Water Quality & Biological Response To Current and Simulated Increases in Atmospheric Deposition of Sulfur and Nitrogen to Four Lakes in the Oregon and Washington Cascade Range

Prepared for the
USDA-Forest Service
Air Program

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July, 2009

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ABSTRACT

Deposition of elevated concentrations and rates of sulfur and nitrogen have the potential to alter the chemistry and lakes and streams causing changes to the biota of these resources. Considerable research has been conducted in eastern North America on the transport and fate of these pollutants, and a moderate degree of research has been conducted in the central Rocky Mountains and California. However, relatively little has been conducted in the Northwestern portion of the United States. The purpose of this report is to describe the results of a study designed to explore the current and future threat to lake resources in the Northwest, with a focus on the lakes in the Cascade Range. Four sub-alpine/alpine lakes were selected from southern Oregon to mid-Washington that had low acid neutralizing capacity (ANC). The lakes were sampled annually from 2004-2008 for major ion chemistry, phytoplankton community composition, and zooplankton community composition, except for Foehn Lake for which sampling did not begin until 2005. Two of the lakes had been cored prior to the start of the study and sediment cores were collected from the two remaining lakes during this study. The sediment cores were dated using ^{210}Pb and analyzed for diatom community composition. The USDA-Forest Service provided modeled deposition of sulfur and nitrogen for the study sites. The lake chemistry response to the estimated deposition inputs was simulated using a hydrodynamic model (CE-QUAL-W2), modified to process major ions. The results indicate that the two Oregon lakes, Notasha and Scout, show no evidence of acidification or other changes that could be considered harmful under current levels of deposition. Summit Lake in the Clearwater Wilderness of Washington shows some evidence of already having received elevated deposition of sulfur based on current water chemistry. However, lakes Notasha, Scout and Summit appear highly resistant to acidification. Although all three of these lakes have ANC values less than 12 μeq/L, internal processes would likely neutralize modest increasing sulfur and nitrogen deposition. Model simulations indicate that sulfur deposition would need to increase on the order of 300 percent for these three lakes to exhibit a moderate decrease in pH or ANC. Summit Lake currently has no measureable ANC, but the diatom community indicates that the lake chemistry has been stable for a well over 100 years. The extensive population of bryophytes may act as a natural ion exchanger and could have contributed to a self-oligotrophication process, independent of any external forces. The northern-most lake in the study, Foehn Lake, appears to have formed within the last 100 years. The accumulated sediment is low and the major ion chemistry indicates that this lake is already slightly acidic, albeit within the error of the measurements. The model simulations indicate that Foehn Lake will respond more rapidly to changes in atmospheric deposition than the other study lakes. Of the four study lakes, Foehn Lake is clearly the most sensitive to changes in atmospheric deposition and may warrant periodic monitoring to track possible changes in lake chemistry. The study design of water quality sampling to define current conditions, paleolimnology to define historical conditions, and modeling to simulate possible changes in future conditions provides a reasonably complete assessment of the lakes. Recommendations are offered to help focus future work in this area.

INTRODUCTION

It has been known for several decades that elevated levels of sulfur and nitrogen deposition can cause damage to lakes and streams, largely through acidification. However, other effects can include climatically-induced acidification (Webster et al. 1990; Koinig et al. 1998), or contamination from deposition of organic compounds (Heit et al. 1981; Fernandez et al. 2002) and toxic metals such as mercury (Krabbenhoft et al. 2002). Most of the early effects of atmospheric deposition on freshwater was reported for eastern North America and northern Europe where the presence of a large number of low-alkalinity waterbodies and high rates of sulfur and nitrogen deposition resulted in widespread response. However, as researchers broadened the geographic scope of their investigations, it was found that anthropogenically-derived compounds in deposition occurred elsewhere. Studies in the central Rocky Mountains and the Sierra Nevada ranges illustrated that even modest increases in deposition of sulfur and nitrogen can cause undesirable responses to dilute freshwater systems (Clow et al. 2002; Williams and Tonnessen 2000; Baron et al. 2000; Wolfe et al. 2003).

Here in the Northwest United States, most of the data suggests that acidification of lakes has not occurred to any significant extent. However, population projections forecast major increases in growth for the region, prompting concerns among federal resource managers that increased population growth and the accompanying economic activity could increase emissions of sulfur and nitrogen to levels that could promote damage to sensitive resources. In addition, the major growth of economic activity in Asia and especially in China raises concerns that long-distance transport of pollutants could impact the Northwest. Currently, officials estimate that China is constructing two new coal-fired power plants every week (Harrabin 2007). Thus, forces within and beyond the Northwest may result in increased deposition of sulfur and nitrogen to the region.

To address this concern, the USDA Forest Service initiated a study to ascertain the potential risks to lakes in the Northwest. Rather than focus on one specific site for this analysis, the federal resource managers elected to fund a study that would assess the likely response of sensitive aquatic systems across a likely north-south gradient of deposition chemistry. The objectives of the study were to describe current lake conditions, place the current conditions in a long-term context through paleolimnology, and forecast a range of possible responses to different levels of sulfur and nitrogen. This report describes the results of this study and provides recommendations for additional information needs to better define the scope of the problem.

METHODS

The first phase of the project consisted of defining the study sites. Optimal study sites were considered lakes that had the following attributes: (1) they were equally-distributed along a north-south transect in the Oregon-Washington Cascades, (2) the lakes were located in designated wilderness areas, preferably Class I areas, (3) the lakes had low ANC (defined as < 25 ueq/L), (4) the lakes were near the crest of the Cascades (5) the lakes were accessible on foot, (6) the lakes had previously-collected information on bathymetry, paleolimnology, and water chemistry. Available data sets were reviewed for lakes that would fit these attributes, the primary data set being the results from the Western Lake Survey (Eilers et al. 1987). However, additional sites were reviewed, including examination of topographic and geologic maps that might help locate other likely locations for lakes that met these attributes.

From these activities, four lakes were selected that appeared to provide the best combination of study lakes. These four lakes included Lake Notasha in the Sky Lakes Wilderness of southern Oregon, Scout Lake, located in the Mt. Jefferson Wilderness of the north-central Oregon Cascades, Summit Lake in the Clearwater Wilderness of the south-central Washington Cascades, and Green Ridge Lake in the Alpine Lakes Wilderness of the north-central Washington Cascades. Sampling began in 2004 and it became clear that Green Ridge Lake was not sufficiently sensitive to meet one of the essential criterions of the project. We re-examined topographic and bedrock maps to identify a substitute for Greenridge Lake and selected Foehn Lake. Based on subsequent sampling, Foehn Lake was retained in the study group, although access to the site was extremely difficult.

Bathymetric maps were available from previous studies for lakes Notasha and Summit. Bathymetric maps were prepared for lakes Scout and Foehn by deploying custom-made portable echosounding equipment time-synched with a WAAS-grade GPS. The echosounder was moved about the lake using a float-tube to generate reasonably complete coverage of the surface area. The resulting raw data were edited for spurious results and a bathymetric map was generated using kriging routines available in Surfer® (Golden Software, Boulder, CO).

Water samples were collected from the surface waters of each of the four study lakes and placed in Nalgene® containers. Snow was often available near the study lakes to keep the samples cool during transit out of the wilderness area. Once back at the vehicle, the samples were placed in coolers and either frozen or shipped overnight to the analytical laboratory for analysis. Aliquots were shipped to the Forest Service analytical laboratory in Ft. Collins, CO for analysis of major ion chemistry. Another aliquot was shipped to the Cooperative Chemical Analytical Laboratory (CCAL), Oregon State University, Corvallis, OR for analysis of nutrients (TP, PO_4, TN, NH_3, NO_3, and Si). Their analytical methods are available at http:ccal.oregonstate.edu/methodology.htm. A third aliquot was preserved with Lugols solution

and shipped to Aquatic Analysts for analysis of phytoplankton community composition. Methods for taxonomic analysis of the phytoplankton samples are provided in Appendix A. A fourth aliquot was treated with $MgCO_3$ and shipped to Aquatic Analysts via overnight courier for analysis of chlorophyll *a*.

Zooplankton samples were collected from near the deepest point in the lake by lowering a net to a prescribed depth and then retrieving the net at a rate of about 0.5 m/sec. The nets used were conical nets with a 64 micron mesh, a 20 cm opening, and a 30 cm reduction collar. The bucket was a modified Wisconsin bucket. The contents of the vertical tow were placed in a container and the samples were preserved with ethanol on site. The samples were sent to Dr. Allan Vogel for analysis of community composition. Methods for processing the zooplankton samples are described in Appendix B.

Qualitative benthic invertebrate samples were collected from near the deepest portion of each lake using an Eckman dredge. In Foehn Lake, the shallow nature of the sediments and high proportion of boulder cover precluded use of a dredge to collect benthic samples. Benthic macroinvertebrate samples in Foehn Lake were collected by skindiving to the sediments and inserting a 5 cm diameter core tube. The samples were preserved in the field with ethanol. The contents of the samples were placed in a sorting tray and invertebrates visible without the aid of magnification were gathered and placed into vials and were shipped to EcoAnalysts, Moscow, Idaho, for taxonomic analysis. Methods for processing the benthic invertebrate samples are described in Appendix C.

In situ measurements included use of a multi-parameter sonde that had been calibrated at the trailhead and was re-calibrated on-site for dissolved oxygen. MaxDepth staff used an In-Situ® Troll 9000 multi-parameter sonde, whereas the Forest Service field crew used an YSI® 650 MDS. The sondes were equipped with sensors for temperature, dissolved oxygen, pH, and conductivity. MaxDepth Aquatics, Inc. was responsible for routine sampling of lakes Notasha and Scout in Oregon, whereas the Forest Service was responsible for sampling Summit Lake and Foehn Lake in Washington. However, MaxDepth staff also sampled Summit Lake and Foehn Lake in 2006 and 2007 for bathymetric mapping (Foehn), sediment coring (Foehn) and collection of benthic samples (Summit and Foehn). Additional on-site measurements included collection of Secchi disk transparency. MaxDepth staff also collected light extinction using a LiCOR® model Li-250A to provide more quantitative measurements of light transmission. MaxDepth staff also sampled several additional lakes in the vicinity of Foehn Lake in 2007.

Thermisters (Onset Computer, Tidbit Ver. 1) were placed in plastic containers and submerged about 0.5 to 1 m below the water surface in each lake for a year to record water temperature regimes in the lakes. The data were downloaded and edited for spurious values defined here as aberrant spikes without adequate transitions.

Paleolimnological reconstructions were also available for Notasha and Summit lakes, but not for Scout and Foehn lakes. Sediment cores were collected from near the deep locations in Scout and Foehn lakes using a gravity core equipped with a 5 cm diameter core tube (Figure 1). The cores were extruded on-site in 1-cm intervals and stored in WhirlPac® bags. The intervals were homogenized and subsamples were sent to laboratories for various analyses. Samples sent to the Soils Science Laboratory at Oregon State University were analyzed for percent water, nitrogen, phosphorus, and loss-on-ignition (http://cropandsoil.oregonstate.edu/cal). Samples sent to MyCore Scientific were analyzed for lead isotopes used to derive age of the surficial sediments (http://www.mycore.ca/). Additional selected intervals from the Scout Lake core were sent to Beta Analytic for analysis of ^{14}C (http://www.radiocarbon.com/). The last set of sediment samples were sent to Dr. Roger Sweets, Indianapolis University, for analysis of diatom community composition. Methods for analysis of sediment diatoms are provided in Appendix D.

Figure 1. Gravity corer used to collect sediment core samples.

The CE-QUAL-W2 model was selected to provide simulation capability for the four study lakes. The model is a two-dimensional hydrodynamic model that provides capabilities for generating estimates of hydraulic residence time, nutrient chemistry, and biological representation of

phytoplankton, zooplankton, and fisheries. Details of the model are available at http://www.ce.pdx.edu/w2/. The publically available version of the model provides capabilities for representing nutrients (N,P, and Si), pH (H^+), carbonate chemistry, and a conservative ion (such as Cl^-), but it does not simulate the full suite of major ions. We modified the model to allow for treatment of major ions.

CE-QUAL-W2 (W2) was selected as the model platform primarily because of its ability to represent lake hydrodynamics and its ability to represent different trophic components of the lakes. Extensions to the model were necessary to simulate base cations and to calculate alkalinity based on the ion balance. W2 is a relatively complex lake hydrodynamic and water quality model, and as such requires a variety of both general and site specific input data. Bathymetry for each of the lakes was developed as part of this project, details of which are described earlier in the report. These data were used directly to develop the model grids used in each of the lake simulations. A depiction of the 2-d grids for each of the lakes is included in Figure 2 through Figure **5**.

The lakes chosen for the project are seepage lakes with no surface inflows or outflows. Groundwater losses were assumed to be small, with direct precipitation inputs balanced by evaporative losses. A small amount of groundwater loss was incorporated into each model to balance the lake stage over the two-year simulation period. Although direct measurements of the groundwater interactions would have been preferable, the calibration does result in a reasonably stable lake stage.

Meteorological data specific to each site was developed as part of the contract. MATLAB code was developed to format these available data for input into the W2 modeling framework. Units required for input to W2 are m/s for precipitation rate, C for precipitation temperature and g/m3 for all precipitation constituents. Deposition values related to N and S were provided to MaxDepth Aquatics, Inc. by the USDA Forest Service. MATLAB code was developed to format these available data for use in W2. Deposition values for other chemical parameters (Ca, Mg, Na, K, Cl) were estimated based on measured in-lake chemistry and standard sea salt ionic ratios.

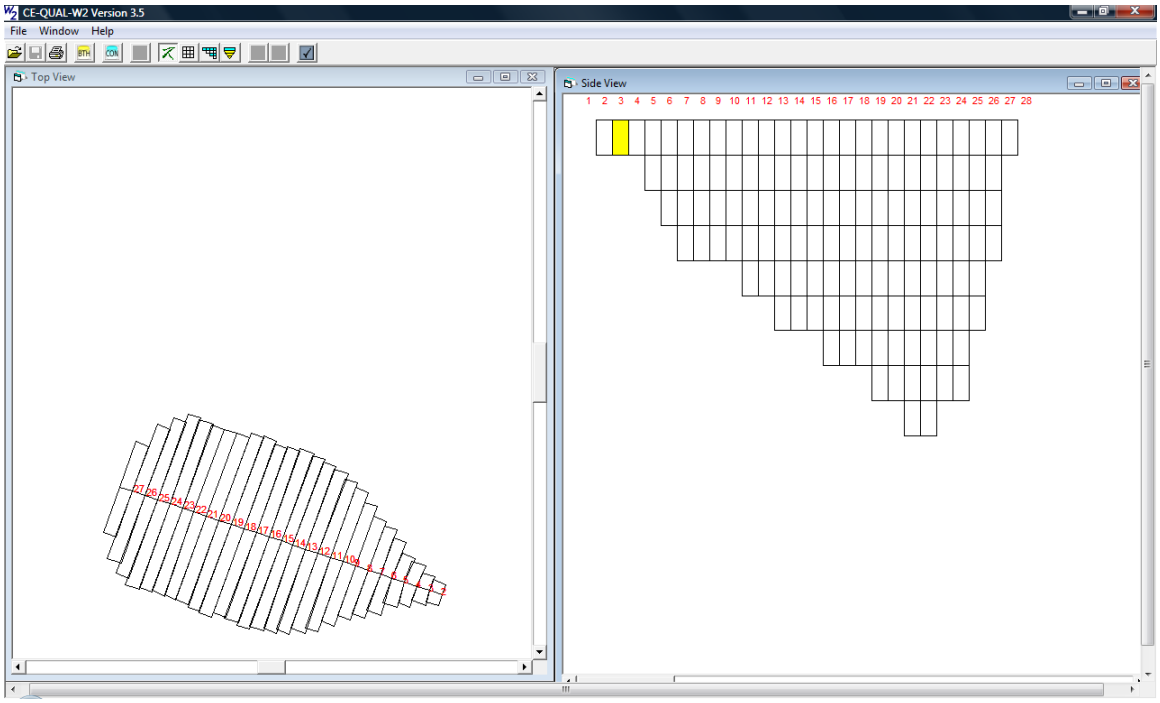

Figure 2. Lake Notasha computational grid.

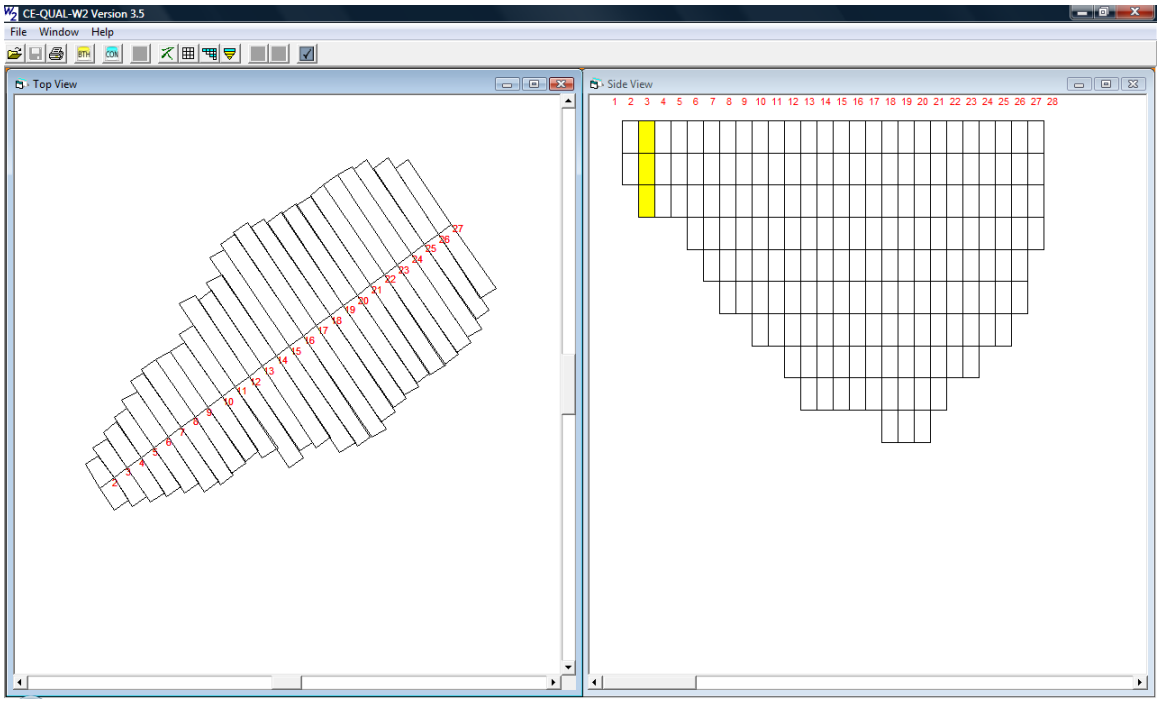

Figure 3. Scout Lake computational grid.

