Assessment and Monitoring of Water Quality in Lake Waughop as a Service-Learning Project: A Case Study Approach

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Abstract

When combined with service-learning and environmental history, restoration ecology can provide a rewarding and innovative approach to education. By using nearby open spaces, be they parks, school grounds, vacant lots, or urban creeks, educational institutions can help students develop a sense of place and a commitment to helping their local communities. There are many open spaces that would benefit from ecological restoration and using nature as a classroom benefits both students and the local community. To facilitate this process a framework based on a historical case study of Lake Waughop was designed so that educational institutions may use it as a guide to incorporate ecological restoration and service-learning into their courses. This small kettle lake in Washington State has been severely degraded due to anthropogenic activities since the 1800s and has several cyanobacterial blooms annually. Water quality sampling of Lake Waughop was done intermittently in 2007, 2008, 2009, and

2011 to provide baseline data for present lake conditions as a comparison to future monitoring. Several methods for restoration of a polluted freshwater lake were investigated; riparian management, limited chemical treatment, mechanical mixing, and dredging may all be options for partial or complete restoration of Lake Waughop. Learning modules were developed to teach students water quality monitoring and ecological restoration methods; instructors may use one component or all. These modules incorporate service-learning and ecological restoration to impart valuable cultural, personal, and scientific learning, benefiting students on many levels.

ACKNOWLEDGEMENTS

Robert Sager, my mentor and role model since I first came to Pierce College as a student in 1990

and

Beth Norman, my teacher and friend since I came back to Pierce College as an employee in 2004

Many thanks for your friendship, encouragement, kindness,
and support throughout this long and interesting process.

Gratitude and appreciation to my family and all my friends and colleagues at Pierce College who lent a shoulder when needed, edited pages and pages of text, and brought me chocolate.

Special kudos to Christian, without whom this thesis would have been completed sooner, but with a great deal less fun.

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DEDICATION

To my parents

Joy Jackson Eshom LaFontaine

Mom, I couldn't have done it without you.

Donald Lawrence LaFontaine

Daddy, I wish so much that you were here to see this.

I love you both very much.

Chapter One: Introduction and History

The health and environmental quality of Lake Waughop, a small kettle lake in Pierce County, Washington, has been in serious decline for many decades. Like many lakes worldwide, Lake Waughop has been subject to increased and excessive nutrient input (Bryhn, 2008). Anthropogenic sources such as sewage discharge, surface water runoff containing fertilizers and animal waste, and contaminated groundwater can provide an overabundance of nutrients, leading to eutrophication of a water body (Wetzel, 2001). Eutrophic lakes are marked by dull murky water (often green in color), larger and more frequent algal blooms – sometimes toxic - and lake bottoms depleted of dissolved oxygen. This frequently leads to deterioration of the lake's ecological system and shoreline habitat (Molles, 2005).

Lake Waughop, located in Fort Steilacoom Park (Figure 1), is currently in a suburban setting, and the lake has been heavily used since the early 1800s for military, agricultural, and recreational use (Artifacts Consulting, Inc., 2008). The lake has had some rather unique anthropogenic inputs starting as far back as the late 19th century, when farmers in the area began raising sheep and cattle near the lake (Skott, 2001). While nutrient inputs from these small herds were relatively low, by the 1930s Western State Hospital had developed a very large farming operation and Lake Waughop became a convenient place to dispose of farm waste (Cooley, 1964) from both fields and the farm slaughterhouse. Workers also used the lake to make "compost tea" by the addition of bovine and porcine manures (Mann, 1957). This "tea" was then pumped out of the lake and

used as fertilizer on the crops. The farm, encompassing Lake Waughop and the surrounding landscape, was in operation from the late 1920s until 1960.

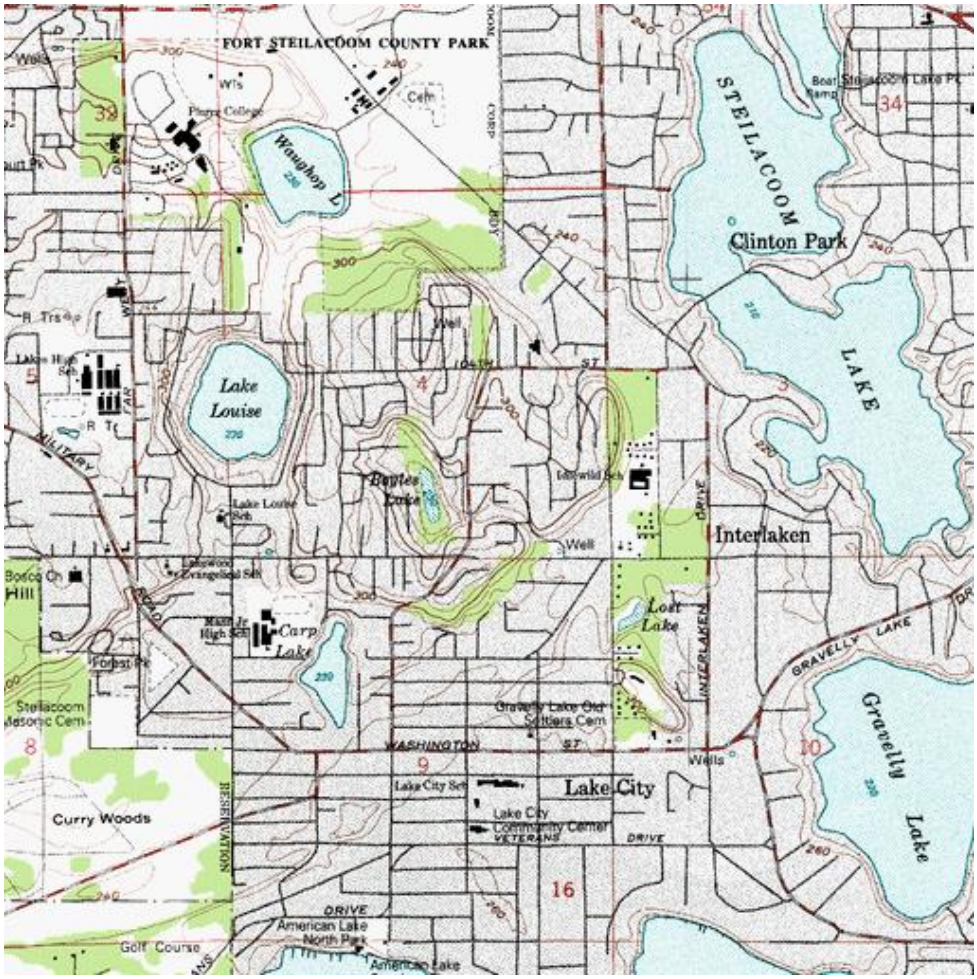


Figure 1. USGS Map of Lake Waughop and Surrounding Area.
US Geological Service,1997.

The sequence of aerial photos in Figure 2, a-d record the increasing development of the land around the park from 1950 to 2005. As can be seen in this photo sequence, the greater part of this development has been residential, particularly to the southwest of the lake. Pierce College was built to the west of the lake in 1970.

Figure 2a. Fort Steilacoom Park in 1950. Photo courtesy of City of Tacoma

Figure 2b. Fort Steilacoom Park in 1998. Photo courtesy of City of Tacoma

Figure 2c. Fort Steilacoom Park in 2002. Photo courtesy of City of Tacoma

Figure 2d. Fort Steilacoom Park in 2005. Photo courtesy of City of Tacoma

No sewer system existed when the majority of these homes were built and all have onsite septic systems. The red dots on the map in Figure 3 indicate the presence of current septic systems, showing a heavy concentration on the south and west slopes above Lake Waughop. Groundwater drainage moves downhill from these residential areas toward Lake Waughop, and may be a source of nutrient input to the lake.

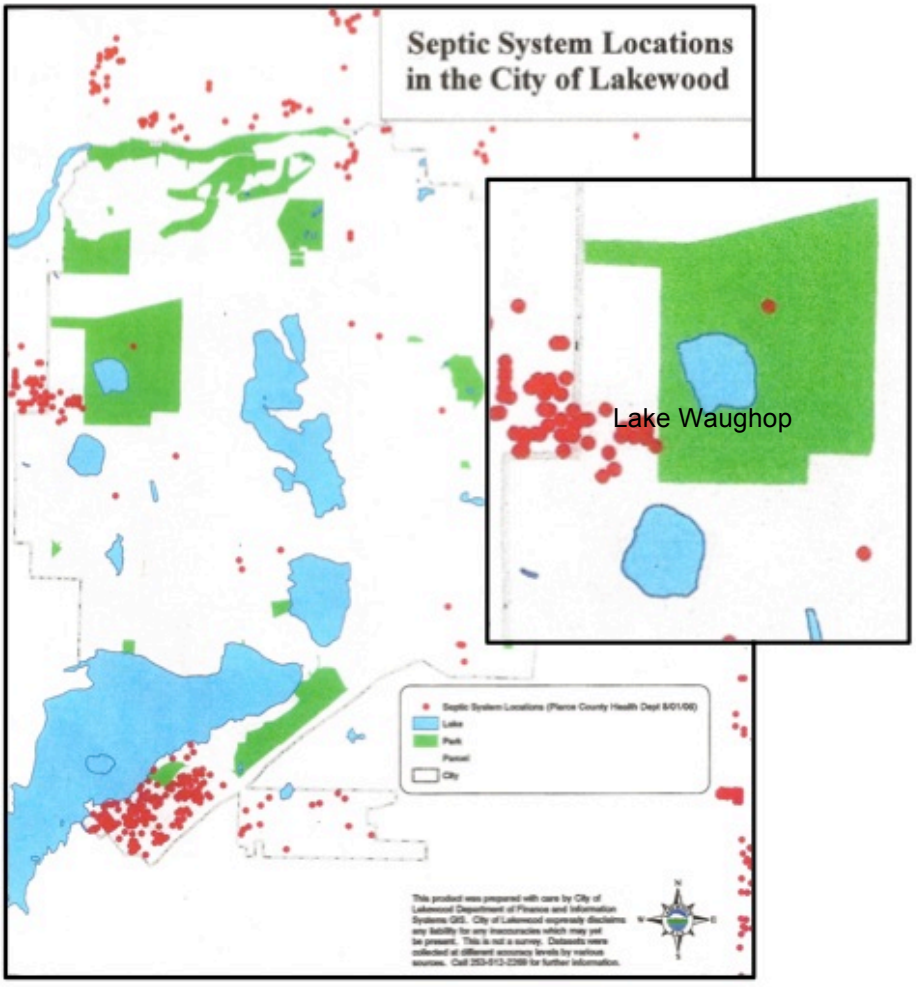


Figure 3. Map of Current Septic Systems in Lakewood.
Image courtesy of City of Lakewood

Lake Waughop is a small kettle lake with no natural inlet or outlet, receiving its water supply via groundwater seepage, precipitation, and surface water runoff. Water also enters the lake through a large drainpipe in the northwest corner of the lake. The pipe brings water from a holding pond on the western hillside above the lake which filters drainage water from Pierce College parking lots. Lake Waughop has no drainage outlet, so water loss is either through evaporation or percolation into groundwater.

Historically there was a natural spring at the bottom of the lake which supplied water input (Mann, 1930). In the early 1900s Lake Waughop was 9.14 meters deep (Mann, 1930). Due mainly to human activity, the depth is now approximately 3.7 meters during the summer and 4.2 meters in winter (Hamel, 2009). As a consequence of this shallow depth, lack of freshwater input, past and present practices, and current high nutrient loads, Lake Waughop is subject to seasonal eutrophication and large algal blooms. The resulting blooms (Figure 4) include species of cyanobacteria, most frequently *Microcystis,* which produces the neurotoxin Microcystin, and *Anabaena* which produces a liver toxin, Saxitoxin, which is also a neurotoxin. Both toxins can be fatal to pets and cause illness in humans (Hamel, 2009).

Figure 4. Lake Waughop Algal Bloom, August 2007.
Michele LaFontaine

Toxic algal blooms are not only unsightly and odoriferous, they are a health hazard as well. In 2005 the Washington State Legislature designated funding for an algae monitoring program. Toxin levels are monitored by the Tacoma-Pierce County Health Department (TPCHD) with assistance from the Washington Department of Ecology (WDOE). TPCHD-trained volunteers collect samples from 30 lakes in Pierce and King Counties throughout the year. If toxin levels are above state established guidelines the affected lakes are posted with warning or closed signs.

Urban lakes and parks offer unique learning environments that are especially valuable in encouraging awareness of environmental issues. They also provide opportunities for students to participate in service-learning projects. Learning and working in real-world environments and situations encourages the development of social responsibility, a sense of participating in worthwhile and useful projects, and a realistic experience of applied, experiential education that can simulate realistic employment.

Although many schools are located near urban parks, few of these institutions take advantage of these outdoor classrooms. I will develop field activities and multiple lab exercises that can be taught as one extended unit or as stand-alone activities. By making this curriculum available to the general educational community, I hope instructors will be motivated to take advantage of their local outdoor classrooms as learning environments.

The proximity of Lake Waughop and Fort Steilacoom Park to Pierce College provides an excellent opportunity for experiential- and service-learning

for students at the college. My project consists of documenting the history of Fort Steilacoom land use and developing a portable course outline including field activities and labs that incorporate the study, monitoring, and restoration of the lake and park. Students in Pierce College Earth Science, Biology, and Chemistry courses will collect and analyze data from Lake Waughop and Fort Steilacoom Park and use the data in designing and implementing restoration programs at the site. This will provide an opportunity for students to learn the scientific method, use scientific protocols, become comfortable using scientific instruments, acquire valuable research skills, develop their sense of place and ownership for the park, establish an on-going, long-term data collection, monitoring, and restoration program for the park, lake, and surrounding land, and improve their communication skills by sharing results with the public. One of my goals is to implement an on-going program of scientific data collection, analysis, and record-keeping for the lake and surrounding park that uses the results of this thesis as the foundation baseline for future studies.

The Chemistry Department at Pierce College has been doing informal studies of Lake Waughop for several years, and the Earth and Space Sciences Department will team up with them on the sampling and analysis of lake water. Students will gain the satisfaction of participating in a scientific study and seeing their work posted on a website for general public dissemination. In addition to learning how to do scientific studies, I want our students to develop a sense of place and a sense of stewardship for our environment. I want them to learn the

difference between a healthy and a compromised ecosystem and some of the things that can be done to restore damaged systems.

The purpose of this thesis is to provide the background foundation and development of a framework for integration of a service-learning project focused on Lake Waughop into the Earth and Space Sciences curriculum at Pierce College which will serve as a case study for other educational institutions. Elements of the project will include:

1. Providing an overview of the environmental and cultural history of Lake Waughop.
2. Building a baseline data set of Lake Waughop water quality parameters using results from recent (2007-2011) data collection and analysis of water samples.
3. Examining components of successful environmental/service-learning modules and create service-learning building blocks for use in academic courses.
4. Developing the framework for a feasible service-learning restoration project for Pierce College students.
5. Creating the basis for a departmental library of data pertaining to Lake Waughop.

Chapter Two: Physical Description of Lake Waughop and Surrounding Landscape With a History of Land Use

2.1 Lake Waughop Watershed Site Characterization

Figure 5. Lake Waughop Algal Bloom, November 2009.
Michele LaFontaine

Lake Waughop, a small shallow kettle lake, located in Fort Steilacoom Park, Lakewood, Washington, is part of the Chambers-Clover Creek Watershed (Figure 5). The lake sits near the edge of one of the remaining remnants of native prairie in Western Washington (Avey,1985). It is 6.4 km east of Puget Sound and 70 m above sea level. The lake is approximately 0.60 km in circumference, has a surface area of 33 acres, an average depth of 3 m, and a

volume of 246,700 m^3 (Hamel, 2009). The land surrounding the lake has been either farmland, parkland, or military base since European settlement. Fort Steilacoom Park property is owned by the Washington State Department of Social and Health Services (DSHS), leased to Pierce County, and currently managed by the City of Lakewood (Dodd, 2007).

In the early 1900s Lake Waughop was 9.14 meters deep (Mann, 1930), but in the decades since the lake has shallowed, filling in with sediments that are unconsolidated and have high organic content. The water-shore interface recedes up to two m during summer due to evaporative water loss.

Lake Waughop is a kettle lake – a basin or depression formed throughout North America in the Pleistocene Ice Age when the Cordilleran Ice Sheet covered Puget Sound. As the glacier advanced, massive pieces of ice broke free from the continental ice sheet and were wholly or partially forced into the ground (a few to tens of meters) and then covered over by glacial drift material (Wetzel, 2001). When the ice sheets retreated and the mass of ice in the hole melted (taking hundreds of years in some instances), pits were left in the sediment. Over time, many of these pits eventually filled with water, creating kettle lakes (Tarbuck and Lutgens, 2005).

During Quarternary glacial advances, 0.1 to 1.8 million years before present, the Puget Lowland was subject to several episodes of extensive glaciation (Tarbuck and Lutgens, 2005). The Cordilleran Ice Sheet, the smaller of two North American ice sheets, extended south into northern Washington and northwestern Montana (Figure 6). The Cordilleran formed several distinct lobes;

18,000 years ago the Puget Lobe extended as far south as Olympia, WA. (Booth et al., 2003). As the climate of Earth began warming the ice slowly melted back and by 14,000 years ago ice sheet had retreated to Seattle (Booth et al., 2003).

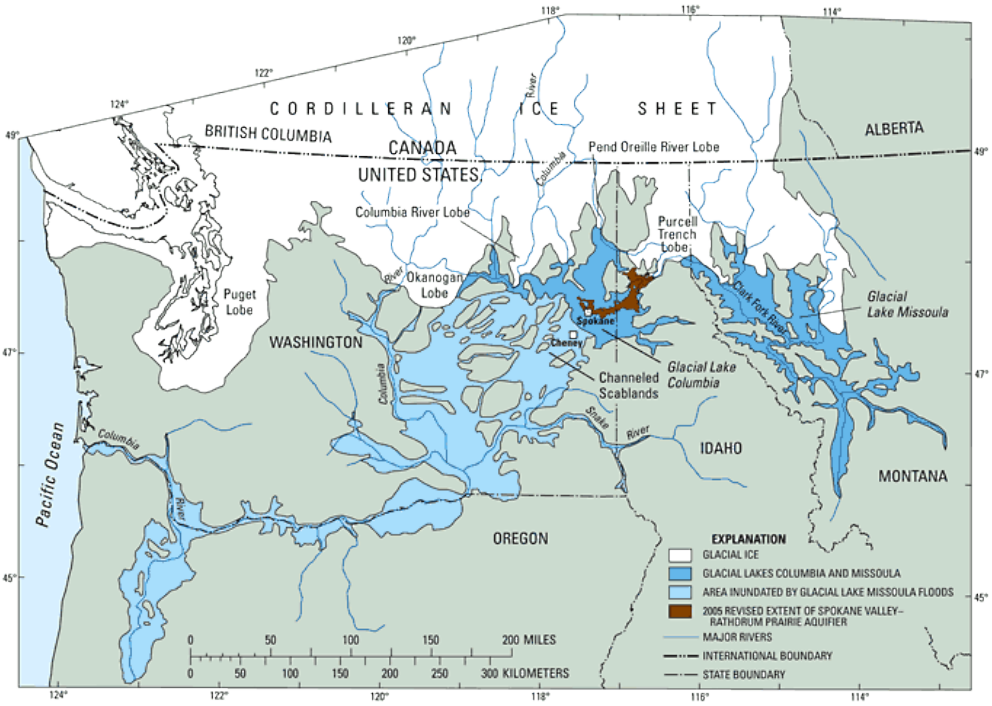


Figure 6. Extent of Cordilleran Ice Sheet 18,000 Years Ago. Modified from Allen and Burns, 1986, and Atwater, 1986. Retrieved from http://pubs.usgs.gov/sir/2005/5227/section5.html

Like many kettle lakes, Lake Waughop has no natural surface water inlet or outlet and receives its water supply via direct precipitation, groundwater flow, surface runoff, and drainage from a 0.7 m diameter inflow pipe located in the northwest corner of the lake (Figure 7), that drains water from a holding pond upslope and to the southwest of the lake (Figures 8 and 9). This pond collects runoff from the Pierce College parking lots and as the accumulated runoff slowly percolates through the soil many of the contaminants from the parking lots and sidewalks are filtered out.

Figure 7. Map of Lake Waughop Showing Locations Referred to in Text.
US Geological Service. Retrieved from Google Earth.

Prior to 1982, when Pierce College constructed a new drainage system, the pipe carried unfiltered runoff directly into the lake (N. Tweed, personal

communication, February 2, 2012). During the early 1980s the college had an accidental drainage from the swimming pool, resulting in chlorinated pool water being discharged into the lake (J. Shelley, personal communication,1991).

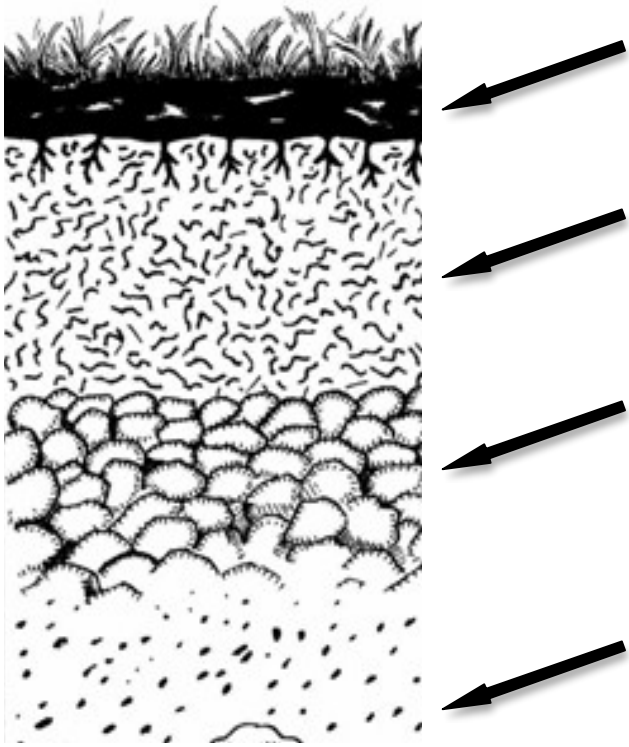
Figure 8. Holding Pond Drain
Michele LaFontaine

Figure 9. Rusty Backflow Pressure Lid.
Michele LaFontaine

Additional fresh water input to the lake historically came from the springs at the bottom of the lake (Mann, 1930), but it is unlikely these springs still serve this function. The main cause of water loss from the lake is evaporation. Water is not removed for anthropogenic purposes other than for water quality analysis.

As the lake was created by a glacier, so it sits in relatively recent glacial deposits of sediment "...formed in glacial outwash and volcanic terraces and plains at elevations of 100 to 500 feet" (Anderson et al., 1955). The soil is composed primarily of silt, volcanic ash, sand, gravel, and cobble with some large boulders mixed in. The sediments are classified as the Spanaway Prairie Soil Series (USDA, 2006). Figure 10 shows a cross-section of soil layers in the Spanaway series, which is widespread throughout the South Puget Sound Region, and historically supported large swaths of native prairie and oak woodland (USDA, 2006).

Only remnant pieces of these vast plains remain today. Note that the A horizon consists of very dark brown gravelly sandy loam (Anderson et al., 1955). Researchers attribute this dark surface soil "...to the repeated burning of the prairies by human or natural activity" (Avey, 1985). Figure 11, a report showing data from a well drilled near Fort Steilacoom Park in 2003, shows a list of the different soil types and their depths (in feet) within the sediment column.



Oa - 0 to 1 inch; black (10YR 2/1) well decomposed organic matter, very dark brown (10YR 2/2) dry; mostly from grass roots and moss. (0 to 1 1/2 inches thick)
A - 1 to 15 inches; black (10YR 2/1) gravelly sandy loam, very dark grayish brown (10YR 3/2) dry; weak fine granular structure; soft, very friable, nonsticky and nonplastic; many fine roots; very high in organic matter content, has mellow, sooty feel; 35 percent pebbles; strongly acid (pH 5.4); clear smooth boundary. (10 to 20 inches thick)
Bw - 15 to 19 inches; dark grayish brown (10YR 4/2) very gravelly sandy loam, grayish brown (10YR 5/2) dry; weak fine subangular blocky structure; soft, very friable, nonsticky and nonplastic; common fine roots; 50 percent pebbles, 10 percent cobbles; moderately acid (pH 5.8); clear smooth boundary. (3 to 8 inches thick
2C - 19 to 61 inches; light brownish gray (10YR 6/2) dry; extremely gravelly sand; single grained; loose; few fine roots; 60 percent pebbles, 10 percent cobbles; slightly acid (pH 6.1).

Figure 10. Soil Profile Showing the Different Layers.
Data retrieved from https://soilseries.sc.egov.usda.gov/osdlist_show.aspx

WATER WELL REPORT

Original & 1st copy - Ecology, 2nd copy - owner, 3rd copy - driller

Construction/Decommission ("x" in circle)
- [X] Construction
- [ ] Decommission *ORIGINAL CONSTRUCTION Notice of Intent Number* 133406

PROPOSED USE: [ ] Domestic [ ] Industrial [X] Municipal [ ] DeWater [ ] Irrigation [ ] Test Well [ ] Other

TYPE OF WORK: Owner's number of well (if more than one)
[X] New Well [ ] Reconditioned *Method:* [ ] Dug [ ] Bored [ ] Driven [ ] Deepened [X] Cable [ ] Rotary [ ] Jetted

DIMENSIONS: Diameter of well 16 inches, drilled 700 ft
Depth of completed well 574 ft.

CONSTRUCTION DETAILS
Casing [X] Welded 20" Diam. from 0 ft. to 300 ft.
Installed: [ ] Liner installed 16" Diam. from 0 ft. to 518 ft.
[ ] Threaded ____" Diam. from ____ ft. to ____ ft.

Perforations: [ ] Yes [X] No
Type of perforator used
SIZE of perfs ____ in. by ____ in. and no. of perfs ____ from ____ ft. to ____ ft.

