Technical Foundation for Future Management of Vancouver Lake

Photo by Vancouver Lake Crew

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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 recurring cyanobacteria (bluegreen algae) blooms that have caused the closure of Vancouver Lake to water contact activities during several summers. Cyanobacteria blooms make the lake unsuitable for water contact activities because cyanobacteria have the potential to produce harmful toxins. Cyanobacteria and other algal blooms can also have detrimental effects on lake ecosystems by depleting oxygen levels and can be aesthetically unappealing through the development of surface scums.

Although cyanobacteria blooms are a central concern at Vancouver Lake, the community also is concerned about other human-caused issues, such as the presence of toxic contaminants and pathogens, high water temperatures, excessive nutrients, and high turbidity levels. These often interrelated problems disrupt community use of the lake 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 cyanobacteria issues and the U.S. Army Corps of Engineers – Portland District, to study lake hydraulics. These two studies have provided information that informs the Partnership’s understanding of lake function. In 2010 the Partnership contracted with the US Geological Survey (USGS) to research the water balance and nutrient budget of Vancouver Lake, a study identified as critical to future management decisions for the lake.

Purpose of this Document

This document is intended to organize and convey the baseline information about Vancouver Lake from a technical perspective regarding cyanobacteria 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 the foundation from which the Partnership develops technical, research, and management strategies.

This document and its appendices identify and prioritize studies necessary to understand the forces driving lake function at the time of this publication. These research priorities are captured in Appendix A. Once the driving forces of the lake condition are better understood, the Partnership will be able to better examine the effectiveness of potential management techniques within the Vancouver lake system.

It is important to note that technical studies on potential lake management techniques will be necessary to determine which techniques would be feasible and effective in Vancouver Lake. Those studies are not identified or prioritized in this Technical Foundation, but will be developed separately.

Many of the potential management techniques have been described in a report entitled *Lake Algal Control Techniques with Implications for Vancouver Lake*. When that report is updated by the end of 2011 it will be attached to this Technical Foundation as Appendix B.

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 written for a lay audience that has interest in the research necessary to make sound management decisions for Vancouver Lake.

Overview of Vancouver Lake

Character of the Lake and the Larger Watershed

Vancouver Lake is a relatively large tidal lake, covering approximately 2,300 acres. It is one of the largest of the shallow lakes in the Columbia River floodplain and in the Portland/Vancouver metropolitan area (see Figure 1-1).

The main water bodies that are hydrologically connected to Vancouver Lake are the Columbia River, Lake River, Salmon Creek, and Burnt Bridge Creek. The Columbia River is connected to Vancouver Lake through Lake River and a flushing channel constructed the early 1980s. The flushing channel has a tide gate so that water only flows into Vancouver Lake from the Columbia River at high tide. Lake River is a 12-mile slough connecting Vancouver Lake with the Columbia 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 before flowing into Lake River. Burnt Bridge Creek drains approximately 27 square miles and flows through the City of Vancouver before entering Vancouver Lake. Smaller waterbodies associated with Vancouver Lake include Chicken Creek, a small tributary that enters the lake from the northeast, and Buckmire Slough, a slough that enters Lake River approximately .6 miles from the confluence of Lake River and Vancouver Lake (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, but can get as deep as 13 feet in late spring. Hydrology is controlled mainly by the stage of the Columbia River and the tides. October typically has the lowest lake and tributary levels. Lake River reverses daily due to tidal fluctuations, and can sometimes reverse flow for days at a time. Starting in November the lake level rises to intermediate levels as Burnt Bridge Creek and Salmon Creek flows increase rapidly. In January, tributary flows peak and lake water is dominated by flows other than the Columbia River. Between April and June the Columbia River rises due to snowmelt, resulting in the highest lake water levels in June; flow in Lake River is typically south into the lake. Between June and July lake level drops rapidly; flow in Lake River is to the north, carrying water away from the lake. Finally, between July and November the lake remains at a low level, and flow in Lake River reverses daily (Wierenga 2005).

Shallow lakes are dynamic because they are easily affected by weather and climate and have a substantial proportion of lake bottom in contact with overlying open water relative to water volume. The large size results in a high surface area relative to shoreline length.

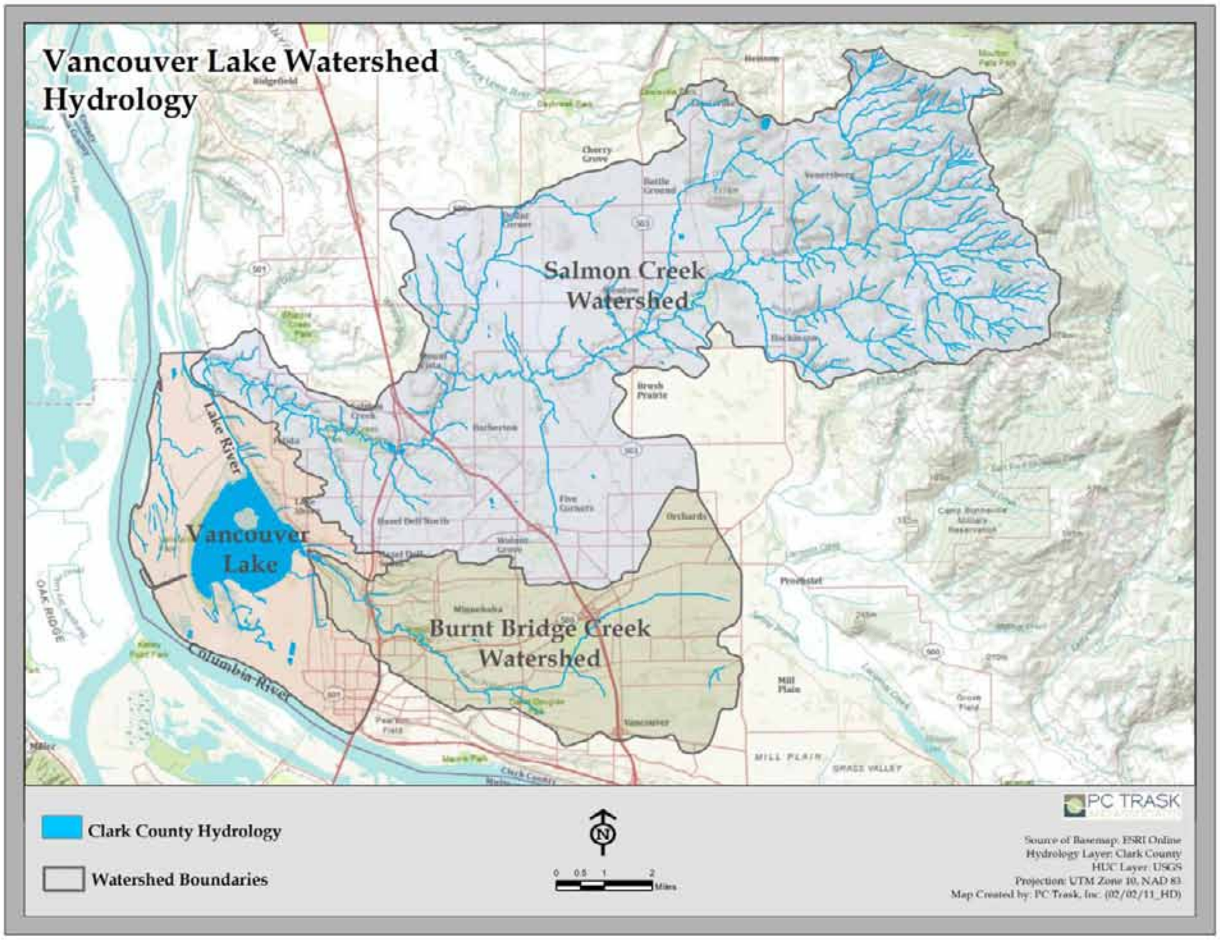


Figure 1-1: Vancouver Lake Hydrology

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.

Previous Restoration Efforts

Vancouver Lake has been the focus of numerous studies over the past 50 years. 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 with the goal of improving 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 the 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 Turtle Island, 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. Two 84-inch culverts with tide gate structures carry the flushing water under Lower River Road (Gary Struthers Associates, Inc. 2005). The restoration effort provided some improvement, but periodic lake monitoring showed that lake water quality problems continued to limit lake uses in the mid-1990s.

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 1-2). The Department of Natural Resources owns the Vancouver Lake lakebeds and Turtle Island.

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. In the winter months, duck and goose hunters use the south and north shores, as well as the areas around Turtle Island. There is also a limited commercial carp fishery at Vancouver Lake. In 2008, 320 common carp were caught (totaling approximately 930 lbs). These fish were caught mostly in April and May. That number is estimated to be about the average per year for the last few years. (John Weinheimer, 2011).

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 Comprehensive Plan, 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).

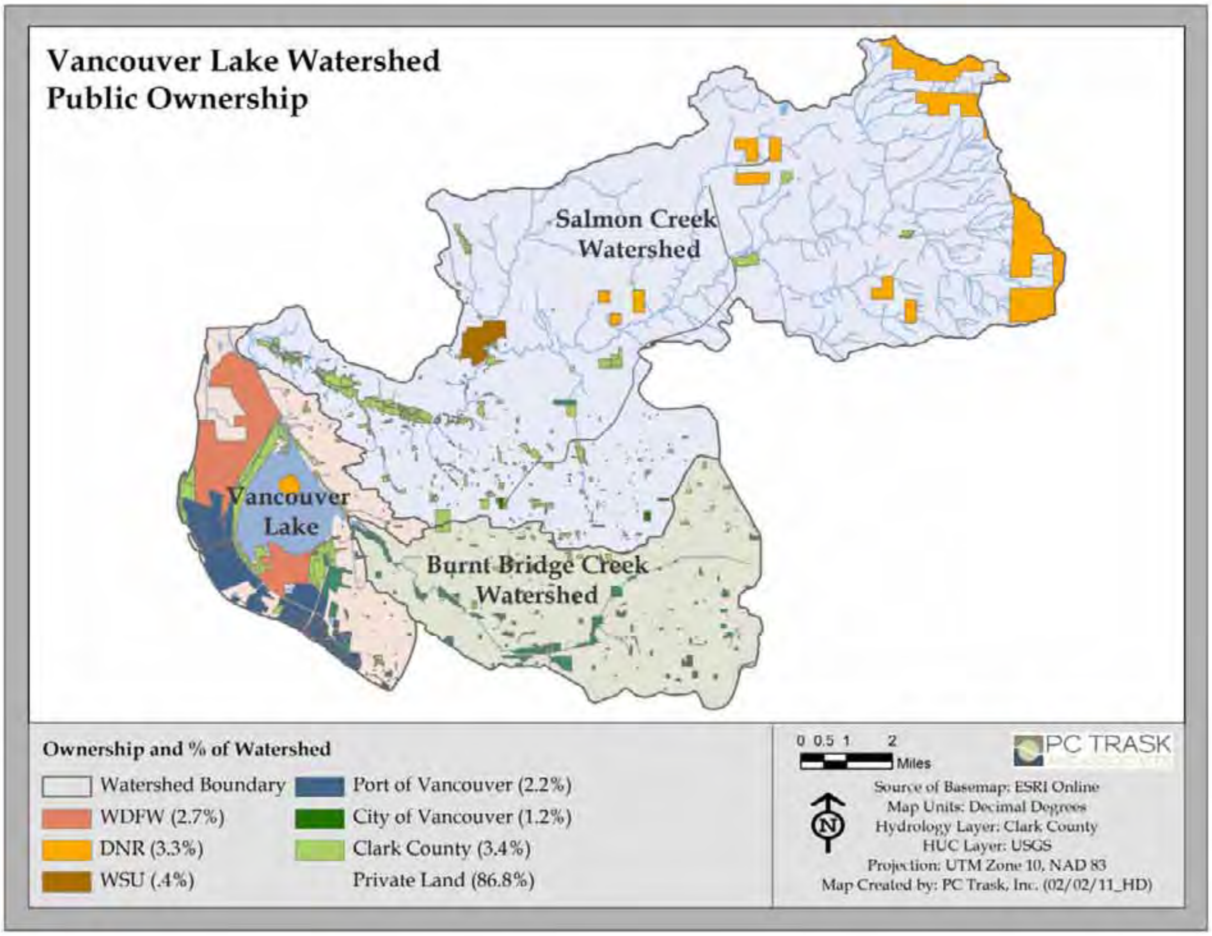


Figure 1-2: Vancouver Lake Public Ownership

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. 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 approximately 2,341-acres of pasture/grassland, forest, riparian areas, and wetlands (WDFW 2006). These areas have been diked historically to manage floodwaters; a recent dike and new management strategy in the Vancouver Lake wildlife area is aimed at allowing more frequent inundation than was allowed in the past.