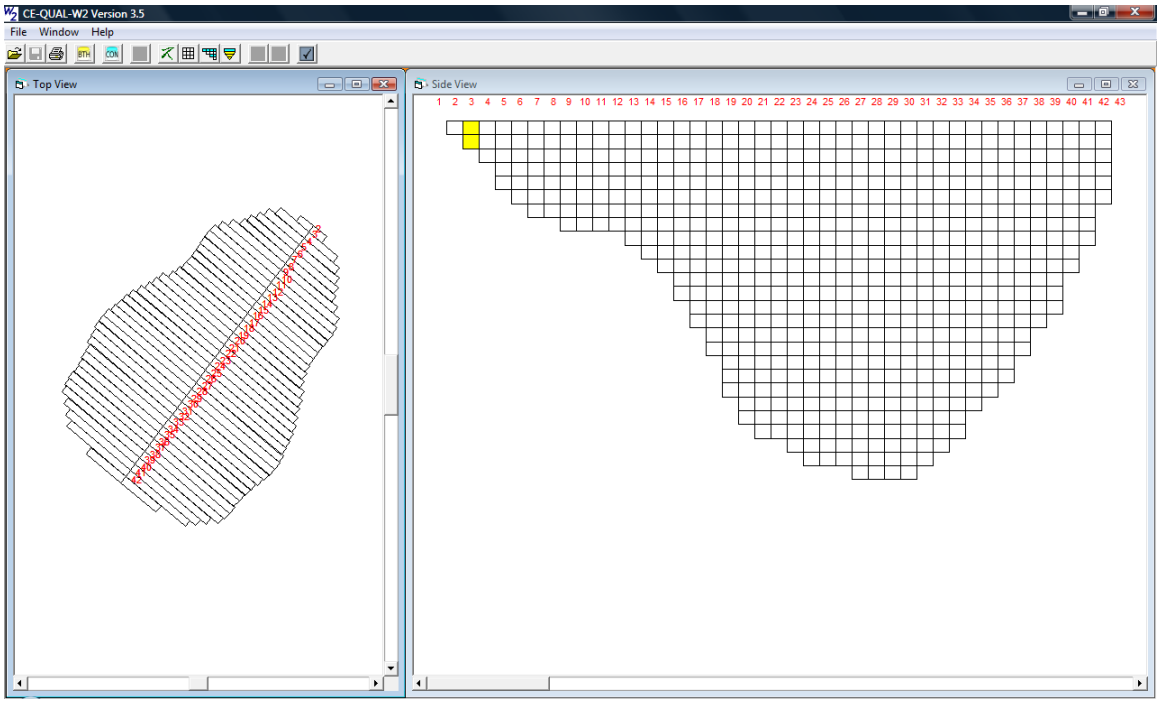

Figure 4. Summit Lake computational grid.

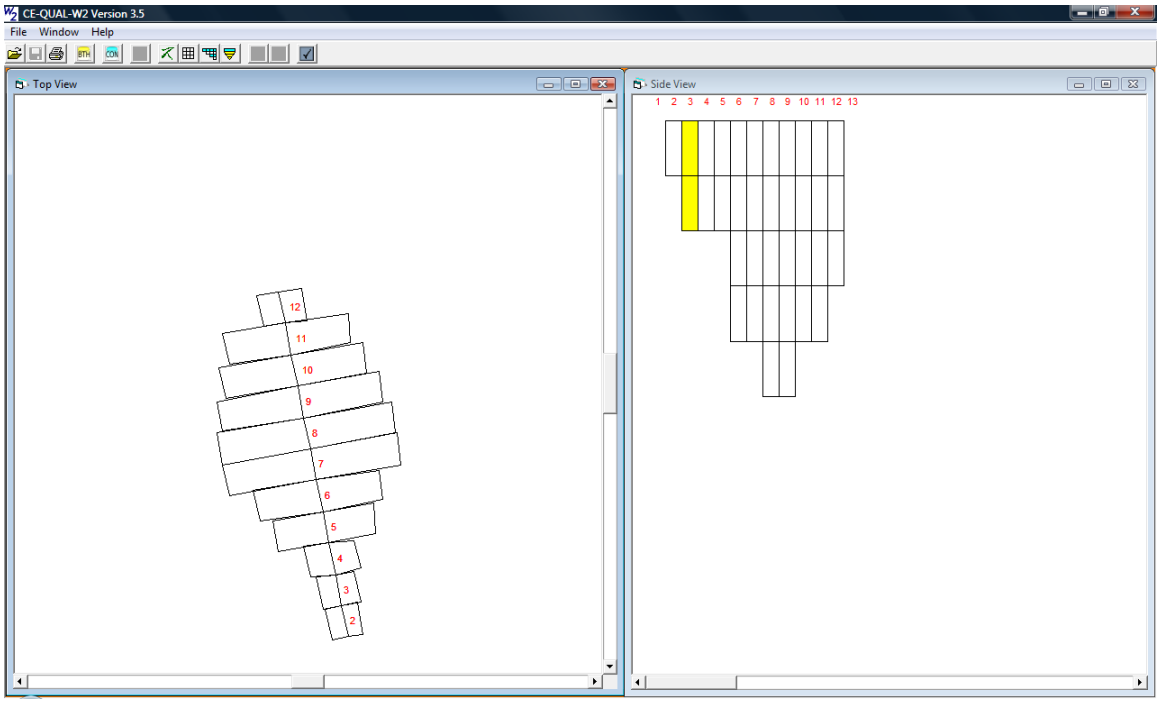

Figure 5. Foehn Lake computational grid.

Deposition inputs to the study lakes were provided by the Forest Service as modeled output. Modeled nitrogen and sulfur deposition values were produced using the 3rd generation Air Indicator Report for Public Access and Community Tracking (AIRPACT-3) modeling system. AIRPACT-3 is a 3-dimentional eulerian air quality forecast modeling system that has at its core the CMAQ photochemical transport model, and uses meteorological inputs from the MM5 meteorological model and emissions from the SMOKE emissions model. AIRPACT-3 anthropogenic emissions data were compiled by Washington State University in collaboration with state air agencies in Idaho, Washington, and Oregon. Area and non-road mobile emissions are based on the 2002 EPA National Emission Inventory data set (available at http://www.epa.gov/ttn/chief/net/2002inventory.html) and adjusted to year 2005 with county and source specific projection factors. On-road mobile emissions are generated outside the SMOKE framework using emission factors from the EPA MOBILE v6.2 model and 2005 state specific activity data. Emissions from large industrial sources are treated as point sources and emissions are based on the same national data set with updates by state air agencies in Idaho, Washington, and Oregon to reflect 2005 operation activities. Anthropogenic emissions over provinces of British Columbia and Alberta, Canada are also included. Biogenic emissions are estimated by the BEIS3 (Biogenic Emissions Inventory System version 3) model. Chemical boundary conditions in AIRPACT-3 are compiled from the MOZART-2 global chemical model to account for seasonal variability of ozone and other chemical species throughout the year. A full description of the AIRPACT-3 system is provided in Chen et al. (2008) and the references therein.

The AIRPACT-3 system predicts nitrogen and sulfur deposition in the Pacific Northwest over a 95x95 grid fully covering the states of Idaho, Washington, and Oregon. Each grid cell is 12 km square, and the predicted deposition in each cell is the average value for the cell. When comparing model to monitor deposition, no effort was made to interpolate the modeled value within the grid cell.

As noted above, AIRPACT-3 is an air quality forecast modeling system. In order to produce historical nitrogen and sulfur deposition values, several modification were made to the AIRPACT-3 system as reported by Chen et al. (2008). First, historical MM5 meteorological data was used in place of the usual forecast data. Historical MM5 data was obtained from an archive maintained by the Department of Atmospheric Science at the University of Washington. Second, no wildfire data was available for the time period modeled. Hence, wildfire emissions processing in the SMOKE emissions model was turned off for these simulations. Third, we used the 'DENRATE' mass conservation scheme within the CMAQ model rather than the default 'YAMO' scheme. The YAMO mass conservation scheme has been found to induce unrealistic downward vertical transport in areas of complex terrain (currently unpublished work, EPA

Region 10), hence the DENRATE scheme was used for these simulations in the Pacific Northwest (and is now being used by the AIRPACT-3 forecast system).

The output from AIRPACT provided by the Forest Service was used for estimating inputs of atmospheric deposition to the four study lakes with the following exceptions. The file labeled RG02_Dry_Dep_Summary_Model_Total_N_OR_S, representing Summit Lake, appears to consist of the wet deposition values for site RG01, representing Foehn Lake. We substituted the dry deposition values from RG01 (Foehn) for these data. We did not receive wet deposition values for Scout Lake, and substituted values generated for Lake Notasha to fill the gap.

The only known source for Cl^- in these lakes is deposition. There are no known watershed sources, a fact that was used to develop deposition estimates for the ionic chemistry included in the lake acidification components of the model: Cl, Ca, Mg, Na, and K. Hydraulic residence time for each lake was calculated as:

$$HRT = \frac{LakeVolume}{\mathrm{Pr}\,ecipRate}$$

Where HRT is in years, LakeVolume is in m^3, and PrecipRate is in m^3/yr. Assuming that the lake volume was replaced over this period of time, we estimated the precipitation concentration of Cl^- as the average measured in-lake mass (concentration*LakeVolume) over the precipitation volume occurring during the HRT.

$$[Cl]_{precip} = \frac{[Cl]_{inlake} * LakeVolume}{\mathrm{Pr}\,ecipVolume_{HRT}}$$

Of course, given equation 1, LakeVolume drops out of the equation, simply indicating that the measured concentration of Cl (given a calibrated evapo-concentration factor) was assumed equivalent to the deposition concentration. We used an average value for Cl deposition (Nelson 1991), and sea salt ionic ratios between Cl and the remaining cations were used to then directly estimate atmospheric deposition values. This process resulted in estimates of atmospheric deposition values, against which other sources were calibrated, to achieve relatively stable in-lake concentrations over the two-year simulation period. Measured estimates of input chemistry patterns (including atmospheric and watershed sources), similar to those available for N and S species were unavailable for these systems.

The modeling work uses a standard two-part strategy comprised first of calibration and validation and second, the use of the calibrated models in the evaluation of potential responses to changing patterns of deposition. The period over which model calibration was developed was

selected based primarily on the availability of both input and evaluation data sets. The two-year period from January 2004 to December 2005 was selected, because this period included the largest overlap of input data that was available for the project, over all four lakes. We focus most of the results representing current conditions during this period of time.

CE-QUAL-W2 incorporates a large suite of water quality variables, however the water quality components of the model have primarily been developed for use in eutrophication studies. As such, some key aspects of water quality as it relates to acidification studies are not included in the standard version of W2. These include the base cations (Ca, Mg, Na, and K) as well as the anions SO_4 and CL. Additionally, in the standard version of W2, alkalinity is treated as a conservative value. The chosen value of alkalinity is used in calculations of pH, but is spatially and temporally constant. To apply the model in this project, the above items were addressed through expansion of the code base. Specific modifications included the use of the generic constituent features to simulate the missing ions, and modification of the code to utilize a full ion balance in the calculation of alkalinity. Code modifications are as follows. Note that the CG array values are used to represent CA, MG, NA, K, SO4 and CL. An example of the full input code for Foehn Lake is provided in Appendix E.

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!**************************************************************************
**************************************************
!**             A L K A L I N I T Y
!**  Alkalinity is treated as a non-conservative quanity, calculated as
!    difference between sum of base cations and sum of base anions
!    Kellie Vache, January 28, 2009
!**************************************************************************
**************************************************

ENTRY ALKALINITY
! sum of base cations-sum base anions
DO I=IU,ID
   DO K=KT,KB(I)
         ALK(K,I) = ((CG(K,I,1)*49.9)+(CG(K,I,2)*82.26)+
            (CG(K,I,3) *43.5)+(CG(K,I,4)*25.57))-((CG(K,I,5)*20.82)+
            (CG(K,I,6)*28.21)+(NO3(K,I)*16.13))

