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GENERAL ADMINISTRATION
DIVISION OF FACILITIES

February 23, 2009

Nathaniel Jones
Department of General Administration, Division of Facilities
P.O. Box 41011
Olympia, Washington 98504-1011

Subject: Potential Water Quality Conditions Associated with a Dredged Lake Alternative

Dear Nathaniel—

As part of the Budd Inlet, Capitol Lake, and Deschutes River Total Maximum Daily Load (TMDL) Study, Ecology developed a series of modeling tools to help the community understand potential effects of various management actions. In anticipation of the upcoming recommendation between the current Capitol Lake and a potential future Deschutes Estuary, Ecology simulated water quality under a simple estuary alternative (Roberts et al., 2008). However, the Capitol Lake Adaptive Management Plan (CLAMP) steering committee and General Administration have expressed interest in understanding how the dredged lake alternative would affect water quality within Capitol Lake itself as well as influences on Budd Inlet.

In your December 8, 2008 letter, you requested that Ecology address three questions related to a dredged lake alternative:

1. *If Capitol Lake were to be managed as a lake with routine dredging of a nominally uniform thirteen feet, how would this affect the five TMDL water quality factors*[1] *for the lake and for Budd Inlet?*
2. *If the upland shading improvements proposed in the water quality study findings were implemented, how would this affect the five TMDL water quality factors for the lake and for Budd Inlet?*
3. *And finally, what would be the effect of implementing both the shading improvements and the lake dredging on the lake and on Budd Inlet relative to the five TMDL water quality factors?*

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[1] Dissolved oxygen, temperature, pH, fecal coliform bacteria, and fine sediment

Roberts et al. (2008) recommends actions that would address water quality impairments upstream of Capitol Lake within the Deschutes River watershed, including riparian vegetation restoration that would improve shade. Originally we had hoped to use the water quality models to address your three questions directly. Given time and resource limitations, Ecology agreed to address these questions in this letter based on best professional judgment. We have quantified as much as possible given the information available.

Following your letter, we requested the geometry of the current lake and dredged lake alternative. You provided us with the current surface area, volumes, and average depths by basin in your February 4, 2009 email, but the volumes for the dredged lake alternative are not available beyond the "nominal 13 feet water depth." Therefore, we have estimated these values in the calculations presented below.

Description of Dredged Lake Alternative

A potential future lake alternative would rely on routine dredging to maintain the lake at a nominal 13 ft (4.0 m) water depth below the summer setpoint elevation (6.22 ft NGVD29 or 14.31 ft MLLW, as clarified in your January 28, 2009 email). Portions of the north basin are somewhat deeper and would not change. A 100-ft buffer near the shoreline would remain undisturbed. Following dredging, the sediments are expected to achieve a natural angle of repose.

In the February 4 email, you provided the values in Table 1. The overall average lake depth determined from total lake volume and surface area is 10.4 ft. We estimated dredged lake volumes by assuming the nominal 13 ft water depth was equivalent to the average depth presented in Table 1 for the entire lake. This results in no change to the north basin value because the current mean depth is given as 13 ft. The assumption likely underestimates the north basin volume under a dredged lake. The assumption likely overestimates the volume of the middle, south, and Percival basins because it applies the mean depth to the entire surface area of all three basins. Only nominal changes to bathymetry in the south basin and Percival are planned, and a 100-foot buffer (approximately 15% of the total surface area) would remain unchanged. The resulting dredged lake estimates represent the best available values.

Existing and Potential Dredged Lake Conditions

The existing lake suffers from poor water quality, and several parameters do not meet the State water quality standards. Portions of the Deschutes River, its tributaries, and Percival Creek also do not meet water quality standards.

Based on modeling conducted under the TMDL, the current level of nonpoint sources in the Deschutes River and Percival Creek watersheds contribute to >0.2 mg/L changes to dissolved oxygen within the lake. Factors likely contributing to degraded water quality include low circulation, shallow water depths, warm temperatures, high phosphorus from the sediments and watershed, high macrophyte biomass, and algae blooms. Natural sources contribute high watershed sediment loads. Large watershed and sediment phosphorus fluxes enhance both phytoplankton and macrophyte growth within the lake.