Action and Decision making Strategy

This Technical Foundation serves as an informational basis for decisions on research needed to fill critical data gaps. As the necessary data is being collected, the Partnership will investigate potential management alternatives. The steps toward developing management alternatives are outlined below in Figure 1-4. This process is described further in Chapters 4 and 5 of this Technical Foundation.

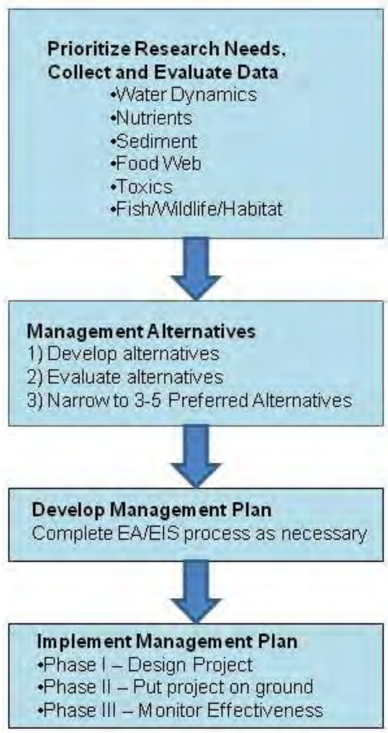


Figure 1-3: Strategic Approach to identifying Management Alternatives

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 basins many miles long, or to large, shallow systems like Vancouver Lake. Each of these systems is 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 influenced by its physical character as a large 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. Specifics about the current issues facing the lake are described in Chapter 4 and are not covered in this chapter.

How is Vancouver Lake different from Deep Lakes and Other Shallow Lakes?

Shallow lakes are different from deep lakes for several reasons. One of the main reasons is that in a deep lake water typically stratifies, or separates into layers by temperature; 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 decay of dead organic matter. Oxygen is consumed during this process, and can result in oxygen depletion in the deeper waters in stratified eutrophic lakes.

Vancouver Lake is shallow and therefore 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 in shallow lakes than in deeper lakes and occur throughout the water column.

In general, most shallow lakes are well-mixed and do not stratify. As a result a shallow lake's physical characteristics tend to vary little with depth, and oxygen depletion is typically less common except during times when a lake is frozen over.

Vertical profile data show that Vancouver Lake does not stratify for significant amounts of time. Water temperature varies seasonally and annually. Summer temperatures can be very warm, with surface temperatures sometimes reaching 25^o C, or about 77^o F (Clark County Public Works 2007).

A critical difference between Vancouver Lake and other shallow lakes is that Vancouver Lake rarely freezes over in the winter. Shallow lakes in other parts of the northern United States and Canada often freeze in the winter, causing the death of lake vegetation, the decomposition of which leads to oxygen depletion of the water.

The lake is frequently mixed by wind, and because the lake is shallow, this results in distributing oxygen throughout the water column. Oxygen levels vary, from supersaturated conditions near the surface as a result of algae photosynthesis, to lower levels near the bottom during times of stagnant wind conditions. In 2009, WSU found oxygen levels as low as 3 mg/L, and once as low as 0.69 mg/L (Bollens and Rollwagen Bollens, 2010).

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, the lake bottom sediment is in contact with much of 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 re-suspension of sediment, is often important in shallow lakes. Release of phosphorus from bottom sediments can occur in both shallow and deep lakes under low oxygen and high pH conditions.

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 (Cooke et al., 2005).

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 (Cooke et al., 2005).

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 (Cooke et al., 2005). Vancouver Lake currently exists in this state.

Because each state is relatively stable, shallow lake management is challenging, as it typically involves identifying and mitigating the cause of the shift in lake state (Cooke et al., 2005).

Hydrology of Vancouver Lake

Vancouver Lake is unique from other shallow, turbid, algae-dominated lakes due to its connection to the lower Columbia River. This connection subjects the lake to influences by tidal cycles and changes in river stage. This relationship to the Columbia River through Lake River and the flushing channel creates a dynamic environment for Vancouver Lake and ultimately presents challenges to understanding and managing the lake.

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 historical 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 extent of cool-water refuges in the lake today—if they exist—is unknown.

In 2010, the Partnership entered into a Joint Funding Agreement with the US Geological Survey (USGS) to study the water balance and nutrient budget of Vancouver Lake. A final report is expected in 2013 which will provide a more detailed understanding than what is currently known about the hydrology of the lake. Our current understanding is described below.

Columbia River, the Flushing Channel, and Lake River

The hydrology of the Columbia River is influenced by tributaries, the hydropower system, 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 average 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).

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 from this elevation difference pushes the gates open to allow water to pass from the flushing channel to Vancouver Lake (Drake & Associates 2004). However, the gates are currently in position to not allow water to move from Vancouver Lake back to the flushing channel when the elevation gradients are reversed.

Salmon Creek and Burnt Bridge Creek

The two largest tributaries to Vancouver Lake are Burnt Bridge Creek and Lake River. Lake River includes flow from Salmon Creek. Water inputs fluctuate throughout the year, and flow contributions could vary depending on season and activities occurring upstream in the watershed. The estimated average annual flow rates in Salmon Creek and Burnt Bridge Creek are 100 cfs and 20 cfs, respectively (Lower Columbia Fish Recovery Board, 2001). More recent flow data for Salmon Creek is for Water Years 2003 - 2006 with a mean annual flow ranging from 128cfs to 177 cfs (Clark County stream flow data accessed 2011). Salmon Creek's contribution to Vancouver Lake would be limited to times when Lake River is flowing into Vancouver Lake, but with much greater volume than Burnt Bridge Creek, it may still be significant. The proximity of both Salmon Creek and Burnt Bridge Creek to urban areas could have significance for pollutant loading; however, pollutant loads to the lake are poorly understood at this time. The influence of flows of each creek on the water quality of Vancouver Lake is unknown, but will be addressed in the current USGS study for nutrients, and by a study by Washington Department of Ecology on toxic pollutant inputs to Vancouver Lake.

Figure 2-1: Flushing Channel, Lake River, and Vancouver Lake

Smaller Tributaries

Several smaller tributaries, such as Chicken Creek, enter Vancouver Lake from the northeast. Although the flow volumes of 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, nutrient or contaminant concentrations.

Groundwater

Groundwater that originates in shallow, underground aquifers enters Vancouver Lake through the lake bottom and nearby seeps. 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). The US Geological Survey will conduct a general survey of groundwater seepage at 5-10 sites along the lake bottom and examine seasonal changes as part of their 2010-2012 water balance study.

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 of 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 fish 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. (USACE 2007). 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 et al., 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 abundant 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 Shillapoo 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

Knowledge of the extent and distribution of aquatic invertebrates at Vancouver Lake is limited. WSU conducted benthic sampling between April 2007 and February 2008, taking a total of 97 samples at eight locations. Benthic samples primarily consisted of oligochaetes (worms), which composed 57-75% of the samples numerically. The next most numerous taxa, with a maximum of 13% each, were chironomid larvae (midges) and nematodes. Bivalves (clams and/or mussels) made up only .1 to .5% of the samples (Bollens and Rollwagen-Bollens, 2009).

Clams were collected at three locations within Vancouver Lake and at two locations in the flushing channel as part of a Site Assessment of the lake (EPA 2010). These clams were collected in September during low water; high water in March prevented clam sampling. The species of clam is not noted, but Asian clams (*Corbicula fluminea*) are documented at the mouth of the flushing channel by the Columbia Riverkeeper (2008). There are anecdotal reports of historical clam and mussel beds present in Vancouver Lake.

Aquatic Vegetation

An informal investigation of the presence of aquatic plants in Vancouver Lake indicated that submerged aquatic plants are almost completely absent (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).

Wetland and shoreline vegetation

Vegetation surrounding Vancouver consists of a mosaic of wetland and riparian plant communities. Integrated patches of tidally influenced emergent and forested wetlands are evident at the northern end of the lake near the Lake River outlet. Another larger wetland complex is present as part of the Shillapoo Wildlife Area –Vancouver Lake Unit at the lake's southern end. This wetland complex has a gradient from lower elevation emergent plants to high elevation wetland forest plant types. These wetlands are managed for waterfowl and other wildlife species via water control structures and are only minimally connected to Vancouver Lake. Further away from the lake are a series of semi-connected depressional lakes and sloughs to the west, a remnant of the historical connection to the Columbia River during Columbia spring freshets. Some of these wetlands have been fragmented through undersized culverts and fill placement.

Chapter 3

Concerns at Vancouver Lake

Although there were several converging reasons why the Vancouver Lake Watershed Partnership formed in late 2004, toxic cyanobacteria blooms were the catalyst for the Partnership's formation and continued efforts. At the same time, these 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 toxic contaminants and sedimentation may not impact blooms, but have been a concern for the Vancouver Lake Watershed Partnership.

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 and 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.

Temperature

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 temperature and 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 (e.g., dead algae) that settles to the lake bottom.

What Is the Source?

Elevated water temperature decreases the saturation capacity, and subsequently may limit the amount of dissolved oxygen in the water column. Vancouver Lake, like other large shallow lakes often become warm in the summer because of their high surface water to depth ratio and the small amount of shoreline shading relative to the size of the lake. 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.

For general reference, Washington State's designated Aquatic Life Temperature Criteria in Fresh Water for providing protection for salmon rearing or migration is a 7-day average daily maximum temperature (7-DAD Max) of 63.5°F. In comparison, the 7-DAD Max designation for protection of indigenous warm water fish (such as sucker and northern pikeminnow) is 68°F (WDOE 2006).

Excess Nutrients

What Is the Concern?

Eutrophication is a very slow natural aging process of some shallow lakes and ponds. However, in situations where water bodies receive excess nutrients such as phosphorus or nitrogen as a result of human-caused impacts, this process can speed up and can result in 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. When this happens, the process of eutrophication is often accelerated.