         ALK(K,I) = ALK(K,I)/19.98  !convert back to g/m-3 as CaCO3
         CGSS(K,I,1) = CGSS(K,I,1)
    END DO
 END DO
RETURN
```

STUDY SITES

The study area is comprised of a narrow band of the Cascade Range extending from southern Oregon up to the northern portion of Washington (Figure 6). The four study sites are all located on the west slope or near the crest of the Cascades. Indeed two of the study lakes (Notasha and Scout) border the Pacific Crest Trail. Summit Lake is located northwest of Mt. Rainier across the Carbon River. Foehn Lake is also west of the Cascade crest in King County east of Seattle. Information on the location of the study lakes is shown in Table 1. Several lakes in close proximity to Foehn Lake were also sampled once for comparative purposes.

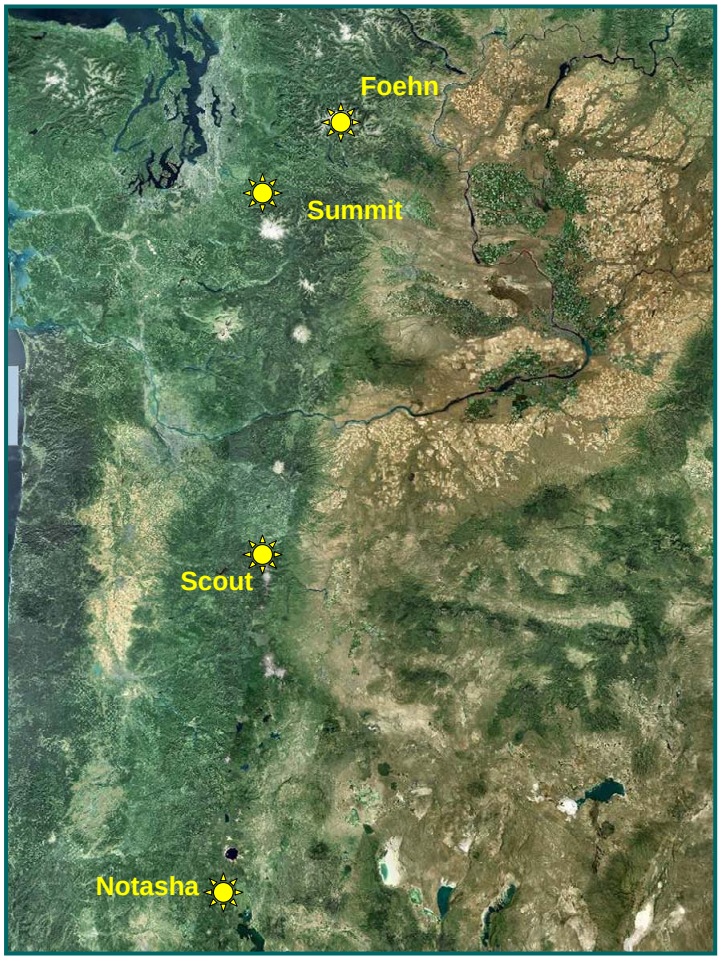

Figure 6. Location of the four study lakes in the Cascade Range.

Table 1. Location information for the four study lakes.

Attribute	Units	Notasha	Scout	Summit	Foehn
Elevation	m	1836	1780	1658	1737
Latitude	d.d	42.5680	44.70865	47.03994	47.56711
Longitude	d.d	122.2097	121.81013	121.83147	121.25857
Forest	---	Rogue-Winema	Willamette	Mt. Baker-Snoqualmie	Mt. Baker-Snoqualmie
Wilderness	---	Sky Lakes	Mt. Jefferson	Clearwater	Alpine Lakes

Lake Notasha

Lake Notasha is located just east of the Cascade crest in a cluster of shallow lakes about 20 km south of Crater Lake National Park. The surrounding area is densely forested in mixed conifers comprised of lodgepole pine, mountain hemlock, and true firs. The topography is comparatively flat with hummocks in the immediate area (Figure 7 and 8). Lake Notasha has no surface inlets or outlets and the lake stage often declines in late summer and fall in the absence of any significant groundwater recharge. The lake is over 7,700 years old, a feature that was confirmed when we were unable to penetrate the Mazama ash layer during multiple attempts in coring the lake (Eilers et al. 1996). The ash layer was deposited during the eruption of former Mt. Mazama, which is now known as Crater Lake (Zdanowicz et al. 1999). The watershed is comprised of material that is highly permeable as evidenced by the paucity of well developed stream networks and surface drainage channels.

The area surrounding Lake Notasha has never been logged and the only known anthropogenic activities that might impact the lake include the adjacent Pacific Crest Trail and associated campsites and the history of fish stocking. The lake was stocked with brook trout and rainbow trout for a number of years, but fish stocking was discontinued in the 1990s by the Oregon Department of Fish & Wildlife. There are no macrophytes visible in the lake, however there is a large amount of woody debris on the shore and in the lake (Figure 9 and 10). A bathymetric map was generated for Lake Notasha in an earlier study (Figure 11). Further descriptions of the lake are available in Eilers et al. (1990) and (1996).

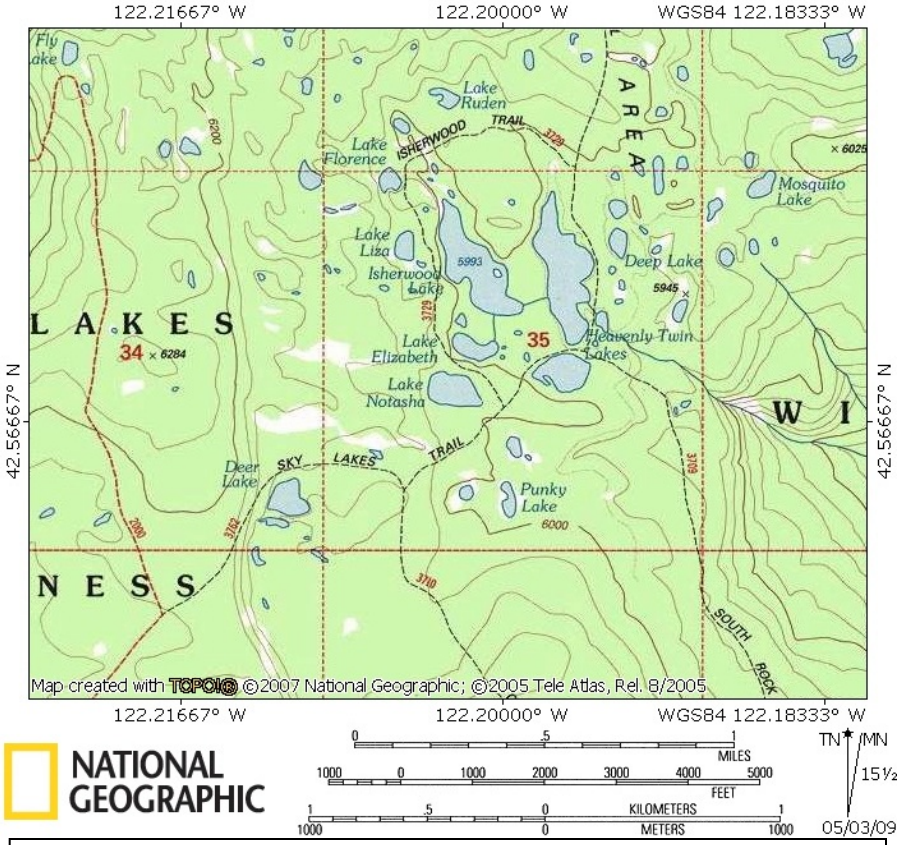

Figure 7. Topographic map of the southern portion of the Sky Lakes Wilderness with Lake Notasha near the center.

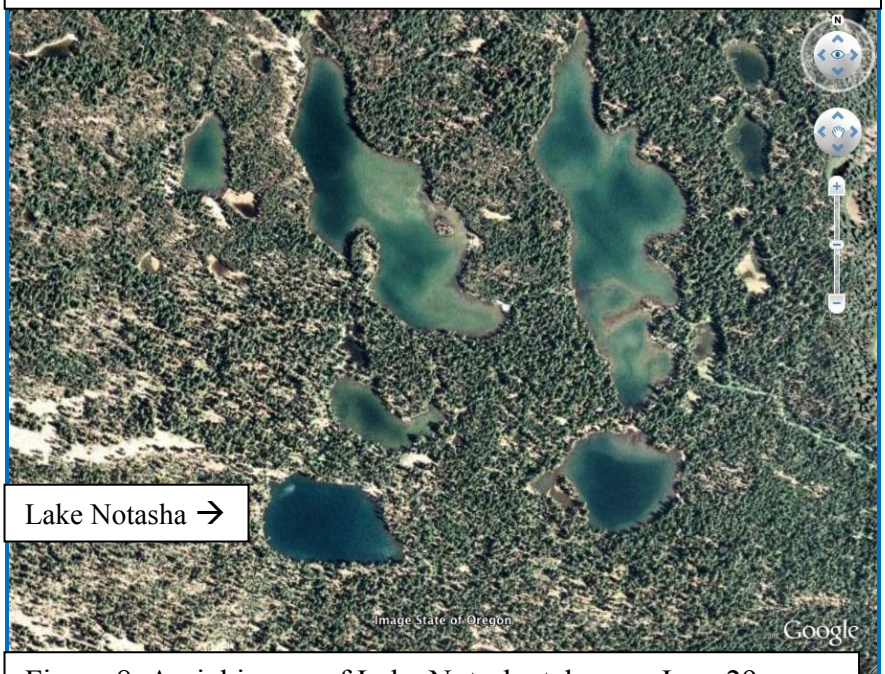

Figure 8. Aerial image of Lake Notasha taken on June 29, 2005. Google image.

Figure 9. Lake Notasha looking northwest.

Figure 10. Southeast shore of Lake Notasha showing abundant woody debris.

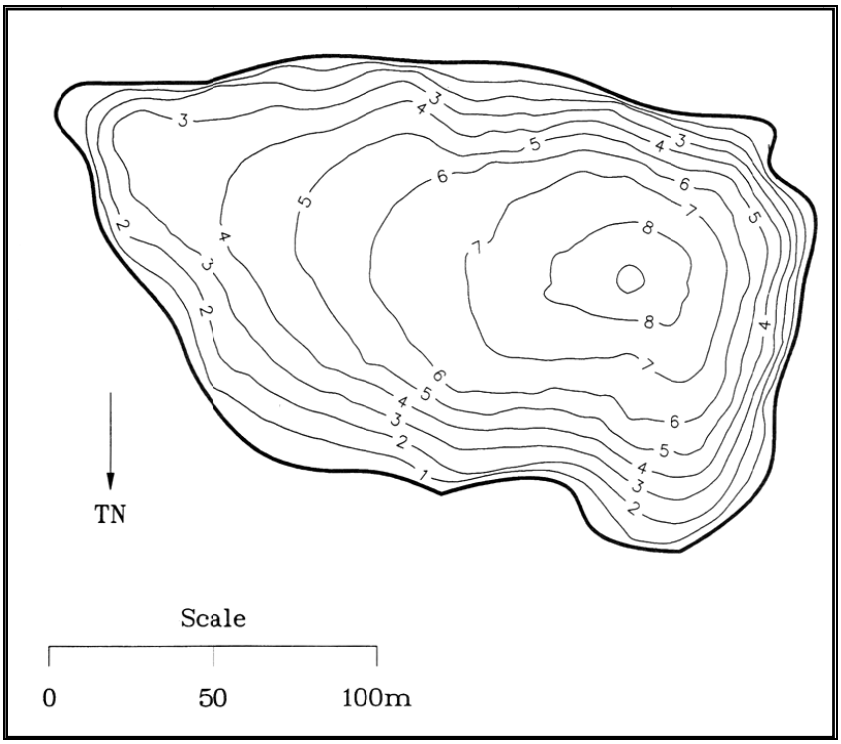

Figure 11. Bathymetric map of Lake Notasha (from Eilers et al. 1996). Contours are in meters.

Scout Lake

Scout Lake was believed to have been formed several hundred years ago when small tributary valleys became dammed by glacial moraines (Hoblitt et al. 1987). Scout Lake is located adjacent to the Pacific Crest Trail, which passes by the northwest flank of Mt. Jefferson in Jefferson Park. The area immediately surrounding the lake has relatively little topographic relief, although its proximity to Mt. Jefferson (3,199 m) immediately to the southeast gives the impression of a massive slope towards the lake (Figure 12 and 13). Mt. Jefferson is a stratovolcano that has had no recorded eruptions in the last 200 years (Walder et al. 1999). The rocks types are primarily basaltic andesite, andesite, and dacite (Hoblitt et al. 1987).

Scout Lake still receives occasional stocking of rainbow trout, although the abundance of fish present is believed to be low based on multiple years of observations preceding and during this project. Vegetation in the immediate vicinity of Scout Lake is relatively sparse and is comprised of mixed conifers with extensive mats of heather. There are no macrophytes visible in the lake (Figure 14 and 15).

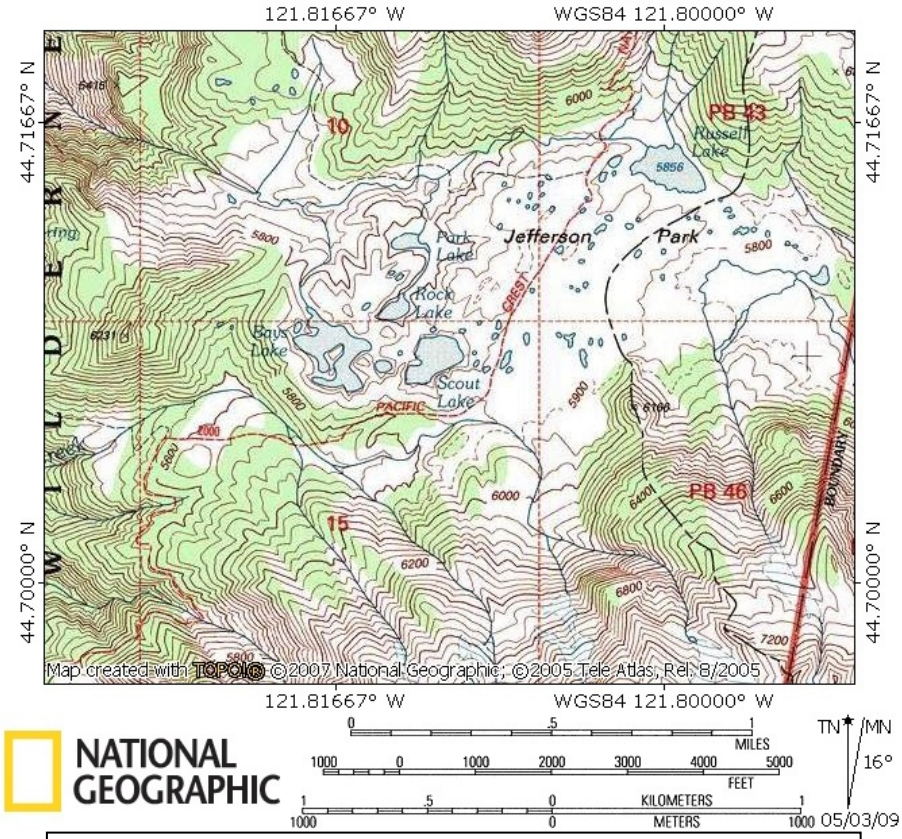

Figure 12. Topographic map of the Jefferson Wilderness showing Scout Lake near the center.

Figure 13. Aerial image of Scout Lake from June 29, 2005. Google image.

Figure 14. Scout Lake on July 28, 2007 looking southeast towards Mt. Jefferson.

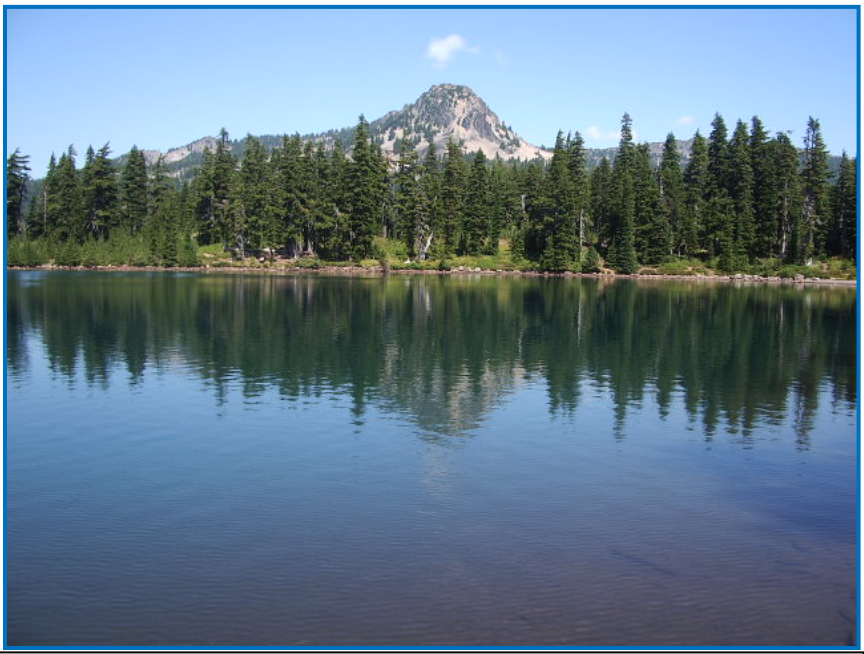

Figure 15. Scout Lake on July 28, 2007 looking west towards the Sentinel Hills.

Summit Lake

Summit Lake is located northwest of Mt. Rainier, separated from Mt. Rainier National Park by the Carbon River valley. Summit Lake is believed to have been formed in a volcanic crater located near the summit of a ridge (Figure 16). The lake is quite deep and possesses extensive mats of bryophytes at considerable depth throughout much of the lake. The lake used to be a popular destination hike and camping area, but a major flood in 1996 destroyed easy access from the south. Only a few fish have been observed in the lake and the stocking history is unknown. There is a moderate degree of heather growing as understory near the lake and mixed confers growing around much of the lake (Figure 17 and 18). A bathymetric map of Summit Lake is available from an earlier study (Figure 19).

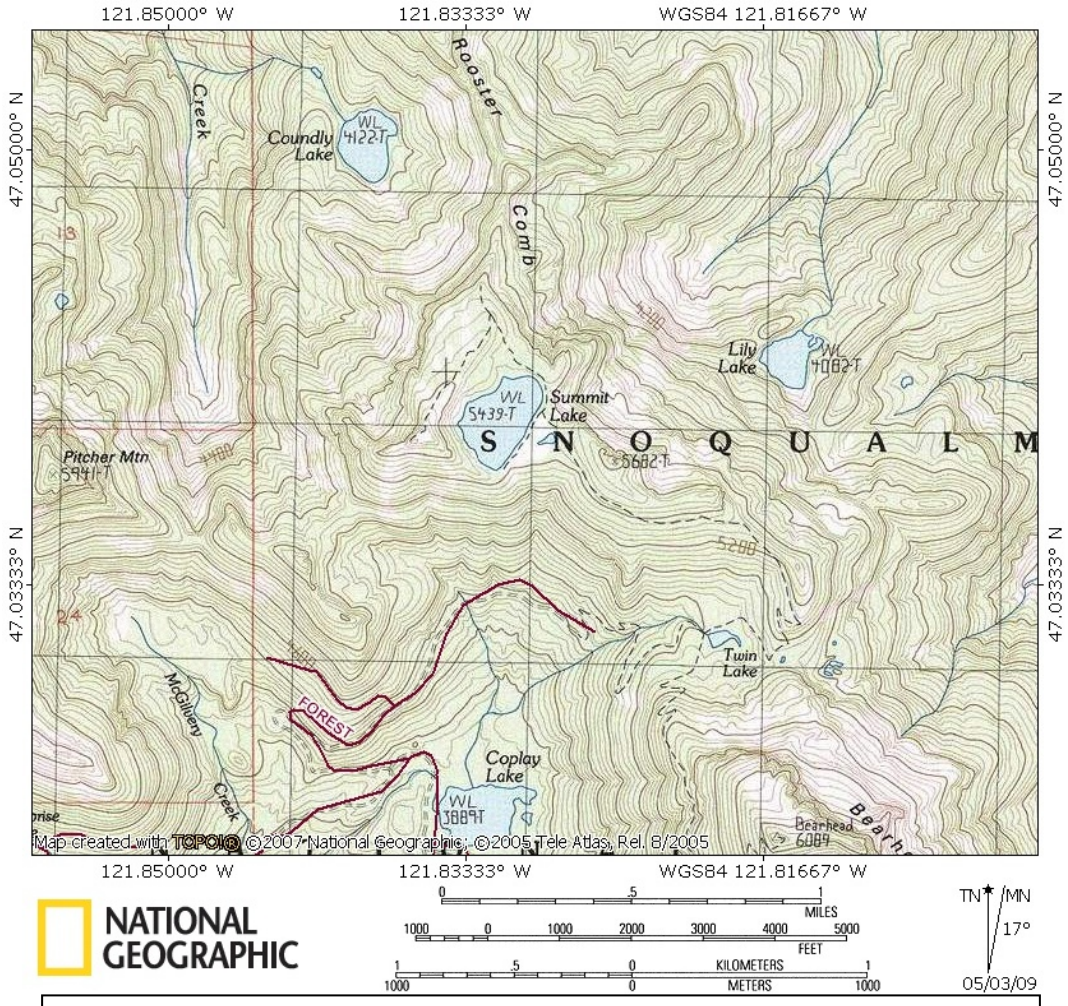

Figure 16. Topographic map of the Clearwater Wilderness showing Summit Lake near the center.

Figure 17. Summit Lake looking west

Figure 18. Summit Lake looking north.

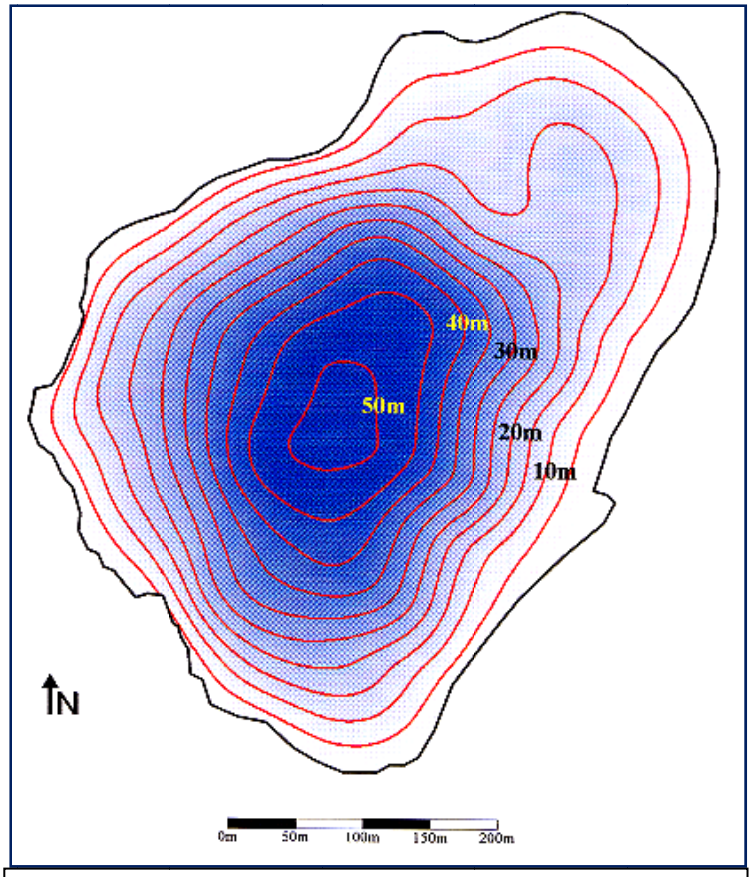

