Oregon DEQ Harmful Algae Bloom (HAB) Strategy

Appendix C

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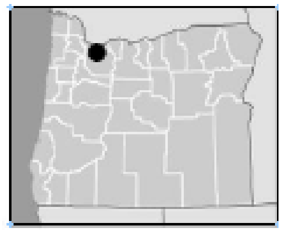


Multnomah County, Willamette/Sandy Basin, Willamette Valley Ecoregion

State of Oregon Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Blue Lake is a 61 acre natural lake in east Multnomah County that lies parallel to the Columbia River and about 1000 feet south of it. It is a floodplain lake and was formerly connected at high water with the Columbia River, at which time river water ran through the lake into the Columbia Slough. A dike (along which Marine Drive runs) now extends along the south shore of the Columbia, blocking any surface connection with the river.


Source: Oregon National Guard, 1981-82. View looking north.

The lake lacks any natural surface inflows or outflows. Instead, groundwater inflow, precipitation and overland runoff are the major hydrologic inputs, while groundwater seepage, surface evaporation and controlled releases via a weir on the northeast end of the lake control hydrologic losses. The direction of groundwater flow (into or out of the lake) relates to the stage of the Columbia River; when the river elevation is higher than that of Blue Lake, there is sufficient hydrostatic pressure to drive groundwater flows into the lake, and the opposite occurs when Blue Lake's water elevation exceeds that of the Columbia. Additionally, the City of Portland typically pumps groundwater into the lake each summer in order to maintain a water level sufficient for in-lake recreation and to avoid damage to structures such as docks. In 2009, approximately 17 million gallons were pumped into the lake on August 20 and 21. (Temple, 2009)

Twenty-one percent of the 128 acre watershed is privately owned, while the remaining 79% comprises Blue Lake Park, which is owned and managed by Metro. The lake's proximity to the Portland metropolitan area and its easy access have made it an important recreational resource for boating, waterskiing, swimming, fishing and picnicking. Warm water fish species such as black crappie, bluegill, largemouth bass, carp and brown bullhead are the major components of the fish population. Rainbow trout are stocked by the Oregon Department of Fish and Wildlife.

Blue Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake, now diked **Use:** recreation **Elevation:** 14 ft (4.3 m)
Location: 11.5 miles east of Portland city center

Drainage Basin Characteristics:

Area: 128 acres **Relief:** low **Precipitation:** 43 in (109 cm)
Land Use: Water-59.4%; Ir Ag-21.4%; Urban-17.6%; Other-1.7% (park)

Lake Morphometry:

Area: 61 acres (24.7 hect) **Depth:** Maximum - 24 ft (7.3 m); Average - 11ft (3.5 M)
Ave/Max Depth Ratio: 0.480 **Volume:** 692 acre ft (.85 cu hm)
Shoal area: 46% **Volume factor:** 1.42 **Shape factor:** 1.81
Length of Shoreline: 2 mi (3.2 km) **Retention time:** indeterminate

Water Quality: Water quality problems have been a long-standing issue in Blue Lake with the use of herbicides to control both algae and macrophytes beginning as early as the 1940's (Beak, 1979). Cooper sulfate was applied from 1940 until as late as 1982 to the swim area and margins of the lake to control algae. A variety of herbicides have been applied overtime to address invasive aquatic plants including: curly leaf pondweed (*Potamogeton crispus*), fragrant waterlily (*Nymphea odorata*), and Eurasian watermilfoil (*Myriophyllum spicatum*). (Temple, 2009)

A lake study (Beak, 1979) and follow-up Clean Lakes Study (Beak, 1983) were conducted for Multnomah County (who owned and managed Blue Lake Park before its transfer to Metro) to make recommendations for lake restoration. At that time, aquatic macrophytes extended to the water's surface over much of the lake during the summer months. Algal blooms reduced water clarity. In 1976, the swim area was closed because life guards could not see below the water's surface. The death and decay of the aquatic growth produced obnoxious odors apparent to visitors and residents. A provisional nutrient budget found that nutrients were accumulating in the sediment and that major sources of nutrients were internal sources (sediment release of phosphorus, nitrogen fixation by algae) and groundwater. The Blue Lake Aquifer is high in both nitrogen and phosphorus, part of this may be due to legacy loading from cesspools in mid-Multnomah County. This area is now sewered. Other external sources such as water fowl and fertilizers were found to be relatively low.

A range of recommendations for lake and watershed management were made. The initial study recommended: modifying the swimming area; discontinuing the use of phosphorus-containing fertilizers in the lake watershed; if used, applying herbicides in a more systematic manner than had been done in the past and accompanying the application with a pesticide monitoring program; and adding low-phosphorus water to the lake to dilute nutrients, flush algae, possibly oxygenate bottom waters during the summer and reduce lake water temperature. The subsequent 1983 study recommended a unified lake management program (combining efforts of Multnomah County and the Homeowners Association) with a plan that included: the systematic application of 2,4-D to control water-milfoil accompanied with a water, sediment and tissue monitoring program; an application of Alum to reduce total phosphorus; continuation of dilution and flushing of the lake with Bull Run Reservoir water with the Portland Water Bureau; a plan to improve fish habitat and angler access; a plan for continued water quality and macrophyte monitoring; and the use of lake drawdown to control macrophytes if the use of 2,4-D was not possible or permitted. Lake level drawdown to control weeds was tested in winter of 1981-1982 and was not recommended a primary means of controlling watermilfoil.

Paleolimnology has indicated that Blue Lake has changed substantially in the 20th century (Eilers, 2004). The sediment accumulation rate has increased although the dominant erosional inputs from major floods have been controlled by the dams along the Columbia River. Nitrogen is increasing in the sediments reflecting either increased N-fixation or increased inputs from the watershed with sediment nutrient concentrations increasing by about 60% over pre-development rates. Increase of phosphorus in the sediments appears to be on the order of 40 – 50% greater than pre-development rates. The signature of copper from copper sulfate usage from 1940 to the early 1980's was clear in the sediment with elevated copper levels found in the strata that reflected the period of usage. Based on akinete (cyanobacteria resting cells) data, *Anabaena* densities were relatively low in the lake prior to development with current densities now 5-8 times higher. *Anabaena spp* was the dominant akinete genus present in the sediments with *Aphanizomenon* also present. While the results, when viewed collectively, illustrated that Blue Lake has been dramatically altered with initial changes coinciding with early development and extending to the present, the changes have not been linear as suggested in the akinete and phosphorus data found for the mid-1990's in the sediment core. One of the major activities during this period was the use of groundwater pumping into the lake. The benefit of this activity needs to be further explored especially since the nutrients concentration of the pumped water varies significantly depending on its source. The shallowest ground water generally has higher nutrient concentrations.

Focus of lake management activities in the 1980's into the early 1990's was to control the aquatic weeds – mainly Eurasian watermilfoil using applications of 2,4-D, Aqua Kleen and SONAR. Watermilfoil had been brought under control – in 2003, it was found at only one site in the lake. However, in 2003, Blue Lake Park was temporarily closed due to large *Anabaena* blooms and, in 2009 and 2010, recreational health advisories were posted due to *Anabaena and Microcystis and Aphanizomenon* blooms respectively.

In 2007, three SolarBee units were installed to help reduce nuisance algal blooms. According to the manufacturer, these long-distance circulators can prevent harmful algal blooms, reduce invasive and nuisance macrophyte stands, and aerate the hypolimnion (bottom layer of water) and sediment to lessen the release of sediment-bound nutrients. In Blue Lake, the water intake was set at 3 meters (10 feet) below the surface and above the thermocline for the east and west units and at 4.5 meters (15 feet) for the central unit, in order to reduce summertime cyanobacterial blooms. Mixing is thought to hinder internal buoyancy regulation by cyanobacteria and redistribute oxygen, nutrients, bacteria and algae throughout the lake, reducing the likelihood of optimal conditions for cyanobacterial blooms. Macrophyte reduction could occur by two possible means. Oxygenating the sediments would convert ammonia, the preferred form of nitrogen, to nitrate, gradually causing a reduction in rooted macrophytes and/or the reduction in nitrogen-fixing cyanobacteria could decrease the amount of ammonia available to macrophytes by reducing the availability of organic nitrogen from decomposing algal biomass. A framework was developed to assess the effectiveness of the SolarBee units which looks for improving water quality in any of three parameters – pH, secchi depth and cyanobacteria cell counts.

Secchi depth (water transparency) has increased since 2007 and average chlorophyll a values are lower and anecdotal accounts indicate that algal productivity has decreased in recent years (although limited data makes it difficult to trend). Problems still exist in the lake in 2009 with 16 of 19 weekly surface water measurements exceeding the pH standard and values appeared to have increased. Cyanobacteria blooms still occur and values do not appear to be different from before SolarBee installation. *Anabaena sp* (*Anabaena flos-aquae* dominated in 2007 and *Anabaena planctonica* was the most common in 2003, 2006 and 2007) were the most common cyanobacteria with *Aphanizomenon* and *Microcystis* also present some years. A recreation Health Advisory was issued by the Department of Human Services from October 14 – November 6, 2009 after the fall lake turnover and from August 26 – October 4, 2010. Eurasian watermilfoil is spreading back throughout the lake; it is thought that the increased clarity has allowed for the increase spread of macrophytes. The increase in the macrophytes may account for the increase in pH. It was also noted that rainbow trout have also been stocked in Blue Lake since at least 2003 and may have induced greater grazing pressure on the zooplankton. (Temple, 2009)

Temple's 2009 Report concluded that the lake has historically had sufficient nutrients to support abundant algal and macrophyte growth with high nutrients in the ground water and the physical characteristics of the lake (soft sediments, shallow depth, gentle slope, high light availability and warm water temperature) ideal for macrophyte and algal growth. Reducing anthropogenic nutrient loading from groundwater may not be viable or will take years as the shallow aquifer flushes out nutrients from the legacy cesspool loading. Similarly, the use of SolarBee units for eplimnion circulation to control algae is still be tested and may take several years, needing more data to detect changes. Blue Lake highlights the ecological theory of alternate stable states in small shallow lakes: a shallow eutrophic lake can support high levels of algae, but if the populations are lowered, increased water clarity and high levels of available nutrients allow for profuse growth of aquatic plants. Alternately, the removal of aquatic plants may lead to increased sediment re-suspension and nutrient diffusion into the water column, which may increase algal populations and turbidity.

Current recommendations include: developing lake goals among the Blue Lake Improvement Association, Metro and DEQ; taking into account groundwater and groundwater pumping into the lake; continuing the use of SolarBee units and monitoring their effectiveness; and for macrophyte control, preserving some macrophyte cover for fish habitat, controlling sediment re-suspension and using control methods in target areas (e.g. around boat docks), such as harvesting, bottom barriers or small-scale herbicide applications. (Temple, 2009). Blue Lake Improvement Association received a grant from DEQ in September 2010 to fund the release of a native weevil (*Euhrychiopsis lecontei*) as a control for Eurasian watermilfoil.

Summary of Data from Blue Lake - Average and Ranges

Date	Depth (meters)	pH (SU)	Total Phosphorus (mg/l)	Dissolved Ortho Phosphorus (mg/l)	Nitrate & Nitrite (mg/l)	Ammonia (mg/l)	Total Kjeldahl (mg/l)	Chlorophyll a (ug/l)
1978 – 1979 (Beak, 1979)	1	8.3 (6.8-9.2)	0.037 (.012-.068)	0.010 (.001-.042)	0.025 (.001-.050)	0.19 (.10-.31)	0.385 (.03-.78)	
1981 – 1982 (Beak, 1983)	0.5	(6.8-8.8)	.078 (.035-.481)	.019 (<.001-.095)	.037 (<.005-.145)	.072 (<.010-.144)	0.671 (.119-1.010)	
1981 – 1982 (Beak, 1983)	0.5 above bottom	(6.2-7.9)	0.267 (.052-.574)	0.021 (<.001-.086)	0.138 (.010-.385)	0.305 (<.010-1.46)	1.10 (.201-2.53)	
Later data not available at time of report								
Groundwater data								

(nitrate and organic nitrogen shown in 1981 – 1982 for Nitrate & Nitrite and TKN respectively)

<u>Hazardous Algal Bloom Health Advisories:</u> Health Advisories were issued by the Oregon Health Authority in 2003, 2009 (23 days) and 2010 (40 days). Dominant species varied for each of these blooms with *Anabaena sp* and *Microcystis aeruginosa* dominating in 2009 and *Aphanizonmenon flos-aquae* dominating in 2010. Microcystin was detected above the recreational criteria of 6.0 ug/l in 2003 and 2009. Microcystin was not sampled for in 2010.

Summary of Public Health Advisories in Blue Lake

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[1]	Maximum Toxin Measured (ug/l)
2003				*Anabaena flos-aquae,* *Anabaena Affinis* *Microcystis aeruginosa*		Microcystin – 6.1
2009	10/14	11/6	23	*Anabaena sp* (1,559,708) *Microcystis aeruginosa* (118,821) *Anabaena planctonica* (19,095) *Aphanizonmenon flos-aquae* (2,126)	1,559,708	Microcystin – 11.9 Anatoxin - nd
2010	8/26	10/5	40	*Aphanizonmenon flos-aquae* (1,804,000) *Anabaena planctonica* (23,993) *Microcystis aeruginosa* (18,040)	1,846,033	

Likely or Suspected Cause of Blooms: High background loading of nutrients from groundwater, some of which could be due to legacy cesspool loading and potentially from current groundwater pumping into the lake, and high internal loading of nutrients. Lake is naturally eutrophic but a balance is needed between macrophyte and algal management.

303(d) List Status: The 2004/2006 Integrated Report identifies Blue Lake as being water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae, chlorophyll a and pH. The Health Advisories will be added as a reason for listing for Aquatic Weeds and Algae in the 2010 Integrated Report. TMDL work has been initiated.

References

Beak Consultants Inc. April 1979. Environmental Investigations and Recommended Modifications for Blue Lake, Multnomah County, Oregon. Prepared for Multnomah County. Beak Consultants, Portland, OR.

Beak Consultants Inc. January 1983. Blue Lake EPA Clean Lakes Program 1981 – 1982 Phase 1 Diagnostic/Feasibility Study. Prepared for Multnomah County. Beak Consultants, Portland, OR.

Eilers, J. and A. St. Amand. October 2004. Recent Paleolimnology of Blue Lake, OR – A Report to the Oregon Department of Environmental Quality. Max Depth Aquatics, Inc. Bend, OR. 33 pp.

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

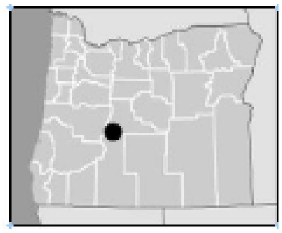
Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Temple, W. October 2009. 2009 Blue Lake Water Quality Summary Report. METRO. 600 NE Grand Ave, Portland, OR 97232. 34 pp.

[1] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected.

Crane Prairie Reservoir

Deschutes County, Deschutes Basin
Eastern Cascade Slopes and Foothills Ecoregion



State of Oregon Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Crane Prairie Reservoir is a large, shallow impoundment on the upper Deschutes River in Central Oregon. It is a component of the Deschutes Project, a Bureau of Reclamation project which includes Wickiup Dam and Reservoir, Haystack Dam and Reservoir, North Unit Main Canal and lateral system, and the Crooked River Pumping Plant. The Project furnishes a full supply of irrigation water for about 50,000 acres of land within the North Unit Irrigation District, and a supplemental supply for more than 47,000 acres in the Central Oregon Irrigation District and Crook County Improvement District[2]. It is an earthfill structure 36 feet high and 285 feet long at the crest. The reservoir has a capacity of 55,300 acre-feet when full (Johnson et al, 1985).

Source: US Bureau of Reclamation, 1970. View looking northwest.

Crane Prairie is the home of the largest nesting colony of ospreys in the Pacific Northwest. It is also home to blue herons, cormorants, kingfishers, and many other species of birds. A Wildlife Management Area, covering 10,600 acres, was established in 1970 to preserve this special habitat.

Crane Prairie Reservoir is a very popular site for camping and fishing. The watershed is entirely on U.S. Forest Land (Deschutes National Forest). Several good Forest Service campgrounds are located around the shoreline, accessible from a number of access roads, and there are several places from which to launch boats. Crane Prairie Resort on the east side rents boats and supplies. Fishing had been excellent for large trout, particularly rainbow trout and brook trout. Kokanee, stocked by the state in recent years, also provide good angling. However, the reservoir has 5-6 species of introduced, non-native fish species (three-spined stickleback, brown bullhead, black crappie, tui chub, largemouth bass). The zooplankton community has been greatly altered by the predation of the introduced fish, which most likely contributes to the intense blooms of *Anabaena* in recent years (Eilers et al, no date)

Crane Prairie Characteristics (from Johnson et al, 1985)

Setting:

Type: reservoir | **Use:** irrigation, recreation, wildlife | **Elevation:** 4,445 ft (1,354.8 m)
Location: 30 mi SW of Bend, 15 mi N of Willamette Pass, in Deschutes N.F.

Drainage Basin Characteristics:

Area: 254 sq mi (657.9 sq km) | **Relief:** moderate | **Precipitation:** 25-80 in (64-203 cm)
Land Use: Forest-93.6%; Water-5.4%; Other-1% (wetlands)

Lake Morphometry:

Area: 4,167 acres (1,686.4 hect) | **Depth:** Maximum - 20 ft (6.1 m); Average - 11ft (3.3 M)
Ave/Max Depth Ratio: 0.540 | **Volume:** 45,420 acre ft (56.11 cu hm)
Shoal area: 50% | **Volume factor:** 1.64 | **Shape factor:** 2.47
Length of Shoreline: 22.3 mi (35.9 km) | **Retention time:** 4 mo.

Water Quality: Crane Prairie Reservoir is extremely shallow. At full pool it has an average depth of only 11 feet, and a maximum depth of just over 20 feet. The reservoir is lowered in the late summer by the withdrawal of water for irrigation, thereby exposing extensive areas of mud bottom.

Summertime pH values frequently exceed the water quality standard of 8.5 SU, with pH values associated with algal blooms often above 9. Total phosphorus values are high and available nitrogen values (ammonia, nitrate & nitrite) were quite low (near detection). Nitrogen is the limiting nutrient in the summer. Plenty of phosphorus, limited

2 http://www.usbr.gov/projects/Project.jsp?proj_Name=Deschutes+Project

nitrogen and warm water (surface temperature often ranging between 20 – 23º C at mid-lake locations) make ideal conditions for blue-green algal blooms.

Summary of Mid-lake Data from Crane Prairie Res (USBR data collected 1 meter from surface and bottom)

Date	Depth (meters)	pH (SU)	Total Phosphorus (mg/l)	Dissolved Ortho Phosphorus (mg/l)	Nitrate & Nitrite (mg/l)	Ammonia (mg/l)	Total Nitrogen (mg/l)	N:P Ratio[3]	Chlorophyll a (ug/l)
8/21/81 - Johnson 1985		9.8	0.108	-	-	-	-	-	5.7
7/24/1995 (USBR)	1	8.7	0.044	0.018	<0.01	0.03	0.37	8.4	2.2
"	3.7	8.8	0.045	0.014	<0.01	0.02	0.36	8.0	
7/25/2001 (USBR)	1	9.0	0.026	<.0.003	<0.01	0.03	0.27	10.4	2.4
"	4.1	8.7	0.028	0.004	<0.01	0.01	0.28	10.0	
7/14/2004 (USBR)	1	9.1	0.028	<0.003	0.03	<0.01	0.65	23.2	11.5
"	4.1	8.2	0.029	<0.003	0.01	0.02	0.54	18.4	
7/24/2007 (USBR)	1	8.9	0.040	<0.003	0.01	<0.01	0.70	17.5	15.0
"	4.4	7.6	0.046	<0.003	<0.01	<0.01	0.71	15.4	

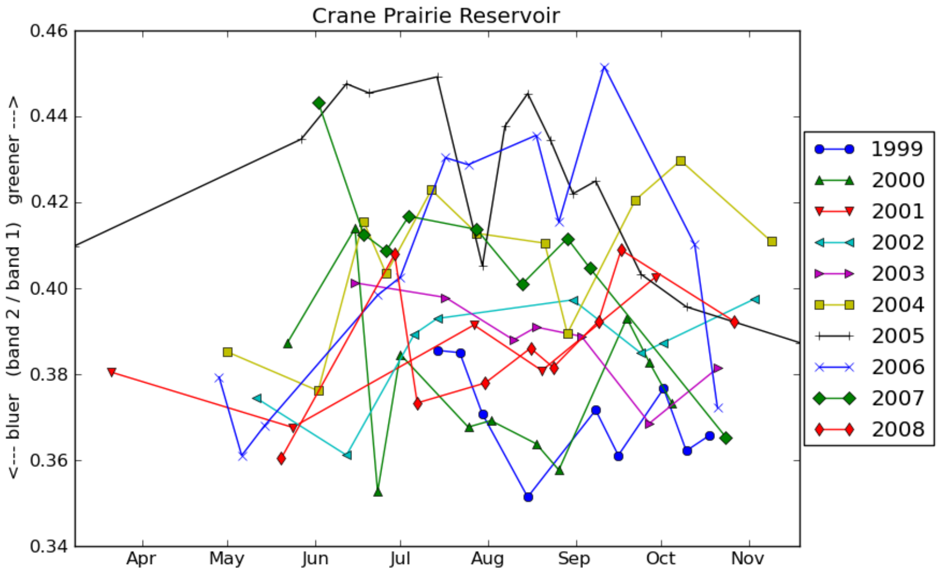
Hazardous Algal Bloom Health Advisories: Public Health Advisories have been issued by the Oregon Health Authority in 2004, 2005 and 2009 for Crane Prairie Reservoir.

Summary of Public Health Advisories in Crane Prairie Reservoir

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb Cell Count[4]	Maximum Toxin Measured (ug/l)
2004	July	Sept		*Anabaena flos-aquae*	670,863	Microcystin – 7.4
2005	6/24	7/22	28	*Anabaena flos-aquae*	146,575	
2005	8/10	8/31	22	*Anabaena flos-aquae*	150,333	
2009	6/18	7/9	21	*Anabaena flos-aquae* (389,363) *Anabaena planctonica* (167,417) *Anabaena circinalis* (27,272) *Aphanizomenon flos-aquae* (11,438)	556,780	
2009	7/31	8/12	12	*Anabaena flos-aquae* (103,730) *Aphanizomenon flos-aquae* (24,949) *Anabaena planctonica* (5,915)	103,730	

Remote sensing of chlorophyll *a* concentrations using Landsat data suggests a quite an unusual pattern in algal blooms in Crane Prairie Reservoir. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values shown from 1999 through 2003 were generally below the ratio of 0.4. Values from 2004 through 2007 were generally above 0.4, especially from June into October. 2005 and 2006 were peak years. 2008 showed lower values.

[3] N:P ratio below 7.2 is Nitrogen Limiting
[4] N:P ratio below 7.2 is Nitrogen Limiting
[4] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected.



Likely or Suspected Cause of Blooms: Elevated phosphorus (source may be natural but data is needed to verify this). Non-native, introduced fish may play a key role in increasing the internal loading.

303(d) List Status: 2004/2006 Integrated Report identifies Crane Prairie Reservoir as being of concern for aquatic growth and pH but needing supporting data (Category 3 – insufficient data). Crane Prairie Reservoir has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in Oregon's 2010 Integrated Report based on the health advisories issued. TMDL related work has not been initiated.

References

Eilers, J.M. and A. St. Amand. No date. Multiple Scenarios for Fisheries to Increase Potentially Toxin-Producing Cyanobacteria Populations in Selected Oregon Lakes

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

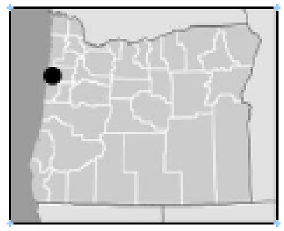
Oregon Health Authority - Public Health Advisories:
http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Turner, Dan. June 2010. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality.

U.S. Bureau of Reclamation. Unpublished Data, STORET

Devils Lake

Lincoln County, Mid Coast Basin
Coast Range Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Devils Lake lies immediately east of Lincoln City on the Oregon Coast. It is entirely within the Lincoln City Urban Growth Boundary and portions of the western shoreline are within the city limits. The lower reaches of the lake are less than 300 yards from the active beach zone of the Pacific Ocean.

Source: US Geological Survey, no date. View looking north.

The recreational value of a freshwater lake adjacent to the local beach environment and adjacent to a growing population center is very high. Lincoln City maintains several municipal properties on Devils Lake and the state of Oregon operates parks near the south end. Devils Lake State Park has two public use areas. East Devils Lake Park is available for day use and boat launching. Devils Lake Campground is located on the southwest side of the lake, less than half a mile from the Oregon Coast Highway. Lincoln City owns and maintains three smaller parks on the lake.

The lake is heavily used for boating. Fish include: native populations of coho salmon, cutthroat and steelhead trout; stocked rainbow trout; introduced warm water game fish including largemouth bass, bluegill, black crappie, yellow perch and brown bullhead; and introduced sterile triploid grass carp (DLWID).

Devils Lake is unique in many ways as will be described below. Another unique feature is the Devils Lake Water Improvement District (DLWID), which was formed in 1984 to address lake problems and manage the lake. It was the first water improvement district of its kind in the State of Oregon and was set up as a special taxing district which receives funding from area property owners to work for improvement of the lake. This provides staff and a base of funding for lake management activities.

Devils Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake **Use:** recreation **Elevation:** 20 ft (6.1 m)
Location: eastern city limits of Lincoln City; east of US Hw y 101

Drainage Basin Characteristics:

Area: 24.3 sq mi (62.9 sq km) **Relief:** moderate **Precipitation:** 90-112 in (229-284 cm)
Land Use: Forest-88.9%; Range-3.4%; Water-4.3%; Urban-3.4%;

Lake Morphometry (area, depth, volume - Eilers, 2005):

Area: 685 acres (277 hect) **Depth:** Maximum – 21.1 ft (6.4 m) Average – 8.4ft (2.6 m)
Ave/Max Depth Ratio: 0.40 **Volume:** 5,750 acre ft (7.1 cu hm)
Volume factor: 1.33
Shoal area: 49% **Shape factor:** 2.93
Length of Shoreline: 10.7 mi (17.2 km) **Retention time:** 2 mo.

Water Quality: The footprint for development of the lake and its watershed was established early, by the settlement that had occurred by the 1940's. Sedimentation rates, based on sediment core data, have steadily increased since that time (Eilers et al, 1996). With this settlement, Devils Lake has had an early history of dealing with lake problems – which includes addressing sewage disposal issues, aquatic weeds, nuisance fish and algae problems.

Poorly treated sewage, which had been discharged to the lake, was removed from the basin in the early 1970's after Lincoln City incorporated. However, many of the homes on the northern, eastern and portions of the western shores developed without sanitary sewers and still use septic systems of varying integrity. DLWID has recently initiated a septic tank revitalization and native vegetation restoration program. (DLWID)

In the early 1980's, a Section 314 Clean Lakes Study was conducted to address nuisance aquatic weeds, primarily *Myriophyllum spicatum* and *Egeria densa.* Monthly data collected from April – September 1982 (DEQ, 1982) showed chlorophyll a values ranging from 14- 31 ug/l with cyanobacteria abundant from May through September - *Microcystis* (May), Gleotrichia *echinulata* (June – August)*, Anabaena* (September). Total Phosphorus ranged from 0.027 – 0.057 mg/l and with nitrate and ammonia near or less than detection (0.02 mg/l) in late June through August, indicating that nitrogen was likely limiting during that time. In the 1990's, phosphorus levels were documented with a wider range (0.009 – 0.118 mg/l) with an average of 0.023 mg/l. Unlike the previous study, these samples were taken throughout the calendar year.

A series of recommendations were made based on the Clean Lakes Study that included vegetation harvesting, land use control of nutrients, herbicides and limited dredging. An alternative developed after the study, the introduction of the herbivorous Chinese Grass Carp (*Ctenopharyngoden idella*), was approved by Oregon Fish & Wildlife Commission with the grass carp stocked in 1986, 1987 and 1993. This full introduction of the carp resulted in the full eradication of macrophytes from the lake after the last stocking event. It also led to an increase in the cyanobacteria blooms. Sediment core data shows an abrupt increase in the deposition of both *Anabaena* and *Gloeotrichia* akinete (resting) cells in the sediments of Devils Lake after 1994. It is likely that the elimination of macrophytes opened up a great portion of the lake to competition among planktonic species (Eilers et al, 2005).

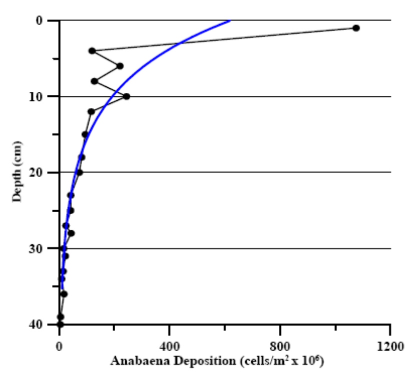


Figure 12. Deposition rate of *Anabaena* akinetes in the sediment of Devils Lake. The blue curve is a logarithmic fit to the observed data.

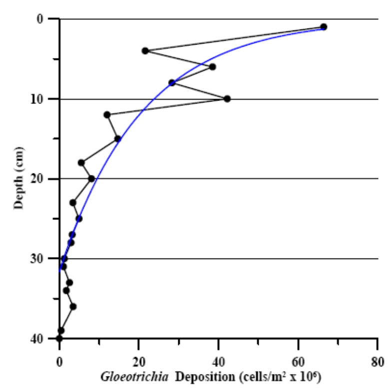


Figure 13. Deposition rate of *Gloeotrichia* akinetes in the sediment of Devils Lake. The blue curve is an exponential fit to the observed data.

While the grass carp are of concern, given the eradication of the macrophytes and the habitat that they provide as well as being a factor for increasing blooms, there are several concerns about eliminating the grass carp from the lake. Boaters are concerned that macrophyte growth could return to the extent that is interferes with boating as was the case before the introduction of the grass carp. Fishery biologists have also observed that, following the macrophyte elimination, panfish quickly declined and largemouth bass were declining at a slower rate due to loss of protective habitat. These warmwater gamefish are thought to be detrimental to native coho salmon through both competition for food and space and direct predation (Buckman et al, 1999).

<u>Hazardous Algal Bloom Health Advisories:</u> DLWID has conducted a Cyano-Watch Program since 2007. The lake is observed for blooms. Weekly Microcystin sampling at up to 12 sites within the lake and along the shoreline is made during bloom periods, typically July – September, using ELISA test kits. Appropriate warnings are made, based on DHS recommendations, based on levels of Microcystin, cell counts or visual observations. Health advisories were issued for Devils Lake in 2008 and 2009. In 2008, the advisory was issued from 8/14 – 11/3/2008 (81 days). During that period, detectible levels of Microcystin ranged from .21to 169 ppb. Sampling protocols at the time followed an event sampling model utilizing single grabs for analysis, almost exclusively from the nearshore. Toxigenic cyanobacteria present in the waters included *Microcystis, Gleotrichia echinulata* and *Anabaena.* The combined concentrations of all cyanophytes peaked above 1,000,000 cells/ml, but no direct relationship between cell counts and Microcystin concentrations could be drawn. In 2009, sampling protocol was changed to a method based on composite sampling, deemed to be more representative of the sampling sites. This sampling method further

included an equal number of pelagic sites to littoral ones, 12 in all. An advisory was issued from 7/31 – 9/8/2009 (39 days). During that period, detectible levels of Microcystin ranged from 0.6 – 50 ppb. While peak concentrations were significantly lower than the previous year, Microcystin levels notably exceeded water quality standards in both littoral and pelagic zone samples in near equal numbers. In 2009, less emphasis was placed on cell enumeration and none of the enumerations exceeded the state's guidelines. Thus, advisories in 2009 were prompted by visual indicators and/or Microcystin concentrations.
Likely or Suspected Cause of Blooms: Elevated nutrients from watershed; internal loading further enhanced by introduction of Grass Carp.

303(d) List Status: 2004/2006 Integrated Report identifies Devils Lake as being water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for chlorophyll *a* and pH and of concern for nutrients. A Category 5 listing for Aquatic Weeds and Algae has been proposed in Oregon's 2010 Integrated Report based on Health Advisories issued. TMDL work is being initiated.

References

Buckman, Bob and Kin Daily. 1999. Effects of Grass Carp on Warmwater Fish and Coho Salmon; ODFW. 10 pp.

City of Lincoln City and Oregon Department of Environmental Quality. 1982. 1982 Water Quality and Biomass Sampling and Analysis Program – Devils Lake, Lincoln County, Oregon.

Devils Lake Water Improvement District Website - http://dlwid.org/index.html

Department of Human Services. Public Health Advisories: **get advisories**

Eilers, J, J Bernert, C Gubala, M Whiting, D Engstrom, and D Charles. 1996. Recent Paleolimnology of Devils Lake, Oregon. Northwest Science, Vol 70, Special Issue No 2. pg 13 – 26.

Eilers, J, B Eilers, R Sweets and A St. Amand. 2005. Updated Bathymetry and Paleolimnology of Devils Lake, Lincoln County, Oregon. MaxDepth Aquatics. Bend, OR. 25 pp

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

McHugh, Robert. 1972. An Interim Study of Some Physical, Chemical and Biological Properties of Selected Oregon Lakes. Oregon Department of Environmental Quality. 124 pp.

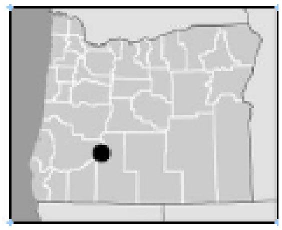
McHugh, Robert. 1979. Some Highly Eutrophic Oregon Lakes, with Recommendations for the Restoration of their Quality. Oregon Department of Environmental Quality. 33 pp

Oregon Health Authority - Public Health Advisories - **http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx**

Robertson, Paul. 2008. The Devils Lake Plan – Draft. Devils Lake Water Improvement District. 43 pp.

Diamond Lake

Douglas County, Umpqua River Basin
Cascade Ecoregion



State of Oregon Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Diamond Lake, a large and heavily used lake in the southern Oregon Cascades, lies at an elevation of 5183 feet in a scenic glacial valley between Mt. Thielsen and Mt. Bailey. Diamond Lake and its drainage basin are entirely within the Umpqua National Forest. The major inlet streams to Diamond Lake are Silent Creek from the southwest and Short Creek from the southeast. Other tributaries are primarily intermittent and contribute significant flow only from snowmelt. Surface outflow is continuous into Lake Creek, a tributary of the North Umpqua River. Flashboards are generally installed in Lake Creek after spring runoff to maintain the lake level during summer, and then are removed in fall.

Source: US Geological Survey, 1979. View looking north.

