Appendix B.

Lake Leota Analysis for City of Woodinville Sustainable Development Program, C. Michael Falter

LAKE LEOTA ANALYSIS

FOR

CITY OF WOODINVILLE

SUSTAINABLE DEVELOPMENT PROGRAM

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1.0 INTRODUCTION

This sub-report reviews the limnology of Lake Leota, emphasizing its physical and chemical aspects, plant communities, and apparent environmental controlling factors in the watershed. The lake's trophic status is then discussed with respect to the above controlling factors. Future analysis would address changes in lake condition in response to possible management alternatives. An evaluation of Lake Leota with respect to the Litowitz criteria follows. This sub-report is a component of a larger technical study by Steward and Associates that examines controlling issues in the watershed relevant to present and future land management in the city of Woodinville. This larger study explores the role of development density in the R-1 zone on critical issues to determine relevance to the Litowitz criteria, namely whether they are large in scope, have complex structures and functions, and a high rank order (following). Lake Leota is the critical area that is the focus of this sub-report.

2.0 CRITICAL AREA REVIEW

2.1 Setting of Lake Leota

2.1.1 Geology and Soils

Lake Leota is located near the southeastern corner of Woodinville, Washington, in King County, approximately 1.3 mile south of the Snohomish/King County line. The lake basin, like neighboring lake basins and stream channels, was formed in the undulating terrain of irregularly deposited glacial outwash left by southward flowing glacial melt waters. Vashon advance glacial outwash gravels underlie soils in the immediate vicinity of the lake. These materials extend slightly more than a mile up gentle flowages to the northwest and north (App. A to the Environmental Report, Figure 4) of the lake basin. These slopes contain the northwest and northern tributary channels to the lake. From 60 – 100 ft. above the lake extending further upward in elevation, Vashon glacial till underlies soils. A pocket of alluvium underlies soils approximately 0.3 mile north-northwest of the lake.

The peaty soil on the very flat slopes of land immediately adjacent to the lake are most likely wetland meadows formed by the process of lake aging where productive littoral (nearshore) aquatic plant communities gradually replace shallow water with dense emergent vegetation -filled shallow contours around the lake. Wet, peat-filled meadows eventually resulted. The present ring of vegetation-rich littoral (shallow, where light penetrates to the bottom) waters around the lake is a continuation of this aging process (Photograph 1). In the early phases of its history after basin formation some 11,000 years ago, Lake Leota would have been 3 – 4 times its present area and much deeper. The basin shape is indicative of a kettle lake basin, one left behind after blocks of erratic ice buried in the glacial outwash melted and left behind a recession in the gravels that would become the lake basin.

Soils near the lake are basically a dark sandy loam with prominent distinct redoximorphic accumulations (App. C to the Environmental Report). Wetlands are common along the northwest tributary channel and predominant around the lake in a nearly continuous band. Although wetlands are common around the lakeshore, with a few extending up tributary channels and swales, present wetlands are but a small remnant of pre-settlement wetlands. Their earlier presence, however, is important for the soils left behind. These old wetland soils are wet with high organic content. This type of soil tends to be oxygen-deficient, the low redox potential facilitating de-nitrification (nitrogen loss) and soluble phosphorus release from chemically bound states in the soils. These soils, therefore, have low phosphorus binding capacity rendering them poor substrate for septic drain fields. Much of the discharged phosphorus in sanitary systems around Lake Leota will rapidly saturate subsoil groundwater and flow to the lake.

The 506-acre watershed is steepest away from the lake. As described above, lands close to the lake slope more gradually and flatten out close to the water. There were no eroding soils or cut banks at the shoreline seen on my two visits to the lake in June and July 2006.

2.1.2 Watershed Vegetation

Vegetation cover in the watershed and around the lake tends toward the coastal climax forest, which once dominated these near-ocean hills. Douglas fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) remain the dominant large trees with western yew (*Taxus brevifolia*) and Sitka spruce (*Picea sitchensis*) common co-dominants. In the old growth stands, larger trees exceeded 250 ft in height and 12 ft diameter. Although species composition is similar to climax stands, present second or third growth trees tend to be considerably smaller and sporadic in small clumps or individual trees. Cedar, Douglas fir, and hemlock dominate the remaining second growth timber around the lake. Native understory was bracken fern, sword fern, salal, elderberry, black alder, big-leaf maple, and devil's club. Present understory plant communities are similar but spotty and may be dominated by the exotic shrubs blackberry and Scotch broom in sunny areas.

Shoreline vegetation composition and pattern is described in Appendix C of the environmental report. In general, however, the lake shoreline is nearly100% vegetated, either with the wetland communities described by Cooke or by lawns on the nearly flat lower slopes near the lake. Much of these lower lawn areas are developed from or built over the original wetlands, which surrounded the lake (Lake Leota Community Club, 2006).

2.1.3 Lakeshore Development Around Lake Leota

The watershed of Lake Leota was first platted and settled by newcomers to the Pacific Northwest in 1891 with a deed of surrounding lands to a Clinton West from the federal government. In 1902, Edward Brady, a lawyer prominent in the rebuilding of Seattle after the 1889 fire, acquired the land around Summit Lake (as Lake Leota was named at the time) and developed a cedar shake mill on its northeastern shore. Several other sawmills soon developed in the lake's watershed as the extensive cedar stands were harvested. By the mid-1920s, the watershed had been clearcut with the result that some of the stump lands were sold for taxes. As surrounding brush fields developed, Summit Lake became a destination for recreation trips but it was considered "still a seep lake, bog, and brush [sic]"(Leota Community Club 2000). In the 1932 original plat of Lake Leota Farms, the lake was first recorded as Lake Leota, named after Brady's wife. Restrictive covenants were in the original deeds restricting uses to recreational and residential only with specific prohibition of "any sewer drainage into the lake or any pollution of the water". Any use for manufacturing or public amusement was also prohibited by those original documents.

Twenty-eight platted tracts within a rectangle formed by the outer boundaries now surround the lake. All but 4 of the tracts extend to the water's edge. The seasonal cabins of the 1940s and 1950s have since developed into year-round homes on most of the properties. Tract development preceded incorporation into the City of Woodinville so individual, active septic systems surround the lake. Land use throughout the watershed is suburban low density residential with one small urban shopping area located to the northwest.

2.2 Limnology of Lake Leota

2.2.1 Basin Shape and Volume

The morphometric map of Lake Leota (Figure 1 below) depicts bottom contours and scale. These data are necessary for water, sediment, and nutrient loading estimates as well as zonal water and sediment volumes for lake rehabilitation work.