Table 2 summarizes geometry for both the current lake and the dredged lake based on the assumptions described above. Only the Deschutes River inflows are included because long-term gaging data for Percival Creek are not available and would not change the overall findings described below. Both annual mean and summer low flow values are provided for context, and the sources of information are described in the final column. Residence time is calculated for both the annual average discharge and the summer low flow discharge.

Phosphorus loading rates and other derived coefficients are presented based on the current TMDL study as well as previous efforts. Data collected September 28, 2004 provide an indication of late summer conditions on one particular date. The date itself is not meaningful, only that it provides summer context to compare with annual average values. The summer river loads normalized by the lake surface area are equivalent to 1.9 $g/m^2/yr$ of phosphorus.

Annual phosphorus loads were developed in a previous study that included the Deschutes River. Albertson et al. (2002) and Roberts and Pelletier (2001) describe the statistical method used to estimate annual loading rates from monthly monitoring data and flow gaging. The annual areal loading rate developed for 1996-97 (wetter-than-average conditions) was equivalent to 25.9 $g/m^2/yr$. The value is much higher than summer loads because the flows are much higher in the winter months and most of the sediment transport occurs in the winter; phosphorus tends to associate with sediment particles.

Areal loading rates provide an indication of the trophic state of lakes. Generally, the higher the loading rate, the more eutrophic the system. Vollenweider (1968) summarized depth and loading rate information for a large number of lakes into a graphic of trophic state to produce a planning-level tool for lake managers. Vollenweider (1975) revised the earlier graphic to account for differences in residence times of lakes.

Figures 1 and 2 plot values for the annual and summer loading rates against the depth or depth normalized by residence time. For both the current and dredged lake alternatives, the combination of phosphorus loading and lake geometry plots well into the eutrophic zone of both figures. Figure 1 shows he proposed increase in water depth associated with dredging produces only a small shift to the right. The dredged lake alternative would still fall well into the eutrophic range, either for the annual loading or for only the summer loading rate. Because the depth increase would produce an offset in residence time, the only shift occurs due to rounding values in the calculations.

Without reductions in the areal phosphorus loading rate, the lake depth would need to be >100 m to fall into the mesotrophic range in Figure 1. With the proposed nominal depth of 14 ft (4.0 m), the annual areal loading rate would need to be reduced one to three orders of magnitude to achieve the mesotrophic range.

Vollenweider's areal loading analyses were based on loads from the watershed. However, total phosphorus fluxes from the sediments also are significant. Sediment fluxes vary over time, but the highest fluxes often coincide with warm temperatures and high pH values within the lake. The mean nutrient flux used in the Capitol Lake model is 1.6 $g/m^2/yr$, which is well into the eutrophic range of Figure 1 for all but the deepest lakes. If residence time is considered, sediment fluxes alone (1.6 $g/m^2/yr$ and 334 m/yr) would plot in the middle of the mesotrophic range in Figure 2. The combined sediment and watershed nutrient fluxes plot in the eutrophic range of Figure 2.

Even if the watershed sources decrease substantially, sediment fluxes are likely to continue contributing significant phosphorus loads. No information currently available suggests that the underlying sediments that may be revealed by dredging would increase or decrease the sediment fluxes. Algae blooms that raise the pH of Capitol Lake could produce maximum sediment fluxes that are at least six times higher than the mean value used in modeling.

Capitol Lake is eutrophic based on the Vollenweider graphics. Ongoing monitoring by Thurston County (Davis, 2008) indicates that the north basin is eutrophic (Carlson Trophic State Index using chlorophyll and phosphorus). The middle basin is eutrophic to mesotrophic. Because the depth changes are relatively small relative to current conditions under the dredged lake alternative (22% increase), we do not expect significant changes in water quality and related parameters.