Diamond Lake receives a great amount of recreational use for swimming, fishing, boating, and camping. On the shoreline is a private lodge, over 100 seasonal dwellings, three Forest Service campgrounds, and two picnic areas to accommodate visitors. A Forest Service road encircles the lake, providing access at all points

Diamond Lake was naturally fishless. In the early 20th century, the Oregon Game Commission (now ODFW) began stocking the lake with trout and it developed a well-established reputation for its large rainbow trout. This fishery has declined, several times in the past, due competition from tui chub which were inadvertently introduced to the lake, probably as live bait for trout fishing. The lake has been treated with rotenone to eradicate the fish in 1954 and 2006 and has been restocked with rainbow trout in the year following each treatment. The fish have also affected the water quality of the lake, as described below.

Diamond Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake, now diked | **Use:** recreation | **Elevation:** 5,183 ft (1,579.8 m)
Location: 5 miles north of Crater Lake National Park in Umpqua N.F.

Drainage Basin Characteristics:

Area: 54.9 sq mi (142.2 sq km) | **Relief:** moderate | **Precipitation:** 55-65 in (140-165 cm)
Land Use: Forest-88%; Water-9%; Other-3% (rock outcrops)

Lake Morphometry:

Area: 3,214.0 acres (1,300.7 hect) | **Depth:** Maximum - 52 ft (15.8 m); Average - 24ft (7.3 M)
Ave/Max Depth Ratio: 0.460 | **Volume:** 77,136 acre ft (95.29 cu hm)
Shoal area: 18% | **Volume factor:** 1.39 | **Shape factor:** 1.21
Length of Shoreline: 9. mi (14.5 km) | **Retention time:** 1.6 yr

Water Quality: In 1979, the Environmental Protection Agency completed a study of the lake. The purpose of the study was to define the nutrient budget, as a sewage collection system had been completed around the lake with wastewater that was collected from the campgrounds and resort being treated in lagoons outside of the watershed, and to describe the benthic macroinvertebrate population (Lauer et al 1979). Their conclusions were:

- Diamond Lake was mesotrophic to eutrophic as a result of natural nutrient loading from the tributaries, groundwater and bottom sediments.

- The nutrient contribution from cultural activity in the basin was relatively insignificant compared to natural sources. Heavy use for water-based recreation undoubtedly contributed additional nutrients to the lake.
- During the period of investigation no change was found in the trophic status of the lake that could be attributed to the wastewater diversion system although there was a 14% reduction of phosphorus and 18% reduction of nitrogen loads.
- The trophic status of Diamond Lake was appropriate in satisfying present recreational demands. Because of the natural loading of phosphorus, algal blooms frequently develop in the lake. Species commonly observed include eutrophic diatoms and a nitrogen fixing blue green alga (*Anabaena circinalis*).

Data collected from 1992-2003 indicated that State standards for algae were not being met at Diamond Lake (Eilers et al, 2003). Dissolved oxygen was depleted in the hypolimnion and pH values often exceeded the standard of 8.5 SU with values often ranging above 9.0 SU. In the summers of 2001, 2002, and 2003, Diamond Lake experienced severe blooms of *Anabaena flos-aquae*. *Microcystis aeruginosa*, was also present in the 2003 bloom. Health Advisories were issued by Douglas County.

Table 2. Summary of water quality data for Diamond Lake (Source: Salinas and Larson 1992-1994, Salinas 1995-2002, DEQ 2001-2002, Eilers 2003)

	Median	1992-1997	1998-2003
pH*	8.1	7.7 - 9.1	7.4 - 9.7
Chlorophyll a (mg/L)	0.006	0.001 - 0.027	0.005 - 0.064
Total dissolved phosphorus (mg/L)	0.016	0.011 - 0.025	0.008 - 0.030*
Total Phosphorus**(mg/L)	0.020		0.010 - 0.060
Conductivity (µS/cm)	39	33.2 - 51.7	32.1 - 76.6
Nitrate-Nitrogen (mg/L)	0.001	0 - 0.011	0 - 0.516
Ammonia-Nitrogen (mg/L)	0.009	0.001 - 0.527	0 - 0.516

*Derived from maximum measured values
**Data from years 2001-2003

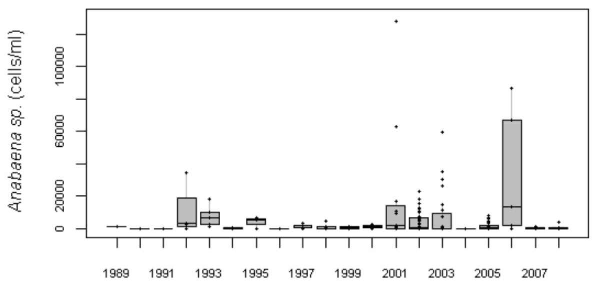
Also, see Jones et al, 2007

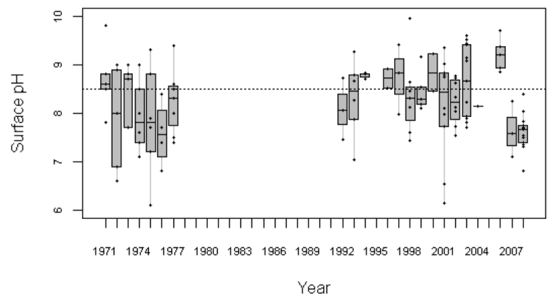
<u>TMDL findings:</u> A TMDL was developed for Diamond Lake in 2006. Findings from studies and modeling conducted to develop the TMDL included:

- Phosphorus inputs to the lake are largely from natural sources with anthropogenic sources less than 2%. Nitrogen inputs from the watershed were only slightly greater than the phosphorus inputs, resulting in a system that would appear to be N-limited for periods of the year.
- Watershed inputs of N and P were much less than the internal load of nutrients and the acceleration of internal nutrient cycling associated with loss of larger herbivorous zooplankton, loss of larger zoobenthos, persistent anoxia in the hypolimnion and excretion from fish and nitrogen fixation by cyanobacteria.
- Most of the changes in the ecology and nutrient cycling of Diamond Lake appear to be the direct result of the large biomass of tui chub.
- The two pathways by which the tui chub enhance algal blooms are by reducing the number of larger sized zooplankton that can filter algae from the water column and by increasing the water column nutrient concentration through excretion of nitrogen and phosphorus in forms available for algal growth. Subsequent data analysis (Eilers et al, In press -2011) concluded that water quality improved as a consequence of the reduction in fish biomass and reduction in excretion of nutrients by fish rather than enhanced grazing of zooplankton. The internal load of phosphorus associated with tui chub was estimated to be approximately four times the external load of phosphorus.
- The models show that the biomass of tui chub can largely explain the frequency of the cyanobacterial blooms, although the intensity of the blooms appears to be strongly influenced by weather conditions associated with extended periods of high temperature, low average wind speed and abundant solar radiation.

A loading target of cyanobacteria biomass (4,000 kg/yr) was set which limited the: external nutrient load to 2006 levels; nutrient inputs from fish bait, fish stocking and septic systems to 1975 levels; and internal loading to one half of the 1975 levels. To meet the internal loading levels required elimination of 90 – 100% of the tui chub population and monitoring of the trout population in case a reduction of the trout population is needed based on the monitoring.

Based on recommendations of the Diamond Lake Restoration Project FEIS (USDA, 2004), tui chub were removed in 2006 using rotenone and implementing a put-grow-take stocking strategy. Education and monitoring programs were implemented as part of the overall strategy. Follow up monitoring (Eilers et al, in press/2011; Sytsma et al, 2009) indicates a remarkable improvement in water quality, although some concerns for further monitoring were identified. While *Anabaena flow-aquae* was present an 2 of 12 surface samples collected in 2008 and dominated one of those samples, values were low compared to those collected in between 2001 – 2006. However, it should be noted that an *Anabaena* bloom did occur in July 2010 and another advisory was issued.





The monitoring program is targeted to get data to be used in a Diamond Lake Fish Stocking Index (FSI). This is particularly important to track because, depending on stocking rates and timing, fingerling trout can have a negative impact on water quality and trout health. The FSI consists of a series of water quality and fish health parameters normalized to a scale of zero to ten with ten being the best water quality condition. FSI parameters were selected based on their theoretical response to fingerling trout stocking levels and include (Systma et al, 2009):

- Secondary consumer parameters: trout growth, condition and survival;
- Primary consumer parameters: large *Daphnia sp* density, benthic macroinvertebrate biomass and amphipod density;
- Primary producer parameters: chlorophyll a, *Anabaena sp* density and secchi disk transparency;
- Chemical parameters: surface water pH, surface water dissolved oxygen concentration and Hypolimnetic dissolved oxygen concentration.

Trout stocking levels are currently being reviewed and will be modified based on this information.

Hazardous Algal Bloom Health Advisories: Diamond Lake has had a history of algal and toxin monitoring prior to the Rotenone Treatment in 2006. A number of Public Health Advisories have been issued for Diamond Lake by the Douglas County Health Department (2001 – 2003) and Oregon Health Authority in 2006. It should be noted that a bloom recently occurred in 2010 and an advisory was issued for 19 days. *Anabaena flos-aquae* has been the dominant species during these blooms.

Summary of Data from Blue Lake - Average and Ranges

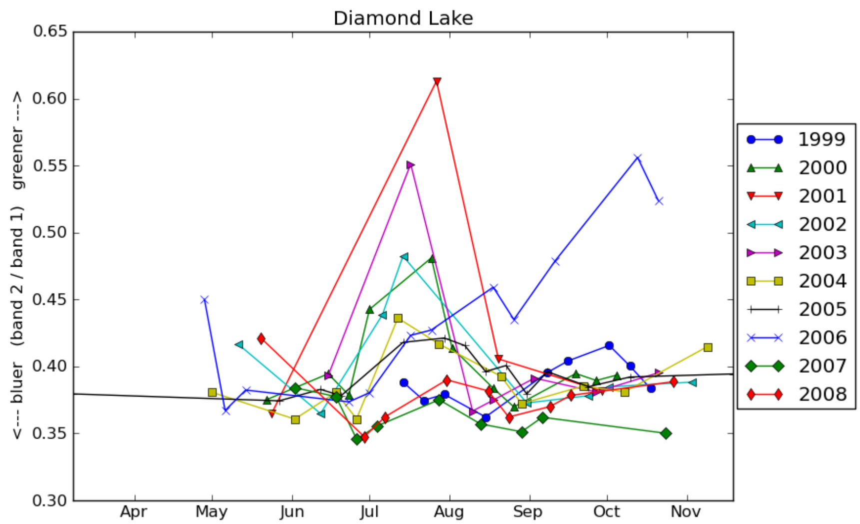
Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[5]	Maximum Toxin Measured (ug/l)
2001				*Anabaena flos-aquae*		Microcystin – Anacystin
2002						
2003						
2005				*Anabaena flos-aquae*	2,241,052	
2006	10/5	11/16	42	*Anabaena flos-aquae*	159,729	
2010	7/15	8/3	19	*Anabaena flos-aquae* (371,615)	371,615	

Remote sensing of chlorophyll *a* concentrations using Landsat data (see next page) shows the impact of tui chub and their removal from Diamond Lake. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). As shown, blooms started occurring in mid-June to late August from 2000 to 2005. A late season bloom (September – November) occurred in 2006, the year of the draw down prior to Rotenone Treatment. Blooms did not occur in the years following treatment (2007 – 2008).

[5] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Likely or Suspected Cause of Blooms: Primarily internal loading of nutrients (N and P) due to the large biomass of tui chubs. The internal load of phosphorus associated with tui chub was estimated to be approximately four times the external load of phosphorus (Eilers et al, In press - 2011).

303(d) List Status: The 2004/2006 Integrated Report identifies Diamond Lake as being water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae, dissolved oxygen, pH. A TMDL has been completed and is being successfully implemented. These parameters have been identified as Category 4A (TMDL Approved) in the proposed 2010 Integrated Report.



References

Eilers, J.M., H.A. Truemper, L.S. Jackson, B.J. Eilers and D.W. Loomis. May 2011 – In press. Eradication of an Invasive Cyprinid (*Gila bicolor)* to Achieve Water Quality Goals in Diamond Lake, Oregon (USA).

Eilers, Joseph, B. Eilers and J. Kann. December 2003. TMDL Modeling and Analysis of Diamond Lake, Oregon. J.C. Headwaters, Inc. Bend, OR. 102 pp.

Eilers, Joseph and J. Kann. April 2002. Diamond Lake Database 2001. Prepared for the Umpqua National Forest, Roseburg, OR. 47 pp.

Jones, Mikeal, J. Eilers and J. Kann. 2007. Water Quality Effects of Blue-Green Algal Blooms in Diamond Lake, Oregon. From M. Furniss, C. Clifton and K. Ronnenberg, eds., 2007. *Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth SciencesConference, San Diego, Ca, 18-22 October 2004,* PNW-GTR-689, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

Lauer, W.L., G. Schuytema, W. Sanville, F. Stay and C. Powers. 1979. The Effects of Decreased Nutrient Loading on the Limnology of Diamond Lake, Oregon. U.S. Environmental Protection Agency, Research and Development Report, EPA-600/8-79-017a. USEPA Corvallis Environmental Research Laboratory, Corvallis, OR 60pp

Oregon Department of Environmental Quality. October 2006. Umpqua Basin Total Maximum Daily Load (TMDL) and Water Quality Management Plan (WQMP).

Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Sytsma, Mark and R. Miller. July 2009. Diamond Lake 2008: assessment of long term water quality trends. Prepared for USDA Forest Service Agreement 06-CR-11061503-015. Portland State University. Portland, OR. 25 pp.

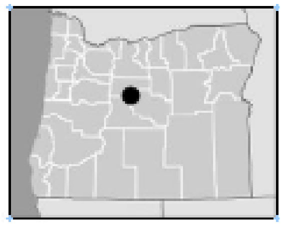
Turner, Dan. June 2010. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality.

USFS. November 2004. Diamond Lake Restoration Project Final Environmental Impact Statement. USDA

USFS Diamond Lake Website: http://www.fs.fed.us/r6/umpqua/projects/projectdocs/diamondlkresto/#projectdocuments

Haystack Reservoir

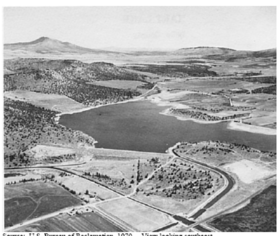
Jefferson County, Deschutes Basin
Blue Mountain Ecoregion



State of Oregon Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Haystack Reservoir, located in the semi-arid rangeland of Central Oregon, was constructed in 1950 to store water for irrigation of agricultural lands in the Deschutes River Basin. It is a component of the Bureau of Reclamation's Deschutes Project which includes Wickiup Reservoir and Crane Prairie Reservoir. Flow from Haystack Creek is stored in the reservoir created by Haystack Dam. However, most of the stored water in the reservoir is supplied by feeder canals, and the impoundment provides for regulatory storage of the releases from Wickiup Reservoir.



Source: U.S. Bureau of Reclamation, 1970. View looking southeast.

An 80-foot high, earthfill dam impounds the intermittent flow in Haystack Draw, a tributary of the Crooked River Arm of Lake Billy Chinook. Releases from the reservoir are diverted into a canal which leads to the North Unit Main Canal. Both the reservoir and its contributing drainage basin are within the boundaries of the Crooked River National Grassland, administered by the Ochoco National Forest. This is land that was mostly reclaimed from abandoned homesteads on which the natural ground cover had been depleted. Resources of the Grassland are managed on a multiple use-sustained yield basis with a goal of restoring and maintaining productivity.

Haystack Reservoir has developed into a popular recreation site. It has been heavily stocked with rainbow trout by the Oregon Department of Fish and Wildlife and provides a fairly successful angling experience; largemouth bass and crappies have also been stocked. Boats can be launched from several points on the shore and fishing from the bank is easy. A Forest Service campground is available for visitors as well as a private resort with boat rentals.

Haystack Reservoir Characteristics (from Johnson et al, 1985)

Setting:

Type: reservoir **Use:** irrigation, recreation **Elevation:** 2,848 f t (868.1 m)
Location: 10 miles south of Madras in the Crooked River Nat. Grasslands

Drainage Basin Characteristics:

Area: 10.2 sq mi (26.4 sq km) **Relief:** moderate **Precipitation:** 10 in (25 cm)
Land Use: Range-81.6%; Water-3.7%; Non Irrigated Agriculture-14.7%

Lake Morphometry:

Area: 282.0 acres (114.1 hect) **Depth:** Maximum - 75 ft (22.9 m); Average - 27ft (8.3 m)
Ave/Max Depth Ratio: 0.360 **Volume:** 7,660 acre ft (9.46 cu hm)
Shoal area: 21% **Volume factor:** 1.09 **Shape factor:** 1.63
Length of Shoreline: 3.8 mi (6.1 km) **Retention time:** indeterminate

Water Quality: There is limited water quality data available for Haystack Reservoir. Data collected by Johnson et al (1985) and USBR indicate that the phosphorus concentration was high with a great deal of available phosphorus (often 50- 60% of total phosphorus). Available nitrogen (nitrate & nitrite, ammonia) were often at or near detection and the N:P ratio indicated that the reservoir was often nitrogen limited. Phytoplankton blooms were reported by USBR as occurring frequently with conspicuous blooms that included blue - green algae floating near the surface. Chlorophyll a is quite high. The reservoir is distinctly eutrophic.

Summary of Mid-lake Data from Haystack Reservoir (USBR data collected 1 meter from surface and bottom)

Date	Depth (meters)	pH (SU)	Total Phosphorus (mg/l)	Dissolved Ortho Phosphorus (mg/l)	Nitrate & Nitrite (mg/l)	Ammonia (mg/l)	Total Nitrogen (mg/l)	N:P Ratio[6]	Chlorophyll a (ug/l)
6/18/1982 (Johnson et al, 1985		7.2	0.066	-	<0.02	<0.02	<0.2	-	4.4
7/25/1995 (USBR)	1	8.5	0.121	0.065	0.12	0.07	1.12	9.3	75.2
"	12.1	8.3	0.117	0.076	0.14	0.1	0.62	5.3	
7/23/2001 (USBR)	1	9.2	0.075	0.052	0.02	0.03	0.23	3.1	110
"	12.9	8.5	0.119	0.015	<0.01	0.03	1.33	11.2	
7/15/2004 (USBR)	1	8.5	0.043	0.028	<0.01	0.02	0.30	7.0	6.6
"	12.4	7.7	0.066	0.039	<0.01	0.04	0.46	7.0	
7/26/2007 (USBR)	1	8.1	0.057	0.029	<0.01	0.01	0.26	4.6	1.8
"	15.4	8.1	0.083	0.051	0.01	0.08	0.38	4.6	

Hazardous Algal Bloom Health Advisories: Health Advisories were issued by the Oregon Health Authority in 2009 and 2010. In both years, both *Aphanizomenon flos-aquae* and *Microcystis aeruginosa* were dominant species at different times during the bloom period.

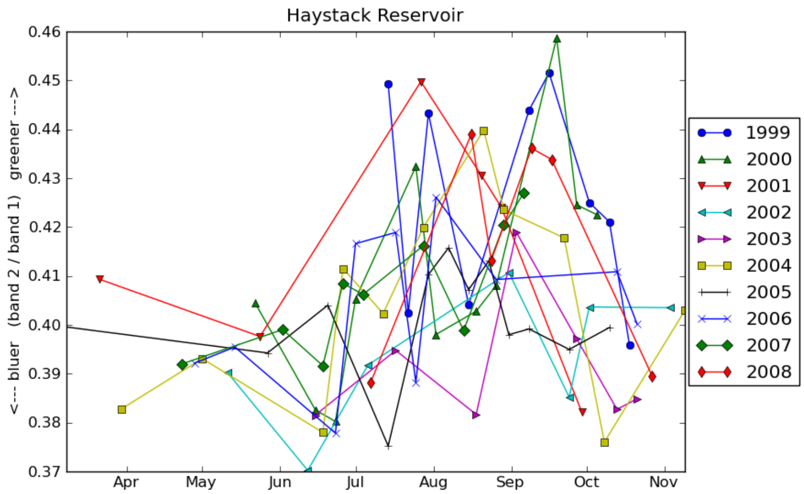
Summary of Public Health Advisories in Haystack Reservoir

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[7]	Maximum Toxin Measured (ug/l)
2009	9/18	11/2	45	*Microcystis aeruginosa* (6,742,239) *Aphanizonmenon flos-aquae* (228,467) *Anabaena flos-aquae* (15,132)	6,802,513	
2010	8/4	12/13	131	*Aphanizonmenon flos-aquae* (16,912,500) *Microcystis aeruginosa* (848,536) *Anabaena flos-aquae* (69,873)	16,947,734	

Remote sensing of chlorophyll *a* concentrations using Landsat data suggests a pattern where peak algal blooms occur from July through October (see Figure). A band 2 /band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l which equates to a visible bloom based on regression estimates (Turner, 2010). In most years, values are below 0.4 until mid June/early July and stay above 0.4 until mid October.

[6] N:P ratio below 7.2 is Nitrogen Limiting

[7] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected



Likely or Suspected Cause of Blooms: Elevated nutrients, cause unknown.

303(d) List Status: The 2004/2006 Integrated Report does not contain any listings for Haystack Reservoir. A Category 5 (Section 303(d) list – a TMDL is needed) listing for Aquatic Weeds and Algae has been proposed in Oregon's 2010 Integrated Report based on the Health Advisory Issued. TMDL related work has not been initiated.

References

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

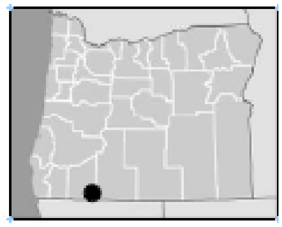
Oregon Health Authority - Public Health Advisories:
http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Turner, Dan. June 2010. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality.

U.S. Bureau of Reclamation. Unpublished Data, STORET

Hyatt Reservoir

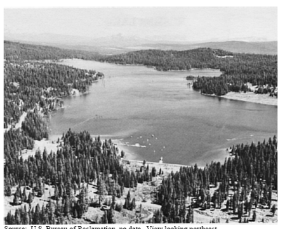
Jackson County, Klamath Basin
Cascade Ecoregion



State of Oregon
Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Hyatt Reservoir, a large impoundment located just east of the Cascade crest in southern Oregon, was formed in 1923 with the completion of a rock-faced, earthfill dam on Keene Creek. Although developed privately, it now forms an important component of the Talent Division of the Rogue River Basin Project, a multi-purpose water resource project of the U.S. Bureau of Reclamation. Howard Prairie Lake, the largest reservoir in this project, is three miles to the northeast. These reservoirs, although located in the Klamath drainage basin, store water for transfer and use in the Rogue River drainage basin where they contribute to irrigation of about 35,000 acres in the Medford area. Hyatt Reservoir stores the runoff from the headwaters of Keene Creek and releases them downstream to Little Hyatt Reservoir. From there, the water joins the outflow from Howard Prairie Lake and is transported via the Ashland Lateral Canal to Emigrant Lake, a component of the Project upstream from Medford.



Source: U.S. Bureau of Reclamation, no date. View looking northeast.

The small, forested drainage basin of Hyatt Reservoir is a mixture of private land and federal land administered by the Bureau of Land Management. The shoreline itself is predominantly federal land and the B.L.M. has designated it as the High Lakes Recreation Site with associated facilities such as campgrounds and boat launches. There is also a private resort on the lake providing recreational services. Hyatt Reservoir has been heavily used for water based recreation for many years and supports a good population of rainbow and brook trout along with bass, bluegill and crappie. It is not fished as much as Howard Prairie Lake, but pressure from anglers has increased in recent years.

Hyatt Reservoir Characteristics (from Johnson et al, 1985)

Setting:

Type: reservoir
Use: irrigation, recreation
Elevation: 5,016 f t (1,528.9 m)
Location: 14 miles east of Ashland

Drainage Basin Characteristics:

Area: 8.1 sq mi (21.0 sq km)
Relief: moderate
Precipitation: 33-40 in (84-102 cm)
Land Use: Forest-73.0%; Range-9.0%; Water-18%

Lake Morphometry:

Area: 957 acres (387.3 hect)
Depth: Maximum - 38 ft (11.6 m); Average - 18ft (5.4 M)
Ave/Max Depth Ratio: 0.470
Volume: 16,939 acre ft (20.92 cu hm)
Shoal area: 27%
Volume factor: 1.40
Shape factor: 1.72
Length of Shoreline: 7.5 mi (12.1 km)
Retention time: indeterminate

<u>Water Quality</u> (Johnson et al, 1985: Hyatt Reservoir shallow, eutrophic reservoir; the average depth is only 18 feet and the water is well-mixed, so that much of the bottom is exposed to warm surface water. Thus, the recycling of algal nutrients is enhanced. In 1968 the reservoir was treated with rotenone to eliminate rough fish. As a result, the trout population has flourished, a further indication that a productive food chain exists. The reservoir was the site of an illegal attempt to introduce a non-native fish (pike) in 1973.

Summary of Mid-lake Data from Hyatt Reservoir

Date	pH (SU)	Total Phosphorus (mg/l)	Dissolved Ortho Phosphorus (mg/l)	Nitrate & Nitrite (mg/l)	Ammonia (mg/l)	Total Nitrogen (mg/l)	Surface N:P Ratio[8]	Chlorophyll a (ug/l)
9/7/1981 (Johnson et al, 1985	7.3	0.046	-	-	-	-	-	18.5

Hazardous Algal Bloom Health Advisories: A Public Health Advisory was issued by the Oregon Health Authority for Hyatt Reservoir in 2006.

Summary of Public Health Advisories in Hyatt Reservoir

Year	Start Date	End Date	Duration	Dominant Species	High Cell Count[9]	Maximum Toxin Measured (ug/l)
2006	9/12	9/19	7			

Likely or Suspected Cause of Blooms: Unknown

303(d) List Status: The 2004/2006 Integrated Report does not contain any listings for Hyatt Reservoir. A Category 5 (Section 303(d) list – a TMDL is needed) listing for Aquatic Weeds and Algae has been proposed in Oregon's 2010 Integrated Report based on the Health Advisory Issued. TMDL related work has not been initiated.

References

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

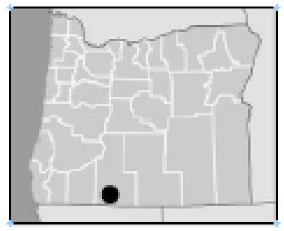
Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

[8] N:P ratio below 7.2 is Nitrogen Limiting

[9] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Upper Klamath Lake

Klamath County, Klamath Basin
Eastern Cascades Slopes & Foothills Ecoregion



State of Oregon
Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Upper Klamath Lake, with a surface area of 61,543 acres (over 70,000 acres including Agency Lake), is the largest freshwater lake in Oregon and one of the largest in the United States. It is a natural water body lying in the structural valley known as the Klamath Graben. Including Agency Lake and its connecting channel, it is about 25 miles long and ranges in width from 2.5 to 12.5 miles. Although historically a natural lake system, the ability to artificially lower lake levels to supply irrigation water to the USBR Klamath Project was achieved in 1921 by cutting a channel through a natural rock reef at the outlet of the lake (Kann et al, 2005). The drainage basin is about 3800 square miles, much of it a mountainous volcanic area covered with pumice deposits derived from the formation of the Crater Lake caldera. Elevations in the basin range from 4147 feet at the lake to over 9000 feet at some of the higher peaks in the Cascade Mountain Range to the west. The mountains create a rain shadow over much of the area, and precipitation varies from as little as 15 inches at lower elevations, to more than 60 inches at higher elevations. Consequently, vegetation also varies; the mountainous regions have forests of Douglas fir, ponderosa pine, lodgepole pine and true firs, while the open flatlands are associated with large pumice deposits occupied by grass-shrub communities. Large marshes exist throughout the drainage basin. The Sycan (995 acres) and Klamath Marshes (8121 acres) cover the basins of former Pleistocene lakes and extensive marsh areas surround much of the present Upper Klamath and Agency Lakes. Flora associated with the marsh area is a typical sedge-reed community. Since World War I, large sections of marsh have been drained for agricultural use (see later discussions).

Upper Klamath Lake sampled June 17, 2001 - Extensive blooms of the cyanobacterium *Aphanizomenon flos-aqaue* (AFA) are apparent. Image courtesy USGS EROS Data Center and the Landsat 7 Science Team (http://visibleearth.nasa.gov/cgi-bin/viewrecord?9863) and consists of high-resolution (i.e. 15 meter) multispectral data.

The major tributary of Upper Klamath Lake is the Williamson River, accounting for about 46 percent of the inflow to the lake. The origin of this river is a large spring, and it flows through pasture land before entering Klamath Marsh. The river flowing out of the marsh is a dark brown color due to very high dissolved aquatic humus concentrations. The timing of the annual *Aphanizomenon* bloom in Klamath Lake has been correlated with the flow, occurring in the summer when the marsh stops flowing and occurring earlier in dry years than wet year (Perdue et al, 1981). The Sprague River joins the Williamson River just prior to entering Upper Klamath Lake on the north shore. Wood River is the second largest tributary, and drains into Agency Lake and then into Upper Klamath Lake on the north shore. Other tributaries, mostly draining agricultural areas, also enter the lake. The outlet is the Link River flowing out of the south end of the lake into Lake Ewauna and into the Klamath River which eventually enters the Pacific Ocean in northern California.

Upper Klamath Lake fills a vital role in water-resource utilization in south central Oregon: water from the lake is used for irrigation of reclaimed agricultural land; it is regulated to enhance power generation at the Pacific Power and Light projects on the Link River and farther downstream on the Klamath River at the John C. Boyle hydropower facility; and it is used extensively by waterfowl, the marshy habitat being an important stopover during fall and spring migrations on the Pacific flyway. Recreational use of Upper Klamath Lake has always been a major focus, particularly for fishing and boating. However, water-contact sports are discouraged by the poor water quality. Several resorts are located at various places around the lake, especially on the west side near the Lake of the Woods road, and there are numerous public campgrounds, picnic areas and boat launching sites. Two endangered sucker species, Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*), occur in the lake. For the angler, rainbow trout are the major attraction and some very large fish have been caught. Most of the fishing is done along the western shore, from Pelican Bay south to Wocus Bay and most of it close to shore because of rough waters commonly encountered farther out in the lake. In addition to trout, warm-water species also thrive in Upper Klamath Lake. Two genera of Cyprinidae, blue chub (Gila coerulea) and tui chub (Gila bicolor), constitute 90 percent of the fish population in the lake.

Klamath Lake Characteristics (excluding Agency Lake; from Johnson et al, 1985)

Setting:

Type: natural with dam
Use: recreation, wildlife, irrigation, power
Elevation: 4,139 ft (1,261.6 m)
Location: extends northward from Klamath Falls for 22 miles

Drainage Basin Characteristics:

Area: 3,810 sq mi (9,867.9 sq km)
Relief: low
Precipitation: 15-60 in (38-152 cm)
Land Use: Forest-72.9%; Range-13.3%; Water-3.5%; Irrigated Ag-7.6%; Other-2.5% (Wetlands)

Lake Morphometry:

Area: 61,543 acres (24,906.5 hect)
Depth: Maximum - 50 ft (15.2 m); Average - 14ft (4.2 m)
Ave/Max Depth Ratio: 0.280
Volume: 849,290 acre ft (1,049.12 cu hm)
Shoal area: 14%
Volume factor: .83
Shape factor: 2.52
Length of Shoreline: 87.8 mi (141.3 km)
Retention time: 0.5 mo

Water Quality: Klamath Lake has had a long history of algal blooms, dominated by *Aphanizomenon flow-aquae*. High pH (often exceeding 9.5 SU in the summer) and high un-ionized ammonia concentrations are associated with the blooms when algae are actively growing. Low dissolved oxygen concentrations follow when the blooms decline in mid to late summer. Fish kills, with high mortalities of endangered sucker species, often occur especially in years of low wind and high water column stability (Kann et al, 2005).

While Upper Klamath Lake appears to have been eutrophic since the earliest known records from the mid-1800s, a transition took place between the late 1800s and the early to mid-1990s, when major changes in land use and hydrology occurred in the watershed and lake and the current bloom-forming cyanobacteria became prevalent. Sediment core analysis showed that that sediment accumulation rates have substantially increased with post-settlement sediments being enriched in both nitrogen and phosphorus and with a significant decrease in the nitrogen to phosphorus ratio indicating that the phosphorus loading has increased relative to the nitrogen loading. These changes were related to various changes in land use in the watershed including: diking and draining of wetlands and conversion to agriculture; water diversion from tributaries and out of the lake; and construction of dam to allow the lake to be operated as a storage reservoir (Eilers et al, 2004). A USGS study (Snyder and Morace, 1997) estimated that over 35,000 acres of wetlands had been lost from the lake from between 1889 – 1971, which was the period when diking and draining of wetlands occurred.

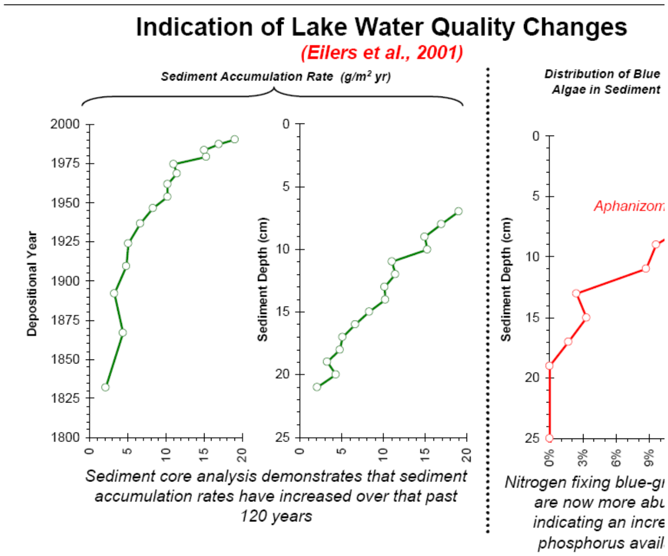
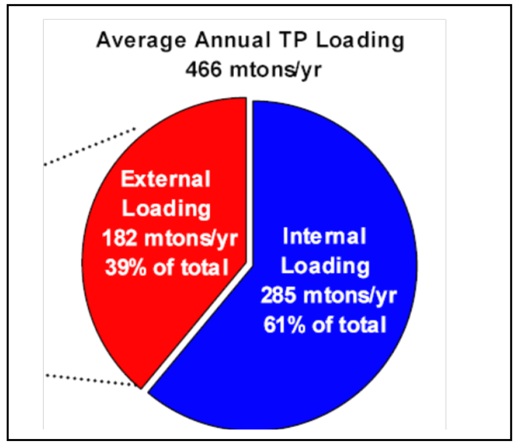
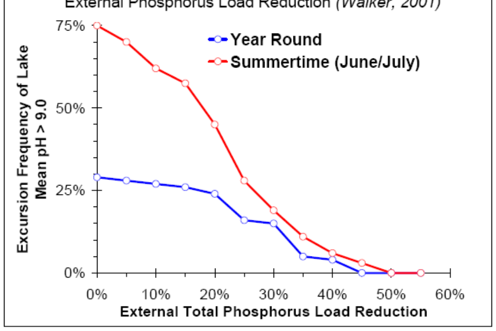


Figure 2-6. Upper Klamath Lake Sediment Core Analysis (Eilers et al. 200



<u>TMDL Findings:</u> A Total Maximum Daily Load (TMDL)was developed for Klamath Lake in 2002 that addressed the phosphorus loading. Seasonal maximum algal growth rates and their impact on elevated pH and low DO levels were found to be controlled primarily by phosphorus availability and secondarily by light and temperature. High nutrient concentrations were from the lake sediments and the watershed. Year to year variations in the timing and development of algal blooms were largely temperature dependent. Internal loading, sediment regenerated phosphorus delivered to the lake water column, accounted for approximately 61% of the average annual total phosphorus load. An important mechanism for the release of phosphorus in shallow productive lakes that are continuously mixed is photosynthetically elevated pH. Elevated pH increases phosphorus flux to the water column by solubilizing iron-bound phosphorus in both bottom and resuspended sediments as high pH causes increased competition between hydroxyl ions and phosphate ions decreasing the sorption of phosphate on iron. It appears that a pH of approximately 9.3 SU is the level at which the probability of the internal loading sharply increases. A flux of phosphorus to the water column from lake sediments increases the water column phosphorus concentration and further elevates the algal biomass and pH, setting up a positive feedback loop (DEQ, 2002).