Screens: [X] Yes [ ] No [ ] K-Pac Location
Manufacturer's Name Johnson PQ Products
Type Johnson STAINLESS STEEL Model No.
Diam. 12" Slot Size 100 from 560 ft. to 520 ft.
Diam. 12" Slot Size 100 from 491 ft. to 486 ft.

Gravel/Filter packed: [X] Yes [ ] No [ ] Size of gravel/sand PEA Gravel
Materials placed from 480 ft. to 570 ft.

Surface Seal: [X] Yes [ ] No To what depth? 20 ft
Materials used in seal Cement
Did any strata contain unusable water? [ ] Yes [X] No
Type of water? Depth of strata
Method of sealing strata off

PUMP: Manufacturer's Name
Type: H.P.

WATER LEVELS: Land-surface elevation above mean sea level 235 ft.
Static level 70.7 ft. below top of well Date 4/4/03
Artesian pressure lbs. per square inch Date
Artesian water is controlled by (cap, valve, etc.)

WELL TESTS: Drawdown is amount water level is lowered below static level.
Was a pump test made? [X] Yes [ ] No If yes, by whom? Robinson & Noble
Yield: 1200 gal./min. with 560 ft. drawdown after 24 hrs.
Yield: 1188 gal./min. with 37.25 ft. drawdown after 12 hrs.
Yield: 1200 gal./min. with 34.9 ft. drawdown after 1 hrs.

Recovery data (time taken as zero when pump turned off) (water level measured from well top to water level)

Time	Water Level	Time	Water Level	Time	Water Level
1:00	92.75	20:00	82.6	2:00:00	75.5
5:00	86.75	40:00	79.2	3:00:00	74.7
10:00	86.1	60:00	77.2	4:00:00	74.8

Date of test 4/4/03
Bailer test gal./min. with ft. drawdown after hrs.
Airtest gal./min. with stem set at ft. for hrs.
Artesian flow g.p.m. Date
Temperature of water Was a chemical analysis made? [ ] Yes [ ] No

CURRENT
Notice of Intent No. W155906
Unique Ecology Well ID Tag No. AFC 930
Water Right Permit No. G2-09303C / G2-09847C
Property Owner Name WA STATE Dept. of Health & Social Services
Well Street Address 9601 Steilacoom Blvd. SW
City LAKEWOOD County: PIERCE
Location NW 1/4 - 1/4 NE 1/4 Sec. 4 Twn. 19N R 2 (E)WM or WWM *circle one*
Lat/Long: (s,t,r still REQUIRED) Lat Deg ____ Lat Min/Sec ____ Long Deg ____ Long Min/Sec ____
Tax Parcel No.

CONSTRUCTION OR DECOMMISSION PROCEDURE
Formation: Describe by color, character, size of material and structure, and the kind and nature of the material in each stratum penetrated, with at least one entry for each change of information. Indicate all water encountered. (USE ADDITIONAL SHEETS IF NECESSARY.)

MATERIAL	FROM	TO
Brown Silty Sand & Gravel	0	34
Gray med to coarse Sand & Gravel	34	56
Gray Sandy & Gravel	56	82
Gray Silt & Clay	82	128
Gray Silt	128	155
Gray Silt, Sand & Gravel till-like	155	182
Gray Silty Clay	182	213
Gray Clay	213	263
Gray Silty Sand & Clay	263	333
Gray Sand & Gravel	333	345
Gray Silty Sand & Gravel	345	348
Gray Silty Sand & Gravel some clay	348	355
Gray Silty Sand	355	375
Dark Gray Sand	375	398
Gray layered Silt & Clay	398	429
Gray Silty Sand	429	440
Gray layered Silty Sand & Clay, Brown Sand & Gravel wood chips	440	486
Brown Sand & Gravel	486	491
Brown Clay, Sand & Gravel	491	518
Brown Gravel (Dirty) some Sand	518	528
Brown Sand & Gravel	528	532
Brown Sand, Silt & Gravel Some Cobbles	532	553
Brown Clay, Boulders Gravel	553	565
Gray Silty clay some Gravel & Sand	565	650
Gray Silty Black Sand	650	665
Gray Silty Clayey Sand	665	670
Gray Clay, Silt & Sand / Silty Layers	670	700
Log Prepared by Robinson & Noble		

Start Date 8/19/02 Completed Date 4/1/03

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

[X] Driller [ ] Engineer [ ] Trainee Name (Print) DAVE CHARON
Driller/Engineer/Trainee Signature Dave Charon
Driller or Trainee License No. 1190
If trainee, licensed driller's Signature and License no.

Drilling Company CHARON DRILLING, INC.
Address 12719-224 ST EAST
City, State, Zip GRAHAM, WA 98338
Contractor's Registration No. CHARODI133NF Date 5/8/03

RECEIVED
MAY 14 2003
Washington State Department of Ecology

Ecology is an Equal Opportunity Employer. ECY 050-1-20 (Rev 4/01)

Figure 11. Description of Sediment Types and Their Depths in Feet. Image courtesy of Washington Department of Ecology.

Vegetation

Lake Waughop sits in a basin surrounded by slopes on the North, South, and West, with open flat meadows to the East. The northern slope, which parallels Steilacoom Boulevard, has fallen victim to the ubiquitous Scot's broom (*Cytisus scoparius)* and Himalayan blackberry (*Rubus discolor)* and several non-native grasses; the same is true for the western slope, which borders Pierce College and the Pierce Oak Woodland Restoration Site. The old moraine that forms the north slope also has large sections of apple, pear, and cherry trees that were a part of the orchard operated by Western State Hospital (Cooley, 1964).

The slope vegetation on the southern side of the basin consists of a Douglas fir (*Pseudotsuga menziesii*) forest toward the eastern end and Scot's broom/ Himalayan blackberry/grass regime on the western edge. The prairie to the east contains many non-native black locust (*Robinia pseudoacacia*) trees, a few Douglas fir (*Pseudotsuga menziesii*), and on the far eastern side near Angle Lane, a remnant native Garry oak (*Quercus garryana*) woodland with snowberry (*Symphorcarpos albus*), Oregon grape (*Mahonia nervosa*), and Nootka rose (*Rosa nutkana*) shrubs. Covering the woodland floor beneath the *Q. garryana* are mixed native and non-native grasses and herbaceous flowering plants, including the common camas (*Camassia quamash*), a signature plant of oak prairies. This woodland ecosystem is used as a reference plot for current and future restoration efforts. The land beyond the college and park-owned property at the top of the southern slope is now a fully developed residential area.

The lake itself is encircled by an old paved road (presently driven on only by park staff and researchers) which visitors use for walking, jogging, horse riding, biking, dog walking, and other recreational activities. Sections of the road are lined with Lombardy poplar (*Populus nigra*) trees and Black locust (*Robinia pseudoacacia*) trees, both aggressive non-natives. Planted randomly along both sides of the road are Horse chestnut (*Aesculus x carnea*), Giant sequoia (*Sequoiadendron gigantieum*), and California redwood (*Sequoia sempervirens*) trees, also non-natives. The understory is composed of both native and non-native shrubs and herbaceous plants. The most common are Indian plum (*Oemleria cerasiformis*), Oregon grape (*Mahonia nervosa*), Periwinkle (*Vinca major),* English ivy (*Hedera helix*), Scot's broom (*Cytisus scoparius*), and Himalayan blackberry (*Rubus discolor)*. In the past few years poisonous bittersweet nightshade, (*Solanum dulcamara*) has seeded in at the north side of the public beach area and continues to spread along both the north and south shorelines.

The non-native trees surrounding the lake were planted by Elizabeth Waughop, wife of Dr. John W. Waughop, who was second superintendent of the hospital, serving 1880 to 1897; the lake was named in his honor. Mrs. Waughop hired a gardener from England to landscape the banks of the lake to create a peaceful retreat (Cooley, 1964). The landscaped area under the trees and up the slopes from the lake has been taken over by native and non-native plants and is now mostly covered by invasive English ivy (*Hedera helix*) and Himalayan blackberry (*Rubus discolor*); this location is a future Pierce College restoration

site. The shore around the lake has both submergent and emergent plants in the lake, mostly non-native, with Cattails (*Typha latifolia),* Reed canary grass (*Phalaris arundinacea*), and Yellow pond lily (*Nuphar polysepalum*), being the most dominant.

Climate

The marine temperate climate of the area is characterized by cool, dry summers and mild, wet winters. The region is dominated by the onshore flow of marine air from the west, which brings a steady pattern of anticyclonic storms inland from the Pacific Ocean (Lutgens and Tarbuck, 2004). These storms deliver an average of 98.9 cm of rain to the region per year. Though rain can, and usually does, fall most months of the year, the majority of Lakewood's precipitation falls in the months of November, December, and January. Air temperatures average 21.1°C during the summer and 4.4°C during the winter (www.weather.com, 2012). See Appendix 1 for more detailed weather information for specific sample collection days.

2.2 History of Land Use

The following is a brief history of the land and cultural uses of Western State Hospital Land. The entire Fort Steilacoom/Western State Hospital site has a rich past, from pre-historic and aboriginal uses, through early European settlement and military functions, to the decades long (1871-Present) role of Western State Hospital as a mental health institution. This site is one of Washington State's most significant cultural resources, listed on the National Register of Historic Places (NRHP) and Washington Heritage Register (WHR) as the Fort Steilacoom Historic District on November 25, 1977. The listing cited significance in government/military, agriculture, and social/humanitarian (the hospital) areas. (Artifacts Consulting, Inc., 2008). While extremely interesting and educational, it is beyond the scope of this paper to cover the historic past in any great detail. However, the following list shows the site's diverse uses from pre-historic times through 2012 and a brief description of the history follows:

- Native American (archeological-pre-historic, historic)
- Government – Military Base, Post Office, Maintain Law and Order
- Education – school
- Funerary – cemetery, graves/burials, mortuary
- Recreation and Culture – theater, auditorium, monument/marker, museum, park
- Agriculture/Subsistence – processing, storage, agricultural, field, animal husbandry, horticultural facility, agricultural outbuilding, farmstead
- Health Care – hospital
- Defense – fortification
- Landscape – gardens, natural features
- Transportation – rail-related, road-related

2.2.1 Native American

The land that comprises Western State Hospital and Fort Steilacoom Park lies within the traditional territory of the Steilacoom Indians, a Southern Coast Salish People. The site was one of their hunting grounds (Western State Hospital Historical Society, 2002). Little ethnographic information is available about the Steilacoom Tribe, though evidence shows they have lived in the area for more than 140 years (Historic Fort Steilacoom Association, 1975). No reports mention any traditional Steilacoom settlements immediately adjacent to the hospital property, but as there is little information about any traditional settlements, absence of mention does not mean settlements did not exist (Cooley, 1968). A large Steilacoom Settlement has been documented at the mouth of Chambers Creek and is usually referred to as “Steilacoom Village”. Only two other Steilacoom villages have been identified – one located approximately four miles east of “Steilacoom Village” and the other located further away in Spanaway (Carpenter, 1986).

Even though little evidence exists of any significant Steilacoom settlements close to Fort Steilacoom, research has shown the prairie was used for the hunting and gathering of both plants and animals (Avey, 1985). It is likely that seasonal camps existed on the site, especially during salmon runs, since Chambers Creek is a salmon stream and people still fish for salmon along the estuary of Chambers Bay (Carpenter, 1986).

2.2.2 Fort Steilacoom

The Nisqually Plains of Oregon Territory that would eventually become Fort Steilacoom were settled in 1839 by a few families from the Red River Valley of Manitoba, Canada. These families came to the area in 1841 under the auspices of the Puget Sound Agricultural Company, a subsidiary of Hudson's Bay Company (Skott, 2001). By the late 1830s, Hudson's Bay Company (HBC), long a major power and landowner in the region, recognized that, with the removal to reservations of Native Americans and the subsequent influx of Euro-American settlers, their profit from the fur trade had declined significantly. The prospect of turning their vast land holdings in the region into agricultural land presented a new opportunity for profit (Historic Fort Steilacoom Association, 1975).

To this end, the Canadian families agreed to lease land owned by Hudson's Bay Company (HBC) for the purpose of establishing farms in the region. The Puget Sound Agricultural Company (PSAC) was to supply equipment, livestock, and seed to these families as compensation for moving to the area. The company was to receive a portion of their harvest and farm profit in return. However, the Company failed to uphold the contract, and the future farm sites were abandoned by 1843 (Artifacts Consulting, Inc., 2008). The agreement fell apart so rapidly that most of the settlers moved on before even beginning cabin construction. However, one cabin was completed in 1842 and is the first known evidence of Euro-American settlement on the Fort Steilacoom prairie (Historic Fort Steilacoom Association, 1975).

In 1844 Joseph Thomas Heath arrived at Fort Nisqually from London. Heath learned of the opportunity for tenant farming from his younger brother William, an employee of the Hudson's Bay Company. By December of 1844, Heath had leased the abandoned farm with the cabin and moved in. The site was near the Steilacoom River, now Chambers Creek, and was comprised of 640 acres (Carpenter, 1986). During his brief tenure on the farm, Heath cleared 170 acres, and built eight structures including three barns and a granary. He raised sheep and cattle, grew wheat, cabbages, and potatoes, using local Native Americans as his labor force (Cooley, 1968).

Heath suffered from poor health and a melancholy nature. The demands of developing a profitable farm out of the marginal agricultural soils of the Steilacoom Prairie, as well as his isolation from friends and family, led to his early death at the age of 44 in 1849. Once again, the land was abandoned (Artifacts Consulting, Inc., 2008).

Two months after Heath's death the United States Army arrived at Fort Nisqually (then located on the Nisqually Delta south of the Steilacoom Prairies) in response to increased conflicts between the settlers and the Native American population (Carpenter, 1986). As part of their presence in the area, the Army leased one square mile of the Heath Farm (terms being $50 per month for twenty years), using the barns as a barracks and the house as the officer's headquarters. Several other buildings were quickly constructed and "Fort Steilacoom" continued to develop on the site intermittently from 1849 to 1868 (Artifacts Consulting, Inc., 2008). It served as a military headquarters, a supply

depot, and in 1855 a refuge for settlers when hostilities with Native American tribes increased (Historic Fort Steilacoom Association,1975).

From 1857 to 1858, the U.S. Army further enlarged Fort Steilacoom; concurrent with construction at Fort Steilacoom, Congress appropriated $35,000 to build a military road between Fort Steilacoom north to Fort Bellingham (Reese, 1984). The fort remained under military control during the brief 1859 Pig War between the United States and England. The Fort served as the largest military post in Puget Sound during the Civil War, and while no U.S. military personnel were stationed there at that time, the Fort was maintained and operated by local volunteers (Cooley, 1968).

In 1865 the role of Fort Steilacoom as a military outpost was re-evaluated. As its primary responsibility was to maintain peace and control Native American uprisings, which were no longer of major concern in the area, Fort Steilacoom was officially abandoned on August 22, 1868 (Reese, 1984). The land remained under the ownership of the HBC and PSAC, however, the buildings constructed after 1853 belonged to the United States. Increasing numbers of settlers continued to homestead the area. As a result, conflicts arose between PSAC and the settlers regarding land ownership. These conflicts continued throughout the late 1860s, and even into the early 1870s (Carpenter, 1986).

In 1869 The War Department offered to sell the fort buildings to Washington Territory for use as an "...asylum for the insane and for no other purpose" (Historic Fort Steilacoom Association, 1975). The Washington Territorial Legislature purchased the 26 buildings that comprised Fort Steilacoom

at an auction in 1870. Compensation negotiations with HBC and PSAC for purchase of the land began in 1870 and all claims and payments were finally settled by March of 1873; the land was finally ceded to the territory (Artifacts Consulting, Inc., 2008). Several other land purchases nearby solidified the institution's ownership of approximately 640 acres. The Insane Asylum for Washington Territory was established in 1871 and on August 19, 1871, 21 patients were transferred to the new asylum (Cooley, 1968).

The first 21 patients (15 men and 6 women) lived in the old military barracks building and doctors and staff moved into the houses on Officer's Row. The commanding officer's quarters became the home of the hospital superintendent. From the time the asylum opened in 1871, care for the patients was contracted out, but by 1875 a series of inquiries about patient care revealed unsanitary conditions and inadequate treatment (Artifacts Consulting, Inc., 2008). The Territorial Legislature renamed the hospital the "Hospital for the Insane in Washington Territory" and appointed a Board of Trustees to oversee the workings of the institution. In 1915, the institution's name was changed one last time and it became know as Western State Hospital (Western State Hospital Historical Society, 2002).

2.2.3 The Farm

Figure 12. Western State Hospital Farm.
Photo courtesy of Tacoma Public Library.

One of the most interesting facets of Western State Hospital history was the hospital farm (Figure 12); it was in existence from 1876-1965. Though the size and scope fluctuated through the decades and according to administrative interest, some type of farm or garden had existed on the site since the days of the Puget Sound Agricultural Company and the tenant farms of Joseph Heath and others (Carpenter, 1986). Over the years, the institution steadily increased the property it owned. In 1921 institutional grounds totaled 670 acres and by the 1940s had increased to 860 acres (Skott, 2001). Patient numbers steadily rose and the institution quickly outgrew existing facilities. Beginning in 1874, several expansion phases occurred and patient dormitories, medical facilities, and staff housing increased on a regular basis (Skott, 2001).

One of the many growth periods occurred in 1877, when Dr. Rufus Willard was appointed superintendent of the Washington State Hospital for the Insane (Avey, 1985). He recommended and supervised the planting and cultivation of an orchard of 300 fruit trees and several acres of gardens (Cooley, 1968).

Dr. Willard left the position after only three years and was replaced by Dr. John W. Waughop in 1880; his arrival ushered in a new era for the institution

(Skott, 2001). Dr. Waughop served as hospital superintendent from 1880-1897 and his tenure in the position was marked by expanded growth and development of the hospital (Avey, 1985), with the construction of an administration building, a central kitchen, a powerhouse, laundry, and three additional wings containing nine new wards (Artifacts Consulting, Inc., 2008).

In addition to making these improvements to the hospital, Dr. Waughop instituted improvements in patient care. Dr. Waughop paid close attention to hospital patients and his observations convinced him that they needed not only custodial care, but occupation as well (Cooley, 1968). The farm provided the perfect solution. During his years as superintendent, Dr. Waughop expanded the farm, thereby giving patients the opportunity to work raising crops, expanding and maintaining the orchard, and tending the livestock, including a prize-winning dairy herd (Herbert, 1949). This work became a therapeutic occupation for patients and was considered part of their treatment (Bence, 1958).

Development of the hospital grounds was not neglected. Elizabeth Waughop, Dr. Waughop's wife, took on the responsibility of landscaping and was instrumental in both design and choice of plant species to be used (Skott, 2001). Most of the large, old trees found at Western State Hospital and in Fort Steilacoom Park were planted during this time (Cooley, 1968).

Throughout the farm's history, hospital patients and staff were actively involved in clearing the land for agricultural purposes, including the land around Lake Waughop (Cooley, 1968). Originally, many wetland areas surrounded the lake but as early as 1881 workers began clearing a large swale near the lake.

This process continued for many years; the wetlands were drained and the land was used for agriculture (Artifacts Consulting, Inc., 2000).

While some staff and patients worked on this project, others were busy in different areas of the farm. They planted 100 more fruit trees, expanded the vegetable and fruit gardens to 20 acres, and added 200 acres of grassland pasture (Skott, 2001). As discovered by early settlers like Joseph Heath, glacially-derived gravelly prairie soils are notoriously difficult for raising crops, due in part to their rapid drainage. Because of this, early farm staff concentrated on vegetables that needed little irrigation and could grow in the marginal soils of the farm (Western State Hospital Historical Society, 2002).

By 1881, a saddle horse, two mules, several cows, twelve hogs, twelve pigs, and 100 chickens were in residence at the farm. These animals provide the hospital population with dairy products, meat, and eggs (Artifacts Consulting, Inc., 2008). In 1885 twenty-five sheep were added to the animal population, to be used for wool and for meat (Cooley, 1964).

While the hospital farm was in operation, a slaughterhouse was located on the west side of Lake Waughop. A 0.3 m pipe drained the offal from the slaughterhouse directly into the lake (N. Tweed, personal communication, February 1, 2012). In addition, the pig sty was located to the south of the slaughterhouse and built partially out over the lake. It had a slatted floor, allowing sty refuse to enter the lake (Cooley, 1968). As these practices went on for decades, a considerable amount of organic material built up in the lake.

Every year WSH increased the amount of land in cultivation and the number of animals, in order to keep pace with the hospital's growing population (Herbert, 1949). The poor soil quality continued to be a problem and led to the development of a tract just east of the hospital that became known as the ranch, where a greater variety of produce could be grown (Western State Hospital Historical Society, 2002).

By 1890 the hospital menagerie had grown to include peahens, turkey, geese, and ducks (Bence, 1958). The farm staff continued land clearing and expansion of the orchards on the slopes facing Steilacoom Boulevard (Artifacts Consulting, Inc., 2008). Farm operations employed between 100-200 patients, depending on the season. By the early 1900s enough food was raised to feed the staff and nearly 3000 patients of the hospital, with any excess being sold to other state intuitions and private enterprises (Bence, 1958). The income from these food sales (which saved the hospital over $300,000 annually in the late 1940s) offset one-third of patient maintenance costs, as well as providing staff and patients with fresh, local foods (Herbert, 1949).

In an effort to improve soil quality, manure from the farm livestock was added to the soil as fertilizer. Better yields of produce resulted, though the pastureland's thin topsoil did not hold water well and those areas suffered from excessive drainage. By summer the grass was browned and the animals could no longer graze. The hospital was forced to supplement the meager grazing with hay for feeding the livestock (Artifacts Consulting, Inc., 2008). Significant growth in the swine and dairy departments continued through the 1910s and 1920s and

the farm's dairy herd (Figure 13) became known as one of the best in the region (Herbert, 1949).

Figure 13. Hospital Farm Holstein Dairy Cows.
Photo courtesy of Tacoma Public Library.

Farm staff continually worked at refining and developing high quality breeds and one of the results of this effort was a milk cow named Steilacoom Prilly Olmsby Blossom who lived from 1921 to 1938 and "...held the world record for production of 258,210 pounds of milk containing 9,558 pounds of butterfat" (Skott, 2001). Her record remains unbroken as of 2012.

Shortly after being appointed as superintendent of the hospital in 1927, Dr. Charles E. Taylor went on an inspection tour of the farm. Taylor noticed that the best vegetables came from one small garden plot near Lake Waughop. Intrigued, he made inquires and discovered that the patient who tended that plot had taken mud from the lakeshore and packed it around the roots of the plants (Mann, 1927). This mud was the only fertilizer used on the plot and it not only provided nutrients to the plant, but it helped retain soil moisture. Dr. Taylor, impressed by the gardener's results, did some investigating and discovered that several attempts to transport the mud to the crop areas had been attempted by hand but because of the difficulty encountered these attempts were all abandoned (Herbert, 1949).

Irrigation water for the farm crops had long been pumped from Lake Waughop and conveyed to the various gardens by a system of pipes and ditches. Every summer, the lake level dropped and the pumps had to be shut off. Dr. Taylor decided to move the intake pipe out into the middle of the lake, thus accessing more irrigation water (Cooley, 1968). The pump was barged out to the middle of the lake and started pumping water again. One summer during pumping, the intake for the pump dropped down into the lake bottom sediment and began pumping a thick slurry of fine mud and water through the irrigation system (Mann, 1930).

After this discovery in early 1927, the hospital began pumping up to 350,000 gallons of the mixture daily and distributing it over the fields and gardens. When the water evaporated, a fine layer of mud was left behind. Using this method, over 40 acres of the farm was covered with six inches of mud. Pumping continued throughout the summer and the lake was dry by autumn (Mann, 1927). As the mud became hard enough to shovel out and transport to the fields, the bottom of the lake was eventually exposed, revealing three natural springs. The inflow from the springs fed the lake with a flow of 150 gallons per minute (Mann, 1930). This inflow kept the lake bottom continually stirred up and the resulting slurry was spread over the fields through the sprinkler system already in place. When pumping first started, farm staff estimated the mud to be six meters deep over a layer of clay (Bence, 1958). According to hospital documents, the amount of mud in the lake was likely so deep because the

sewage system for the farm, dairy, and slaughterhouse emptied into the lake (Cooley, 1968).

Beginning in the 1950s new treatments using psychotropic medications allowed many patients to be discharged from state institutions, decreasing the farm labor force. In the decade between 1955 to1965, patient population at Western State Hospital dropped from 3067 to 1350 (WSHHS, 2002). Reforms for patient treatment enacted in the early 1960s required institutions to pay prevailing wages to patients who had previously worked at the farm as volunteers (Artifacts Consulting, Inc., 2008). Western State Hospital complied, but labor costs soon outpaced the savings gained from operating the farm to provide food for the institution (Western State Hospital Historical Society, 2002). As a result, Washington State began closing down its institutional farms in 1963. Like other state institutional farms, Western State Hospital Farm continued to lose money and in 1965 the Washington State Legislature and Governor Albert Rossellini made the decision to close the farm down (Western State Hospital Historical Society, 2002). In 1967 Pierce County opened the old farmland as Fort Steilacoom County Park (Artifacts Consulting, 2002).

Chapter Three: History of Water Quality Data for Lake Waughop

3.1 Study Site

Lake Waughop is located in the southwestern region of the Chambers-Clover Creek Watershed in Pierce County, Washington (Figures 14 and 15). The lake is within the boundaries of Fort Steilacoom Park, Lakewood, Washington, and is a small, shallow, kettle lake.