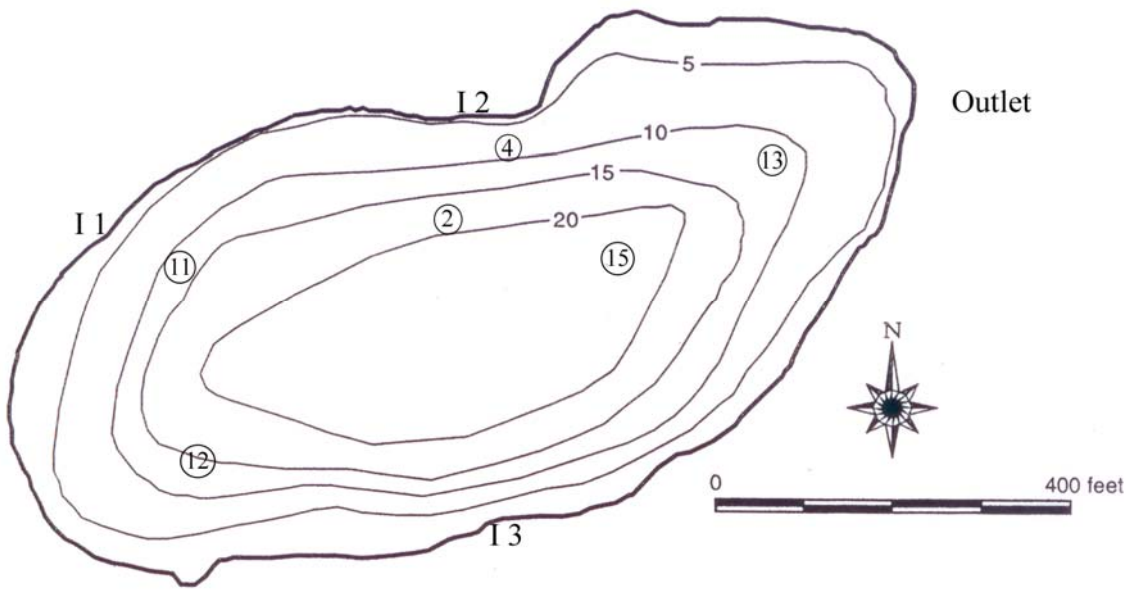


Figure 1. Morphometry of Lake Leota (Washington Dept. of Ecology, 1976). I1, I2, and I3 refer to lake inlet channels. Circled numbers refer to benthic sampling points, July 2006.

Table 1. Morphometric data calculated from the Lake Leota map (Falter 2006).

Measure	English	Metric
Maximum Length	1,100 ft	335 m
Maximum Width	520 ft	158 m
Watershed Area	506 Ac	202 ha
Lake Area at summer pool	10.44 Ac	4.2 ha
Maximum Depth	23.0 ft	7.0 m
Mean Depth	12.4 ft	3.8 m
Relative Depth (Mean Depth/Maximum Depth)	0.54	0.54
Mean Bottom Slope	6.0%	6.0%
Lake Volume	129.9 Ac ft 5,657,000 ft^3	 160,180 m^3
Area of lake when filled to the -2.5 ft contour*	12.34 Ac ft	4.9 ha
Area of lake when filled to the -5.0 ft contour	14.60 Ac ft	5.8 ha
Volume of 0 to -2.5 ft stratum	1,238,000 ft^3	35,083 m^3
Volume of 0 to –5.0 ft stratum	1,465,000 ft^3	41,515 m^3

* Using an estimated –2.5 ft contour line from the topographic map supplied by Appendix A to the environmental report.

The surface area of Lake Leota at summer water level is 10.4 acres (4.2 ha) or 2.1% of the watershed area. Since the lake has been observed to raise 2.5 ft following precipitation events, I calculated the lake area to be 12.34 acres if the lake rose 2.5 ft over typical mid-summer level. Maximum depth of that normal summer pool is 23.0 ft (7.0 m) while mean depth of the lake is 12.4 ft (3.8 m). Mean depth is 54% of the maximum depth. This moderately high relative depth suggests a greater tendency for water stratification in summer, freezing in winter, and relative isolation of deeper water and sediments from the unlimited light and oxygen available at the surface.

Mean slope of the lake bottom from shore to the deep point is 6.0%. Lake water volume is 129.9 AcFt; volume of the 0 to –2.5 ft stratum is 1,238,000 ft^3 or 22% of the lake at typical summer pool level. A 2.5 ft raise in lake surface elevation with a runoff event into the lake would then represent an approximate 22% increase in lake water volume. This large increase in lake volume with a small surface elevation occurs because of the very flat gradient of shoreline above the 0 depth contour.

2.2.2 Hydrology

Inflows to the Lake. Residents and King County Volunteer Lake Monitoring Program (KCVLMP) reports have long described Lake Leota as a seepage lake. It has three surface tributary channels, but is considered to receive most of its inflowing water *via* groundwater seepage (King County 1998-2005). These surface channels enter the lake from the northwest, north, and south slopes of the lake basin. The *northwest* channel,

although draining the largest land area (~291 acres), was the least scoured above the lake and had most heavily vegetated channel to its mouth at the lake. Its watershed has the gentlest slopes adjacent to the surface channel of Lake Leota's three sub-watersheds. Thus it is the most stable of the three tributary channels (Photograph 2). There is one stormwater retention facility about half way up that channel. On some maps, this northwest channel is designated as "Cold Creek" even though still upstream of the lake.

The *north* channel drains a higher density housing development on the north side of Woodinville-Duvall road as well as a length of that heavily trafficked road. Draining some 100 acres, this north channel shows some evidence of channel scouring. A lakeshore resident (J.D. White) who lives along lower reaches of the north channel reports past out-channel flooding of this channel as flows through a braided, but still heavily vegetated reach just above the lake.

The *south* channel drains approximately 115 acres. This channel shows recent severe scour and bank cutting in its lower reaches just above the lake (Photograph 5). This south sub-watershed is the steepest of the three Lake Leota sub-watersheds. Out-of-channel flows have resulted from culvert clogging at NE 180th St. just above the lake (Personal Communication, Rosie Paulgen). At the point of entry to the lake, all three tributary channels are very low gradient with thickly vegetated stream mouths (Photographs 2, 3, and 4).

Since the early 1990's, the KCVLMP has maintained at least weekly precipitation and lake level records on the lake. The lake surface elevation varies from annual lows in late summer/fall to highs late in winter and early spring (January to April). The annual range of fluctuation is commonly 2.5 ft (0.75 m) but has been up to 3.2 ft (~1.0 m). These records show a fairly rapid (within a week) response in lake level to precipitation events although the absence of tributary flow volumes and flow rates of groundwater seepage prohibits parsing the relative contributions of the varied water sources to the lake. The weekly resolution of precipitation and lake level data does not permit a fine analysis of lake response to precipitation but the data do commonly show a rise in lake level elevation of 10-15 cm in the week following a 4-6 cm precipitation event. In late December 1996 following a record very heavy snowfall (~2 wet feet) the lake rose 60 cm rise over the following week. We cannot tell how fast the lake rose within the week given the data resolution. Differences in lake response to comparable precipitation events over a year are most likely due to intensity of the precipitation and whether it occurred as rain or snow.

Outflows from the Lake. Lake Leota is "perched" above the Qva aquifer (Appendix A to the environmental report); perched lakes commonly lose most of their outflow as seepage, a common phenomenon in glaciated lands across the northern states. In lower valleys, the lake basins are on glacial alluvium and/or till with water retained in the lake by a relatively thin layer of muck. This "seal" may only be a few meters thick, permitting significant or all water loss from the lake as seepage to groundwater. The King County lake monitoring reports have stated that nearly all outflowing water leaves Lake Leota *via* groundwater flow. This is an important point and will be discussed later

in Section 2.3. Inspection of the lake outlet channel on July 19, 2006 showed the lake level was about 40 cm below the level necessary to deliver surface flow to the channel (Photograph 6). Vegetation development in the meandering outflow channel suggested that no surface outflow had occurred at least since the previous winter.

Surface outflows down the lake's single eastside surface outlet probably do occur most years in winter months but because of seepage outflows, not as often as inflow channels bring water into the lake. Seepage probably occurs mostly through the outflow sill. Surface outflows from the Lake Leota can be regulated by a drop board structure if flows are high enough. Lake Leota's surface outflow is commonly accepted as the beginning of Cold Creek even though still an intermittent stream at this point. These intermittent surface outflows are not gauged until the Cold Creek stream gage (02K) maintained by King County (App. A) about 1 mile below Lake Leota. Initial intermittent flows below Lake Leota gradually increase downstream from spring seepage until the stream has year-round flow by Gage 02K. Flows at the gage vary little around the year, averaging 3.5 – 4.0 cfs over all seasons (five-year record 2000-2005). Stream temperature at the gage also varied little with a 8 – 11 degree Celsius range (App. A) while Lake Leota surface temperatures showed a ~20 C temperature range over the year (King County Volunteer Lake Monitoring Reports 1998-2005).