Figure 2-23. Lake-Mean pH Frequency as a Function of External Phosphorus Load Reduction *(Walker, 2001)*



A 40% reduction in external total phosphorus loading to Upper Klamath Lake was selected as a TMDL target as it would reduce the frequency of pH excursions over 9.0 SU (which drive the internal loading of phosphorus) to approximately 5% and it appears that it can be achieved or is feasible. This reduction could be achieved through a variety of activities, some of which are already underway, including: near-lake wetland restoration and upland hydrology and land cover restoration. Phosphorus target concentrations that correlate with the targeted 40% external total phosphorus loading reduction are:

- ~110 ug/l annual lake mean TP;
- ~30 ug/l spring (March – May) lake mean TP;
- ~66 ug/l annual mean TP from all inflows;

A major focus for restoring Upper Klamath Lake (including Agency Lake) has been to reclaim wetlands that were adjacent to the lakes and had formerly been associated with both lakes prior to diking and draining for farming and ranching purposes. The elimination of over 35,000 acres of wetland from within the lakes and their transformation to other uses is believed to be a primary factor that caused the lake to change from eutrophic to hypereutrophic and altering algal populations to dominance of *Aphanizomenon flos-aquae* (Geiger et al, 2011). The isolation of 35,390 acres of wetlands from the lake would have meant a loss of nitrogen and phosphorus update capacity by the wetland plants (estimated as 9,882 metric tons of total nitrogen and 143 metric tons of total phosphorus per year) making increased amount of nutrients available to plants within the undiked portions of the lakes. The seasonal uptake by the wetland plants would occur at approximately the same season as the need for nutrients by phytoplankton in the lake. Not only are the wetlands nutrient sinks but they may have additional value by providing dissolved organic carbon that can suppress cyanobacteria as shown in replicate jar assays and in-lake assays conducted by Oregon State University (Geiger et al, 2011). Humic carbon or humates can comprise over 50% of the dissolved organic carbon concentrations. These wetland vegetation decomposition products have been identified as agents that suppress the growth of Cyanobacteria. To date, (early 2011), the intended reclaimed wetland area is in excess of 17,500 acres.

A recent preliminary study by the U.S. Geological Survey has linked lesions found in two endangered species, Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*), with exposure to algal toxins (associated with *Aphanizonmenon flos-aquae* and *Microcystis aeruginosa*). The route of exposure to toxins was an oral route through the food chain rather than exposure to dissolved toxins at the gills (VanderKooi et al, 2010).

Data collected over the past ten years is being reviewed and will be the basis for an updated nutrient loading analysis. A technical review of the TMDL is also occurring.

For more detail on Klamath Lake, see USGS website - http://or.water.usgs.gov/klamath/index.html or the selected bibliography of Klamath Lake Research through 1994 - http://or.water.usgs.gov/pubs_dir/Html/OFR95-285/klamath_bib.html .

Hazardous Algal Bloom Health Advisories: One of the first public health advisories issued in Oregon occurred in 1996 for Klamath Lake based on a bloom dominated by *Microcystis aeruginosa*.

Summary of Public Health Advisories in Klamath Lake

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[10]	Maximum Toxin Measured (ug/l)
1996	9/13	11/27	75	*Microcystis aeruginosa* *Aphanizomenon flos-aquae*		

Likely or Suspected Cause of Blooms: Excessive internal and external total phosphorus loading to the lake, considerable loss of adjacent wetland area.

303(d) List Status: The 2004/2006 Integrated Report identifies Upper Klamath Lake and Agency Lake as being Water Quality Limited with an approved TMDL (Category 4A) for Chlorophyll a, dissolved oxygen and pH.

References

Department of Environmental Quality. 2002. Upper Klamath Lake Drainage Total Maximum Daily Load (TMDL) and Water Quality Management Plan (WQMP).

Eilers, J., J. Kann, J. Cornet, K. Moser, A. St. Amand and C. Gubala. 2004. Paleolimnological evidence of change in a shallow, hypereutrophic lake: Upper Klamath Lake, Oregon, USA. *Hydrobiologia.* 520:7-18.

Geiger, Stan, K. Haggard and A. Milligan. 2011. Changes at Upper Klamath Lake, OR. Lakeline Spring 2011. North American Lake Management Society.

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

Kann, J. and E. Welch. 2005. Wind Control on the Water Quality in Shallow Hypereutrophic Upper Klamath Lake, Oregon. Lake and Reservoir Management 21(2): 149-158, 2005. North American Lake Management Society

[10] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Public Health Advisories

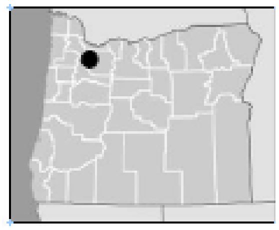
Perdue, E. M., C. R. Lytle, M. S. Sweet and J. W. Sweet. 1981. The chemical and biological impact of Klamath Marsh on the Williamson River, Oregon. WRRI-71. Water Resources Research Institute, Oregon state University, Corvallis, OR. 199 pp.

Snyder, Daniel and J. Morace. 1997. Nitrogen and Phosphorus Loading from Drained Wetlands Adjacent to Upper Klamath and Agency Lakes, Oregon. U.S. Geological Survey, Water-Resources Investigations Report 97-4059. Prepared in cooperation with the Bureau of Reclamation. Portland, OR.

VanderKooi, S. P., S. M. Burdick, K. R. Echols, C. A. Ottinger, B. H. Rosen, and T. M. Wood. 2010. Algal toxins in Upper Klamath Lake, Oregon: Linking water quality to juvenile sucker health. U.S. Geological Survey Fact Sheet 2009-3111, 2p.

Lake Oswego

Clackamas County, Willamette Basin
Willamette Valley Ecoregion



State of Oregon
Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Lake Oswego, located in the heart of the city of the same name, is a well-known but difficult to see lake in the Portland metropolitan area. The entire shoreline is private land and rimmed with residential neighborhoods, and the lake is visible only in glimpses from the roads surrounding it. The lakebed is owned and maintained by the Lake Oswego Corporation (LOC), a corporation whose members have lake frontage or access rights to the water and recreational facilities through property agreements. Even with this restricted access, Lake Oswego receives very heavy recreational use. According to Frenkel (1975), it is the seventh busiest body of water in Oregon, and perhaps the busiest for use by water-skiers.

Source: Oregon National Guard, 1981-82. View looking northwest.

The lake has three basins: West Bay, the Main Lake, and Lakewood Bay. There are also two shallow, man-made canals, Blue Heron Canal and Oswego Canal. Oswego Canal is a 1.5 mile diversion from the Tualatin River at River Mile 6.7. Oswego Lake's two watersheds include the natural, 7.5-mi^2 urban basin around the Lake (10:1 watershed to lake-area ratio) and the larger 700-mi^2 Tualatin River basin (1,000:1 ratio) when the LOC Head gate is opened. Major inflows from the watershed include Springbrook Creek, Lostdog Creek, Blue Heron Creek, and 70-plus storm drains from the City of Lake Oswego. The LOC has water rights from the Tualatin River with a primary water right for hydropower generation (57.5 cfs obtained in 1906 that allows year around diversion) and secondary uses that include irrigation (up to 500 ac-ft from Scoggins Reservoir during March – November), aesthetic viewing, contact recreation, fishing and boating (maintenance/evaporation – 3.36 cfs that can be diverted between September 16th to July 30th). (Rosenkranz, 2008).

Lake Oswego Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake with dam
Use: recreation (privately owned)
Elevation: 99 ft (30.2 m)
Location: within Lake Oswego city boundary, 8 mi. S of Portland

Drainage Basin Characteristics:

Area: 6.6 sq mi (17.1 sq km)
Relief: steep
Precipitation: 40 in (102 cm)
Land Use: Forest-12.6%; Water-9.7%; Irrigated Ag-0.2% Non Irrig Ag-5.4%; Urban- 72.1%

Lake Morphometry:

Area: 395 acres (159.9 hect)
Depth: Maximum - 55 ft (16.8 m); Average - 26ft (7.8 m)
Ave/Max Depth Ratio: 0.460
Volume: 10,055 acre ft (12.42 cu hm)
Shoal area: 20%
Volume factor: 1.39
Shape factor: 3.82
Length of Shoreline: 10.6 mi (17.1 km)
Retention time: 2 mo

Water Quality: DEQ developed Total Maximum Daily Loads for phosphorus and ammonia for the Tualatin River in 1988. The phosphorus TMDL was developed to reduce algal growth and address DO and pH problems in the lower Tualatin and Lake Oswego. As part of the TMDL, Lake Oswego developed a management plan to address water quality problems in the lake.

The 1988 TMDL was revised in 2001 to include load and wasteload allocations for total phosphorus entering Oswego Lake from streams and stormwater runoff. The waste load allocation for stormwater is implemented by the City of Lake Oswego, through their stormwater management permit. A load allocation in the form of a maximum phosphorus concentration in the Tualatin also limits summertime inputs to Oswego Lake (Geiger et al, 1988).

Lake has been adaptively managed since that time. A summary of the conditions in the lake and management actions in recent years follows:

Oswego Lake Watershed Management Summary: The following is primarily from Management Summaries for Lake Oswego Corporation (Clean Water Services 2003 - 2008):

The goal for the annual LOC Water Quality Management Plan is to reduce cyanobacteria productivity and maximize the aesthetic value of the Lake by focusing on flow management, water quality treatment, and macrophyte issues.

Water Quality: Oswego Lake has maintained a water quality monitoring program that includes six sites where water clarity, nutrient content, biological productivity, and chemical profiles are measured. Monitoring is conducted weekly from June through September and bi-weekly from October through May. Annual reports (Clean Water Services 2003 – 2008) contain summaries. 2008 averages are shown below.

2008 OSWEGO LAKE WATER QUALITY SUMMARY AVERAGES

Location	Season	Chlorophyll-a (µg/L)	Total P (µg/L)	SRP (µg/L)	Total N (µg/L)	Secchi (m)	Turbidity (NTU)
Lakewood Bay	Annual	5.6	19	2	283	2.8	1.3
	Summer	3.7	18	2	246	2.9	1.4
Main Lake	Annual	10.1	27	7	403	3.3	2.1
	Summer	8.6	24	3	308	3.5	1.7
West Bay	Annual	5.7	45	13	1048	1.3	2.6
	Summer	4.9	28	2	519	1.3	1.4
Oswego Canal	Annual	11.5	140	59	3613	0.8	3.5
	Summer	**15.5**	**133**	**46**	**3536**	0.8	3.4
Blue Heron Canal	Annual	5.3	37	4	715	1.1	4.0
	Summer	5.0	30	2	554	1.2	2.13
Outlet	Annual	8.5	22	3	379	3.3	2.1
	Summer	5.4	19	1	289	3.6	1.2

Bold = highest average during the summer; Underline = lowest average during the summer Summer=June–September
Abbreviations: Total P = Total Phosphorus, SRP = Soluble Reactive Phosphorus, Total N = Total Nitrogen, Secchi = Secchi depth, Turb = Turbidity; ug/L = micrograms per liter, m = meters, NTU = nephelometric turbidity units, C = Celsius

Algae Control: Cyanobacteria are typically the dominant form of algae. *Gleotrichia* and *Lyngbya* often dominated and created surface mats prior to 2005, when alum treatments were started to reduce available phosphorus. In 2004, a large *Microcystis* bloom occurred in response to large rain events in late August and mid-September and water contact recreation was restricted. The alum program has evolved in its focus and means of delivery. For example, in 2005, sediment in Oswego Canal, Blue Heron Canal and West Bay was treated with powdered aluminum sulfate buffered with sodium bicarbonate. Preliminary sediment testing showed sediment phosphorus concentrations as high as 18 grams per kilogram. During the summer, this phosphorus was released into the water and fed algal blooms. The goal was to lock up phosphorus using aluminum sulfate to bind with the nutrients. In 2008, LOC surface applied 24,000 gallons of liquid alum and injected an additional 16,000 gallons. Surface applications occurred in Lakewood Bay, West End, Main Lake, and the NE Arm. Alum injectors are installed in Lakewood Bay, Half Moon Bay, West Bay, Oswego Canal, and Blue Heron Canal. The alum program has been effective in reducing phosphorus and the resultant cyanobacteria growth, and it will be continue as needed.

Since 2001, an aeration system has been operating in Blue Heron Canal. Prior to aeration, anoxia from decaying organic matter would cause fish mortality and odor problems along with nutrient release from the sediment. Aeration generally keeps Dissolved Oxygen levels above 6 mg/l year around with no reports of major fish mortality in the canal. A layered aeration system was installed in the Main Lake during the summer of 2001 and activated in August 2001. The first full year of Main Lake aeration was in 2002. Prior to aeration, the entire hypolimnion would be anoxic. In 2002, only the bottom meter was anoxic and the summer of 2003 showed an additional increase in the volume of oxygenated water in the hypolimnion.

Nutrient input from the watershed and Tualatin River also need to be dramatically reduced in order to greatly reduce the amount of active management required to control phosphorus. A number of projects have been implemented over time including: reducing Tualatin River flows to a minimum as it contains high concentrations of phosphorus and sediment, using it to only to keep the lake full; encouraging use of a lake-friendly, inorganic non-phosphorus turf fertilizer since 2000; doing stream restoration projects to reintroduce the natural floodplain in tributary streams;

and doing tributary and storm water monitoring to develop a basin-wide hydrologic model that will be coupled with nutrient concentrations to refine the watershed phosphorus budget.

Macrophyte Control: In 2008, herbicide applications were used only to control non-native aquatic weeds in Lakewood Bay, Half Moon Bay, Oswego Canal, Blue Heron Canal, West Bay, and the northern shoreline. A spring application of fluridone to Lakewood Bay helped reduce the amount of invasive *Potamogeton crispus* (curlyleaf pondweed) that dominates this area. Later applications of diquat to West Bay, both canals, and spots along the northern shore helped control *Egeria densa* (Brazilian elodea).

In addition to herbicides, macrophytes were controlled by an aquatic weed harvester and diver hand-pulling. Harvesting is most effective when large areas of vegetation have reached the surface. Harvesting clips the vegetation about five feet below the surface. Hand-pulling is an effective long-term control solution used for removing complete plants from root to stem. A barge is equipped with a four inch suction hose that draws in plants which are then macerated and emptied into a tote for removal.

Management in the Future: LOC continues to monitor the lake and watershed to better understand the ecosystem. Future plans are:

- Continue to implement the integrated aquatic plant management plan involving hand pulling, harvesting, and herbicides;
- Continue educating watershed residents about water quality impacts;
- Assess conditions in bays and canals and propose localized solutions;
- Work with the City to improve surface water runoff to the Lake;
- Maximize the water quality improvements with the 2-layer lake aeration system;
- Continue to use alum (aluminum sulfate) as a phosphorus reduction tool.;

Hazardous Algal Bloom Health Advisories: A Public Health Advisory was issued by the Lake Oswego Corporation for Lake Oswego in 2004.

Summary of Public Health Advisories in Lake Oswego

Year	Start Date	End Date	Duration	Dominant Species	High Cell Count[11]	Maximum Toxin Measured (ug/l)
2004				*Microcystis aeruginosa*	500,000	11

Likely or Suspected Cause of Blooms: Primarily cultural eutrophication with high phosphorus loading from both the immediate watershed and extended watershed (Tualatin Subbasin).

303(d) List Status: The 2004/2006 Integrated Report identifies Lake Oswego as being Water Quality Limited with an approved TMDL (Category 4A) for Aquatic Weeds and Algae, dissolved oxygen, pH and phosphorus.

References

Clean Water Services. 2003 through 2008. Tualatin River Flow Management Technical Committee Annual Reports. These contain a 2003 - 2008 Oswego Lake Management Summary by Mark Rosenkranz, Water Resource Specialist, Lake Oswego Corporation. Prepared by Bernie Bonn.

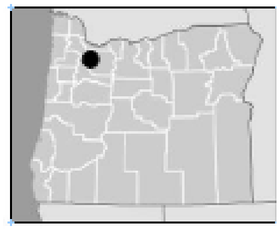
Geiger, Stan and Aquatic Analysts. 1988. Lake Oswego Lake and Watershed Assessment 1986 - 1987. Diagnostic and Restoration Analysis. Volume 1: Final Report; Volume 2: Appendices. Prepared for the Lake Oswego Corporation, the Unified Sewerage Agency, and the Oregon Department of Environmental Quality. Prepared by Scientific Resources, Inc., Lake Oswego, Oregon. Project 8628.

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

[11] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Lake Oswego

Clackamas County, Willamette Basin
Willamette Valley Ecoregion



State of Oregon
Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Lake Oswego, located in the heart of the city of the same name, is a well-known but difficult to see lake in the Portland metropolitan area. The entire shoreline is private land and rimmed with residential neighborhoods, and the lake is visible only in glimpses from the roads surrounding it. The lakebed is owned and maintained by the Lake Oswego Corporation (LOC), a corporation whose members have lake frontage or access rights to the water and recreational facilities through property agreements. Even with this restricted access, Lake Oswego receives very heavy recreational use. According to Frenkel (1975), it is the seventh busiest body of water in Oregon, and perhaps the busiest for use by water-skiers.

Source: Oregon National Guard, 1981-82. View looking northwest.

The lake has three basins: West Bay, the Main Lake, and Lakewood Bay. There are also two shallow, man-made canals, Blue Heron Canal and Oswego Canal. Oswego Canal is a 1.5 mile diversion from the Tualatin River at River Mile 6.7. Oswego Lake's two watersheds include the natural, 7.5-mi^2 urban basin around the Lake (10:1 watershed to lake-area ratio) and the larger 700-mi^2 Tualatin River basin (1,000:1 ratio) when the LOC Head gate is opened. Major inflows from the watershed include Springbrook Creek, Lostdog Creek, Blue Heron Creek, and 70-plus storm drains from the City of Lake Oswego. The LOC has water rights from the Tualatin River with a primary water right for hydropower generation (57.5 cfs obtained in 1906 that allows year around diversion) and secondary uses that include irrigation (up to 500 ac-ft from Scoggins Reservoir during March – November), aesthetic viewing, contact recreation, fishing and boating (maintenance/evaporation – 3.36 cfs that can be diverted between September 16th to July 30th). (Rosenkranz, 2008).

Lake Oswego Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake with dam
Use: recreation (privately owned)
Elevation: 99 ft (30.2 m)
Location: within Lake Oswego city boundary, 8 mi. S of Portland

Drainage Basin Characteristics:

Area: 6.6 sq mi (17.1 sq km)
Relief: steep
Precipitation: 40 in (102 cm)
Land Use: Forest-12.6%; Water-9.7%; Irrigated Ag-0.2% Non Irrig Ag-5.4%; Urban- 72.1%

Lake Morphometry:

Area: 395 acres (159.9 hect)
Depth: Maximum - 55 ft (16.8 m); Average - 26ft (7.8 m)
Ave/Max Depth Ratio: 0.460
Volume: 10,055 acre ft (12.42 cu hm)
Shoal area: 20%
Volume factor: 1.39
Shape factor: 3.82
Length of Shoreline: 10.6 mi (17.1 km)
Retention time: 2 mo

Water Quality: DEQ developed Total Maximum Daily Loads for phosphorus and ammonia for the Tualatin River in 1988. The phosphorus TMDL was developed to reduce algal growth and address DO and pH problems in the lower Tualatin and Lake Oswego. As part of the TMDL, Lake Oswego developed a management plan to address water quality problems in the lake.

The 1988 TMDL was revised in 2001 to include load and wasteload allocations for total phosphorus entering Oswego Lake from streams and stormwater runoff. The waste load allocation for stormwater is implemented by the City of Lake Oswego, through their stormwater management permit. A load allocation in the form of a maximum phosphorus concentration in the Tualatin also limits summertime inputs to Oswego Lake (Geiger et al, 1988).

Lake has been adaptively managed since that time. A summary of the conditions in the lake and management actions in recent years follows:

Oswego Lake Watershed Management Summary: The following is primarily from Management Summaries for Lake Oswego Corporation (Clean Water Services 2003 - 2008):

The goal for the annual LOC Water Quality Management Plan is to reduce cyanobacteria productivity and maximize the aesthetic value of the Lake by focusing on flow management, water quality treatment, and macrophyte issues.

Water Quality: Oswego Lake has maintained a water quality monitoring program that includes six sites where water clarity, nutrient content, biological productivity, and chemical profiles are measured. Monitoring is conducted weekly from June through September and bi-weekly from October through May. Annual reports (Clean Water Services 2003 – 2008) contain summaries. 2008 averages are shown below.

2008 OSWEGO LAKE WATER QUALITY SUMMARY AVERAGES

Location	Season	Chlorophyll-a (µg/L)	Total P (µg/L)	SRP (µg/L)	Total N (µg/L)	Secchi (m)	Turbidity (NTU)
Lakewood Bay	Annual	5.6	19	2	283	2.8	1.3
	Summer	3.7	18	2	246	2.9	1.4
Main Lake	Annual	10.1	27	7	403	3.3	2.1
	Summer	8.6	24	3	308	3.5	1.7
West Bay	Annual	5.7	45	13	1048	1.3	2.6
	Summer	4.9	28	2	519	1.3	1.4
Oswego Canal	Annual	11.5	140	59	3613	0.8	3.5
	Summer	**15.5**	**133**	**46**	**3536**	0.8	3.4
Blue Heron Canal	Annual	5.3	37	4	715	1.1	4.0
	Summer	5.0	30	2	554	1.2	2.13
Outlet	Annual	8.5	22	3	379	3.3	2.1
	Summer	5.4	19	1	289	3.6	1.2

Bold = highest average during the summer; Underline = lowest average during the summer Summer=June–September
Abbreviations: Total P = Total Phosphorus, SRP = Soluble Reactive Phosphorus, Total N = Total Nitrogen, Secchi = Secchi depth, Turb = Turbidity; ug/L = micrograms per liter, m = meters, NTU = nephelometric turbidity units, C = Celsius

Algae Control: Cyanobacteria are typically the dominant form of algae. *Gleotrichia* and *Lyngbya* often dominated and created surface mats prior to 2005, when alum treatments were started to reduce available phosphorus. In 2004, a large *Microcystis* bloom occurred in response to large rain events in late August and mid-September and water contact recreation was restricted. The alum program has evolved in its focus and means of delivery. For example, in 2005, sediment in Oswego Canal, Blue Heron Canal and West Bay was treated with powdered aluminum sulfate buffered with sodium bicarbonate. Preliminary sediment testing showed sediment phosphorus concentrations as high as 18 grams per kilogram. During the summer, this phosphorus was released into the water and fed algal blooms. The goal was to lock up phosphorus using aluminum sulfate to bind with the nutrients. In 2008, LOC surface applied 24,000 gallons of liquid alum and injected an additional 16,000 gallons. Surface applications occurred in Lakewood Bay, West End, Main Lake, and the NE Arm. Alum injectors are installed in Lakewood Bay, Half Moon Bay, West Bay, Oswego Canal, and Blue Heron Canal. The alum program has been effective in reducing phosphorus and the resultant cyanobacteria growth, and it will be continue as needed.

Since 2001, an aeration system has been operating in Blue Heron Canal. Prior to aeration, anoxia from decaying organic matter would cause fish mortality and odor problems along with nutrient release from the sediment. Aeration generally keeps Dissolved Oxygen levels above 6 mg/l year around with no reports of major fish mortality in the canal. A layered aeration system was installed in the Main Lake during the summer of 2001 and activated in August 2001. The first full year of Main Lake aeration was in 2002. Prior to aeration, the entire hypolimnion would be anoxic. In 2002, only the bottom meter was anoxic and the summer of 2003 showed an additional increase in the volume of oxygenated water in the hypolimnion.

Nutrient input from the watershed and Tualatin River also need to be dramatically reduced in order to greatly reduce the amount of active management required to control phosphorus. A number of projects have been implemented over time including: reducing Tualatin River flows to a minimum as it contains high concentrations of phosphorus and sediment, using it to only to keep the lake full; encouraging use of a lake-friendly, inorganic non-phosphorus turf fertilizer since 2000; doing stream restoration projects to reintroduce the natural floodplain in tributary streams; and doing tributary and storm water monitoring to develop a basin-wide hydrologic model that will be coupled with nutrient concentrations to refine the watershed phosphorus budget.

Macrophyte Control: In 2008, herbicide applications were used only to control non-native aquatic weeds in Lakewood Bay, Half Moon Bay, Oswego Canal, Blue Heron Canal, West Bay, and the northern shoreline. A spring application of fluridone to Lakewood Bay helped reduce the amount of invasive *Potamogeton crispus* (curlyleaf pondweed) that dominates this area. Later applications of diquat to West Bay, both canals, and spots along the northern shore helped control *Egeria densa* (Brazilian elodea).

In addition to herbicides, macrophytes were controlled by an aquatic weed harvester and diver hand-pulling. Harvesting is most effective when large areas of vegetation have reached the surface. Harvesting clips the vegetation about five feet below the surface. Hand-pulling is an effective long-term control solution used for removing complete plants from root to stem. A barge is equipped with a four inch suction hose that draws in plants which are then macerated and emptied into a tote for removal.

Management in the Future: LOC continues to monitor the lake and watershed to better understand the ecosystem. Future plans are:

- Continue to implement the integrated aquatic plant management plan involving hand pulling, harvesting, and herbicides;
- Continue educating watershed residents about water quality impacts;
- Assess conditions in bays and canals and propose localized solutions;
- Work with the City to improve surface water runoff to the Lake;
- Maximize the water quality improvements with the 2-layer lake aeration system;
- Continue to use alum (aluminum sulfate) as a phosphorus reduction tool.;

Hazardous Algal Bloom Health Advisories: A Public Health Advisory was issued by the Lake Oswego Corporation for Lake Oswego in 2004.

Summary of Public Health Advisories in Lake Oswego

Year	Start Date	End Date	Duration	Dominant Species	High Cell Count[12]	Maximum Toxin Measured (ug/l)
2004				*Microcystis aeruginosa*	500,000	11

Likely or Suspected Cause of Blooms: Primarily cultural eutrophication with high phosphorus loading from both the immediate watershed and extended watershed (Tualatin Subbasin).

303(d) List Status: The 2004/2006 Integrated Report identifies Lake Oswego as being Water Quality Limited with an approved TMDL (Category 4A) for Aquatic Weeds and Algae, dissolved oxygen, pH and phosphorus.

References

Clean Water Services. 2003 through 2008. Tualatin River Flow Management Technical Committee Annual Reports. These contain a 2003 - 2008 Oswego Lake Management Summary by Mark Rosenkranz, Water Resource Specialist, Lake Oswego Corporation. Prepared by Bernie Bonn.

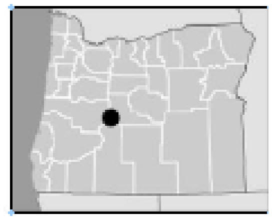
Geiger, Stan and Aquatic Analysts. 1988. Lake Oswego Lake and Watershed Assessment 1986 - 1987. Diagnostic and Restoration Analysis. Volume 1: Final Report; Volume 2: Appendices. Prepared for the Lake Oswego Corporation, the Unified Sewerage Agency, and the Oregon Department of Environmental Quality. Prepared by Scientific Resources, Inc., Lake Oswego, Oregon. Project 8628.

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

[12] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Lava Lake

Deschutes County, Deschutes Basin, Klamath Mountain Ecoregion



State of Oregon
Department of Environmental Quality

Setting and Lake Uses

Lava Lake is one of many scenic mountain lakes on the east slope of the Central Oregon Cascades accessible from the Cascade Lakes Highway. It takes its name from the surrounding lava flows, which are prominent along the east shoreline. Lava flows from Bachelor Butte probably altered drainage patterns in the area and formed the lake with a lava dam. Very little surface drainage has developed in this volcanic terrain, and there are no permanent surface streams entering the lake (Johnson et al, 1985).

Source: Oregon National Guard. 1981-82. View looking north.

Lava Lake has a complex hydrology with much of inflow coming from groundwater and precipitation and outflow coming from out-seepage and evaporation. No surface flows enter Lava Lake and surface discharge only occurs in wet years through the swale between Lava Lake and Little Lava Lake. The lake level can vary 1 – 2 meters over the course of the year with lower levels in the Spring and higher levels in the Fall. The apparent lag between the increase in lake stage and snowmelt would suggest that Lava Lake is receiving groundwater input from the regional aquifer – which tends to flow in a southerly direction. Inflowing springs are generally found along the northeast part of the lake and out-seepage likely occurs in the southern part of the lake. (Eilers et al, 2006)

The entire watershed is within the Deschutes National Forest. There is a Forest Service campground and a private resort on the south shore – in the vicinity of the swale that leads to Little Lava Lake. Indigenous fish were bull trout, redband trout and whitefish but their disappearance was attributed to a combination of early chemical treatments and angler harvest. Both brook trout and rainbow trout have been stocked and are the current sport fishery. Tui chub have long been a major impediment to an abundant salmonid sport fishery in Lava Lake. They were abundant in the lake in 1940 and the lake has been treated with rotenone in 1941, 1946, 1949, 1963 and 1980 with numerous other spot treatments. Since the 1980's, the chub population has been kept in check by netting of the chub as they move into the shallows to spawn in the spring with 3,000 to 26,000 pounds of tui chub trapped per year. The total estimate of fish present in the lake is approximately 21,000 pounds (likely an underestimate). (Eilers et al, 2006)

Lava Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake **Use:** recreation **Elevation:** 4,740 f t (1,444.8 m)
Location: 25 miles west-southwest of Bend in Deschutes National Forest

Drainage Basin Characteristics:

Area: 8.4 sq mi (21.8 sq km) **Relief:** low **Precipitation:** 45 in (114 cm)
Land Use: Forest-92.7%, Range-0.2%; Water-6.4%; Other-0.7% (wetland)

Lake Morphometry (area, depth, volume - Eilers, 2006):

Area: 332 acres (134.4 hect) **Depth:** Maximum – 36.4 ft (11.1 m); Average – 23.7 ft (7.2 m)
Ave/Max Depth Ratio: 0.560 **Volume:** 7,839 acre ft (9.64 cu hm)
Volume factor: 1.69
Shoal area: 18% **Shape factor:** 1.27
Length of Shoreline: 3.4 mi (5.5 km) **Retention time:** 1.3 yr

Water Quality: A study of Lava Lake was conducted by MaxDepth Aquatics and DEQ in 2004. The following is a brief summary from that report (Eilers et al, 2006).

The lake was sampled monthly, from June through September. During this study, the lake did not form a hypolimnion during the summer as temperatures continued to decline to the lake bottom. Dissolved Oxygen declined to less than 5.0 mg/l below 5 meters depth during July, August and September. The highest pH values occurred in June with values exceeding 9 SU down to 6 meters depth. This corresponded to the highest chlorophyll measurement (12 ug/l) and highest *Anabaena flos-aquae* densities (over 50,000 cells/ml) measured during the study. As this occurred on the first sampling date, there is no way of determining if these were the maximum values observed for that year or the duration of the bloom. pH levels in the water column generally decreased over the course of the summer. Other diatoms, *Asterionella Formosa* and *Fragilaria crotonensis* that are associated with eutrophic waters, were abundant in other periods. Total Phosphorus was from 0.02 – 0.05 mg/l with higher values found at 6 meters depth versus 1 meter depth. Dissolved ortho phosphorus showed a similar pattern but with a dramatic increase near the bottom in September. Three different groundwater input sites were sampled and showed high phosphorus concentrations (0.1 – 0.11 mg/l) with most of it in a dissolved form (0.077 – 0.091 mg/l), which is readily available for plant growth. Concentrations of nitrogen were generally low (e.g. nitrate: 0.035 – 0.046 mg/l) indicating that nitrogen is likely a limiting nutrient.

Paleolimnologic analysis of sediment cores showed that the lake has become more productive in the 20th century, with significant increases in planktonic diatoms and *Anabaena* akinetes and a four-fold increase in the sediment accumulation rate. However, evidence from the sediments shows that Lava Lake experienced equally higher productive periods during the pre-1800 period but an alternate dating technique of the sediment would need to be used to resolve some uncertainty about the data.

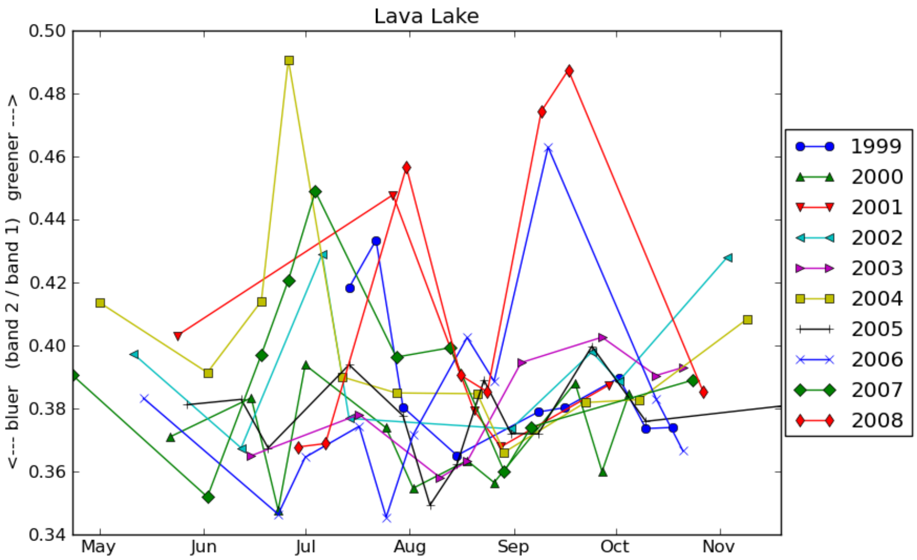
A preliminary nutrient budget developed from this study estimated the following:

	Percent Annual Load	
	Phosphorus	**Nitrogen**
Groundwater:	91%	41%
Precipitation:	5%	48%
Fish:	4%	11%

While there is considerable uncertainty in the estimates, especially related to the hydrologic budget, it was felt that most of the current loading is from natural sources. The study noted that any nutrient contribution from the resort and campgrounds would like drain to the south and away form Lava Lake. While the tui chub was the most abundant fish species in the lake, it was felt that the estimates of the biomass was insufficient to generate enough internal loading of nutrients to account tor the magnitude of plant productivity found in the lake. The variations seen in the paleolimnology may indicate that the lake may be experiencing a period of high groundwater input.