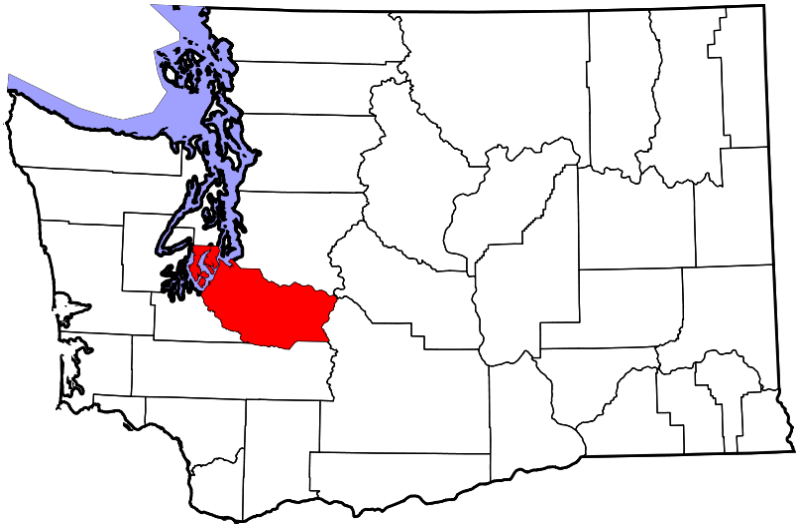


Figure 14. Map of Washington with Location of Pierce County Highlighted.
Map courtesy of Pierce County, WA., Public Works Department.

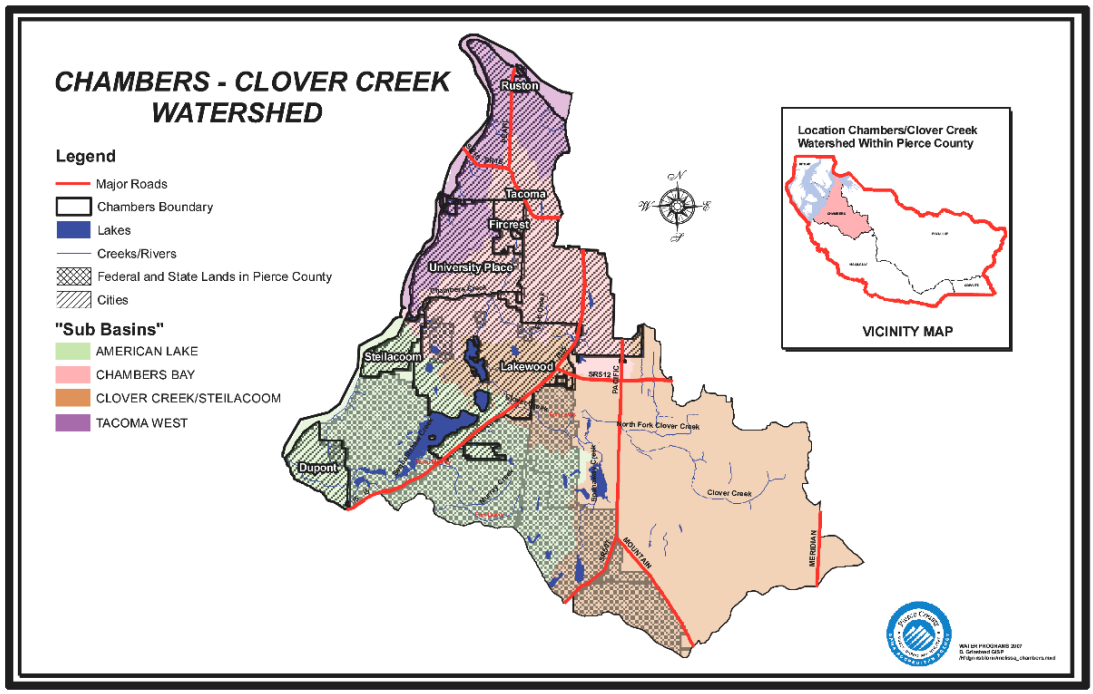


Figure 15. Map of Chambers-Clover Creek Watershed (inset shows watershed location within Pierce Co.) Map courtesy of Pierce County, WA., Public Works Department.

The lake (Figure 16) sits near one of Western Washington's few remaining areas of the endangered native oak woodland ecosystem (Avey, 1985). Fort Steilacoom Park property is owned by the Washington State Department of Social and Health Services (DSHS), leased to Pierce County, and currently managed by the City of Lakewood (Dodd, 2007). Waughop suffers from recurring algae blooms that lead to poor water quality. A water sampling and analysis study was started in 2007 in order to develop a baseline of water quality conditions for future reference.

Figure 16. Bathymetric Map of Lake Waughop. Image courtesy of US Geological Service.

Water samples were collected and analyzed for four years: June and July 2007, February and March 2008, August and October 2008, January through June 2009, and May through August 2011. By-weekly or monthly water samples were collected.

3.2 Nutrient Loading to Lakes

Lakes have a great capacity to take in, absorb, use, and flush nutrients; how well they can do so depends on several factors: lake size, lake depth, residence time and flushing rate of water, and mixing of the water column (Herath, 1997). The smaller and shallower the lake and the longer the residence time, the lower the input of nutrients the lake can assimilate without detrimental impacts on water quality. Efficient nutrient cycling is often beyond an urban lake's processing ability due to the large amount of nutrients generated in a municipal landscape which end up in the lake. An increase in these nutrients, especially nitrogen and phosphorus, typically causes an increase in biological production in the lake leading to massive algae blooms (Wetzel, 2001).

Nutrients are delivered to lakes from a variety of allochthonous sources such as stormwater runoff, old septic systems, and the atmosphere, and from autochthonous sources, including lake sediments. Shallow lakes are particularly vulnerable to such autochthonous inputs resulting in rapid nutrient cycling. This is due to a low dilution volume, wind-induced sediment suspension, and an inability to buffer the effects of temperature swings (Ruley, 1993). Shallow lakes often have a consistent temperature throughout the water column for a large part of the year, as is seen with Lake Waughop. Water has a high heat capacity and can absorb large amounts of heat energy without a change in temperature, but in a shallow lake the volume of water can be so small that this characteristic has little buffering effect.

3.3 Sample Collection Methods

Sampling was done from one location in a deep area of Lake Waughop (four meters) where a small buoy was anchored at 47°33’50”N, 122°10’27"W (Figure 7). The sampling site was accessed from the developed beach area on the east side of the lake. A small inflatable boat was launched from this point and rowed to the sampling site.

A Van Dorn bottle was used for water collection. Water samples were collected at the surface, 0.5 m, 1 m, 1.5 m, 2 m, 2.5 m, and 3 m meters. As the lake became shallower in late summer, the deepest measurement sometimes had to be taken at 2.5 m. All analyses for temperature, pH, and dissolved oxygen (DO) were done immediately upon retrieval of the Van Dorn sampling bottle. pH was determined using test strips, a HACH OX-2P kit using drop count titration was used for dissolved oxygen, and temperature was determined using an Oakton SALT 6 digital probe. When available, a multi-parameter YSI 55 probe was used to measure temperature and DO in collected samples. See Appendix B for study data.

Samples were collected in 125 ml sterile (acid-washed) plastic bottles, rinsed three times with sample water, and filled three-quarters full. The filled bottles used were stored on ice in a small plastic cooler until transported to the laboratory for phosphorus analysis. All samples were stored at 4°C until analysis was done. Tests for Total Phosphorus were done using Hach™ test procedures; available at *http://www.hach.com/*. Total phosphorus was only sampled in 2007.

Water samples for *chlorophyll a* were kept cool and dark during transport to the lab and filtered as soon as possible. A vacuum pump and glass filter were used to extract the algae from the sample. A spectrophotometer was used to determine *chlorophyll a* levels.

Secchi depth was measured before collecting the water samples. Secchi depth (transparency) was determined using a standard limnological black and white Secchi disk, eight inches in diameter. Current lakewater (color, size of algal blooms, algal types, and waterfowl counts) and weather conditions were also recorded.

3.4 Lake Eutrophication

Eutrophication is the result of excessive nutrient enrichment, which results in the overproduction of algae and other aquatic plants (Wetzel, 2001). While small levels of nutrients are necessary for a well-functioning and healthy lake ecosystem, over-enrichment of nutrients, particularly nitrogen and phosphorus, can cause drastic changes and severe impacts to a lake ecosystem. In fact, nutrients are considered a pollutant in many U.S. lakes (Carpenter et al., 1998).

All plants require carbon, hydrogen, oxygen, nitrogen, and phosphorus; if any of these nutrients are in short supply, algae growth is limited by its absence. There is abundant carbon, hydrogen, and oxygen in aquatic systems, while bioavailable nitrogen and phosphorus are in relatively small amounts (Wetzel, 2008). In most cases of freshwater eutrophication, phosphorus is the limiting factor controlling algal growth with nitrogen next in line.

Natural eutrophication can be caused by activity in a lake's watershed, such as flooding, landslides, volcanic eruptions, and wildfires. It is a slow and natural succession in the life of a lake, proceeding from lake to wetland to meadow (Figure 17). When this process is initiated or accelerated by human actions, it is known as cultural eutrophication (Figure 18). Examples of causative actions include land use changes, construction, fertilizer application (agricultural, lawn, and garden), faulty septic systems, and the feeding of ducks or other waterfowl.

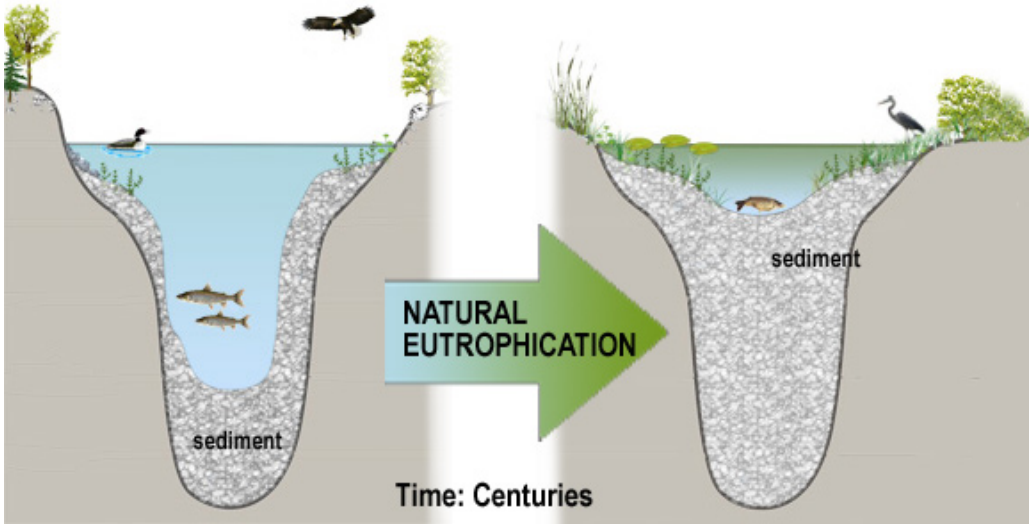


Figure 17. Process of Natural Eutrophication in a Lake. © Seven Hills Lake Property Owners Association. Retrieved from http://sevenhillslake.com/technical.html-inc.

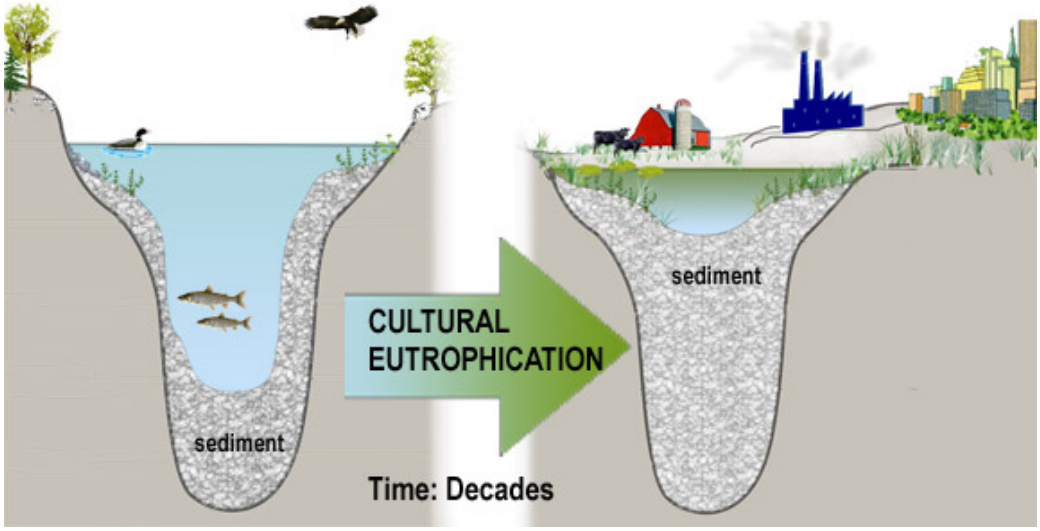


Figure 18. Process of Cultural Eutrophication in a Lake. © Seven Hills Lake Property Owners Association. Retrieved from http://sevenhillslake.com/technical.html-inc.

A eutrophic lake is one of three trophic categories of lakes, the other two being mesotrophic and oligotrophic; characteristics of each are shown in Table 1.

Table 1. Characteristics of Lake Types. Washington Department of Ecology, 2008.

Eutrophic	Mesotrophic	Oligiotrophic
High nutrient content	Moderate nutrient content	Low nutrient content
High planktonic growth	Moderate planktonic growth	Little planktonic growth
Extensive aquatic plant beds	Some aquatic plants	Few aquatic plants
Much sediment accumulation on bottom	Some sediment accumulation over most of bottom	Sand or rock along most of shoreline
Low dissolved oxygen on bottom	Variable dissolved oxygen content	High dissolved oxygen content
Only warm water fish species	Usually supports warm water fish species	Only cold water fish species

The trophic state index (TSI) of a lake is an assessment tool and an indication of lake health. The index rates lakes using a scale of 0 to 100, with each numerical category (10, 20, 30, etc.) representing doubling of the algae biomass (King County, 2001). While traditional methods divide lakes into the three classes shown in Table 1, often the boundary between the classes is unclear (Carlson, 1977). Using only these three divisions is restrictive and often ambiguous as it doesn't take into account the often gradual changes that occur as a lake moves along a continuum from one trophic state to another (Carlson, 1977). A lake's trophic state may be determined using diverse criteria including the oxygen curve, species composition of bottom organisms or phytoplankton, nutrient concentration, climate, and various measures of productivity.

3.5 Results

During the monitoring period, water quality parameters in Lake Waughop showed a marked seasonal fluctuation, alternating between algal bloom peaks and water clarity peaks throughout the year, including instances of algae growth in January and February. Due to evaporation during the summer, at times water level dropped to 2.7 meters. Lake level was determined using a measuring stick posted on the east side of the lake just north of the beach area (Figure 19).

Mixing of the water column (spring or autumn turnover) has both positive and negative effects on a lake and its algal blooms, especially in warmer months (Lawson and Anderson, 2007). Wind-generated mixing carries dissolved oxygen enriched surface water to deeper layers of the lake, which can help prevent anoxic zones in lake depths (positive), but it can also resuspend nutrients from the lake bottom up into the water column where they can increase algal productivity (negative) (Herath, 1997).

Figure 19. Depth Gauge.
Michele LaFontaine

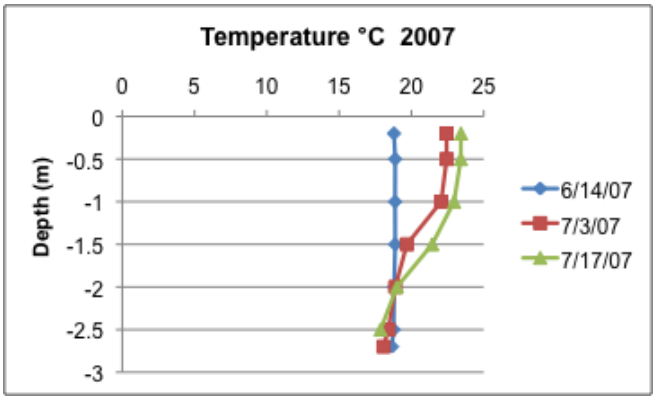
Temperature

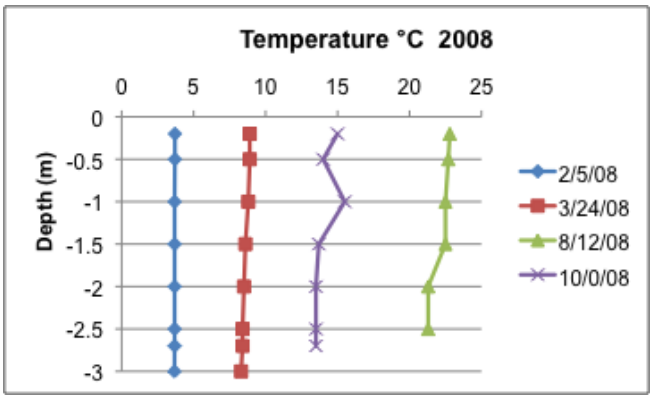
Due to the shallow maximum depth of Lake Waughop, water temperature showed slight variation throughout the water column for most of the year. Temperatures in June averaged 18.8°C at the surface with only a slight drop to 18.6°C at 2.7 m. The highest temperature was recorded on July 17, 2007, when surface temperature was 24°C, dropping to 18°C at 2.5 m.

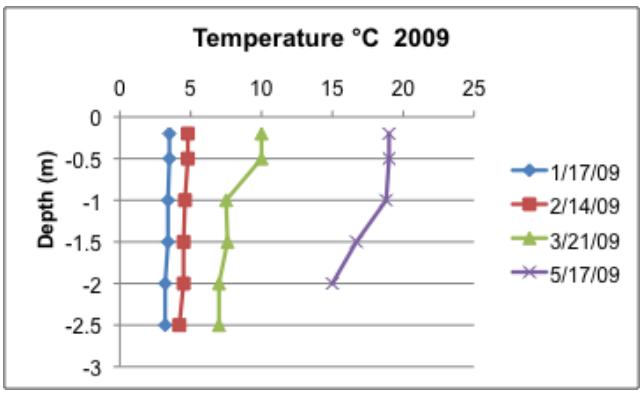
During winter months there was an even smaller temperature change with depth, usually less than a tenth of a degree. For most of December 2009 water temperatures were between 5 to 7°C, and on December 23, 2009 the water temperature was 3.7°C surface and 3.6°C at 3.1 m. That afternoon a thin sheet of ice extended about 1.5 m from the shoreline on the west side of the lake, thick enough to support a person (Figures 20 and 21). As with transparency, warmest temperatures coincided with algal blooms since blooms absorb light and increase heat, leading to stratification (Figure 22).

Figure 20. R. Thissen.
Michele LaFontaine.

Figure 21. Frozen West Shore of Lake.
Michele LaFontaine.







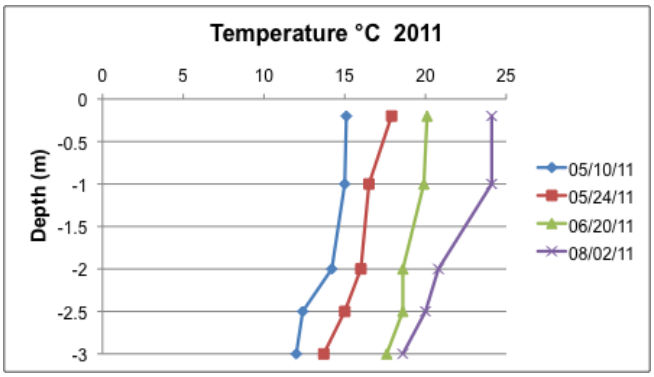
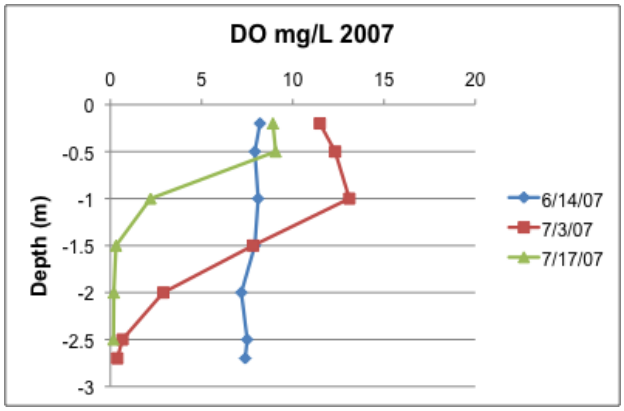


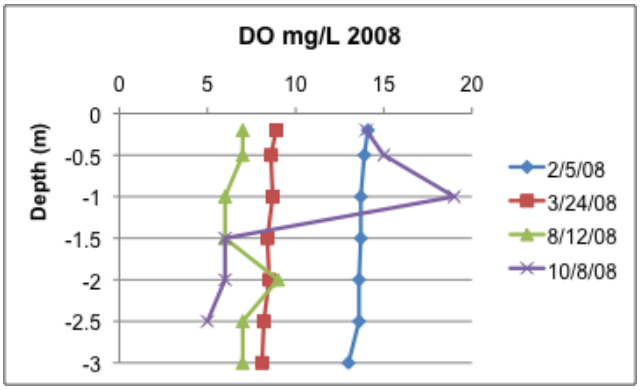
Figure 22. Temperature Change with Depth.

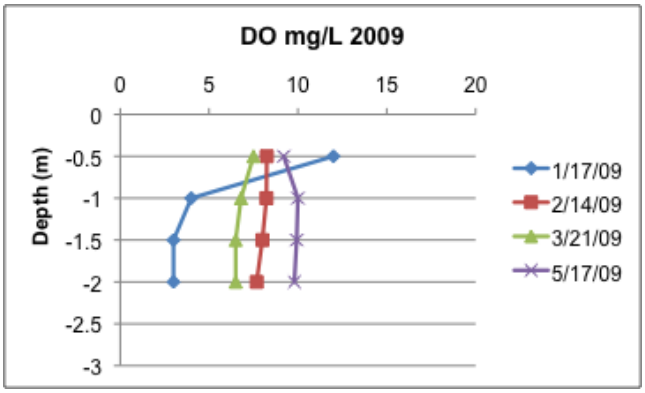
Dissolved Oxygen

Lake Waughop surface concentrations of DO ranged from 4.0 to 14.8 mg/L (Figure 23). While values for DO showed little difference, usually less than 0.5 mg/L, from surface to bottom most of the year, during the months of July and August readings showed a much larger variation, with values differing as much as 7 to 11 mg/L between the surface and lake bottom. Throughout the summer, daytime values for DO fluctuated between high and low levels due to photosynthetic activity by the algae, and the highest concentrations (14 mg/L) occurred during early August, concurrent with algal blooms.

Oxygen concentrations are a function of photosynthetic activity of algae and vertical mixing by physical processes such as wind or inhibition of mixing by strong stratification. In summer months, the warmer epilimnion (less dense surface water) floats on top of the cooler hypolimnion (more dense bottom water) separated by the metalimnion – a layer of water where temperature changes rapidly with depth. This stratification is normally maintained for the duration of warm summer temperatures, and deters complete lake mixing. The warm epilimnion is circulated and mixed by the wind, but temperature differences prevent mixing through the cool, dense hypolimnion. This stratification prevents oxygen from reaching the lake bottom where respiration by animals and aerobic bacteria can quickly deplete the limited oxygen supply. Dead algae that sink to the lake bottom are decomposed by bacteria, also using up oxygen. Eventually, the lake bottom can become anoxic and anaerobic bacteria start to decompose the organic material.







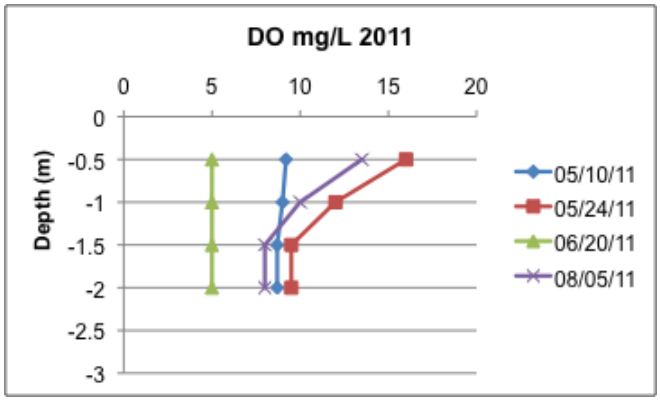
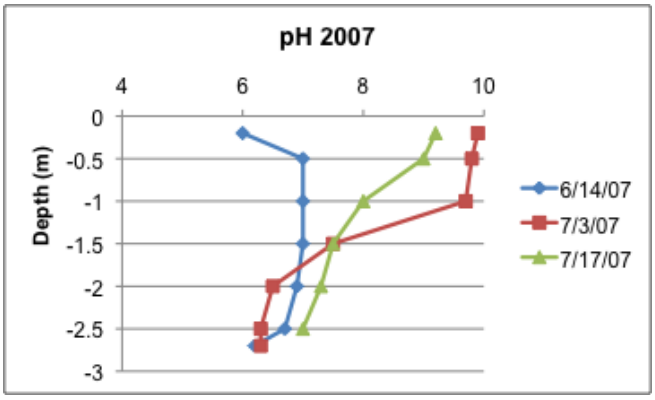


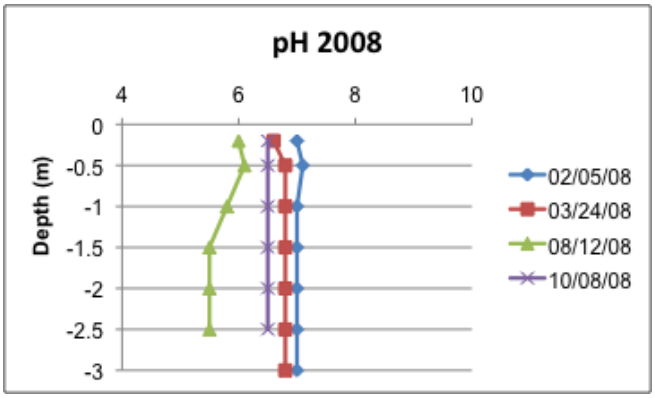
Figure 23. DO Change with Depth.