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 Source?

It is likely that Vancouver Lake acts as a sink for nutrients in the watershed. Excess nutrients can enter from agricultural areas, stormwater runoff, 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 over many years. These nutrients likely become re-suspended in the water column through wind mixing and fish activity during the summer months.

The USGS started a study in 2010 that will help local stakeholders understand the temporal and spatial patterns of nutrient delivery to the lake. The USGS will develop a water balance and nutrient budget for the lake. This will provide managers with important information on the source and timing of nutrient delivery to the lake in order to more effectively maintain or improve the health of Vancouver Lake.

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 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, if left to its current trajectory, Vancouver Lake could become even shallower and begin to form more extensive wetland areas.

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

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, increasing urbanization and the subsequent erosion from 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 re-suspended as a result of wind or other disturbances to the lake bed (such as fish activity) and are either re-deposited or moved out of the lake into the Columbia River.

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 suspended particulates 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 that decreases 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 Source?

An important limiting factor for water clarity is that intense algal blooms limit light penetration – an issue that increases as the summer progresses. In addition, Vancouver Lake's great size and shallow depth, coupled with the simple shoreline morphology (the lake's shoreline is over seven miles long and is very uniform with very few backwater bays or inlets), lead to frequent wind-induced mixing. Because the lake's bottom sediments are fine grained and unconsolidated, they are easily re-suspended by wind. Fish may also disturb bottom sediments when searching for food.

Cyanobacteria and Algal Blooms

What Is the Concern?

Studies since the late 1960s have shown that Vancouver Lake supports intense cyanobacteria blooms that can limit lake use in the summer (Bhagat and Orsborn 1971, Cooper Consultants 1985). Two types of blooms occur at Vancouver Lake: general algal blooms (such as those caused by diatoms and chlorophytes) and cyanobacteria blooms (bluegreen algae). Both types can be aesthetically unappealing and contribute to poor water quality.

One important difference between the two types of blooms is that cyanobacteria blooms are capable of producing toxins that can be harmful to wildlife, domestic animals, and people. Clark County Public Health uses World Health Organization (WHO) and State of Washington guidelines when analyzing water samples and considers Vancouver Lake unsafe for swimming if cyanobacteria levels in the water exceed 100,000 cells per milliliter (40,000 cells for Microcystis). Toxin levels that are greater than 6µg/L of Mycrocystin or 1.0µg/L of Anatoxin-a will be cause for posting an advisory at the lake. In addition, if there is a scum on the beach from the cyanobacteria, an advisory will be posted (Marty McGinn, Clark Public Health, personal communication). Cyanobacteria levels have exceeded the WHO criteria during 6 of the 7 years from 2004-2010 (inclusive), forcing periodic closures of the lake to swimming in recent years. In August 2004, the cyanobacteria level at Vancouver Lake was nearly ten times the guideline value (Clark County Public Works 2006).

Lakes are generally described as being in one of three possible classes: *oligotrophic*, *mesotrophic* or *eutrophic*. However lakes with extreme trophic indices may also be considered *hyperoligotrophic* or *hypereutrophic*. Measurements of chlorophyll *a*, a pigment present in algae that is used for photosynthesis, are used to estimate the quantity of general algae in a lake. This is then used to correlate to the classification of the trophic level of a lake. Eutrophic lakes typically have maximum chlorophyll *a* summer concentrations ranging between 9 and 25 micrograms per liter (µg/L) and are considered hypereutrophic if summer concentrations are greater than 25µg/L. For comparison, oligotrophic lakes with chlorophyll *a* summer concentrations of less than 9µg/L are characterized as having low primary productivity, the result of low nutrient content. These lakes have low algal production, and consequently, often have very clear waters, with high water quality.

What Conditions Influence Cyanobacteria and Algal Concentrations?

In general, cyanobacteria and algal booms 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 summer, algal populations multiply rapidly, leading to blooms. Competition for nutrients and light among major groups of algae and cyanobacteria determines the composition of a bloom at different times of the year. How cyanobacteria and algae interact with each other and their surrounding environment is poorly understood, and the exact cause of their blooms at Vancouver Lake is not known at this time.

Another influence on abundance is a process called grazing. This term describes the consumption relationships of plankton and the transfer of energy between organisms. Phytoplankton, which derives energy from the sun, serves as food for other planktonic organisms, including protozoans and zooplankton. From March 2007 – February 2010, the WSU research team assessed the relationship between plankton populations and trophic interactions. This research looked at impacts of planktonic grazers on cyanobacteria blooms. It was determined that zooplankton do have the capacity to significantly consume algae and cyanobacteria and are likely to have a strong enough impact on algal and cyanobacterial growth rates to impact the timing and magnitude of cyanobacteria blooms (Bollens and Rollwagen-Bollens, 2010)

Exotic 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. Exotic plants are often invasive and may outcompete native plants within years or decades of their introduction. Wildlife species often are not adapted to the exotic plant species in terms of diet and other aspects and cannot keep pace with changes to their environment over the same time scale. Non-native animals, including fish, can similarly outcompete native wildlife species, or impact the native plant species in ways for which the plant is not adapted.

What Is the Source?

The sources of exotic species are numerous and wide ranging. Exotic plants and animals can be imported accidentally or deliberately, by human or natural means. Plant seeds and clippings that enter 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 plant species spread in lowland areas. In general, exotic plant species are opportunistic, colonize disturbed lands, and have few natural enemies. Transportation via boat traffic is a common means of introducing non-native animals.

Plant Communities

What Is the Concern?

Mature, diverse plant communities are important to healthy lakes in several ways. Shoreline vegetation of multiple strata (tall grasses/shrubs/trees) is important for erosion control, shading of lake edge, and wildlife habitat. Wetland plants in particular are important because they provide refuge for young fish to escape predation and supply food inputs (including insects) to shallow-water lakes. They also use nutrients from the water, making fewer nutrients available for algal/cyanobacterial growth.

However, too much aquatic vegetation can interfere with recreational activities (for example, dense mats of floating plants may reduce opportunities for boating and swimming). Also if a large number of plants die off at one time the decaying plants can contribute to degraded water quality conditions (i.e. low dissolved oxygen).

What Conditions Influence Plant Communities?

The scarcity of aquatic plant communities in Vancouver Lake is likely due to many factors occurring over a long period of time. Vancouver Lake bottom sediments are unconsolidated (easily re-suspended) and their frequent re-suspension causes high turbidity, limiting light penetration to the lake bottom so that rooted plants cannot be established (Caromile et al., 2000).

Pathogens

What Is the Concern?

Fecal coliforms such as *Escherichia coli (*E.coli) are bacteria that typically originate in the gut of warm-blooded animals. 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).

Organic matter with untreated pathogens 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 Source?

Potential sources of *E. coli* bacteria and other pathogens in Vancouver Lake and tributaries are numerous, but the actual sources are largely unknown. 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 known source of *E. coli* bacteria. Waterfowl congregating and using the lakeshore habitat can elevate bacteria counts in localized areas.

Toxic Contaminants

What Is the Concern?

Toxic contaminants in water and sediment are a concern for human and ecosystem health. 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 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). Re-suspension of sediments can be a concern for toxins that typically settle in bottom sediments; when re-suspended in the water column these toxins may come in contact with susceptible organisms. In areas such as Vancouver Lake where sediments suspended in waters entering the lake 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).

Chapter 4

Data Gaps

A technical understanding of Vancouver Lake is a prerequisite for identifying and initiating important changes to the lake. The Partnership conducted extensive literature and data reviews pertinent to the issues identified in chapter three. With the help of its Technical Group, the Partnership developed a list of critical data gaps. These areas are considered critical because the information required to fill them is a necessary foundation from which to make sound lake management decisions.

The Partnership recognizes that the lake system is complex, technical studies are expensive, and resources are limited. With those caveats in mind, the Partnership has developed an unrestrained vision and set of values for Vancouver Lake that describes the desired future condition for the lake in terms of common ideals. The vision is currently broad and abstract, but represents important guidance for management efforts and decisions about what technical information to obtain.

Technical Questions

To focus on the critical questions for Vancouver Lake, the Partnership identified technical and management questions 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 in 2008. The Technical Group has revisited and updated the tables since the 2008 Technical Foundation with any new questions and the status of studies (if any) that would address those questions. The tables are followed by a discussion of what information is currently available to help answer these questions and what information is still needed. Combining the perceived urgency of the questions with an analysis of what information is available will help guide the direction of new technical studies.

It is important to note that there are also questions regarding potential lake management techniques. As described earlier, this document focuses on information needed to understand the current function of Vancouver Lake. As potential management techniques are examined, specific research may be necessary to determine if certain techniques would be feasible and effective in Vancouver Lake. Such research activities will not be looked at in this document.

Water/Sediment Quality

As described previously, water and sediment quality are important concerns at Vancouver Lake. With summer cyanobacteria blooms often closing the lake to water contact uses, understanding the water quality conditions that facilitate the blooms (nutrients, temperature, etc.) is essential. The presence and extent of pathogens such as *E. coli* and toxins such as PCBs are also very important to the community, although not specifically to cyanobacteria blooms. 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 beneficial uses of the lake.

TABLE 4-1
WATER/SEDIMENT QUALITY QUESTIONS

Questions	Urgency	Status
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?	↑	In study[1]
What are the sources and quantities of nutrients entering Vancouver Lake?		In study[1]
What are the sources and quantities of contaminants entering Vancouver Lake?		In study[5]
What is the type, amount and distribution of contaminants in Vancouver Lake sediment?		Complete[2]
Does Vancouver Lake exceed water quality standards for pathogens or cyanobacteria and thereby compromise beneficial uses?		In study[3]
Where does Vancouver Lake sediment come from and what is the quality of that sediment?		In study[1]
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 during the year?		Complete for lake[4]
What is the oxygen profile of Vancouver Lake?		
What causes summertime structural changes in bottom sediments?		
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?	LOW	
What is the relationship between Alcoa site contaminants and Vancouver Lake?		
What is the influence of the Willamette River on Vancouver Lake water quality?		

1: US Geological Study; 2: EPA Site Inspection; 3: Clark Public Health monitoring; 4: Clark County Public Works 5: Washington Department of Ecology

Available Information

Vancouver Lake is listed as an impaired water body for high phosphorus concentrations on Washington State's 303(d) list of impaired water bodies. The listing of impaired water bodies is described in 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 (Clark County Public Works 2007).

Total nitrogen levels are also typically high and variable. Volunteer monitoring data collected by Clark County from 2004-2007 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. The data are of good quality and are useful for describing levels and temporal trends 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 pre- and post- restoration data sets for Vancouver Lake from the 1970s and 1980s.

Summer water temperatures in Vancouver Lake can be very warm, with surface temperatures sometimes reaching 77^{o} F (25^{o} C). 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 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 algal photosynthesis and somewhat 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.

Lake water quality information was collected by WSU-Vancouver in conjunction with their cyanobacteria research. Information was collected from March 2007 to February 2010 at the Vancouver Lake Sailing Club dock (Bollens and Rollwagen-Bollens, 2010).

The USGS began collecting water quality information for Vancouver Lake in October 2010, and will continue through September 2012. This is part of an examination of both water and nutrient inputs and outputs to Vancouver Lake, a study considered top priority in understanding and addressing the cyanobacteria issues of Vancouver Lake. Data analysis for the study will be completed in September 2013.