Hazardous Algal Bloom Health Advisories: A Health Advisory was issued by the Oregon Health Authority in June 2004 and lifted on 7/16/2004. This Health Advisory was based on use of the drinking water advisory criteria (15,000 cells/ml) rather than the recreational advisory criteria (100,000 cells/ml) that is currently used. The advisory was based on cell counts from a bloom dominated by *Anabaena flos-aquae* with a maximum combined cell count of 70,893 cells/ml.

Remote sensing of chlorophyll *a* concentrations using Landsat data suggests that algal blooms commonly occur in Lava Lake. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values typically exceeded 0.4 from mid-June to mid-August in most years with some years, such as 2006 and 2008, having later blooms starting in September.



Likely or Suspected Cause of Blooms: Appear to be natural sources of nutrients, but internal loading may be higher due to Tui Chub.

303(d) List Status: 2004/2006 Integrated Report identifies Lava Lake as being water quality limited (303(d) list) for Dissolved Oxygen and of concern for phosphorus and pH. A Category 3 (Potential Concern) listing for Aquatic Weeds and Algae has been proposed in Oregon's 2010 Integrated Report based on Health Advisories issued. This Health Advisory was based on use of the drinking water advisory criteria (15,000 cells/ml) rather than the recreational advisory criteria (100,000 cells/ml) that is currently used. A TMDL has been initiated (scoping and data collection) for Lava Lake.

References

Eilers, J., B. Eilers, R. Sweets and A. St. Amand. April 2005. *Revised January 2006*. An Analysis of Current and Historic Conditions in Lava Lake in Support of a TMDL Nutrient Loading Assessment. MaxDepth Aquatics, Inc. Bend, Or. 60 pp

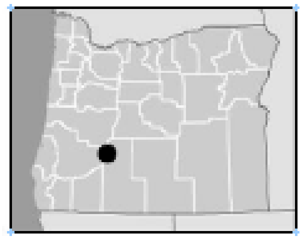
Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

Oregon Health Authority - Public Health Advisories:
http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Turner, Dan. June 2010. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality.

Lemolo Reservoir

Douglas County, Umpqua Basin, Cascade Mountain Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Lemolo Lake is the largest reservoir in the North Umpqua Power Development Project, a project which also includes Toketee Lake about 15 miles downstream. The reservoir was created by Pacific Power and Light in 1954 by impounding the headwaters of the North Umpqua River with a 120-foot high rockfill dam. Lake Creek which drains Diamond Lake higher in the drainage basin is the second major surface inflow.

Source: Oregon National Guard, 1981-82. View looking northeast.

The primary purpose of the project is power generation for cities in Douglas County and the reservoir is operated accordingly. However, it has also become very popular as a recreation site for water-skiing and swimming from good pumice beaches. Mt. Thielsen forms a picturesque backdrop for the lake which has three Forest Service campgrounds and a private resort to accommodate visitors. The entire watershed in on U.S. Forest Service lands (Umpqua National Forest).

Angling for trout is good from spring through fall, although it usually slacks off in midsummer. Some very large brown trout were taken in past years, but this no longer appears to be the case. There is still good fishing for small brown trout. Tui chub appear to have become more dominant in recent years.

Lemolo Reservoir Characteristics (from Johnson et al, 1985)

Setting:

Type: reservoir **Use:** power, recreation **Elevation:** 4,142 f t (1,262.5 m)
Location: 12 miles north of Diamond Lake in Umpqua N.F.

Drainage Basin Characteristics:

Area: 170.0 sq mi (440.3 sq km) **Relief:** moderate **Precipitation:** 54-70 in (137-178 cm)
Land Use: Forest-94.8%; Water-3.2%; Other-2.0% (Rock Outcrops)

Lake Morphometry:

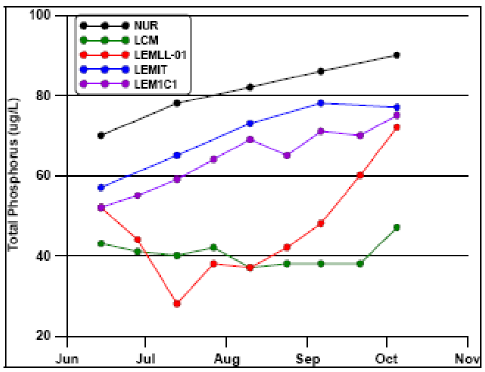
Area: 450 acres (182.1 hect) **Depth:** Maximum - 100 ft (30.5 m); Average - 30ft (9.0 m)
Ave/Max Depth Ratio: 0.300 **Volume:** 13,344 acre ft (16.48 cu hm)
Shoal area: 7% **Volume factor:** .89 **Shape factor:** 2.65
Length of Shoreline: 7.9 mi (12.7 km) **Retention time:** 0.5 mo

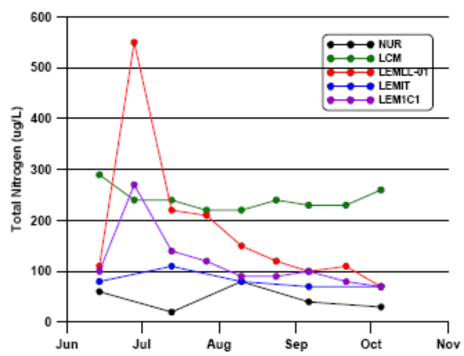
Water Quality: Data collected in 2008 indicated that pH values in the epilimnion exceeded the standard of 8.5 SU in June and July. Nutrient values collected at one meter depth from a site near the dam (site LEMLL-01 shown in red in the figures below) showed that Total Phosphorus generally increased from June to October, total nitrogen peaked in late June and rapidly declined in subsequent samplings and the ratio of TN:TP showed that the reservoir was generally nitrogen limiting except for a one month period from June 28 to July 27 when it appeared to be phosphorus limited. Anabaena, a nitrogen fixer, was also most abundant during the June 28 to July 27 time period. Phytoplankton samples in some locations of the lake, such as Poole Creek Campground, continued to yield sufficient densities of cyanobacteria to cause the recreational Health Advisories to be issued. Trap net sampling of fish showed that tui chub were the dominant species of fish collected. This agreed with data collected using gill nets by ODFW in 2006 and 2007 although, in 2006, the majority of fish caught in gill nets were brown trout. Water quality in 2008 appeared to improve (in terms of intensity of the blooms) over conditions observed in 2006 and 2007 when

dense scums of *Anabaena* formed in various areas of the lake. It should also be noted that Diamond Lake, upstream of Lemolo Reservoir, was treated with rotenone in 2006. While the cause of the recent algal blooms are not known for certain, it was suspected that the recent increase in the biomass of tui chub has increased the internal cycling of nutrients to favor the growth of cyanobacteria over diatoms (Eilers, 2009).
The lake is continuing to be monitored and data is reviewed with the interagency North Umpqua Lakes Management Group which reviews information for both Lemolo and Diamond Lakes.

Summary of data collected near the dam from Lemolo Reservoir

Date	pH (SU)	Total Phosphorus (mg/l)	Dissolved Ortho Phosphorus	Nitrate & Nitrite (mg/l)	Ammonia (mg/l)	Total Nitrogen (mg/l)	N:P Ratio[13]	Chlorophyll a (ug/l)
8/22/82 - Johnson 1985	9.5	0.028	-	<0.02	0.03	0.54	19.3	15.2





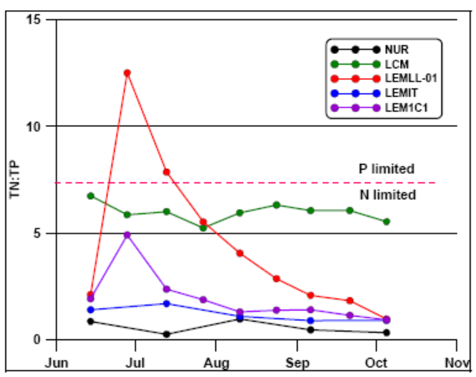


Figure 23. Ratio of total nitrogen to total phosphorus (mass basis) for tributaries and outlets of Lemolo Lake compared to values from Lemolo Lake (LEMLL) at 1 m depth.

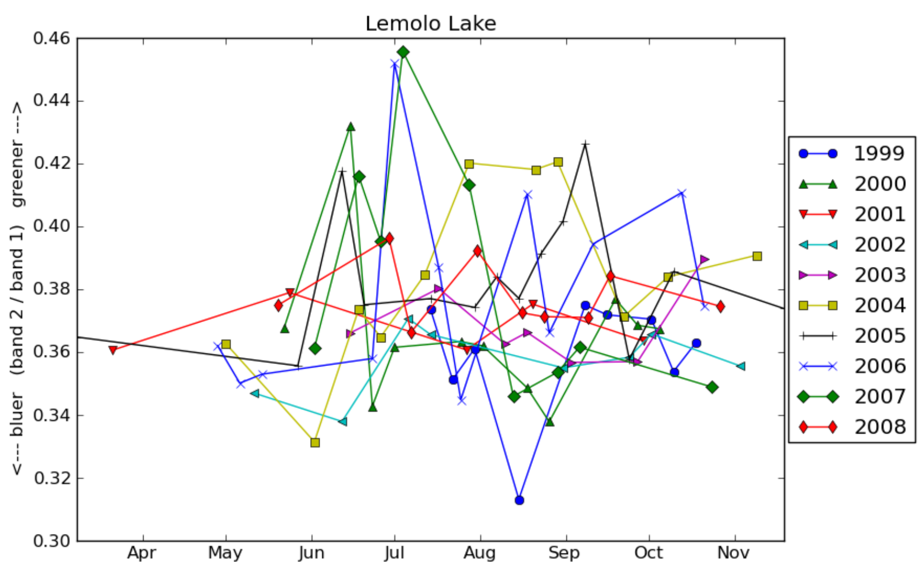
Hazardous Algal Bloom Health Advisories: A number of Public Health Advisories have been issued by the Oregon Health Authority in 2006, 2007, 2008, 2009 and 2010 based on blooms dominated by *Anabaena flos-aqua*. Advisories have typically occurred in late June/early July and end in mid-August and occasionally are reissued in mid-September through mid-October.

[13] N:P ratio below 7.2 is Nitrogen Limiting

Summary of public health advisories for recreation use in Lemolo Reservoir

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[14]	Maximum Toxin Measured (ug/l)
2006	7/12	8/2	21	*Anabaena flos-aquae*	7,216,000	
2006	9/26	10/13	17	*Anabaena flos-aquae*	92,885	
2007	6/26	8/20	55	*Anabaena flos-aquae*		
2008	7/10	8/27	48	*Anabaena flos-aquae* (1,716,195) *Anabaena circinalis* (5,617)	1,716,195	Microcystin – ND Anatoxin - ND
2008	9/18	10/15	27	*Anabaena flos-aquae* (15,930) *Anabaena planctonica* (371)		Microcystin – ND Anatoxin - ND
2009	7/23	8/18	26	*Anabaena flos-aquae* (298,182) *Gloeotrichia enchinulata* (32,472) *Anabaena planctonica* (1,628) *Aphanizomenon flos-aquae* (752)	298,182	
2010	7/1	8/2	32	*Anabaena flos-aquae* (5,154,286) *Microcystis aeruginosa* (15,033) *Aphanizomenon flos-aquae* (1,789) *Anabaena planctonica* (783)	5,154,286	Microcystin – ND Anatoxin - ND

Remote sensing of chlorophyll *a* concentrations using Landsat data suggests a trend in increasing algal blooms in Lemolo Reservoir over the 10 year period when data was analyzed, beginning around 2004. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). As shown, values often exceed 0.4 from early to mid June until mid September in 2000 and then from 2004 on; although it appears like the late bloom period in 2008 (from 9/18 – 10/15/2008) did not have useable satellite coverage.



Likely or Suspected Cause of Blooms: The cause is not known but non-native, introduced fish (tui chub) may play a key role in the internal recycling of nutrients. Further study of the reservoir is occurring.

303(d) List Status: 2004/2006 Integrated Report does not identify any concerns for Lemolo Reservoir. Lemolo Reservoir has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is

[14] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

needed) for Aquatic Weeds and Algae in Oregon's 2010 Integrated Report based on the health advisories. Studies of Lemolo Lake have been initiated.

References

Eilers, J.M. April 2009. Water Quality Monitoring for Lemolo Lake, OR 2008. MaxDepth Aquatics, Inc. Bend, OR. 32 pp

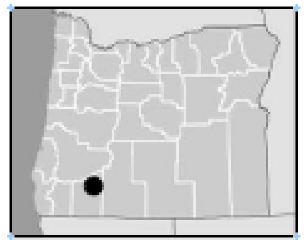
Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Turner, Dan. June 2010 Draft. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality.

Lost Creek Reservoir

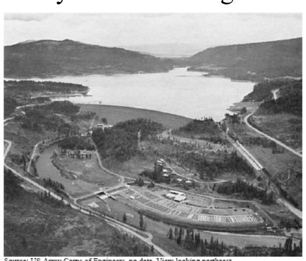
Jackson County, Rogue River Basin
Cascade Ecoregion



State of Oregon
Department of
Environmental
Quality

Setting and Lake Uses (Johnson et al, 1985)

Lost Creek Lake is a large, multi-purpose reservoir built and operated by the U. S. Army Corps of Engineers in a scenic, mountainous region of the upper Rogue River Basin. It was the first of three proposed Rogue River Basin water resources projects, the others being Applegate Lake (since completed) and Elk Lake (no longer under consideration). These dams and reservoirs were authorized by the Flood Control Act of 1962 to alleviate flooding and enhance water resource development in the basin. Additional purposes identified included irrigation, power generation, fish and wildlife enhancement, recreation, and water quality improvement. Construction of the 345 foot high, 3600 foot long Lost Creek Dam was begun by the Corps of Engineers in 1972 and completed during a drought in mid-October 1976. However, the decision to begin filling was delayed until late January 1977. Considerable concern was originally expressed about the construction of a dam on this river system due to its valuable fishing and a past history of temperature and turbidity problems. In response to this concern, the dam was constructed with a multi-level withdrawal structure. Water can be withdrawn from five levels within the impoundment; the system thereby takes advantage of the temperature stratification in the lake to provide cooler water to the Rogue River.



Source: US Army Corps of Engineers, no date. View looking northeast.

Lost Creek Lake is situated 158 miles upstream on the mainstem of the Rogue River in the northeast portion of the basin on the western slope of the Cascades near Crater Lake. Its 674 square mile drainage basin is approximately 13 percent of the total area of the Rogue River Basin. It is mountainous and timber-covered topography. About 85 percent of the land is administered by the federal government (Bureau of Land Management, National Forest Service, and National Park Service) and 15 percent is privately owned. The climate of the area is dominated by maritime influences which contribute to mild, wet winters and warm, dry summers. Annual precipitation ranges from less than 40 inches at the dam to nearly 80 inches in the headwater areas. Snow in the higher elevations accumulates during the winter to become the principal source of runoff in late spring.

Several major public access areas, park sites, boat ramps, and a trail system along 30 miles of shoreline are included among the facilities for visitors. McGregor Park, dedicated in July 1977, was specifically designed for the convenience of handicapped visitors. Stewart State Park offers a day-use area, boat ramp, and camping sites. The lake is stocked annually with rainbow trout, and also has native populations of cutthroat trout, brook trout, and brown trout, plus a variety of warm-water species.

Lost Creek Reservoir Characteristics (from Johnson et al, 1985)

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 1,872 ft (570.6 m)
Location: 26 miles north of Medford

Drainage Basin Characteristics:

Area: 674 sq mi (1,745.7 sq km) **Relief:** moderate **Precipitation:** 40-80 in (102-203 cm)
Land Use: Forest-94.5%; Range-2.3%; Water-1%; Ir Ag-0.6%; Non Ir Ag-0.1%; Urban-0.1%; Other-1% (rock outcrops)

Lake Morphometry:

Area: 3,428.0 acres (1,387.3 hect) **Depth:** Maximum - 322 ft (98.1 m); Average - 136ft (41.5 M)
Ave/Max Depth Ratio: 0.420 **Volume:** 465,000 acre ft (574.41 cu hm)
Shoal area: 5% **Volume factor:** 1.26 **Shape factor:** 3.78
Length of Shoreline: 31.1 mi (50.0 km) **Retention time:** 4 mo

Water Quality: The limnology of Lost Creek Reservoir has undergone various physical and chemical changes since it was constructed. During the first years of operation, oxygen concentrations in the deeper water were sometimes too low for fish survival and artificial aeration of the discharge water was required for safe operation of the hatchery. The oxygen depletion was apparently caused by the decay of algae produced by short-lived blooms in the surface water. Species involved were primarily blue-greens, including *Aphanizomenon flos-aquae, Anabaena circinalis* and *Anabaena flos-aquae*. Data collected by the Corps of Engineers and others indicate that the reservoir's water quality has improved steadily since 1977. By the mid-1980's, the hypolimnion showed little depletion of dissolved oxygen. Water quality has generally improved from eutrophic to mesotrophic based on trophic state indices using secchi depth and phytoplankton biovolume (Larson, 1999). However, Lost Creek Reservoir continues to get cyanobacterial blooms, especially in June to early July and in mid-September. *Anabaena flos-aquae* is usually the dominant species. pH values often exceed 9.0 during the early bloom.

Hazardous Algal Bloom Health Advisories: A number of Public Health Advisories have been issued by the Oregon Health Authority from 2006 - 2010 based on primarily on blooms dominated by *Anabaena flos-aqua* but dominant blooms of *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* also occur, typically later in the season.

Summary of public health advisories for recreation use in Lost Creek Reservoir

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[15]	Maximum Toxin Measured (ug/l)
2006	6/24	7/19	25	*Anabaena flos-aquae*	14,577,778	
2007	6/12	7/10	28			
2008	9/15	1/27/09	134	*Anabaena flos-aquae* (7,449,459) *Microcystis aeruginosa* (212,235) *Aphanizomenon flos-aquae* (145,912)	7,807,606	
2009	6/15	6/29	14	*Anabaena flos-aquae* (1,607,597) *Anabaena circinalis* (4,720)	1,609,779	
2009	9/18	10/13	25	*Anabaena flos-aquae* (120,906)	120,906	
2010	6/4	6/22	18	*Anabaena flos-aquae* (4,036,123) *Anabaena circinalis* (8,254) *Anabaena plactonica* (633)	4,036,123	Anatoxin-a – nd Microcystin - nd
2010	9/20	1/4/11	106	*Aphanizomenon flos-aquae* (375,285) *Gloeotrichia echinulata (87,786)* *Anabaena flos-aquae* (17,557)	480,628	

Likely or Suspected Cause of Blooms: Unknown

303(d) List Status: 2004/2006 Integrated Report does not identify any concerns for Lost Creek Reservoir. A Category 5 (Section 303(d) list – a TMDL is needed) listing for Aquatic Weeds and Algae has been proposed in Oregon's 2010 Integrated Report based on the Health Advisories issued. TMDL related work has not been initiated.

References

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

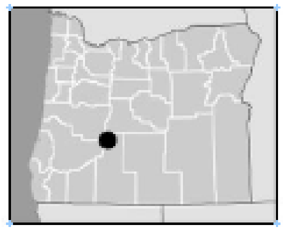
Larson, Douglas. 1999. Lost Creek Lake, Oregon – Limnological and Water-Quality Studies 1976-1998. Portland State University. 418 pp.

Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

[15] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species in a single sample > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Odell Lake

Klamath County, Deschutes Basin, Cascade Ecoregion



State of Oregon
Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Odell Lake, 3582 acres in surface area, is one of the largest lakes in the Oregon Cascades. It lies near the summit of the Cascade range and adjacent to Oregon Highway 58. The lake basin is generally considered to be a glacial trough formed during the Pleistocene Epoch when a layer of ice hundreds of feet thick covered the Cascades at high elevations. The lake probably filled 10,000 to 12,000 years ago behind a terminal moraine which impounded the headwaters of Odell Creek. An important subsequent event in the history of the lake was the eruption of Mt. Mazama 6,600 years ago. Volcanic ash was carried northward where it showered onto the loamy soils and andesite lava of the basin. A mantle of this permeable, volcanic residue now covers the drainage basin and allows for rapid percolation of water. Thus, there is a considerable contribution of groundwater into Odell Lake, particularly along the south shoreline. One large surface stream, Trapper Creek, feeds the lake, and there are numerous short, smaller streams entering from the north. Odell Creek, the major outlet, flows eastward for 13 miles where it discharges into Davis Lake.

Source: Oregon Department of Transportation, no date. View looking southwest.

The first access road to Odell Lake was built in 1910, and a resort lodge was built in 1927; but recreational use on the lake was low until the construction of Highway 58 in 1940. By the mid-1950s the lake had become a popular recreational site and use has increased steadily since. In 1981, the lake received 133,000 visitor days. Many summer homes, two private resorts, a marina, and five Forest Service campgrounds are on the shoreline. The entire watershed is in the Deschutes National Forest.

Odell Lake has indigenous populations of Bull Trout, Rainbow Trout and Whitefish. Additional fish species have been introduced during the 20th century and are still present, primarily through intentional stockings by the Oregon Department of Fish and Wildlife (Kokanee, Lake Trout, Rainbow Trout, Brook Trout) or through illegal introductions (Tui Chub). (Eilers et al, 2005)

Odell Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake with dam | **Use:** recreation | **Elevation:** 4,787 ft (1,459.1 m)
Location: 3 mi N of Crescent Lake, adjacent to Hw y 58, in Deschutes N.F.

Drainage Basin Characteristics:

Area: 37.4 sq mi (96.9 sq km) | **Relief:** steep | **Precipitation:** 48-70 in (122-178 cm)
Land Use: Forest-81%; Water-15%; Other-4% (rock outcrops)

Lake Morphometry (from Eilers 2006)

Area: 3,418 acres (1,383 hect) | **Depth:** Maximum - 291 ft (88.7 m); Average - 138ft (40.0 M)
Ave/Max Depth Ratio: 0.474 | **Volume:** 471,342 acre ft (584.4 cu hm)
Shoal area: 4% | **Volume factor:** 1.41 | **Shape factor:** 1.59
Length of Shoreline: 12.9 mi. (20.8 km) | **Retention time:** 6.7 yr.

Water Quality: Early studies of the lake (1941) indicated that the lake was oligotrophic but later studies (1970s, 1980s) indicated that it was mesotrophic. The apparent change in condition was attributed to lake shore development (campgrounds and cabins). It was felt that conditions were improving (early 1990s) in response to reduced nutrient loading associated with a decision by the Forest Service to replace the septic systems at the campgrounds with holding tanks. However, studies in the 2000s showed that the lake was having blooms of *Anabaena flos-aquae*, chlorophyll values ranged up to 50 ug/l and pH values that often exceeded the standard of 8.5 SU with values often approaching or exceeding 10 SU. (Eilers et al, 2005)

Summary of mid-lake data from Odell Lake

Date	pH (SU)	Total Phosphorus (mg/l)	Dissolved Ortho Phosphorus (mg/l)	Nitrate & Nitrite (mg/l)	Ammonia (mg/l)	Total Kjeldahl Nitrogen (mg/l)	N:P Ratio[16]	Chlorophyll a (ug/l)
8/21/81 -Johnson 1985	9.3	0.028	-	<0.02	0.06	.27[17]	9.6	2.2
2001 and 2004 DEQ Data Summary								
Count:		58	58	58	58	58		55
Minimum:		ND	ND	ND	ND	ND		0.2
Average:		.03	0.014	0.014	0.023	0.2		9
Maximum:		.08	.029	0.099	.09	1.6		112

Changes in Odell Lake were assessed over a ~ 130 year span by analysis of a lake sediment core. The sediment accumulation rate has increased about five-fold over the period of record with over 95% of the accumulated material derived from in-lake sources, reflecting a change in productivity of the lake. Sediment chemistry (carbon, nitrogen and phosphorus) all show substantial increases in concentration and deposition rates over the past 30 years. This suggests that nutrients that were formerly exported from Odell Lake are now incorporated into biomass and retained in the lake – some of which may become available to further stimulate phytoplankton growth in the lake. Qualitative and quantitative changes in the diatom community, found in a sediment core, indicate that Odell Lake became mesotrophic to eutrophic in the 1960s. The pattern of *Anabaena sp* akinetes showed a similar increase to that found for the sediment chemistry and first showed an increase in ~ 1961 (Eilers et al, 2005).

Fish sampling in recent years has found kokanee and tui chub making up a large portion of the fish biomass. The increased abundance of kokanee occurred in the 1960's based on a concerted stocking programs initiated in 1950. This abundance is associated with the change in water quality observed in the sediment data. Initial analysis of nutrient loadings have found that anthropogenic sources of nutrients, such as cabin and resort waste systems, comprise a small percentage of total inputs. Natural sources appear to make up the largest source of nutrient loads to the lake with fisheries and nitrogen fixation by cyanobacteria making up a large portion of the internal loading. (Eilers et al, 2005 and 2007)

Additional work is occurring to confirm the nutrient budget, internal loading and relationship of the fishery and water quality changes.

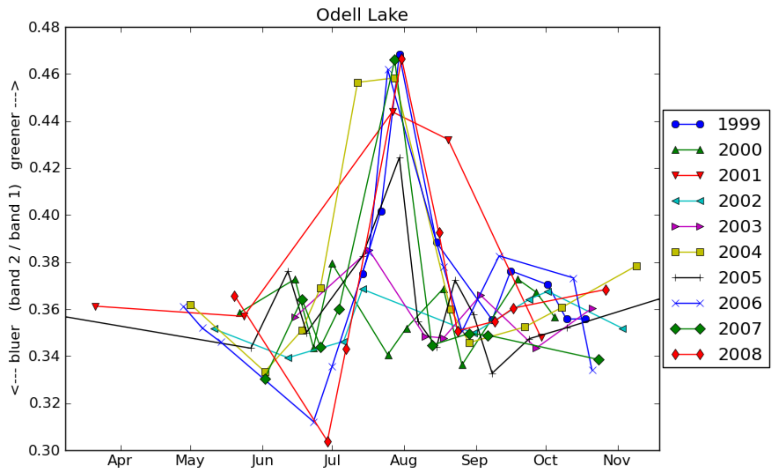
<u>Hazardous Algal Bloom Health Advisories:</u> A number of Public Health Advisories have been issued by the Oregon Health Authority in 2005, 2007, 2008 and 2009 based on blooms dominated by *Anabaena flos-aqua*.

Summary of Public Health Advisories for Recreation Use in Odell Lake

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[18]	Maximum Toxin Measured (ug/l)
2004	7/29	8/16	18	Anabaena flos-aquae	335,000	
2005	7/18	8/4	17	Anabaena flos-aquae	322,143	
2007	7/25	8/13	19	Anabaena flos-aquae	1,064,997	
2008	8/7	8/22	15	Anabaena flos-aquae (2,642,578)	2,642,578	
2009	7/22	8/12	21	Anabaena flos-aquae (669,226)	669,226	

[16] N:P ratio below 7.2 is Nitrogen Limiting
[17] Total Nitrogen
[18] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Remote sensing of chlorophyll *a* concentrations using Landsat data suggests a strong pattern in the algal blooms in Odell Lake. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). As shown, values typically exceed 0.4 from early to mid July until mid August in most years.



Likely or Suspected Cause of Blooms: Elevated phosphorus (source may be natural). Non-native, introduced fish (kokanee and tui chub) may play a key role in the internal recycling of nutrients. This is still being studied.

303(d) List Status: 2004/2006 Integrated Report identifies Odell Lake as being water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for chlorophyll *a* and pH. A Category 5 listing for Aquatic Weeds and Algae has been proposed in Oregon's 2010 Integrated Report based on Health Advisories issued. TMDL related work has been initiated (scoping and data collection) for Odell Lake.

References

Eilers, J. M., B. Eilers, K. Moser and A. St. Amand. June 2005, Revised February, 2006. An Analysis of Current and Historic Conditions in Odell Lake in Support of a TMDL Nutrient Loading Assessment. MaxDepth Aquatics, Inc, Bend, OR and Carollo Engineers, Walnut Creek, CA.

Eilers, J. M. and K. Vache. July 2007. Draft Model Development of Water Quality and Fish Interactions in Odell Lake, Oregon. MaxDepth Aquatics, Inc, Bend, OR

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

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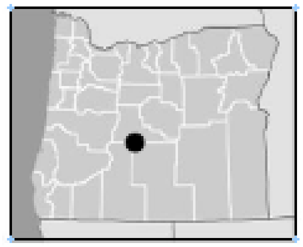
Turner, Dan. June 2010. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality.

Paulina Lake

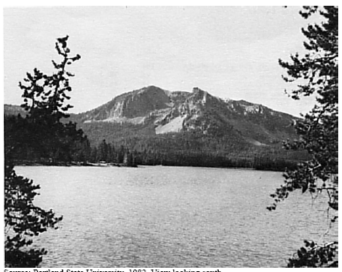
Deschutes County, Deschutes Basin, Cascade Ecoregion



State of Oregon
Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Paulina Lake is one of two lakes occupying Newberry Crater, a volcanic caldera nearly five miles in diameter located at the summit of the Paulina Mountains. Paulina Lake is slightly larger in surface area and 40 feet lower in elevation than its neighbor, East Lake.



Source: Portland State University, 1982. View looking south

The entire area of the Newberry Crater, including East Lake and its drainage basin is topographically tributary to Paulina Lake. East Lake has no surface outlet and loses water entirely by evaporation from the surface and by subsurface seepage. A portion, but not all, of this seepage makes its way into Paulina Lake through the volcanic obstruction between the two lakes. Thus, surface inflow to Paulina Lake is only from the eight square mile area. There are no perennial streams, but considerable runoff during the snowmelt season. Water is lost from the lake by surface evaporation and by discharge through Paulina Creek.

Although East and Paulina Lakes are favorites with fishermen, both were devoid of fish until a Central Oregon sportsman packed in trout late in the nineteenth century. Since then they have been stocked by the Oregon Department of Fish and Wildlife. It is estimated now that over 60,000 anglers visit the lakes each year, although they are among the last lakes to open in the spring because of road blockage by heavy snows. Record German brown trout taken from East Lake have enhanced its reputation over Paulina Lake, but the larger lake has been a consistent producer from year to year, with good catches of rainbow trout and occasional eastern brook trout. Several campgrounds are at the lake, maintained by the Deschutes National Forest. There are a number of summer homes on land leased from the Forest Service and a private resort on the west end.

Paulina Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake | **Use:** recreation | **Elevation:** 6,331 ft (1,929.7 m)
Location: 12 mi NE of LaPine, 25 mi SSE of Bend, in Deschutes N.F.

Drainage Basin Characteristics:

Area: 8.4 sq mi (21.8 sq km) | **Relief:** very steep | **Precipitation:** 35 in (89 cm)
Land Use: Forest-55.5%; Water-25.7%; Other-18.9 (lava fields)

Lake Morphometry:

Area: 1,531 acres (619.6 hect) | **Depth:** Maximum - 250 ft (76.2 m); Average - 163ft (49.7 m)
Ave/Max Depth Ratio: 0.650 | **Volume:** 249,850 acre ft (308.64 cu hm)
Shoal area: 3% | **Volume factor:** 1.96 | **Shape factor:** 1.21
Length of Shoreline: 6.7 mi (10.8 km) | **Retention time:** 46 yrs

Water Quality (Johnson et al, 1985): Paulina is a biologically productive lake. The concentration of phosphorus is sometimes rather high, contributing to overall mesotrophic conditions. Chlorophyll concentrations are variable, due to the occasional algal blooms in the lake. Water transparency is also quite variable, ranging from a Secchi disk maximum of 62 feet (18.8 meters) reported in June 1940 to a minimum 13 feet (4 meters) observed during an algal bloom on 8/21/82. The phytoplankton also reflects the varying ecological conditions. One sample collected in late summer of 1981 indicates oligotrophic conditions, whereas in 1982 a sample collected at about the same time of the year was more eutrophic in character with an Anabaena bloom occurring on 8/21/82.

Summary of Mid-lake Data from Paulina Lake

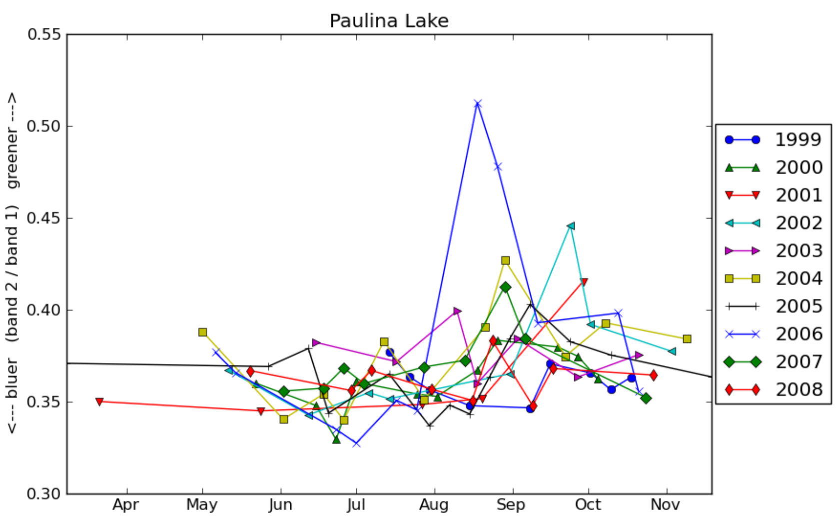
Date	pH (SU)	Total Phosphorus (mg/l)	Dissolved Ortho Phosphorus (mg/l)	Nitrate & Nitrite (mg/l)	Ammonia (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Chlorophyll a (ug/l)
9/13/81 -Johnson 1985	8.3	0.020	-	-	-	-	1.2
8/21/82 -Johnson 1985	8.5	0.045	-	<0.02	0.03	0.5	24.7

Hazardous Algal Bloom Health Advisories: Public Health Advisories were issued by the Oregon Health Authority in 2004, 2006 and 2009 based on bloom dominated by *Anabaena flos-aquae*

Summary of Public Health Advisories for Recreation Use in Paulina Lake

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max. Comb. Cell Count[19]	Maximum Toxin Measured (ug/l)
2003				*Microcystis; Anabaena*		High counts, late report – no advisory
2004	9/3	9/17	14			
2006	8/21	9/1	11	*Anabaena flos-aquae*	1,522,125	
2009	8/27	9/21	25	*Anabaena flos-aquae* (328,398)	328,398	

Remote sensing of chlorophyll *a* concentrations using Landsat data suggests a pattern of algal blooms in Paulina Lake. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values above 0.4 indicate blooms starting from mid-August until early September, although they may occur later in September as in 2001 and 2002.