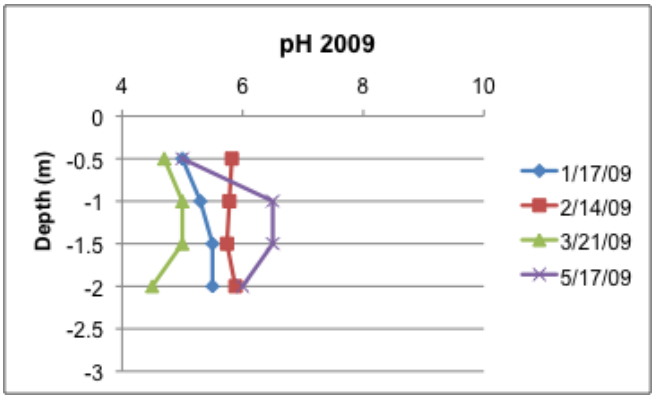
pH

The broad range of pH readings, 4.5 to 9.9, in Lake Waughop are in keeping with the pattern shown in the other parameters tested, indicating the growth and die-off of algal blooms (Figure 24). As a preliminary sampling assessment, a simple pH test can give valuable information regarding water quality.

pH measures the H^+ ion concentration of a substance – its acidity or alkalinity – using a logarithmic scale. The pH of pure deionized water is 7; if a reading is below 7 the sample is acidic and above 7 is basic (alkaline). pH is an important introductory test that can reflect organic decomposition, pollution inputs, and surface photosynthetic activity. A small change, as little as 10^{-3} H^+ difference in pH can equate to relatively large changes in other water quality parameters, such as the solubility of metals and the proportions of carbon dioxide, bicarbonate, and carbonate. Many organisms have adapted to life in water with an optimal pH and cannot tolerate even slight changes (Table 2). Other organisms, including cyanobacteria, have adapted to a broad range of pH and can survive under extreme fluctuations. Very high and low pH values in water make it unsuitable for most organisms (Mitchell et al., 1994).







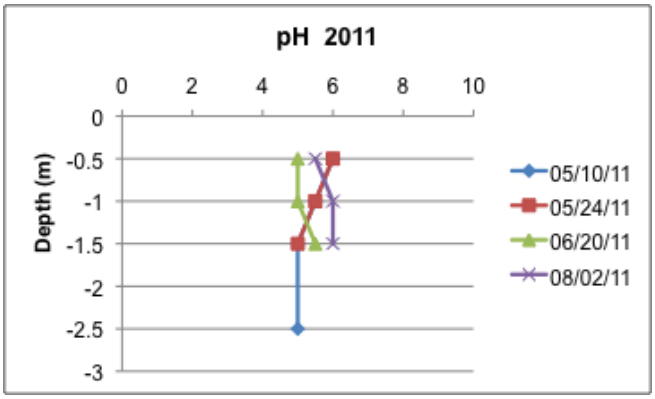
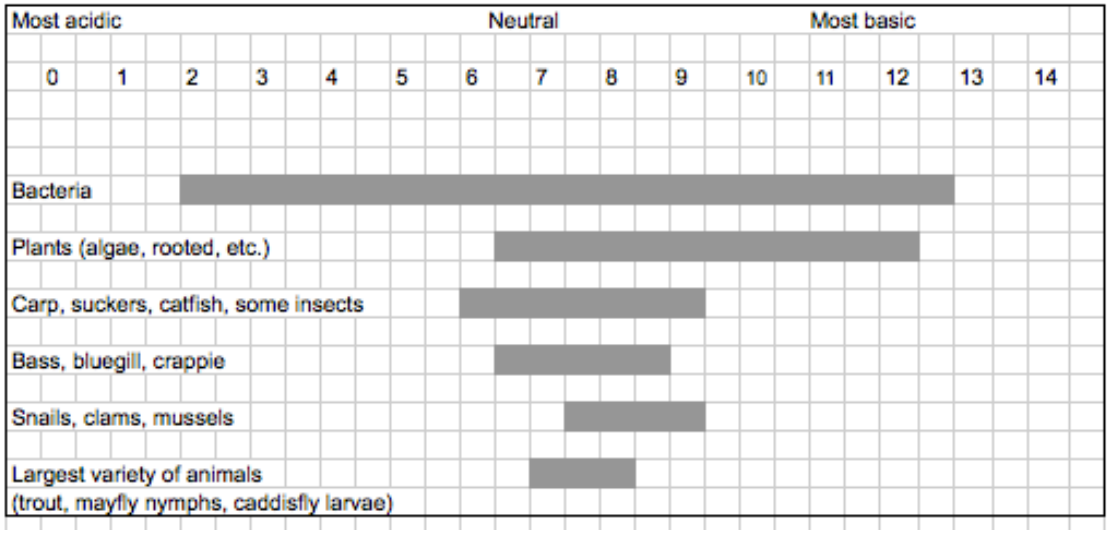


Figure 24. pH Change with Depth.

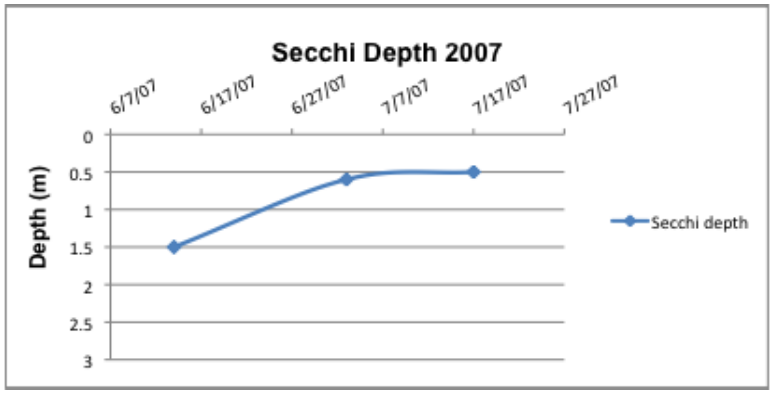
Table 2. pH ranges for select aquatic organisms. After Mitchell and Stapp, 1994.

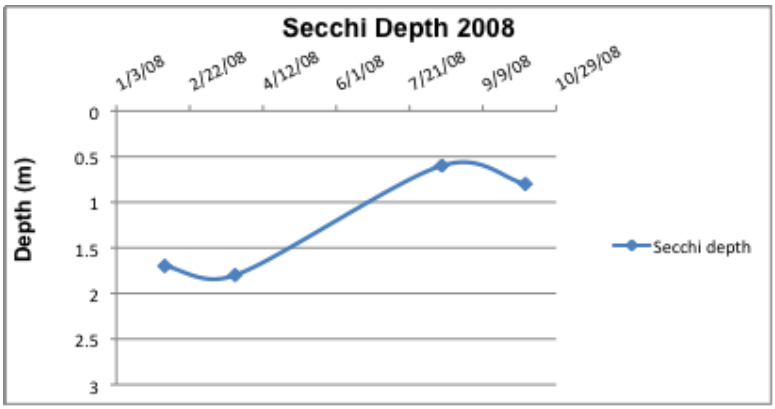


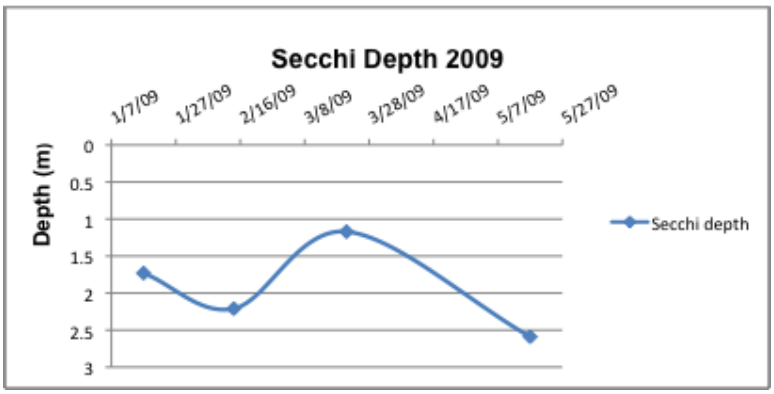
Transparency

During the four monitoring periods, a similar pattern of water transparency was observed, with low Secchi readings in late spring and high readings in mid-summer (Figure 25). Water transparency ranged from a low of 0.3 m in late May of 2011, when there was a large algal bloom, to a summer maximum of 3.3 m (lake bottom depth) in July of 2011. In all three spring/summer monitoring periods, after the May algal bloom die-off, water transparency increased throughout June and July to the summer maximum before decreasing in the first week of August, during a second algal bloom.

Every year after die-off of this second bloom, Secchi depth increased from late August through September and by October water clarity had improved significantly and was again approximately 3.3 m. The consistently highest values were seen during the winter months when air and water temperatures were cooler and storms brought increased precipitation and surface runoff water causing lake level to rise. Fluctuations in Secchi depth during the study most commonly coincided with algal blooms.







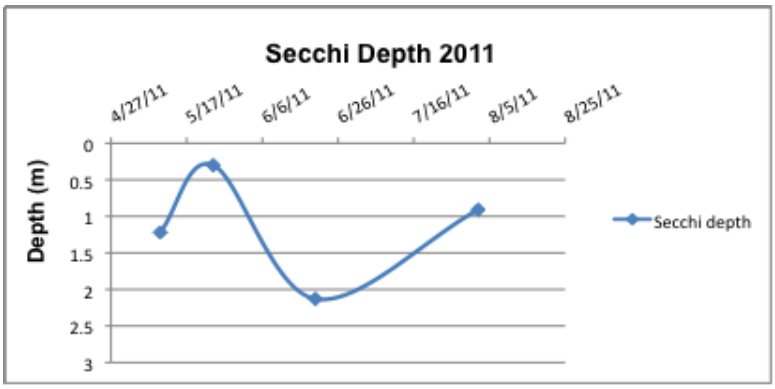


Figure 25. Secchi Change with Depth.

Using the Trophic State Index (TSI), a lake's trophic state is most often determined using three common water quality indicators: water transparency (Secchi depth), nutrient levels (total phosphorus), and phytoplankton productivity (chlorophyll *a*); the TSI calculation is shown in Table 3 while Table 4 lists the characteristics of the three lake types (Carlson, 1977). The TSI for Lake Waughop in 2007 is shown in Table 5: a eutrophic classification. Secchi depth and chlorophyll *a* are often strongly correlated to Total Phosphorus (TP) and Total Nitrogen (TN) (King County, 2001).

Table 3. Trophic State Index Calculation. Carlson, 1977

Parameter	**Trophic State Index Calculation**
Secchi Depth (SD)	=10*(6-(1n(SD)/1n(2)))
Chlorophyll *a* (chl *a*)	=10*(6-((2.04)-(0.68*1n(chl *a*)))/1n(2))
Total Phosphorus (TP)	=10*(6-(1n(48/(TP))/1n(2)))

Table 4. Trophic Classification of Lakes. Wetzel, 1983

Measured Parameter		Oligotrophic	Mesotrophic	Eutrophic
Total Phosphorus (mg/m^3)	Average	8	26.7	84.4
	Range	3.0 – 17.7	10.9 – 95.6	16 – 386
Chlorophyll *a* (mg/m^3)	Average	1.7	4.7	14.3
	Range	0.3 – 4.5	3 – 11	3 – 78
Secchi Disk Depth (m)	Average	9.9	4.2	2.45
	Range	5.4 – 28.3	1.5 – 8.1	0.8 – 7.0

Table 5. TSI for Lake Waughop in 2007

TSI (SD)	TSI (TP)	TSI (Chl *a*)
58	60	70

Phosphorus

The only nutrient monitored during the study was total phosphorus and all samples were collected and analyzed in 2007 (Figure 26). TP concentrations in all Lake Waughop samples showed a drop between the 1 m and the 2 m depth, then an increase at 3 m. The exceptions to this pattern are June 14 and August 12, 2007, when there is an increase of approximately 6 μg/L and less than 5 μg/L from the 1 m to the 3 m depth, respectively. The July 17 samples show a slight increase from 1 to 2 m followed by a sharp increase between 2 and 3 m, reaching the highest level of the study, 85 μg/L at 3 m.

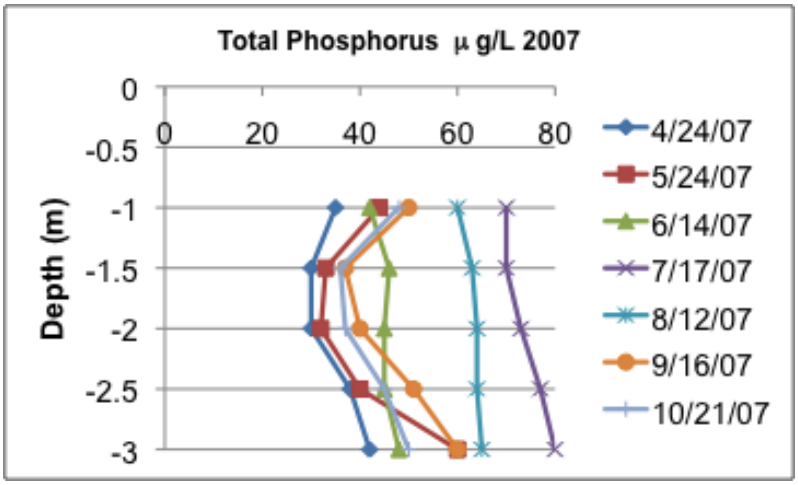
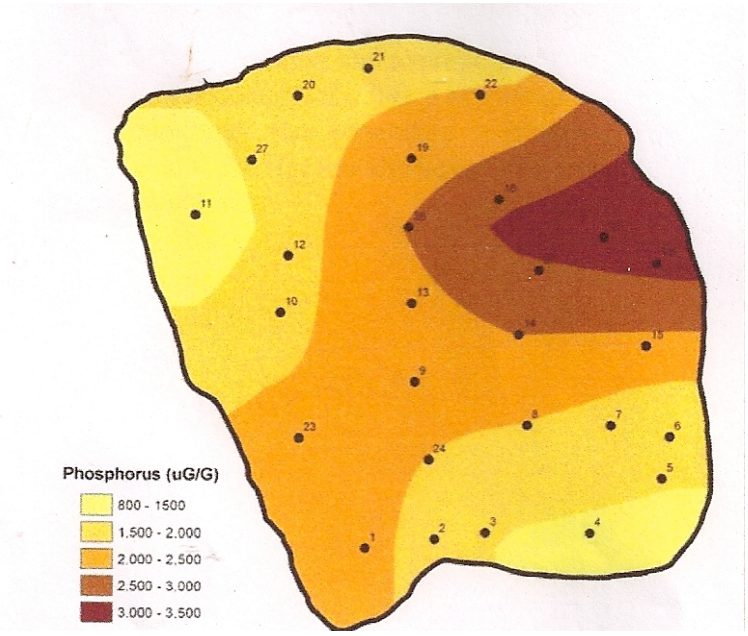


Figure 26. Total Phosphorus for 2007.

In addition to the phosphorus detected in the water, phosphorus has also accumulated in the lake sediment. A recent study of Lake Waughop sediments showed phosphorus levels that ranged from a low of 741.19 μg/g to a high of 3443.28 μg/g in one area of the lake bottom (Gawel and Mason, 2008). The

lowest levels were located at the northwest and southeast corners of the lake. The highest levels were found near the public beach area with the high reading of 3443.28 μg/g closest to shore. The study results show Lake Waughop has a total phosphorus load of 2267 kg P as calculated by the authors (Figure 27).



Point ID	Northing	Easting	P µG/G
1	5224049.47	532953.821	2195.27
2	5224056.093	533033.713	1679.3
3	5224061.005	533040.102	1293.96
4	5224060.934	533114.837	741.19
5	5224099.802	533166.372	1208.57
6	5224129.956	533171.907	1324.02
7	5224137.82	533129.889	2194.06
8	5224137.638	533069.699	1684.22
9	5224168.826	532989.51	1534.51
10	5224217.846	532893.298	1749.85
11	5224287.423	532832.325	1038.54
12	5224250.342	532898.859	2268.13
13	5224224.79	522987.297	2530.14
14	5224202.662	533063.686	2940.39
15	5224195.217	533155.005	2333.97
16	5224254.349	533162.093	3849.22
17	5224272.766	533124.482	3096.86
18	5224299.639	533049.354	3443.28
19	5224328.819	532987.017	2886.31
20	5224343.254	532905.565	2284.76
21	5224393.45	532955.786	1826.54
22	5224374.716	533036.017	1482.19
23	5224342.438	533096.323	2321.34
24	5224248.432	533078.013	3076.77
25	5224279.293	532984.919	2859.56
26	5224327.037	532872.489	2240.58
27	5224127.83	532906.63	834.11

Figure 27. Total phosphorus Load in Surface Sediments in Lake Waughop 2008
Prepared for Jim Gawel by Bridget Mason

The vast majority of phosphorus within a lake system is contained within the sediments (Wetzel, 2001). The extent to which phosphorus is deposited in sediments and how rapidly it is released into the overlying water depends on many physical, chemical, and biological factors (Wetzel, 2001). In general, the three factors governing this process are the ability of the sediments to retain phosphorus, the conditions of the overlying water, and the biota within the

sediments that affect phosphorus transport back into the water (Wetzel, 2001). Table 6 shows the various mechanisms whereby phosphorus is released from lake sediments.

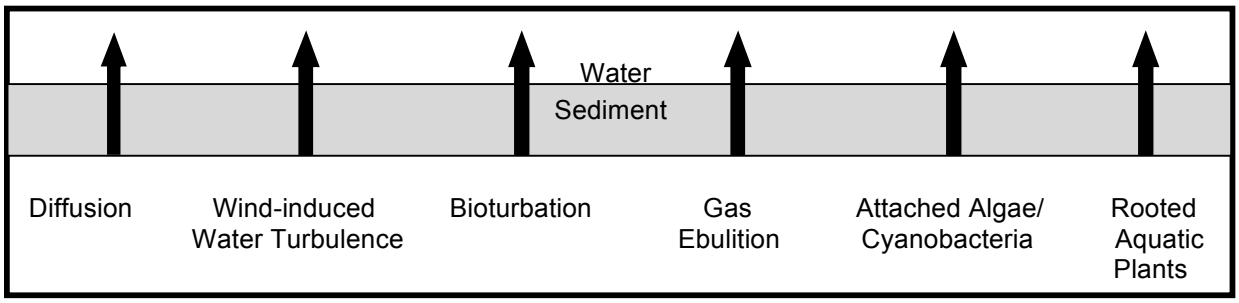
During periods of aerobic conditions phosphorus exchange is largely toward the sediments. Phosphorus exchanges occurring within the sediments are effectively trapped by an oxidized layer above the sediment-water interface. However, when oxygen content in the overlying water begins to decrease, this oxidized microzone weakens, creating reducing conditions in which phosphorus is released (Wetzel, 2001). The oxygen levels in this microzone are chiefly influenced by the metabolism of bacteria, algae, fungi, planktonic invertebrates, and sessile benthic invertebrates. The rate of organic loading to the hypolimnion primarily determines the rate of oxygen depletion near the sediment-water interface. The depth of the sediment involved in this release and time determine the amount of phosphorus released to the water (Wetzel, 2001).

There are steep concentration gradients of phosphorus between interstitial water and the overlying water (Wetzel, 2001). Due to this gradient molecular diffusion becomes a primary transport of phosphorus in anaerobic conditions. Gas ebullition from microbial generation of gases can disrupt this gradient causing an acceleration of phosphorus diffusion into the water (Wetzel, 2001).

Another process by which phosphorus can be released is through sediment disturbance. Sediments that are agitated by wind-induced water turbulence can release great amounts of phosphorus into the overlying water. Sediments can also be disturbed by living organisms, a process referred to as

bioturbation. Aquatic plants, especially submersed macrophytes, can slowly leach phosphorus as foliage begins to age. Dead macrophytes can rapidly leach much of the phosphorus they contain (Wetzel, 2001).

Table 6. Mechanisms for Sediment Release of Phosphorus. Christian DeFazio after Wetzel, 2001.



Available phosphorus content in a lake is most commonly the factor that determines water quality, and it is considered the long-term limiting nutrient in lake eutrophication (Brhyn, 2008). According to Wetzel (2001) of all the structural and nutritional elements available to living organisms, " . . . (carbon, hydrogen, nitrogen, oxygen and sulfur), phosphorus is least abundant and most commonly limits biological productivity." Most phosphorus is found in mineral deposits and marine sediments, and is slowly released into the environment through the weathering of rocks (Molles, 2005). As phosphorus becomes available in soil, plants use dissolved phosphorus compounds to construct molecules used for growth. The plants are eaten by herbivores, the herbivores are eaten by carnivores, thus each organism obtains the phosphorus they need. When an organism excretes waste products or dies, phosphorus is cycled back into the soil and moves on to the next stage of the phosphorus cycle (Figure 28).

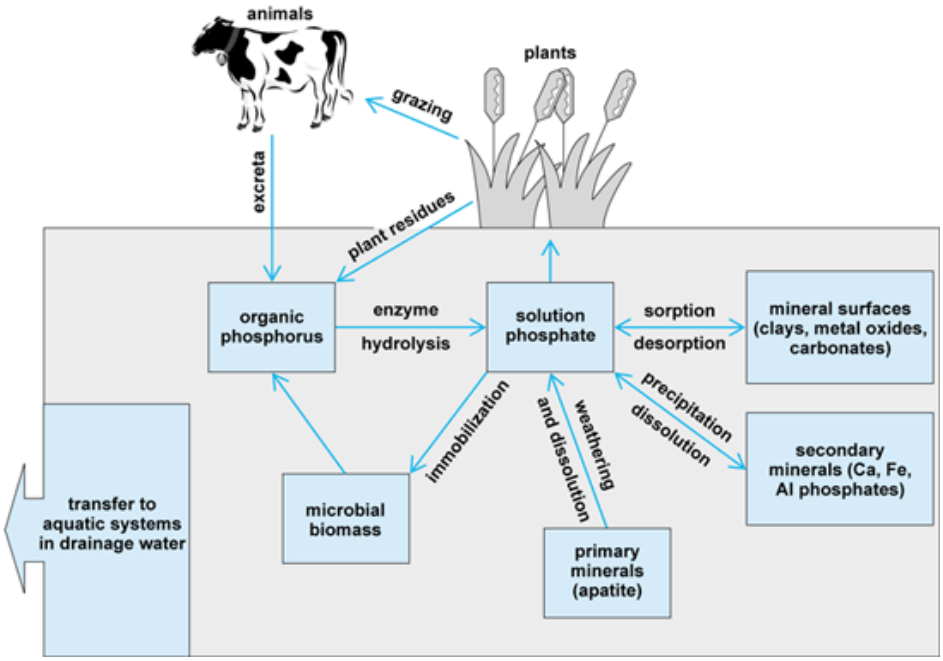


Figure 28. The Phosphorus Cycle. Retrieved from http://accessscience.com/content.aspx?searchStr=phosphorus&id=YB030535http://accessscience.com/content.aspx?searchStr=phosphorus&id=YB030535

Lakes subjected to high inputs of phosphorus have a high probability of experiencing algal blooms and turbid water conditions, frequently causing undesirable biological changes, especially if the inputs continue for long periods (Søndergard et al., 2003). Depending on the composition and severity of the bloom, these changes may include loss of biodiversity, submerged macrophyte decline, loss of desirable fish species, and an increase of non-native plant and animal species (Hamel, 2009).

Phosphorus inputs come from multiple sources, both point (agricultural runoff, wastewater treatment plants, etc.) and non-point (surface runoff, wildlife waste, etc.), with the latter being more difficult to identify and control. Unless the excessive input is managed, lake recovery is problematic, since any phosphorus removed will quickly be replaced and phosphorus loading into the lake's water column and sediments will continue. Over time, phosphorus will accumulate in

the sediment of a lake and may reach extremely high concentrations. The level of phosphorus retained in lake sediments is determined by two processes:

> 1) the downward flux caused mainly by sedimentation of particles continuously entering the lake or produced in the water column (algae, detritus, etc.) and 2) the upward flux or gross release of phosphorus driven by the decomposition of organic matter and phosphorus gradients and transport mechanisms established in the sediment (Søndergard et al., 2003).

Phosphorus that has settled into the sediment layer contributes to the phosphorus load in the water column by releasing phosphorus through diffusion and advection processes (Ruley, 1993). Treatment options must take into consideration any future release of phosphorus from sediments. Phosphorus that is buried in the deeper sediment layers is unavailable for release unless resuspended by wind or other physical disturbance. The upper layers are active in releasing phosphorus but the deeper layers do not contribute to phosphorus loading. What are considered to be the deep sediments vary with each water body; researchers have found active release sediment depths from as deep as 8 to 12 cm (Holdren et al., 1980).

Shallow lakes have a high sediment surface:water column ratio compared to deeper lakes, so the potential influence on phosphorus concentrations in lake water can be much higher. In addition, the sediments in shallow lakes are always in direct contact with the photic zone. This factor, combined with the

regular mixing common to shallow lakes, produces the most advantageous conditions for primary production (Søndergard et al., 2003).

When determining routes of phosphorus loading, both point (drainage pipe from Pierce College) and non-point (surface runoff, groundwater seepage, etc.) sources must be considered. Of the two, non-point is harder to track as phosphorus may enter the system from many sources. Regarding Lake Waughop and the high phosphorus levels in its sediment, the major historical source of phosphorus loading can be attributed to the hospital farm (Mann, 1930).

Livestock had been raised on the site since the early settlement days of Joseph Heath, but the number and variety of animals greatly increased with the opening and development of the farm (Cooley, 1964). The increased levels of livestock manure not only entered the lake via surface runoff; workers purposely added manure to the lake to create liquid fertilizer, called “compost tea” for the farm crops (Mann, 1930). Effluvium from the slaughterhouse also drained into the lake for many decades (N. Tweed, personal communication, February 2, 2012). Throughout its history, from first settlement to the closing of the farm, the lake was a convenient receptacle not only for animal waste but for many other unwanted materials as well. Brick pieces and other building materials have regularly been found in the lake. This organic and non-organic dumping continued for many years resulting not only in the high phosphorus sediment levels, but also a reduction of lake depth by several meters.

The quantity of available phosphorus within the sediment of Lake Waughop provides autochthonous loading of phosphorus into the water column. The contribution from sediments may be so great that even if phosphorus is eliminated from the water, it will often be rapidly replaced with phosphorus released from the sediment (Søndergard et al., 2003). This release into the water may be so intense and persistent that any effort at water quality improvement will likely fail. Thus, it is doubtful that any phosphorus mitigation work done at Lake Waughop will be successful unless treatment of the sediment is completed first.