Figure 19. Bathymetric map of Summit Lake (from Eilers et al. 1998).

Foehn Lake

Foehn Lake is a small lake located at the terminus of the Necklace Valley on the east flank of a ridgeline in the Alpine Lakes Wilderness (Figure 20). Although the topographic map indicates the presence of an outlet stream from Foehn Lake (Figure 20), the on-site visits showed no evidence of a surface outlet. The area was reported to be a "permanent" snowfield at the beginning of the 20th century, although the basis for this report is not known. Soil development in the vicinity of Foehn Lake is limited and most of the terrain consists of exposed boulders (Figure 21 and 22).

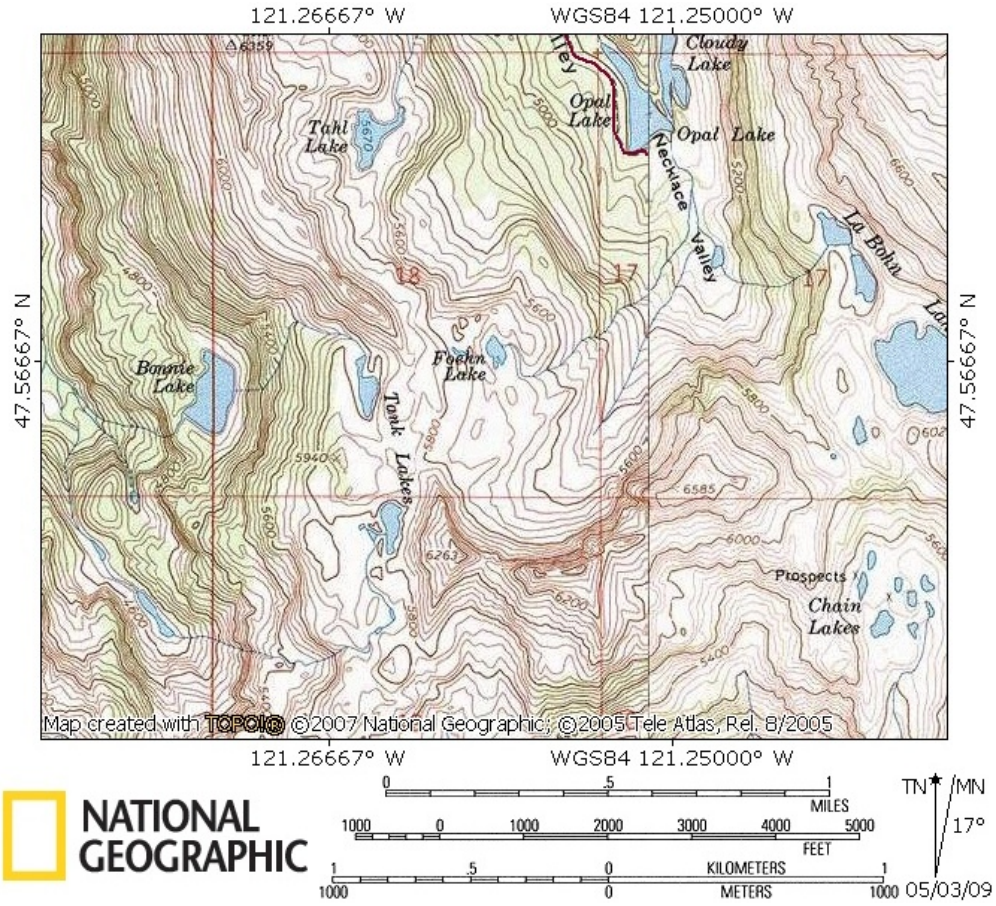

Figure 20. Topographic map of a portion of the Alpine Lakes Wilderness showing Foehn Lake near the center.

Figure 21. Image of Foehn Lake looking north, September 2, 2006.

Figure 22. Image of Foehn Lake looking northwest, September 2, 2006.

RESULTS

Physical Limnology

Bathymetry

Data on the bathymetry of the study lakes was necessary to determine the volume and depth properties of the lakes for input into the hydrodynamic model. Bathymetric maps were already available for Lake Notasha and Summit Lake, but mapping was conducted as part of this project for Scout and Foehn lakes. The bathymetries for the two study lakes mapped during this project are shown in Figures 23 and 24. The morphometry of the four study lakes is summarized in Table 2. The physical characteristics of Lake Notasha and Scout Lake are similar, whereas Summit Lake is deeper and larger than the other study lakes and Foehn Lake is shallower and smaller than the other sites. This results in Foehn Lake having a short hydraulic residence time (HRT), whereas Summit Lake has a long HRT. Whereas most of the study lakes have a relatively simple bathymetry and lake shape, Foehn Lake has a convoluted shoreline and two basins separated by a sill.

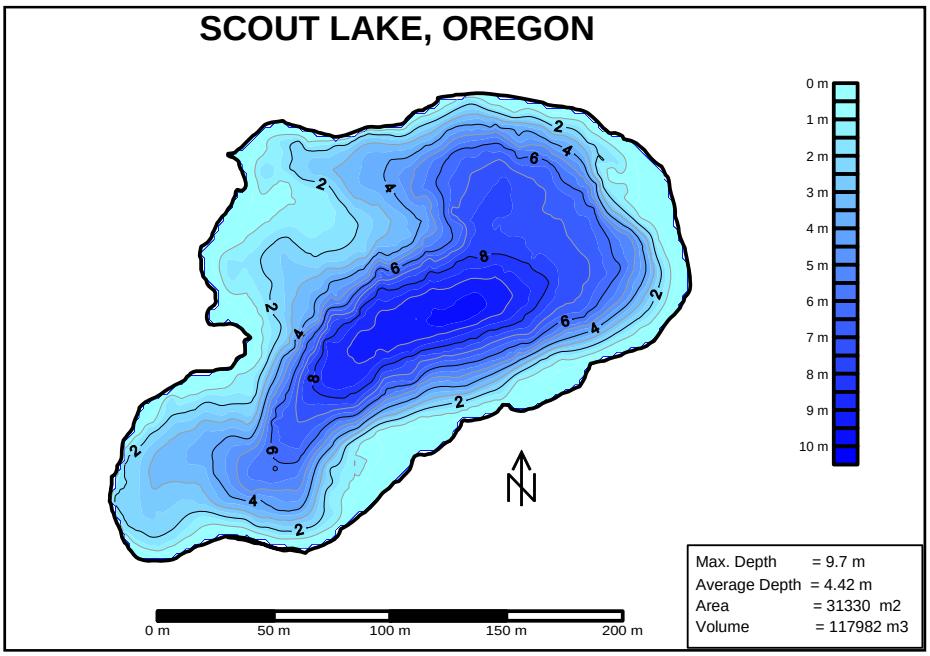

Figure 23. Bathymetric map of Scout Lake using data collected on July 9. 2004.

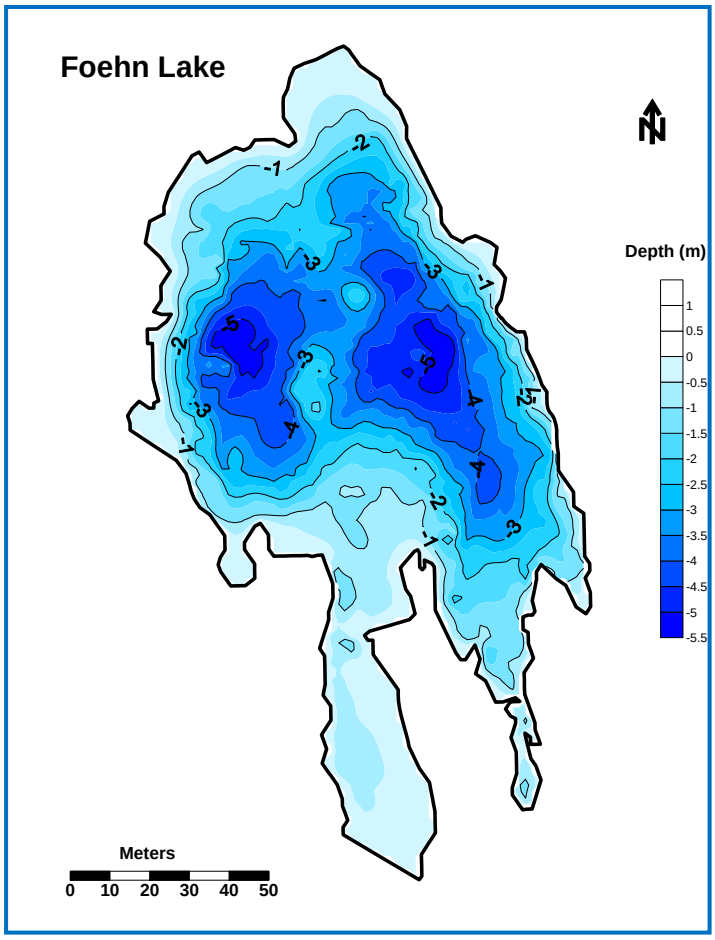

Figure 24. Bathymetric map of Foehn Lake generated using data collected on September 2, 2006.

Table 2.Lake morphometry based on the bathymetric mapping of the four study lakes.

Attribute	Units	Notasha	Scout	Summit	Foehn
Elevation	m	1836	1780	1658	1737
Surface Area	ha	2.7	3.1	8.82	0.43
Depth $_{max}$	m	10.6	9.7	50.9	5.4
Depth $_{mean}$	m	3.6	4.4	21.2	2.2
Volume	m^3	9.6×10^4	1.18×10^5	1.87×10^6	9.57×10^3
Precipitation	cm	160	230	230	300
HRT	yr	1.4	1.5	8.4	0.9

Thermal Properties

All four lakes are located in alpine or subalpine settings and therefore they experience extended periods of ice and snow cover. Unlike many high elevation lakes in the interior of the continent that accumulate a thick, uninterrupted layer of solid ice, lakes in the Cascades generally do not experience the intense cold winters and as a consequence the ice cover is often comprised of alternating layers of ice, snow and slush. Nevertheless, the accumulation of ice and snow effectively covers the Cascade lakes from about late November through May or June. Thermisters placed in the study lakes illustrate this thermal regime (Figure 25-28). Both Summit and Foehn Lake experienced ice-out at the end of June and reached maximum temperatures of about 18 ºC. Scout Lake also experienced ice-off near the end of June, but reached a temperature of 21 ºC. Lake Notasha was the warmest lake of the study set and experienced ice-off at the end of May and reached a maximum temperature over 25 ºC.

Of the four study lakes, Summit Lake exhibited the greatest degree of thermal stratification (Figure 29). Even in October, Summit Lake had yet to become isothermal, a feature attributed to its considerable depth. Scout Lake often showed a 3 to 4 degree temperature decrease from top to bottom during the summer, but no thermal stratification was observed in Notasha or Foehn lakes during the study period.

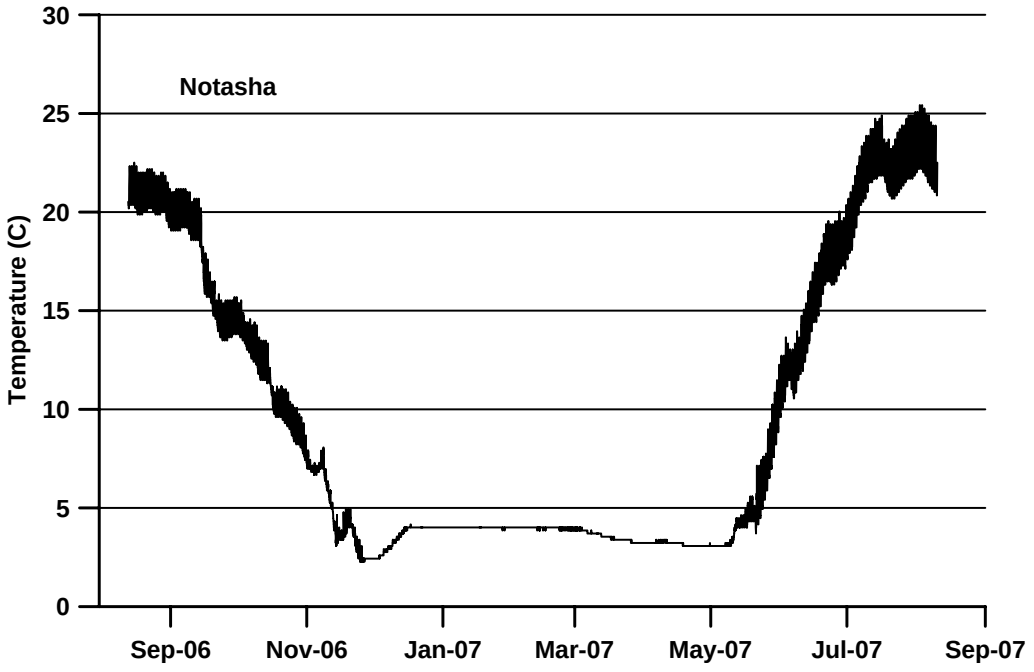

Figure 25. Epilimnetic temperature of Lake Notasha from August 2006 to August 2007.

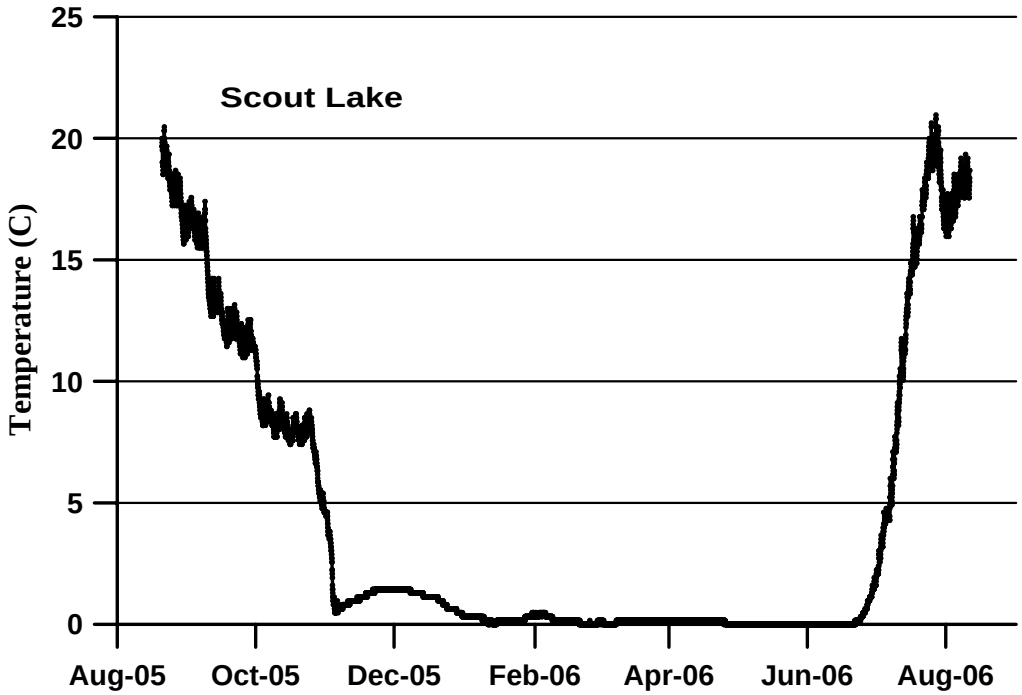

Figure 26. Epilimnetic temperature of Scout Lake from August 2005 to August 2006.

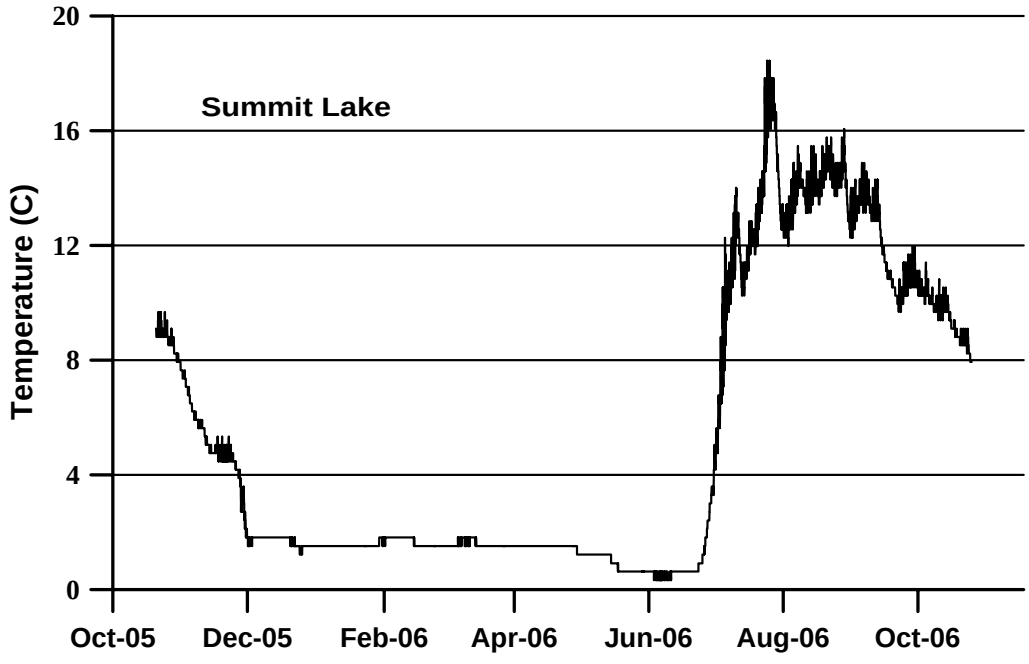

Figure 27. Epilimnetic temperature of Summit Lake from October 2005 to October 2006.

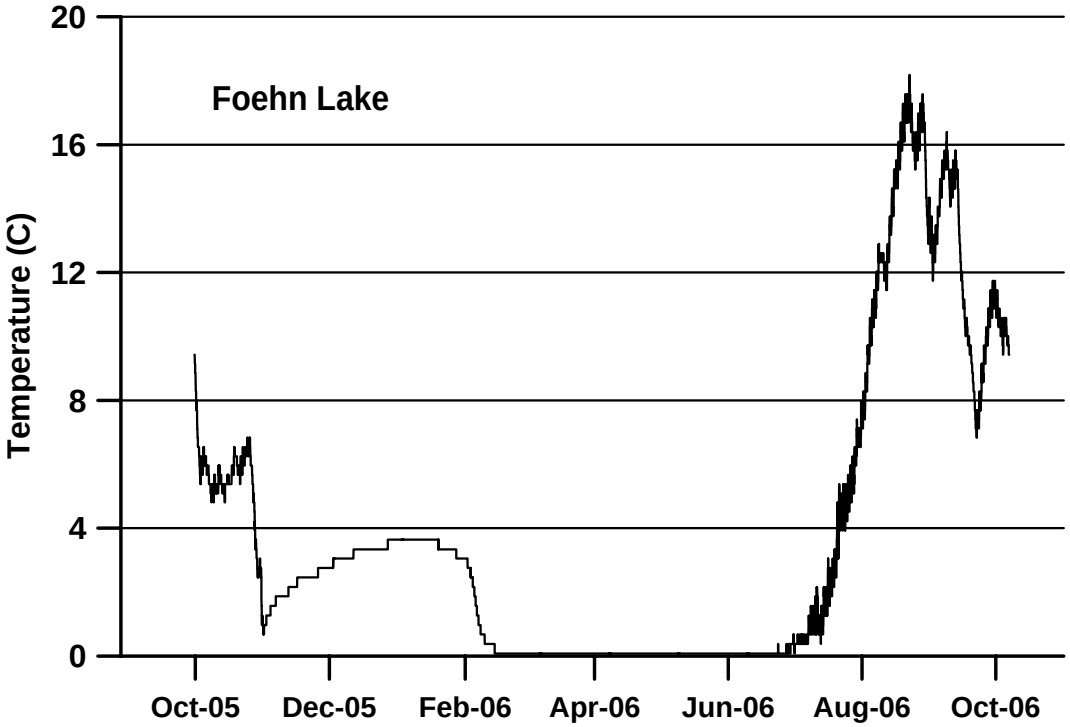

Figure 28. Epilimnetic temperature of Foehn Lake from October 2005 to October 2006.

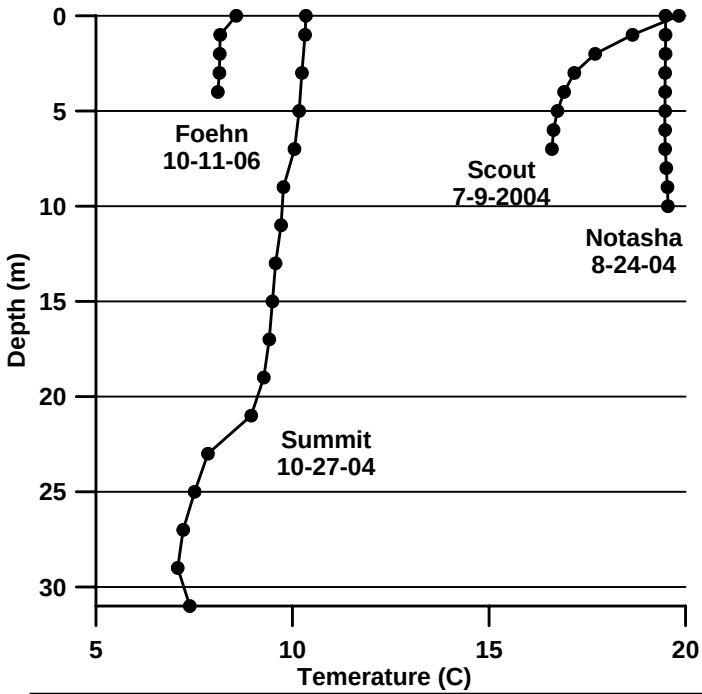

Figure 29. Temperature profiles for the four study lakes reported for 2004 (2006 for Foehn Lake).

Light Transmission and Substrate

Secchi disk visibility extended to the bottoms of Notasha, Scout, and Foehn lakes on all sampling visits. Secchi disk transparency was reported at 17 m and 20 m for Summit Lake in 2004 and 2006, respectively. There was no apparent color to any of the lakes that suggested the presence of any substantial amounts of humic compounds. The high degree of transparency allowed for examination of much of the lake substrate. Beyond the rocky shores, lakes Notasha and Scout had substrate that consisted of fine –grained sediment with little overlying flocculent material. Abundant large woody debris extended from the shore to deeper areas of Lake Notasha. The bottom of Foehn Lake was comprised mostly of large boulders with small patches of accumulated sediment in between. Although we could not see to the lake bottom throughout Summit Lake, the areas from shore to about 10 m were comprised of exposed rock. Deeper in the lake, the bottom was covered by bryophytes, which was confirmed for those areas beyond 20 m by lowering sediment core samplers and dredges.

Water Chemistry