Likely or Suspected Cause of Blooms: Elevated nutrients, likely natural, from the watershed and possible elevated internal loadings from introduced fish populations; additional data needed.

[19] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

<u>303(d) List Status:</u> 2004/2006 Integrated Report does not identify any concerns for Paulina Lake. Paulina Lake has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in Oregon's 2010 Integrated Report based on the health advisories issued. TMDL related work has not been initiated.

References

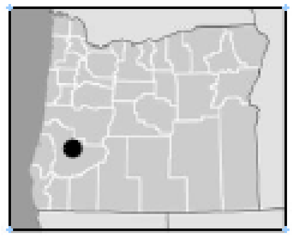
Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Turner, Dan. June 2010. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality

Elk Creek/Umpqua River

Douglas County, Umpqua Basin, Klamath Mountain Ecoregion



Setting

Elk Creek is a tributary to the Umpqua River and enters the Umpqua River at River Mile 48.5 at the City of Elkton.

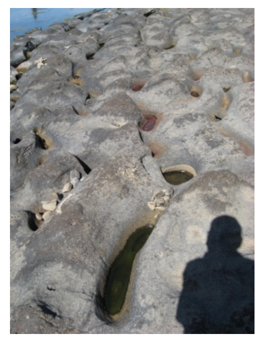
Elk Creek at mouth entering Umpqua River

Elk Creek at mouth (looking upstream)

Stagnant pool in area near mouth

Stagnant pool in area near mouth

Umpqua River at Elkton Park Tyson Access (400 m downstream of Elk Creek)



Stagnant pools in area near mouth

Hazardous Algal Bloom Health Advisories: A Health Advisory was issued from September 4-22, 2009 by the Oregon Health Authority following the deaths of two pet dogs near Elkton. The advisory was issued for Elk Creek from the mouth at the Umpqua River to the Elk Creek Tunnel on Highway 38 (~River Mile 0 - 5.5), and for the Umpqua River from Sawyers Rapids to the mouth of Elk Creek (~River Mile 38.5 – 48.5). Toxin samples were collected in the area on 9/1/09 and 9/15/09. Microcystin values of 15 ug/L and 0.2 ug/L were measured on the respective sampling dates from composite of pools located in the Umpqua R @ Alfred Tyson Park and 0.2 ug/l from composite of pools located near the mouth of Elk Ck on 9/1/09 with other sites having non-detects. Detectable Anatoxin was found at 0.5 ug/L from composite of pools at the mouth of Elk Ck and with a value of 0.1 ug/L in Elk Ck at the mouth on 9/1/09 with other sites having non-detects.

Autopsy results later confirmed the death of at least one dog was associated with ingestion of cyanotoxins. Exposure was presumed to have occurred at or near the area where cyanotoxins were detected in surface water samples[20].

Water Quality: Not summarized – see Umpqua Basin TMDL[21].

[20] http://www.oregon.gov/DHS/news/2009news/2009-0911.pdf
[21] http://www.deq.state.or.us/wq/tmdls/umpqua.htm

Likely or Suspected Cause of Blooms: Multiple factors probably combined to produce conditions favorable to cyanobacteria growth in isolated, stagnant bedrock pools on the Umpqua River, including high nutrient levels, high temperature and low flow. This situation could potentially occur in sections with exposed bedrock channel and may produce HABs in isolated pools or other suitable environments under similar weather and low flow conditions.

This hypothesis is consistent with existing knowledge about conditions in the Umpqua Basin (i.e., documented in the TMDL) and recent observations at other locations with similar conditions (i.e., Lawson Bar in 2010). It is not known whether the toxin-producing cyanobacteria have recently been introduced into the system, or whether toxin producing species were already present, and the recent dog deaths were the result of random probability of exposure.

303(d) List Status: The 2004/2006 Integrated Report identifies the lower portion of Elk Creek (River Mile 0 – 6.5) as: being Water Quality Limited but not needing a TMDL for flow and habitat modification; being of potential
concern but needing data for nutrients; and having a TMDL developed for dissolved oxygen, pH and E. coli. Elk Creek (River Mile 0 – 6.5) has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in Oregon's 2010 Integrated Report based on the health advisories issued. A TMDL has been developed for Sediment Oxygen Demand to address low DO in Elk Creek. In the TMDL, the following was noted: "The diel swings in pH (noted in Elk Creek) are likely caused by growth of periphyton similar to the other pH analysis in this chapter which shows natural pH in the basin can be as high as 9.0 (see Calapooya Creek pH TMDL). If a pH impairment exists due to anthropogenic sources, the nonpoint source load reductions required to meet the DO standard and temperature TMDL will likely lead to nutrient reductions that result in pH attainment. If future data indicate exceedances of the pH standard, allocations and targets will be carried over from the pH TMDL for Calapooya Creek which is a similar and neighboring watershed."

The 2004/2006 Integrated Report identifies the Umpqua River (River Mile 36.4 – 46.8) as: being Water Quality Limited but not needing a TMDL for flow modification; being of potential concern but needing data for nutrients; and having a TMDL developed for dissolved oxygen, pH and E. coli. The Umpqua River (River Mile 36.4 – 46.8) has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in Oregon's 2010 Integrated Report based on the health advisories issued. It was felt that the phosphorus TMDL (which was developed to address pH and DO issues) for the basin did not directly address this HAB listing as it addressed nutrients in the South Umpqua and several other tributaries (Calapooya, Cow, Deer, Jackson and Steamboat Creeks) but not for the lower mainstem.

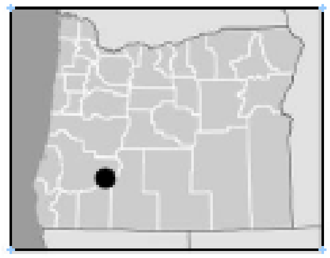
References

Oregon Department of Environmental Quality. 2006. Umpqua Basin TMDL - http://www.deq.state.or.us/wq/tmdls/umpqua.htm

Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

South Umpqua Below Lawson Bar

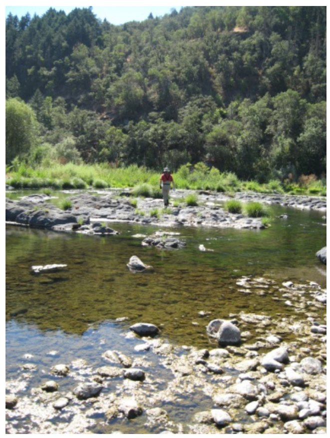
Douglas County, Umpqua Basin, Klamath Mountain Ecoregion



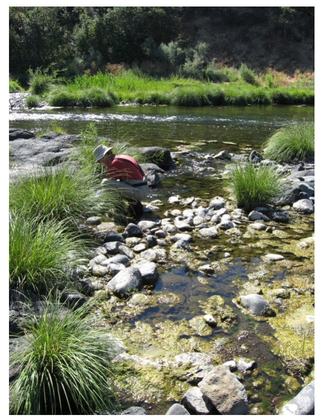
Setting

The South Umpqua River below Lawson Bar is located on the South Umpqua River near River Mile 47 just below the confluence of Cow Creek near the towns of Riddle and Canyonville.

Lawson Bar



Lawson Bar



South Umpqua River at Lawson Bar

Lawson Bar

South Umpqua River below Lawson Bar

South Umpqua River at Lawson Bar

Hazardous Algal Bloom Health Advisories: A Health Advisory was issued by the Oregon Health Authority for the South Umpqua River at Lawson Bar (~River Mile), off Interstate 5Exit 102 near Canyonville, from August 24-December 8, 2010 (106 days) following the death of a pet dog that had been at Lawson Bar that day and shortly thereafter exhibited symptoms of poisoning. Total numbers of potentially toxigenic cyanobacteria in a sample collected on 8/24/2010 were 229,545 cells/ml that included *Phormidium favosum* (186,449 cells/ml) as well as *Anabaena* and *Aphanizomenon.* Composite samples (10 discrete pools composited) collected on 8/24/2010 had Anatoxin-a concentrations of 9 ug/L and 200 ug/L, with upstream and downstream samples collected in the South Umpqua having Anatoxin-a concentration of 0.3 ug/l each. Samples collected on 9/8-9/9/2010 were at the limit of quantification (0.1 ug/L) or not detected.

Water Quality: Not summarized – see Umpqua Basin TMDL[22].

[22] http://www.deq.state.or.us/wq/tmdls/umpqua.htm

Likely or Suspected Cause of Blooms: Multiple factors probably combined to produce conditions favorable to cyanobacteria growth in isolated, stagnant bedrock pools on the Umpqua River, including high nutrient levels, high temperature and low flow. This situation could potentially occur in sections with exposed bedrock channel and may produce HABs in isolated pools or other suitable environments under similar weather and low flow conditions.

This hypothesis is consistent with existing knowledge about conditions in the Umpqua Basin (i.e., documented in the TMDL) and recent observations at other locations with similar conditions (i.e., Elk Creek and Umpqua River in 2009). It is not known whether the toxin-producing cyanobacteria have recently been recently introduced into the system, or whether toxin producing species were already present, and the recent dog deaths were the result of random probability of exposure.

Phormidium favosum is a benthic cyanopyte that lives on or within cracks in rocks. It often prefers limestone and marble substrates and has a gelatinous sheath that acts as a reservoir of water allowing it to colonize storn even when dry conditions prevail.[23]

303(d) List Status: The 2004/2006 Integrated Report identifies the South Umpqua River (River Mile 36.4 – 46.8) as being: being of potential concern but needing data for flow modification; and having a TMDL developed for dissolved oxygen, pH and E. coli. The phosphorus TMDL which was developed to address pH and DO concerns in the South Umpqua River should also address the HABs issue. However, the South Umpqua River (River Mile 37.8 – 52.2) has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in Oregon's 2010 Integrated Report based on the health advisories issued but was being further reviewed at the time of this report.

References

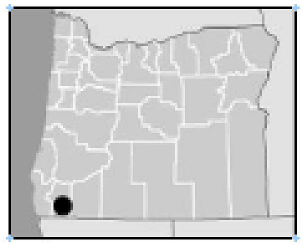
Oregon Department of Environmental Quality. 2006. Umpqua Basin TMDL - http://www.deq.state.or.us/wq/tmdls/umpqua.htm

Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

[23] http://mic.sgmjournals.org/cgi/content/full/155/11/3476

Selmac Lake

Josephine County, Rogue River Basin, Klamath Mountain Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Source: Oregon National Guard, 1981-82. View looking south.

Selmac Lake is a reservoir that was completed in 1961 with the construction of the 36 foot high, 1000 foot long, earthfilled McMullin Creek Dam. The dam is located on McMullin Creek which flows into Deer Creek and is seven miles upstream from Deer Creek's confluence with the Illinois River near the town of Selma. Selmac Lake is owned and operated by the Josephine County Parks and Recreation Department and serves a variety of purposes – recreation, irrigation, and domestic use. Lake Selmac County Park includes campgrounds, boat launching, picnic, playground and other recreational facilities. There is also a small private campground at the lake. Recreational use by people from the Grants Pass area is quite heavy and the park hosts a number of events – fishing derbies, music festivals, etc. The majority of the watershed upstream of the reservoir is forested, and timber harvesting is the predominant land use. Rainbow trout were first stocked after construction, followed by other species such as crappies, bluegills, largemouth bass, and catfish. Selmac Lake has developed a reputation for excellent bass fishing, with several record largemouth bass caught from the lake.

Selmac Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: reservoir **Use:** irrigation, recreation; domestic water supply **Elevation:** 1,390 ft (423.7 m)
Location: 8 mi NE Cave Junction, 23 mi SW Grants Pass

Drainage Basin Characteristics:

Area: 12.4 sq mi (32.1 sq km) **Relief:** moderate **Precipitation:** 40 in (102 cm)
Land Use: Forest-94%; Range-1.7%; Water-1.8%; Ir Ag-0.5%; Non Ir Ag-1.9%

Lake Morphometry:

Area: 148 acres (59.9 hect) **Depth:** Maximum - 33 ft (10.1 m); Average - 7ft (2.1 M)
Ave/Max Depth Ratio: 0.210 **Volume:** 1,014 acre ft (1.25 cu hm)
Shoal area: 73% **Volume factor:** 62 **Shape factor:** 1.90
Length of Shoreline: 3.2 mi (5.1 km) **Retention time:** indeterminate

Water Quality: Selmac Lake is a productive lake which experiences periodic algae blooms. Sampling from July – September 1998 conducted by Southern Oregon University as part of the Oregon Citizen Lake Watch Program (Parker et al, 1998) found:

- elevated chlorophyll *a* concentrations ranging from 13.4 – 19.4 ug/l in the July and August samples;
- near surface pH ranging from 8.1 to 9.2 during July and August with standard (pH 8.5) exceedences occurring in July;
- cyanobacteria dominating the phytoplankton assemblage (described as *Anabaena sp)*;
- Although a shallow lake, the lake was stratified during these months with oxygen depleted near the bottom (in the hypolimnion) in August. Secchi depths ranged from 1.9 – 3.4 meters during the three sampling events.

Nutrients were not collected during this survey. A total phosphorus value of 0.048 mg/l was measure on 9/4/1981 in the Atlas of Oregon Lakes (no nitrogen data were recorded). Based on the occurrence of cyanobacterial bacteria blooms, elevated chlorophyll *a* concentrations and depletion of oxygen in the hypolimnion, Lake Selmac is a eutrophic lake.

Hazardous Algal Bloom Health Advisories: In 2004, the first documented toxic cyanobacterial (blue-green algae) bloom occurred (Kahn, 2005). High concentrations of *Anabaena* (initially identified as *A. flos-aquae,* subsequent identification indicated *A. spiroides* or possibly *A. circinalis*) and *Microcyctis aeruginosa* were measured and a public health advisory was issued by the Oregon Health Authority on August 19, 2004 advising that skin contact and ingestion of the water and eating of fish be avoided. The public water supply was closed down. Microcystin, one of a group of toxins produced by cyanobacteria, was measured in the lake water and the drinking water advisory was continued on September 3. It also cautioned against the use of piped water for toothbrushing and bathing. All advisories were lifted by December 3, 2004. Cell Count and Toxin data during 2004 Advisory Period (range of data, non-detect data not included):

- *Anabaena sp* (cells/ml) 7,654 – 2,373,684 (11 of 13 samples, other values = 0)
- *Microcystis aeruginosa* 7,107 – 236,775 (3 of 13 samples, other values = 0)
- Microsystin (untreated lake water) 0.19 – 13.5 ug/l (8 of 13 samples, other values = non-detect)
- Microsystin (treated lake water) 0.01 – 2.38 ug/l (8 of 13 samples, other values = non-detect)

Josephine County continues to monitor the lake for algal blooms and has arranged for alternative means of providing water in the case that the public water systems needs to be closed down (there are two systems which draw from the lake). The monitoring follows guidance from the Oregon Health Authority and consists of several steps: visually observing for blooms and floating scum – if so, a warning is posted telling people to stay out of the scum, especially kids and pets, and to do catch and release fishing. If blooms persist or worsen, additional monitoring consisting of algal identification and cell counts to determine the presence and abundance of toxigenic species – if above a certain concentrations an advisory would be posted and additional monitoring for the presence of toxins would occur. While periodic blooms have occurred since 2004, they have not been of the magnitude as the 2004 bloom and advisories have not been issued.

Likely or Suspected Cause of Blooms: Unknown

303(d) List Status: 2004/2006 Integrated Report identifies Selmac Lake (McMullin Creek/Unnamed Lake) as being of concern for algae but needing supporting data (Category 3 – Insufficient Data). Selmac Lake has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in Oregon's 2010 Integrated Report based on the health advisories issued. TMDL related work has not been initiated.

References

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press

Parker, Michael, Keri Thorpe, and Brian Thorpe. 1998. Limnological Investigations of Five Southern Oregon Reservoirs, Summer 1998. Department of Biology, Southern Oregon University.

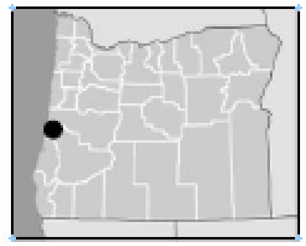
Kahn, Jake. March 2005. Lake Selmac Toxic Algae Sampling: 2004 Summary Report. Aquatic Ecosystems Sciences. LLC.

Oregon Health Authority - Public Health Advisories:
http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Personal communications with Steve Schalk of Josephine County Parks and Recreation Department.

Siltcoos Lake

Douglas County, Mid Coast Basin, Coast Range Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Siltcoos Lake, with a surface area of 3164 acres, is the largest lake on the Oregon coast. It is located along the coastal reach from Florence to North Bend, an area which contains dozens of lakes. In comparison with most other sand dune-dammed coastal lakes, Siltcoos Lake is unusual in that it is not distinctly dentritic in shape; its main body is very broad. It is also a very shallow lake; the water surface is about eight feet above mean sea level and the deepest point in the lake basin lies about 14 feet below sea level. Surface inflow is from several small streams; the four major tributaries are Woahink, Fiddle, Maple, and Lane Creeks. Woahink Creek drains Woahink Lake, lying less than one mile north of Siltcoos Lake. The perennial outlet is through Siltcoos River to the Pacific Ocean, two and one-half miles distant. The outflow and water level of Siltcoos Lake is regulated by a dam on the Siltcoos River 4 km upstream from the Pacific Ocean.

Source; Oregon National Guard, 1981-82. View looking northwest.

Siltcoos Lake receives as much use for recreation as any lake on the Oregon coast and the primary activity is fishing. It has long carried a well-deserved reputation as one of the premier warm-water fishing lakes in the Pacific Northwest. A tremendous variety of warm water species are found in the lake in both quantity and quality, as well as anadromous species such as silver salmon, steelhead, and cutthroat trout. Best known are the largemouth bass that have been caught at weights over nine pounds. Fishing for perch, catfish, crappies, and bluegill is best in the summer months when most other species are hard to catch. To provide services for the many visitors to the lake, there are six private resorts situated around the shoreline, a county park with a boat ramp on the west end of the lake, and a small Forest Service campground with a boat ramp at the Siltcoos River outlet.

The lake is also the domestic drinking water source for approximately 125 of the 1330 residents of Dunes City and numerous residents outside of the city limits with Lane and Douglas Counties (Sytsma and Miller, 2010)

Siltcoos Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake **Use:** recreation, industrial **Elevation:** 8 ft (2.4 m)
Location: 7 miles south of Florence, 0.5 miles east of US Hwy 101

Drainage Basin Characteristics:

Area: 68.3 sq mi (176.9 sq km) **Relief:** moderate **Precipitation:** 78-92 in (198-234 cm)
Land Use: Forest-87.9%; Range-1.3%; Water-8.7%; Non Ir Ag-1.1%; Urban-0.5%; Other-0.5% (wetland)

Lake Morphometry:

Area: 3,164 acres (1,280.5 hect) **Depth:** Maximum: 22 ft (6.7 m); Average: 11ft (3.3 m)
Ave/Max Depth Ratio: 0.490 **Volume:** 33,931 acre ft (41.91 cu hm)
Shoal area: 32% **Volume factor:** 1.46 **Shape factor:** 3.53
Length of Shoreline: 27.8 mi (44.7 km) **Retention time:** 2 months

Water Quality: Siltcoos Lake has had a long history of water quality problems including dense algal growth and excessive growth of the non-native aquatic macrophytes Brazilian elodea (*Egeria densa*), parrotsfeather (*Myriophyllum aquaticum*) and two-leaf water milfoil (*Myriophyllum heterophyllum*). During the Fall of 2007, a dense bloom of the potentially toxigenic blue-green algal species, *Anabaena planctonica*, prompted Dunes City, the South Coast Water District, the Lane County Health Department and the Oregon Health Authority to issue an advisory against usage of Siltcoos Lake water for drinking and other domestic uses.

Because of water quality problems, DEQ placed the lake on the 303(d) list of impaired water bodies and Dune City has acted on water quality concerns for both Siltcoos and Woahink Lakes by issuing a temporary building moratorium, a septic tank maintenance ordinance and an ordinance limiting phosphorus use. In June 2008, Portland

State University and several project partners initiated a study: to better define water quality conditions within the lake as well as potential nutrient sources to the lake; to contribute to the development of a total maximum daily load for the lake; and to assist in identifying and prioritizing restoration activities within the lake and its watershed (Sytsma et al, 2010).

The following is from Sytsma et al, 2010: Total nitrogern (TN) and Total Phosphorus (TP) concentrations followed a similar seasonal pattern as Silica concentrations: an increase through the summer and winter followed by a decrease in the spring (Figure 1). TP concentrations in Siltcoos Lake throughout most of the survey period were consistent with a eutrophic lake. Concentrations of TN and TP were higher at the Fiddle Arm site than other sites throughout much of the summer period which indicates that there was either a higher nutrient load or that water currents concentrated algae in Fiddle Arm.

TN:TP ratios ranged between 10:1 and 20:1 by weight during the summer and fall and up to 25:1 during the winter (Figure 1). N_2-fixing cyanobacteria species such as *Anabaena spp.* and *Aphanzomenon flos-aquae* are thought to be more common in lakes with N:P values less than 30:1 (Nõges et al. 2008) or 22:1 (Smith et al. 1995).

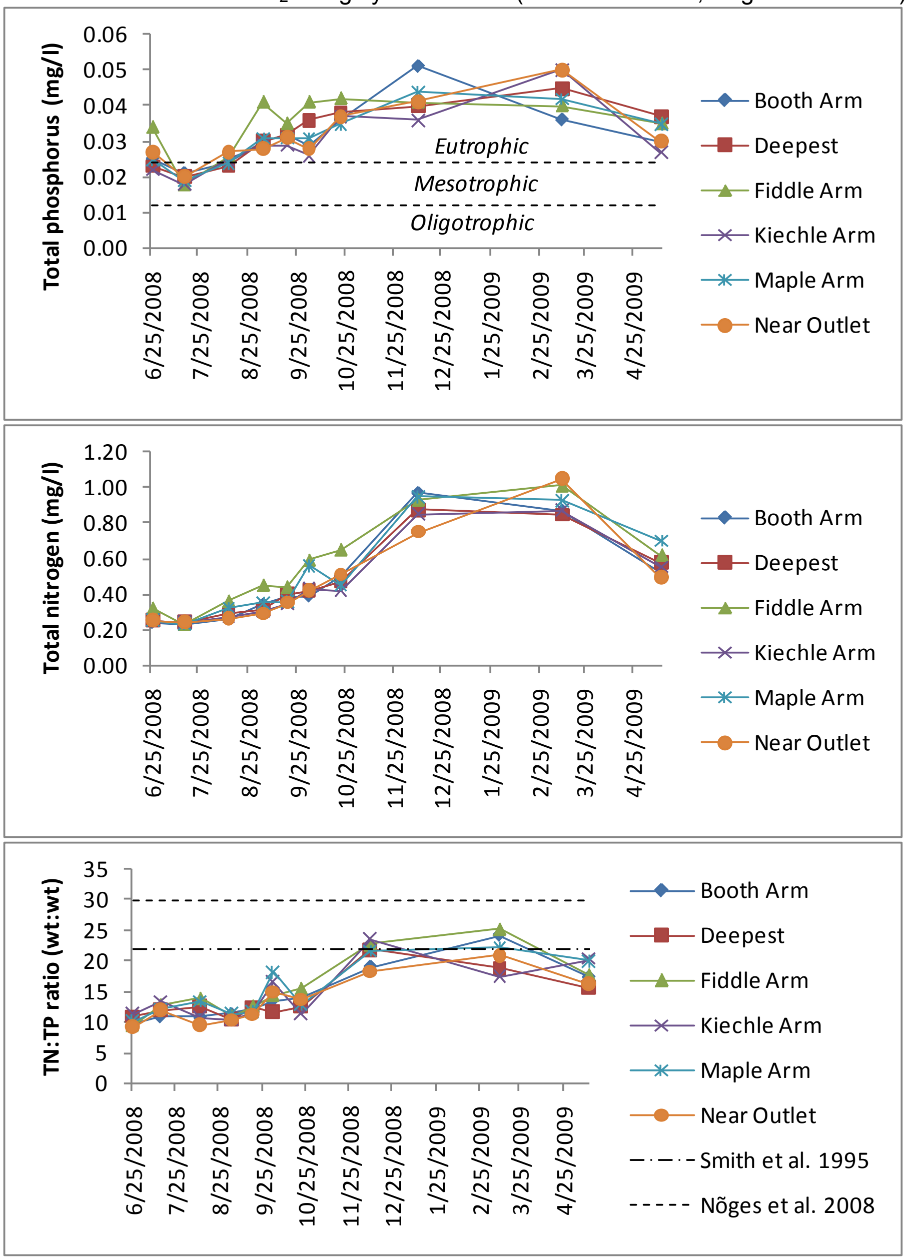
Lake-wide average chlorophyll-a concentrations were not significantly related to TN or TP when using data from all sampling dates; however, when the two winter dates were excluded, TN explained 96% of the variation in chlorophyll-a ($p<0.001$) and TP explained 66% of the variation ($p<0.05$). The exceptionally strong relationship between TN and chlorophyll-a indicates that phytoplankton in Siltcoos Lake were limited by N concentrations during much of the year. This observation is consistent with inferences derived from TN:TP ratios and the presence of N_2 fixing cyanobacteria. It is important to note that although N appears to be the limiting algal production, N mitigation alone will not decrease algal biomass because cyanobacteria have the endless supply of N_2 gas from the atmosphere (Schindler et al. 2008; Lewis and Wurtzbaugh 2008). To improve water quality conditions in Siltcoos Lake, P loading must be reduced to the level where P is limiting algal production.

Five species of cyanobacteria were common in Siltcoos Lake: three species of *Anabaena*, *Aphanizomenon flos aquae*, and *Gloeotrichia echinulata*. Although the three *Anabaena* species were not identified to species, they were morphologically similar to *A. planktonica*, *A. flos aquae*, and *A. circinalis*.

Nutrient loading rates for Siltcoos Lake were estimated based on the 2008-2009 monitoring data, comparisons with areal watershed loading rates for nearby Tenmile Lakes watersheds (TMDL) and septic loadings based on population and literature estimates. Rough estimates indicate much of the nutrient loading is derived from Fiddle and Maple Creeks and that the loss of lowland wetlands has contributed to watershed nutrient loading increases.

The report (Sytsma, M. and R. Miller, 2010) should be referenced for further information.

Figure 1. TP and TN concentrations and TN:TP ratios in Siltcoos Lake. TP trophic status categories are according from Carlson (1977). Dashed lines on the TN:TP plot are critical values below which conditions are considered favorable for N_2-fixing cyanobacteria (Smith et al 1995; Nõges et al. 2008).



Hazardous Algal Bloom Health Advisories: Two Public Health Advisories have been issued by the Oregon Health Authority for Siltcoos Lake.

Summary of Public Health Advisories in Siltcoos Lake

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[24]	Maximum Toxin Measured (ug/l)
2007	9/18	11/09	52	*Anabaena planctonica* (198,934)	198,934	
2008	10/28	1/29/09	93	*Anabaena sp*		

[24] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Likely or Suspected Cause of Blooms: Increased nutrients loads, both phosphorus and nitrogen, due to activities that create or transport nutrients and sediment in the watershed, on-site septic systems, loss of lowland wetlands, internal loading of nutrients due to non-native fish species, uptake of phosphorus from sediments by cyanobacterial akinetes and macrophyte decomposition.

303(d) List Status: The 2004/2006 Integrated Report identifies Tenmile Lakes as being water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds or Algae. A modification to the listing has been proposed in Oregon's 2010 Integrated Report to note that Health Advisories have also been issued. TMDL work has been initiated.

References

Dunes City. 2006a. Ordinance number 181. An ordinance imposing a moratorium on land development prohibiting the acceptance of applications for partitions, subdivisions and planned unit developments in the city of Dunes City, and declaring an emergency. Dunes City, OR. http://dunescity.com/ord_docs/Ord181.htm

Dunes City. 2006b. Ordinance number 173. An ordinance to establish a new chapter 157 within the Dunes City Code of Ordinances entitled "Septic System Maintenance." Dunes City, OR. http://dunescity.com/ord_docs/ordinance_173.htm

Dunes City. 2007. Ordinance number 190. An ordinance creating title XIV "Water quality protection" to the code of Dunes City and adding Chapter 140 "phosphorus reduction to that title, and declaring an emergency. Dunes City, OR. http://dunescity.com/ord_docs/ORDINANCE%20NO.%20190.htm

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

Lewis, W.M., and W.A. Wurtzbaugh. 2008. Control of lacustrine phytoplankton by nutrients: Erosion of the phosphorus paradigm. International Revue of Hydrobiology 93: 446–465

Nõges T., R. Laugaste, P. Nõges. and I. Tõnno. 2008. Critical N:P ratio for cyanobacteria and N_2-fixing species in the large shallow temperate lakes Peipsi and Võrtsjärv, North-East Europe. Hydrobiologia 599:77–86.

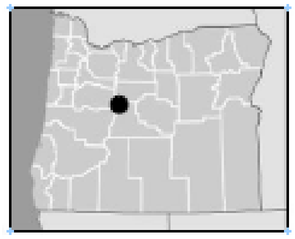
Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Smith V.H., V.J. Bierman Jr, B.L. Jones, and K.E. Havens. 1995. Historical trends in the Lake Okeechobee ecosystem. IV. Nitrogen:phosphorus ratios, cyanobacterial dominance, and nitrogen fixation potential. Arch Hydrobiol 107(Suppl):71–88.

Sytsma, M. and R. Miller. 2010. Siltcoos Lake Nonpoint Source Implementation Grant – Water Quality Conditions and Nutrient Sources. Portland State University. Project Number W08714.

Suttle Lake

Jefferson County, Deschutes Basin, Cascade Ecoregion



State of Oregon Department of Environmental Quality

Setting and Lake Uses (Johnson et al, 1985)

Suttle Lake is a very well known and heavily used lake on the east slope of the Cascade Range. It is easily seen by all travelers along U.S. Highway 20 about five miles east of Santiam Pass. The shape of Suttle Lake reflects its glacial origin. It is long and narrow, conforming to the symmetry of the glacial valley, and consists of a single deep basin with relatively steep sides. Much of the lake is deeper than 60 feet, yet the deepest point is only about 75 feet.

Source: Oregon National Guard, 1981-82. View looking southwest.

The drainage basin of Suttle Lake is a densely forested region of steep slopes with all of the lands in the watershed managed by the Deschutes National Forest. Permeable volcanic rocks cover much of the basin and permit a substantial amount of ground water movement. Thus, a major source of water to the lake is subsurface seepage. The only permanent surface inflow to the lake is Link Creek from Blue Lake.

The shoreline of the lake is federal land and there are a number of Forest Service campgrounds and boat launching sites. This is an extremely popular outdoor recreation area in all seasons of the year. A large private resort is located at the east end of the lake on land leased from the Forest Service, while Suttle Lake Lodge at the north end provides supplies and cabins. There are several other private resorts in the Suttle Lake-Blue Lake area, as well as a number of church camps. All sorts of water recreation opportunities exist: fishing, swimming, camping, picnicking, water-skiing and small boating. Fishing centers on kokanee, or land-locked blueback salmon, taken most successfully early in the season. Rainbow trout and brown trout are also taken, but in smaller numbers. Rainbow trout are stocked regularly by the Oregon Department of Fish and Wildlife. The watershed is starting to recover from infestations of the Spruce Bud Worm and a devastating forest fire that it experienced in 2003.

Suttle Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake with dam | **Use:** recreation | **Elevation:** 3,438 ft (1,047.9 m)

Location: 40 mi NW of Bend in Deschutes National Forest

Drainage Basin Characteristics:

Area: 21.3 sq mi (55.2 sq km) | **Relief:** steep | **Precipitation:** 54-80 in (137-203 cm)

Land Use: Forest-90%; Range-1%; Water-2.7%; Other-3.3% (rock outcrops)

Lake Morphometry:

Area: 253 acres (102.4 hect) | **Depth:** Maximum -75 ft (22.9 m); Average - 44ft (13.5 M)

Ave/Max Depth Ratio: 0.590 | **Volume:** 11,184 acre ft (13.82 cu hm)

Shoal area: 10% | **Volume factor:** 1.77 | **Shape factor:** 1.59

Length of Shoreline: 3.6 mi (5.8 km) | **Retention time:** 5.2 yrs.

Water Quality: [Note: Other data on Suttle Lake was not readily available so the following is from the Atlas of Oregon Lakes (Johnson et al, 1985). The parts in quotes are directly from that source and are provided because it describes the reasons that the authors of the Atlas felt Suttle Lake was similar to three other lakes, two of which - Diamond and Odell, are discussed in detail where internal loading due to introduced fish appear to be the nutrient driver for the cyanobacteria blooms. Marion Lake is the third lake described that also experiences cyanobacteria blooms. It should be noted that Suttle Lake has a kokanee fishery, similar to Odell Lake, but the Suttle Lake kokanee fishery may be native to the system. Obviously more data is needed on Suttle Lake before any conclusions can be made.]

Suttle Lake was sampled three times in 1982 as part of the effort for developing the Atlas of Oregon Lakes. "The concentration of phosphorus was found much higher than might be anticipated and promotes the active growth of planktonic algae, sometimes to bloom proportions. The lake has a history of algal blooms; Newcomb'(1941) reported a high abundance of phytoplankton. In general, high densities of diatoms occur throughout the year, but in summer and early fall the lake also had high densities of blue-green algae. In spring Asterionella formosa predominates; summer algae are mostly Fragilaria crotonesis and Anabaena species; in the fall, Stephanodiscus astrea is most common. In their 1978 study of Suttle Lake, the U.S. Environmental Protection Agency in the National Eutrophication Survey reported Melosira, Dactylococcopsis, Anabaena, Stephanodiscus, Fragilaria, Chroomonas, and Cryptomonas as predominant algal species (E.P.A. 1978). Transparency of the water is reasonably good, but it may have been reduced somewhat in recent decades due to cultural activities in the area. Newcomb (1941) measured a Secchi disk depth of 35 feet (10.6 meters) in 1940; several studies in the early 1970s report values ranging from 14 to 16 feet (4.3 to 5.0 meters); and measurements in 1982 in this survey were 22 feet (6.7 meters) or lower. Although not conclusive, these limited data suggest a decline in water transparency concurrent with increased recreational use in recent decades."