3.6 Algae

Samples collected by the author in July and August of 2007 and the Washington State Department of Ecology (bi-weekly from March to October, 2008) were used to identify types and concentration of cyanobacteria toxins found in Lake Waughop (Appendix 3). Two of the most common cyanobacteria, *Mycrocystis aeruginosa* and *Anabaena sp.*, found in Lake Waughop are shown in Figures 29 and 30 respectively; non-toxic species of algae were not identified in the study.

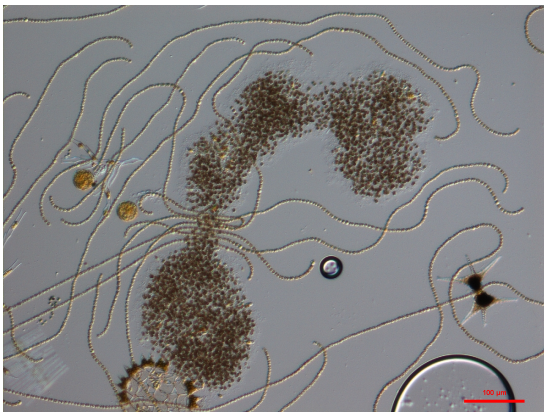


Figure 29. *Mycrocystis aeruginosa* 100x
Karl Brunn.

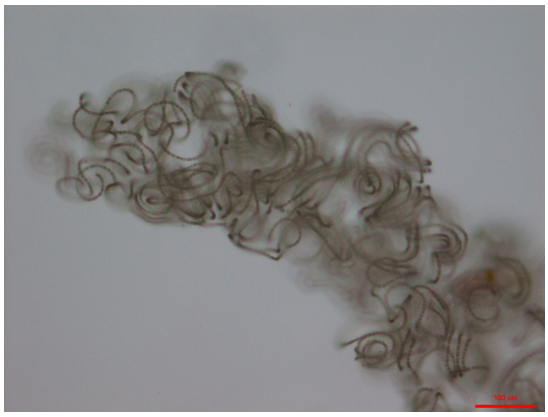


Figure 30. *Anabaena sp.* 100x
Karl Brunn.

Multiple cyanobacteria blooms were observed at Waughop Lake during the study, many of which led to the posting of caution signs and in some instances, lake closures. Most visitors seem to pay little attention to the signs and closures, particularly fishers who not only continue to fish, but actually eat their catch (author observations on tri-weekly lake walks). The public does not seem to be aware of the toxic effects of freshwater harmful algal blooms (author conversations with visitors).

The algae species that form blooms are diverse, and several different species can co-exist in a lake at the same time (Herath, 1997). While not all

species are toxic, large numbers can still harm a lake ecosystem in many ways. Algal blooms can build up as large, slimy, odoriferous mats in the shallow waters of a lake. These blooms may kill other plants and animals, add excess organic carbon to the lake and sediments, and deplete dissolved oxygen. This reduces clarity of the water, thereby diminishing the ability of aquatic plants to photosynthesize (Ruley, 1993).

In 2007, the Washington State Department of Ecology (WDOE) began a study of freshwater algae with the goal of identifying algae species and testing toxin levels from cyanobacteria in 53 state lakes (Hamel, 2009). Toxic algal blooms are a health risk to humans and animals. These blooms also negatively impact recreational activities on affected lakes, causing economic losses (Hardy, 2010). A single species of cyanobacteria can have toxic and non-toxic strains; algal species identification is not enough to determine whether a bloom is toxic. The only reliable way to establish the bloom toxicity status is with laboratory tests (Hamel, 2009). Washington State is currently conducting a study to determine if fish in lakes with a cyanobacterial bloom accumulate toxins in their edible flesh. Preliminary results show they do (Hamel, 2009).

Toxic algae, the filamentous cyanophytes (cyanobacteria) and some chlorophytes (green algae) are macroscopic types that can be seen floating on the surface of a lake. They may form extensive blooms and can cover the entire surface of a lake, especially small, shallow lakes such as Lake Waughop (CDC-FAC, 2010). These algae blooms appear as “...foam, scum, or mats on the lake

surface and can be blue, bright green, brown, or red and may look like paint floating on the water" (CDC, 2010).

Cyanobacteria spend the winter in cyst form, buried in the lake sediments. These algae originate in the sediments of a lake, nourished in the early growth stage by the nutrients accumulated in the upper layers of the lake sediments. As the algae mature, their natural buoyancy and trapped decompositional gases, mainly methane (CH_4), and hydrogen sulfide (H_2S), carry the algae up to the lake surface where it forms into dense floating mats. Some types of cyanobacteria produce toxins which are very powerful natural poisons (CDC, 2010). There are no known antidotes for these toxins. Table 7 shows a list of these toxins and their effects; neurotoxins affect the nervous system and hepatotoxins affect the liver.

Table 7. Cyanobacteria Toxins and Their Effects on the Body. Washington DOE, 2008.

Toxin	Produced by	Found in Waughop	Acute Effect
Anatoxin-a	*Anabaena, Aphanizomenon, Planktothrix*	Yes	Neurotoxicity
Anatoxin-a (s)	*Anabaena, Planktothrix*	Yes	Neurotoxicity
Cylindrospermaopsin	*Cylindrospermopsis*	Yes	Hepatoxicity (liver), renal toxicity
Microsystins	*Anabaena, Microcystis, Planktothrix*	Yes	Hepatoxicity
Saxitoxin, neosaxitoxin	*Anabaena, Cylindrospermopsis, Planktothrix anizomenon*	Yes	Neurotoxicity

Of all the WDE lake samples collected in 2009, Lake Waughop had over 25% of the samples with levels above state recreational guidelines (WDOE-REHAB, 2009). Cyanobacterial Harmful Algal Blooms (HABs) are “Dangerous and harmful to people, animals, and the environment” (CDC, 2010). Often one of the first signs of a HAB is a sick dog – a dog that has been swimming in an algae-filled lake and subsequently becomes ill. Over the past few years, local newspapers in Washington and Oregon have published several articles about dogs that have died after exposure to cyanobacteria toxins, including one occurrence at Lake Waughop where the dog washed itself after wading in the lake and died soon after (Hamel, 2009).

Waterfowl

Lake Waughop is a haven for several species of waterfowl (Figure 31) and their excreta adds a significant amount of phosphorus to the lake (Manny et al., 1994). The most common waterfowl species found at thelake are Canada geese (*Branta canadensis*), mallard ducks (*Anas platyrhynchos*), and American coots (*Fulica americana*). The area around the lake provides abundant food, shelter, and nesting sites for these birds and some populations remain in the area year-round rather than migrating south (Ragland, 2005).

Figure 31. Gathering of mallard ducks at beach area.
Michele LaFontaine.

Figure 32. Waterfowl sign posted at lake.
Michele LaFontaine.

People like seeing the birds around the lake, and are frequently seen feeding them despite posted “Do Not Feed Waterfowl” signs (Figure 32). Birds quickly learn where an easy handout can be found and they will congregate near the lakeshore eating and defecating, especially at the beach area, where they are often fed. During late spring and early summer, over 40 mallards have been

counted on the lake, along with smaller numbers of coots and Canada geese. While Canada geese are fewer in number, their large body size makes up for that. These are big birds with big appetites that defecate profusely; at times, going for a walk around the lake is like navigating a mine field. Research has shown that the total daily nutrient load of one Canada goose contributes 0.49g P per day to a lake, while the input from diving ducks like coots and mallards contribute 0.19 g day^{-1}P. (Manny et al., 1994). Rip, and others (2006) believe this value to be on the conservative side, citing a 2003 study published by Anderson and others. Wetzel (2001) gives some examples of nutrient loading from waterfowl in other kettle lakes, see Table 8 below.

Table 8. Nutrient Loading to Lakes from Waterfowl (Wetzel, 2001).

Lake & Location	% of Total Nitrogen Input	% of Total Phosphorus Input
Wintergreen Lake, MI	27	70
Kettle Lake, MA	unknown	49
Grand-Lieu Lake, FR	37	70

Waterfowl droppings can have high bacterial counts and contribute to lake eutrophication by stimulating algae growth (Ragland, 2005). Excreta from waterfowl can add large quantities of nutrients to lakes, the inputs varying seasonally as some waterfowl migrate through the area (Rip et al., 2006). Waterfowl droppings can be a significant source of phosphorus loading in lakes, and these inputs must be reduced as part of the treatment regime for Lake Waughop, though it may be one of the most difficult due to public interest in interacting with the wildlife at the lake, as noted previously.

3.7 Summary

Much of the data collected on Lake Waughop reflects a shallow, spring fed eutrophic lake. Water quality parameters are driven in large part by seasonal fluctuations in solar radiation. As with many temperate eutrophic lakes, Lake Waughop follows a progression from a uniform vertical distribution profile of temperature, pH, and DO in winter months to an increasingly stratified profile through mid-summer. As light and heat increase in the spring, increased biological activity causes a loading of organic matter in the hypolimnion and sediments. Microbial respiration consumes an increasing amount of oxygen at lower depths causing a similar decline in pH. Lake productivity generally increases with total phosphorus. As the lake begins to cool in the autumn the water column becomes less stratified and biological productivity slows. pH, DO, and temperature all become more uniform with depth as winter approaches.

In winter months the lake receives little solar radiation resulting in cold temperatures and an isothermal water column. Biological productivity is slowed during this period, but can still produce algal blooms. Data from winter months shows uniform temperatures, DO, and pH at all depths. Water clarity improves during this period with the data showing three Secchi disk measurements at more than 1.5 m in depth.

As the lake receives more solar radiation in the spring, water temperatures progressively warm. Preceding weather seems to determine when and how fast the lake begins to show signs of stratification. On one sample date in June of 2007 the lake still showed no sign of stratification even though it had warmed

about 15 °C since winter. On another sample date in May of 2011 there was a more than 4 °C difference in temperature from surface to bottom. DO in the spring can vary, but the data shows little sign of stratification. DO levels are likely more influenced by the warmer water absorbing less oxygen from the atmosphere than any biological production or use. pH shows no consistent trends in the spring months.

Water clarity fluctuations in the spring are most likely due to algal blooms and die-offs and mixing from wind. In the spring of 2009 the Secchi disk depth increased 1.4 m in less than two months. Total phosphorus during the spring increased with increasing water temperatures. All three samples taken during this period showed higher concentrations near the lake bottom, and two of the three samples showed a decline to 2 m, then a sharp increase at the 3 m mark. Soluble phosphorus can increase sharply near the sediment water interface where there is a loading of organic matter during sedimentation.

Summer months bring the most dramatic changes in water quality parameters. In July when air temperatures rise, the lake shows a pronounced thermal stratification. Prominent summer stratification has profound effects on DO, pH, and total phosphorus. Of the six samples collected within the summer months there was an average of 3.5 °C difference between surface and lake bottom. DO levels showed the greatest difference with depth during periods of increased thermal stratification. Three of the samples taken during summer months followed a positive heterograde curve in which DO increased in the

metalimnion before decreasing to near zero approaching lake bottom, creating anoxic conditions.

The pH also follows a pattern of great change with depth during periods of intense thermal stratification. Those samples that did show a stratified pH had readings in the 8 to 10 range at the surface, far higher than all other readings. pH tends to increase as a result of phytoplankton and littoral plants consuming large amounts of CO_2 in the trophogenic zone. Alternately, the pH tends to decrease throughout the hypolimnion with the respiratory generation of CO_2. Secchi disk depth data showed fluctuations in water clarity, likely following algae blooms and die-offs. It is common during times of increased thermal stratification for the phosphorus to show marked increase in the lower hypolimnion. This can be observed in the data showing readings of 65 and 85 µg/L at the 3 m mark compared to the average of all other readings of 52.8 µg/L at similar depth.

No specific conclusion can be made about conditions in Lake Waughop during the autumn months as there was only one sample date during those months. But in general the summer stratification begins to weaken with cooler weather. There can still be large algal blooms in late summer/early autumn when the lake is warm throughout, as seen in the toxic algae report in Appendix 3. This would have an influence on DO, pH, and water clarity. The lake normally returns to a more uniform vertical distribution of temperature, pH, and DO profile by late autumn.

3.8 Monitoring History and Mitigations

The earliest monitoring data on Lake Waughop found was from a study done by Pierce County in 1973 which covered physical and water quality data. Data for 1981 was collected by students enrolled in a Pierce College Ecology course taught by biology instructor Norm Tweed. In 1987, a student at Pierce College completed a research paper on Lake Waughop which detailed the status of the lake at that time.

No records of historical mitigation or treatment were found. The most recent treatment efforts were done in 2008 in response to the toxic algae problem. The State Legislature appropriated funds to conduct an experimental calcium hydroxide (slurried lime) treatment in the lake (Hamel, 2008). The treatment consisted of a broadcast application of calcium hydroxide over the lake surface in order to strengthen the lake's natural buffering ability.

The goal of adding the calcium hydroxide was to increase the 26mg/L ($CaCO_3$) alkalinity of Lake Waughop to level of 45 mg/L ($CaCO_3$), the natural alkalinity for groundwater fed lakes in the area (Russell, 2007). In addition to moderating the pH swings of the lake, another goal of the treatment was the inactivation of phosphorus entering the lake via surface runoff and groundwater flow. A similar treatment was done at Steilacoom Lake in mid-June of 2008 Neither treatment had the desired effect, but valuable information was gained. The first treatment failed because the calcium hydroxide slurry was not properly dissolved before application, the second because the calcium oxide caused an

exothermic reaction melting the application pipe (D. Russell, personal communication, December 10, 2011).

No other documented mitigation or restoration efforts were found.

3.8.1 Remediation Recommendations – Do Nothing

This is, of course, the simplest and least expensive action that can be taken. Regarding Lake Waughop, this has been the long-term action taken by the accountable parties – no action except the posting of Warning and Caution signs. Though two calcium hydroxide treatments were completed in 2008, they were done more as a test than as a dedicated effort to clean the lake. The treatments did not solve the algae problem and no further action was taken. Bloom problems have continued to increase.

If this course is continued, authorities may be forced to cordon off Lake Waughop to public access as the risk of illness due to toxin in cyanobacterial blooms, possibility leading to litigation, increases. This would invariably lead to anger and resentment from park users and a probable demand that stronger clean-up measures be undertaken. The benefit of continuing this option is that costs remain low (regular water quality analysis and monitoring plus wages for employees posting the signs) and minimal work is necessary. The disadvantage is an increasingly impacted and unusable lake and negative public reaction.

3.8.2 Riparian Management

Non-point nutrient inputs can be reduced by managing the type of riparian vegetation surrounding a lake (Carpenter et al.,1998). Removal of invasive aquatic plant species in and around a lake and replacing them with native species can aid in restoring historical flow patterns for surface water runoff. The budget for the project would need to cover invasive plant removal, the cost of native vegetation, and labor to plant, although plant contributions and volunteer labor could be solicited to partially reduce the total expense (Berman, 2006). Lake Waughop's chances for improvement would be greatly increased by removing the pavement from the road that encircles the lake and replacing it with native landscaping or pervious pavement. This would be a significant under-taking. Cost of removal and disposal of the material must be included in the total cost of the project. One advantage of this mitigation would be that phosphorus loading from surface runoff (mainly from waterfowl feces) would be reduced since soil and plants have replaced pavement. The soil is permeable and will soak up surface runoff and filter it; soil microbes will break down organic material.

This option offers the benefit not only of improving surface water drainage, but would add a large area of native habitat for wildlife, especially songbirds. A larger ecosystem habitat would also benefit existent fish and wildlife and enhance local biodiversity (Carpenter, 1998). This option would cause disturbance of the soil in and around the lakeshore; installation of barriers to prevent sediment runoff from the site from flushing into the lake would be required for the duration of the restoration project.

3.8.3 Chemical Treatment

In 2008 Lake Waughop was treated with 17,000 pounds of calcium hydroxide in an effort to inactivate the soluble reactive phosphorus. The calcium hydroxide (liming) treatment attempted in Lake Waughop did not produce the desired effect, but important information about the process was gained. The calcium hydroxide was applied by spraying water and calcium hydroxide flakes through perforated pipes suspended behind a floating barge. The solution was mixed on site just before application. According to Don Russell (personal communication, 2011) the treatment failed due to insufficient mixing before application and in any future attempts the solution should be mixed beforehand and the calcium hydroxide completely dissolved. A similar treatment was applied to Lake Steilacoom, again, with disappointing results. In this attempt, application was made by spraying the solution through a hose; the process caused an exothermic reaction and the solution became so hot it melted the application hose. Knowing the reasons for the disappointing results ensures the errors will not be repeated. Liming is a well-proven technique for phosphorus management in lakes and should not be discounted due to previous poor results.

Liming imitates a natural process, calcite biogenic precipitation, in which calcite incorporates the phosphorus into its crystal structure, precipitating the phosphorus out of solution. Because of this, calcium hydroxide treatments have fewer negative effects than other minerals used to control algal blooms.

Eutrophication treatment using aluminum or ferric compounds has been common in the past, but both can produce unwanted side effects. Wapato Lake,

a small lake near Lake Waughop, was treated with 33,000 gallons of alum and 16,000 gallons of sodium aluminate. An error in preparation of the chemicals for application resulted in a mixture that was poorly buffered, causing a large pH drop and a massive fish kill in the lake (Tucker, September 2007). Though the treatment was effective in producing very clear water, that clarity only gave a view of a lake devoid of life. To prevent similar incidents, when using chemical treatments in lakes, better quality control must be implemented when treating lakes.

Various algacides are available but their use only treats the symptom (algal blooms) not the problem, and would be more of a short-term, bloom by bloom action.

3.8.4 Mechanical Enhancement of Lake Mixing

Stagnant, stratified water is often found in shallow eutrophic lakes and thorough mixing of the water column can aid in lake recovery (Lawson and Anderson, 2007). Microbial respiration often results in oxygen depletion in the deeper parts of a lake, causing anoxia near the water-sediment interface (Wetzel, 2001). In some situations, this may lead to nutrient release from the sediments. This state is often found in Lake Waughop which has high nutrient levels, especially phosphorus, in its sediments. When mixing occurs after a prolonged period of stratification, nutrients are carried to the surface waters and are available to fuel algal blooms and other undesirable events (Lawson et al., 2007).

If the stratification of the lake can be reduced or eliminated it may assist in preventing this internal release of nutrients (Björk, 2009). Using the action of moving water will mix the water column as well as incorporating oxygen from the atmosphere into the lake via the air-water interface.

Initiating mixing in the water column can be done from the lake bottom (upward mixing) or the lake surface (downward mixing). The former consists of injecting pressurized air into the bottom water where it then expands and rises, inducing a mixing cycle in the water column. The latter method uses axial flow pumps placed below lake surface water, forcing this warm oxygenated water toward the lake bottom, again inducing a mixing cycle in the water column (Lawson et al., 2007). This is a feasible method for Lake Waughop because of the lake's small size, although the cost of the pumps (U.S. $2500 – 3000 in 2011)

and other operating and maintenance equipment may be prohibitive (Björk, 2009).

An axial flow pump study was conducted over a three year period at Lake Elsinore, California, which had conditions similar to those at Lake Waughop. Unfortunately, the axial pump method was minimally effective in Lake Elsinore. Lawson and Anderson (2007), who conducted the study, determined that three factors were responsible for the failure.

> "Excessive turbulence and local circulation near the axial flow pumps, combined with the shallow depth and flat bottom topography, are responsible for the very low efficiency in net mixing energy transfer to the water column in Lake Elsinore" (Lawson et al., 2007).

Since Lake Waughop is also shallow and flat-bottomed, the same failure could result. If the design and operation of the axial flow pumps were thoroughly and carefully undertaken, water quality may improve using this method.

For many years, the Thames-Valley Reservoirs in the United Kingdom have used artificial aeration combined with other phosphorus removal methods to control cyanobacteria blooms (Herath, 1997). However, a similar program instituted in Australia resulted in only about 30% of reservoirs showing reduced algal biomass (Herath, 1997). These mixed results require further investigation of this method.

3.8.5 Dredging

One sediment gravity core of Lake Waughop was taken during the study using a gravity corer. Upon retrieval the three-foot cylinder contained sediment of a pudding-like consistency, being very wet and jelly-like. This finding supports a historical account of 1930 tests done on Lake Waughop sediment which ". . . showed it to be a pure vegetable mold, of bluish-green color. . . that took the formation of a thick vegetable jelly" (Mann, 1930).

The optimum method for dredging this soft, organic sediment is suction-dredging, a method which uses a special box-form nozzle to literally "vacuum" up the sediment (Björk, 2009). Unlike scoop-dredging with large machinery, suction-dredging prevents water turbidity and its resulting suspension of nutrients from the sediment back into the lake. There is potential to use the removed sediment as fertilizer but such action would be dependent on toxic content of the sediment.

One concern about dredging Lake Waughop is the possibility of disturbing old arsenic deposits from herbicide treatments used on the farm or deposited from the Asarco Smelter plume (King, 2007). A 2007 sediment study completed by Kara King, a student at the University of Washington, showed an arsenic pulse of 90 mg/kg at approximately 15 cm. Less than 10mg/kg of arsenic was detected below 25 cm, rising to 30 mg/kg at 20 cm, and then the 15 cm pulse followed by a drop to 40 mg/kg at 8 cm. Arsenic levels remained at 40 mg/kg from 8 cm to the top of the sediment deposit. As a preliminary assessment,

sediment cores should be analyzed to locate these or other contaminants which could be hazardous if disturbed.

A second concern is the impact any dredging (entire lake or spot dredging) will have on the ecosystem of the lake. Entire lake dredging will disrupt the entire ecosystem, at least temporarily. Spot dredging, in which selected spots are dredged, would be less damaging than whole lake dredging, but disturbances would still occur. Either dredging method would in all probability leave some contaminated sediment in the lake. If dredging is done, the disposal of sediment removed must be included in the restoration. If hazardous levels of heavy metals or other toxic pollutants are found, the material may need to be disposed of as hazardous waste. If not, a proposal has been made to use the nutrient-rich lake sediment as fertilizer for park grounds.

The third concern is cost. Though dredging would be the most expensive treatment for restoring Lake Waughop, it may well be the longest lasting fix if undertaken correctly and carefully as possible. Disposal cost of the removed sediment may be rather high if the sediment is contaminated, or low if it is not. Grants from government agencies and non-profit groups may be available to offset some or all of the cost.

Fourth, the possibility exists that the lake bottom may be covered with a sediment layer, most likely clay that may form a natural seal that keeps water in the lake. Dredging may compromise this seal, causing the lake to drain out into the glacial till. Conceivably, the lake would not recover and could disappear permanently.

Lastly, the permitting process for dredging could become very complex considering all the city, county, state, and non-profit organizations that are stakeholders in Lake Waughop and Fort Steilacoom Park.

3.9 Future Treatment Possibilities

Algal blooms have increased worldwide over the past century, causing increasing problems in water bodies (Brynn, 2008). This situation has driven research into methods of controlling these blooms, particularly those involving toxic cyanobacteria. Several treatment options exist, the type used depending on the problem within the lake, severity of algal blooms, the size of the lake, and lake toxicity.

Hypolimnitic aeration (water circulation through use of bubblers), regulation of pH levels, bioremediation, and dredging are some of the proven restoration methods available (Björk, 1988). With any of these methods, removal and/or neutralization of contaminated sediments in lakes must be the first step considered, as leaving them in place may lead to further release of excess nutrients. The case of Lake Trummen near Växjö, Sweden is a good example. Decades of pollution from sewage and industrial wastes caused the lake ecosystem to collapse. Restoration efforts began with the diversion of sewage water to a treatment plant. However, intensive internal loading continued. “Eleven years after the sewage diversion the lake was as green as before, with a transparency of only 10-20 cm” (Björk, 92).

Costs for treatment are also dependent on these variables, showing a correlation of rising treatment costs with severity of the contamination. Treatment options have both positive and negative issues; no one solution will give only positive results. All factors must be considered when deciding on a treatment option.

3.10 Topics for Future Research

Hopefully the on-going Pierce College analysis and monitoring program of Lake Waughop will continue to expand in the future and take on additional research projects. The waterfowl species that frequent Lake Waughop should be monitored and data collected to include species, numbers, dates of appearance, behavior, and their nutrient input to the lake. Another important topic is to research methods for waterfowl control.

In the development stage is a field guide of Lake Waughop plankton, to be used for identification of lake organisms in order to compile data and track plankton species changes in the lake both seasonally and annually. Other valuable research projects are to map the pattern of vegetation around the lake by species and range size; determine direction of groundwater flow in the Lake Waughop watershed, and research how removal of the asphalt road would impact the lake.

3.11 Conclusions

Figure 33. Sunrise Over Mt. Rainier and Lake Waughop. Michele LaFontaine.

Lake Waughop sits in a scenic area of open meadows and forests with Mt. Rainier visible to the southwest (Figure 33). This pleasant aspect is frequently marred by the sight (and smell) of Lake Waughop during a heavy algal bloom. Visitors to the park are there to enjoy the plants, birds, and scenery and find such conditions in the lake unattractive and upsetting. A lake in a heavily-used park such as Fort Steilacoom should not remain in such a contaminated state. Not only is it unattractive, it is unhealthy as well.

There are many benefits of restoration including reduced nutrient levels, a decline or elimination of toxic algal blooms, return of native species, enhanced water clarity and quality, and increased recreational use of the lake.

The restoration and management of Lake Waughop presents a prolonged, comprehensive, and difficult undertaking. If no action is taken regarding clean-up, the condition of the lake will continue to deteriorate; it will not be an asset to the park. Complex and challenging as the situation is, the stakeholders responsible need to develop a realistic and practical restoration plan for Lake Waughop. While it is doubtful the lake can be returned to its unpolluted historical state, on-going restoration and monitoring efforts could improve Lake Waughop's condition a great deal. Decreased nutrient levels, chiefly phosphorus, will result in reduction of algal blooms and increase oxygen levels in the lake. Dredging will increase both depth and volume of Lake Waughop which may encourage stronger thermal stratification and seasonal lake turnover. After dredging, phosphorus management strategies must be implemented – dredging will remove most of the autochthonous phosphorus input, but the allochthonous inputs, especially from waterfowl, will still need to be controlled.