Responses to Three Questions and Links Between Potential Watershed Improvements and Future Lake Water Quality

Question 1 - If Capitol Lake were to be managed as a lake with routine dredging of a nominally uniform thirteen feet, how would this affect the five TMDL water quality factors[2] for the lake and for Budd Inlet?

We anticipate little change to dissolved oxygen, temperature, or pH within the lake or within Budd Inlet. The previous documents the background. Deepening the lake also would not significantly affect fecal coliform bacteria because it does not address bacteria sources. Dredging the lake would limit the accumulation of sediments in the lake but would not address the sources of sediment in the watershed.

Question 2 - If the upland shading improvements proposed in the water quality study findings were implemented, how would this affect the five TMDL water quality factors for the lake and for Budd Inlet?

Upland shading should reduce peak water temperatures within the Deschutes River itself, with secondary benefits within the Deschutes River due to oxygen saturation effects[3]. Studies elsewhere also suggest that establishing healthy riparian forests and stream channels mitigates nutrient delivery to streams and rivers (National Research Council, 2002).

Decreased temperatures could translate to benefits in the south basin and parts of the middle basin. Because the ratio of surface area to volume is high, solar radiation (heat load) and temperature (heat concentration) likely equilibrate within the lake. So that temperatures in the north and middle basins are more sensitive to the incoming solar radiation than to water temperatures in the Deschutes River. Decreased river temperatures would not translate through the middle basin to the highly productive north basin. In addition, the height of the falls likely equilibrates water temperature to air temperature and also produces dissolved oxygen levels close to saturation. Additional model runs could quantify any benefits, but watershed actions are not likely to resolve water quality issues within Capitol Lake or Budd Inlet. They could mitigate the effects in portions of the south and middle basins. Additional modeling could quantify the magnitude and area influenced by these changes.

Question 3 - What would be the effect of implementing both the shading improvements and the lake dredging on the lake and on Budd Inlet relative to the five TMDL water quality factors?

Combining upland improvements and deepening the lake also would not resolve water quality issues within Capitol Lake. Both activities theoretically improved conditions, and we do not foresee these activities causing further harm. Because Capitol Lake currently and under the dredged lake alternative falls well within the eutrophic range, based on available indices, these improvements are unlikely to translate into measurable or significant lake improvements. No changes to Budd Inlet are expected

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[2] Dissolved oxygen, temperature, pH, fecal coliform bacteria, and fine sediment

[3] Cooler water temperatures hold more oxygen than warmer temperatures, so the same percent saturation translates to higher oxygen concentrations.

either. Additional modeling could quantify the improvements but are unlikely to change the overall finding of continued poor water quality based on best professional judgment.

Future Collaboration

This letter includes our best professional judgment of the potential changes associated with the proposed dredged lake alternative. Given the large areal phosphorus loading and continued relatively shallow depths in Capitol Lake, we do not believe that the proposed dredged lake alternative would result in measurable improvements in water quality. We have mentioned potential model runs that could address several questions quantitatively. We should continue to discuss in the coming months.

As always, please let me know if you have any questions.

Sincerely,

Mindy Roberts

Mindy Roberts, Ph.D., P.E.

Cc: Sally Toteff, Southwest Regional Office Director
Lydia Wagner, TMDL Lead, Southwest Regional Office, Water Quality Program

Tables and Figures

Table 1. Capitol Lake geometry by basin (provided by Nathaniel Jones via email, February 4, 2009).

Basin Name	Surface Area (Acres)	Volume (Cubic Feet)	Volume (Cubic Yards)	Volume (Acre Feet)	Approximate Average Depth (Acre Feet / Acres)
North	97	56,774,100	2,102,744	1,303	13.4
Percival	18	6,539,864	242,217	150	8.2
Middle	121	48,642,826	1,801,586	1,117	9.2
South	25	6,587,641	243,987	151	6.1
All Basins	261	118,637,065	4,393,965	2,724	10.4

Note: Calculations made based upon the bathymetric DEM assembled by USGS from a variety of sources. Sources are know to have errors where accurate soundings were unable to be captured due to aquatic vegitation, or shallow depths. Calculations should be treated as approximations rather than precise measurements. All calculations made utilizing the Area and Volume Statistics tool available through the 3D analyst extension of ArcMap 9.3.