"The various indicators of trophic status are contradictory. Secchi disk measurements clearly suggest mesotrophic conditions, whereas the standing crop of algae clearly indicates eutrophic conditions. Other Cascade lakes also exhibit this apparent contradiction between water transparency and density of phytoplankton; for example Odell Lake, Diamond Lake and Marion Lake. All four of these lakes have two attributes in common: (1) high phosphorus concentration, and (2) similar physiographic location, geologic origin, and morphometry. It may be that the long mountain winters limit biological productivity for most of the year; but during the short summer growing season, high phosphorus levels drive the lakes to a higher than expected trophic state. The blue-green algae which occur in the lake (Anabaena spp) are capable of nitrogen fixation. Bioassays (E.P.A. 1978) indicate that nitrogen limits algal growth in the lake, a reflection of the generous phosphorus supply. The source of the high phosphorus levels is debatable. It is certainly due in part to natural sources; however, the fact that the trophic state has increased in recent decades suggests contributions from the increased level of human activity around and on the lake (McHugh 1972). If this is so, the trend is likely to continue. The source(s) of the high nutrient levels should be determined and if cultural activities are responsible, the feasibility of various lake manipulations should be considered. A D.E.Q. study found high phosphate levels in Blue Lake close to its outlet, and the E.P.A. (1978) credited this outlet stream with 81.9 percent of the total phosphorus input. If the phosphate source can be located and eliminated, Suttle Lake should be a very good candidate for phosphorus inactivation (McHugh 1979). In summary, Suttle Lake would be classified as mesotrophic according to transparency data; however, the abundance of phosphorus and algae appear to be the overriding consideration and the lake is classified as eutrophic."

Summary of Mid-lake Data from Suttle Lake

Date	pH (SU)	Total Phosphorus (mg/l)	Dissolved Ortho Phosphorus (mg/l)	Nitrate & Nitrite (mg/l)	Ammonia (mg/l)	Total Kjeldahl Nitrogen (mg/l)	N:P Ratio[25]	Chlorophyll a (ug/l)
5/25/82 -Johnson 1985	7.9	0.031	-	-	-	-	-	1.3
7/21/82 -Johnson 1985	8.4	0.024	-	<0.02	<0.02	0.4	-	15.7
11/7/82 -Johnson 1985	8.7	0.066	-	-	-	-	-	25.1

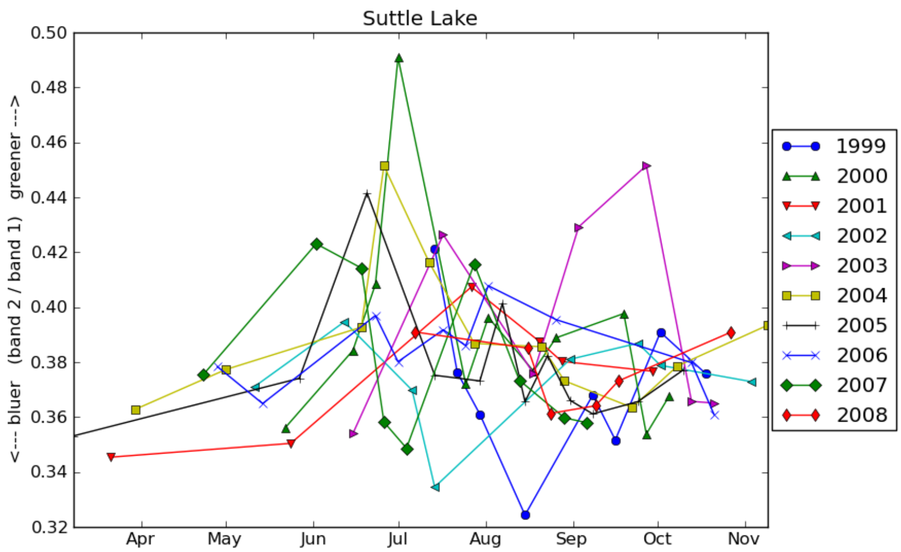
Hazardous Algal Bloom Health Advisories: A Public Health Advisory was issued by the Oregon Health Authority in 2004 based on high densities of *Anabaena flos-aquae.* This Health Advisory was based on use of the drinking water advisory criteria (15,000 cells/ml) rather than the recreational advisory criteria (100,000 cells/ml) that is currently used.

[25] N:P ratio below 7.2 is Nitrogen Limiting

Summary of Public Health Advisories for Recreation Use in Suttle Lake

Year	Start Date	End Date	Duration	Dominant Species	High Cell Count[26]	Maximum Toxin Measured (ug/l)
2004	June	7/16		*Anabaena flos-aquae*	64,210	Microcystin – 0.51

Remote sensing of chlorophyll *a* concentrations using Landsat data suggests a pattern in the algal blooms of Suttle Lake. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values are generally above 0.4 from mid-June until late July in most of the years assessed, with the exception of 2002.



Likely or Suspected Cause of Blooms: Nutrients loads both externally from the watershed as well as internally from introduced fish populations are suspected.

303(d) List Status: 2004/2006 Integrated Report identifies Suttle Lake as being of concern but needing supporting data (Category 3 – Insufficient Data) for chlorophyll a, nutrients and pH. A Category 3 (Potential Concern) listing for Aquatic Weeds and Algae has been proposed in Oregon's 2010 Integrated Report based on Health Advisories issued. This Health Advisory was based on use of the drinking water advisory criteria (15,000 cells/ml) rather than the recreational advisory criteria (100,000 cells/ml) that is currently used. TMDL related work has not been initiated.

References

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

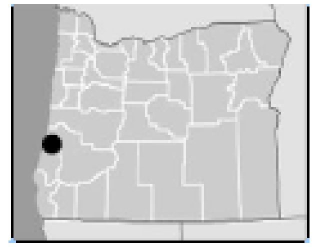
Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Turner, Dan. June 2010. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality.

[26] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

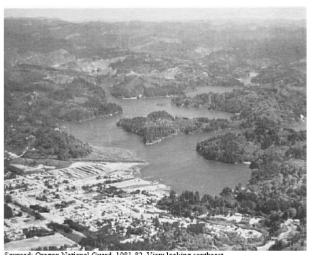
Tenmile Lakes

Coos County, South Coast Basin, Coast Range Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

The drainage basin of the Tenmile Lakes is quite large and includes both North and South Tenmile Lakes within it. The following text will use "Tenmile Lake" but will be referring to both lakes unless otherwise noted. Other major tributaries entering the various arms include Shutter Creek, Adams Creek, Johnson Creek and Benson Creek. The Tenmile Lakes are quite shallow and have filled in with rich organic matter which washes in from the drainage basin; narrow marshes border the lakes in several areas. The bottom material is sand, muck and peat. In some places around Tenmile Lake the surface topography is very steep and there is frequent slumping of overlying sedimentary material into the water, thereby gradually reducing lake depth. The upland area of the drainage basin is primarily covered by forest and is almost totally in private ownership, as is the shoreline of the lake.



Sourced: Oregon National Guard, 1981-82. View looking southeast.

Tenmile Lake has long been popular with recreationists from the local area as well as with large numbers of users from the interior valleys. In fact, Tenmile Lake receives more use by boaters (over 40,000 boater use days per year) than any other lake in Oregon. Tenmile has good rainbow trout fishing but it is the success with bass and panfish that attracts most anglers. Tenmile Lake is currently an important site for bass fishing tournaments in Oregon

In spite of the excellent fishing now found in Tenmile Lake, the history of the fishery is an unfortunate one. Earlier this century large populations of cutthroat trout, silver salmon and steelhead passed through the Tenmile Lakes system to spawn in the tributary streams. The rich, productive lakes provided an ideal habitat for fish growth. In an attempt to create more variety and to develop a warm water fishery, yellow perch and brown bullhead were introduced, probably in the 1920s. These new species prospered, but at the expense of the salmon and trout. In time the quality of the salmon and trout fishery declined drastically as the increased numbers of warm water fish decreased the food supply. Studies of the problem were begun by the State Game Commission about 1938 and in 1953 an intensive study program was started with the goal of eliminating undesirable species and rebuilding the salmon and trout runs. These runs had also been adversely affected over the years by the deterioration of spawning grounds. Logging operations made some tributaries unsuitable for spawning salmon, while on others siltation reduced productivity. Much loss has also resulted from rechanneling of streams by landowners to obtain better drainage and more farming areas, usually in the flatter areas around the mouths of tributaries that make good pasture.

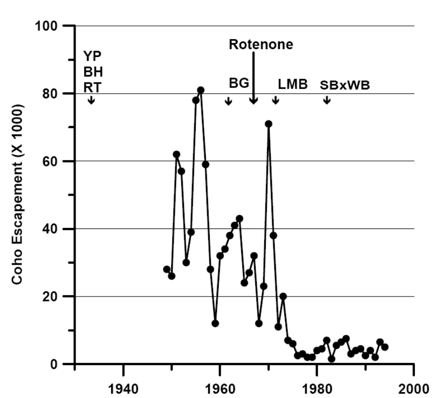


Figure 4. Coho escapement (return) to Tenmile Lake over the last 50 years (after Abrams et al. [1991]), where YP=yellow perch, BH=brown bullhead, RT=rainbow trout, BG=bluegill, LMB=largemouth bass, and SMxWB=smallmouth bass x white bass hybrid.

The first major effort at rehabilitation involved the removal of tons of fish by poisoning. Success was not achieved. Finally, after years of controversy, a more drastic method was employed - a complete eradication of the entire population of fish. In 1968 the Tenmile Lakes and adjacent waters (including Eel Lake) were treated with the rotenone; only the brown bullhead survived. The lake had been subsequently restocked and there was a tremendous overabundance of bluegill. In 1971, largemouth bass were introduced to prey on the bluegill. Following the introduction of largemouth bass, coho return into the Tenmile Lakes has remained below 10,000 adults and jacks. (Johnson et al, 1985;Eilers et al, 2002)

Tenmile Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: natural lake **Use:** recreation **Elevation: Elevation:** 9 ft (2.7 m)
Location: 8 miles south of Reedsport, 0.5 miles east of US Hw y 101

Drainage Basin Characteristics:

Area: 69.7 sq mi (180.5 sq km) **Relief:** moderate **Precipitation:** 67-100 in (170-254 cm)
Land Use: Forest-93%; Water-5%; Urban-2%;

Lake Morphometry – South Tenmile Lake:

Area: 1,627 acres (658.4 hect) **Depth:** Maximum - 22 ft (6.7 m); Average - 10ft (3.0 m)
Ave/Max Depth Ratio: 0.450 **Volume:** 16,212 acre ft (20.03 cu hm)
Shoal area: 42% **Volume factor:** 1.36 **Shape factor:** 4.05
Length of Shoreline: 22.9 mi (36.9 km) **Retention time:** 1 mo.

Lake Morphometry – North Tenmile Lake:

Area: 1,098 acres (444.4 hect) **Depth:** Maximum - 23 f t (7.0 m); Average - 11f t (3.4 m)
Ave/Max Depth Ratio: 0.480 **Volume:** 12,142 acre f t (15.00 cu hm)
Shoal area: 41% **Volume factor:** 1.66 **Shape factor:** 4.16
Length of Shoreline: 19.3 mi (31.1 km) **Retention time:** 2 mo.

Water Quality: Studies were conducted in Tenmile Lake in 1998 and 1999 for TMDL development (Eilers et al, 2002). Water quality was generally the most favorable in winter, although the lake was visibly impacted by high inputs of suspended solids and nitrate. In spring, the lake experienced a major diatom bloom and produced chlorophyll *a* concentrations exceeding 60 ug/l. A second major bloom occurred in late summer dominated by cyanobacteria. Despite being relatively shallow, significant oxygen depletion occurred below 4 meters with bottom waters occasionally being anoxic. Secchi disk transparency varied from a high of 4.9 m in November to a low of 0.6 m following a storm. Total Phosphorus averaged 25 ug/l.

The analysis of the lake sediments showed that the sediment accumulation rate (SAR) has increased substantially (2 – 4 times) over pre-development conditions with the greatest increase occurring in the Coleman Arm near Big Creek. Sediment chemistry showed an increase in nitrogen with nitrogen ratios suggesting a change in the source of nitrogen. This was consistent with akinete data indicating an increase in the biomass of cyanobacteria in the latter half of the 20th century. The diatom community composition changed significantly over time toward taxa found in highly productive lakes.

SWAT modeling indicated that loads of sediment and nutrients have increased throughout the watershed that were associated with land use disturbances that are persistent and close to the lake or streams. These include residential development, livestock grazing, stream channelization/loss of wetlands and timber harvesting. Septic inputs represented about 20% of the watershed loading however, during the summer when tributary loads are small, the relative contribution of septic inputs increases to about 50% and constitute an important component of the load. (Eilers et al, 2002)

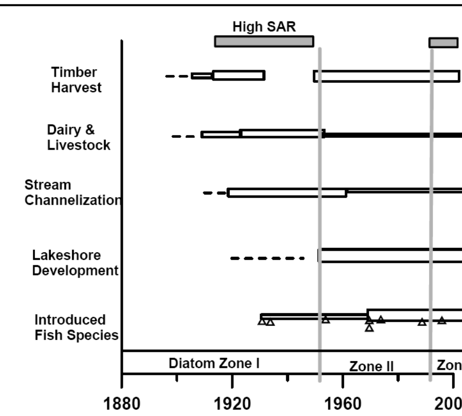


Figure 49. Zonation of the sediment diatoms (from Figure 47) compared to approximate timing of major watershed and in-lake changes. The width of the bars reflect perceived changes in the status of anthropogenic activities.

Other in-lake factors that were not addressed in the study but are likely to influence the water quality and algal blooms include the presence and abundance of macrophytes, particularly *Egeria densa*, and the fishery dominated by highly planktivorous fish (e.g. bluegill and yellow perch). Macrophytes can extract nutrients from the sediments and, upon senescing in the fall, their nutrients are made available through mineralization and the decaying macrophytes exert a biochemical oxygen demand – both of which release nutrients for algal growth. Planktivorous fish are efficient at consuming larger zooplankton species which in turn, reduces grazing pressure on the phytoplankton which allows the algal biomass to increase.

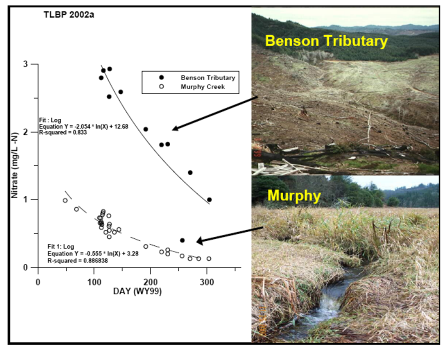
TMDL: The TMDL established a target of no measureable increase in annual sediment and phosphorus loading rates beyond that of reference streams. A reference sediment load for tributary streams and drainages was set at 0.07 tones/ha/yr. A target of attaining a 50% reduction in annual sediment loads within the next 25 years was incorporated. A phosphorus target to work towards for lake water of 7.1 ug/l was proposed as an all season average (values collected from 1998 – 2002 ranged from 23 – 38 ug/l, depending on the site).

Hazardous Algal Bloom Health Advisories: Numerous Public Health Advisories have been issued by the Oregon Health Authority for Tenmile Lakes.

Likely or Suspected Cause of Blooms: Increased nutrients loads, both phosphorus and nitrogen, due to activities that create or transport nutrients and sediment in the watershed and internal loading of nutrients due to exotic fish species and macrophytes.

303(d) List Status: The 2004/2006 Integrated Report identifies Tenmile Lakes as being water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds or Algae. A TMDL has been completed and is being implemented. The lakes are proposed to be listed as Category 4A (TMDL Approved) in the 2010 Integrated Report.

Figure 31- Nitrate (NO_3-N, mg/L) Concentrations
1999 Water year (October 1, 1998 to September 30, 1999



Summary of Public Health Advisories in Tenmile Lakes

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[27]	Maximum Toxin Measured (ug/l)
1997	10/3	12/1	60	*Microcystis aeruginosa*		Microcystin – 1.65
2000						Microcystin – 2.3
2001	8/31					
2002	7/6			*Microcystis aeruginosa*		
2003	9/22	3/11		*Microcystis aeruginosa*		
2004	March?			*Microcystis aeruginosa*		
2009	9/18	11/30	73	*Microcystis aeruginosa* (4,664,468) *Aphanizomenon flos-aquae* (730,620) *Anabaena planctonica* (145,222)	4,664,468	Microcystin – 20.1
2010	9/23	1/13/11	112	*Microcystis aeruginosa* (5,939,379) *Anabaena planctonica* (2,301,942) *Aphanizomenon flos-aquae* (1,143,380)	5,939,379	Microcystin – 149 - 705 Anatoxin 0.2

References

Department of Environmental Quality. February 2007. Tenmile Lakes Watershed Total Maximum Daily Load (TMDL). Portland, OR

Eilers, Joseph, K. Vache and J. Kann. November, 2002. Tenmile Lakes Nutrient Study – Phase II Report. E&S Environmental Chemistry, Inc. Corvallis, OR. 136 pp.

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

Kann, Jacob and D. Gilroy. 1997. Ten Mile Lakes Toxic *Microcystis* Bloom. Oregon Health Division. Portland, OR. 7 pp.

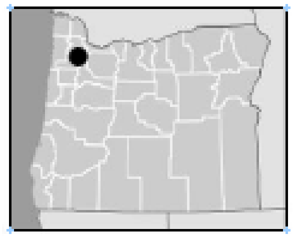
Kann, Jacob and D. Stone. 11/8/2005. Overview of Oregon Cyanobacterial Experience.

Oregon Health Authority - Public Health Advisories:
http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

[27] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Wapato Lake

Washington County, Willamette Basin, Willamette Valley Ecoregion



State of Oregon Department of Environmental Quality

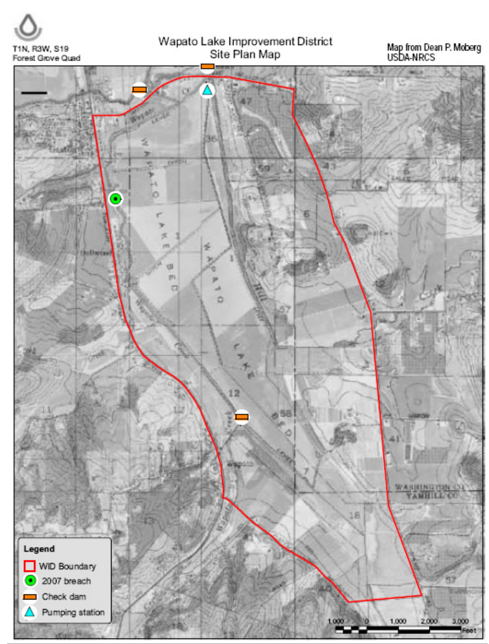
Setting and Lake Uses

Historically, Wapato Lake, located southeast of Gaston, Oregon near Forest Grove, was one of the most important waterfowl sites in the Willamette Valley. The lake basin held water year-round, supporting a large wetland scrub-scrub community, which included diverse wildlife and the wetland plant known as Wapato, whose tuber was an important potato-like staple for native and early Americans. With seasonal floodwaters of the Tualatin River, the lake would spread from approximately 600 to nearly 1,500 acres. (Metro website)

The former Wapato Lake bed normally is drained during spring so that it can be farmed during the summer. The Wapato Lake area has been leveed and drained since the 1930s by the Wapato Improvement District to support local agricultural activities. A levee protects the former lake bed from severe flooding during the winter, thus allowing easier drainage in the spring. The water pumped out of Wapato Lake in springtime typically has a minimal downstream water-quality effect as a result of high river flow and ample dilution. Some increased difficulties in treating municipal drinking water at the Joint Water Commission's plant downstream, however, have been reported to coincide with these springtime discharges from Wapato Lake. (Clean Water Services, 2008)

Even with vast changes over the years, the lake is still used extensively by tundra swans, geese and dabbling ducks. Much of the Wapato Lake area was recently designated a National Wildlife Refuge. In February 2007, The U.S. Fish & Wildlife Service approved the acquisition of a 4,300 acre Wapato Lake Unit to the Tualatin River National Wildlife Refuge and began purchasing land within the Wapato Lake bed.

<u>Water Quality:</u> On December 2-3, 2007, more than 6 inches of total rainfall were recorded at several weather stations across the Tualatin River basin. By December 3rd, the Tualatin River at Gaston and at Dilley was cresting at near-flood levels. During these high-water conditions, a small section of the levee on the west side of Wapato Lake failed, causing flood water to inundate the lake bed to a depth of approximately 8 feet, although no reliable measurements were taken. Without first repairing or temporarily patching the levee, Wapato Improvement District personnel could not pump flood waters out of the lake. Any water pumped out would simply re-enter the lake through the levee breach. The levee, however, could not be patched because flood water prevented access. Consequently, the lake could not be drained in the springtime, and water remained ponded in the Wapato Lake bed until early summer when river levels finally receded below the levee breach. Once the levee was patched, pumps were turned on to transfer the ponded water into Wapato Creek, which discharges to the Tualatin River just upstream of the mouth of Scoggins Creek. While ponded on the peat soils of the lake bed, however, the water had a chance to warm up, pick up nutrients, and grow a substantial population of algae and zooplankton. The water quality effects of this discharge on the Tualatin River were not discovered until weeks later.



Map of Wapato Lake showing location of levee breach.

In July 2008, unusual conditions were noticed in the Tualatin with floating algal mats composed primarily of *Anabaena flos-aquae* were observed between RM 9.9 and 16.2. Floating mats of nuisance algae had not occurred in the Tualatin since the early 1970's. Results of cell counts revealed *Anabaena* concentrations less than 30,000 but Microcystin concentrations were ranged from 0.14 to 2.4 in samples from three locations. While below DHS action levels, an advisory was issued based on the presence the floating mats. Sampling was conducted by U. S. Geological Service and Clean Water Services to locate the source of the algae. Available streamflow, chemical and biological data was consistent with the hypothesis that the bloom of *Anabaena* came from Wapato Lake and was discharged on or about June 30th. Taste and Odor problems were occurring at the Joint Water Commission water treatment plant that were also linked to the discharge from Wapato Lake (Clean Water Services, 2008) Additionally, concerns were raised about the potential for health impacts on farm workers who come in contact with the irrigation water and use of the water for irrigating crops.

A Wapato Lake Water Quality Management Plan for the Wapato Improvement District has been developed by Wapato Improvement District, DEQ, Joint Water Commission, NRCS, and the Washington County SWCD and was adopted by the Wapato Improvement District in July 2009. The management plan addresses pumping, dike maintenance, communication and contingency actions for future problems.

Hazardous Algal Bloom Health Advisories: A Public Health Advisory was issued by the Oregon Health Authority for the Tualatin River in 2008.

Summary of Public Health Advisories for the Tualatin River

Year	Start Date	End Date	Duration	Dominant Species	High Cell Count[28]	Maximum Toxin Measured (ug/l)
2008	7/12	7/25	13	*Anabaena flos-aquae*	30,000	2.4

Likely or Suspected Cause of Blooms: Unusual sequence of events that occurred in 2008 that resulted in water ponding on the lake bed later than the typical practice. While ponded on the peat soils of the lake bed, the water had a chance to warm up, pick up nutrients, and grow a substantial population of algae and zooplankton. Given the history of the site, a bloom was likely natural but current land and water use created a larger problem.

303(d) List Status: The 2004/2006 Integrated Report does not contain any listings for Wapato Lake. The Tualatin River is identified as being Water Quality Limited with an approved TMDL (Category 4A) for Aquatic Weeds and Algae, dissolved oxygen, pH and phosphorus. The lower segment (RM 0 – 10.5) of the Tualatin River was proposed for listing as 4A (Water Quality Limited, TMDL Approved) for Aquatic Weeds or Algae on the Oregon's 2010 Integrated Report to note where the advisory was issued based on the toxin data.

References

Clean Water Services. 2008. Tualatin River Flow Management Technical Committee 2008 Annual Report – Water Quality Effects of Wapato Lake Drainage in 2008 by Bernie Bonn and Jane Miller, Clean Water Services in consultation with Stewart Rounds, U.S. Geological Survey. Prepared by Bernie Bonn.

Metro website: http://www.oregonmetro.gov/index.cfm/go/by.web/id=24627
Public Health Advisories

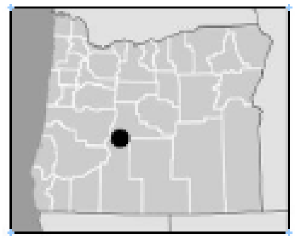
Oregon Health Authority - Public Health Advisories:
http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Wapato Improvement District, Department of Environmental Quality, Joint Water Commission, USDA – Natural Resources Conservation Service, Washington County Soil and Water Conservation District. July 2009. Wapato Lake Water Quality Management Plan for Wapato Improvement District.

[28] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Wickiup Reservoir

Deschutes County, Deschutes Basin, Cascade Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Source: Oregon National Guard, 1981-82. View looking northwest.

Wickiup Reservoir, when full, is the largest body of water in the Deschutes National Forest and is the second largest reservoir in Oregon; only Owyhee Lake (reservoir) is larger in surface area. However, Wickiup Reservoir is a relatively shallow impoundment (mean depth 20 feet) and several in the state have greater storage capacity. It is a component of the Deschutes Project, a Bureau of Reclamation project which includes Wickiup Dam and Reservoir, Haystack Dam and Reservoir, North Unit Main Canal and lateral system, and the Crooked River Pumping Plant[29]. The Project furnishes a full supply of irrigation water for about 50,000 acres of land within the North Unit Irrigation District, and a supplemental supply for more than 47,000 acres in the Central Oregon Irrigation District and Crook County Improvement District. The 100-foot high, earth-fill dam was completed in 1949. Flow to Wickiup Reservoir comes from the Deschutes River, which is water released from Crane Prairie Reservoir, and Davis Creek, which is fed by springs and underground flow from Davis Lake.

Wickiup Reservoir is perhaps the busiest in terms of recreational use among the many lakes accessible from the Cascade Lakes Highway. It has several campgrounds and its watershed is fully within the Deschutes National Forest. It is used extensively by fishermen. A large number of scrap fish (chubs) have occupied the reservoir for years, yet a productive sport fishery has been maintained. Large brown trout, rainbow trout, kokanee and coho salmon have been caught in the lake.

Wickiup Reservoir Characteristics (from Johnson et al, 1985)

Setting:

Type: reservoir | **Use:** irrigation, recreation | **Elevation:** 4,338 ft (1,322.2 m)
Location: 10 mi W of LaPine in Deschutes National Forest

Drainage Basin Characteristics:

Area: 253 sq mi (655.3 sq km) | **Relief:** moderate | **Precipitation:** 20-55 in (51-140 cm)
Land Use: Forest-79.5%; Water-16%; Other-4.5% (rock outcrops, wetlands and lava fields)

Lake Morphometry:

Area: 10,334 acres (4,182.2 hect) | **Depth:** Maximum - 70 ft (21.3 m); Average - 20ft (6.1 M)
Ave/Max Depth Ratio: 0.290 | **Volume:** 206,880 acre ft (255.56 cu hm)
Shoal area: 34% | **Volume factor:** .86 | **Shape factor:** 3.54
Length of Shoreline: 50.5 mi (81.3 km) | **Retention time:** 5 mo

Water Quality: The phosphorus concentration is relatively high, perhaps reflecting contribution from Crane Prairie upstream and release from bottom sediments (higher Total and Dissolved Ortho Phosphorus and Ammonia values in the table below were from samples collected near the bottom where dissolved oxygen values were in the 3-4 mg/l range). The pH values in the surface waters often exceeded the standard of 8.5 SU with values typically ranging from 8.5 to 9.2 in the summer. N:P ratios showed an interesting pattern with low values (nitrogen limiting) near the bottom (where phosphorus is released and there is plenty available) and higher ratios near the surface.

[29] http://www.usbr.gov/projects/Project.jsp?proj_Name=Deschutes+Project

Summary of Mid-lake Data from Wickiup Res (USBR data collected 1 meter from surface and bottom)

Date	Depth (meters)	pH (SU) (from 1 to 5 meters)	Total Phosphorus (mg/l)	Dissolved Ortho Phosphorus (mg/l)	Nitrate & Nitrite (mg/l)	Ammonia (mg/l)	Total Nitrogen (mg/l)	N:P Ratio[30]	Chlorophyll a (ug/l)
7/17/1982 (Johnson et al, 1985		7.6	0. 033	-	0.03	<0.02	<0.2	-	1.7
7/24/1995 (USBR)	1	8.7	0.022	0.009	<0.01	<0.01	0.33	12.8	14.5
"	19.3	6.8	0.085	0.05	0.01	0.04	0.18	2.1	
7/25/2001 (USBR)	1	9.3	0.02	<.0.003	<0.01	0.01	0.28	14	8.1
"	19.2	7.4	0.07	0.033	<0.01	0.05	0.22	3.1	
7/14/2004 (USBR)	1	8.6	0.02	<0.003	0.01	<0.01	0.3	15	3.1
"	19.2	7.1	0.082	0.045	0.02	0.04	0.29	3.5	
7/24/2007 (USBR)	1	8.8	0.018	<0.003	<0.01	<0.01	0.41	22.8	6.3
"	16.7	7.6	0.127	0.040	<0.01	0.17	0.48	3.8	

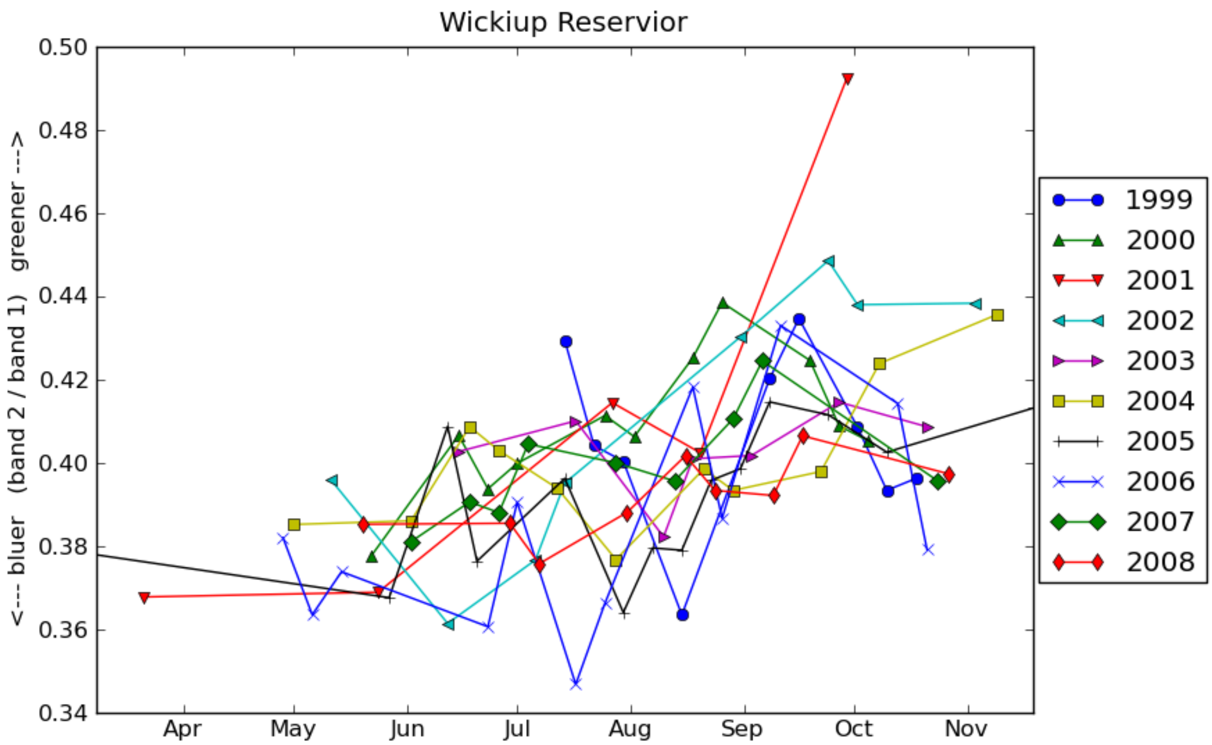
Hazardous Algal Bloom Health Advisories: A number of Public Health Advisories have been issued by the Oregon Health Authority in 2004, 2005 and 2006 based on blooms dominated by *Anabaena flos-aqua, Gloeotrichia echinulata* or *Microcystis aeruginosa*.

Summary of Public Health Advisories for Recreation Use in Wickiup Reservoir

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[31]	Maximum Toxin Measured (ug/l)
2004	9/10	9/24	14			
2008	9/11	9/25	14	*Gloeotrichia echinulata* (445,402) Unidentified Blue-Green (339,038) *Anabaena flos-aquae* (52,512) *Anabaena planctonica* (240)	836,952	Microcystin - .2 Anatoxin - ND
2008	10/2	10/27	25	*Anabaena flos-aquae* (318,353) *Microcystis aeruginosa* (281,543) *Anabaena circinalis* (120)	599,896	
2009	8/12	8/31	19	*Anabaena flos-aquae* (4,008,889) *Microcystis aeruginosa* (1,002) *Aphanizomenon flos-aquae* (126)	4,008,889	
2009	9/2	9/25	23	*Anabaena flos-aquae* (1,449,989)	1,451,038	

[30] N:P ratio below 7.2 is Nitrogen Limiting
[31] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Remote sensing of chlorophyll *a* concentrations using Landsat data confirms this pattern of blooms starting in early August and continuing into mid-October in Wickiup Reservoir. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values shown from 1999 through 2008 were generally below the ratio of 0.4 until late June/early July and start increasing with peak values found in late August through mid-late September.



Likely or Suspected Cause of Blooms: Elevated phosphorus (source may be natural but additional data is needed). Non-native, introduced fish may play a key role in the internal loading.

303(d) List Status: 2004/2006 Integrated Report identifies Wickiup Reservoir as being of concern but needing supporting data (Category 3 – Insufficient Data) for pH. Wickiup Reservoir has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae and pH in the 2010 Integrate Report based on the health advisories issued. TMDL related work has not been initiated.

References

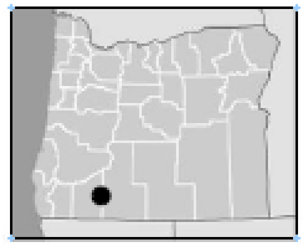
Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Turner, Dan. June 2010. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality.

Willow Lake

Jackson County, Rogue River Basin, Cascade Ecoregion



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Environmental
Quality

Setting and Lake Uses (Johnson et al, 1985)

Source: Oregon National Guard, 1981-82. View looking southeast.