It is clear that nearly all the water delivered downstream from Lake Leota to Cold Creek is as sub-surface seepage. Flow through the glacial gravels to surface springs in the downstream Cold Creek wetlands is sufficiently buffered by intra-gravel storage so that the seepage yield to Cold Creek is nearly constant in flow volume and temperature year-round. Anderson concluded that a 10-15% reduction in seepage to Cold Creek would result in a summer temperature increase of 0.5-1.0 C even in Cottage Lake Creek downstream of Cold Creek. Temperature impacts to Cold Creek *per se* have apparently not been estimated.

Lake hydraulic retention time (HRT) could be estimated if inflow rates were available. There is, however, no estimate of either surface or seepage inflow volumes per unit time. The implications of variable HRT, therefore, especially in relation to USRO (urban storm runoff) can only be estimated. Lake volume, necessary for evaluating sensitivity to nutrient loading, can be calculated, however. Given the weekly lake level change measurements published, we can roughly estimate lake volume change to some storm events. At this point, we can say that a 60 cm rise in lake level from a moderate 5-7 cm precipitation event can cause a ~20% increase in lake water volume. This increase is undoubtedly from a combination of surface and groundwater (seepage) flow but mostly surface flow since median hydraulic conductivity of the underlying Qvt and Qva materials is estimated at 53-86 ft/day. If watershed areas had hydraulic conductivities near the maximum range of those materials (1,000-3,056 ft/day), a significant proportion of flows to the lake as seepage within a week is possible after a precipitation event. This, however, is unlikely. At this point, we conclude that lake level rises following precipitation often occur within a week, are mostly due to surface inputs, and over a year's time can contribute a significant proportion of the lake's volume. Lake Leota HRT is probably less than 2 years. More important than the proportion of water

delivered to the lake, however, is the loading of sediments, nutrients, and heavy metals delivered to the lake (Section 2.4.2).

2.2.3 Physical-Chemical Aspects and Trophic Status of Lake Leota

Lake Leota is a shallow, mesotrophic, slightly colored (yellow in mid-summer; brown in late fall, winter, and early spring) lake with both its sediments and water dominated by watershed runoff (a combination of surface and seepage inflows).

Temperature and Thermal Stratification. The lake thermally stratifies in summer with surface temperatures ~23-25 C; 4-5 m water temperatures ~13-16 C; and 6-7 m temperatures ~8 C. Winter low temperatures in the water column are ~2-5 C cooling slightly near the surface towards ~ 0 C in an inverse stratification. Ice formation may occur along shorelines in some years; total ice cover occasionally occurs for a few weeks but is rare. Summer stratification is probably stable most years through summer into fall because of the basin's protection from wind-driven summer overturn of the water column. The resulting isolation of deep waters and sediments from surface water through the summer limits the strength and duration of warm season algae blooms as phytoplankton uptake depletes nutrients from surface layers. Phytoplankton in late summer-early fall should be very responsive to occasional runoff events resupplying needed nutrients during the long stratification period.

If surface outflow were to occur during stratification, it would be warm, certainly above 20 C. But since lake outflow at that time is as seepage, the temperature of summer water delivered to Cold Creek is closer to 10 C. Such seepage through the summer dry spells is further indicated by the steady decline in lake surface elevation.

Dissolved Oxygen. Levels of dissolved oxygen have not been included in the KCVLMP so we cannot calculate summer oxygen deficits of the deep-water layer over recent decades. Some surface oxygen data are available from the early '70s (Lake Leota Community Club files) but the inherent variability of surface oxygen data according to time of day, weather patterns, and water depth of samples sheds little light on lake dynamics. With thermal stratification through the summer-fall, we expect gradual oxygen depletion in deeper waters under the thermocline (zone of rapid temperature decline with depth creating a density gradient). With elevated phytoplankton growth in surface waters during algae blooms late in summer and fall, large amounts of organic matter settle into deep waters following senescence and death of the algae thereby depleting deep water oxygen, even to zero. The oxygen deficit may extend down into the sediments reducing oxygen levels there to zero also. This phenomenon becomes more intense and lasts for longer time periods as the lake progresses into eutrophy (sustained high levels of phytoplankton production). A self-sustaining cycle will develop as oxygen-depleted sediments release soluble phosphorus to the water column, sustaining continuance of phytoplankton blooms in warm, well-lit surface waters through fall overturn.

When zero oxygen levels in sediments cause reducing conditions, black deposits of heavy

metal sulfides (mostly FeS, MnS, PbS, CuS, and ZnS) may form in the sediments. These black layers (varves) will persist in the sediments as a permanent record of past periods of deoxygenation. In most lakes, these periods will be restricted to summer and winter stratification. Deepwater Lake Leota sediments we sampled on July 19, 2006 showed some black lenses of past metallic sulfide deposition (Photograph 8). Sediment odor and predominant brown color indicated oxygen-depleted, but likely not zero oxygen sediments at that time. It's likely that dissolved oxygen in the overlying water column on that day was present down through the entire water column to the lake bottom, *albeit* in very low concentrations towards the bottom.

Lake Monitoring and Lake Trophic Status. A very limited amount of Level I data (temperature, and water transparency) with occasional water chemistry and chlorophyll *a* data points are available in Lake Leota Community Club files. The absence of sampling and laboratory protocols for much of those data, however, prevents their inclusion in the long-term water quality trend comparison.

The KCVLMP managed a Level I sampling effort over the WY 95 to present period. The Level II data gathering level of effort managed by the KCVLMP from WY 98 to present adds water Secchi depth transparency, total nitrogen, total phosphorus, and chlorophyll *a* (a measure of phytoplankton production) in the water column over the lake's deep point. This level of sampling has produced a data record from WY 1994 (WY 94 = Oct. 1, 1993 - Sept. 30, 1994; WY 95 = Oct. 1, 1994 – Sept. 30, 1995; etc.) to the most recent published report for WY 2004. Resident volunteers carry out both Level I and II sampling efforts with samples sent to King County Water and Land Resources laboratories for analysis. KCVLMP believes the resulting data is reliable because they train the volunteers in water sampling and sample handling, analyze the data, and prepare data summaries. Annual mean values for these Level II parameters are presented in Table 2.

Table 2. Mean summer level II monitoring values for Secchi transparency, total nitrogen, total phosphorus, N:P ratios, and chlorophyll *a* from Lake Leota (KCVLMP data and selected files of the Lake Leota Community Club).

Water Year WY	**Secchi Transparency m**	**Total Phosphorus µg/l**	**Total Nitrogen µg/l**	**TN:TP Ratio**	**Chloro-phyll *a* µg/l**	**Precipi-tation at Everett Inches**
95-97 Mean	2.4					
1998	2.4	15.6	418	27	4.6	35.2
1999	2.8	21.3	669	31	18.6	47.9
2000	2.6	20.0	540	27	12.3	39.3
2001	2.0	22.0	540	23	15.7	29.9
2002	4.0	17.0	610	36	5.0	36.9
2003	3.7	18.1	463	27	4.9	25.2
2004	3.7	19.1	544	31	8.2	40.4

Water Year WY	Secchi Transparency m	Total Phosphorus µg/l	Total Nitrogen µg/l	TN:TP Ratio	Chlorophyll *a* µg/l	Precipitation at Everett Inches
98-04 Mean	**3.0 m**	**19.0 µg/l**	**540.6 µg/l**	**28.9**	**9.9 µg/l**	**36.4**

Secchi transparency is a measure of water transparency, the maximum depth that a standardized disk can be seen when lowered in the water column. Average summer water transparency in Lake Leota over the seven recent summer periods was 3.0 m, a value in the middle of the mesotrophic range of productivity. Transparency on individual days has ranged from observed highs of 4.5 m down to 1.25 m. Residents report that the lake may turn brown and very turbid with low transparency after precipitation events. The data in Table 2 show a marked increase in water transparency in 2002-2004 compared to 1999-2001 (3.8 m compared to 2.5 m), concurrent with a pronounced lower 3-year trend in plankton chlorophyll (6.0 µg/l in 2002-2004 compared to 15.5 µg/l in 1999-2001). Rainfall was lower in the 3-year high transparency/low chlorophyll period, averaging 34.2 inches in those water years *vs.* 39.0 inches in the 3 low transparency/high chlorophyll water years (Western Regional Climate Center 2006).