The lakes are characterized as extremely dilute systems, all with specific conductance values less than 4 µS/cm (Table 3). The measured pH values correspond well to those expected given these measured ANC values. pH values for the four lakes are increasingly lower as one proceeds from south to north among the study sites. The measured acid neutralizing capacity (ANC) for lakes Notasha and Scout are positive, whereas those for Summit and Foehn lakes are slightly negative. Comparison of the measured ANC with calculated alkalinity ($C_B - C_A$) shows that the measured values are consistently less than the calculated values. This may reflect some uncertainty in the analytical measurements at these low ionic strengths. Alternatively, unmeasured organic anions could be present in sufficient concentrations to cause the calculated alkalinity values to overestimate the actual neutralizing capacity.

The base cations are lowest for Foehn Lake, indicating little watershed input of weathering products to this lake. Among the base cations, Na+ is greatest for Summit Lake. This combined with the high Cl- indicates a much greater input of marine aerosols in Summit Lake compared to the other sites. Sulfate concentrations are very low for the two Oregon lakes, but moderately high for Summit and Foehn lakes. Examination of sea-salt corrected concentrations of sulfate (SO_4^*) shows that most of the sulfate in these lakes is not derived from marine sources.

All four lakes have similarly low concentrations of phosphorus. However, the lakes differ with respect to nitrogen, whereby the Washington lakes have significantly lower concentrations of total nitrogen. If use of stoichiometric ratios of P and N constitute an appropriate method of assessing nutrient limitation, then it appears these lakes are P limited.

Table 3.Major ion and nutrient chemistry measured in the four study lakes. These values represent the average of all measurements.

Analyte	Units	Notasha	Scout	Summit	Foehn
pH	sa	6.16	6.06	5.71	5.50
ANC	µeq/L	11.1	7.8	-0.8	-3.1
Conductivity	µS/cm	2.52	2.24	3.64	3.25
Cations					
H	µeq/L	0.70	0.87	1.96	4.25
Ca	µeq/L	9.58	7.93	7.40	6.39
Mg	µeq/L	6.46	3.74	3.81	2.02
Na	µeq/L	5.37	7.89	10.73	5.98
K	µeq/L	2.30	2.88	0.20	0.77
NH_4	µeq/L	0.13	0.15	0.11	0.05
Anions					
F	µeq/L	0.68	0.05	0.11	0
CL	µeq/L	4.41	4.25	8.89	3.23
NO_3	µeq/L	0.01	0.01	0	0
SO_4	µeq/L	1.81	1.73	6.34	9.20
Derived					
SO_4*	µeq/L	1.34	1.28	5.41	8.86
C_B	µeq/L	23.71	22.45	22.14	15.15
C_A	µeq/L	7.21	6.33	15.33	12.43
C_B-C_A	µeq/L	16.50	16.12	6.81	2.72
Nutrients					
TP	µg/L	3.7	2.7	3	2
PO4	µg/L	0.7	0.3	1	1
TN	µg/L	77	63	40	30
NO3	µg/L	0.3	0.3	0	0
NH4	µg/L	2.3	2.7	2	1

*SO_4 = sea-salt corrected concentrations of sulfate.

The analytical chemistry for the additional lakes in the Washington Cascades sampled as part of the process of trying to locate a substitute for Green Ridge Lake and for supplemental sampling adjacent to Foehn Lake is shown in Table 4.

Table 4. Major ion chemistry of additional candidate lakes examined in the Washington Cascades , including three lakes in proximity to Foehn Lake (N. Tank, S. Tank, & Tahl).

Analyte	Units	Green Ridge	Found	Holden	Hart	Lyman	North Tank	South Tank	Tahl
Date	--	9/24/04	10/08/04	8/30/05	8/30/05	8/31/05	8/28/07	8/28/07	8/28/07
pH	sa	6.19	6.73	6.86	6.99	6.81	5.83	6.04	6.20
ANC	µeq/L	26.0	40.6	88.9	116.7	63.3	7.3	19.1	11.6
Conductivity	µS/cm	8.56	9.13	13.66	27.3	30.1	1.9	3.1	3.23
Cations									
H	µeq/L	0.64	0.18	0.14	0.10	0.15	1.48	0.91	0.63
Ca	µeq/L	32.1	58.1	94.2	174.8	167.7	1.2	9.1	8.7
Mg	µeq/L	7.7	6.2	10.0	33.2	41.4	0.5	4.4	2.4
Na	µeq/L	35.3	16.7	17.3	29.1	22.8	5.9	9.4	9.9
K	µeq/L	4.6	6.2	3.7	13.9	18.1	0.7	0.7	2.2
NH_4	µeq/L	0	0.66	1.4	0.66	1.1	0	0	0
Anions									
F	µeq/L	0.5	1.3	0.2	.8	0.63	0.1	0.1	0.1
CL	µeq/L	15.4	3.4	1.7	10.9	2.3	4.8	6.8	6.5
NO_3	µeq/L	1.1	0	2.0	0	0.7	0.02	0.02	0.2
SO_4	µeq/L	18.4	23.5	15.3	97.3	161.7	2.1	2.4	3.0

Lake Biota

Phytoplankton

Phytoplankton abundance as indicated by algal biovolume was low in all four lakes (Figure 30). However, algal biovolume is incredibly low in Summit Lake and surprisingly low in Scout Lake. Algal biovolume was more moderate in Foehn Lake, perhaps because of its shallow depth. Algal cell density followed a generally similar ranking as biovolume among the four lakes, although cell density was comparatively higher in lakes Notasha and Scout because of high numbers of small taxa.

For lakes with multiple phytoplankton samples, Notasha and Scout, the dominant taxa remained relatively stable from year to year (Table 4). The dominant group in Lake Notasha was the dinoflagellates, with green algae as sub-dominants. In Scout Lake, the dinoflagellates were also important, although there was a more balanced population of green algae and chrysophytes. Summit Lake was totally dominated by diatoms, whereas Foehn Lake was again a dinoflagellate community.

Chlorophyll *a* concentrations were low in all four lakes, although again Summit Lake exhibited the lowest observed values (Figure 31). Concentrations in the other three lakes were similar with median values between 1-2 μg/L.

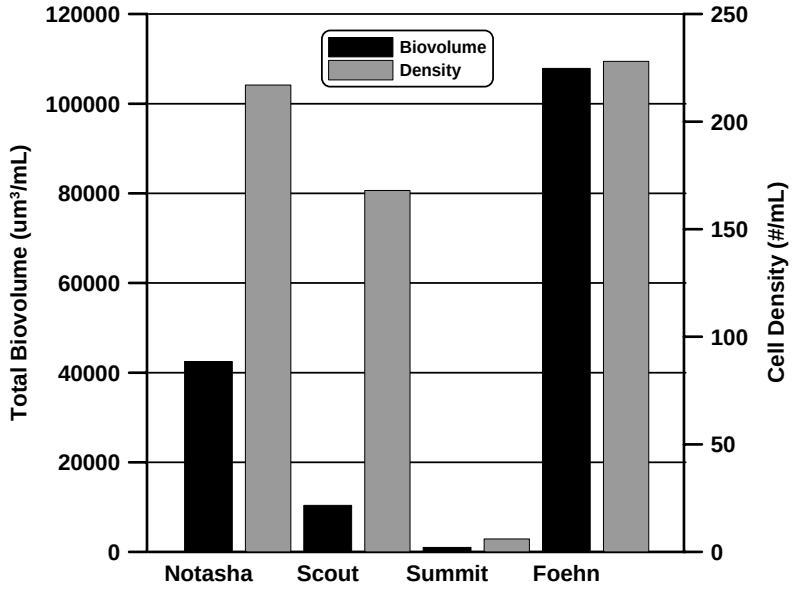

Figure 30. Total biovolume and cell density of phytoplankton samples collected from the four study lakes.

Table 5. Dominant algae in the study lakes.

Taxon	Group	Notasha			Scout			Summit	Foehn
		2004	2006	2007	2004	2006	2007	2004	2005
Dinobryon setularia	dinoflagellate	49.6	82.3	31.1					
Glenodinium sp.	dinoflagellate	17.7	6.3	49.0	31.3	46.9	10.2		87.3
Hemidinium sp.	dinoflagellate								12.3
Oocystis spp	green	14.3	7.3	13.9					
Sphaerocystis schroeteri	green	8.9	1.3						
Mougeotia sp.	green				31.6				
Ulothrix sp.	green						59.5		
Chromulina	chrysophyte				27.0	42.5	24.5		
Synedra rumpens	diatom							32.1	
Eunotia pectinalis	diatom							47.2	
Cymbella minuta	diatom							12.1	

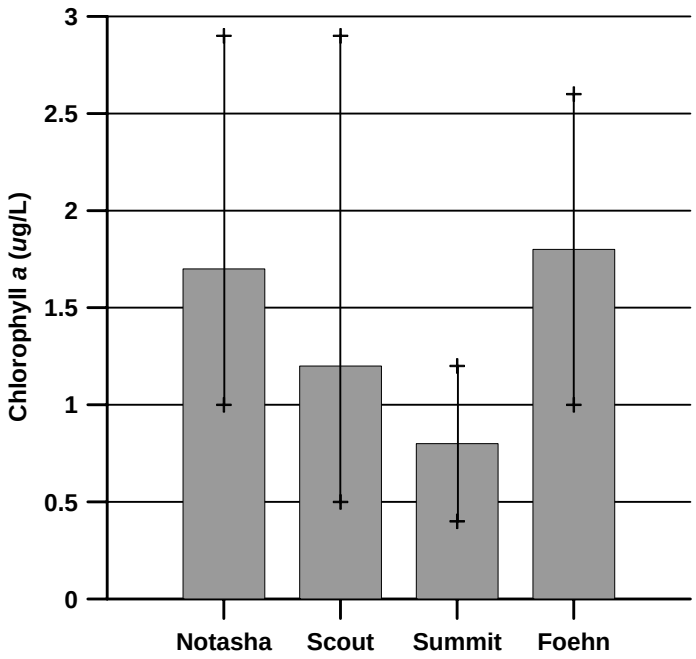

Figure 31. Average chlorophyll a concentrations measured in the study lakes (bars) and the range of values observed during the study (vertical lines).

Zooplankton

Community composition and abundance of zooplankton varied greatly among the study lakes (Tables 5-8). Lake Notasha had an abundant and diverse zooplankton population characterized by high densities of cladocerans, copepods, and rotifers. Although most of the cladocerans were relatively small, Lake Notasha had *Daphnia rosea*, a large cladoceran present in all samples. The zooplankton population in Scout Lake was comprised of low densities of cladocerans, but high densities of large diaptomid copepods (Figure 32) and abundant rotifers. Zooplankton density and diversity was very low in Summit and Foehn Lakes. Cladocerans were rare in both of these lakes, although copepods were moderately abundant in Summit Lake. Rotifers were also sparse in both Summit and Foehn lakes.