Augmenting large-scale restoration efforts (such as riparian management, chemical treatment, mechanical agitation, and dredging) with public education and outreach, such as college-level service-learning projects is necessary to ensure public buy-in to restoration efforts and for the long-term success of nutrient control efforts.

Chapter Four: A Service-Learning Project Combining Environmental Science and History

"Human brains learn more, remember longer, and grow more connections when the learning occurs in a real world setting" (Berman, 2006).

In discussing the discipline of service learning, two definitions are most often cited in the literature. The National Service Learning Clearinghouse defines service-learning as " . . . a teaching and learning strategy that integrates meaningful community service with instruction and reflection to enrich the learning experience, teach civic responsibility, and strengthen communities" (servicelearning.org, 2008). Additionally, The National and Community Service Trust Act of 1993 states that "Service-learning engages students in the educational process, using what they learn in the classroom to solve real-life problems" (learnandserve.gov, 2009).

It can be argued that service-learning is as old as civilization itself – it has always been a part of community; it just wasn't specifically defined and directed. Service to one's community was part of everyday life and people accepted as a part of that life that they would participate in the well being of their community.

Service-learning as we consider it in America dates back to the early 1900s when John Dewey, an American psychologist, philosopher, educator, social critic and political activist established the intellectual foundations of service-learning (Hildebrand, 2009). Dewey believed that "...experience, with its accompanying reflection, is the foundation of learning and service learning immerses students in experience and encourages them to reflect" (Berman, 2006).

Dewey's foundations were built upon and implemented throughout past decades. The creation of the Peace Corps by John F. Kennedy in 1961 and Volunteers in Service to America (VISTA) by Lyndon B. Johnson in 1964 led to a revival of public service work in the United States (Jacoby, 1996). Awareness of the value that service-learning offered for achieving academic goals was recognized with the endorsement of service-learning in 1993 by the Association for Supervision and Curriculum Development and the creation of the National Service-Learning Clearinghouse in 1997. Subsequently, at the school district and state levels, service-learning requirements were incorporated into school curricula (servicelearning.org, 2008). There are many reasons for doing service-learning projects. The benefits to students are many-fold: (Berman, 2006).

- Learning both in the classroom and in real-world settings
- Development of sense of being part of and contributing to their community
- Encourage a life-long habit of community involvement
- Achieve academic goals
- Integrate multiple disciplines into one course
- Experience in the role of service provider rather than service receiver
- Reflective journaling to deepen self-awareness and assist learning

An important and necessary component of service-learning is the inclusion of reflective writing (journaling) throughout the project. Reflection allows students to analyze and investigate their experience and how it has benefited their personal growth and self-understanding (McClam et al., 2008). In recent

decades, service-learning has been incorporated into school curricula nationwide and is considered one of the fundamental learning experiences for students. Service-learning projects benefit students and the communities in which they live; an advantageous partnership for everyone involved. By engaging students in real-world volunteer work and research, we can provide them with a holistic experience that has both academic and personal benefits (McClam et al., 2008).

Many students are unaware of the environmental and cultural history of their surroundings, particularly in higher education where many students are from outside the community, and often from outside the state or country (Jacoby, 1996). Offering students an opportunity to fulfill academic requirements and goals, as well as the chance to give something back to the local community is an entirely beneficial plan: academic goals and learning are achieved, the community benefits from service-learning and historical research projects, and students gain benefits in academic, personal, and social growth (McClam et al., 2008).

Ecological restoration, the effort to return a compromised ecosystem to a more historic natural state, is an excellent method to incorporate service-learning and environmental history into a curriculum (Society for Ecological Restoration, 2002). By designing service-learning efforts related to restoration projects in local natural areas (or even along roadsides and vacant lots), students are able to contribute valuable and much-needed assistance in improving their communities (Ewert and Sibthorp, 2009). These labors are not only valuable in that they help restore compromised areas to a more natural state, but they are

economically valuable as well. Every year government agencies spend millions of dollars on restoration efforts and on the control or removal invasive species at the community, regional, state, and national level (SER, 2002). Many projects do not get done, mainly due to lack of funding. If service-learning coordinators and governmental agencies cooperate on these projects, funding needs could be decreased, in part because service-learning volunteers would do much of the work. In some restoration projects, this funding can then be directed toward expenses associated with the particular project, such as the purchase of plants, tools, and equipment.

Another benefit of service-learning experiences for students can be the confirmation of a student's career choice when they engage in service-learning courses within their chosen field (McClam et al. 2008). Of equal benefit, their experience may also lead them to realize they don't want to pursue a career choice after doing volunteer work in the subject area.

Colleges and universities can use service-learning projects to achieve academic and institutional goals, using teamwork and hands-on learning to engage students in more meaningful educational experiences, foster the growth of good citizenship and innovative instruction, and allow these institutions to become more integral parts of their surrounding community.

The benefits to communities include a volunteer labor force (without which many community improvement and assistance projects could not be attempted), citizens who are better informed, tolerant, and community oriented, and completed projects that enhance the community and help it function in a more

efficient, sustainable, and satisfactory way, building a better connection between the community and centers of learning.

One of the goals of this thesis is to lay the foundation for implementing a service-learning project integrated into the curriculum (Appendix C) at Pierce College . The following section provides an outline for developing this project which in turn can be used as a case study for other educators in developing hands-on environmental science activities in their own communities. Learning modules are included that can be used in this project, as well as adapted by others for their own classes. Examples of some of the forms used in service-learning projects are included in Appendix D.

4.1 Framework for Development of a Service-Learning Project at Pierce College

The Pierce College campus and the surrounding area provide an ideal location for the development of an environmental education program involving faculty, staff, students (kindergarten through university), and local communities in native habitat restoration. A feasible service-learning project for Pierce College students will consist of two concurrent components:

1. Complete the present (2007-2012) limnological evaluation of Lake Waughop, Fort Steilacoom Park. Use the data gathered to develop a long-term restoration and monitoring program to be incorporated into Pierce College courses.
2. Continue working with the University of Washington Restoration Ecology Network (REN) to restore the native Oak Woodland Ecosystem on college and adjacent park property.

Goals:

1. Restoration and monitoring of Lake Waughop and native Oak Woodland habitat on Pierce College property, adjacent state property, and Fort Steilacoom Park property.
2. Develop long-term monitoring and restoration of these ecosystems as service-learning components of the curriculum of Pierce College.
3. Use project sites as an educational tool through which students, parents, faculty, and staff will better understand and appreciate northwest native ecosystems.
4. Create a project research library, project website, and a database of all historic Lake Waughop data, which is ready to accept new data. Do the same for the Oak Woodland site.
5. Develop Planting Kits for both projects that include seeds, small planting containers (with greenhouse covers), instructions for planting and care of seedlings, and appropriate planting medium. These kits will be distributed to elementary school teachers within the local community for use in their classes; they will also provide the lake and woodland restoration efforts with native plants for on-going restoration of these areas.
6. Develop restoration modules/kits appropriate to middle and high school students, specific topics to be developed in conjunction with teachers to

insure appropriate grade level projects.

7. Encourage ways to continue to use the site for monitoring, evaluation, and enhancement educational projects.

4.2 Project Implementation

1. Incorporate habitat restoration into an appropriate existing course (ecology, plant biology, environmental science), or create a new course.
2. Begin with a small project needing few supplies and in subsequent quarters and years build up stock of tools, equipment, etc.
3. Develop a long-term master plan with clearly defined goals and tasks including team member roles:

    - Project Lead
    - Communication/Liaison
    - Plant/Supplies Coordinator
    - Budget/Fundraising/Donations
    - Volunteer Coordinator
    - Logistics
    - Permissions/Permits/Licenses

4. Use an accurate map of the restoration area to plan restoration sequence.
5. Document the site including habitat types present, site conditions, plants and animals present, any contamination or pollution found, soil conditions, etc
6. Back-up site documentation with photographs. Keep albums with pre-restoration photos and continue a photo record throughout the entire project.

4.3 Learning Modules

These modules are designed to introduce students to basic field and laboratory techniques used in aquatic (and terrestrial) environmental restoration. In general the labs require minimal equipment and can be modified for use in classes from middle school to college; some labs could be modified for the primary grades. The modules were written for use in an undergraduate course in ecological restoration that consists of both lecture and fieldwork. The fieldwork for our Pierce College Course takes place in a 340-acre community park with a small lake (Lake Waughop), Fort Steilacoom Park, located next to the college campus. However, each lab can be used as a stand-alone unit and most labs have various exercises and procedures that can be tailored to student needs, time allotted, and facilities available. While Pierce College is especially fortunate to have a park next to campus, most schools do not have such a resource. However, in many instances it may be possible to complete most of the activities by taking field trips to several sites, including woodlands, water systems, and prairie environments. With a little creativity and imagination, some fieldwork can even be done inside; an example is included in Module Six of this manual.

Laboratory Safety

1. Behave responsibly and safely. The lab is a scientific environment and horseplay is not appropriate.

2. No food or beverages allowed in the lab room, including gum, chew tobacco, etc.
3. Consider all chemicals and solutions to be toxic and act accordingly. Do not pipette by mouth, always use a mechanical device to pipette solutions. Please wear protective gloves and goggles when handling any chemicals.

4. Read all labels and know what chemicals you are using. Discard excess chemicals into an appropriate container.

5. Do not pour solutions or powders down the drain. Dispose of them as instructor directs.

6. Do not wear clothing with loose sleeves and tie back long hair.

7. Treat living organisms with care and respect.

8. Locate and remember the location of all safety equipment such as the eyewash station, fire extinguishers, and first aid kit.

9. Use of the lab is allowed only when an instructor or lab technician is present.

10. Always stay with an experiment in progress.

11. Before leaving lab for the day make sure your area is clean and that all equipment and materials are put away in the proper place.

12. Ingest nothing; don't handle unknown specimens except when wearing gloves.

13. Boiling solutions are to be moved while wearing hot-pad gloves or by tongs.

14. Handle all tools properly and be aware of your surroundings when using tools.

15. Dress appropriately for outdoor activities, which will take place rain or shine.

16. All hot plates are to be turned off and unplugged when not actively being used.

Field Equipment List

It is helpful to have a lab for field gear introduction and practice before going out in the field. Students should be familiar with all equipment and it's use before making a field trip to do sample collection.

General Items:

data sheets and pen/pencil	thermometer for air temperature
Secchi disk on marked line	GPS unit
depth finder	laboratory tape/permanent markers
ice packs and cooler	extra distilled water
extra battery for depth finder	duct tape/scissors

Depth Profiles: probes, single or multiprobe and cable

Water Chemistry:

water sampler on marked line	clean sample bottles
__ml syringe	__ filters

Phytoplankton:

plankton net on marked line	plastic small mouth 1 L bottles
plankton bottle	Lugol's solution w/eyedropper

Zooplankton:

plankton net on marked line	spray squeeze bottle of distilled water
plastic sample jars	Lugol's solution w/eyedropper
Alka-Seltzer tablets	small container for narcotizing

Benthic macroinvertebrates:

sediment sampler	plastic wide-mouth sample bottles

wash bucket with sieve simple wash container to rinse sieve (bucket or bowl)

Sediment Chemistry:

sediment sampler	teflon pan & teflon ladle
clean lab bottles	towels(for wiping sediment jars)

Boat and Safety: anchor, rope

paddles/oars	PFDs (life vests)
phone/radio	first aid kit
drinking water	sunscreen
rain gear/hat	

Adapted from *Inland Lakes Manual*

Module One: Metric System

Answer the following questions from metric and English measurements.

1. A football field is 100 yards long. What is its length in meters? _____ m

2. You are _____ feet, _____ inches tall. You are _____ tall in centimeters.

3. The average radius of the earth is about 3,957 miles. What is its radius in kilometers? _____ km

4. The earth's circumference is _____ miles or _____ km (**use $2\pi r$**)

5. The Sound to Narrows run is 10 kilometers; how far is it in miles? _____ mi

6. If the speed limit in is l00 KPH, what is it in miles/hr? _____ MPH

7. A hurricane has a windspeed of 140 MPH. What is it in KPH? _____ KPH
   What is it in knots? _____ knots

8. A weather balloon (upon ascent) bursts at 35 kilometers. What is the burst altitude in feet? _____ feet

9. If the cloud base is 6,000 feet, what is the altitude in meters? _____ m

10. A storm drops 1.25 inches of rain. What is the rainfall in millimeters? ___mm

11. A gallon of water has a mass of about 8 pounds. What is its mass in kilograms? _____ kg

12. Two kilograms of grapes equal how many pounds? _____ pounds

13. If you were in France and wanted to buy 3 lbs of cheese how many kilograms would you buy? _____ kg

14. Convert the following temps:

32ºF = _____ ºC	10ºC = _____ ºF
50ºF = _____ ºC	15ºC = _____ ºF
- 40ºF = _____ ºC	15ºC = _____ K
0K = _____ ºC	385K = _____ ºC

15. a. The **elevation** of Mt. Rainier: _____ ft _____ m

b. The **elevation** of Mt. Everest: _____ ft _____ m

c. The **elevation** of Death Valley: _____ ft _____ m

d. The maximum **relief** in Washington: _____ ft _____ m

e. The maximum **relief** in California: _____ ft _____ m

f. The maximum **relief** in Colorado: _____ ft _____ m

16. One degree of **latitude** equals _____ miles or _____ km.
(Note – Clue: You know the circumference)

17. How far are the following locations from the equator?

	Degrees	**Miles**
a. Seattle, Washington	_____	_____
b. Santiago, Chile	_____	_____
c. Honolulu, Hawaii	_____	_____
d. Sydney, Australia	_____	_____
e. North Pole	_____	_____

Module Two: Water Quality Analysis

1. Dissolved Oxygen
2. Nitrate
3. Phosphorus, Total
4. pH
5. Temperature
6. Turbidity

Dissolved Oxygen (DO)

Dissolved oxygen (DO) is one of the most critical components for healthy lakes and rivers, being a part of both photosynthesis and respiration processes. DO enters water through plant respiration and wind agitation of the water surface. Oxygen in water is a positive sign, while its absence can signal severe pollution. If oxygen levels are too low, water bodies will support minimal life as most aquatic plants and animals need oxygen to survive. Some fish, like trout and pike require medium-to-high levels, 6 gm/L of dissolved oxygen, while carp thrive in waters with low dissolved oxygen levels, as low as 1 mg/L (Matthews and Berg, 1997). If dissolved oxygen levels drop, the aquatic community will quickly change as organisms needing higher oxygen levels die or leave. Water bodies with high dissolved oxygen are considered healthy and have stable ecosystems with high biodiversity.

Sampling Procedure
HACH Tritation Method

DO should be sampled immediately upon collection as delays may result in change in oxygen level.

1. Fill the sample bottle almost to overflowing; tilt slightly to avoid introduction of air bubbles and quickly insert stopper into bottle. Process the sample immediately.

2. Open one DO 1 Reagent powder pillow and one DO 2 Reagent powder pillow. Carefully remove the stopper and add the contents of both pillows to the bottle. Incline the bottle slightly and insert the stopper with a quick thrust. Check the inside edge of the stopper to make sure all air bubbles have been forced out. Grip the bottle and stopper firmly and shake vigorously to mix. A flocculent (floc) precipitate will form.
   (**Note**: If oxygen is present in the sample the precipitate will be a brownish orange in color. A small amount of the powdered reagent may not dissolve, but this will not affect test results).

3. Allow the sample to stand until the floc has settled halfway down in the bottle, leaving the upper half of the sample clear. Shake the bottle again, and once more let the sample stand until the floc settles halfway down.
   (**Note**: If the sample has a high chloride concentration, the floc will not settle. Wait five minutes after shaking (twice) and proceed to step 4).

4. Open one DO 3 reagent powder pillow. Remove the stopper from the bottle and add the contents of the pillow. Carefully restopper the bottle and shake to mix. The floc will dissolve and a yellow color will develop.

5. Fill the thin plastic measuring tube from the kit to the brim with the yellow sample. **Do not** use the whole glass sample bottle for step 6.
6. Pour the contents of the measuring tube into the square mixing bottle.

7. Place the bottle on a white surface so the color change is easy to see. Add Phenylarsine Oxide (PAO) Standard solution to the bottle **exactly** one drop at a time, holding the dropper straight up. Swirl to mix after each drop. Count the number of drops until the sample changes completely from yellow to colorless. Then add one more drop and look for color change – if there is no change do not count the last drop.

8. Empty the used solution from the measuring tube and mixing bottle into the DO waste bottle and rinse both completely. Repeat the procedure with a second sample from the bottle.

9. Each drop of PAO is equal to 1 mg/L of dissolved oxygen.

Adapted from *Inland Lakes Manual*

Total Nitrogen

Tests for Total Nitrogen were done using Hach ™ test procedures; available at http://www.hach.com/

Plants and animals use nitrogen to build protein. In aquatic ecosystems Nitrogen is present in many forms. Nitrogen is most commonly found in its molecular form (N_2), which makes up 79% of Earth's atmosphere, but most plants cannot use nitrogen in atmospheric form. Cyanobacteria (blue-green algae) can take N_2 and convert it into ammonia (NH_3) and nitrate (NO_3); plants can absorb these forms through their roots and use them for growth.

Aquatic animals get the nitrogen to build proteins in two ways: they eat aquatic plants (producers) or eat organisms that eat aquatic plants (consumers). After the death of aquatic plants and animals, bacteria, producing ammonia, break down the large protein molecules in their bodies. Other specialized bacteria then combine the ammonia with oxygen (oxidation) to form nitrites (NO_2) and nitrates (NO_3).

Waste produced by aquatic organisms is very rich in ammonia, although nitrogen contribution to aquatic ecosystems from these wastes is usually represents a small percentage of the total. In aquatic systems where ducks and geese are plentiful, their excrement contributes a heavy load of nitrogen, and represents a much larger percentage of the total amount of nitrogen added.

Nitrogen in the form of ammonia and nitrates acts as a plant nutrient, so excess nitrogen can also cause eutrophiation. However, unlike phosphorus, nitrogen is rarely a limiting factor of plant growth.

Sampling Procedure

Bottles for nitrogen tests must be thoroughly rinsed with demineralized water, and only demineralized water should be used for the test procedure. Distilled water contains ammonia (NH_3) ions that will interfere with the test. If you don't have the ability to demineralize water on site, it can be purchased from several online vendors.

When collecting sample, rinse clean bottle three times with sample water and then fill ¾ full. Put filled bottles on ice for transport back to lab for analysis.

Total Phosphorus

Tests for Total Phosphorus were done using Hach ™ Test 'n' Tube Reagent Set 27426-45; available at http://www.hach.com/

Phosphorus is usually present in natural waters in the form of phosphate (PO_4-P). Living plants and animals, their by-products, and remains all contain organic phosphorus.

Phosphorus is a nutrient needed for plant growth and is used in the metabolic reactions of plants and animals. The amount of phosphorus available limits plant growth and in most fresh waters it is the limiting factor, usually being present in very low concentrations. This natural scarcity is due to its attraction to organic matter and sediment particles. Unattached or "free" phosphorus is quickly absorbed by algae and larger aquatic plants.

Algae require very small amounts of phosphorus to live, therefore, excess phosphorus leads to excessive algal growth called "algal blooms"; these blooms are one of the classic symptoms of eutrophication. Natural eutrophication occurs, but currently the majority is human-caused (cultural eutrophication). Cultural eutrophication leads to a shift in aquatic life, leaving only species that are pollution tolerant.

Sampling Procedure

Bottles used in total phosphate must be "acid-washed" – many soaps and detergents contain phosphates and will leave residue behind. Wash bottles with phosphate-free soap, rinse well, and then rinse bottles with dilute hydrochloric acid, then rinse thoroughly with distilled water.

When collecting sample, rinse clean bottle three times with sample water and then fill ¾ full. Put filled bottles on ice for transport back to lab for analysis.

Wear protective gloves for this procedure.

pH

Water has both H^+ (hydrogen) ions and OH- (hydroxide) ions. pH measures the H^+ (hydrogen) ion concentration of liquids. pH values range from 0 (very acidic) to 14 (very alkaline) on the pH scale. Every one unit of change on the pH scale is equal to approximately a ten-fold change in how acidic or basic the sample is. For example, a lake with a pH of 4 (acidic) is 100 times more acidic than a lake with a pH of 6.

Pure deionized water has an equal number of H^+ and OH- ions, and has a pH of 7, and is neutral, being neither acidic nor alkaline. Water with more H+ ions is considered acidic and has a pH of less than 7. Water with more OH- ions is considered alkaline and has a pH greater than 7. Figure 1 gives the pH of some common substances.

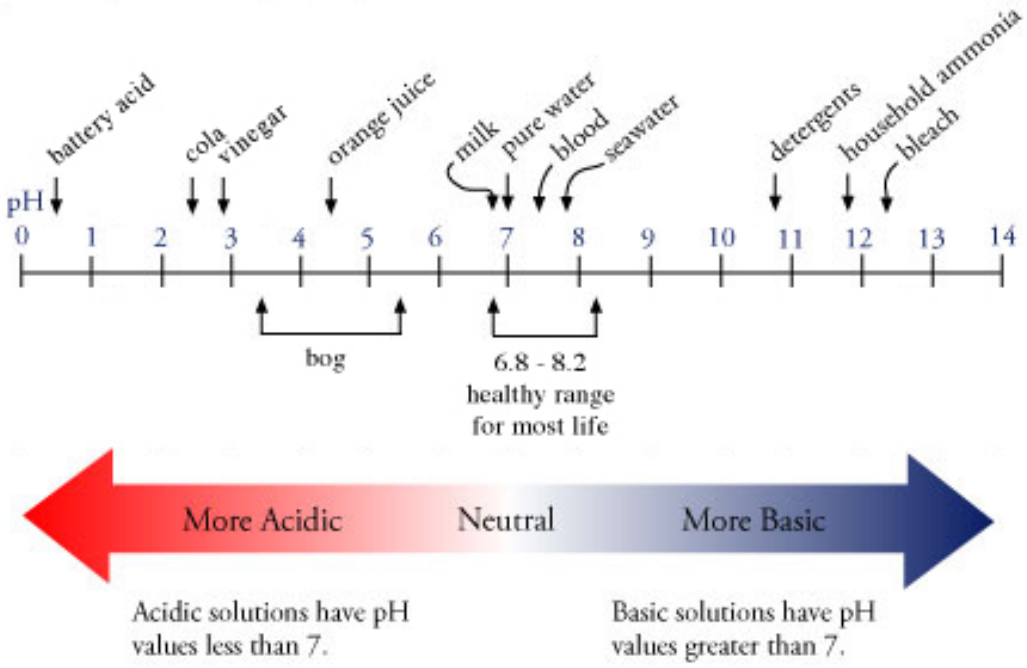


Figure 1. pH scale (Source: Islandwood School)

Most aquatic organisms are adapted to live in specific pH conditions. If the pH changes, sometimes even slightly, the organism may die. In the U.S. the pH range of natural water is generally between 4.0 and 9.0 pH values outside this range make water unsuitable for most organisms.

pH sampling procedures

Collect the sample and measure it immediately as pH value can change with temperature fluctuations. There are two methods for testing pH; with pH strips and with a color comparator test.

pH strips

pH strips are dipped into the sample and matched to the color indicators on the box. This method is more convenient for field sampling.

Color Comparator Test

Both Hach™ and LaMott™ sell tests of this type. Instructions are included. The procedure is similar but one uses a color wheel and the other uses a sliding color strip.

Adapted from *Inland Lakes Manual*

Temperature

Temperature affects many physical, biological, and chemical characteristics of lakes and other water bodies. Cold water can hold more oxygen than warm water so organisms with a high oxygen requirement, for example salmon, are adversely affected if the water they are in warms up. Temperature also influences the rate of photosynthesis by algae and larger aquatic plants, the metabolic rates of aquatic organisms, and the sensitivity of organisms to toxic wastes, parasites, and diseases.

Most aquatic organisms need a specific range of water temperatures to survive. Cool water organisms include trout and stonefly nymphs, while catfish and dragonfly nymphs prefer warmer temperatures. If water temperatures rise permanently, cool water species will die out and be replaced by warm water organisms.

Temperature Testing Procedure

When doing multiple readings, be sure to use the same thermometer each time.

1. As with DO and pH, temperature must be tested immediately upon collecting the water sample, especially on hot days when the sample will warm rapidly.

2. Keep the thermometer in the water until a constant reading is attained (approximately two minutes). If using a digital thermometer, keep the probe immersed until the digital readout stops fluctuating.

3. Record all temperatures in °Celsius. If the thermometer is in °Fahrenheit, subtract 32 from the Fahrenheit temperature and then divide the result by 1.80.

Adapted from *Inland Lakes Manual*

Turbidity

Turbidity is the cloudiness of water caused by particles of suspended solids; the higher the turbidity, the murkier the water. As turbidity increases due to suspended solids in the water, light transmission is reduced.

At high turbidity levels, life support for aquatic organisms is compromised. Suspended particles absorb heat from sunlight, causing the water temperature to increase and oxygen levels to decrease (cold water can hold more oxygen than warm water). Photosynthesis will not occur if light penetration is too shallow and the entire aquatic food chain may be disrupted.

Other problems at high turbidity levels include particle clogging of fish gills, reduced growth rates, greater susceptibility to diseases, and smothering of eggs and larval organisms.

Sampling Procedures

A simple test of turbidity is to use a Secchi disk, a black and white weighted disk attached to a measuring tape.

Readings are taken as the disk is lowered into the water until it is no longer visible, at which point the depth is recorded. The disk is then lowered some distance more and drawn slowly up until it becomes visible again. A second depth is recorded here. Average the two depths to get Secchi depth.

Note: Secchi disk depths cannot be taken in water that is too shallow to allow the disk to disappear.

Adapted from *Inland Lakes Manual*

Module Three: Aquatic Habitats Analysis

Analysis of aquatic environments can be divided into basic measurements such as physical (light, temperature, conductivity), chemical, and biological components. The interactions between these factors are often more complex than in terrestrial habitats and more sensitive to environmental changes. Design and use of a standard form is the most efficient way to record the data from a study of aquatic habitats; this assures complete information is collected for every study done. A blank sample form is included with this lab.