Willow Lake is a popular southern Oregon reservoir which stores the waters of Willow Creek, a tributary of the South Fork of Big Butte Creek. It is commonly known as Willow Creek Reservoir and this name appears routinely on maps. The 52-foot high, earthfill dam was completed in 1952 by the Medford Water Commission to store water as part of the operation of their municipal water system. Other uses are for irrigation and recreation. The contributing drainage basin is primarily within the Rogue River National Forest and drains the west slopes of Mt. McLoughlin. However, there are many sections of privately owned land within the broader National Forest boundaries. The lake itself is on county land, which has been developed by Jackson County as the Willow Lake Recreation Area. It includes facilities for camping and picnicking as well as a paved boat ramp. A small, private resort is also located on the shore. Willow Lake is heavily fished; kokanee were stocked about 1960 and have produced very well. Rainbow and cutthroat trout are also found, although in lesser numbers.

Willow Lake Characteristics (from Johnson et al, 1985)

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 3,014 ft (918.7 m)
Location: 25 miles ENE of Medford

Drainage Basin Characteristics:

Area: 29.5 sq mi (76.4 sq km) **Relief:** steep **Precipitation:** 38-50 in (97-127 cm)
Land Use: Forest-96%; Range-1.3%; Water-1.7%; Other-1% (rock outcrops)

Lake Morphometry:

Area: 345 acres (139.6 hect) **Depth:** Maximum - 38 ft (11.6 m); Average - 24ft (7.2 M)
Ave/Max Depth Ratio: 0.620 **Volume:** 8,178 acre ft (10.10 cu hm)
Shoal area: 21% **Volume factor:** 1.78 **Shape factor:** 1.78
Length of Shoreline: 4.6 mi (7.4 km) **Retention time:** 6 mo.

Water Quality: Algal blooms are not uncommon and they give the water a greenish hue. A past history of sewage discharge into the lake has contributed to water quality problems. In fact, Willow Lake is the location of what was probably the first recorded case, in Oregon, of mass poisoning of swimmers by blue-green algae. Sewage from the campground and the small resort is treated in a small treatment structure. Presumably, the treated effluent eventually enters the water, as evidenced by the fact that oxygen depletion is sometimes pronounced below a depth of 20 feet (6 meters). On the sample date of 7/15/82 a bloom of *Gloeotrichia echinulata*, a blue-green alga, was dominant. Other blue-greens, *Aphanizomenon flos-aquae* and *Anabaena sp.* were also observed. All these species are distinct indicators of enriched conditions. The combination of parameters suggests that a classification of eutrophic is appropriate. Associated nutrient data were relatively low with total phosphorus of 0.012 mg/l and nitrate, ammonia and total kjeldahl nitrogen all at or below detection levels of 0.02 mg/l. (Johnson, 1985)

McHugh (1979) has proposed methods to alleviate this problem of enrichment. The effluent could be piped past the lake and released below the dam or, as is currently done, accumulated and periodically sprayed on adjacent forested areas or dry hillsides. Another suggestion is to take advantage of the seasonal drawdown and deepen the reservoir near the shoreline. Such deepening would limit the now excessive growth of macrophytes in shallow water and, by reducing total surface area, would decrease evaporative loss and water warming.

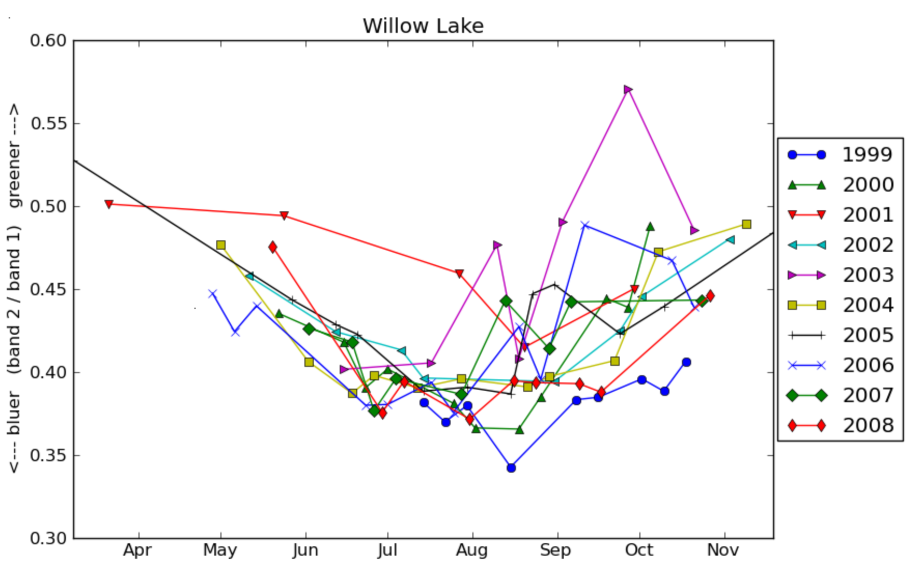
Sampling from July – October 1998 conducted by Southern Oregon University as part of the Oregon Citizen Lake Watch Program (Parker et al, 1998) found a sharp thermocline generally located between 6-9 meters depth with low dissolved oxygen in the hypolimnion (0-4 mg/l). In July and August, dissolved oxygen peaks were found at the thermocline where most of the primary production (algal growth) was likely taking place. Chlorophyll *a* values ranged from 3.2 – 4.6 ug/l in July/August and 6.5-7.0 in October, but were taken from 0.5 meter depth so peak values were likely missed. *Fragilaria crotonenis* and *Aphanizomenon flos-aquae* were common in July with *Anabaena sp* common in August.

Hazardous Algal Bloom Health Advisories: Two advisories were issued by the Oregon Health Authority in 2010 where blooms exceeded the maximum combined cell count of toxigenic species of 100,000 cells/mL. *Aphanizonmenon flos-aquae* was the dominant cyanobacteria from April through June with *Microcystis aeruginosa* dominating from October through December.

Summary of Public Health Advisories in Willow Lake

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[32]	Maximum Toxin Measured (ug/l)
2010	4/21	8/19	120	*Aphanizonmenon flos-aquae* (5,207,879) *Microcystis aeruginosa* (97,200) *Anabaena flos-aquae* (22,800)	5,213,550	Anatoxin – ND Microcystin – 0.2 Saxitoxin - ND
	10/12	12/15	64	*Microcystis aeruginosa* (3,250,000) *Anabaena flos-aquae* (35,000)	3,260,250	

Remote sensing of chlorophyll *a* concentrations using Landsat data suggests a pattern where peak algal blooms occur in the early Spring and early Fall (see Figure). A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l which equates to a visible bloom based on regression estimates (Turner, 2010). In most years, values are above 0.4 during the Spring until late June/early July and then often goes above 0.4 in late summer.



Likely or Suspected Cause of Blooms: Nutrients and possible fish interaction suspected but limited data.

303(d) List Status: 2004/2006 Integrated Report identifies Willow Lake as being of concern but needing supporting data (Category 3 – Insufficient Data) for algae, dissolved oxygen and nutrients. Willow Lake is proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic

[32] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Weeds and Algae on Oregon's 2010 Integrated Report based on the health advisories issued. TMDL related work has not been initiated.

References

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

Parker, Michael, K. Thorpe and B. Thorpe. 1998, Limnological Investigations of Five Southern Oregon Reservoirs, Department of Biology, Southern Oregon University. 24 pp

McHugh, Robert. 1979. Some Highly Eutrophic Oregon Lakes, with Recommendations for the Restoration of their Quality. Oregon Department of Environmental Quality. 33 pp

Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Turner, Dan. June 2010. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality.

Draft Harmful Algal Bloom Strategy - Appendix C

Willamette Basin Reservoir System

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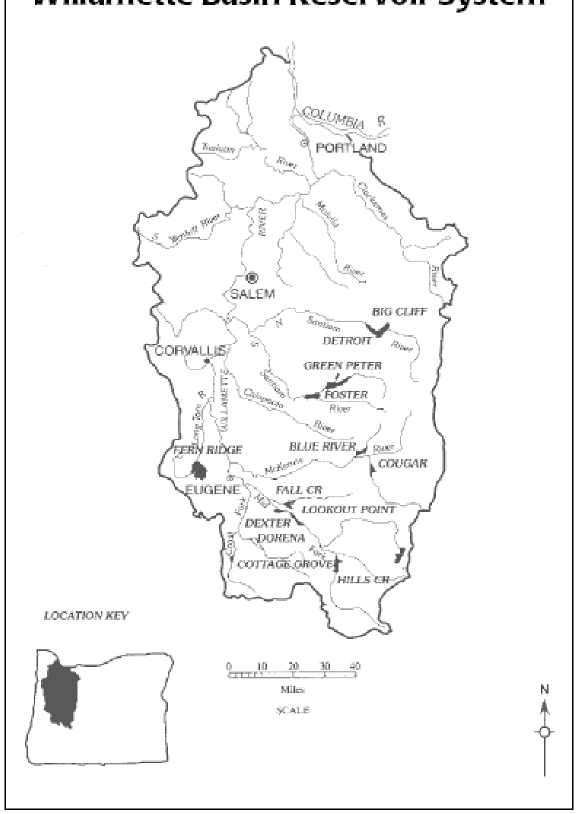
State of Oregon
Department of Environmental Quality

Willamette Basin Reservoir System

Willamette Basin Reservoir System



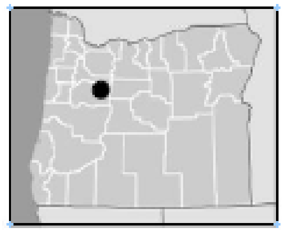
There are 13 reservoirs that were built and operated by the U. S. Corps of Engineers:

- **Detroit** and Big Cliff Reservoirs in the North Santiam Subbasin;
- Green Peter and Foster Reservoirs in the South Santiam Subbasin;
- **Cougar** and **Blue River** Reservoirs in the McKenzie Subbasin;
- **Hills Creek**, **Lookout Point**, **Dorena** and Fall Creek Reservoirs in the Middle Fork Subbasin;
- **Dexter** and Cottage Grove in the Coast Fork Subbasin; and
- Long Tom Reservoir in the Upper Willamette Subbasin.

The seven reservoirs, noted in bold above, have had a recreational Health Advisory(s) issued by the Oregon Health Authority since 2004. All 13 Willamette Reservoirs will be discussed as a unit, in part, because of the same management agency and because Landsat data was available for 10 of the reservoirs.

Big Cliff Reservoir

Marion/Linn County, Willamette Basin North Santiam Subbasin, Cascade Ecoregion



Setting and Lake Uses

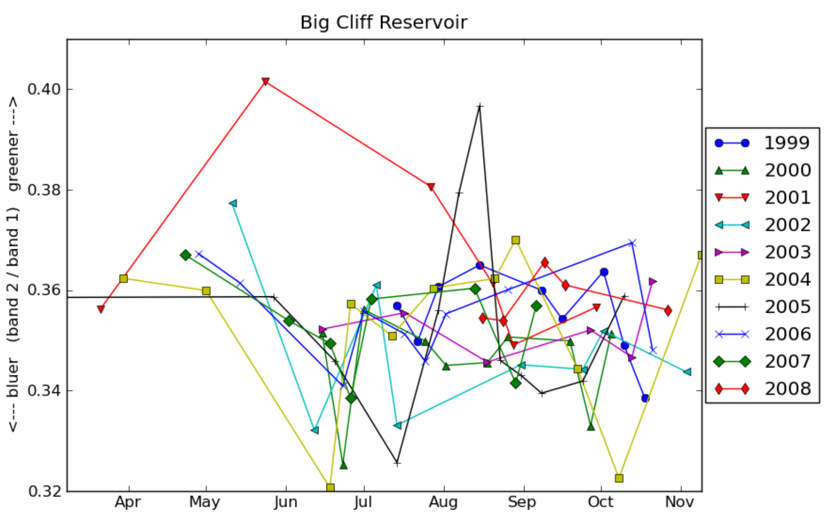
Big Cliff Reservoir is located 3 miles downstream from the Detroit Reservoir on the North Santiam River. The Big Cliff project reregulates the water released from the Detroit powerhouse to provide uniform stream flow in the North Santiam River. This reregulation operation may cause Big Cliff to fluctuate as much as 24 feet daily. Because of this water fluctuation, recreation facilities are limited at this project to one unimproved boat ramp. The watershed is mostly in U.S. Forest Service (Willamette National Forest) ownership (Johnson et al, 1985).

Big Cliff Reservoir Characteristics (from Johnson et al, 1985): Not included in the Atlas

Water Quality: ***[water quality data was not summarized due to lack of time]***

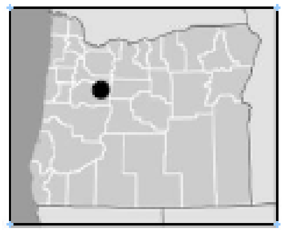
Hazardous Algal Bloom Health Advisories: No Public Health Advisories have been issued by the Oregon Health Authority for Big Cliff Reservoir.

Remote sensing of chlorophyll *a* concentrations using Landsat data shows that Big Cliff Reservoir does not typically have large algal blooms and has similar patterns as Detroit Reservoir which is immediately upstream. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values measured from 1999 to 2008 were typically below 0.40.



Likely or Suspected Cause of Blooms: Blooms do not appear to be a problem

303(d) List Status: The 2004/2006 Integrated Report does not contain any listings for Big Cliff Reservoir and no additional listings were proposed for the 2010 Integrated Report.

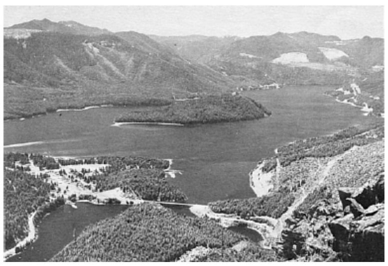


Detroit Reservoir

Marion/Linn County, Willamette Basin North Santiam Subbasin, Cascade Ecoregion

Setting and Lake Uses (Johnson et al, 1985)

Detroit Reservoir is located on the North Santiam River, just above the Big Cliff Reservoir, near the city of Detroit. These projects became operational in 1953 with Detroit Reservoir intended primarily for flood control and power



generation, but the large reservoir has become one of the major recreation resources in western Oregon. Detroit Reservoir is one of the two most popular Corps lakes for recreation. The lake has extensive public recreation facilities which are operated by the US Forest Service and Oregon Parks and Recreation Department. Because of the high demand for water-based recreation at Detroit Lake, its pool is maintained as high as possible through Labor Day. Also, Detroit Lake is rarely drafted for flow augmentation on the mainstem Willamette River in the summer. Recreation activity associated at Detroit Lake is a major contributor to the local economy. The watershed is mostly in U.S. Forest Service (Willamette National Forest) ownership.

Detroit Reservoir is popular for fishing, camping and boating. About 85% of the catch is rainbow trout, which are stocked annually by the Oregon Department of Fish and Wildlife. Brook trout, cutthroat trout, kokanee, and bullhead supplement the rainbow trout fishery and Chinook salmon have occasionally been stocked. Detroit Lake also receives some of the heaviest pleasure boating use in the state. Based on the total number of boating days estimated for 1975 **update**, this was the third "most used" lake in the state, following coastal Tenmile Lake and Diamond Lake.

Detroit Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir **Use:** multipurpose **Elevation:** 1,569 ft (478.2 m)
Location: 46 miles southeast of Salem

Drainage Basin Characteristics:

Area: 423 sq mi (1,095.6 sq km) **Relief:** steep **Precipitation:** 65-120 in (165-305 cm)
Land Use: Forest-96.3%; Range-0.2%; Water-1.6%; Urban-0.1%; Other-1.9% (rock outcrops)

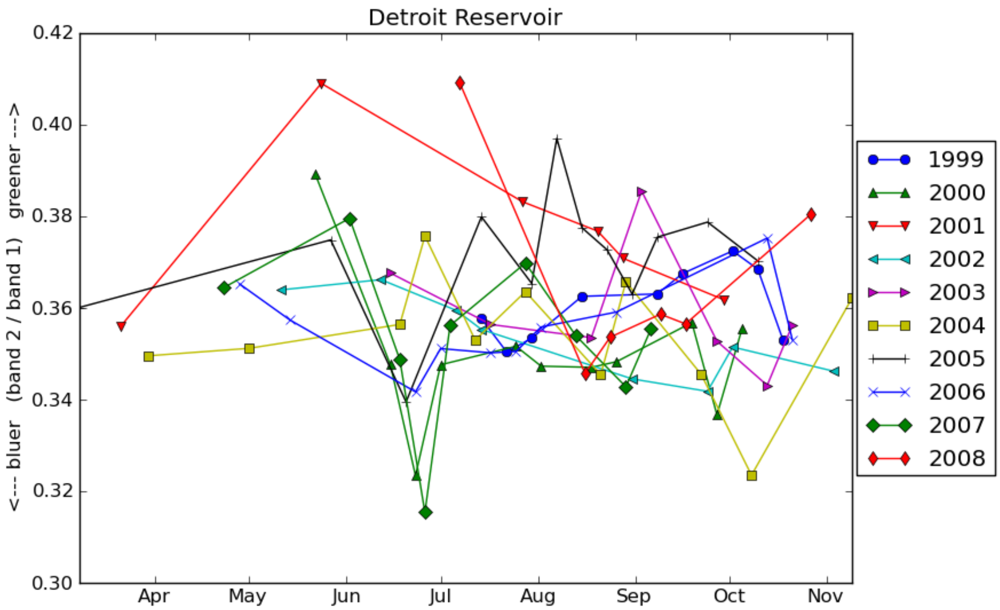
Lake Morphometry:

Area: 3,580 acres (1,448.8 hect) **Depth:** Maximum - 440 ft (134 m); Average - 121ft (36.9 m)
Ave/Max Depth Ratio: 0.280 **Volume:** 455,000 acre ft (562.06 cu hm)
Shoal area: 5% **Volume factor:** 1.10 **Shape factor:** 4.10
Length of Shoreline: 35.5 mi (57.1 km) **Retention time:** 3 mo.

Water Quality: ***[water quality data was not summarized due to lack of time]***

Hazardous Algal Bloom Health Advisories: A Public Health Advisory was issued by the Oregon Health Authority for Detroit Reservoir on 5/30/2007 to 6/13/2007. This advisory was based on cell counts from a bloom dominated by *Anabaena flos-aquae* with a maximum cell count of all toxigenic species of 5,132,069.

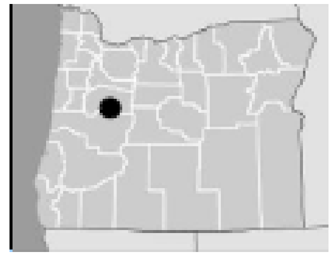
Remote sensing of chlorophyll *a* concentrations using Landsat data shows Detroit Reservoir does not typically have large algal bloom but may have short term blooms such as that which was observed in 2005. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). A value in 2001 and 2008 was above 0.4.



Likely or Suspected Cause of Blooms: Unknown at this time

303(d) List Status: 2004/2006 Integrated Report identifies Detroit Reservoir as being of concern for algae but needing supporting data (Category 3 – insufficient data). Detroit Reservoir has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in the 2010 Integrated Report based on the health advisories issued. TMDL related work has not been initiated.

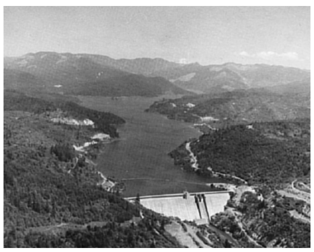
Green Peter Reservoir



Linn County, Willamette Basin, South Santiam Subbasin, Cascade Ecoregion

Setting and Lake Uses (Johnson et al, 1985)

Construction on the Green Peter Dam and on Foster Dam downstream began in 1961and was completed in 1968. Green Peter Dam on the Middle Santiam River is a 380-foot, concrete structure with a gated spillway for regulation of lake levels. Green Peter is operated to maintain fixed releases from Foster Lake because of its fishery needs and outflow requirements. Releases are made to augment flows at Salem, when necessary during low flow years. The 3,720 acre lake offers a variety of recreational opportunities, and its public recreation areas are operated by Linn County.



Land in the drainage basin is managed, in part, by federal agencies (Willamette National Forest, Bureau of Land Management) and, in part, by private interests. Most of the private land consists of forested slopes near the lake. The Corps of Engineers administers the shoreline.

Green Peter Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 1,015 f t (309.4 m)

Location: 8 miles northwest of Sweet Home

Drainage Basin Characteristics:

Area: 277 sq mi (684 sq km) **Relief:** steep **Precipitation:** 70-100 in (178-254 cm)

Land Use: Forest-98%; Water-2%

Lake Morphometry:

Area: 3,720 acres (1505.5 hect) **Depth:** Maximum - 315 ft (96 m); Average - 114ft (34.7 m)

Ave/Max Depth Ratio: 0.36 **Volume:** 430,000 acre ft (530.2 cu hm)

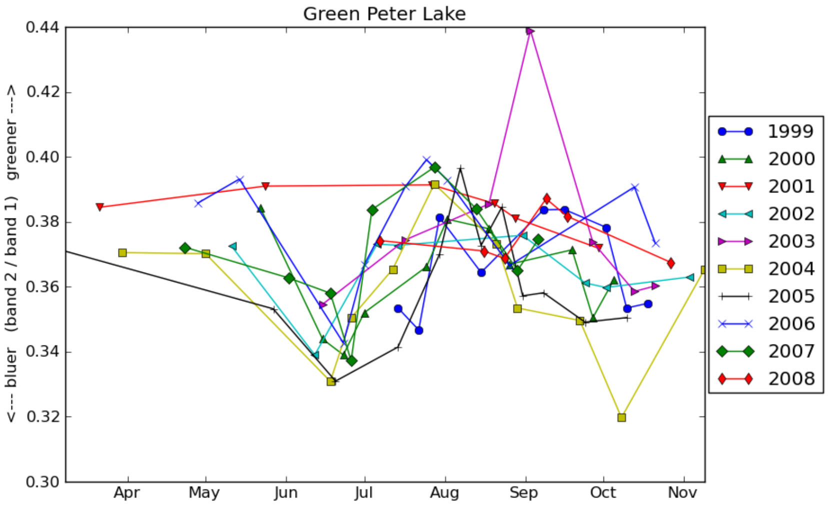
Shoal area: 6% **Volume factor:** 0.98 **Shape factor:** 6.4

Length of Shoreline: 48 mi (77.2 km) **Retention time:** 4.8 mo

Water Quality: ***[water quality data was not summarized due to lack of time]***

Hazardous Algal Bloom Health Advisories: No Public Health Advisories have been issued by the Oregon Health Authority for Green Peter Reservoir.

Remote sensing of chlorophyll *a* concentrations using Landsat data shows that Green Peter Reservoir does not typically have large algal blooms. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values measured from 1999 to 2008 were typically below 0.40 with one notable exception in 2003.

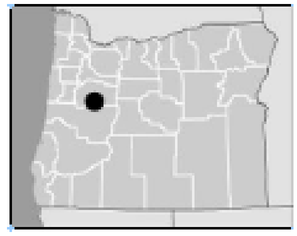


Likely or Suspected Cause of Blooms: Blooms do not appear to be a problem

303(d) List Status: The 2004/2006 Integrated Report does not contain any listings for Green Peter Reservoir and no additional listings were proposed for the 2010 Integrated Report.

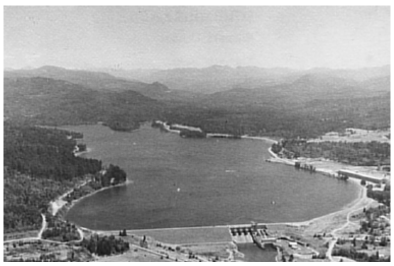
Foster Reservoir

Lane County, Willamette Basin, North Santiam Subbasin, Cascade Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Construction began on Foster Reservoir and on Green Peter Reservoir, six miles upstream, in 1961 and was completed in 1968. Foster Reservoir is immediately below the confluence of the Middle Santiam and



South Santiam Rivers, and impounds waters from both. The Foster project reregulates the water released during power production at Green Peter to provide a more uniform stream flow in the South Santiam River. Foster Lake is the most popular water-oriented recreation resource in Linn County and its recreation facilities are operated primarily by Linn County. The lake is stocked with rainbow trout and kokanee. Because of its high priority for recreation, the lake is rarely drafted for flow augmentation of the mainstem Willamette River.

Land in the drainage basin is managed, in part, by federal agencies (Willamette National Forest, Bureau of Land Management) and, in part, by private interests.

Foster Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 641 f t (195.4 m)

Location: 3 miles east of Sweet Home

Drainage Basin Characteristics:

Area: 217 sq mi (536 sq km) **Relief:** moderate **Precipitation:** 60-140 in (152-356 cm)

Land Use: Forest-96.6%; Water-1.6%; Non Irrigated Ag-1.8%

Lake Morphometry:

Area: 1,220 acres (493.7 hect) **Depth:** Maximum - 110 ft (33.5 m); Average - 50ft (15.2 m)

Ave/Max Depth Ratio: 0.45 **Volume:** 61,000 acre ft (75.2 cu hm)

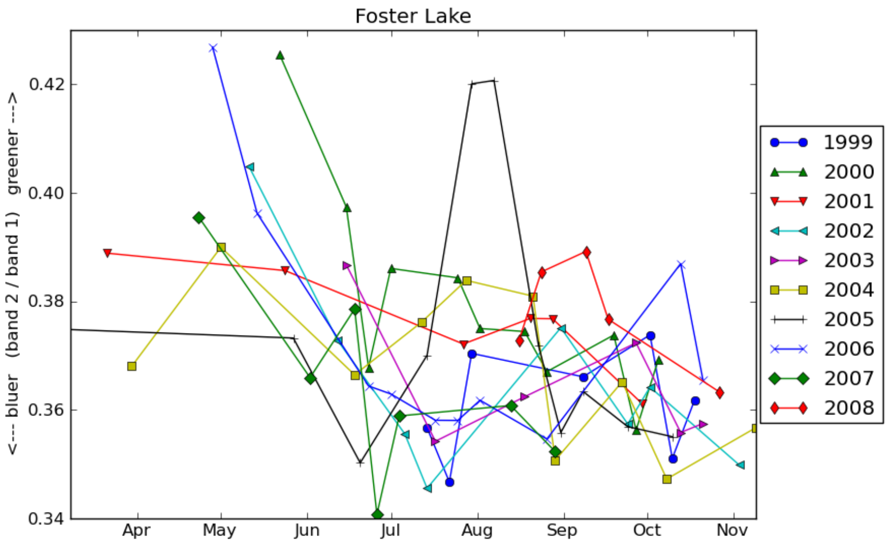
Shoal area: 10% **Volume factor:** 1.36 **Shape factor:** 4.1

Length of Shoreline: 19.7 mi (31.7 km) **Retention time:** 1 mo

Water Quality: ***[water quality data was not summarized due to lack of time]***

Hazardous Algal Bloom Health Advisories: No Public Health Advisories have been issued by the Oregon Health Authority for Foster Reservoir.

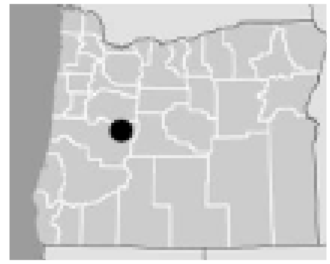
Remote sensing of chlorophyll *a* concentrations using Landsat data shows that Foster Reservoir might have occasional blooms, most typically in May - June. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values measured from 1999 to 2008 were typically below 0.40 but single values were above this ratio in 2000, 2002, 2005 and 2006.



<u>Likely or Suspected Cause of Blooms:</u> Blooms have not been reported to be a problem but may be a concern based on Landsat data.

<u>303(d) List Status:</u> The 2004/2006 Integrated Report does not contain any listings for Foster Reservoir and no additional listings were proposed for the 2010 Integrated Report.

Blue River Reservoir



Lane County, Willamette Basin, McKenzie Subbasin, Cascade Ecoregion

Setting and Lake Uses (Johnson et al, 1985)

Source: Oregon National Guard, 1981-82. View looking northeast.

Blue River Lake is a long, narrow, winding flood control reservoir formed in 1968 by damming the Blue River 1.8 miles above its confluence with the McKenzie River. The drainage basin is almost entirely within the Willamette National Forest. Some of the land adjacent to the lake is in private ownership and commercial timber has been harvested from much of it. The Corps of Engineers also administers a large part of the shoreline. Steep shoreline slopes restrict the amount of flat land around the lake, thereby limiting the potential for public access and recreation. The Forest Service maintains one campground and an unpaved boat ramp at the north end of the lake. Late summer use is frequently limited by reservoir draw-down. The lake is stocked annually with cutthroat trout and also has native cutthroat trout and coho salmon. In addition to fishing the lake is popular for swimming and water skiing. The intake tower was modified to improve downstream water temperatures in 2002.

Blue River Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 1,350 f t (411.5 m)

Location: 45 miles east of Eugene in Willamette National Forest

Drainage Basin Characteristics:

Area: 88 sq mi (217 sq km) **Relief:** steep **Precipitation:** 75-100 in (191-254 cm)

Land Use: Forest-97.5%; Range -0.5%; Water-1.5%; Other-0.5% (rock outcrops)

Lake Morphometry:

Area: 935 acres (378.4 hect) **Depth:** Maximum - 248 ft (75.6 m); Average - 91ft (27.7 m)

Ave/Max Depth Ratio: 0.37 **Volume:** 85,000 acre ft (104.8 cu hm)

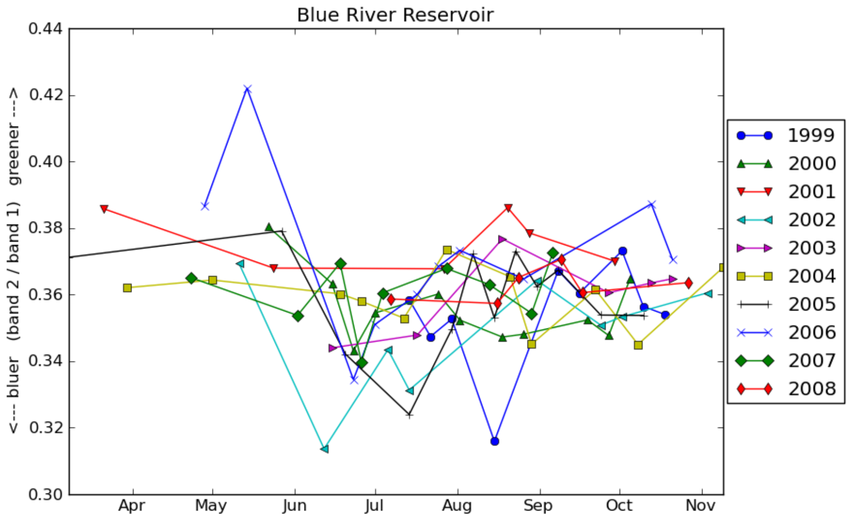
Shoal area: 6% **Volume factor:** 1.10 **Shape factor:** 4.3

Length of Shoreline: 17 mi (27.4 km) **Retention time:** 3 mo

Water Quality: ***[water quality data was not summarized due to lack of time]***

Hazardous Algal Bloom Health Advisories: A Public Health Advisory was issued by the Oregon Health Authority for Blue River Reservoir on 9/10/2010 and lifted 10/5/2010 (25 days). This advisory was based on cell counts from a bloom dominated by *Gloeotrichia echinulata* with a maximum cell count of 4,700,000. A Microcystin analysis was made on the same day as the maximum cell count and was not detected.

Remote sensing of chlorophyll *a* concentrations using Landsat data shows that Blue River Reservoir does not typically have large algal blooms although the USFS and the Corp have had reports of blooms in 2009 (personal communications). A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values measured from 1999 to 2008 were typically below 0.40 with one notable exception in 2006.

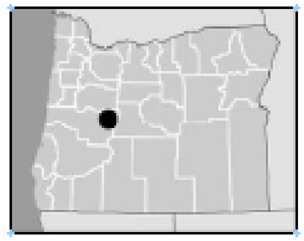


Likely or Suspected Cause of Blooms: Unknown at this time.

303(d) List Status: The 2004/2006 Integrated Report does not contain any listings for Blue River Reservoir. Blue River Reservoir has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in the 2010 Integrated Report based on the health advisories issued. TMDL related work has not been initiated.

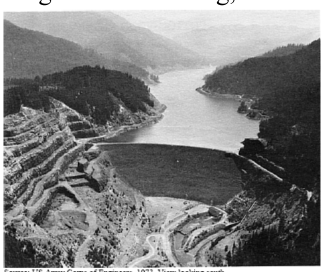
Cougar Reservoir

Lane County, Willamette Basin, McKenzie Subbasin, , Cascade Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Cougar Lake is a long, narrow multi-purpose reservoir, built by the Corps of Engineers in 1963 by damming the South Fork of the McKenzie River about three miles south of Rainbow. Operation is primarily for flood control and hydroelectric power generation. Recreational use is, of course, important and the lake is used all year, although maximum use occurs during the early summer months. Boating and fishing pressure is heavy; the lake contains coho salmon, rainbow, cutthroat and Dolly Varden trout. Overnight camping is available at three Forest Service parks around the lake. The drainage basin is entirely within the Willamette National Forest.



Source: US Army Corps of Engineers, 1973. View looking south.