The USGS study will fill critical water quality data gaps for Vancouver Lake. This study will determine the annual loading of certain water quality parameters such as nutrients and suspended sediment from Burnt Bridge Creek, Lake River, and smaller tributaries surrounding the lake. Filling these gaps will help identify the most significant contributors of nutrients and improve the Partnership's understanding of them in relation to cyanobacteria blooms and other documented water quality problems.

Vancouver Lake, Burnt Bridge Creek, and Salmon Creek, are 303(d) listed waterways for fecal coliform. Fecal coliform bacteria are significant for human health as an indicator of the presence of disease-carrying organisms. It commonly comes from livestock and failing septic tanks. *E. coli* bacteria (which is an indicator microorganism for other pathogens that may be present in feces) levels have been monitored at the Vancouver Lake Park swimming beach since 2004 by Clark

County Public Health. 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, with two one-week closures in the past eight years due to high *E. coli* levels.

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 of fish tissue (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 and chlordane exceeded the wildlife criteria in a fillet sample (Davis and others 1995, Seiders and Kinney 2004).

In 2005, Department of Ecology (Ecology) conducted a 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 large-scale 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.

Ecology completed data collection in October 2010 for a one year study entitled *Toxic Study of Vancouver Lake Inflows* that investigated concentrations of chlorinated pesticides, PCBs, and dioxins/furans from major surface water inputs to Vancouver Lake. The proposed toxic analytes are hydrophobic and not typically detected in whole water samples. Semi-permeable membrane devices (SPMDs), which mimic fat tissue, were used for sample collection in order to see if toxins that accumulate in fat tissue (dioxins/furans, and chlorinated pesticides) are in the water column. Ecology is currently analyzing the data and a report on these levels is expected in the spring of 2011 (Coots, 2011).

The potential level of toxins in Vancouver Lake sediments has been a concern. In 2009, EPA studied toxins in sediments as part of a Site Inspection of the Vancouver Lake Flushing Channel to assess the threat to public health posed by the site, to determine the potential for release of toxic substances into the lake, and to determine whether it is warranted to place the site on the National Priorities List. The sampling included clam tissue samples in addition to sediment. The results (Figure 4-1) showed that metals, arsenic, beryllium, and cobalt were found in the sediment samples and low levels of metals and PCBs were found in the clam samples. In further examination of these samples, the EPA found: Four of the 33 sediment samples contained contaminant concentrations that exceeded NOAA designated Threshold Effects Levels (TEL). Substances found in levels that exceeded TEL levels were chrysene, flouranthene, and pyrene (polycyclic aromatic hydrocarbons that are often found together), mercury, and lead. No samples contained contaminant concentrations that exceeded NOAA designated Probable Effect Levels (PEL), above which concentrations probably have toxic effects. The EPA determined that no further remedial action is warranted by the EPA, as the contaminants found at Vancouver Lake were not at a level to reach National Priority List ("Superfund") caliber and the lake does not present a risk to human or environmental health based on toxic components in lake sediments and clam tissues (EPA, 2010). The table below shows the findings of the EPA study.

Contaminant	Range of significant Concentrations (Sediments)	# samples w/significant concentrations/ total # samples	NOAA SQuirT (TEL)	# exceeds TEL/ #samples
Copper	20.0 - 24.7 ppm	7/33	35.7 ppm	0/33
Mercury	0.33 ppm	1/33	.174 ppm	1/33
Lead	45.7 ppm	1/33	35 ppm	2/33
Arochlors	7.8 - 27 ppb	5/33	34.1 ppb	0/33
Crysene	280 ppb	1/33	57.1 ppb	1/33
Flouranthene	510 ppb	1/33	76.4 ppb	1/33
Pyrene	510 ppb	1/33	44.27 ppb	1/33

Figure 4-1: 2010 Site Investigation of Vancouver Lake, EPA

In August 2009 Ecology completed the data collection for a total maximum daily load (TMDL) study on Burnt Bridge Creek. This study involved intensive monitoring of surface water, ground water, and stormwater for the following water quality parameters: temperature (including shade analysis), flow, bacteria, pH, and dissolved oxygen. Data analysis is ongoing and expected to be complete late spring 2011. Once data analysis is complete, the TMDL technical advisory committee will determine management scenarios to be modeled. A draft technical report will be issued in fall of 2011, and meetings will be initiated to develop a clean-up plan. By summer 2013 Ecology will submit the combined technical report and water cleanup plan to EPA. Starting in 2014 Ecology will conduct monitoring to determine if the cleanup plan is working and make adjustments as needed (WDOE, 2011).

Water turbidity can be caused by suspended sediments and by plankton within the water column. Monitoring by Clark County Public Works has found poor water clarity at Vancouver Lake throughout most of the year. 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 (visible depth) 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).

In terms of sediment quality, the primary data gaps are the rate and mechanism of sediment movement and accumulation within the lake, and the release of nutrients from sediment to the water column. Identifying and describing mechanisms of sediment re-suspension and distribution will help characterize the effects of sediment on water quality. Sediment re-suspension, and the release of phosphate from anoxic sediments, have been identified as important drivers for water quality problems in many shallow lakes, whether it is caused by wind or foraging fish.

The USGS study will look at sediment transport at the lake bottom as well as input of suspended sediments from the tributaries to Vancouver Lake. Sediments will be analyzed for percent solids (to determine sediment density), total carbon (organic matter), and the nutrients nitrogen and phosphorus.

The potential release of nutrients from lake bottom sediments will also be examined by USGS through laboratory experiments on sediment cores to quantify phosphate and nitrogen release to the water column under varying conditions, as well as examining water chemistry within the sediment at varying depths.

Data Gaps

Remaining data gaps include the characteristics of sediment throughout the system, specifically particle size distribution. Understanding the nutrient inputs from groundwater, stormwater outfalls, and aquatic animal populations could also be helpful. If pollutants are found in levels of concern from Ecology's *Toxic Study of Vancouver Lake Inflows* then a follow up study would be needed to identify the sources of contamination.

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 watersheds, 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 organizes them according to urgency as determined by the Technical Group in 2008. Funded studies have or will answer some of the more urgent questions in this category.

TABLE 4-2 PHYSICAL ENVIRONMENT QUESTIONS		
Questions	**Urgency**	**Status**
What is the quantity and timing of flows within the flushing channel and what is its effect on lake conditions?	HIGH	In study[1]
What is the physical bathymetry of Vancouver Lake, the flushing channel and Lake River and its tributaries?	↑	Complete for lake[2]
What is the quantity and timing of flows from Lake River into and out of Vancouver Lake?		In study[1]
What are the water circulation patterns within Vancouver Lake?		Complete[2]
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?		In study[1]
What is the quantity and timing of flows from other tributaries into Vancouver Lake and/or Lake River?	↓	In study for lake[1]
What effect does the island play on water circulation patterns?	LOW	
What is the impact of sea level rise on Vancouver Lake?		

1: US Geological Study 2010-2012; 2: US Army Corps of Engineers model

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, although the change was not considered significant for lake water quality. 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 (U.S. Army Corps of Engineers 2008).

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 model 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 2009).

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 slightly increased velocities within the lake, specifically along the western and northern shore, and removing the tide gates had a negligible effect on hydrodynamics. In both cases, wind effect would likely have a larger influence on mixing than flow in the flushing channel. It was also noted that dredging decreases average velocities due to through-flow from the flushing channel (U.S. Army Corps of Engineers 2009).

This modeling effort is important in understanding circulation and velocity patterns and how sediment moves within Vancouver Lake. However, given the limited boundary conditions and short representative time frames modeled, questions remain about additional water inputs, seasonal changes, and wind effects. Model results can be helpful when developing management alternatives that address sedimentation issues.

The current USGS study is filling a critical data gap in terms of the basic water balance of Vancouver Lake. This will allow us to understand how much water enters, exits, and circulates within the system. 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. Once the hydraulics are better understood, water-quality sampling for nutrients from each water source can be incorporated in order to develop a nutrient budget. The product of water volume and nutrient concentration will give the nutrient loading from each source. This will inform what sources need to be addressed in lake management, and at what levels.

The Port of Vancouver monitored flow and water level in the flushing channel previous to the launch of the USGS study, from 2006 to late summer 2010.

The USGS study will include a general survey of groundwater seepage at 5-10 sites along the lake bottom and examine seasonal changes. This information on groundwater will be in addition to the groundwater modeling of the Vancouver lowlands conducted by the Port of Vancouver and Clark Public Utilities (CPU). CPU and the Port monitored 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.

Data Gaps

If the USGS study determines that groundwater volume and/or nutrient inputs should be looked at more closely, new groundwater modeling efforts should be initiated or the Partnership may be able to build on the joint Port/CPU modeling effort.

The USGS study will be filling the majority of the remaining physical environment data gaps, with the exception of the timing and quantity of flows from Salmon Creek into Lake River, the effect of the island on water circulation, and the impact of sea level rise on Vancouver Lake. These questions, while good to understand, are considered of lower priority to the Technical

Group in terms of understanding the driving forces of the current water quality conditions of Vancouver Lake.

Biology

Partnership questions regarding the biological aspects of the lake system are wide ranging and cover topics from cyanobacteria to wildlife. Questions about cyanobacteria in Vancouver Lake are especially important to answer because large 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 and improving overall ecosystem health, but also in understanding potential biological drivers of the current condition of Vancouver Lake. These include the potential for plankton populations to impact cyanobacteria bloom size and timing and the potential of bottom feeding fish to re-suspend nutrients from the sediment into the water column.

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	Status
What is the type, amount and distribution of cyanobacteria and algae in Vancouver Lake?	HIGH ↑	Complete[1]
What conditions facilitate cyanobacteria and algal booms?		Complete[1]
What is the type, amount and distribution of cyanobacteria in Vancouver Lake?		Complete[1]
What is the type, amount and distribution of plankton in Vancouver Lake?		Complete[1]
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?		
How do fish, plant and animal distributions change through time?		
What is the type, amount and distribution of wildlife in and around Vancouver Lake?	↓ LOW	

1: WSU-Vancouver 2007-2010

Available Information
Planktonic algae and cyanobacteria have been studied recently by Clark County and WSU. 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), putting it well within the hypereutrophic category.

Cyanobacteria levels in Vancouver Lake often exceed World Health Organization (WHO) guidelines in late July and August. Clark County Public Health 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 three summer seasons, sample results have shown variable timing and duration of cyanobacteria blooms. Figure 4-2 shows cyanobacteria blooms in the lake, lake closures due to cyanobacteria blooms, and lake closures due to *E. coli* bacteria.