Table 6.Zooplankton samples results for Lake Notasha.

		Zooplankton Densities (in no. per m^3)		
Date	Sampled	24-Aug-04	16-Aug-05	23-Aug-08
Depth	Sampled	7.3152	7	9
Volume	(m^3)	0.05745	0.05498	0.07069
CLADOCERA		Density	Density	Density
Diaphanosoma	*brachyurum*	20608	29393.6	962
Daphnia	*rosea**	278.5	2910.3	113.2
Bosmina	*longirostris*	8633.1	27356.5	4923.2
Chydorus	*sphaericus*	278.5		
Holopedium gibberum				4866.6
Total	cladocerans	29798	59660.4	10865
COPEPODA				
Leptodiaptomus tyrrelli			20953.9	
*Hesperodiaptomus kenai**				113.2
Epischura	*nevadensis*	278.5		
Leptodiaptomus	*tyrrelli*	31469		1754.2
diaptomid	*copepodite*	54583.3	77121.9	9450.3
Microcyclops	*varicans*	557		
cyclopoid	*copepodites*	278.5		
copepod	*nauplii*	14202.8	50056.5	1924
Total	copepods	101369	148132.3	13241.7
chironomid larvae*			18.2	28.3
ROTIFERA				
Keratella	*taurocephala*	2784.9	4074.4	
Kellicottia	*bostonensis*	557		
Polyarthra	*doliochoptera*	11208.9	21244.9	6734
Monostyla crenata			291	
Ploesoma	*truncatum*	557		
Difflugia sp.			582.1	
Concochilus	*unicronis*	77419.2	127760.5	3848
Total	rotifers	306891.9	132707.9	10582
Total	Density	438059	340518.8	34717

Table 7. Zooplankton sampling results for Scout Lake.

Date Sampled	10-Aug-04	18-Aug-05	14-Aug-06	28-Jul-07	4-Aug-08
Depth Sampled	8	7	6.2	8	8.23
Volume (m^3)	0.25133	0.05498	0.04869	0.06283	0.06464
CLADOCERA	Density	Density	Density	Density	Density
Daphnia ambigua		145.5	0	0	0
Bosmina longirostris		363.8	985.7	0	0
Holopedium gibberium	334.2	654.8	0	1018.6	0
Chydorus sphaericus		72.8	3614.4	127.3	0
Total cladocerans	334.2	1236.9	4600.1	1145.9	0
COPEPODA					
large diaptomid copepodite	3183.1	37615.1	114016.5	56149.9	7008.6
small diaptomid copepodite	230.8				
Microcyclops varicans	15.9	72.8		0	0
cyclopoid copepodite	8	145.5	657.2	0	0
copepod nauplii	15.9	0	0	891.3	2274.3
Total copepods	3453.7	37833.4	114673.7	57041.1	9282.9
MISC. ARTHROPOD ZOOPLANKTERS					
chironomid larvae		0	0	0	0
ROTIFERA & PROTISTA					
Keratella cochlearis	11204.5	55877	31543.5	8148.7	4069
Keratella taurocephala	233257.5	791591.2	1035677.7	549020.9	0
Kellicottia longispina		0	0	0	0
Hexarthra sp.		6984.6	0	0	0
Polyarthra vulgaris			0	0	46.4
Conochiloid			0	0	15.5
Total rotifers & protists	244462	854452.9	1067221.2	557169.6	4069
Total Density	248249.9	893523.1	1186495	615356.7	13351.9
Total Count		537	769	1004	863

Table 8. Zooplankton sampling results for Summit Lake.

	4-Oct-04	12-Oct-05	27-Oct-06	6-Sep-07
Volume Sampled (in cubic feet)	50	50	40	
Volume (m^3)	1.41584	1.41584	1.25664	0.11781
CLADOCERA	Density			
Daphnia rosea *	33.9			
Acroperus harpae			25.5	
Total cladocerans	33.9	0	25.5	0
COPEPODA				
Diaptomus (L.) sicilis	3898.7		2094.5	
diaptomid copepodite (Small)	440.7		38.2	
diaptomid copepodite (Large)		9989.8		458.4
copepod nauplii	11.3	226	12.7	365
Total copepods	4350.8	10215.8	2145.4	823.4
ROTIFERA				
Notommata sp.			6.4	
Total rotifers	0	0	6.4	0
Total Density		10215.8	2183.6	831.9
Density of Edible Zooplankton (*)		9989.8	0	458.4
% Edible Zooplankton		97.8	0	55.1

Table 9. Zooplankton samples results for Foehn Lake.

Date Sampled/Split size	27-Sep-05	11-Oct-06	3-Sep-07
Depth Sampled (m)	4	4	4
Volume (m^3)	0.12566	0.12566	0.12566
CLADOCERA	Density		
Total cladocerans	2.5	0	0
COPEPODA			
diaptomid copepodite (Sm)*		8	
Microcyclops varians	0.1		2
cyclopoid copepodites	0.4	8	23
harpacticoids			6
copepod nauplii	1	63.7	43
Total copepods	2	87.5	74
Misc. Zooplankters			
Chironomid larvae *	0.2	8	1
ROTIFERA			
Keratella taurocephala	0.1	8	
Kellicottia bostonensis	0.3		2
Monostyla closterocerca	0.1	8	1
Polyarthra doliochoptera	0.7	238.7	1
Filinia terminalis			1
Total rotifers	1.2	254.6	5
PROTOZOA			
Difflugia sp.	0.1		1
Total Density	6.0	350.1	86
Density of Edible Zooplankton (*)	2.8	8	1
% Edible Zooplankton	5.3	8.3	1.3

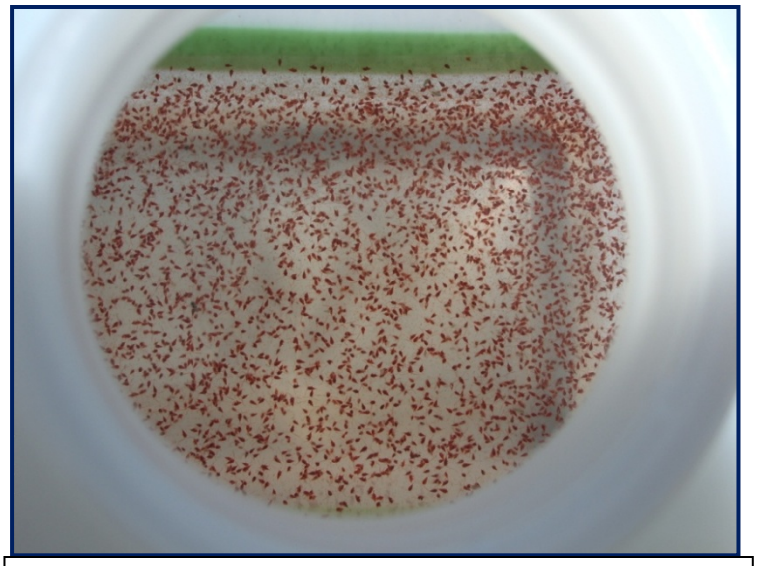

Figure 32. Large diaptomid copepodites present in a net two collected from Scout Lake, August 14, 2006, as viewed through the top of a 500 mL Nalgene bottle.

Benthic Macroinvertebrates

The benthic macroinvertebrate populations in all four study lakes are depauperate based on these qualitative samples (Table 9). Only Scout Lake exhibited a reasonable abundance of chironomids, with six genera and 198 individuals collected in the three Eckman dredge samples. The extensive mats of bryophytes over the substrate of Summit Lake may have hindered collection of additional invertebrates because of the difficulty in penetrating the vegetation. A sediment core tube was used to sample the benthic invertebrates in Foehn Lake, but despite repeated attempts, only one individual was collected (Figure 33).

Table 10. Benthic macroinvertebrates collected from each of the study lakes in 2007.

Taxonomic Group	Genera	Notasha	Scout	Summit	Foehn
Ephemeroptera	*Callibaetis sp.*	2	0	0	0
Diptera-Chironomidae	*Chironomini*	0	1	0	0
	Chironomus sp.	4	1	0	0
	Cladotanytarsus sp.	0	170	0	0
	Cryptochironomus sp.	0	1	0	1
	Dicrotendipes sp.	1	0	0	0
	Pagastiella sp.	1	0	0	0
	Procladius sp.	6	5	0	0
	Protanypus sp.	0	0	1	0
	Sergentia sp.	0	0	3	0
	Stictochironomus sp.	0	20	0	0
	Tanytarsus sp.	1	0	0	0
	Tribelos sp.	1	0	0	0
Trichoptera	*Oecetis sp.*	1	0	0	0
Annelida	*Tubificidae*	0	0	1	0
	TOTAL	**17**	**198**	**5**	**1**

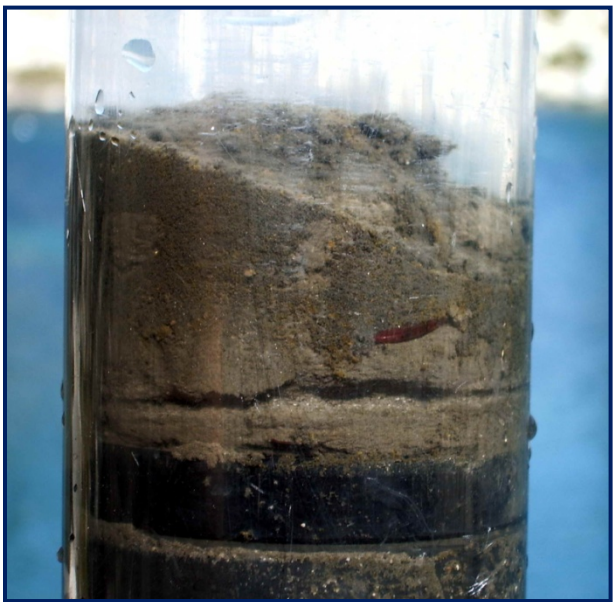

Figure 33. A *Cryptochironomus* (red midge) present in the sediment of Foehn Lake.

Paleolimnology

Sediment cores were collected from Scout and Foehn lakes as part of this project. Paleolimnological reconstructions were previously conducted for Lake Notasha and Summit Lake, but these results are summarized here for completeness.

Lake Notasha