Figure 2. TP vs. Precipitation, WY 1998-2004.

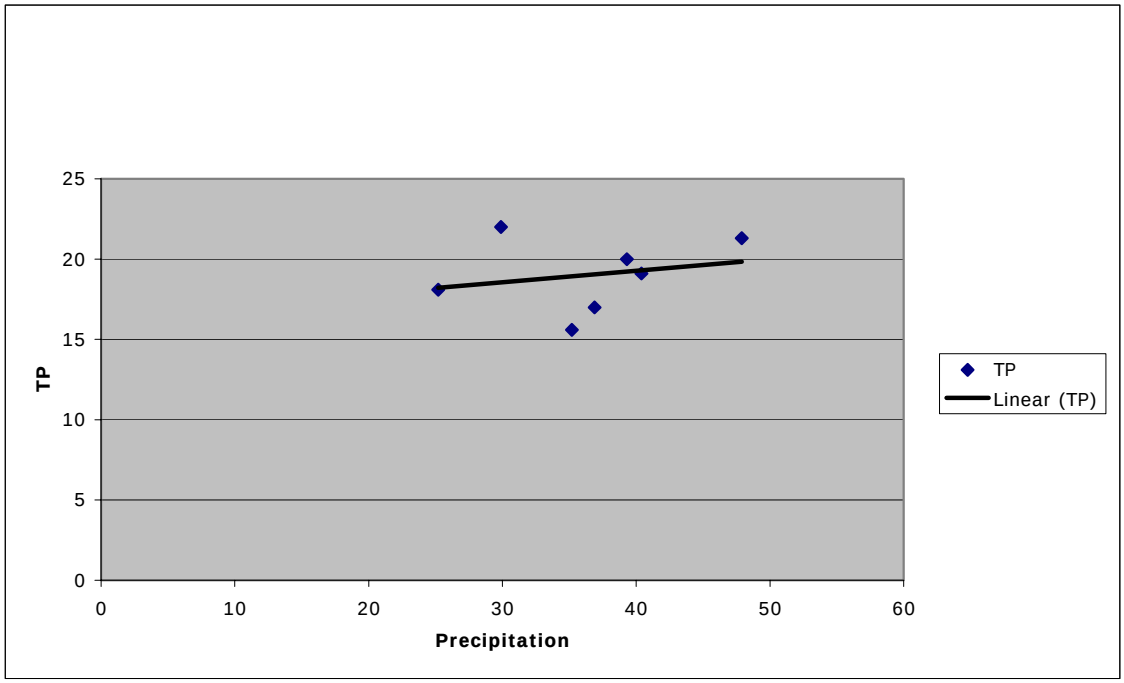
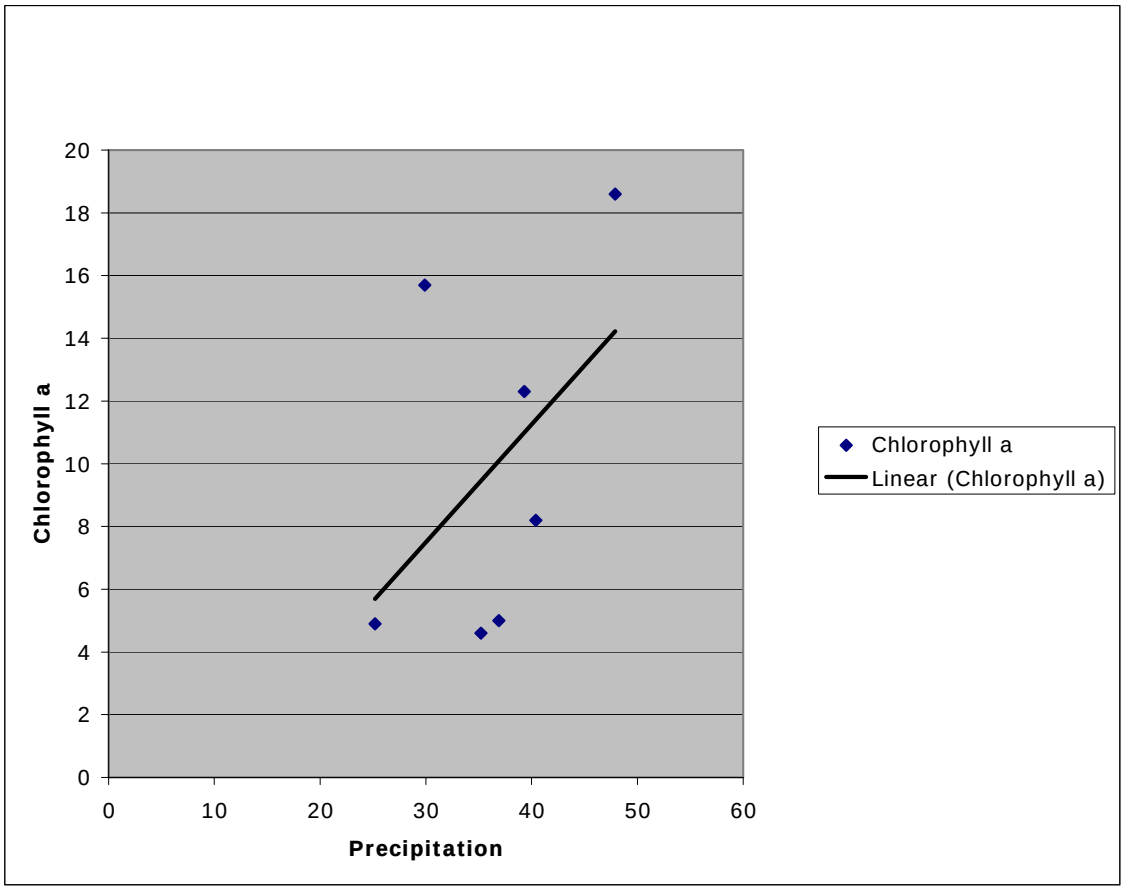


Figure 3. Chlorophyll a vs. Precipitation, WY 1998-2004.



Precipitation will increase phosphorus loading to the lake by increasing shallow groundwater flow to the lake as well as the occasional surface flush of the ground surface. This would explain the higher chlorophyll levels during higher precipitation years. There was no apparent relationship in those water years between annual precipitation and water transparency.

Phosphorus and nitrogen are the two plant nutrients that are most often limiting plant growth in fresh water in the northwestern U.S. The summer Total Nitrogen to Total Phosphorus ratio (TN:TP ratio) over the monitored time period averaged 28.9 (Table 2). Values over 16 indicate a phosphorus-limited lake (Cooke et al 2005). In Leota, mean TN:TP ratios were well above that threshold of 16 showing that the lake is clearly phosphorus-limited, thus responsive to either enhanced phosphorus loading (moving into eutrophy) or reduced phosphorus loading (moving below mesotrophy towards oligotrophy).