Cougar Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 1,699 f t (517.9 m)

Location: 46 miles east of Eugene in Willamette National Forest

Drainage Basin Characteristics:

Area: 206 sq mi (533.5 sq km) **Relief:** steep **Precipitation:** 68-80 in (173-203 cm)

Land Use: Forest-98%; Water-2%

Lake Morphometry:

Area: 1,280 acres (518 hect) **Depth:** Maximum - 425 ft (129.5 m); Average - 171ft (52.1 m)

Ave/Max Depth Ratio: 0.400 **Volume:** 219,300 acre ft (270.9 cu hm)

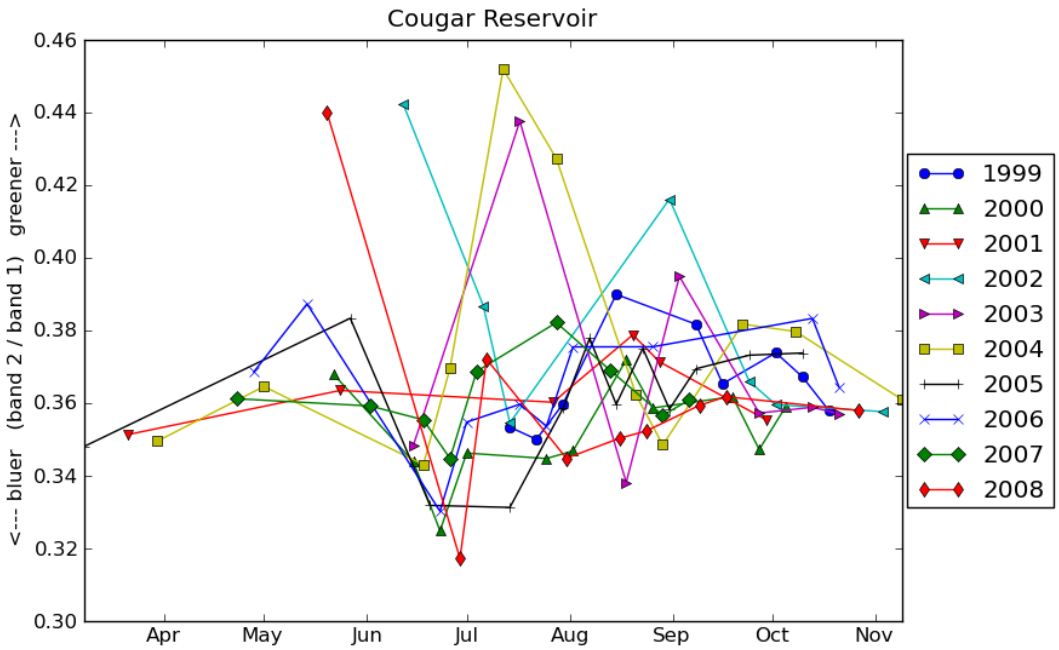
Shoal area: 3% **Volume factor:** 1.19 **Shape factor:** 3.82

Length of Shoreline: 17 mi (27.4 km) **Retention time:** 4 mo

Water Quality: ***[water quality data was not summarized due to lack of time]***

Hazardous Algal Bloom Health Advisories: No Public Health Advisories had been issued by the Oregon Health Authority for Cougar Reservoir through 2010. However, at the time that this report was being finalized, a bloom of *Anabaena flow-aquae* occurred and a recreational Health Advisory was issued on 6/14/2011 by the Oregon Health Authority (OHA). It should also be noted that OHA issued a bloom notice in 2002.

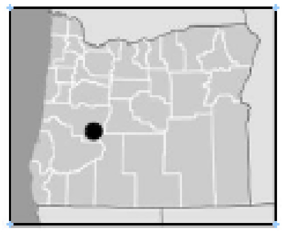
Remote sensing of chlorophyll *a* concentrations using Landsat data shows that Cougar Reservoir might have occasional blooms, most typically in May - July. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values measured from 1999 to 2008 were typically below 0.40 but single values were above this ratio in 2002, 2003and 2008 and two values above this ratio in 2004.



Likely or Suspected Cause of Blooms: Unknown at this time.

303(d) List Status: The 2004/2006 Integrated Report does not contain any listings for Cougar Reservoir and no additional listings were proposed for the 2010 Integrated Report.

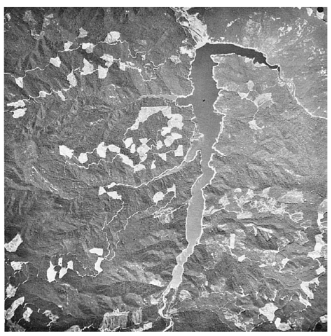
Hills Creek Reservoir



Lane County, Willamette/Sandy Basin, Middle Fork Willamette Subbasin, Cascade Ecoregion

Setting and Lake Uses (Johnson et al, 1985)

Hills Creek Reservoir is the upstream reservoir in a sequence of three (with Lookout Point and Dexter Reservoir) along the Middle Fork of the Willamette River. It was built primarily for flood control and power generation. It is a deep "coldwater" storage type reservoir, formed in 1961 with the completion of a 304-foot high, rockfill dam where Hills Creek joins the Middle Fork. The watershed is within the Willamette National Forest.



Source: US Forest Service, 1974. Vertical photograph.

Hills Creek is operated in conjunction with Lookout Point downstream to meet flow needs on the mainstem Willamette River during the summer. The lake is held at the highest possible level from May through mid-September for recreation purposes, before being lowered during the fall and winter to allow storage of potential flood waters. The Willamette National Forest operates four parks around the lake, two of which have overnight camping, and there are boat launches available. The Corps also operates a park at the base of the dam. The lake supports a reasonably good fishery, and is fished quite heavily. Before construction of the dam, the Oregon Department of Fish and Wildlife removed all the scrap fish from the area and also from the streams above. The whole system was then restocked with rainbow trout and there are also some native cutthroat trout

Hills Creek Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 1,543 ft (470.3 m)

Location: 40 miles southeast of Eugene

Drainage Basin Characteristics:

Area: 389 sq mi (1,007 sq km) **Relief:** steep **Precipitation:** 45-70 in (114-178 cm)

Land Use: Forest-98%; Water-2%;

Lake Morphometry:

Area: 2,735 acres (1,106.9 hect) **Depth:** Maximum - 299 ft (91.1 m); Average - 130ft (39.6 m)

Ave/Max Depth Ratio: 0.430 **Volume:** 356,000 acre ft (439.8 cu hm)

Shoal area: 5% **Volume factor:** 1.00 **Shape factor:** 3.88

Length of Shoreline: 32. mi (51.5 km) **Retention time:** 1.4 mo

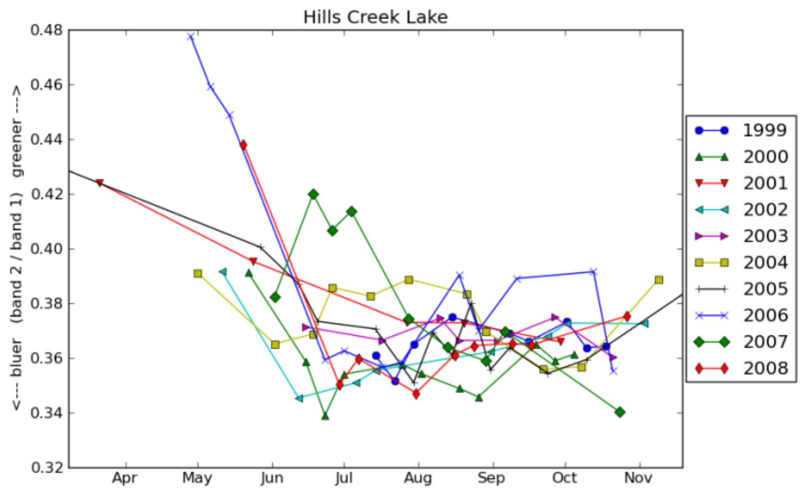
Water Quality: ***[water quality data was not summarized due to lack of time]***

Hazardous Algal Bloom Health Advisories: A number of Public Health Advisories have been issued by the Oregon Health Authority for Hills Creek Reservoir in 2005 to 2009 based on blooms dominated by *Anabaena flos-aquae* in the Spring and dominated by *Microcystis aeruginosa* (2005) and *Gloeotrichia echinulata* (2009) in the Summer. The Packard Arm appears to have the most apparent blooms.

Summary of Public Health Advisories for Recreation Use in Hills Creek Reservoir

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[33]	Maximum Toxin Measured (ug/l)
2005	6/24	7/21	27			
2005	8/19	9/26	38	*Microcystis aeruginosa*	2,477,288	
2006	6/2	6/22	20			
2007	5/11	6/6	26	*Anabaena flos-aquae*	9,681,093	
2008	5/15	7/16	62	*Anabaena flos-aquae* (28,358,059)	28,358,059	
2009	5/21	6/16	26	*Anabaena flos-aquae* (16,891,024)	16,893,355	
2009	7/30	8/31	32	*Gloeotrichia echinulata* (16,435,251)	16,435,251	

Remote sensing of chlorophyll *a* concentrations using Landsat data also shows the pattern of algal blooms typically occurring early in the season (May through June) and since 2005 in Hills Creek Reservoir. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values shown from 1999 through 2004 were generally below the ratio of 0.4. Values from 2004 through 2008 were generally above 0.4 in the Spring. The bloom that occurred later in the Summer of 2005 did not show up, however.



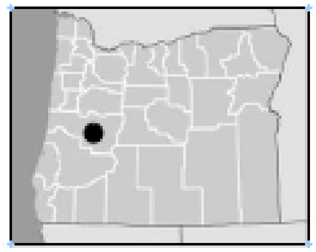
Likely or Suspected Cause of Blooms: Unknown at this time

303(d) List Status The 2004/2006 Integrated Report does not contain any listings for Hills Creek Reservoir. Hills Creek Reservoir has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in the 2010 Integrated Report based on the health advisories issued. TMDL related work has not been initiated.

[33] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Lookout Point Reservoir

Lane County, Middle Fork Willamette Subbasin, Willamette Basin, Cascade Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Lookout Point Lake is a very large reservoir which extends for more than 10 miles along the Middle Fork of the Willamette River into the Calapooya Mountains southeast of Eugene. Lookout Point Lake and Dexter Lake, a re-regulating basin immediately downstream, were both completed in 1954. About three-quarters of the basin is managed by the Willamette National Forest, with significant private holdings upstream around Oakridge and around the lower half of the lake.

Source: Oregon National Guard, 1981-82. View looking southeast.

Lookout Point receives only a moderate amount of recreational use. Use of this project is constrained by a lack of facilities, difficult access, and high degree of reservoir fluctuation. In 1996, Lane County constructed a boat launch facility at Signal Point which provides the only boat launching access throughout the year to the lake. Lookout Point has a large storage capacity and is drafted first for meeting flow requirements on the mainstem Willamette River in the summer. The lake is poor for fishing as it is heavily infested with rough fish, suckers and squawfish.

Lookout Point Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 929 ft (283.2 m)
Location: 22 miles southeast of Eugene

Drainage Basin Characteristics:

Area: 602 sq mi (1,559 sq km) **Relief:** moderate **Precipitation:** 48-70 in (122-178 cm)
Land Use: Forest-97.7%; Water-1.8%; Non Irrigated Ag-0.5

Lake Morphometry:

Area: 4,360 acres (1,764 hect) **Depth:** Maximum - 234 ft (71.3 m); Average - 104ft (31.7 m)
Ave/Max Depth Ratio: 0.450 **Volume:** 453,000 acre ft (559.6 cu hm)
Shoal area: 3% **Volume factor:** 1.24 **Shape factor:** 4.00
Length of Shoreline: 34.8 mi (56.0 km) **Retention time:** 1.9 mo

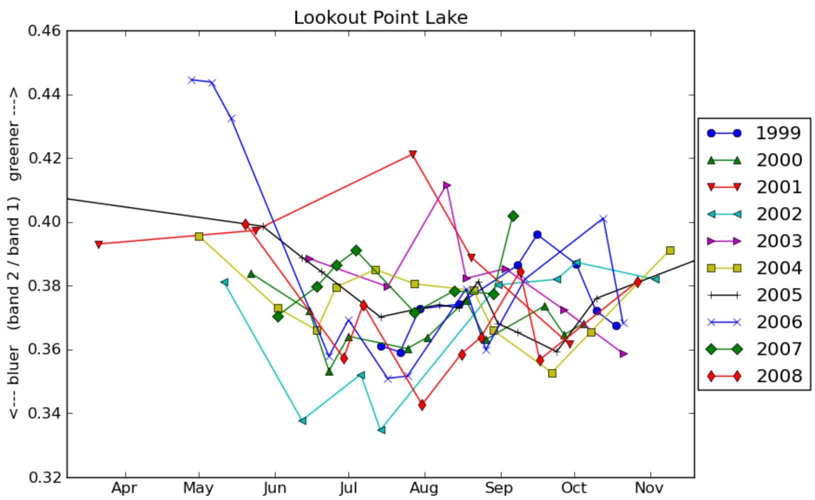
Water Quality:

Hazardous Algal Bloom Health Advisories: Public Health Advisories have been issued by the Oregon Health Authority for Lookout Point Reservoir in 2005 based on a bloom dominated by *Gloeotrichia echinulata* in the Summer and a Fall bloom.

Summary of Public Health Advisories for Recreation Use in Lookout Point Reservoir

Year	Start Date	End Date	Duration	Dominant Species	High Cell Count[34]	Maximum Toxin Measured (ug/l)
2005	7/13	8/22	40	*Gloeotrichia*		
2005	9/14	9/26	12			

Remote sensing of chlorophyll *a* concentrations using Landsat data shows Lookout Point Reservoir may have blooms in other years as well. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values were above 0.4 om 2003, 2005, 2006 and 2007.



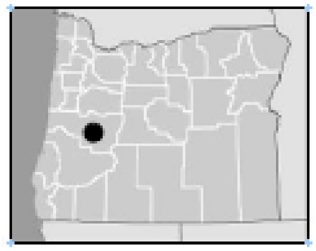
Likely or Suspected Cause of Blooms: Unknown at this time

303(d) List Status: 2004/2006 Integrated Report identifies Lookout Point Reservoir as being of concern but needing supporting data (Category 3 – insufficient data) for nutrients. Lookout Point Reservoir has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in the 2010 Integrated Report based on the health advisories issued. TMDL related work has not been initiated.

[34] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

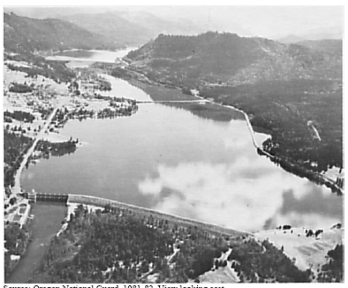
Dexter Reservoir

Lane County, Willamette Basin, Middle Fork Willamette Subbasin, Cascade Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Dexter Lake is a relatively small, shallow reservoir which functions as a reregulating basin for Lookout Point Lake immediately upstream. Dexter and Lookout Point Lakes were completed in 1954 with the construction of dams on the Middle Fork of the Willamette River. A small amount of hydroelectric power is also generated from a powerhouse at Dexter Dam with one generating unit.



Source: Oregon National Guard, 1981-82. View looking east.

Dexter Lake is very popular for boating because it only fluctuates up to 5 feet daily and has no large seasonal drawdown. Lane County parks on both the north and south shores provide full day-use facilities. Angling is also a popular activity and the lake is open for fishing all year, although there have been problems with infestation by rough fish in recent years.

About three-quarters of the drainage basin is managed by the Willamette National Forest. There are significant amounts of private holdings upstream around the town of Oakridge and adjacent to the lower half of Lookout Point Lake and around Dexter Lake.

Dexter Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir
Use: multi-purpose, reregulating dam
Elevation: 695 ft (211.8 m)
Location: 20 miles southeast of Eugene

Drainage Basin Characteristics:

Area: 5.0 sq mi (13.0 sq km)
Relief: moderate
Precipitation: 48-70 in (122-178 cm)
Land Use: Forest-96.3%; Water-2.4%; Irrig Ag-1.2%; Urban-0.1%

Lake Morphometry:

Area: 1,025 acres (414.8 hect)
Depth: Maximum - 56 ft (17.1 m); Average - 27ft (8.2 m)
Ave/Max Depth Ratio: 0.480
Volume: 27,500 acre ft (33.97 cu hm)
Shoal area: 21%
Volume factor: 1.27
Shape factor: 1.78
Length of Shoreline: 7 mi (11.3 km)
Retention time: <1 mo.

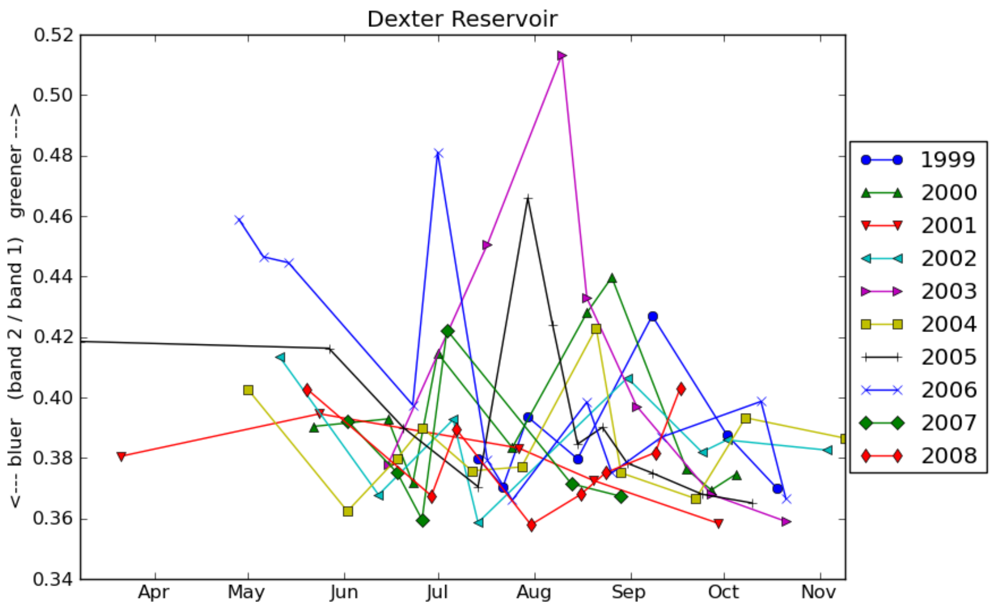
Water Quality: ***[water quality data was not summarized due to lack of time]***

Hazardous Algal Bloom Health Advisories: Public Health Advisories have been issued by the Oregon Health Authority for Dexter Reservoir in 2008, 2009 and 2010 based on blooms dominated by *Anabaena flos-aquae* and *Anabaena circinalis* typically in the late summer/early fall.

Summary of Public Health Advisories for Recreation Use in Dexter Reservoir

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb Cell Count[35]	Maximum Toxin Measured (ug/l)
2008	9/18	10/22	34	*Anabaena flos-aquae* (86,642) *Anabaena circinalis* (47,364)	134,006	
2009	8/13	9/28	46	*Anabaena flos-aquae* (957,876) *Anabaena circinalis* (7,982)	965,858	
2010	8/11	9/20	40	*Anabaena flos-aquae* (4,092,407) *Anabaena circinalis* (153,117) *Aphanizomenon flos-aqua* (5,259)	4,245,524	Microcystin – ND Anatoxin - ND

Remote sensing of chlorophyll *a* concentrations using Landsat data shows that the pattern of algal blooms may occur most years and happen most typically in the summer or early fall. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values were found to exceed 0.4 in all ten years shown.

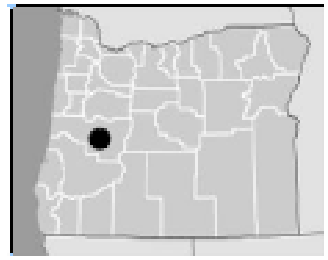


Likely or Suspected Cause of Blooms: Unknown at this time

303(d) List Status: 2004/2006 Integrated Report identifies Dexter Reservoir as being of concern but needing supporting data (Category 3 – insufficient data) for nutrients. Dexter Reservoir has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in the 2010 Integrated Report based on the health advisories issued. TMDL related work has not been initiated.

[35] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

Fall Creek Reservoir



Lane County, Willamette Basin, Middle Fork Willamette Subbasin, Cascade Ecoregion

Setting and Lake Uses (Johnson et al, 1985)

Source: US Army Corps of Engineers, 1975. View looking east.

Fall Creek Lake is located on a small tributary of the Middle Fork Willamette River in the rolling hill country southeast of Eugene. It became operational in 1966 and exists primarily to control downstream flooding on the Willamette River. The impoundment is shaped by two main arms, the southern arm fed by Winberry Creek and the northern arm by Fall Creek. The upper watershed is forested and is managed by the Willamette Nation Forest. In the lower portion of the watershed is in private ownership.

Fall Creek Lake has a moderate level of recreation facilities with two public day-use areas operated by Lane County and a campground operated by the Corps. The lake is heavily used for recreation, especially boating, fishing, swimming, and water-skiing. Fall Creek has high capability for future expansion of camping and other recreation facilities. The lake has a low drawdown priority for augmenting stream flows on the mainstem Willamette River in the summer, reflecting its relatively high priority for recreation. Fishing at Fall Creek Lake is primarily for stocked rainbow and native cutthroat trout that drift down from the tributaries. The Oregon Department of Fish and Wildlife uses Fall Creek reservoir as a rearing facility for spring chinook salmon. The project is operated to flush fingerlings from the reservoir in late fall.

Fall Creek Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir
Use: multi-purpose, reregulating dam
Elevation: 834 ft (254.2 m)
Location: 22 miles southeast of Eugene

Drainage Basin Characteristics:

Area: 184 sq mi (455 sq km)
Relief: moderate
Precipitation: 48-66 in (122-168 cm)
Land Use: Forest-93.8%; Water-1.6%; Irrig Ag-2.8%

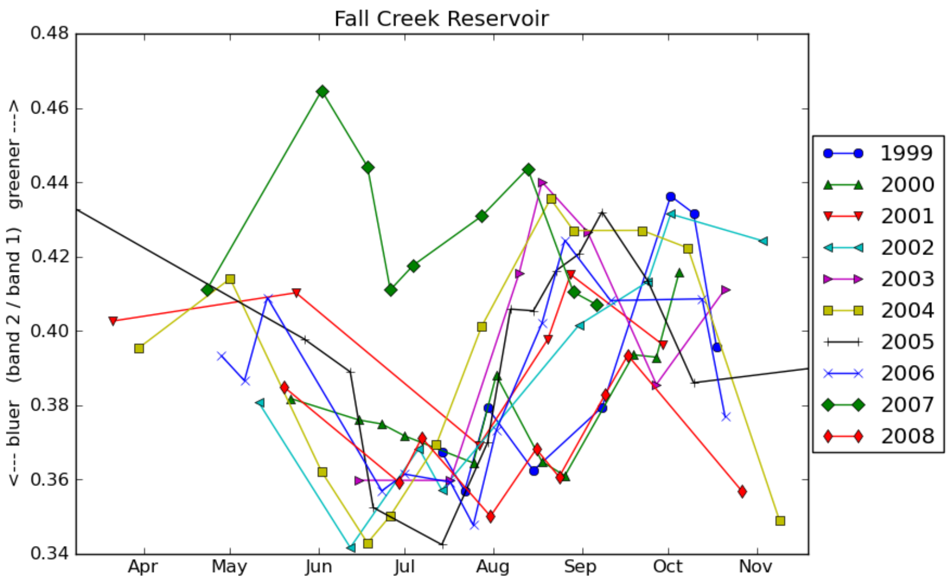
Lake Morphometry:

Area: 1,860 acres (752.7 hect)
Depth: Maximum - 161 ft (17.1 m); Average - 67ft (20.5 m)
Ave/Max Depth Ratio: 0.420
Volume: 125,000 acre ft (154.1 cu hm)
Shoal area: 10%
Volume factor: 1.16
Shape factor: 3.7
Length of Shoreline: 22.4 mi (36 km)
Retention time: 3.5 mo.

Water Quality: ***[water quality data was not summarized due to lack of time]***

Hazardous Algal Bloom Health Advisories: No Public Health Advisories have been issued by the Oregon Health Authority for Fall Creek Reservoir.

Remote sensing of chlorophyll *a* concentrations using Landsat data shows that Fall Creek Reservoir might consistently have blooms, most typically from August - October. A band 2/band 1 ratio (the ration of the visible green band to the visible blue band) of 0.4 is approximately equivalent to a chlorophyll *a* of 15 ug/l, which equates to a visible bloom based on regression estimates (Turner, 2010). Values measured from 1999 to 2008 were typically above 0.40 sometime between August and October with the exception of 2008. All 2007 values exceeded 0.4.

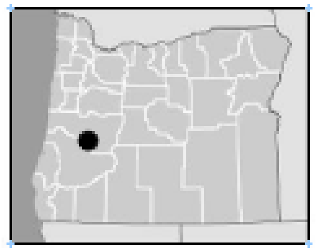


Likely or Suspected Cause of Blooms: Unknown at this time

303(d) List Status: The 2004/2006 Integrated Report does not contain any listings for Fall Creek Reservoir and no additional listings were proposed for the 2010 Integrated Report.

Dorena Reservoir

Lane County, Willamette Basin, Coast Fork Subbasin, Cascade Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Dorena Reservoir was formed by impounding the waters of the Row River about seven miles upstream of its confluence with the Coast Fork of the Willamette River. It was one of the first of the Willamette Reservoirs be operated, having been constructed in 1949. The primary function of Dorena Reservoir, as with nearby Cottage Grove Reservoir, is flood control.

Dorena Lake is located only about 20 miles from the center of Eugene and is thus extremely popular for recreation. Boaters and swimmers use the lake extensively and angling is considered to be very good. Large numbers of rainbow trout are planted annually; other species include bluegill, largemouth bass, cutthroat trout and catfish. Lane County operates two parks with boat ramps at the lake and camping is available on the southwest shore. The shoreline of the lake is under management of the Corps of Engineers. Private land encompasses most of the lower half of the drainage basin, while the Umpqua National Forest administers most of the upper half.

Dorena Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 835 ft (254.5 m)
Location: 5.5 miles east of Cottage Grove

Drainage Basin Characteristics:

Area: 265 sq mi (686 sq km) **Relief:** moderate **Precipitation:** 50-80 in (127-203 cm)
Land Use: Forest-97%; Water-1%; Non Irrig Ag-2%

Lake Morphometry:

Area: 1,840 acres (744 hect) **Depth:** Maximum - 97 ft (29.6 m); Average - 42ft (12.9 m)
Ave/Max Depth Ratio: 0.440 **Volume:** 77,600 acre ft (95.9 cu hm)
Shoal area: 15% **Volume factor:** 1.37 **Shape factor:** 1.80
Length of Shoreline: 13 mi (20.9 km) **Retention time:** 1.7 mo

Water Quality: ***[water quality data was not summarized due to lack of time]***

Hazardous Algal Bloom Health Advisories: Public Health Advisories have been issued by the Oregon Health Authority for Dorena Reservoir in 2008, 2009 and 2010 based on blooms dominated by *Anabaena flos-aquae* in the mid-summer/early fall.

Summary of Public Health Advisories for Recreation Use in Dorena Reservoir

Year	Start Date	End Date	Duration	Dominant Cyanobacteria Species and Maximum Cell Count	Max Comb. Cell Count[36]	Maximum Toxin Measured (ug/l)
2008	8/22	9/24	33	*Anabaena flos-aquae* (453,325)	453,325	
2009	8/13	10/23	71	*Anabaena flos-aquae* (3,507,778) *Anabaena planctonica* (161)	3,507,778	
2010	9/10	10/4	24	*Anabaena flos-aquae* (3,855,772)	3,855,772	

Remote sensing of chlorophyll *a* concentrations using Landsat data was not done for Dorena Reservoir.

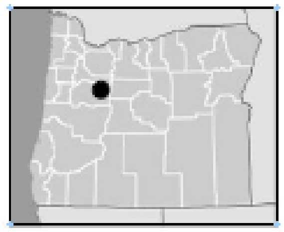
Likely or Suspected Cause of Blooms: Unknown at this time

303(d) List Status: The 2004/2006 Integrated Report does not contain any listings for Dorena Reservoir. Dorena Reservoir has been proposed for listing as water quality limited (Category 5 – Section 303(d) list – a TMDL is needed) for Aquatic Weeds and Algae in the 2010 Integrated Report based on the health advisories issued. TMDL related work has not been initiated.

[36] DHS currently issues a Public Health Advisory for recreational uses when the combined cell count of all toxigenic species > 100,000 cells/ml or Microcystin > 8 ug/l or anatoxin-a is detected

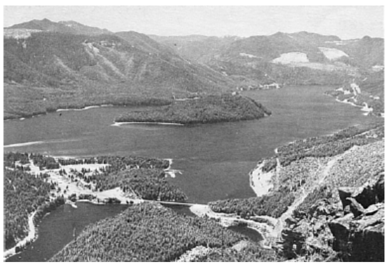
Cottage Grove Reservoir

Lane County, Willamette Basin, Coast Fork Subbasin, Cascade Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Cottage Grove Lake is on the Coast Fork of the Willamette River. The primary function of Cottage Grove Lake, in concert with nearby Dorena Lake, is to control flooding on the Coast Fork as well as to help reduce floodstages farther downstream on the mainstem of the Willamette.



Although the shoreline of the lake is managed by the Corps of Engineers, about half of the forested drainage basin is private land and the rest is federal land managed by the Bureau of Land Management. Cottage Grove Lake is very popular for all water-based recreation activities, especially boating. Trout are stocked by the state each year and the lake is also managed for warmwater game fish, primarily largemouth bass and black crappie. The Corps of Engineers has provided five recreational sites for camping, picnicking and boat launching.

Cottage Grove Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 790 ft (240.8 m)

Location: 6 miles south of Cottage Grove

Drainage Basin Characteristics:

Area: 104 sq mi (257 sq km) **Relief:** moderate **Precipitation:** 48-62 in (122-157 cm)

Land Use: Forest-96.5%; Range -1%, Water-2%; Other-0.5% (rock outcrops)

Lake Morphometry:

Area: 1,139 acres (461 hect) **Depth:** Maximum - 73 ft (22.3 m); Average - 29ft (9 m)

Ave/Max Depth Ratio: 0.40 **Volume:** 33,500 acre ft (41.3 cu hm)

Shoal area: 17% **Volume factor:** 1.2 **Shape factor:** 2.1

Length of Shoreline: 7.6 mi (12.2 km) **Retention time:** 2 mo

Water Quality: ***[water quality data was not summarized due to lack of time]***

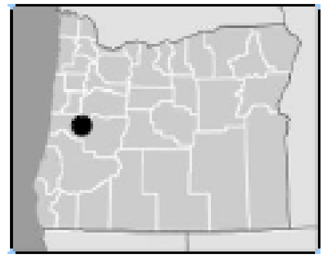
Hazardous Algal Bloom Health Advisories: No Public Health Advisories have been issued by the Oregon Health Authority for Cottage Grove Reservoir. Remote sensing of chlorophyll *a* concentrations using Landsat data was not done for Cottage Grove Reservoir.

Likely or Suspected Cause of Blooms: Unknown at this time

303(d) List Status: The 2004/2006 Integrated Report does not contain any algal or nutrient related listings for Cottage Grove Reservoir and no additional listings were proposed for the 2010 Integrated Report.

Fern Ridge Reservoir

Lane County, Willamette Basin, Upper Willamette Subbasin, Cascade Ecoregion



Setting and Lake Uses (Johnson et al, 1985)

Fern Ridge Lake is a large reservoir near Eugene, built by the Corps of Engineers in 1941 by the damming of the Long Tom River. It is operated primarily for recreation in the summer and flood control in the winter, and is also part of a major wildlife management area. Fern Ridge is physically much different than other Corps of Engineers reservoirs in the Willamette Valley. Originally, it was a flat swampy portion of the valley floor, and one long, low dam and supplementary dikes were required to contain the water.

Source: Oregon National Guard, 1981-82. View looking south.

Fern Ridge Lake is among the most heavily used recreation sites in Oregon and provides for a variety of uses, including swimming, picnicking, all forms of boating, fishing, and assorted other activities. For most activities, users come from the local area in the southern end of the Willamette Valley, although the good, steady winds attract many sailors from farther away. Annual park usage is 1 to 1.5 million recreational user-days. Three public parks (two by the Corps, one by Lane County) have been developed for high density use, while two other public parks (one Corps, one county) are less developed. The fishery does not attract many anglers since non-game fish predominate. However, there are crappie, bluegill, largemouth bass and trout in small numbers.

Fern Ridge Reservoir Characteristics (from Johnson et al, 1985):

Setting:

Type: reservoir **Use:** multi-purpose **Elevation:** 374 f t (114 m)

Location: 12 miles west of downtown Eugene

Drainage Basin Characteristics:

Area: 275 sq mi (712 sq km) **Relief:** moderate **Precipitation:** 40-55 in (102-140 cm)

Land Use: Forest-57.7%; Range-8%; Water-5.3%; Non Irrigated Ag-23.7%; Urban-5.3%

Lake Morphometry:

Area: 9,360 acres (3,788 hect) **Depth:** Maximum - 33 ft (10.1 m); Average - 11ft (3.2 m)

Ave/Max Depth Ratio: 0.33 **Volume:** 101,200 acre ft (125 cu hm)

Shoal area: 52% **Volume factor:** 1.00 **Shape factor:** 2.64

Length of Shoreline: 30.1 mi (48.4 km) **Retention time:** 3 mo

Water Quality: Lane Council of Governments investigated the water quality and pollution sources in Fern Ridge Lake from March 1981 to September 1982 under a study funded by the Clean Lakes Program (LCOG 1983). Until this EPA-funded study was done, there had been only limited testing of water quality in the lake, even though it had a history of turbidity problems. In addition, bacteria problems and problems from excessive plant and algal growth were suspected. The study was intended to identify water quality problems and identify measures to restore or improve water quality.

Inflowing tributaries bring high concentrations of nitrogen (Long Tom River and Amazon Channel), phosphorus (Amazon Channel and Coyote Creek), bacteria and organic material (Coyote Creek and Amazon Channel), contaminants from chemical spills (Amazon Channel), and high levels of turbidity

(Long Tom River and Coyote Creek), especially during winter storms. Bacteria counts in the reservoir were found to be low during the summer, giving no indication of a threat to human health. Similarly, most of the nutrients appear to be taken up by rooted wetland plants; thus algal growth is limited by nutrients and reduced transparency due to high turbidity. However, algal species present indicated an enriched lake system.

A final report of the LCOG study states that the lake quality should be improved to protect water contact recreation and warm water fisheries and to achieve water clarity for public safety and aesthetic acceptability during the June through September period. The report evaluates and recommends a series of restoration techniques including beach improvement, rocking banks, restricting water circulation, agriculture best management practices, and reentrainment through the construction of dikes and establishing vegetation on clay deposits. Restoration has been discussed with the U.S. Army Corps of Engineers since they are one of the entities responsible for the lake. (Johnson et al, 1985)

TMDLs were developed in 2006 for Fern Ridge Reservoir to address e. coli and turbidity problems[37].

Hazardous Algal Bloom Health Advisories: No Public Health Advisories have been issued by the Oregon Health Authority for Fern Ridge Reservoir.

Remote sensing of chlorophyll *a* concentrations using Landsat data was not done for Fern Ridge Reservoir.

Likely or Suspected Cause of Blooms: Unknown at this time

303(d) List Status: 2004/2006 Integrated Report identifies Fern Ridge Reservoir as being of concern but needing supporting data (Category 3 – insufficient data) for algae and nutrients. No additional listings are proposed in the 2010 Integrated Report.

References

Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Newhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. OSU Press, 319 pp

Oregon Department of Environmental Quality. 2006. Chapter 10: Upper Willamette Subbasin TMDL. **http://www.deq.state.or.us/WQ/TMDLs/docs/willamettebasin/willamette/chpt10upperwill.pdf**

Oregon Health Authority - Public Health Advisories: http://public.health.oregon.gov/HealthyEnvironments/Recreation/HarmfulAlgaeBlooms/Pages/Blue-GreenAlgaeAdvisories.aspx

Turner, Dan. June 2010. Remote sensing of chlorophyll *a* Concentrations to Support the Deschutes Basin Lake and Reservoir TMDLs. Oregon Department of Environmental Quality.

[37] http://www.deq.state.or.us/WQ/TMDLs/docs/willamettebasin/willamette/chpt10upperwill.pdf