The sediments of Lake Notasha were previously sampled and reported by Eilers et al. (1996). The major results from that study are summarized here. The sediment core from Lake Notasha reached down to the Mazama ash layer, which could not be penetrated after multiple attempts with a push-rod corer. The upper 3-4 cm of the sediment represented the modern period back to about 130 ybp. The core exhibited surprising variability in LOI and percent water, decreasing from the sediment surface to about 9 cm (circa 390 ybp), increasing abruptly and then showing minor changes to the base of the core (Figure 34).

A total of 82 diatom taxa were identified in the core and the core represented two distinct community types, with a demarcation near 3,600 ybp (Figure 35). The dominant taxa in the upper portion of the core were *Navicula tenuicephala* and *Pinnularia braunii,* although *Achnanthes marginulata* and *Cymbella triangulum* increased in the upper sediments. The base of the core was dominated by *Pinnularia brebissonii*, with sub-dominants being Melosira *(Aulocoseira) distans* and *Frustulia rhomboides.*

The diatom-inferred changes based on the diatom community composition as analyzed with WACALIB (Birks et al. 1990) showed little change in pH and conductivity over the last 3,000 years (Figure 36). A change appears to have occurred before that date, although the magnitude of the shift is relatively small.

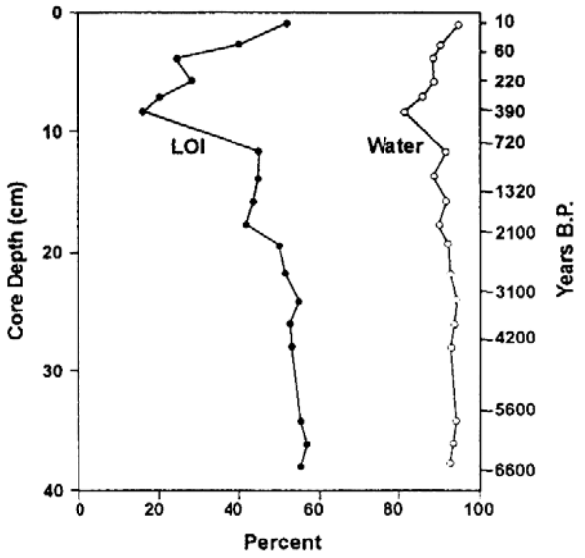

Figure 34. Loss-on-ignition (LOI) and percent moisture for the sediments in Lake Notasha plotted against sediment depth and age of sediments (from Eilers et al. 1996).

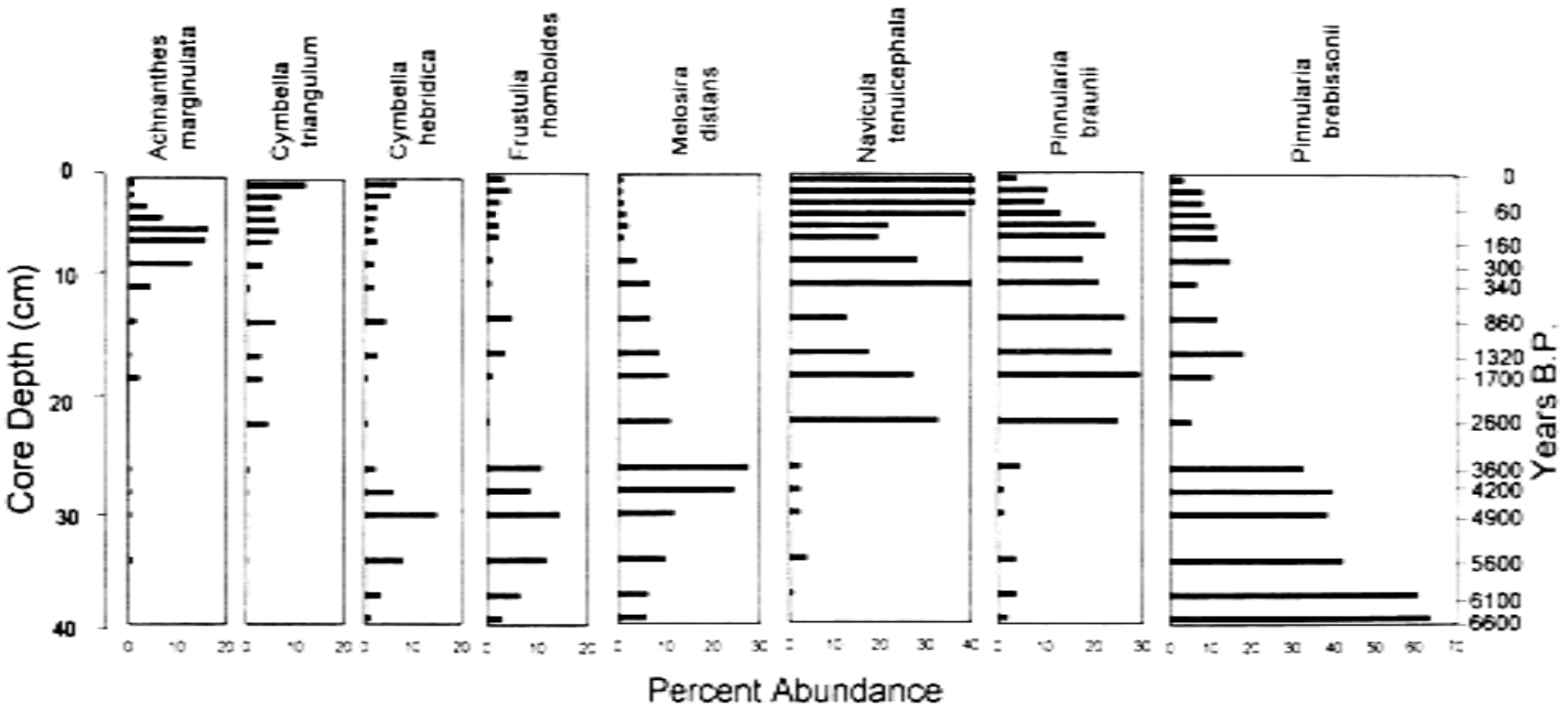

Figure 35. Diatom stratigraphy of the dominant diatoms in the sediments of Lake Notasha (from Eilers et al. 1996).

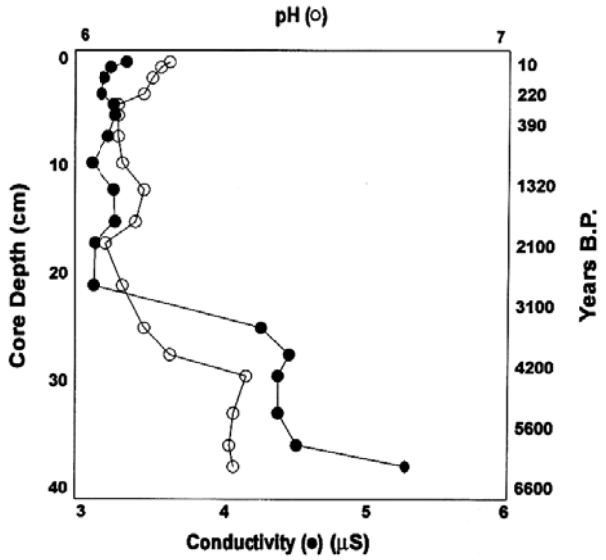

Figure 36. Diatom-inferred changes in pH and conductivity for Lake Notasha (from Eilers et al. 1996).

Scout Lake

Three sediment cores were collected from Scout Lake. All were approximately the same appearance with about 12 cm of accumulated sediment overlying volcanic ash (Figure 37). Apparently the dense volcanic ash limited further penetration, despite the addition of more weight to the corer. The percent moisture shows a sharp decline at the interface with the tephra, reflecting the dense composition of the volcanic ash (Figure 38). The ^{210}Pb activity reaches background levels at 5 cm depth in the sediment, which should correspond to accumulations over the last 130 years or so (Figure 39). The sediment accumulation rate (SAR) shows a slight increase in the upper sediments, perhaps associated with increased erosional inputs (Figure 40). The age of the upper sediments was compared with dating of three sediment intervals using ^{14}C. The results show general agreement between the two dating methods accounting for the much higher uncertainty in the ^{14}C dates (Figures 41 and 42). The upper 8 cm of the core exhibit stable concentrations of carbon and nitrogen, although phosphorus is much more variable (Figure 43). The concentrations of all three nutrients declined considerably deeper in the core, reflecting the increased proportion of ash in the sediment.

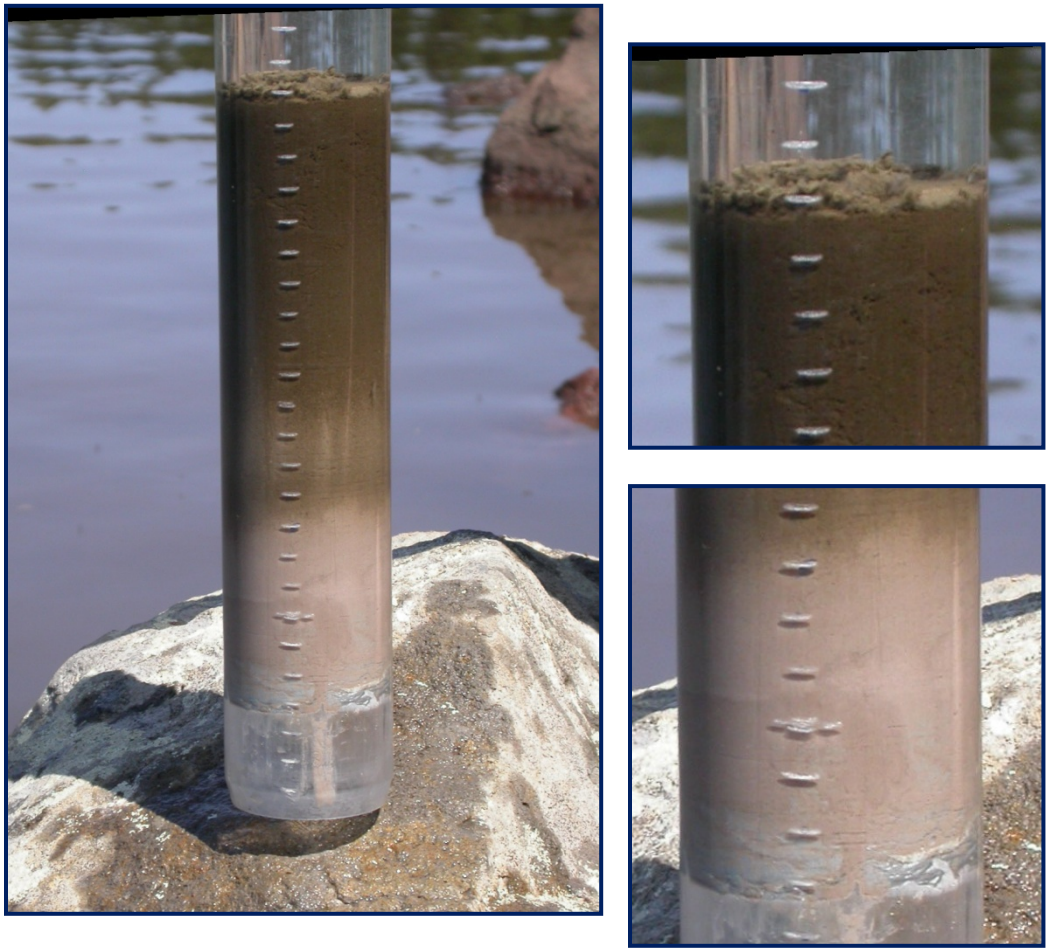

Figure 37. Sediment core from Scout Lake. The marks on the core tube indicate intervals of 1 cm. The brown material represents accumulation of organic matter and fine-grained soil. The light-colored material at the bottom of the core is volcanic ash.

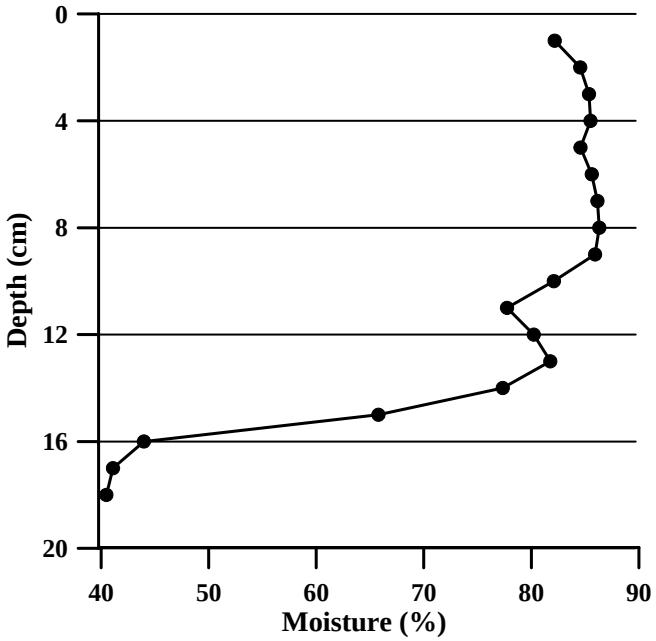

Figure 38. Moisture content of the sediment from Scout Lake.

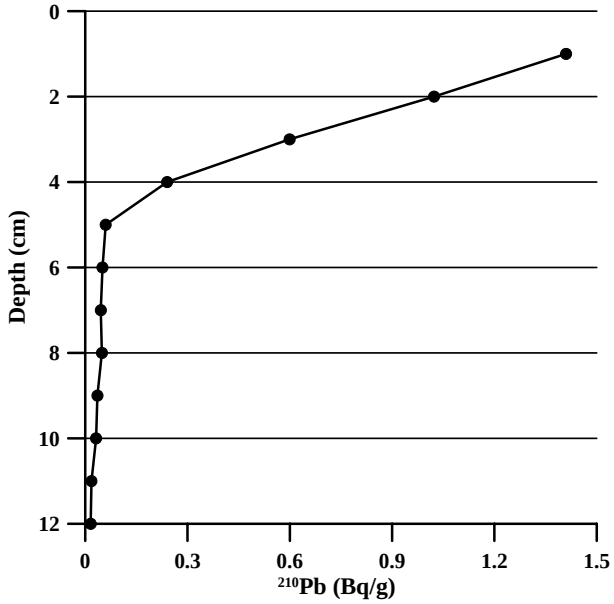

Figure 39. Activity of ^{210}Pb in the sediments of Scout Lake.

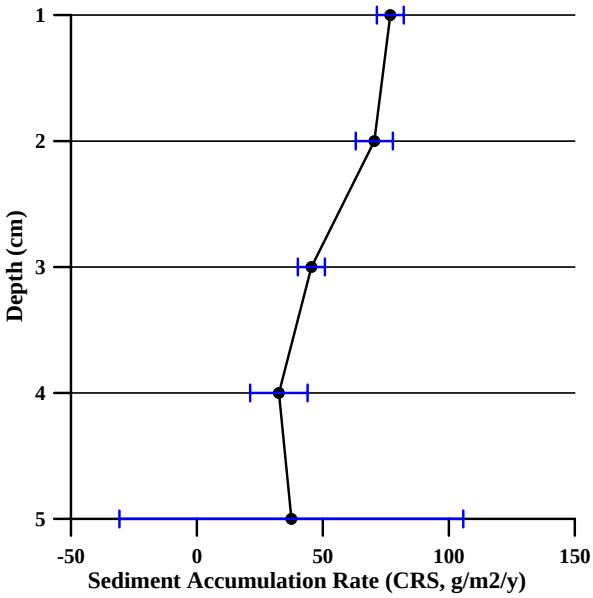

Figure 40. Sediment accumulation rate computed for the upper 5 cm of Scout Lake.

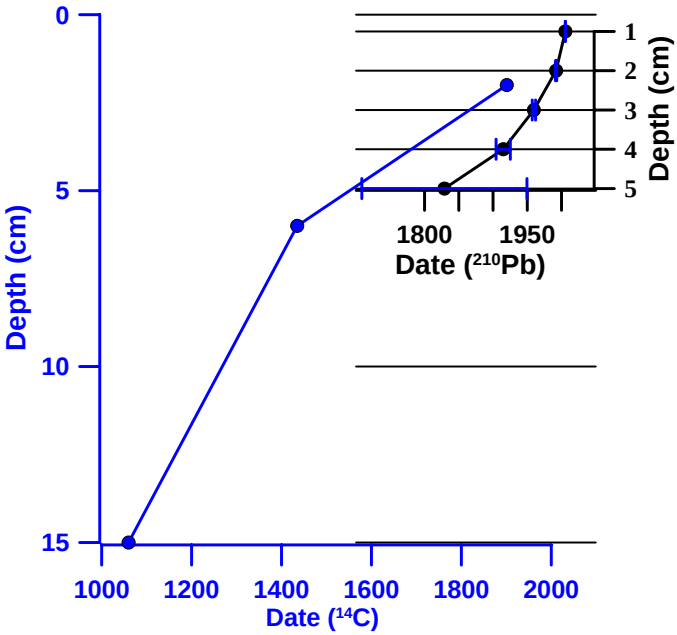

Figure 41. Age of sediments in Scout Lake computed using ^{14}C versus the results from the ^{210}Pb dating in the upper sediments (insert).

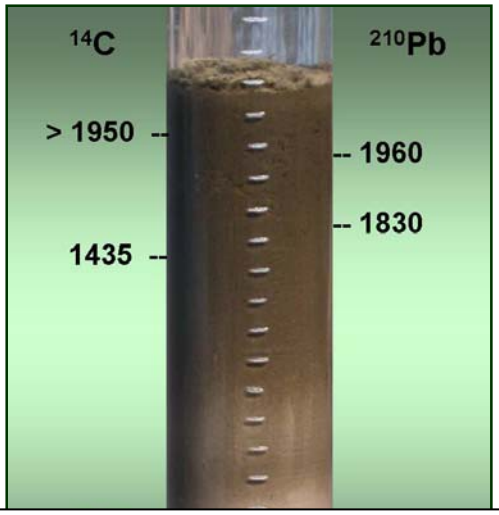

Figure 42. Sediment core from Scout Lake showing the estimated age of the sediments using results from three analyses of ^{14}C on the left and the selected intervals from the ^{210}Pb on the right.

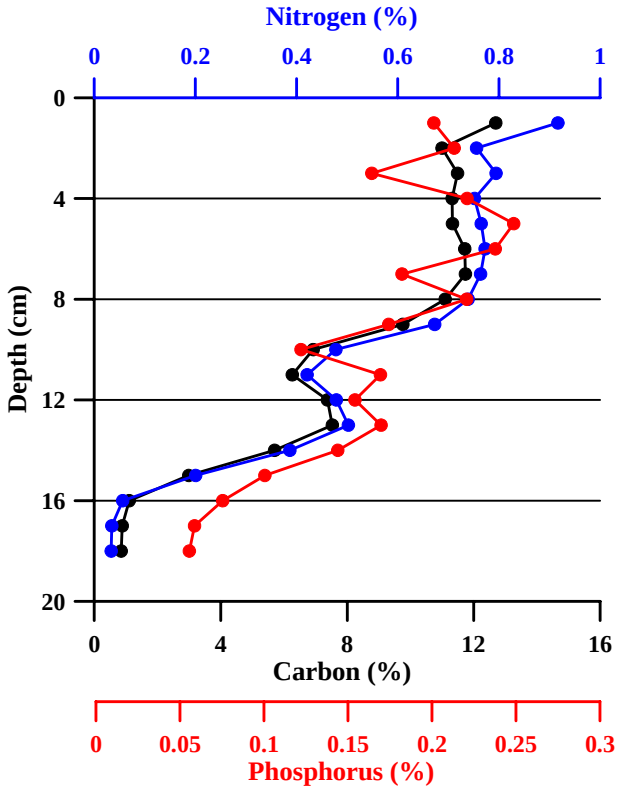

Figure 43. Concentrations of carbon (black), phosphorus (red), and nitrogen (blue) in the sediments of Scout Lake.

The diatom community composition in the upper sediment intervals is relatively stable (Figure 44). The dominant taxon is *Aulocoseira distans*, a facultative planktonic species that prefers planktonic conditions, but has no means to remain in suspension. The DI-pH and total phosphorus in Scout Lake show no significant change in the modern era (Figures 45-46).

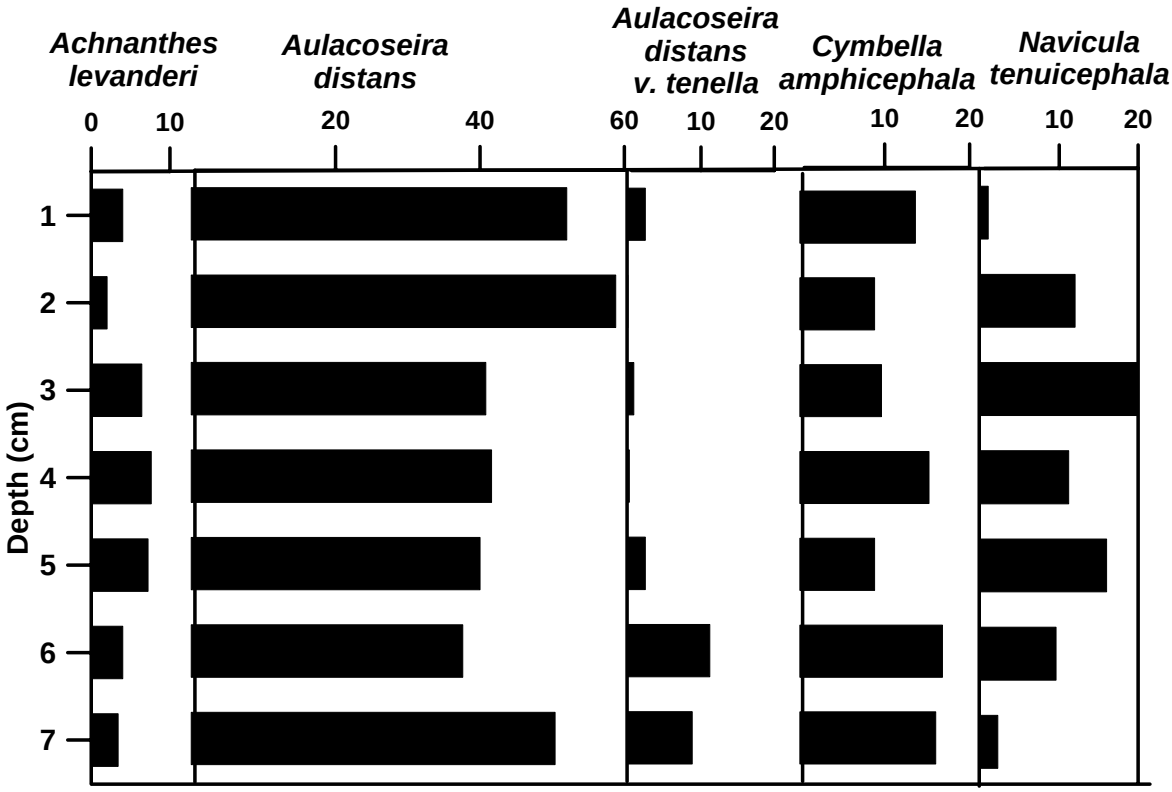

Figure 44. Relative abundance of dominant taxa of diatoms in the sediments of Scout Lake in the upper 7 cm.

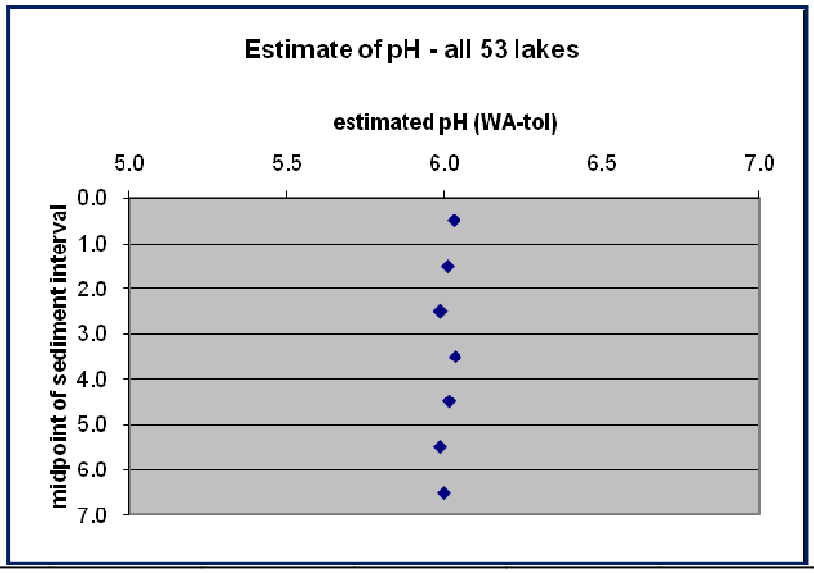

Figure 45. Diatom-inferred (DI) pH for sediments in Scout Lake based on weighted-average (WA-tol) boot-strapping statistical techniques. 53 lakes refers to the number of lakes used in the diatom calibration set for the Cascade lakes. Refer to the report by Eilers et al. (1998) for additional details on the methodology for constructing the DI-pH and DI-TP (below).

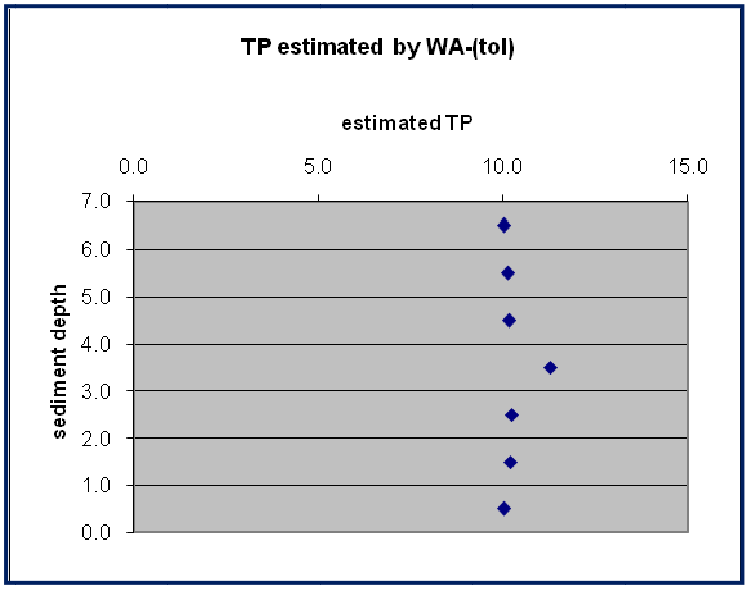

Figure 46. Diatom-inferred (DI) total phosphorus for sediments in Scout Lake based on weighted-average boot-strapping statistical techniques

Summit Lake

A paleolimnological analysis of Summit Lake was conducted earlier (Eilers et al. 1998a), but the major findings are repeated here for completeness. The sediment core collected from Summit Lake was capped at the surface by a layer of bryophytes (Figure 47). The core contained one and possibly two layers of tephra that corresponded to previous eruptions from Mt. Rainier. The sediment accumulation rate increased in the upper 4 cm of the sediment and showed a substantial increase over the long-term SAR based on a regression analysis (Figure 48).

Figure 48. Sediment core from Summit Lake.

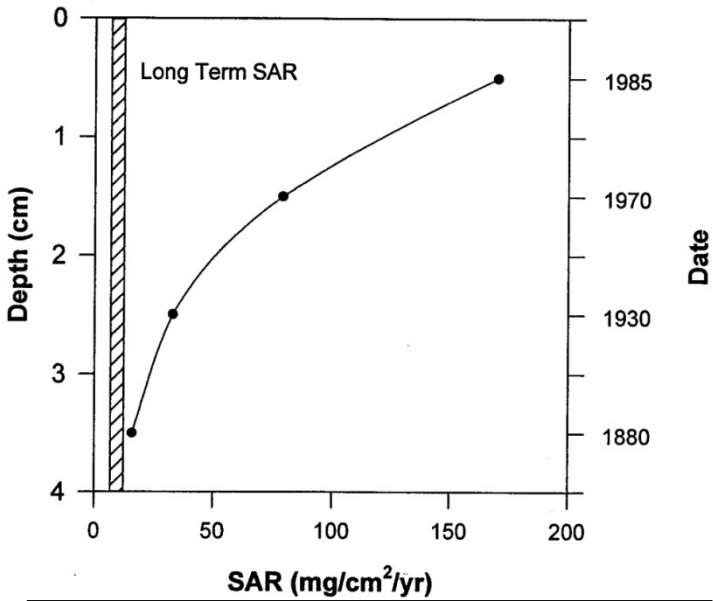

Figure 47. Sediment accumulation rate for the upper 4 cm of sediment in Summit Lake compared to a computed long-term average SAR.