Average TP in that time period was 19.0 µg/l, TN was 541 µg/l, and chlorophyll *a* was 9.9 µg/l. The nutrients placed the lake in the middle of mesotrophy whereas resulting (chlorophyll *a* (phytoplankton production) gave a higher productivity, in the meso-eutrophic range. The anoxic days boundary values are included to show how many deep-water anoxic days might be expected in a mesotrophic to meso-eutrophic lake (20 to 40

days) even though anoxic days of deep waters were not quantified in Lake Leota. Its measured chlorophyll *a* suggests that Lake Leota averages 20-40 days of anoxic bottom waters in the summer-fall.

These data are an excellent long-term record of water column measures relevant to the lake's productivity potential. The above metrics, along with the Trophic Status indices presented in Table 4, efficiently track phytoplankton potential and actual growth over the summer period. These values can be compared with "standard" values prepared from a large number of lakes with varying trophic status (Table 3 below).

Table 3. Trophic state boundary values (Cooke et al. 2005).
CMF note: "Boundary" values are the break points between the trophic categories of oligotrophy, mesotrophy, and eutrophy.

Metric	Unit	Oligo-Mesotrophic	Meso-Eutrophic	Eutrophic-Hypereutrophic
Secchi Transparency	m	4	2	1
TP	µg/l	10	25	100
TN	µg/l	350	650	1,200
Chlorophyll *a*	µg/l	3.5	9	25
Anoxic Days	#	20	40	60

Trophic state is further defined by the Trophic Status Index (TSI), an integrative measure of lake potential and actual productivity (North American Lake Management Society et al. 2001; Cooke et al. 2005). TSI values from the KCVLMP are presented in Table 4.

Table 4. Trophic Status Index (TSI) values calculated from the KCVLMP water column-monitoring program for Lake Leota, Water Years 1998-2004.

Water Year	Trophic Status Index Secchi	Trophic Status Index TP	Trophic Status Index Chlorophyll *a*	Trophic Status Index Overall	Apparent Trophic State
1998	48	44	46	46	Mesotrophic
1999	44	48	53	49	Mesotrophic
2000	46	48	55	50	Mesotrophic
2001	49	49	54	51	Mesotrophic
2002	46	46	48	47	Mesotrophic
2003	41.4	44.8	44.9	43.7	Mesotrophic
2004	41.5	46.4	45.7	44.5	Mesotrophic
Mean	**45.1**	**46.6**	**49.5**	**47.3**	**Mesotrophic**

Since TSI values of 40 to 50 are considered mesotrophic, these calculated TSI values for water transparency and TP place Leota in the upper mesotrophic range (Cooke et al 2005, KCVLMP 1997-2005). TSI values for chlorophyll *a* place the lake right at and sometimes into the lower range of eutrophy (TSI > 50). Actual realized chlorophyll development is then slightly greater than water transparency and nutrient concentrations would predict. This is not uncommon in a shallow lake where nutrients are more efficiently utilized than in a deeper lake. The shallow water column permits phytoplankton to spend more time in warmer, better-lit surface waters thereby using available nutrients more efficiently.

2.2.4 Lake Leota Plant and Animal Communities

Phytoplankton. The phytoplankton community of Lake Leota is dominated by Chrysophytes, the flagellated golden brown algae. The Chrysophytes *Dinobryon*, *Synura*, *Ceratium*, and *Gloeobotrys* consistently dominate the plankton through much of the low flow seasons, accounting for the lake's brown water during times of little of no surface inflows. Minor, but common, members of the plankton community are the diatoms *Fragilaria*, *Asterionella*, and *Cyclotella*. Bluegreen algae numbers are low and seldom mentioned in the KCVLMP reports. Although blue-green blooms have not been a concern to date in Lake Leota Chrysophyte blooms are not rare. In September-October, 1999, a fall bloom persisted into mid-October with up to 35 µg/l chlorophyll *a* and water transparency of 2.0 m. Late summer blooms of Chrysophytes in 2001 produced chlorophyll *a* levels of 45 µg/l, exceeding 20 µg/l for 7 weeks. Secchi transparency dropped to 0.8 m at the bloom peak. A 7-week algae bloom is a very long bloom, again indicating the lake is moving into eutrophy. In 2002 there was a spring bloom of 17 µg/l chlorophyll *a* and 2004 had a fall bloom with 40 µg/l chlorophyll *a* and 2.2 m transparency. In recent years, Lake Leota has been clearly experiencing eutrophic algae levels of Chrysophyta blooms in recent late summer-fall periods even with mesotrophic nutrient concentrations.

The absence of blue-green algae blooms is notable as most north temperate zone lakes that are phosphorus-limited show increasing incidence of blue-green blooms in mesotrophic lakes. Seepage lakes with more highly colored water from a peat-rich, conifer-dominated watershed, however, commonly have an algae community dominated by diatoms and chrysophytes, the golden brown, flagellated algae.

Wetlands and the Shoreline Littoral Community. (The following is based on observations of Mike Falter, as well as Sarah Cooke in Appendix C.) Lake Leota has been identified on the King County Wetland Inventory as Big Bear Creek 9, a Class 2 wetland. The wetland described by the County encompasses the shoreline area with a few larger non-wetland areas (identified below and on App. C. All waterfront lots appear to have a narrow band of wetland vegetation at the interface of the lawn and water's edge. The City has documented a series of discrete wetlands along the lakeshore on various maps

that show critical areas. Appendix C shows the approximate extent of wetlands along the edge of the lake.

The dominant emergent plants observed in this littoral band around the lake are: Douglas spirea (*Spirea douglasii*), willows (*Salix sitchensis, Salix lucida, and Salix scouleriana),* Nootka rose (*Rosa nutkana*), Soft rush (*Juncus effusus*), Yellow flag iris (*Iris pseudacorus*), reed canarygrass (*Phalaris arundinaceae*), marsh cinquefoil (*Potentilla palustris*) Slough sedge (*Carex obnupta*), sawbeak sedge (*Carex stipata*), common cattail (*Typha latifolia*), creeping buttercup (*Ranunculus repens),* common horsetail (*Equisetum arvense),* giant horsetail *(Equisetum telmateia),* redtop *(Agrostis gigantea*), and Japanese knotweed (*Polygonum cuspidatum*). Further out in deeper water (0.5-2.5 m) the aquatic plant community shifts to one dominated by the long-stemmed emergents the yellow water lily (*Nuphar polysepala*) and exotic white water lily (*Nymphaea odorata*) as well as submergent plants dominated by coontail (*Ceratophyllum demersum*), elodea (*Elodea canadensis*), common bladderwort (*Utricularia vulgaris*), whorled watermilfoil (*Myriophyllum verticulattum*), and common naid (*Najas flexilis*). We collected low-growing muskwort (*Chara* sp.), stonewort (*Nitella* sp.), and moss (*Fontinalis* sp.) on the lake bottom beneath these afore-mentioned emergents and submergents out to 2.5 m depth, at the deepest observed limit of rooted aquatic plants in the lake.

Reed canarygrass, Japanese knotweed, and the white water lily are three of the more aggressive exotic emergent plants in Lake Leota. Apart from the adverse effects of these aggressive exotics on native plant diversity, they do have a positive role in nutrient absorption in the littoral zone. This band of emergent plants very effectively protects the shoreline from wave erosion and further buffers open lake waters from overland and shallow seepage flow of nutrients through nutrient uptake. The exotic submergent, Eurasian watermilfoil (*Myriophyllum spicatum*) or a possible hybrid with the whorled watermilfoil had been suspected with increased plant growth in the lake in 2004 (Patti An, personal communication with John Lombard 2/3/07). The King County Lake Monitoring Program (Drew Kerr working with Sally Abella) did genetic testing on the plants and concluded that it is not Eurasian Milfoil, but a native *Myriophyllum* species behaving aggressively. Plant morphology and filament counts by the author suggested that the milfoil common in Lake Leota around its margin is a hybrid of *M. spicatum* and *M. verticullatum* but since the Eurasian, whorled, and hybrid variants all have similar morphology, genetic testing is the definitive assessment.