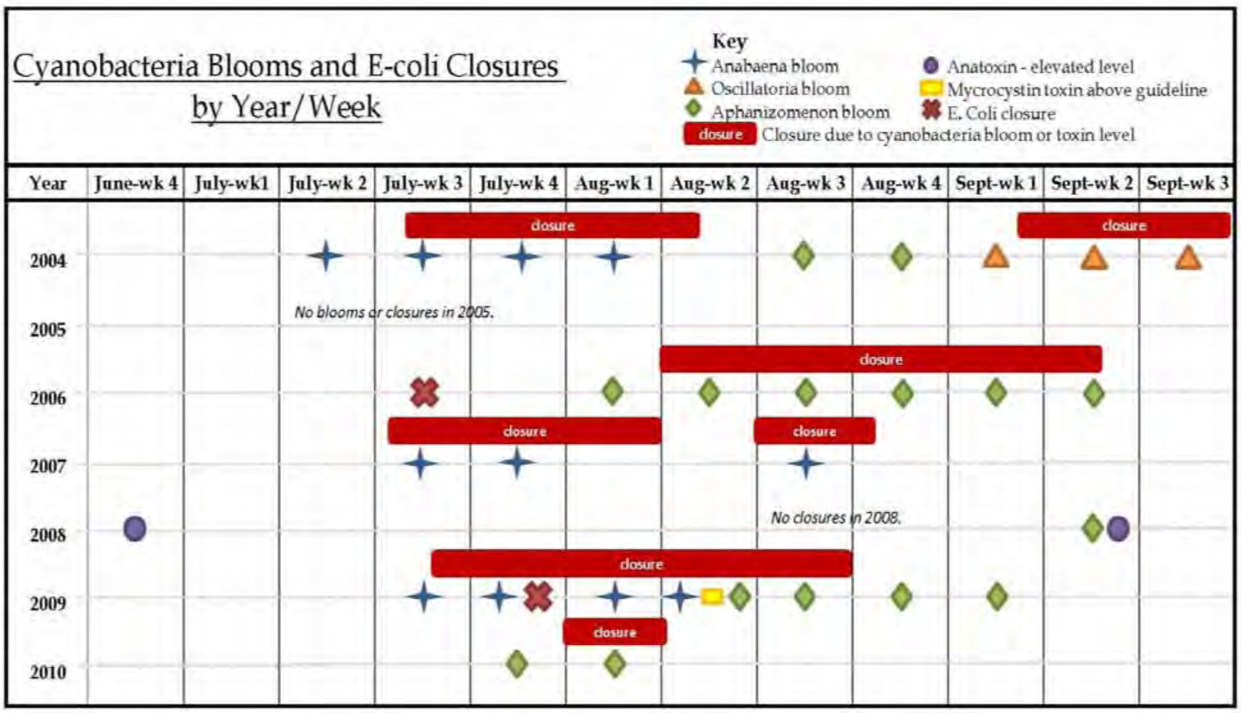


Figure 4-2: Cyanobacteria Blooms and Bacteria Closures

WSU conducted a three year study from 2007-2010 to understand and quantify the factors that influence seasonal cyanobacteria blooms in Vancouver Lake. In the first year they found that there was little spatial variability in phytoplankton and zooplankton abundance across the distributed lake sampling stations. This indicated that a plankton sample taken from the sailing club dock is a good representation of what is present in the lake as a whole. This simplified sampling strategies for the remainder of the study.

By measuring growth rates of cyanobacteria and algae along with zooplankton grazing rates, WSU researchers determined that both protozoan and metazoan zooplankton have the capacity to significantly consume algae and cyanobacteria, as well as other zooplankton. This suggests that the protozoan and metazoan zooplankton grazers are likely having a strong enough impact on particular algae and/or cyanobacteria species at certain times during the bloom to counter population growth rates and thereby impact the timing and magnitude of cyanobacteria blooms. (Bollens and Rollwagen-Bollens 2010).

The WSU study has provided important information about the lake's food web at the planktonic scale. The role of fish and other wildlife in the lake's food web has not been a part of a study to date.

Available information about aquatic plant and animal species at Vancouver Lake is limited. The broadest biological studies took place in the late 1970s and 1980s, when the flushing channel was being evaluated and constructed (Miller 1977 and Envirosphere 1986).

The condition of the wetland fringe around Vancouver Lake has not been formally assessed since prior to the 1980s (Miller and Hazel 1977), after which many changes have occurred. More recent informal site visits to the lake and the adjacent Buckmire Slough indicate relatively healthy scrub-shrub vegetation at higher water levels with lower elevations dominated by reed canary grass. During high flows associated with the Columbia River spring freshets, these wetlands are inundated and provide aquatic habitat for fish and wildlife species. Some wetlands to the south of Vancouver Lake are managed for waterfowl and other wildlife species and are seasonally connected to the lake via surface water hydrology during high-water periods. Other wetlands, specifically on the northeast and northwest sides of the lake are connected to the lake under a range of river flow conditions. A relatively few wetlands exhibit a tidal prism sufficient to maintain secondary channels to the lake.

Previous studies have revealed a startling lack of diversity of components that make up aquatic habitat in the lake for fish and other aquatic wildlife. In a 1998 report by the WDFW, biologists found "overall, a near complete lack of complex habitat" (Caromile and others 2000). An informal Ecology investigation on the presence of aquatic plants in Vancouver Lake indicated that submerged aquatic plants are almost completely absent from the lake environment, although several exotic species are present (Fullerton 2007).

The presence of exotic plants in the Vancouver Lake system has not been systematically documented. The 2007 survey noted purple loosestrife and milfoil; there are also anecdotal reports of false indigo in the wetland fringes of the lake.

The WDFW management plan for Shillapoo Wildlife Area, including the Vancouver Lake unit, has documented Canada thistle, Himalayan blackberry, poison hemlock, reed canary grass, Purple loosestrife, and to a lesser extent, Scotch broom, in the Vancouver Lake unit. Himalayan blackberry and reed canary grass are noted as limiting habitat quality in the area (WDFW 2006).

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.

The Fishman Environmental Services study included a low-tide snorkel survey in which several dozen 30- to 60-mm salmonids, several 50- to 60-mm juvenile pikeminnow, a stickleback, and unidentified juvenile cyprinid were observed (Fishman Environmental Services 2002).

Salmonid use of the flushing channel was determined to not be precluded by current habitat conditions, with habitat suitability being seasonally dependent on water quality conditions and river levels. There were no clear indicators of adverse effects from 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).

Fish surveys in the 1980s, prior to and after the construction of the flushing channel, documented presence of many fish species. Species collected included largemouth bass, bluegill, brown bullhead, carp, channel catfish, black crappie, white crappie, starry flounder, goldfish, peamouth, yellow perch, northern pikeminnow, pumpkinseed, rainbow trout, chinook salmon, coho salmon, American shad, prickly sculpin, threespine stickleback, white sturgeon, largescale sucker, walleye, and mountain whitefish (Envirosphere 1983, 1984, 1985). It was noted that in April 1982, densities of juvenile chinook were higher in Vancouver Lake than in nearby sampling areas in the Columbia River (Envirosphere 1983). A concerted salmonid study in Vancouver Lake has not been undertaken in the 25 years since these surveys were conducted.

The 1998 WDFW warm-water fishery report is the most recent study of Vancouver Lake by the agency, and 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 general lack of habitat for fish.

Invertebrates were sampled during the 2002 habitat survey by Fishman Environmental Services. Macroinvertebrate species eaten by juvenile salmonids, such as gammarid amphipods ("scuds"), cladocera ("water fleas"), spiders, aquatic worms, and chironimid (midge) larvae were found during the study (Fishman Environmental Services 2002).

Benthic invertebrate sampling by WSU from 2007-2008 found a predominance of oligochaetes (worms), followed by chironomid larvae (midges) and nematodes. Although there are anecdotal reports of historical clam and mussel beds, clams and/or mussels made up only .1 to 0.5% of the WSU samples (Bollens and Rollwagen-Bollens, 2009). Some clams were also collected from Vancouver Lake and the flushing channel as part of the EPA Site Assessment of the lake (EPA 2010).

Data Gaps

Gaps in biological information at Vancouver Lake are numerous. In addition to a lack of recent 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, descriptions of shoreline, near-shore, and open-water habitat structure, and fish species. There is little contemporary information 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.

Two post survey summary reports identified biological data gaps after site assessments and review of existing information. Fishman Environmental Services (2002) commented on the lack of current information on salmonid use of the channel and lake. 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 gathering and incorporating new Vancouver Lake data into a decision-making framework designed to identify and evaluate potential management solutions. This approach supports the overarching long-term goal of the Vancouver Lake Watershed Partnership, which is to make sound management decisions for Vancouver Lake. The strategy outlined in this chapter starts with the identified data gaps captured in Chapter Four, and from there is meant to be specifically informed by the Five Year Research Plan (Appendix A).

Several important assumptions underlie the approach to a Vancouver Lake technical strategy.

1. This document describes a strategy and framework for accomplishing our goals.
2. The supporting documents (Five Year Research Plan and Algal Control Techniques report) will guide data collection, drive implementation planning, and be periodically updated as work is completed and additional data needs are identified.
3. While Chapter Four serves to document the process that guided the Partnership toward development of its approach to meeting research goals, new data gaps identified as a result of research completed will be incorporated into the adaptive Research Plan, not in Chapter Four.
4. The ultimate goal of this document and its supporting appendices is a thorough and dynamic look at most of the key issues facing Vancouver Lake, and the steps necessary to address these issues. At least one additional update to the Technical Foundation is envisioned to guide data collection needs.
5. It is important to understand that this is a strategy, not an implementation schedule, and will change with new information over time. Research implementation will be driven by evolving data needs, cost, and time constraints.

Research Goals

The overarching research goals laid out in the Research Plan (Appendix A) provide a tool to prioritize studies that can guide management decisions for Vancouver Lake. Six study areas emerged while developing the Technical Foundation, and thus shape the Research Plan:

- Water Dynamics
- Nutrients
- Sediment
- Food Web
- Toxic contaminants
- Fish/Wildlife/Habitat

The plan details questions and actions to address each of these key issues, with the primary goal of addressing cyanobacteria blooms to enhance beneficial uses of Vancouver Lake.