Table 2. Current lake and dredged lake parameters.

Parameter		Current	Dredged Lake	Relative Change (%)	Source
Geometry					
A	Surface area (ac)	261	261	0%	GA
A	Surface area (ft^2)	11,369,160	11,369,160	0%	calculation
A	Surface area (m^2)	1,056,230	1,056,230	0%	calculation
V	Volume (ft^3)	118,637,000	147,799,080	22%	GA
V	Volume (m^3)	3,359,426	4,185,204	22%	calculation
d	Mean depth (ft)	10.4	13.0	22%	GA, ECY assumption
d	Mean depth (m)	3.2	4.0	22%	calculation
River Inflows					
$Q_{mean,1991-2007}$	Deschutes (1991-2007 annual mean, cfs)	396	396	0%	USGS data, ECY calculation
$Q_{mean,1991-2007}$	Deschutes (1991-2007 annual mean, cms)	11.2	11.2	0%	USGS data, ECY calculation
$30Q10_{1991-2001}$	Deschutes (1991-2001 30Q10, cfs)	59.8	59.8	0%	USGS calc
$Q_{Sept,1945-2007}$	Deschutes September mean (1945-2007, cfs)	97	97	0%	USGS data, ECY calculation
	Deschutes late-summer flow (9/28/04, cfs)	113	113	0%	USGS data
	Deschutes late-summer total phosphorus (9/28/04, mg/L)	0.0202	0.0202	0%	ECY data
Residence Time					
$T_{res,annual}$	Mean Annual (Vol/Qmean, days)	3.5	4.3	22%	calculation
$T_{res,summer}$	Summer Critical (Vol/30Q10, days)	23.0	28.6	22%	calculation
$T_{res,summer}$	Late summer Critical (Vol/$Q_{09/28/04}$, days)	12.2	15.1	22%	calculation
Phosphorus Loading Rates					
	Annual TP Deschutes* (1996-97, kg/d)	75	75	0%	calculation
	Annual Areal Loading Rate, river only (g/m^2/yr)	25.9	25.9	0%	calculation
	TP Deschutes 9/28/04 (kg/d)	5.6	5.6	0%	calculation
	9/28/04 Areas Loading Rate, river only (g/m^2/yr)	1.9	1.9	0%	calculation
	Model TP sediment flux** (kg/d)	4.7	4.7	0%	calculation
	Model TP sediment flux** (g/m^2/yr)	1.6	1.6	0%	calculation
	Max TP sediment flux *** (kg/d)	30.6	30.6	0%	calculation
	Max TP sediment flux *** (g/m^2/yr)	10.6	10.6	0%	calculation
Vollenweider Coefficient					
$d/Q_{mean,1991-2007}$	Depth/Mean annual residence time (m/yr)	334	340	0%	calculation

