CPU groundwater model might have info.	GW input is low according to model. Many wells in lowlands. Is there WQ data associated with them that could shed some light?	Separate study to determine impacts and remediation if shown to have impacts in other studies.
WQ-7	What is the relationship between Alcoa site contaminants and Vancouver Lake?	Could be difficult to determine.	this is a followup project, only necessary if WQ-9 suggests reason for concern specifically about the Alcoa site		upcoming Alcoa sediment dredge	EPA assessment of Alcoa Cleanup?; Ecology Alcoa Cleanup;			EPA		Do not know. We do not have the ability to implement changes in the water quality of that waterbody.
WQ-6	What is the influence of the Willamette river on Vancouver Lake water quality?				Portland Harbor data?	I'm sure a model/expert answers or could answer this question with an email;	DOE has proven that Combined Sour overflow from the Willamette regularly contaminate the Frenchmen's Bar beach It might also be entering Vancouver Lake through the Flushing Channel.	little or no impact		Little influence	