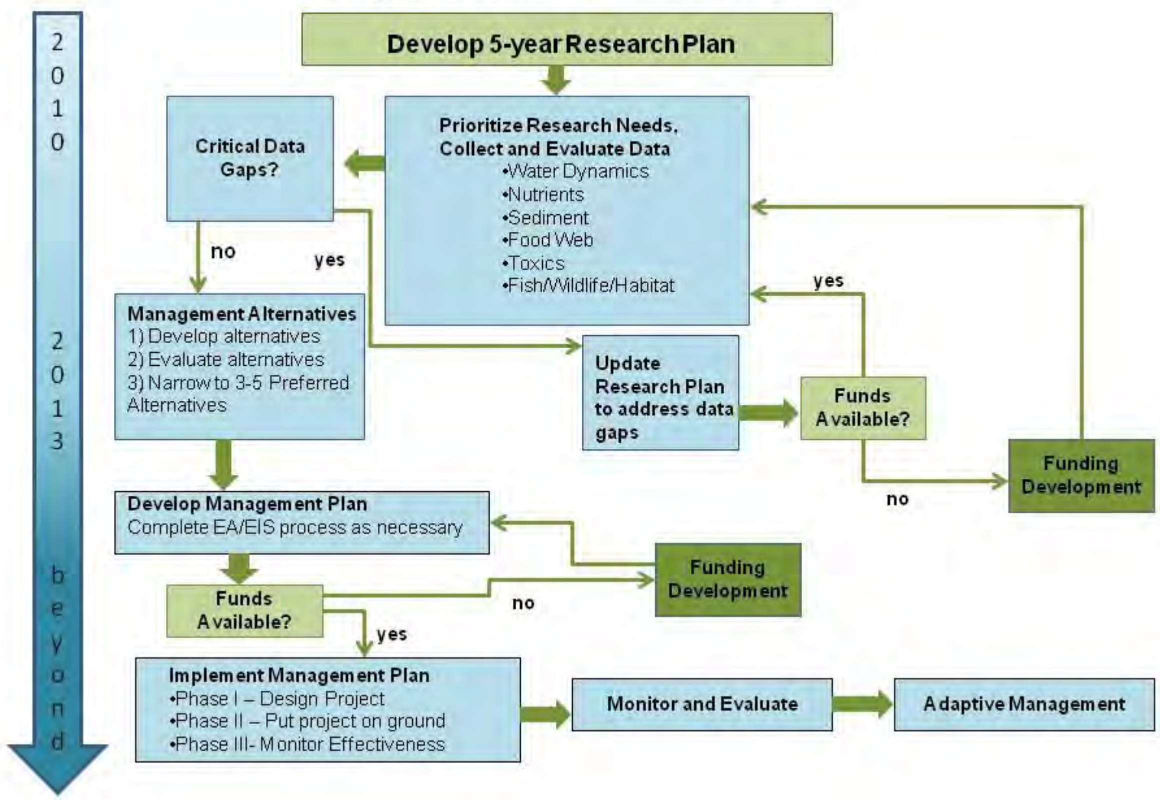
Research and Implementation Strategy

The central point of the research strategy is that cyanobacteria blooms are a point of entry into a complex system with complex issues. Controlling cyanobacteria is the primary management goal and resolving data gaps regarding algal blooms is the highest priority for the Partnership. With that in mind, other data gaps are prioritized considering relevance to potential management approaches.

The approach used for developing this strategy builds upon steps already taken by the Partnership. This includes the Partnership's vision for Vancouver Lake, questions identified by the Partnership, historical information, on-going studies, and proposed research identified in the Five Year Research Plan. Figure 5-1 is a conceptual framework of how the strategy moves the Partnership from research to identifying and evaluating a few promising management alternatives.

The result is the identification of a set of alternatives that lead to the development of a Management Plan, and the completion of an EIS process if necessary. An implementation plan will be developed for the preferred management alternatives. Pending sufficient funding, the Partnership will proceed to design, implement, and monitor the results of the selected actions.

Figure 5-1: **Vancouver Lake Research and Management Management Alternatives Selection Process**



Five Year Research Plan

The Five Year Research Plan, (Appendix A), is intended to prioritize and guide technical studies needed to better understand how the lake functions. This information is the foundation from which management alternatives will be developed. The research plan is organized into the six major study areas: 1) water dynamics; 2) nutrients; 3) sediment; 4) food web interactions; 5) toxic contaminants; and 6) fish, wildlife and habitat. In each of these areas study tasks are identified, with cost and status of each activity identified.

Ultimately, the information collected through the studies identified here will be used to populate a comprehensive numerical water quality model to allow for improved understanding of the physical, chemical, and biological processes in the Vancouver Lake system. With that information, the Partnership can move forward and develop management alternatives for the lake. Depending on the management alternatives chosen, additional research may be needed to effectively implement the selected approach.

Summary

The Vancouver Lake Watershed Partnership identified toxic algal blooms as a focus of common concern from which to ultimately identify management directions for the lake. The Partnership worked together to identify the major research needs and the data necessary to better understand the lake's ecosystem processes and make appropriate management decisions. This Technical Foundation outlines that process and will serve as the platform from which the Partnership can move forward toward selecting management alternatives.

The Five Year Research Plan (Appendix A) is intended to fill data gaps that limit understanding of lake processes, particularly those that cause nuisance cyanobacteria blooms. The research plan and subsequent data collection describes the technical strategy the Partnership will use to identify and select management alternatives for the Lake. These management alternatives will lead to specific actions to be taken by the Partnership and its members in order to address cyanobacteria and enhance beneficial uses of the lake.

CHAPTER 6

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Appendix A

Vancouver Lake Five Year Research Plan

Table of Contents

Vancouver Lake Research Plan

This research plan for Vancouver Lake was originally developed by the Vancouver Lake Watershed Partnership in 2009 based on the Technical Foundation the Partnership developed in the previous year. In the process of updating the Technical Foundation the Research Plan has also been updated and made part of the Technical Foundation as Appendix A. As the Technical Foundation identifies issues, questions, and research needs for Vancouver Lake, the Research Plan gives further detail to the identified research needs.

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

Research Plan Goals

The overarching goal of this research plan is to provide a tool for decision makers to select appropriate studies that lead ultimately to appropriate restoration and management decisions for Vancouver Lake. To that end, this plan seeks to: 1) identify key research needs for the restoration and management of Vancouver Lake; 2) identify the critical path for the research to follow; and 3) develop a clear understanding of the associated costs.

Research Plan Development Strategy

The approach used for developing this research plan is as follows:

1. Identify research steps currently underway.
2. Work with lake experts for technical guidance.
3. Develop approach with the Technical Group.

Research Plan Overview

The Technical Foundation presents many issues that the lake faces, but suggests using nuisance cyanobacteria (blue-green algae) blooms as a “point of entry” to guide our learning about Vancouver Lake. The Technical Foundation identifies six major study areas as critical areas of inquiry. The Steering Group requested a broad prioritization of these research tasks so that a critical path through these study areas could be understood by all Partnership members. As such, this Research Plan looks at all of the research tasks identified in the Technical Foundation.

This research plan is organized into the six major study areas described in the Technical Foundation: 1) water dynamics; 2) nutrients; 3) sediment; 4) food web interactions; 5) toxic contaminants; and 6) fish, wildlife and habitat. In each of these areas study tasks are identified, with cost and timeframe of each study identified. The prioritization of these research tasks is identified in a timeline at eth end of the document that suggests which research tasks should take place in what order.

Ultimately the information collected through the studies identified here will likely be used to populate a comprehensive numerical water quality model to allow for an improved understanding of the physical, chemical, and biological processes in the Vancouver Lake system.

Water Dynamics

A seasonal water balance for Vancouver Lake is important to understanding the fundamental hydrology of the system and factors that cause nuisance algal blooms. Water inputs and outputs are primary pathways for nutrients entering, exiting, or remaining in the system. Vancouver Lake's tidal connection and relationship to the larger watershed makes understanding the water dynamics of the lake particularly important.

Table 1
Water Dynamics Studies

Study task	Description	Status
Task 1.1: Physical Bathymetry	Physical bathymetry mapped by U.S. Army Corps of Engineers	complete
Task 1.2: 1-D Model	1-D model completed by US Army Corps of Engineers. Boundary conditions may not include all areas critical to Vancouver Lake.	complete
Task 1.3: 2-D Model	2-D model completed by US Army Corps of Engineers. Boundary conditions may not include all areas critical to Vancouver Lake.	complete
Task 1.4: Identify and Acquire Water Balance Data	1. Precipitation: use existing data from rain gage on site or nearby 2. Evaporation: use existing pan evaporation data for a nearby site, measure on site using a 3' diameter pan, or calculate using temperature and wind data for a nearby weather station (or a new on-site weather station) 3. Groundwater: calculate by difference in the surface water balance and estimate inflow/outflow using previous studies 4. Surface Waters: Measure water inflows (and outflow at Lake River) at Burnt Bridge Creek, Lake River, Flushing Channel; estimate inflows from small tributaries and nearshore areas using runoff coefficients.	underway

Nutrients

A nutrient budget is a critical first step toward understanding water quality limiting factors in the lake. Data collected on nutrient sources, quantities, and pathways in Vancouver Lake will help to inform this nutrient budget. In particular, the system's nutrient sources and sinks must be understood in order to make informed management decisions with the goal of reducing nutrient availability to cyanobacteria. The primary nutrient of concern is phosphorus because it is typically the nutrient that limits cyanobacteria growth in lakes, but a nitrogen budget will also be developed to identify nitrogen sources if there are periods of the year when it becomes limiting. Potential limitation by inorganic carbon will also be evaluated by calculating the amount of inorganic carbon in the lake using alkalinity and pH data.

Table 2
Nutrient Budget Studies

Study task	Description	Status
Task 2.1: Analyze 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.	underway
Task 2.2: Conduct Nutrient Budget Study	Collect water chemistry data in the lake and at major inputs and outputs to the system for two water years. Lake and tributary samples will be analyzed for total phosphorus, orthophosphate, nitrate and nitrite nitrogen, ammonia nitrogen, total nitrogen, turbidity, total suspended solids (TSS), total organic carbon, alkalinity, and chlorophyll *a* and cyanotoxins (lake only). While collecting grab samples in the field, secchi transparency depth (lake only), pH, water temperature, dissolved oxygen (DO), and conductivity will also be measured. Measure atmospheric inputs of total phosphorus and total nitrogen if local data are not available. Estimate groundwater inputs and outputs using tributary and lake data, respectively. Phytoplankton and zooplankton data will be collected concurrently with the chemistry data as part of Food Web Interactions (Task 4.1)	underway
Task 2.3: Data Analysis and Reporting	Develop a full report detailing the nutrient budget based on collected data. Analyze data to identify primary sources and losses of total phosphorus and total nitrogen in the lake, and determine internal and external loading using a mass balance approach. Describe in-lake recycling of nutrients (net retention and internal loading) and related water quality parameters (chlorophyll *a*, water clarity, oxygen, etc.). Describe relationships between lake chemistry and tributary chemistry, and evaluate relationships between lake chemistry and plankton populations evaluated for Task 4.1.	underway

Sediment

Understanding Vancouver Lake's sedimentation rates, sediment transport, and sediment release rates will be essential to understanding the role of sediment as a nutrient source and/or sink. The three principle mechanisms of internal nutrient inputs should be examined: the physical re-suspension of sediment and associated nutrients and the chemical and biological release of nutrients from sediment.

Table 3
Sedimentation Rate Studies

Study task	Description	Status
Task 3.1: Analyze Existing Sediment Data	Develop short annotated bibliography of existing sediment data.	
Task 3.2: Conduct Sediment Studies	a: Install and monitor sediment traps, to be done by USGS, to measure sedimentation rate in the lake. b: Collect surface sediment grabs with an Ekman or Ponar grab sampler to: 1) measure sheer stress and particle size for estimating sediment suspension from wind; 2) measure release of phosphorus from sediments in small chambers under controlled laboratory conditions, 3) measure	a: underway

Table 3
Sedimentation Rate Studies

Study task	Description	Status
	phosphorus fractions in the sediment to estimate the pool of available phosphorus for physical and chemical release to support Task 3.3 evaluations. c: Estimate inputs of suspended sediment from tributaries using data collected for Task 2.2.	
Task 3.3: Evaluate Mechanisms of Internal Phosphorus Input	a: Physical: Estimate the physical resuspension of sediment and associated phosphorus from wind using a simple model based on data collected in Task 3.2 and existing bathymetric and wind data. b: Chemical/Microbial: Estimate the amount of phosphorus released from lake sediments by chemical dissolution and microbial decay using collected sediment data (Task 3.2) and oxygen data (Task 2.2). c: Biological: Estimate the amount of internal phosphorus input to the lake from decaying aquatic plants, sediment disturbance by benthic fish (e.g., carp), and fecal inputs from waterfowl using information collected for Task 6 and reported in the literature.	
Task 3.4: Investigate Lake History	Collect and analyze lake sediment cores to develop a more complete understanding of historical conditions at Vancouver Lake and determine the degree to which water quality has changed over time. Analyze vertical segments of the cores 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 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 cyanobacteria 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.	