Milfoil populations continue well into the early winter as indicated by a recent plant survey around the lake on November 8, 2004. At that time, the plant dominated the lakeshore emergent community. In July 2006, we noted no rooted aquatic plants beyond 2.5 m depth, thereby defining the littoral zone as the bottom sediments in the 0-2.5 m contour (0-8.2 ft). Since depth is a principal determinant of rooted aquatic plant occurrence, approximately 34% of the lake is potential rooted aquatic plant habitat. On our site visit, we did notice, however, that much of south shore sediments shallower than 8 ft had no obvious submergent rooted plants.

Wetland areas are identified by the city as being present around the lake's edge have been mapped on various maps (App. C). These have been compiled onto acetate overlaid on the aerial photographs (App. C). We visited the two largest wetland systems. The third large wetland system was on property to which we had no access (at the outlet of the lake in the northeast corner of the lake).

Zooplankton and Benthic Macroinvertebrates. Daphnia (water fleas) are a commonly mentioned zooplankton (very small, weakly swimming, open water crustaceans) in the lake by lake monitors. They have not been quantified over the monitoring program years. Routine monitoring reports, however, do indicate that Leota zooplankton may be very abundant at times.

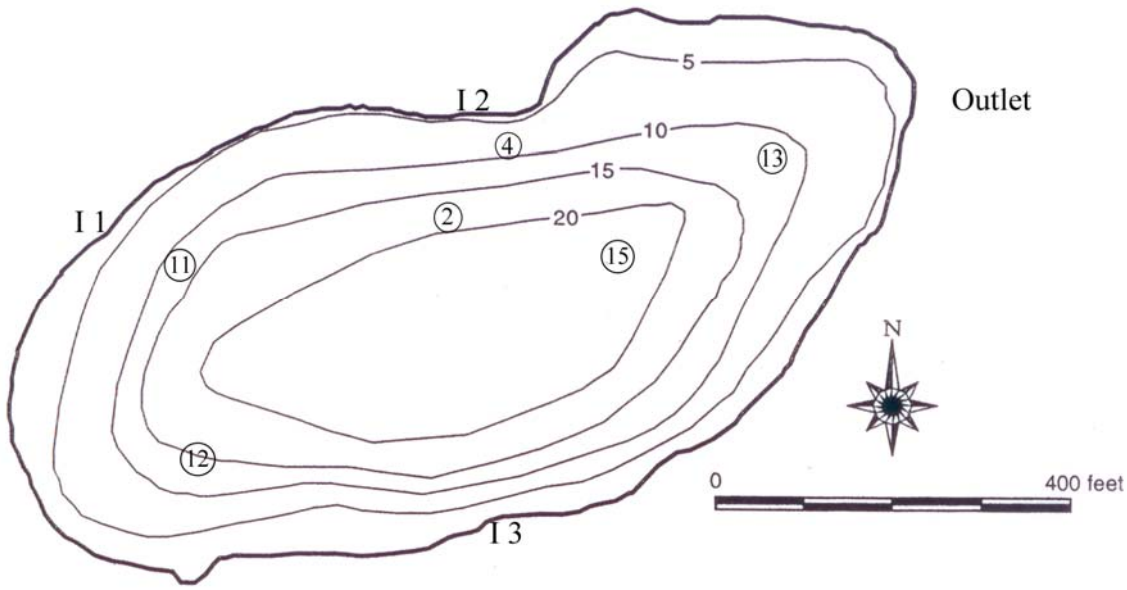
Sediment bottom invertebrate communities are a sparse assortment of midge larvae, mayflies, and caddisflies in littoral sediments where organic content is high beneath rooted vegetation beds. Benthic invertebrates are even more sparse in deeper sediments beyond rooted plants (>2.5 m depth). The sporadic periods of apparent deoxygenation in the deeper sediments would tend to suppress both numbers and diversity of benthic fauna.

2.2.5 Lake Leota Sediments

Sediment Carbon, Nitrogen, Phosphorus, and Sulfur: Sediments in Lake Leota appear to have a surprisingly high (considering it's such a small lake) clay content and very little vegetation and litter from terrestrial sources. That degree of sediment fineness in natural lakes is usually typical of exceptionally deep pelagic (open water) sediments or where sediments have formed very slowly in deep, very large central lake basins far removed from terrestrial influences. Neither is the case with Lake Leota, leaving stormwater inputs as the obvious source of the very fine sediments found there.

Metals in storm runoff to the lake were voiced as a concern at the July 2006 CAP meeting. Because Leota is a seepage lake with no significant loss of inflowing sediments downstream thus retaining its sediments, these sediments are a valid record of past loading of silts, clays, nutrients, and metals. Six sediment Ponar dredge samples collected by Hinson and Falter were therefore sent to the University of Idaho College of Agricultural and Life Sciences Analytical Sciences Laboratory, a lab certified by USEPA and the Idaho Division of Environment. Three samples were from comparatively shallow sediments (2.5-3.7 m) and three were from deeper sediments (4.5-7.0 m)(Figure 4).

Figure 4. Lake Leota with sediment sample sites indicated. Circled numbers refer to sediment samples described in Table 5. The 3 inlets are designated by I1, I2, or I3.



The Ponar dredge samples the top 5 inches of sediments. All samples were very fine-grained with little vegetative litter. Most of the samples had layers (varves) of beige-gray colored clay throughout the darker brown sediments. Dark brown was the predominant color with occasional black patches of reducing sediments left over from past brief anoxic intervals. Sediment descriptions and analytical results follow in Table 5.

Sediment carbon and nitrogen were higher in shallow samples than in deep samples, most likely because of high littoral (shallow water) photosynthesis and production of organic matter and also because of organic matter loss from deeper sediments by decomposition. Carbon content of shallow sediments averaged 19.3% compared to 13.6% in deeper sediments. For similar reasons, total nitrogen was higher in shallow sediments compared to deep sediments (1.40% compared to 0.96%). Loss of organic nitrogen from deeper, more oxygen-starved sediments is common because of denitrification loss to nitrogen gas in addition to high decomposition rates in those environments removed from light and reaeration from surface waters. Both carbon and nitrogen were high, in the eutrophic range, compared to sediments in a very eutrophic reach of the Snake River in southern Idaho where sediment carbon and nitrogen averaged 2.5% and 0.23%, respectively.

Sediment total phosphorus, however, was lower in shallow samples than in deep samples (1,077 µg/g compared to 1,867 µg/g). The heavy emergent and submergent aquatic plant communities at shallow sites will strip much of the available phosphorus from shallow sediments through the growing season, concentrating the phosphorus in above-sediment plant biomass. Deeper sediments, however, actively bind phosphorus with iron oxides during the majority of the months when surface sediments are aerobic. The lakewide mean sediment phosphorus of 1,472 µg/g compares to literature values of ~1,000 for oligotrophic lakes and ~ 2,500 and higher for eutrophic lakes (Cooke et al 2005). In a

eutrophic reach of the sediment-laden Snake River in southern Idaho, Falter et al. (1995) found sediment total phosphorus to average 1,031 µg/l over the summer.

Note: The probable aerobic nature of the lake's sediments for at least most of the year is further supported by the even distribution of sulfur in the sediments…. *if* deep sediments were anaerobic they would be concentrating disproportionately large amounts of sulfur as heavy metal sulfides, especially considering the moderately high availability of heavy metals in Lake Leota. Instead, mean sulfur concentrations were equal between shallow and deep sediments.