Notes

* Includes Percival Creek watershed

** Used for Capitol Lake model

*** Based on highest rate measured in late summer 2004

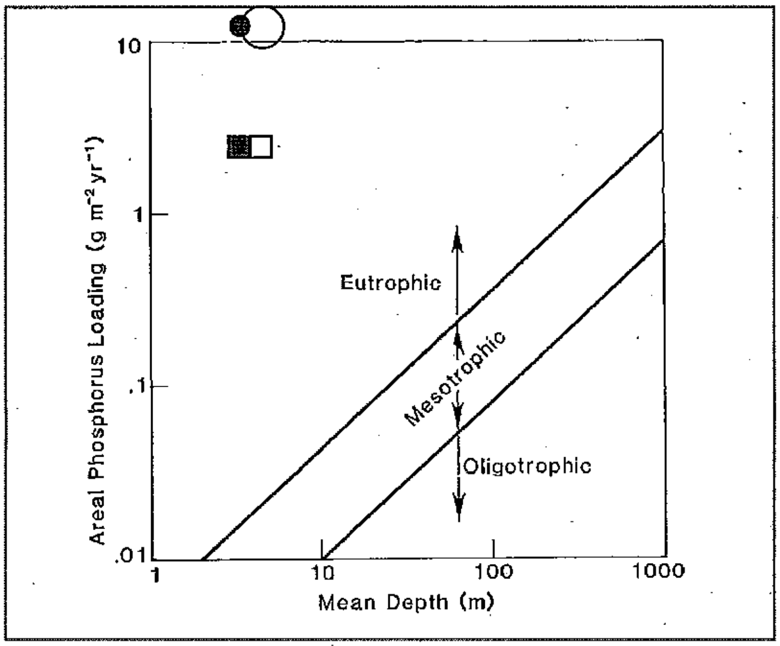

Figure 1. Vollenweider's (1968) phosphorus loading plot showing areal loading vs. mean depth, with the expected trophic state. The circles represent annual values for the current conditions (solid circle) and the dredged lake alternative (open circle). The squares represent the summer current (solid square) and dredged lake (open square) conditions. Source: Reckhow and Chapra (1983).

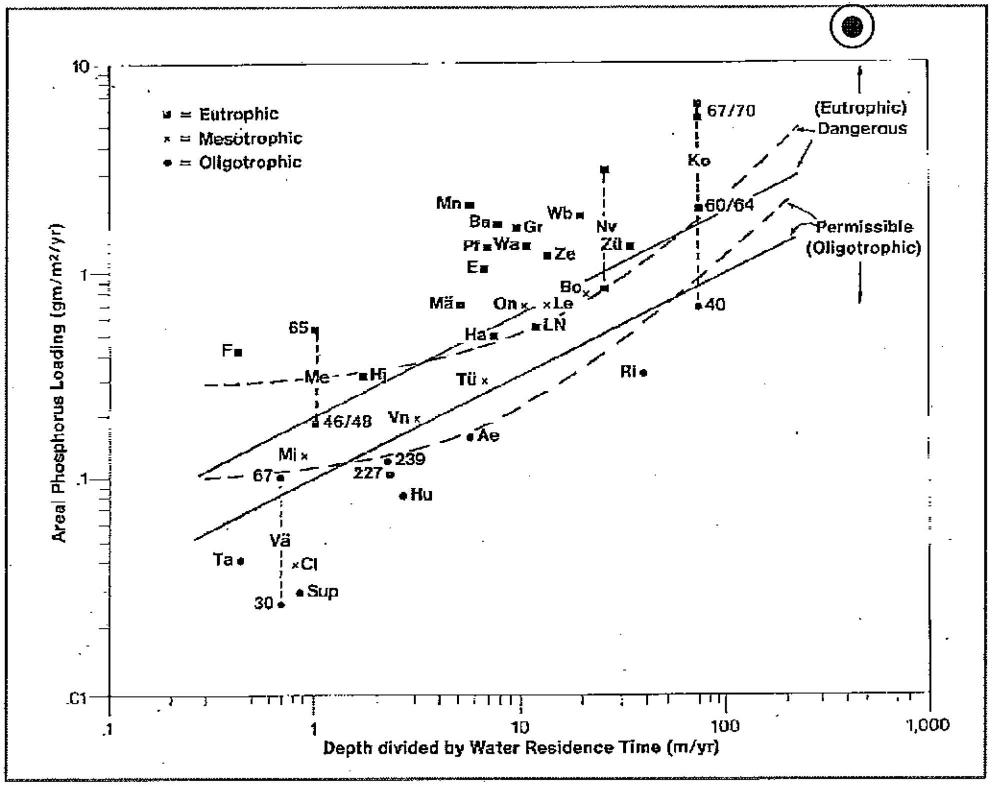

Figure 2. Vollenweider's (1975) phosphorus loading plot to include the residence time with trophic state. The solid circle represents annual values for current conditions and the open circle represents the dredged lake alternative. Source: Reckhow and Chapra (1983).

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Acronyms

ECY	Ecology
ft	Feet
GA	General Administration
MLLW	Mean lower low water
MSL	Mean sea level
USGS	United States Geological Survey