Physical Parameters

The date, time of day, weather (including wind and cloud cover), and the name(s) of the observer(s) are always recorded. Spatial information collected includes the specific locality, topography, land use, type of water body, and watershed characteristics as appropriate. An aerial photograph and topographic map of the habitat is useful in determining accurate surface features such as the shape of the lake, the slope, form, and vegetation cover of the surrounding shoreline, inflows and outflows, and the location of sampling sites. Record the size of the water body and its center depth and use a topographic map to estimate the surface area of a lake. To approximate the volume, a ratio of the width divided by the center depth gives a rough index of surface area-volume ratio.

Atmospheric conditions affect the amount of incipient light at the surface, volume of water (precipitation and evaporation), temperature, water currents, and thus the distribution of organisms in the water column.

The substrate provides habitat for the benthic community (organisms that live on or in the bottom of a water body) therefore, record the type of substrate: clay, silt, sand, gravel, or rock. The bottom slope and depth of loose sediment should also be included.

For a general analysis of an aquatic habitat, in addition to the above parameters, record the following field measurements. Measurements can be taken at surface only, at surface and bottom, or throughout the water column, depending on data required for assignment ad equipment available.

- water temperature
- current velocity (if needed)
- turbidity
- Secchi depth
- pH
- conductivity
- dissolved oxygen
- alkalinity
- type of vegetation present in lake (phytoplankton, free-floating, rooted)
- pollution (organic and chemical) – type and amount

Biological Indicators

Some organisms, such as fecal coliform bacteria, cyanobacterial blooms, can be used as indicators of organically or nutrient enriched water. The quantified

presence or absence of such indicator species is recorded. Often, greater density of these organisms correlates to a greater degree of organic pollution. Estimate macroinvertebrate species diversity - use physical similarity if taxonomy is unknown.

Chemical Analysis of Habitats

Chemical components of a habitat, generally less visible than physical and biotic factors, significantly affect abundance and distribution of species and quality of habitat. While some chemical parameters, notably dissolved oxygen and pH, can be measured in the field, many require analysis in a laboratory setting. Procedures for analyzing these components can be found in Appendix 1. Whenever possible, dissolved oxygen should be tested immediately upon sample retrieval to ensure accurate readings. Samples for laboratory analysis should immediately be placed in a cooler of ice for transport to the analysis location. Analyses requiring sophisticated equipment or long time periods to complete are not included. For educators who have access to such equipment, perhaps at local college laboratories, procedures should be available at such locations.

Suggested Exercises

1. Compare habitat profiles of two different ponds, lakes, or streams. Note differences between the physical and chemical variables. Explain how those differences influence the development of aquatic habitats.

2. Compare habitat profiles of a polluted and unpolluted water body.

3. Use environmental variables such as temperature, turbitity, and oxygen, to determine their profile as a function of depth in a lake or pond.

4. Identify the relative abundance of major taxa of algae or benthic invertebrates. Note the relative abundance of clean-water or polluted-water taxa.

5. Record the progressive changes in as many of the following habitat variables as time allows. If possible, plot several weeks or months in order to see trends developing. Plot each variable and interpret trends and peaks.

conductivity	dissolved oxygen	phosphorus	turbidity
depth	nitrate	substrate type	water temperature

Aquatic Habitat Appraisal Worksheet

Lake Name: _____ County _____ Date _____ Time _____

Monitor Names _____

Secchi Depth in meters: Down _____ Up _____

Weather Conditions: ___ Strong sunlight ___ Bright clouds ___ Overcast

Precipitation: ___ None ___ Light ___ Medium ___ Heavy

Comments: _____

_____

_____

Wind Conditions: ___ Calm ___ Breezy ___ Strong _____ Direction

Water Surface: ___ Calm ___Ripples ___ Sm. waves ___ White caps

Comments: _____

_____

_____

Water Odor: ___ None ___ Fishy ___ Musty ___ Rotten egg ___ Septic-like

Water Conditions: Color _____

Suspended algae: ___ None ___ Light ___ Moderate ___ Heavy

___ Substantial (algal bloom)

Algae species if known: _____

_____

_____

Additional Comments: _____

_____

_____

_____

_____

_____

_____

Wildlife – type and number: _____

_____

_____

_____

_____

_____

_____

Depth/meters	Temp	DO	pH	Alkalinity	Conductivity	Pollution/Other

Key:	Wind:
	C=calm
	B=Breezy
	S=Strong

Water Surface:
C=Calm
R=Ripples
SW=Small Waves
MW=Moderate Waves
WC=Whitecaps

Water Conditions	
Algae:	**Odor:**
None	None
Light	Fishy
Moderate	Musty
Heavy	Rttn Egg
Bloom	Septic
	Other

Weather Conditions
A. Strong sunlight
Hazy sunlight
Bright clouds
Overcast

Waughop Data **Monitor Name**

Date		**Time**			Water	Water	Water	Water	Air	Wind Spd/	Secchi	Lake Depth	Weather
Depth-m	Temp°C	SpCo	DO	pH	Color	Surface	Algae	Odor	Temp°F	Condition	B = bottom	at Guage	Conditions
Comments													

Date		**Time**			Water	Water	Water	Water	Air	Wind Spd/	Secchi	Lake Depth	Weather
Depth-m	Temp°C	SpCo	DO	pH	Color	Surface	Algae	Odor	Temp°F	Condition	B = bottom	at Gauge	Conditions
Comments													

Date		**Time**			Water	Water	Water	Water	Air	Wind Spd/	Secchi	Lake Depth	Weather
Depth-m	Temp°C	SpCo	DO	pH	Color	Surface	Algae	Odor	Temp°C	Condition	B = bottom	at Gauge	Conditions
Comments													

Bird and Wildlife Census

Group/Class: _____

Study Site _____

A - Adult
J - Juvenile
UK - Unknown
F -Female
M- Male

Date	Time	Observer Name	Bird Type/ Animal/Type/	Common Name or Scientific Name (if known)	Gender (F, M, UK)	Age (A, J, UK)	Location/GPS data	Activity

Module Four: Aquatic Primary Productivity

The concentration and distribution of oxygen in aquatic environments are dependent on chemical and physical factors which are affected by biological processes. In both aquatic and terrestrial environments, oxygen is necessary for aerobic metabolic processes for almost all life-forms. Dissolved oxygen is an important indicator of water quality.

The atmospheric concentration of oxygen is about 200 ml of oxygen for every liter of air. In comparison, aquatic concentrations average only 5 to 10 mg of dissolved oxygen in a liter of water. In addition, water's ability to hold dissolved oxygen quickly decreases as water temperature increases. Respiration depletes water's dissolved oxygen concentration. A great deal of dissolved oxygen in water is used up as organic matter, including dead organisms, are decomposed. To avoid anoxia (lack of oxygen) the oxygen must be replenished from the atmosphere and from biological activity of plants in the aquatic environment.

Several factors affect the dissolved oxygen in aquatic systems:

- Temperature – As water temperature increases, dissolved oxygen decreases.
- Wind – As wind blows across the water surface, oxygen is mixed into the water.
- Turbulence – Water traveling in a riverbed is agitated by various natural obstructions such as rocks and trees. This agitation can mix in a great deal of oxygen.
- Trophic State – Nutrients in water determine how much life can be sustained in an aquatic environment. Water with excessive nutrient levels will become eutrophic, having high concentrations of oxygen in surface waters and low concentrations in bottom waters. For most aquatic species dissolved oxygen concentrations of less than 4ppm (parts per million or mg/L) are exceedingly stressful and often result in death. The ideal range for fish populations is 8 to 15ppm.

The energy produced through photosynthesis by plants is called primary production and all production in ecosystems stems from these autotrophs, or primary producers. Energy flow through a community begins with the fixation of sunlight by plants (photosynthesis), a process requiring energy. All solar energy assimilated in photosynthesis is termed **gross** primary production. Energy used in respiration is used in other biological processes such as maintenance and reproduction. The difference between these two processes is stored as energy and termed **net** primary production.

Primary productivity can be calculated by measuring oxygen release during photosynthesis versus oxygen uptake during respiration. For aquatic environments, a common method used for this is the **light bottle-dark bottle oxygen method.** Determining productivity is complicated by the fact that

phototrophs engage in both photosynthesis and cellular respiration. Phototrophs produce oxygen and glucose through photosynthesis, which requires light and carbon dioxide. Phototrophs also use some of the glucose they manufacture as an energy source through respiration, which requires oxygen. Phototrophs respire constantly, but photosynthesize only when light is available. It is therefore necessary to distinguish gross (total) primary productivity from net primary productivity.

Photosynthesis and respiration occur in a light bottle but only respiration occurs in a dark bottle. By comparing changes in DO from light and dark bottles, primary productivity can be calculated by measuring oxygen release during photosynthesis versus oxygen uptake during respiration. Samples of lake water and its phytoplankton are incubated in light and dark bottles suspended at various depths in the lake. The initial concentration of dissolved oxygen (DO_{init}) in the dark bottle decreases due to respiration (DO_{dark}). DO_{init} in the light bottle increases to (DO_{light}) - the difference between photosynthetic O_2 release and respitory O_2 uptake (assuming more O2 is released bu photosynthesis than is consumed by respiration).

Procedure

Day One

Determining the Initial (baseline) DO. Prepare and label three (two clear, one dark) BOD bottles for each depth; one-meter depth intervals are commonly used. One bottle is for baseline determination; the other two will be submerged in the water body for 24 hours. For each depth, fill two light bottles and one dark bottle with water from that depth. Assemble some heavy line and a method to attach the BOD bottles to the line for suspension at various depths.

For the baseline DO (DO_{init}), use a light BOD bottle with sample water. Attach the other light bottle (DO_{light}) and dark (DO_{dark}) bottles to the line at the appropriate depth level and return to the water body for incubation. Suspend the line with bottles from a buoy; attach a weight to the bottom of the line so each pair of bottles is suspended at the correct depth.

While in the field, determine the DO_{init} by following the HACH titration method. Record the data as the baseline in Table 1. **Note:** If your sample contains a heavy algae load, the algae will form a black precipitate that will not go into solution. This will not affect your results.

Incubate the samples in the lake for 24 hours.

Day Two

Retrieve the bottles and while in the field determine the DO of all six DO_{light} and DO_{dark} bottles by following the HACH titration method. Record the results in Table 1.

Calculate net and gross productivity

- (DO_{init} - DO_{dark}) measures respiration per unit volume during incubation.
- **(**DO_{light} – DO_{init}) measures net photosynthetic activity
- The sum of respiration plus net photosynthetic activity [(DO_{init} - DO_{dark}) + DO_{light} – DO_{init})] measures gross photosynthetic activity.

Table 1. Productivity Data

Depth	Bottle ID #	DO mg/L	Net Productivity	Gross Productivity
Surface	DO_{init} bottle ___			
Surface	DO_{light} bottle ___			
Surface	DO_{dark} bottle ___			

Depth	Bottle ID #	DO mg/L	Net Productivity	Gross Productivity
1 m	DO_{init} bottle ___			
1 m	DO_{light} bottle ___			
1 m	DO_{dark} bottle ___			

Depth	Bottle ID #	DO mg/L	Net Productivity	Gross Productivity
2 m	DO_{init} bottle ___			
2 m	DO_{light} bottle ___			
2 m	DO_{dark} bottle ___			

Depth	Bottle ID #	DO mg/L	Net Productivity	Gross Productivity
3 m	DO_{init} bottle ___			
3 m	DO_{light} bottle ___			
3 m	DO_{dark} bottle ___			

Adapted from Carolina Biological Supply

Module Five: Invasive Species Project

Step 1: Choose two partners and sign up for an invasive plant species to research. Each trio will be focusing on a different species.

Step 2: Conduct a literature search in the library and/or online. Write an annotated bibliography with a **minimum** of 10 articles from research journals and a **minimum** of 2 reputable scientific internet sources. Include the APA formatted reference and a paragraph of several sentences summarizing the research or information found in each source. For assistance with APA formatting, go to the website http://www.citationmachine.net.

Example:

Cipollini, M. L., Paulk, E., & Cipollini, D. F.(2002). Effect of nitrogen and water treatment on leaf chemistry in horsenettle (*Solanum carolinense*), and relationship to herbivory by flea beetles (*Epitrix* spp.) and tobacco hornworm (*Manduca sexta*). *Journal of Chemical Ecology*, *28*, 2377-2398.

Researchers were testing the validity of the Carbon Nutrient Balance (CNB) hypothesis by increasing nitrogen content and measuring different aspects of leaf chemistry. Also, they wanted find out if the presence of hornworm feeding altered leaf chemistry or the feeding flea beetles. They did the study both indoors and outdoors. They refuted the CNB hypothesis as increased nitrogen did not increase nitrogen-based secondary metabolites. The researchers did not measure the leaf chemistry before hornworms started to feed, so they think they missed leaf chemistry changes that could have occurred. The flea beetles were

less likely to feed following the hornworm feeding which followed the predictions made. They suggest further research on the Optimal Defense hypothesis which states there is an evolutionary basis for leaf chemistry.

Step 3: Find a representative of your invasive species at Fort Steilacoom Park.

Step 4: Take the class and instructor(s) to your invasive species and give a talk including: origin, classification, identification characteristics, habitat/distribution, removal techniques, and demonstrate at least one removal technique.

Grading: 75 points

		Description	Points	Total per step	Total awarded
Step 1	Submit topic	On time	1	1	
Step 2	Annotated bibliography	Journal/Internet source reliable, proper format good summary	2 X 12	24	
Step 4	Walk & talk	Summary of info: Origin Classification, Identification Characteristics Habitat Distribution Removal techniques	40	50	
		Removal demonstration	10	75	

This is a team grade at every step. Everyone must talk during the presentation.

Module Six: Aliens Among Us
Ecological Assessment of Native and Invasive Species

Aliens Among Us is an assessment activity for comparing the number of native versus invasive species present in an area. The majority of invasive species now in North America are the result of human actions; purposefully introduced or not, human actions and activities have compromised ecological processes all over the world. The restoration of these ecosystems and natural communities is an on-going effort undertaken on small and large scales in an effort to preserve and restore natural ecosystems. In this activity, students will use a scientific protocol to conduct a biological inventory of plant species in a nearby park and do a comparison of native versus invasive species.

This activity is designed to promote an awareness of how the natural world/natural processes function, how these relate to students' (humans') lives, and the effect of human actions on the natural world. Another goal is to develop a sense of the interconnectedness of Earth's components, including humans.

It's important to be aware of invasive species and the potential harm they can cause. Such knowledge can encourage people to understand how natural systems function, what activities will cause negative impacts, encourage planting of native species for home landscaping, and improve the health of native ecosystems.

Introduction and Overview

Biodiversity is an important indicator of the health of an ecosystem. The integrity of an ecosystem, especially in urban areas, is often compromised by invasive plant or animal species (most invasive species are non-native). These invasive species may arrive intentionally (scotch broom brought by settlers) or by accident (zebra mussels in ship ballast water). "A plant, animal, or other organism is considered invasive when it spreads at such a rate that it causes damage or harm to other species" (*Washington Invasive Species Coalition*). Not all invasive species become invasive or pose a threat to the ecosystem, but those that do can cause considerable damage.

Restoration ecology is a growing field in the natural sciences. As we learn more about natural systems and their importance, the more we recognize the need for restoring damaged ecosystems to a healthy state (particularly since humans are usually responsible for the damage). The Society for Ecological Restoration International defines ecological restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed."

Before any ecological restoration project can begin, an assessment of the site is done. Several methods are used to accomplish a complete and accurate assessment. This activity was created as part of a Pierce College course in restoration ecology. Pierce College, Fort Steilacoom campus, is located next to a

360 acre park, which includes a small lake. The park is under assault by several invasive species, and several public and private organizations are working to eliminate these invasive species; Pierce College among them. To conduct the assessment, students use a quadrat system to sample and identify the plant species present and determine whether they are native or invasive.
The activity can be adapted to any natural or semi-natural area that is large enough to have a variety of plant species. The activity is done as a practice run in the classroom before it's done in the park. With some extra set-up work, it can also be simulated inside if no outdoor area is available – just work through the practice activity. A sample species table is included below.

Big Ideas in my discipline: Effect of human activities on ecological processes

Big Ideas in sustainability: Ecosystem and biodiversity assessment

Materials needed
One **quadrat** for every 3-4 students. We made ours from one inch PVC pipe cut into one meter lengths and connected with PVC elbows. We left them unglued so they can be disassembled for easy transport in long, narrow bags (yoga mat bags work great). For those unable to make the quadrates, it's easy to improvise with this – even a hula hoop will work.

Field guides for plant identification – If doing the activity indoors, the following set-up work will be necessary: Find something that can be used to simulate a field of plants. A flowered sheet works well; just be sure there are several different types of flowers on it. Anything that has a random pattern would work, such as a flowered blotchy, or splatter-design floor or carpet. Designate each pattern element as a specific plant species and use the scientific as well as common name for each included (see below for an example using a flowered sheet). Take photos of each "species" and make up several field guides with the photo and name of all the species.

Learning Activity
Divide the students into groups of 3-4. Each group will need a quadrat, field guide, and note-taking materials. If you have a large class, you may need several sheets (fields) to accommodate everyone. Have students assemble the quadrats if necessary and then scatter the groups around the sampling area. Quadrat sampling can be done in two ways: make a numbered grid for the sample site and then select areas of the grid to be sampled by using a random number generator. The second method involves gently tossing the quadrat onto the sample site, using an "over the shoulder toss" to ensure random placement. Wherever the quadrat lands is the sample area. Students then sample the species composition within the sample plot using the Plant Plot Chart (both a blank and partially filled-in example are included below.). After counting the species, assign each one as **Braun-Blanquet** code: each species in the plot is assigned a code based on its contribution to the total area. Note that the **Braun-**

Blanquet code is a ranking indicating a percentage of the total number of species, not a percentage of the number of each species counted. There may be species that students cannot identify – as seen on the example chart, these are listed as an unknown with some identifying remarks. If doing actual fieldwork, a photograph of the unknown is taken for further research on identification. Repeat several times, continuing to use randomly generated sample plots to ensure an unbiased representation of the area. For consistency throughout, always have the same observer make the code classifications. After the counting and coding is done, have the students figure out the ratio of native to invasive species.

Assessment
Each group does a presentation of their research findings, explaining their Braun-Blanquet Code choices, native and invasive species found, best removal methods for invasives, etc. Students at Pierce are required to do a poster or PowerPoint presentation of their research and the collected data is added to our ongoing longterm research data collection. Posters can be displayed around the campus or classroom or in local public areas to inform the community of the status of the local natural areas.

Resources
There is a wealth of material on restoration ecology and invasive species available on the Internet. The Society for Ecological Restoration website is one of the best available: http://www.ser.org/

The federal government maintains an invasive species website: http://www.invasivespeciesinfo.gov/

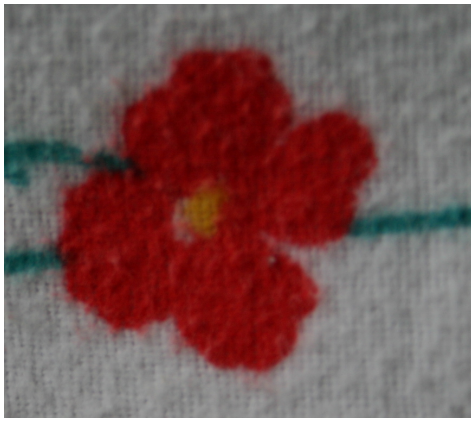
Most states and counties also maintain invasive species websites. Another good activity would be to have students access their local city, county, or state Noxious Weed website and report back on what the main invasive species are in their area.

Instructor Notes/Follow-up Activities
Do an instructor-facilitated discussion of the activity, focusing on what the data revealed. Was the study site all native? All invasive? A mix of both? Query students about why the species mix is the way it is. How did the invasives, if present, get there? If the site is compromised, should restoration be considered? If so, what would be the best restoration method? What would be the cost and who would pay for it?

Other suggestions for discussion/assignments
Student research/report on a single invasive species, including what it is, how it got there, its harmful qualities, and the best removal method
Why are invasive species negative?
Is there a situation where an invasive species may be a positive element?
Mapping of invasive species in an area.

Flowered Sheet Example

Camassia quamash Camas



Rosa nutkana *Nootka* Rose

Hedera helix English Ivy

Quercus garryana Garry Oak

Rubus discolor
Himalayan Blackberry

Lupinus lepidus
Prairie Lupine

Cytisus scoparius
Scotch Broom

Braun-Blanquet Code

0: species not present
1: species <5% of total
2: species <5-10% of total
3: species <10-25% of total
4: species <25-50% of total
5: species <59-90% of total
6: species <90% of total

Species Plot Chart

Plant – Scientific name	N/I*	Plot 1	Braun-Blanquet Code	Plot 2	Braun-Blanquet Code	Plot 3	Braun-Blanquet Code	Plot 4	Braun-Blanquet Code

***** N= native I= Invasive

Sample: Species Plot Chart

Plant – Scientific name	N/I *	Plot 1	Braun-Blanquet Code	Plot 2	Braun-Blanquet Code	Plot 3	Braun-Blanquet Code	Plot 4	Braun-Blanquet Code
Camassia quamash	N	20	3	0	0				
Cytisus scoparius	I	5	1	10	5				
Hedera helix	I	0	0	0	0				
Lupinus lepidus	N	7	1	0	0				
Quercus garryana	N	0	0	0	0				
Rosa pisocarpa	N	3	3	0	0				
Rubus discolor	I	10	3	0	0				
Invasive grasses	I	many	5	many	4				
Unknown small white flower	?	5	2	0	0				

***** N= native I= Invasive

Module Seven: Ecology Research Assignment

Part A. Find five local and different habitat Puget Sound restoration ecology websites and write a half-page summary of each site (covering the information available) and what you learned from it. Is the restoration in progress? Is it complete? If so, was it and success and if not, why not? Who are the stakeholders? Who supplied funding?

Part B. For each pair of terms below, explain how the two terms are related and how they differ.

a. biology and ecology
b. producers and consumers
c. scavengers and decomposers
d. omnivore and carnivore
e. primary consumer and tertiary consumer
f. restoration and rehabilitation
g. invasive and exotic species

Module Eight: Criteria for Writing a Scientific Paper

A. Form

1. Typed, double-spaced. 1.5” margin on the left, 1” margin at top, right, and bottom. A minimum 2” margin is required at the top of the title page. Page numbers placed upper right. Use 12 point font.

B. Format

1. There must be a title page indicating title of paper, author, instructor name, course name, and date. All elements should be centered horizontality and vertically on the page.

2. Spell out all numbers below 10.

3. Do not write in the first person (I believe, I think, etc.). Do not make the paper first person (This paper discusses, this paper talks about, etc.).

4. If you use printed material to substantiate a point, give the author credit. Scientific reports indicate whose material is being used either by quoting “_____”

   a. The (Author, date) refers the reader to the bibliography for that author’s work.

   b. Paraphrasing is putting another person’s thoughts into your own words. You may paraphrase more than one author in a paragraph; put both names and dates at the end of the paragraph, i.e. (Jones, 1995, Williams, 1996).

5. Maps, charts, photographs, or graphs are required and must be labeled and incorporated into the text of the paper at the proper place and the author given credit (Author, date). Graphics must be referred to in the text by number, i.e. (Fig. 1) and mentioned in the text body.

6. The paper should be four to five pages with the material presented clearly, logically, grammatically correct, and will cover your subject.

7. A bibliography is required. Six references minimum; they must be scientific sources (published in a scientific journal or book). Follow APA Style.

8. If you are using a direct quote from a source that is longer than 40 words long, keep the quotation together as a paragraph. Change the left margin for the block quote to be 0.5" (one half inch) to the right of the left margin. Double-space and omit the quotation marks.

9. The first page should be a title page (with header text and page number) that includes the title of the paper, the author, and the institutional affiliation.

10. There must be an **ABSTRACT**, located at the start of your paper and set apart from the body of the paper. The abstract is a short paragraph stating what you are discussing in the rest of the paper and should be written last. The abstract must be indented 10 spaces from both the left and right margins and should be single-spaced.

Research Paper

Write a four to five page (excluding graphics) scientific paper on an aquatic restoration topic or problem (instructor approved). State the topic/problem in the introduction, provide discussion and analysis in the body, and summarize in the conclusion.

Include figures, graphics, or photos as appropriate.

You need a **minimum** of six references excluding textbooks or encyclopedias. Your research should go beyond what you would find in either of these. Your sources must include a book and three scientific journals. Websites are acceptable, however, Wikipedia is **not** a scientific source; do not use it as one. It is a good place to find links to scientific sources. Websites ending in .gov or .org are usually scientific; if in doubt, check with instructor. Cite your references in the body of your paper in parentheses using author and year; **be sure to label and cite figures** and mention them in your text body. List your references completely on the references cited page (bibliography). Follow **APA** style.

Grading

Here are the criteria considered when determining your grade. This is your grading sheet. Please turn it in with your paper.

Content criteria (28 points)

_____ Demonstrated knowledge of the topic, with examples (20)

_____ Appropriate conclusions drawn from evidence (8)

Presentation criteria (52 points)

_____ Title page with informative and appropriate essay title (2)

_____ Informative and appropriate abstract (4)

_____ Introduction is informative, thesis is clearly stated (8)

_____ Figures, tables, diagrams, photos are informative and appropriate (12)

_____ Discussion/analysis is clear, logical and organized (8)

_____ Correct citation within text and complete citation in "Bibliography" (6)

_____ Appropriate grammar, diction, and spelling throughout (10)

_____ Turn in this sheet with paper (2)

_____ Total Points

Note: No title page, abstract, or bibliography will result in grade being dropped a full level for each omission.

Module Nine: Restoration Ecology Showcase Project

PowerPoint Presentation

Assignment: To create and present a PowerPoint presentation to showcase current or past aquatic restoration ecology projects in a local, national, or international context.