Sediment Metals: Metals concentrations from the 2006 sediment sampling are detailed in Table 5. The following observations may be made on the metals data from Lake Leota sediments:

- Shallow sediments were lower in total arsenic than deep sediments (<38 µg/g compared to 49 µg/g).
- Shallow sediments were lower in total chromium than deep sediments (35.3 µg/g compared to 75.6 µg/g).
- Shallow sediments were lower in total cobalt than deep sediments (11.1 µg/g compared to 20.3 µg/g).
- Shallow sediments were lower in total copper than deep sediments (45.3 µg/g compared to 65.6 µg/g).
- Shallow sediments were lower in total lead than deep sediments (111.3 µg/g compared to 173.3 µg/g).
- Shallow sediments were lower in total iron than deep sediments (~14,200 µg/g compared to ~33,000 µg/g).

Sample 4, taken just off the north inlet (I2), was an outlier in metals content, with concentrations of all metals (except those lower than MDL) far less than all other sites (Table 5). That channel drains a small drainage with some storm water retention capability. Even if we discount the one shallow station with very low concentrations of phosphorus and metals we can conclude that deeper sediments seem to collecting phosphorus and most heavy metals.

Table 5. Total carbon, nitrogen, phosphorus, sulfur, and metals concentrations in Lake Leota surface sediments. July 19, 2006. Dry weight concentrations. Phosphorus, sulfur,

			Sample 4	Sample 11	Sample 13	Sample 12	Sample 7	Sample 15	Lake Minimum Value	Lake Maximum Value	Lake Mean Value
		Depth >>	2.5 m	2.75 m	3.7 m	4.5 m	6.0 m	7.0 m			
Sediment Description			Fine brown organic over gray clay lenses, aerobic but few reducing chunks	Very fine brown organic, aerobic	Fine dark brown, highly organic, aerobic	Fine dark brown, scattered clay lenses, aerobic, very fresh	Fine dark brown, gelatinous, gray clay lenses, anaerobic	Fine dark brown, over thick gray clay layer	-	-	-
Element	Unit	MDL									
Carbon	%	0.02	20.0	19.0	19.0	18.0	14.0	8.8	8.8	20.2	**16.5**
Nitrogen	%	0.01	1.5	1.3	1.4	1.2	1.0	0.7	0.7	1.5	**1.2**
Phosphorus	µg/g	38	630	1,200	1,400	1,700	1,900	2,000	630	2,000	**1,472**
Sulfur	µg/g	75	3,500	7,200	6,200	6,600	6,100	4,200	3,500	7,200	**5,633**
Arsenic	µg/g	< 38	<38	<38	<38	43	48	38	<38	48	**<38**
Barium	µg/g	0.75	70	260	210	260	320	370	70	370	**248**
Beryllium	µg/g	0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	**<0.38**
Cadmium	µg/g	1.5	<1.5	3.4	2.9	3.5	3.0	1.7	<1.5	3.5	**2.9**
Calcium	µg/g	7.5	3,300	9,200	8,600	9,300	8,700	7,900	3,300	9,300	**7,833**
Chromium	µg/g	1.5	9.9	54	42	56	75	96	9.9	96	**55**
Cobalt	µg/g	1.5	3.3	18	12	16	19	26	3.3	26	**16**
Copper	µg/g	7.5	17	59	60	61	69	67	17	69	**56**
Iron	µg/g	3.8	3,500	21,000	18,000	23,000	33,000	43,000	3,500	43,000	**23,583**
Lead	µg/g	7.5	34	140	160	210	190	120	34	210	**142**
Magnesium	µg/g	0.75	880	5,900	4,700	6,100	8,200	10,000	880	10,000	**5,963**
Manganese	µg/g	0.38	190	510	340	410	460	560	190	560	**412**
Molybdenum	µg/g	3.8	<3.8	<3.8	<3.8	<3.8	<3.8	<3.8	<3.8	<3.8	**<3.8**
Nickel	µg/g	3.8	12	67	53	70	100	130	12	130	**72**
Potassium	µg/g	38	120	1,400	1,400	1,700	2,200	2,600	120	2,600	**1,570**
Vanadium	µg/g	0.75	16	67	51	75	85	110	16	110	**67**
Zinc	µg/g	1.5	78	310	260	280	250	190	78	310	**228**

and metals by ICP trace element screening scan.

Metals levels are high compared to lakes receiving less urban runoff such (Smith et al 1996, MacDonald et al 2000). Mean lead levels in Lake Leota deep sediments, for example, were 173.3 µg/g compared to the 128 µg/g level determined as a consensus effects level above which ecological impacts are expected to occur more often than not (Consensus-based Probable Effects Concentration) and in more than 50% of benthic organisms (Effects Range Median) (Table 6). Lake-wide mean sediment lead was 142 µg/l compared to the 128 µg/g consensus effects level. Regional northwest background levels of lead in freshwater sediments are accepted as in the 0-33 µg/g range. Mean nickel levels in Lake Leota deep sediments were 100 µg/g compared to the 49 µg/g consensus effects level and to the 50 µg/l median effects level. Lead and nickel were the metals found in highest concentration relative to their likely biological impact.

Table 6. Mean concentrations of selected metals in Lake Leota sediments, July 19, 2006. (Dry weight concentrations) compared to environmental effects thresholds.

Metal	Unit	mdl	Leota Minimum Value	Leota Maximum Value	Leota Mean	Lowest Effect Level	Probable Effects Level	Consensus-Based Probable Effects Concentration	Effects Range Median	Severe Effects Level
						Note 1	Note 2	Note 3	Note 4	Note 1
Arsenic	µg/g	< 38	<38	48	**<38**	6	17	**33**	85	33
Cadmium	µg/g	1.5	<1.5	3.5	**2.9**	0.6	3.5	**5**	9	10
Chromium	µg/g	1.5	9.9	96	**55**	26	90	**111**	145	110
Copper	µg/g	7.5	17	69	**56**	16	197	**149**	390	110
Iron	µg/g	3.8	3,500	43,000	**23,583**	21,200	-	-	-	43,766
Lead	µg/g	7.5	34	210	**142**	31	91	**128**	110	250
Manganese	µg/g	0.38	190	560	**412**	460	-	-	-	1,100
Nickel	µg/g	3.8	12	130	**72**	16	36	**49**	50	75
Zinc	µg/g	1.5	78	310	**228**	120	315	**459**	270	820

Note 1: Ontario Ministry of Environment and Energy 1993.
Lowest Effect Level = Level of sediment contamination at which the majority of benthic organisms are unaffected.
Severe Effects Level = Level of sediment contamination at which pronounced disturbance of the benthic community can be expected,
i.e. adverse effects in >95% of benthic organisms.
= Sediment concentration of a compound that would be detrimental to the majority of benthic species.

Note 2: Smith et al 1996.
Probable Effects Level = Concentration above which adverse effects are expected to occur frequently.

Note 3: McDonald et al 2000; Ingersoll et al 2000.
Consensus-Based Probable Effects Concentration = Consensus-derived concentration above which adverse effects are expected to occur more often than not.

Note 4: Long and Morgan 1991.
Effects Range Median = Chemical concentration above which adverse effects are seen in more than 50% of benthic organisms.

Most of the heavy metals analyzed were elevated over levels for freshwater sediments agreed to cause deleterious effects in benthic organisms living in lake sediments (Ingersoll et al 2000, MacDonald et al 2000, Persaud et al 1993). Stormwater runoff is the obvious source for most of these heavy metals, which mainly come into the lake attached to sediment particles; stormwater runoff flows are the most significant source of particulate matter to Lake Leota.

The conclusion that these elevated metals are coming into the lake from stormwater inputs down the intermittent surface channels rather than from internal lake-wide processes is further supported by the observation that one sediment sample (2.5 m depth, just east of the north inlet, no rooted plants) had low phosphorus and was very low in all the metals tested, relative to the other five sites. Metals at that site approached regional background levels in the range of lowest effects levels (Tables 5 and 6). Such variability could easily be from a localized eroding channel blowout bringing relatively clean, i.e. low metal concentrations, sediments into the lake.