Food Web Interactions

Cyanobacteria blooms at Vancouver Lake frequently cause summer closures of the lake. However, the cycling and timing of these blooms and how other plankton influence these blooms, if at all, are not well understood. Since 2007, Washington State University (WSU) has studied the distribution and species composition of the cyanobacteria, algae and zooplankton throughout the year. Current work by WSU is looking at cyanobacteria growth and death rates, trophic interactions between plankton grazer populations, and factors that influence grazing. Understanding the planktonic community and its trophic interactions will better inform management decisions that attempt to control cyanobacteria blooms.

Table 4
Food Web Interactions

Study task	Description	Status
Task 4.1: Study Planktonic Assemblages	WSU research to: (1) determine the abundance, distribution, and taxonomic composition of cyanobacteria, algae, and zooplankton in Vancouver Lake over a full annual cycle, (2) initiate preliminary investigations of the biotic factors (e.g., grazers) and abiotic factors (e.g., temperature and mixing) that influence these blooms, and (3) analyze the existing data on cyanobacteria blooms in Vancouver Lake for spatial and temporal patterns and trends in abundance.	underway
Task 4.2: Determine Rate Processes	Determine rate processes—the growth and death rates of cyanobacteria — and effects of nutrient concentrations on those rate processes through nutrient manipulation experiments in the laboratory. Work conducted by WSU.	underway
Task 4.3: Broader Food Web Study	Integrate plankton work into broader food web dynamics and other important species in the ecosystem, such as salmonids. With the completion of Task 4.2 and the continuation of background monitoring (e.g., parts of Task 4.1), the Partnership should have a good understanding of the lower trophic levels forming the base of the lake's food web, such as algae, cyanobacteria and zooplankton. However, these parts of the lake's food web will need to be linked to higher trophic levels, such as planktivorous and piscivorous fishes (see also Task 6.4 below), as well as to the benthic (bottom-dwelling) community of invertebrates (see Task 6.2.b below). This "whole lake" food web perspective will be essential to considering any biological manipulation of the lake to manage cyanobacteria blooms.	

Toxic Contaminants

Toxic contaminant studies have been conducted by the Environmental Protection Agency (EPA) and Washington Department of Ecology (Ecology). In 2007, Ecology published the results of a study where they investigated PCBs, chlorinated pesticides, and dioxins in fish tissue and sediment from Vancouver Lake. Contaminants in Lake River fish and sediment also were assessed.

Toxic contaminants, although not directly linked to the cyanobacteria, are a priority for consideration due to the human health issues. Still, because this initial investigation by the Vancouver Lake Watershed Partnership (VLWP) is focused on cyanobacteria blooms, and because toxics studies are still underway, for the purposes of this research plan toxic contaminant studies are supplemental and pending further investigations by EPA and Ecology. A study task for this research plan includes an initial summary of toxic contaminant study findings for Vancouver Lake once the Ecology 2010 study is completed. A second task could then be conducted that identifies needs for additional study of toxic contaminants based on the data gaps identified.

Table 5 *Toxic Contaminants Studies*		
Study task	**Description**	**Status**
Task 5.1: Analyze Existing Data.	Technical review and summary report on existing toxics data and studies. Identify any data gaps.	
Task 5.2: Identify Additional Toxic Contaminant Studies	If data gaps are identified, then determine necessary supplemental studies.	

Fish, Wildlife, and Habitat

The research tasks include an aquatic species survey, fish community study, and salmonid genetic study. Aquatic species population and habitat data are important for understanding how those species affect the phytoplankton community primarily through nutrient cycling (e.g., phosphorus inputs) and food web interactions (e.g., predation on zooplankton). Recent studies on migratory and resident fish and their habitat as well as wildlife species and habitats in and around Vancouver Lake are lacking. Fish population composition surveys and habitat evaluations would inform management decisions, especially as they may impact aquatic habitat and food web interactions. Studies on wildlife composition and habitat may be less critical in decisions aimed at managing cyanobacteria blooms, but are of interest to some lake users.

A waterfowl population survey will be conducted in one study year, and timed with seasonal waterfowl migration patterns. Waterfowl data can be used with literature-derived values for fecal inputs to estimate nutrient loading from waterfowl for Task 2.3.

While not directly related to cyanobacteria and algal blooms, a salmonid genetic study can be used to determine if salmonids present in Vancouver Lake originated from tributaries to the lake or the Columbia River. Knowing the origin of salmonids in the lake will be useful for determining needs for salmonid habitat protection and restoration.

Table 6 *Fish, Wildlife, and Habitat Investigations*		
Study task	**Description**	**Status**
Task 6.1: Analyze Existing Data.	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 6.2: Aquatic Species Survey	a: Conduct an aquatic plant survey on one occasion in late summer to map the distribution of native and exotic emergent, floating, and submersed, aquatic plant species, and measure biomass and phosphorus content of major submersed plant populations to evaluate nutrient uptake and inputs by those plants. b: Conduct a benthic invertebrate survey on one occasion in late summer to measure the density and diversity of benthic invertebrate populations for evaluating water quality impacts and fish habitat. Collect sediment samples	

Table 6
Fish, Wildlife, and Habitat Investigations

Study task	Description	Status
	from representative locations in the lake and analyze them for benthic invertebrate species. c: Conduct an aquatic habitat survey on one occasion in late summer to evaluate habitat conditions in the lake for aquatic plants, benthic invertebrates, and fish. This could be conducted in conjunction with the aquatic plant survey. d: Conduct waterfowl population surveys on four occasions during one study year. Use the collected waterfowl data and literature values for fecal inputs to estimate nutrient loading from waterfowl for Task 2.3	
Task 6.3: Fish Community Study	Conduct a fish community study that samples fish in different regions of the lake at different times of the year. The number of locations and the duration of the study would be based on the anticipated geographic and temporal variability, and available budget. Fish population and health data will be collected using multiple techniques (e.g., mark and recapture method using mid-water net tows for pelagic species, beach seining for littoral species, and fish traps for benthic species), and will include fish gut analysis for assessing feeding habits.	
Task 6.4: Salmonid Genetic Study	Genetic sampling of salmonids in the lake can help identify the origins of salmon that are using the lake at various life stages.	

Lake Water Quality Model

The primary purpose of the water quality model is to predict effects of lake and watershed management activities on the algae and cyanobacteria population dynamics in the lake. An initial task (Task 7.1) will be conducted to identify specific objectives for the water quality model and to select which model will best meet those objectives. Selection of an appropriate water quality model for the lake depends on various factors related to constraints by physical lake features, the amount of input data available, level of detail needed for model output, how the model will be used, and available funds. Examples of water quality models that may be used include CE-QUAL-W2, CE-QUAL-ICM, and MIKE-21. Advantages and disadvantages of these and other models will be summarized once the modeling objectives are defined and historical data are reviewed. Although the relative accuracy of each model will vary with the amount and quality of the input data, it is anticipated that the studies identified above would provide sufficient data for any of the alternative models considered. Recommendations for additional data collection, if any, will be made once the preferred water quality model is selected.

Chemical and biological data collected for the other studies can be used to calibrate a water quality component of the model. The model chosen for Vancouver Lake, once populated with the necessary water dynamic, nutrient, sediment, and biological data, would allow the Partnership to make informed restoration and management decisions, and to evaluate management alternatives for Vancouver Lake. The calibrated water quality model developed for Vancouver Lake will be used to evaluate the effects of lake and watershed management actions on the growth of phytoplankton (suspended algae and cyanobacteria) in the lake.

The model will be useful for examining effects of reduced nutrient loadings to the lake from the watershed, but will not be capable of predicting the effectiveness of watershed nutrient reduction strategies on the those loadings. The potential needs, benefits, and approaches for developing a watershed model and integrating it with the lake water quality model will be explored.

The model also will be useful for examining effects of biological populations on water quality and phytoplankton growth, but will not be capable of predicting impacts of lake and watershed management on populations of higher trophic levels (e.g., aquatic plants, invertebrates, and fish). The potential needs, benefits, and approaches for developing a comprehensive ecological model and integrating it with the lake water quality model will be explored.

Table 7
Lake Water Quality Model

Study task	**Description**	**Status**
Task 7.1: Select Lake Water Quality Model	Review advantages, disadvantages, data needs, model capabilities, and costs of lake water quality models that can be used to predict the effectiveness of management options on hydrology, nutrient dynamics, water quality, and plankton populations in the lake. Select an appropriate lake water quality model based on the lake's physical characteristics, available input data, desired model output/uses, and available funds.	
Task 7.2: Develop Lake Hydrodynamic Component	Develop the hydrodynamic component of the water quality model using existing data and results of the initial water dynamic studies (Tasks 1.1 – 1.3)	
Task 7.3: Develop Lake Water Quality Model	Develop, calibrate, and run the Vancouver Lake Water Quality Model for two years of data collected for Tasks 1 – 6.	
Task 7.4: Evaluate Management Options	Use model to evaluate effectiveness of selected management options. A watershed model may need to be developed and used to evaluate the effectiveness of watershed management options.	

Summary of Lake Research Costs

The table below (Table 8) shows the approximate cost or range of costs for each research task.

Table 8 *Study Area*	**Study Task**	**Cost**
Water Dynamics Studies	Task 1.1: Physical Bathymetry	Complete
	Task 1.2: 1-D Model	Complete
	Task 1.3: 2-D Model	Complete
	Task 1.4: Identify and Acquire Water Balance Data	$350 K in Partnership funds planned for USGS study of all four study tasks.
Nutrient Budget Study	Task 2.1: Analyze Existing Nutrient Data	
	Task 2.2: Conduct Nutrient Budget Study	
	Task 2.3: Data Analysis	
Sediment Studies	Task 3.1: Analyze Existing Sediment Data.	$10 K
	Task 3.2: Conduct Sediment Studies a: Sediment Traps b: Surface Sediment Grabs c: Tributary Suspended Sediment	 a: $10 K b: $10 K c: $10 K
	Task 3.3: Evaluate Internal Phosphorus Input a: Physical Suspension b: Chemical/Microbial Release c: Biological Mechanisms	 a: $40-80 K b: $30-40 K c: $20-40 K
	Task 3.4: Investigate Lake Sediment History	$100-150 K
Food Web Interactions	Task 4.1: Study Planktonic Assemblages	Complete
	Task 4.2: Determine Rate Processes	$100 K
	Task 4.3: Larger Food Web Study	$100 K
Toxic Contaminant Studies	Task 5.1: Analyze Existing Toxic Data	$10-20 K
	Task 5.2: Identify Additional Toxic Contaminant Studies	$10 K
Fish, Wildlife, and Habitat Investigations	Task 6.1: Analyze Existing Data.	$10-20K
	Task 6.2.a: Aquatic Plant Survey Task 6.2.b: Benthic Invertebrate Survey Task 6.2.c: Aquatic Habitat Survey Task 6.2.d: Waterfowl Survey	a: $30-60 K b: $30-40 K c: $20-40 K d: $30-60 K
	Task 6.3: Fish Community Study	$100-150 K
	Task 6.4: Salmonid Genetic Study	$3 – 5k
Lake Water Quality Model	Task 7.1: Select Lake Water Quality Model Task 7.2: Develop Lake Hydrodynamic Component Task 7.2: Develop Lake Water Quality Model Task 7.4: Evaluate Management Options	$10-20 K $40-80 K $85-120 K $15-30 K

Proposed Five Year Research Plan Schedule and Priorities

A proposed five year research plan schedule is shown in the attached timeline (Appendix A). In some cases a task needs to take place first because it then informs a later study. That later study may also be critical but is simply a later step. In other cases a task is listed first because it is more critical to lake decision making than a later study.