Create a PowerPoint presentation; include the following information

- **Location**: include a map
- **Historic state**: describe the historic state of the site
- **Degradive force**: describe why the site is a target for restoration
- **Stakeholders**: explain the groups involved, what motivated the restoration, who owns the land, who is involved in funding for the project, who is actually doing the project
- **Restoration work**: what is being done to restore the site, is it completed, long-term, ongoing, how long ago was restoration started, were the goals of the project reached (explain)
- **Stewardship plan**: what is the plan for maintaining the site after initial restoration project completion
- **References**: where did you get your information (make a reference section so detailed that your exact sources can be found)

Grading:

PowerPoint 50 points

- Includes all required components above (including a title page and a References page)
- Information relevant & summarized (not excessive)
- Grammar, punctuation correct
- Slides are readable with consistent background/font (20+ pt font)
- Pictures relevant

Presentation 25 points

- Knowledgeable about topic
- Organized
- Clear, audible voice
- Interesting & enthusiastic (appropriate humor)
- 10-15 minutes

TOTAL 75 points

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Appendices

Appendix A
Climatological Data For Sampling Dates

	6/14/07	7/3/07	7/17/07	2/5/08	3/24/08	8/12/08	10/8/08	1/17/09	2/14/09	3/21/09	5/17/09	05/10/11	05/24/11	06/20/11	08/02/11
Mean Temperature	13.8 °C	18.8 °C	17.8 °C	4.4°C	3.3°C	17.8°C	8.3 °C	1.1 °C	2.2 °C	2.8 °C	15.6 °C	12.2 °C	11.7 °C	16.1 °C	16.7 °C
Max Temperature	18.8 °C	26 °C	20 °C	6.7°C	9.4°C	25°C	13.9 °C	2.8 °C	7.2 °C	9.4 °C	24 °C	16.7 °C	18.9 °C	21.1 °C	25 °F
Min Temperature	9.4 °C	11 °C	15 °C	1.1°C	-2.2°C	10 °C	3.9 °C	0 °C	-2.2 °C	-3.3 °C	6.7 °C	7.8 °C	5.6 °C	11.7 °C	8.9 °C
Dew Point	6.1 °C	12.8 °C	14.4 °F	2.2°C	-2.2°C	12.8 °C	5 °C	0.6 °C	6 °C	3.3 °C	8.3 °C	6.1 °C	5.6 °C	11.1 °C	10 °C
Maximum Humidity	84	95	94	94	95	95	100	100	100	100	92	87	94	92	90
Minimum Humidity	39	44	64	77	36	50	58	87	61	64	38	52	44	51	43
Precipitation	0.00 in	0.00 in	0.15 in	0.45 in	0.00 in	0.00 in	0.00 in	0.00 in	0.00 in	0.00 in	0.00 in	0.00 in	0.00 in	0.00 in	0.00 in
Wind Speed	11 kph (North)	4.8 kph (NNW)	3.2 kph (West)	17.7 kph (South)	9.7 kph (South)	4.8 kph (West)	6.4 kph (South)	4.8 kph (ENE)	1.6 kph (WSW)	0 kph (NNE)	3.2 kph (WNW)	6.4 kph (WSW)	8 kph (SSW)	1.6 kph (NNW)	----------
Visibility	10 miles	10 miles	10 miles	9 miles	10 miles	10 miles	10 miles	1 miles	9 miles	4 miles	10 miles	10 miles	10 miles	10 miles	10 miles
events			Rain	Rain	Snow	Rain		Fog		Fog					

Appendix B
Lake Waughop Algae History

Date	Toxin Level(ppb)	Algae Species	Action Taken
05/22/08	35.800	*Aphanizomenon*	Monitor
07/15/08	406.000	*Microcystis*	Post Warning Signs/Notify Residents
07/23/08	1050.000	*Microcystis*	Closed Until Further Notice
07/30/08	73.600	*Microcystis*	Post Warning Signs/Notify Residents
08/06/08	138.000	*Gloeotrichia*	Post Warning Signs
08/12/08	56.200	*Microcystis*	Post Warning Signs/Notify Residents
08/20/08	136.000	*Microcystis*	No Decision
08/27/08	4.710	*Microcystis*	Post Warning Signs/Notify Residents
09/03/08	16.700	*Aphanizomenon*	Post Warning Signs/Notify Residents
09/09/08	42.300	*Woronichinia*	Post Warning Signs
09/16/08	148.000	*Woronichinia*	Post Warning Signs
09/23/08	59.600	*Aphanizomenon*	No Decision
10/14/08	92.500	*Aphanizomenon*	Post Warning Signs
10/08/08	22.400	*Asterionella*	Post Warning Signs
10/27/08	67.700	*Aphanizomenon*	Post Warning Signs
11/17/08	67.500	*Anabaena*	Post Warning Signs
11/03/08	0.983	*Aphanizomenon*	Post Warning Signs
11/17/08	65.400	*Microcystis*	Post Warning Signs
12/01/08	67.500	*Anabaena*	Post Warning Signs
12/08/08	51.700	*Anabaena*	Post Warning Signs
02/11/09	20.800	*Microcystis*	Post Warning Signs
02/18/09	68.800	*Microcystis*	Monitor
02/23/09	31.600	*Microcystis*	Post Warning Signs
03/02/09	0.795	*Microcystis*	Monitor
03/18/09	4.590	*Microcystis*	Monitor
04/06/09	58.000	*Microcystis*	Monitor
04/15/09	13.700	*Microcystis*	Monitor
04/20/09	7.910	*Microcystis*	Monitor
04/27/09	16.200	*Microcystis*	Post Warning Signs
05/04/09	256.000	*Microcystis*	Post Warning Signs
05/11/09	3.250	*Microcystis*	Monitor
05/20/09	0.038	*Anabaena*	Post Warning Signs
05/27/09	7.870	*Anabaena*	Post Warning Signs
06/14/09	382.000	*Microcystis*	Unknown
06/24/09	2.950	*Microcystis*	Post Warning Signs
06/29/09	25.530	*Microcystis*	Unknown
07/08/09	14.200	*Microcystis*	Post Warning Signs
07/13/09	31.400	*Microcystis*	Unknown
07/22/09	34.900	*Microcystis*	Post Warning Signs/Notify Residents
07/27/09	60.100	*Microcystis*	Unknown
07/30/09	237.000	*Microcystis*	Unknown
08/05/09	12.900	*Aphanizomenon*	Post Warning Signs
08/10/09	128.000	*Microcystis*	Unknown
08/19/09	1.090	*Microcystis*	Monitor
08/24/09	7.360	*Microcystis*	Unknown
09/01/09	495.000	*Microcystis*	Unknown
09/08/09	79.700	*Microcystis*	Unknown

Date	Toxin Level(ppb)	Algae Species	Action Taken
09/14/09	686.000	*Microcystis*	Unknown
09/21/09	23.700	*Microcystis*	Unknown
09/28/09	44.200	*Microcystis*	Unknown
10/05/09	34.300	*Microcystis*	Unknown
10/07/09	3190.000	*Microcystis*	Post Warning Signs
10/08/09	681.000	*Microcystis*	Unknown
10/08/09	1000.000	*Microcystis*	Unknown
10/08/09	21.600	*Microcystis*	Unknown
10/08/09	1620.000	*Microcystis*	Unknown
10/08/09	1580.000	*Microcystis*	Unknown
10/08/09	702.000	*Microcystis*	Unknown
10/08/09	44.000	*Microcystis*	Unknown
10/08/09	3060.000	*Microcystis*	Unknown
10/08/09	2950.000	*Microcystis*	Unknown
10/12/09	433.000	*Microcystis*	Post Warning Signs
10/19/09	1110.000	*Microcystis*	Unknown
10/27/09	461.000	*Microcystis*	Unknown
11/02/09	60.400	*Woronichinia*	Post Warning Signs
11/11/09	283.000	*Microcystis*	Post Warning Signs
12/01/09	76.000	*Woronichinia*	Monitor
12/01/09	0.725	*Woronichinia*	Monitor
01/06/09	719.000	*Microcystis*	Post Warning Signs/Notify Residents
01/20/10	81.700	*Microcystis*	Unknown
01/20/10	0.593	*Microcystis*	Unknown
02/01/10	419.000	*Microcystin*	Monitor
02/01/10	33.800	*Microcystin*	Unknown
02/02/14	419.000	*Woronichinia*	Monitor
02/09/10	64.200	*Microcystin*	Monitor
02/18/10	0.937	*Woronichinia*	Monitor
02/22/10	141.000	*Microcystin*	Monitor
03/01/10	66.900	*Microcystin*	Monitor
03/09/10	546.000	*Microcystin*	Monitor
03/18/10	10.500	*Woronichinia*	Monitor
03/24/10	128.000	*Microcystin*	Post Warning Signs
03/24/10	5.350	*Microcystin*	Post Warning Signs
03/24/10	0.461	*Microcystin*	Post Warning Signs
03/24/10	0.408	*Microcystin*	Post Warning Signs
04/01/10	8.990	*Woronichinia*	Monitor
04/14/10	28.600	*Woronichinia*	Monitor
04/19/10	316.000	*Woronichinia*	Post Warning Signs
04/26/10	1330.000	*Microcystin*	Post Warning Signs
05/06/10	422.000	*Microcystin*	No Decision
05/06/10	6.170	*Microcystin*	No Decision
05/06/10	0.822	*Microcystin*	No Decision
05/12/10	464.000	*Spirogyra*	Post Warning Signs
05/12/10	4.670	*Microcystin*	Post Warning Signs
05/12/10	0.699	*Microcystin*	Post Warning Signs
05/17/10	169.000	*Woronichinia*	Post Warning Signs

Date	Toxin Level(ppb)	Algae Species	Action Taken
05/17/10	1.190	*Microcystin*	Post Warning Signs
06/03/10	7.030	*Gloeotrichia*	Post Warning Signs
06/17/10	11.300	*Gloeotrichia*	Post Warning Signs
06/30/10	1.540	*Aphanizomenon*	Monitor
07/07/10	10.500	*Aphanizomenon*	Post Warning Signs
07/21/10	41.600	*Woronichinia*	Post Warning Signs
08/04/10	63.700	*Spirogyra*	Post Warning Signs
08/18/10	0.752	*Aphanizomenon*	Monitor
09/02/10	0.900	*Aphanizomenon*	Monitor
09/02/10	47.000	*Woronichinia*	Monitor
09/22/10	760.000	*Woronichinia*	Post Warning Signs
10/06/10	853.000	*Woronichinia*	Post Warning Signs
10/20/10	6.550	*Aphanizomenon*	Unknown
04/11/11	0.668	*Microcystin*	Monitor
04/28/11	4.750	*Microcystin*	Monitor
05/12/11	4.070	*Anabaena*	Monitor
05/25/11	6.450	*Anabaena*	Monitor
06/16/11	297.000	*Microcystin*	Unknown
06/20/11	634.000	*Microcystin*	Unknown
07/10/11	728.000	*Microcystin*	Unknown
07/25/11	3610.000	*Microcystin*	Unknown
08/04/11	7080.000	*Microcystin*	Post Warning Signs
08/17/11	3.760	*Microcystin*	Post Warning Signs
08/17/11	25.200	*Microcystin*	Post Warning Signs
08/22/11	6.500	*Microcystin*	Unknown
08/31/11	5.020	*Microcystin*	Post Warning Signs
09/07/11	14.100	*Microcystin*	No Decision
09/12/11	7.980	*Microcystin*	Unknown
09/20/11	28.600	*Microcystin*	Unknown
10/04/11	219.000	*Woronichinia*	Post Warning Signs
10/19/11	685.000	*Woronichinia*	Unknown
11/01/11	149.000	*Microcystin*	No Decision

Appendix C
Pierce College Field Limnology

COMMUNITY COLLEGE DISTRICT 11
COURSE OUTLINE

Division _Science and Technology__ Intent Code _1_ C.I.P. 40.0601

Department _Earth and Space Sciences Abbreviation & Number __ENVS 165__

Course Title ___Introduction to Field Limnology

Transcript Abbreviation _Field Limnology_ **(Maximum of 24 Characters including Spaces**

Credit Hours	Quarterly	10:1	20:1	30:1	50:1
5	Lecture __40_ Lab _20_			Clinical, Cooperative Education or Work Site _____	Other, e.g., Internships, Externships, Work Exp, Field Experience _____

Prerequisites, if any _____None_____

Submitted by: ___Michele LaFontaine and Elysia Mbuja_____ Date _____
(Name of Instructor)

Approved by: _____ Date _____
(Division Chair)

_____ Date _____
(Professional/Technical)

_____ Date _____
(Learning and Student Success- Instruction & Student Services)

EVALUATION USAGE:

A. Pierce College General Education Requirement (GER) for Associate of Arts Degree (AA):
Yes ___X___ No_____ ***If Yes, please indicate which Core Area:***

Communications	_____		
Humanities	_____	Humanities/Performance Skills only	_____
Natural Science	__X__	Natural Science w/lab	__X__
Quantitative/Symbolic Skills	_____		
Social Science	_____		

B. Pierce College General Transferable Elective (GTE) Yes __X___ No _____

C. Pierce College Professional/Technical Program? Yes _____ No __X____
Name of Professional/Technical Program _____

E.P.C. Code _____ C.I.P. _____

Course intended for: Academic Disadvantage Indicator (ADI)
____ Limited English Proficiency (LEP) ____ Work Based ____

Revised Spring 2005 **See next page for course description and course outcomes.**

CONTENT / OUTCOMES / ASSESSMENT

COURSE NUMBER:	**ENVIR 165**	**COURSE TITLE:**	**Introduction to Field Limnology**		
COURSE CATALOG DESCRIPTION:				**CREDITS:**	5
An interdisciplinary investigation of limnology, urban lakes, eutrophication, water quality, restoration planning, and the methods and challenges of lake restoration, with a focus on Lake Waughop in Pierce County.					
COURSE CONTENT:					
A. The physical environment (Atmosphere, Biosphere, Hydrosphere, and Lithosphere) B. Environmental and Cultural History of Lake Waughop C. Current status of Lake Waughop D. Properties of water and water chemistry E. Watershed Characteristics F. Methods of limnology G. Structure of Aquatic Ecosystems H. Phytoplankton and Zooplankton I. Native and Invasive species J. Urban Lakes and Eutrophication K. Restoration Options for Polluted or Contaminated Lakes L. Developing a complete restoration plan for a contaminated lake					
STUDENT OUTCOMES:					
1. Describe basic limnology principles 2. Apply the Scientific Method to solve environmental problems. 3. Diagram the hydrologic cycle and the movement of water and energy with it. 4. Diagram the major components of a watershed. 5. Summarize the roles of the atmosphere, lithosphere, and hydrosphere within the Earth system and relate each to the biosphere. 6. Explain the bio-geo-chemical cycles and summarize the flow of energy in an ecosystem and a food web. 7. Explain Primary Productivity in aquatic ecosystems and how it affects DO, pH, and nutrient cycles 8. Interpret topographic maps, aerial photographs, and satellite imagery for water resource studies. 9. Access environmental data and information from various sources including library and internet research. 10. Describe the physical and chemical properties of water and do water sampling and analysis. 11. Recognize and define the differences between native and invasive species, and be skilled at methods for scientific identification of both. 12. Evaluate human responsibility for sources and mitigation of water pollution. 13. Identify appropriate methods for removal/control of invasive species in specific situations. 14. Analyze the impact of population growth and human activities on urban lakes. 15. Evaluate the political processes required to attempt any solution to environmental degradation issues at the local level. 16. Use GPS technology to map invasive species distribution on a site. 17. Recognize the interdisciplinary nature of environmental issues and problem solving. 18. Analyze philosophical traditions and relationships between humans, animals, and the natural environment.					

Multiculturalism, Effective Communication, Responsibility, Information Competency and Critical, Creative and Reflective Thinking

CORE ABILITIES OUTCOMES:

1. **Effective Communication:** Ability to do field observation and make field notes of local animal and plant communities and formulate the data gathered into concise reports and presentations.
2. **Responsibility: Interconnectedness.** Sees self as part of more extended humankind and global community. Describes self and others in relation to environment (biotic and abiotic), animal kingdom, society, etc.
3. **Information Competency:** Demonstrate the ability to use the library and the internet as a resource tool for locating and analyzing environmental data and information.

POTENTIAL METHODS AND TOOLS FOR ASSESSMENT:

A. Conceptual Testing (e.g. essay, diagram, etc.)
B. Objective testing (multiple choice, fill in, matching, short answer, and computational)
C. Laboratory exercises
D. Group discussions
E. Extended group assignments
F. Field trip exercises and participation
G. Classroom participation
H. Instructor observation
I. Oral presentations
J. Written reports (field notebook, student journal, research paper, photo/sketch essay, portfolio)

Pierce College
Department of Earth and Space Sciences

ENVR 160: Field Course in Limnology & Lake Restoration

Course Description

Limnology is the study of inland waters including lakes, wetlands, and streams. This course will explore the basics of limnology and limnological field work and will include a student-managed case study of Lake Waughop, a small, shallow lake near campus. The course is a hands on field-oriented course using an interdisciplinary team approach to study and apply limnological principles and the restoration of aquatic ecosystems. Students will do extensive study outdoors using Fort Steilacoom Park and Lake Waughop as our primary work site. Lab work will include sampling aquatic systems, identification of and removal techniques for invasive species, water quality monitoring, measuring and interpreting limnological data, and identification of aquatic organisms.

Participation in numerous field excursions and one Saturday field trip are required, as is completing one service-learning community project. Students will learn and use mapping techniques and common ecology sampling methods.

Materials Required

Readings will be posted on Angel. It is your responsibility to read them on time.
Rite-in-rain notebook (5X7) for data collection
Student Lab notebook; sturdy
Student Journal (see below)
Weather appropriate clothing and shoes (comfortable walking shoes, warm clothing, etc).

Journal requirements

Each student must keep a course journal; each page should be numbered and dated. Take clear notes during every lab and field trip; the better your note-taking, the better your understanding and journal grade. Always include date, time, location, weather conditions, and sketches for every entry. Journals will be collected for grading five times during the quarter.

Make your entries at the time of the lab or field trip; do not try to take minimal notes and rewrite it later.
Write **clearly** and **legibly.**
All final copies of graphs must be computer generated and printed, not hand drawn. Tape them into your notebook giving a title, axis labels, and interpretation/explanation of what the graph shows.

In addition to these journal requirements, the following labs will require additional notes:

A. Field Gear Intro – we will be using this gear on a regular basis.

1. Take notes on how to use all equipment including Secchi disk, VanDorn sampler, plankton net, multi-parameter probe, and conductivity probe.

B. Field Trips

1. Description of sampling site
2. Notes taken at site
3. Record values collected at site
4. Plot depth profiles for variables taken at various depths

C. Organism Identification

1. Sketches of species of algae and invertebrates (zooplankton, insects, protozoa, etc.) should be drawn in the notebook
2. Accompanying each sketch should be an indication of organism identification and size, and a note of location, date, method of collection. A field guide to lake organisms is available in the Department Library.
3. Completing this requirement will likely take time outside normal lab schedule

D. Summary of collected data – take notes on discussion

Attendance

You are expected to attend **all** class sessions. If you miss a class, it is your responsibility to notify the instructor as soon as possible and to obtain the notes, assignments, etc. from another student. Class will begin on time. If you are late and we have moved out of the classroom, it is your responsibility to find our location. If you are habitually late, your grade will be negatively affected.

Field Trip Attendance

Field trips are required for this course and we will make several during the quarter. They will be during regular class hours and one Saturday field trip. Attendance is mandatory. Field trips are too complicated to allow for make-ups.

Academic Professionalism

You will be expected to act as an academic. A college student is one who conducts themselves mature and intelligent manner. Cheating or plagiarism will not tolerated, nor will copying from peers. If caught doing so, you will receive a zero for the assignment. You are expected to conduct yourself at all times in a manner that is respectful to others and conducive to the learning process. You have a lot of learning and exploration to do, so please use your time wisely. Refrain from conversation while instructors are speaking in both the lecture and in the field and turn off cell phones during class.

Course Grading and Requirements

There are 10 labs, a minimum of four field trips, short essays, worksheets (10–30 points), and a mid-term, lab practical, and final exam and practical. Additional assignments may be included.

Exams may use multiple choice questions, essay questions, and diagrams. There will be two exams and two lab practicals. **Make-up exams are not given except for emergency situations**.

Course grade is based on total points earned. Late assignments will be marked down 10%.

4.0 = 95%+	3.4 = 89%	2.8 = 83%	2.2 = 77%	1.6 = 71%	1.0 = 65%
3.9 = 94%	3.3 = 88%	2.7 = 82%	2.1 = 76%	1.5 = 70%	0.9 = 64%
3.8 = 93%	3.2 = 87%	2.6 = 81%	2.0 = 75%	1.4 = 69%	0.8 = 63%
3.7 = 92%	3.1 = 86%	2.5 = 80%	1.9 = 74%	1.3 = 68%	0.7 = 62%
3.6 = 91%	3.0 = 85%	2.4 = 79%	1.8 = 73%	1.2 = 67%	0.6 = 61%
3.5 = 90%	2.9 = 84%	2.3 = 78%	1.7 = 72%	1.1 = 66%	0.5 = 60%

If you choose to stop attending class/lab and do not initiate a Withdrawal (according to college guidelines and dates), you will be given a grade of 0.0.

Assignments

Invasive Species Project 65 Points
Conduct a literature search of your plant species in the library and/or online. Write an annotated bibliography with eight articles from research journals and a **minimum** of two reputable scientific internet sources. Restoration Site PPT

Research Paper 80 Points
Write a scientific research paper on a limnological topic. Topics must be approved by the instructor. Possible topics include pollution in lakes, aquatic invasive species, freshwater plankton, treatment methods for eutrophic lakes, and other related topics.

Restoration Site PPT 75 Points

Create a PowerPoint slide show which showcases a current or past aquatic restoration ecology project. The site may be local, national, or international.

Water Quality Sampling
Water samples will be collected from Lake Waughop throughout the quarter. Samples will be analyzed and graphed. We may sample other water bodies in the area for comparison studies if time allows.

Appendix D
Service-Learning Forms

Orientation Checklist for Service-Learning Project

Before First Day of Service

- ☐ Explain project mission and goals and history of restoration project.
- ☐ Discuss volunteer expectations.
- ☐ Provide students a job description detailing the work they will do.
- ☐ Give students project supervisor's contact information.
- ☐ Provide contact information if students cannot make the scheduled service or will be late.
- ☐ Discuss appropriate attire when providing volunteer service.
- ☐ Provide specific training for the work to be done.
- ☐ What will students learn?
- ☐ What qualities or skills will students develop?
- ☐ Review any risks associated with working on the project.
- ☐ Discuss the service schedule (total number of hours, days, times, etc.).
- ☐ Where do students check in on their first day?
- ☐ Give location of site and driving directions. Include parking information.
- ☐ Emphasize that student is responsible for getting to and from the site.
- ☐ Who will be evaluating the students' service?

On Site Orientation – Complete on or Before First Day of Service

- ☐ Tour of site – location of restroom, break times, where students will be working.
- ☐ Where is the logbook kept?
- ☐ Review safety rules of the site and emergency procedures.
- ☐ Introduce students to other staff at the site.
- ☐ Assign jobs and areas to students.

Adapted from Humboldt State University Form

Service-Learner Time Log

Name ______________________________ School ____________________

Course ______________________________ Professor __________________

Restoration Site ____

Date	Time In	Time Out	Hours	Activities

Student Evaluation

Student Name: _____ Date: _____

Work Site: _____ Supervisor: _____

Evaluation Period: _____ # of Hours Worked _____

Course Name and #: _____ Instructor: _____

A. 1 – Unsatisfactory, 3 – Satisfactory, 5 – Excellent. Use N/A if not applicable.

1. Fulfillment of Learning Plan Objectives	1	2	3	4	5
2. Sensitivity toward other workers	1	2	3	4	5
3. Regular attendance/punctuality	1	2	3	4	5
4. Quality of performance	1	2	3	4	5
5. Commitment to completing tasks	1	2	3	4	5
6. Adaptability to changes	1	2	3	4	5
7. Respect for confidentiality	1	2	3	4	5
8. Awareness of role in the community	1	2	3	4	5
9. Enthusiasm for service activities	1	2	3	4	5
10. Benefit of service provided	1	2	3	4	5

B. Please explain and ratings of 1 or 2.

C. Comment on student's strengths and any areas needing improvement.

_____ _____ _____

Faculty Name Faculty Signature Date

Student Assessment

Name: _____ Date: _____

Course # and name: _____

Service Learning

Site_____

Directions: The questions below relate specifically to the service-learning (SL) component within this course. Beside each statement, rate your level of satisfaction with the SL experiences you participated in.

5= Very Satisfied 1=Very Dissatisfied

I was able to apply the concepts I learned in class to the SL experience.

5 4 3 2 1

The SL experience helped me better understand concepts presented in the course.

5 4 3 2 1

Enough time was spent in class preparing me for my SL experience.

5 4 3 2 1

The time spent on the service project was reasonable.

5 4 3 2 1

Each member of my group contributed to the SL experience.

5 4 3 2 1

SL in this course strengthened the learning experience.

5 4 3 2 1

Overall, I am satisfied with the SL experience in this course.

5 4 3 2 1

Approximately how many children/adults did you work with and/or impact? _____

Approximately how many hours did you expend at or for your SL site? _____

Briefly describe the SL activity that you or your group engaged in at your site.

What difference did you or your group make at the SL site? Cite one example of how you or your group made an impact?

What did you learn as a result of your SL experiences in this course? Check the response that best reflects what you learned as a result of this course and SL.

___ Puts theory into practice

___ A new perspective; connections made between the classroom & real world

___ Hands-on learning is important to learning new concepts

___ Easier to understand class material

___ Enhances and expands the importance of class lectures

___ Benefit from collaborative teamwork

___ Other: Explain

In your opinion, how have you changed as a direct result of your community service? (e. g., I'm more patient, I'm less judgmental, I haven't really changed much, etc.)
Please explain:

What was your biggest challenge?

Do you think SL in this course should be changed or remain the same?

___ Keep SL as it is in this course

___ Change SL in this course

Below please briefly explain your response about what you particularly liked about SL and would keep the same or what you would recommend be changed in the course to enhance SL?

Would you take another course that included SL? YES_____NO _____
Explain below your reasons.

Adapted from Humboldt State University