2.3 Factors Controlling Lake Leota's Condition

2.3.1 Groundwater seepage

Lake Leota is primarily groundwater-fed with a seepage base flow:

- There are no perennial surface channels feeding the lake; surface inflows are intermittent.
- Some, but not large, surface fluctuation occurs after intermittent surface inflows.
- Nearly all outflow leaves the lake as seepage; it is reasonable that near-lake soils and alluvium would be similarly porous with high groundwater conductivity. This is corroborated by Anderson's sub-report.
- Water temperatures below the thermocline (the sharp density gradient in the water column separating warmer surface waters from colder deep waters) remain cold through the summer, colder than would be possible in such a shallow lake in this mild climate without significant cold groundwater seepage into the lake.
- Observation of emergent vegetation in the lake littoral zone indicates little surface elevation change through the summer (Cooke's sub-report) indicating a base inflow through the summer large enough to match outflow.

The underground seepage flows (clear, with low sediments, phosphorus, and bacteria but probably with significant nitrogen levels) dominate lake inflow. Soils around the lake are sandy loam merging into more peaty soils in wetland areas. These have high hydraulic conductivity and tend toward acidity thereby effectively mobilizing septic drainfield effluents.

2.3.2 Overland Flow

Residents report that in many, even moderate, precipitation events, surface flows do enter the lake down its three main, normally dry tributaries (northwest corner, north center, and south center of the lake). Storm events are now causing significant channel-shaping flows close to the lake in these tributaries. Residents and the water quality monitors have reported over the past 20 years that the lake can rapidly become quite colored (brown) following a precipitation event. There are three potential sources for this observed turbidity: 1) in-lake disturbance of shoreline or shallow sediments; 2) phytoplankton blooms; and/or 3) surface flows, either overland or down surface channels.

The lake shorelines are very stable, largely because of: 1) low gradient nearshore riparian lands, and 2) dense riparian vegetation providing soil stability and absorption of any non-channelized overland flows to the lake. Cooke's sub-report has described the 100% vegetative cover of these near-shore lands around the lake. Stable shorelines and apparently stable shallow sediments in the absence of bottom churning by carp eliminate shoreline and lake sediments as turbidity sources. Algae blooms would not muddy the lake so rapidly nor account for the clay deposits in sediments (Section 2.2.5 and

Photograph 8). The only remaining turbidity source is the intermittent surface flows from overland sources down tributary channels. Color (dissolved organic substances from the peaty wetland soils and coniferous tree cover prevalent in the drainage) can come in to the lake in both surface and seepage flows if hydraulic conductivity is high enough.

2.3.3 Nearshore Development and Lake Use

The lakeshore is fully developed and comprised of platted lots with residences, mostly year-round. Apparently all residences are on individual septic systems with drainfields. The soils described above readily mobilize and transport the limiting nutrients, phosphorus and nitrogen, downhill short distances to the lake. The extensive lawns encompassing the lake also undoubtedly supply large amounts of available plant nutrients to the lake. Although landscaping, shoreside riparian plants, and in-lake littoral vegetation comprise a nutrient-absorbing buffer zone, many nutrients still are transported to the lake.

2.3.4 Eutrophication

Lake lifetime is a critical issue since the lake is not static in time; as the basin shallows, it becomes more productive with water increasingly enriched from lake sediments. Since the lake is now mesotrophic to meso-eutrophic, higher rates of nutrient loading would be expected to speed shallowing and lake aging. With advancing eutrophy in the already shallow lake, the lake as a permanent basin is probably in jeopardy given the present stormwater loading further decreasing water depth. Throughout King and Snohomish Counties, untreated urban/suburban stormflows have been shown to contribute high sediment loads, as well as nutrients, toxics, and bacteria to receiving basins. The end result of the aging process is a wetland followed by a wet meadow.

The controlling roles of 1) storm runoff and 2) littoral (inshore) organic-rich sediment deposits from emergent (primary) and submergent macrophytes (secondary) appear to be the major factors setting the lake's life span.

2.3.5 Metals in Lake Sediments

Metal concentrations in the sediments of Lake Leota are elevated; most samples exceeded thresholds of probable injury to the benthic macroinvertebrate community. Lead and nickel were the two metals with highest concentrations relative to toxic thresholds. Evidence suggests sporadic overland flows (mostly from impervious, trafficked paved surfaces) as the major metals source.

So long as lake sediments remain aerobic and effectively bind most metals to the sediments, most metals impacts are to the sediment-dwelling benthic organisms. Anaerobic conditions, however, cause a reducing environment in the sediments whereby significant quantities of toxic metals can be mobilized from to the overlying water

column with potential toxicity to organisms lake-wide. A eutrophic lake with extensive time periods of summer/fall anaerobic sediments would produce those conditions suitable for metals release to the water column and downstream.

2.4 Relationship of Lake Leota to Downstream Stream Habitats

Lake Leota is trapping nutrients (relevant to downstream eutrophication) and heavy metals (relevant to downstream toxicity to migratory and listed salmonids) with potential future negative impacts on sensitive salmonid habitat downstream in the Cold Creek drainage. At present, the lake's deep sediment storage of phosphorus and metals effectively remove these drivers of eutrophication and toxicity from biotic uptake. At present levels of watershed development, stormwater runoff to Lake Leota is sufficient to increase sediment phosphorus to mesotrophic levels and metals to levels exceeding toxic thresholds. Sediment lead levels are higher than consensus concentrations found to produce adverse impacts on more than 50% of the benthic organisms in freshwater sediments. Little of this sediment apparently presently leaves Lake Leota because of its minimal surface outflow.

Most of Lake Leota's outflow is *via* seepage, hence is cooled by underground flow before emerging to lower stream channels. The 1979-2004 25-year monitoring trend by King County Water and Land Resources Division (WLR) in Cottage Creek showed an increase in temperature and decrease in dissolved oxygen over the monitoring period. Temperature and dissolved oxygen are both critical water quality parameters to downstream listed salmonids in the Cold Creek system. Warmer water directly limits salmonids and their food supply as well as reducing dissolved oxygen concentrations. In 2005, King County WLR showed Cottage Creek in the 75th percentile of streams in the WRIA 8 Region. This is a moderately high ranking which also points out is vulnerability to warmer, oxygen-deficient inflows. A lake shallowed by more sediment deposition would be expected to deliver more of its outflow to the surface outlet channel, thereby sending much warmer water downstream to the Cold Creek/Cottage Creek system.

The present lake basin is shallow, with limited sediment storage capacity and vulnerable to future sediment loading. Inflowing channels presently have areas of instability and eroding channels. Increased stormwater inflows resulting from higher density development in the drainage would speed basin filling and progress toward eutrophication, shortening the lake's life and thereby, its sediment and pollutant-trapping capability. Downstream impacts would increase under those conditions. Such downstream impacts of a shallower, warmer, more eutrophic outflowing Lake Leota on the sensitive downstream environment of migratory salmonids would certainly be complex and large in spatial scope, since they would extend well beyond the lake's watershed and the city limits. The linkages of Lake Leota to the downstream Cold Creek system and its salmonid populations gives it a very high environmental value.

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4.0 PHOTOGRAPHS

1. Lake Leota from the north looking south. July 19, 2006

2. Point of northwest tributary entering the lake. July 19, 2006

3. Point of north tributary entering the lake. July 19, 2006

4. Point of south tributary entering the lake, July 19, 2006

5. Culvert in South tributary. July 19, 2006

6. Lake outlet channel. July 19, 2006

7. Nymphaea and iris-dominated littoral, near northeast inlet. July 19, 2006

8. Lake sediments from point 2.5 m deep, 70 feet E of N inlet. Note lenses of fine clay deposits interspersed with orange lenses of oxidized iron. July 19, 2006