Water Dynamics and Nutrients

Research on the water balance (Task 1.1) and nutrient budget (Task 2) that USGS is currently conducting are the most important research plan components for understanding where cyanobacteria are obtaining nutrients for growth, and phosphorus is the most critical nutrient for identifying effective management options to limit cyanobacteria growth. This research will identify the relative contribution of external sources of phosphorus from the various watershed basins and determine the relative importance of internal cycling of phosphorus in the lake for cyanobacteria growth throughout the year. Final results of the water balance and nutrient budget will not be available until Year 4 (June 2013). However, preliminary results will be evaluated in early 2012 and used to identify data gaps that can be filled for the final research analysis.

The water balance and nutrient budget research may identify data gaps concerning watershed phosphorus sources or which internal phosphorus cycling mechanisms are most important. Based on our current knowledge of cyanobacteria blooms in Vancouver Lake, effective management options may include the reduction of both external (watershed) and internal (lake sediment) sources of phosphorus. Reduction of watershed phosphorus sources would require a combination of structural and nonstructural best management practices (BMPs) applied basin-wide. A strategy for reducing watershed sources often depends more on BMP cost effectiveness and implementation constraints rather than targeting specific sources within a basin. Thus, identifying specific phosphorus sources within the watershed basins is not included in this research plan.

Sediment

Research on lake sedimentation (Task 3.2a) and tributary sediment input (Task 3.2c) are important research plan components for understanding the transport of phosphorus to the lake sediments. These two tasks are part of the research USGS is currently conducting. The collection of lake sediment data (Task 3.2b) and research on the physical and chemical mechanisms for internal phosphorus transport from lake sediments (Tasks 3.2a and 3.2b, respectively) are also a high priority for understanding internal cycling of phosphorus.

Research on the biological mechanisms for internal phosphorus transport from lake sediments (Task 3.3c) and the history of lake sedimentation (Task 3.4) are of moderate priority because they are considered to be useful but not critical for cyanobacteria management.

Food Web Interactions

Research on plankton assemblages and rate processes (Tasks 4.1 and 4.2, respectively) was recently completed by Washington State University-Vancouver. This research is considered a high priority and critical for cyanobacteria management to enhance the understanding of phytoplankton succession and grazing impacts on species composition. A broader food web study is proposed for Year 4 (2013) that is currently rated a moderate priority because it is considered to be useful but not critical for cyanobacteria management.

Toxic Contaminants

Research on toxic contaminants (Task 5) in the lake is a low priority because it is useful for general lake knowledge but not for cyanobacteria management. However, toxic contaminant research may become useful in the future for evaluating impacts of cyanobacteria management options depending on the findings of Ecology's toxic contaminant study using semi-permeable membrane devices in 2010.

Fish, Wildlife and Habitat

Research on fish, wildlife, and habitat (Task 6) is of moderate priority because it is considered to be useful but not critical for cyanobacteria management. This research is scheduled to begin in Year 2 (2011), but is not funded and may be conducted at a later time. Analysis of existing data (Task 6.1) and research on waterfowl populations (Task 6.2d) and fish populations (Task 6.3) are considered to be the most important components within this research category because they directly impact cyanobacteria. However, phosphorus inputs from waterfowl and impacts of fish on cyanobacteria grazers may be estimated using existing information. Surveys of aquatic species (Task 6.2a), aquatic habitat (Task 6.2b) and terrestrial species (Task 6.2c) are considered to be less important because either they are not likely to be directly managed or have little effect on phosphorus and cyanobacteria in the lake. The salmonid genetic study (Task 6.4) is currently of low priority because it is not considered to be directly useful for cyanobacteria management, but it may become useful in the future for evaluating impacts of cyanobacteria management.

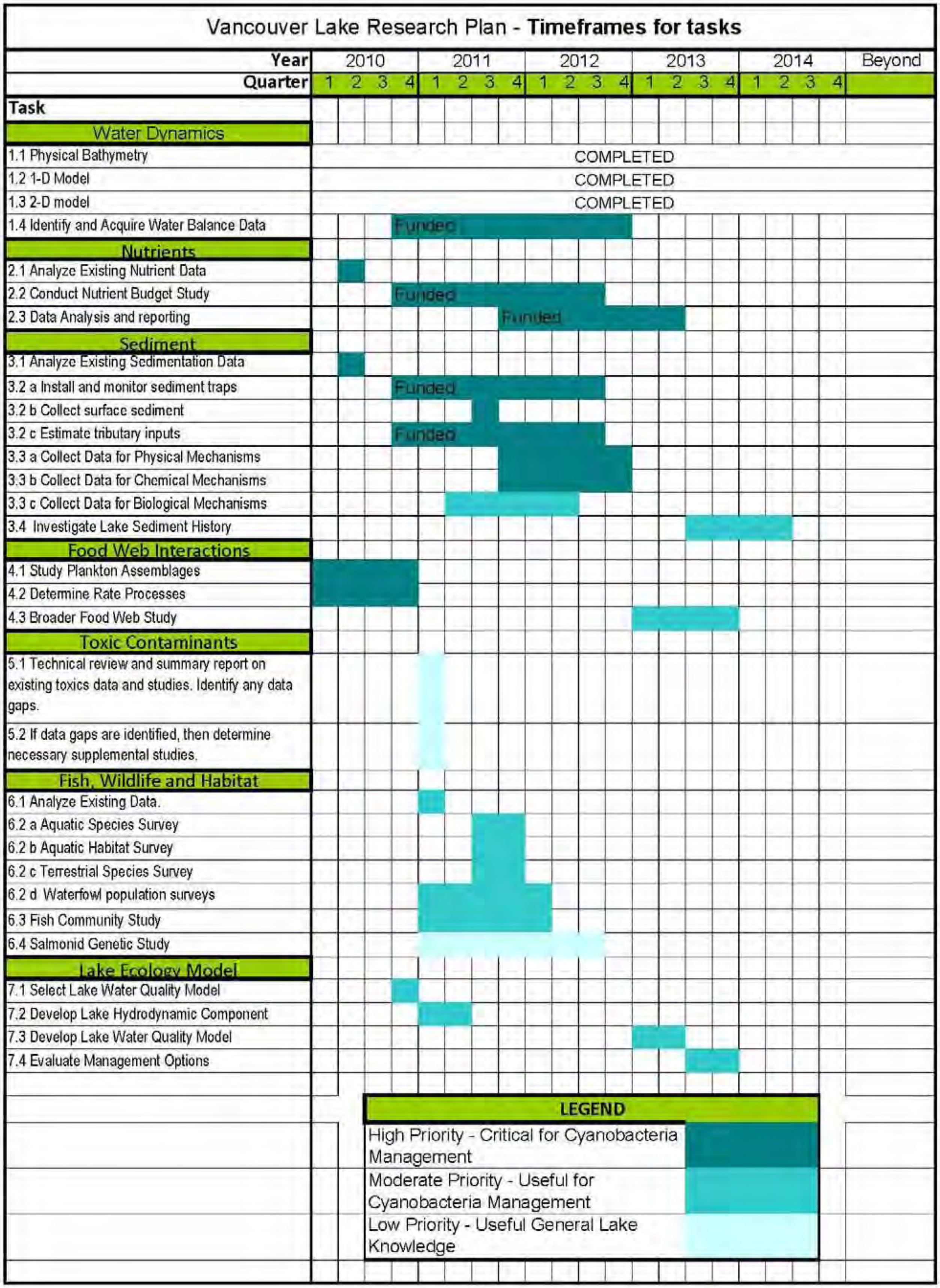
Lake Model

The lake ecology model (Task 7) is of moderate priority because it is considered useful but not critical for cyanobacteria management. This research is scheduled to begin in Year 2 (2011) with the selection of a lake model (Task 7.1) and development of the hydrodynamic component of the model (Task 7.2). Following completion of the water balance and nutrient budget, the water quality model would be developed in Year 4 (2013) and used to evaluate cyanobacteria management options. The lake model may become a high priority in the future if the water balance and nutrient budget prove insufficient for evaluation of cyanobacteria management options.

Summary

The Vancouver Lake Watershed Partnership proposed this research plan to fill data gaps that limit understanding of lake processes, particularly those that cause nuisance cyanobacteria blooms resulting in lake closures in the summer months. This is not a complete list of all that needs to be done for Vancouver Lake. Rather, this document creates a foundation from which restoration and long-term management decision can be based. These studies will result in a more focused set of questions and identify specific data gaps that once filled will inform a clear restoration strategy for the lake.

Restoring Vancouver Lake to a healthy functioning estuarine freshwater lake could take decades, but there are many important steps that can be taken now to address the most urgent problems the lake faces. This research plan proposes a data gathering strategy to begin addressing nuisance cyanobacteria blooms.


Vancouver Lake Research Plan - **Timeframes for tasks**
Year
2010
2011
2012
2013
2014
Beyond
Quarter
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
Task
Water Dynamics
1.1 Physical Bathymetry
COMPLETED
1.2 1-D Model
COMPLETED
1.3 2-D model
COMPLETED
1.4 Identify and Acquire Water Balance Data
Funded
Nutrients
2.1 Analyze Existing Nutrient Data
2.2 Conduct Nutrient Budget Study
Funded
2.3 Data Analysis and reporting
Funded
Sediment
3.1 Analyze Existing Sedimentation Data
3.2 a Install and monitor sediment traps
Funded
3.2 b Collect surface sediment
3.2 c Estimate tributary inputs
Funded
3.3 a Collect Data for Physical Mechanisms
3.3 b Collect Data for Chemical Mechanisms
3.3 c Collect Data for Biological Mechanisms
3.4 Investigate Lake Sediment History
Food Web Interactions
4.1 Study Plankton Assemblages
4.2 Determine Rate Processes
4.3 Broader Food Web Study
Toxic Contaminants
5.1 Technical review and summary report on existing toxics data and studies. Identify any data gaps.
5.2 If data gaps are identified, then determine necessary supplemental studies.
Fish, Wildlife and Habitat
6.1 Analyze Existing Data.
6.2 a Aquatic Species Survey
6.2 b Aquatic Habitat Survey
6.2 c Terrestrial Species Survey
6.2 d Waterfowl population surveys
6.3 Fish Community Study
6.4 Salmonid Genetic Study
Lake Ecology Model
7.1 Select Lake Water Quality Model
7.2 Develop Lake Hydrodynamic Component
7.3 Develop Lake Water Quality Model
7.4 Evaluate Management Options
LEGEND
High Priority - Critical for Cyanobacteria Management
Moderate Priority - Useful for Cyanobacteria Management
Low Priority - Useful General Lake Knowledge