The diatom stratigraphy in Summit Lake showed no change in the modern era or in comparison with intervals analyzed deeper in the core (Figure 49). The dominant taxa in the sediment were benthic or tycoplanktonic acidophilic diatoms. The lack of planktonic diatoms in the sediment suggests the importance of benthic processes in Summit Lake. Diatom-inferred pH and conductivity showed no trend in the sediment (Figure 50). Analyses of metals and nutrients in the sediment of Summit Lake also showed no significant trends (Figure 51). However, both total phosphorus and titanium exhibited declines in the upper sediments that are suggestive of oligotrophication. Similarly, carbon, nitrogen, and sulfur showed no apparent trends in the core (Figure 52).

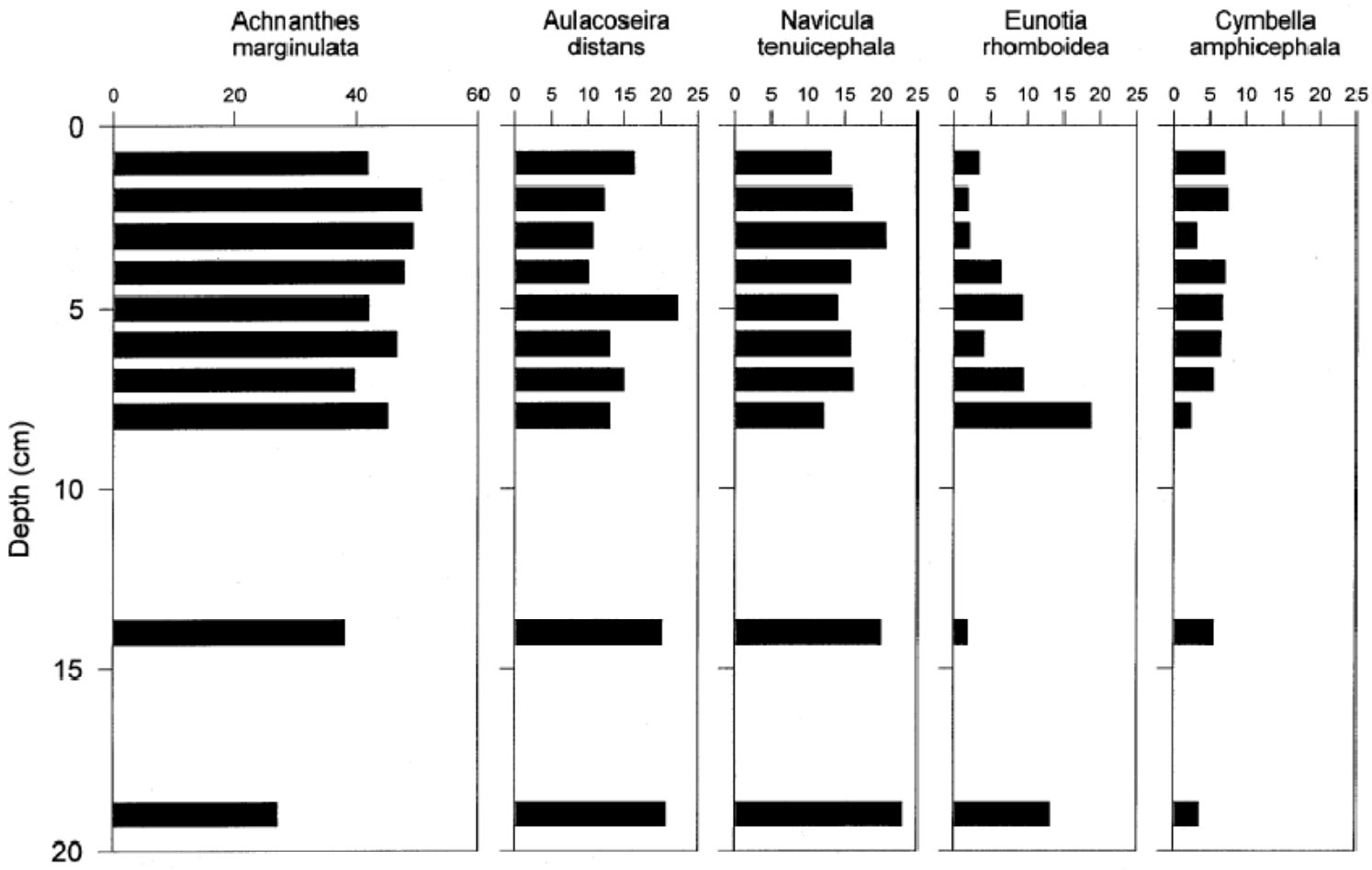

Figure 49. Relative abundance of dominant diatoms in the sediment of Summit Lake (from Eilers et al. 1998).

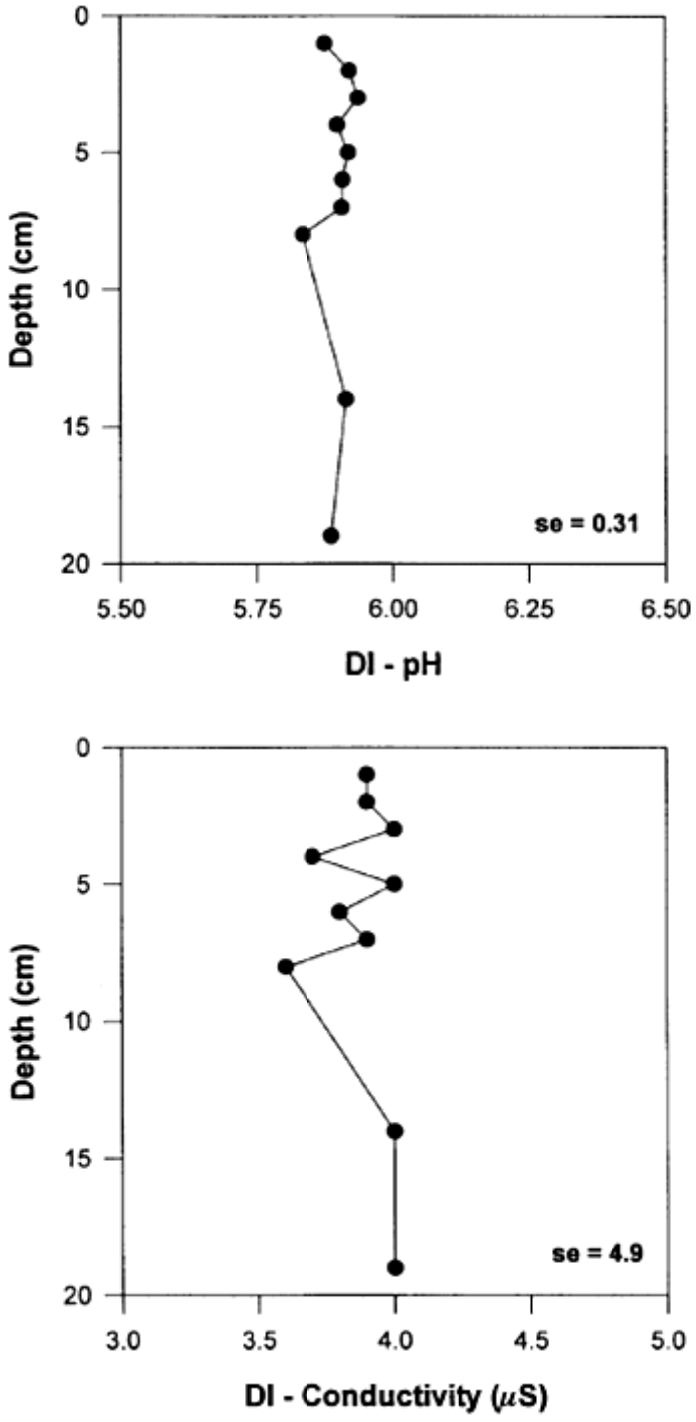

Figure 50. Diatom-inferred (DI) reconstructions of down-core changes in lake pH (top) and lake conductivity (bottom) for Summit Lake (from Eilers et al. 1998a).

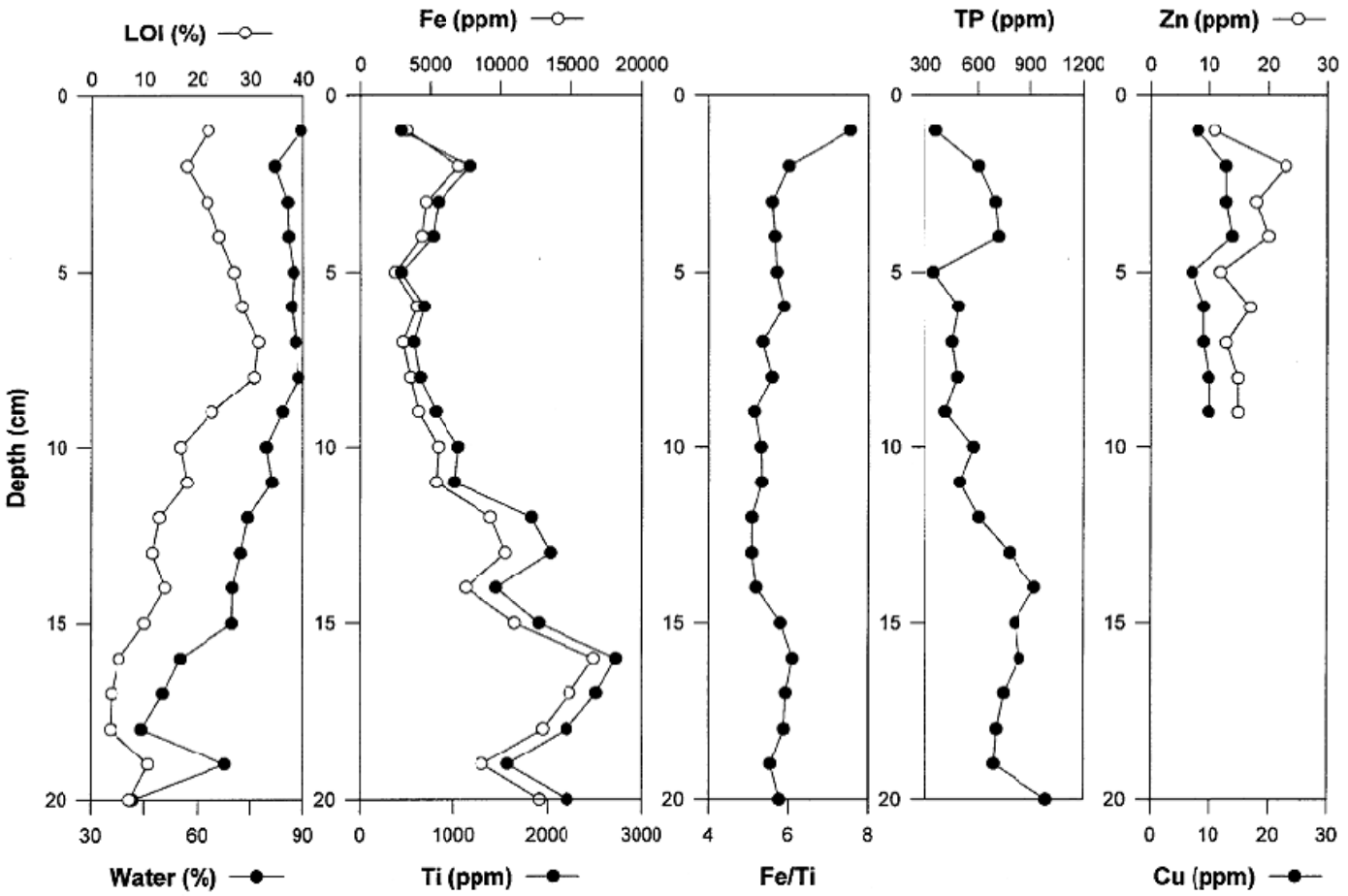

Figure 51. Changes in moisture content and chemical attributes of the sediments of Summit Lake (after Eilers et al. 1998a).

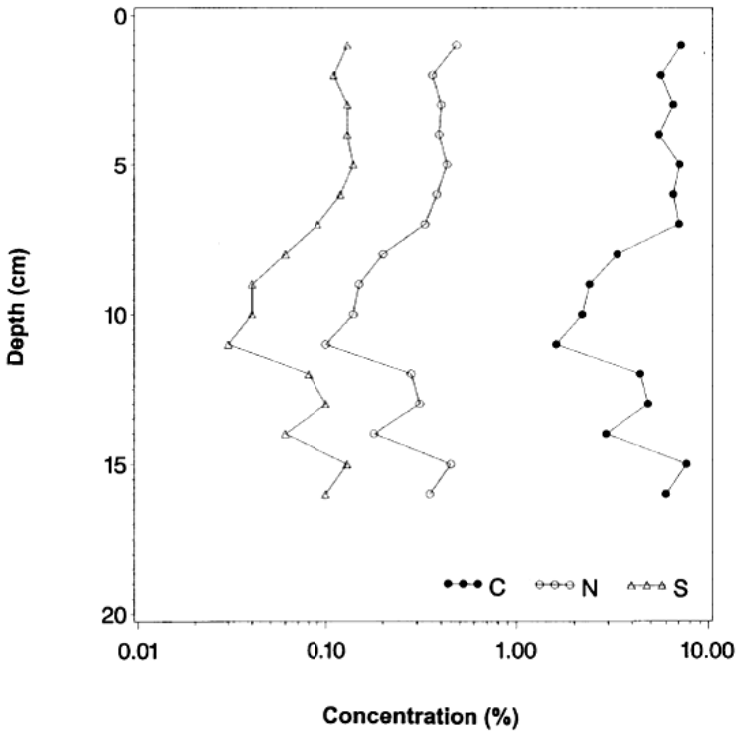

Figure 52. Changes in carbon, nitrogen, and sulfur content of the sediments in Summit Lake (from Eilers et al. 1998).

Foehn Lake

The depth of sediment in Foehn Lake appeared to range from only 3-4 cm based on numerous coring attempts. Because the sediment was so shallow, the cores retained for analysis were sectioned in intervals of 0.5 cm. The consistency of the cores was fine-grained material interspersed with small pebbles and underlain by either sand or ash (Figure 53). Moisture content decreased from near 85 percent at the surface to almost 65 percent at the base of the core (Figure 54).

The carbon and nitrogen content of the sediments declined from the surface to 2.5 cm and increased slightly at the base (Figure 55). Carbon and nitrogen concentrations in the sediments of Foehn Lake were substantially less than observed in the sediments from the other three lakes. The titanium concentrations decreased in the upper portion of the sediments, although it is unclear if the magnitude of this apparent decline is significant.

The ^{210}Pb activity of the sediments declined linearly from the surface to 2.5 cm depth (Figure 56). The apparent baseline activity in Foehn Lake is much greater than observed for other Cascade lakes, perhaps reflecting sediment focusing of the available sediments or mixing of the

initially-deposited sediments. The ^{210}Pb isotopic data indicate that Foehn Lake appears to be a recently formed lake, on the order of 100 years old (Figures 57 and 58). The sediment accumulation rate for the core shows a stable SAR, except for interval 2.5 cm (Figure 59).

Figure 53. Sediment core collected from Foehn Lake.

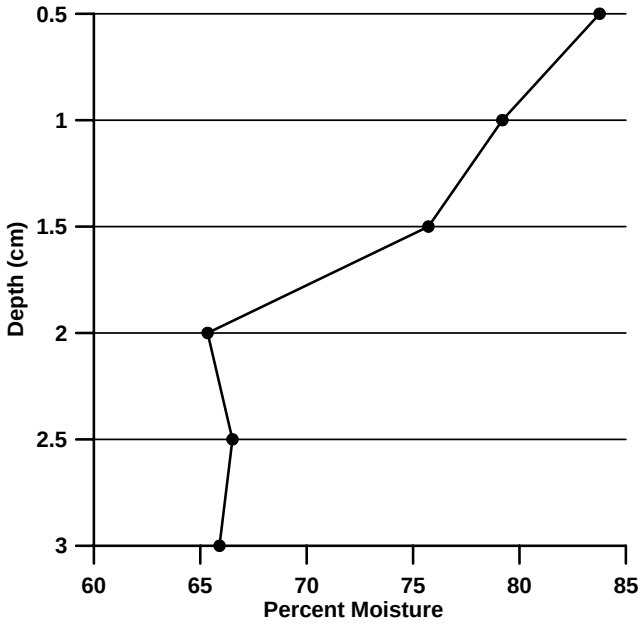

Figure 54. Percent moisture in the sediments of Foehn Lake.

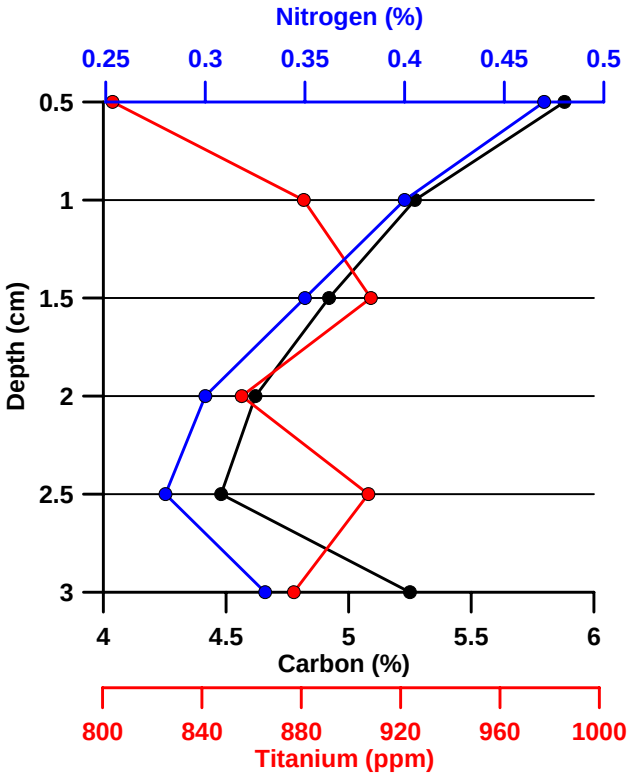

Figure 55. Concentrations of carbon, nitrogen, and titanium in the sediments of Foehn Lake.

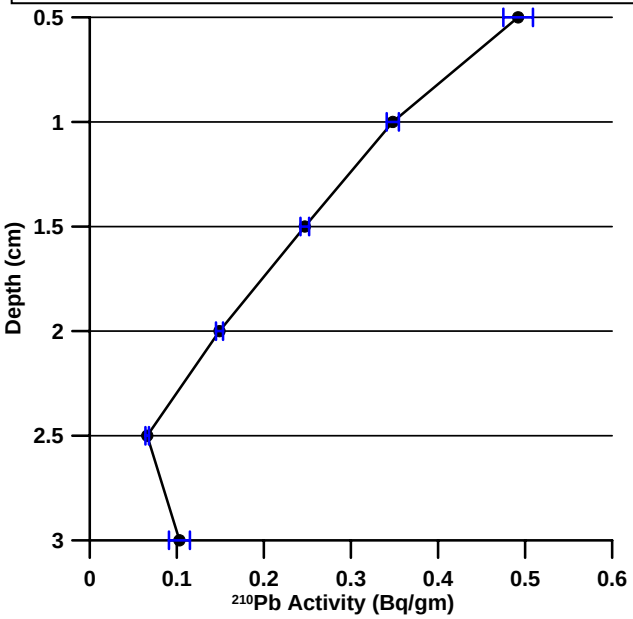

Figure 56. Activity of ^{210}Pb in the sediments of Foehn Lake.

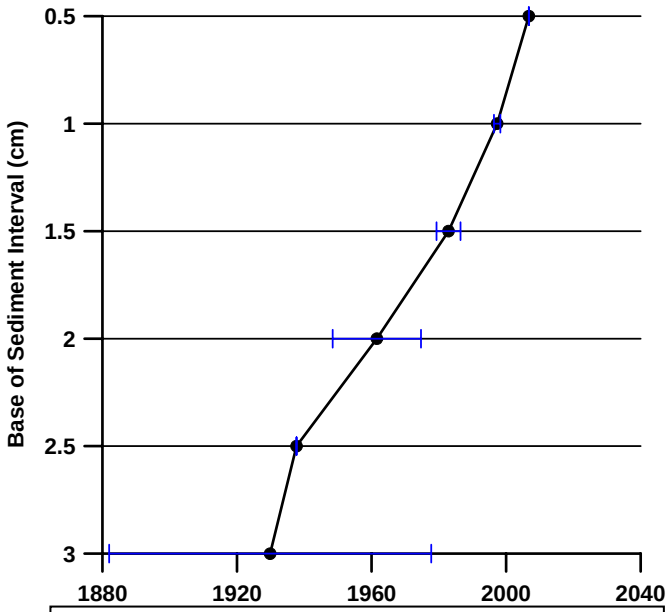

Figure 57. Sediment dating for Foehn Lake.

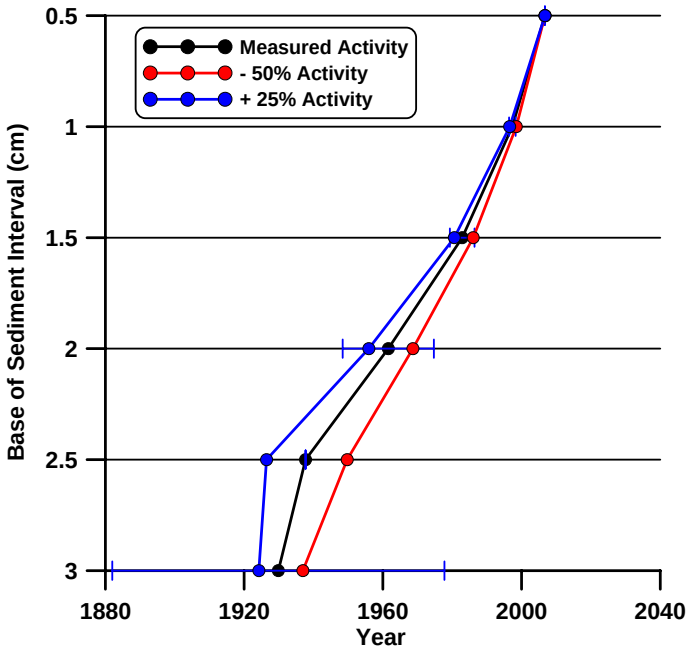

Figure 58. Modeled dating for Foehn Lake (black) and a sensitivity analysis, assuming a 50% decrease in background ^{210}Pb activity (red) and a 25% increase in ^{210}Pb activity (blue).

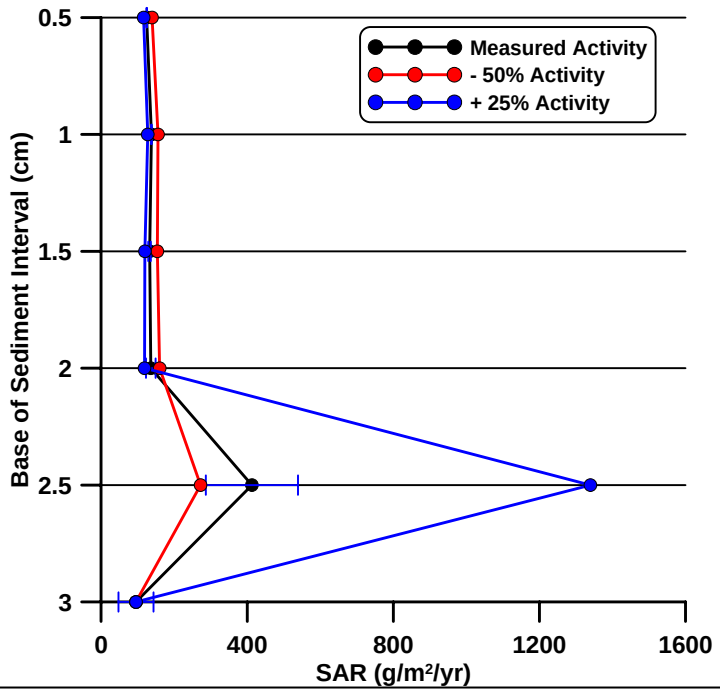

Figure 59. Sediment accumulation rates (SAR) for Foehn Lake, shown with results from sensitivity analyses.

The diatom assemblage of Foehn Lake is dominated by *Aulacoseira distans* at frequencies of 50 percent (Figure 60). Other *Aulacoseira* spp. that are closely related bring the genus total to around 60 percent. *A. distans* is most commonly thought of as tychoplanktonic, or, expressed another way, facultatively planktonic. These diatoms settle onto the sediments, survive, and await physical resuspension. Diatoms have no active way to remain in the water column. *A. distans* prefers neutral to slightly acidic waters and its optimum pH in the Northwest calibration set is about 6 pH units and in total phosphorus (TP) 10.2 ug/L as it is typically found in oligotrophic or slightly mesotrophic conditions. In more eutrophic environments the species is commonly shaded out by planktonic forms or colonial blue-greens.

Very similar optima are found for the two other most common species in the sediments, *Pinnularia subcapitata* and *Achnanthes levanderi*. However, these species are, respectively, benthic and epiphytic. Virtually all other species identified from the sediments outside of the *Aulacoseira* are found on substrates throughout the life cycle. Taken as a whole, the diatom assemblage of Foehn Lake is extremely depauperate in number of species. Only 47 species in 13 genera were identified in the 500 valve count and a survey of an additional 500 species added only 4 to 8 additional taxa at very low numbers. The three common species noted before are extremely common throughout the Northwest calibration set (Eilers et al. 1998b). All three belong to complexes of similar diatoms that are difficult to separate taxonomically and are also found together. The assemblage is even more depauperate when these complexes of species are considered as most of the 47 are likely closely related to each other and are also very common in

Northwest lakes. The core assemblage is similar to other cores from Cascade Range, such as Scout Lake.

An interesting qualitative observation is that the core diatoms are well preserved, with relatively few broken valves. This could indicate there has been very little microanimal activity. Alternatively, the *Aulacoseira* genus is strongly silicified. Most of the other diatoms found in the sediments of Foehn Lake are substrate dwellers. The counts did not record a single commonly planktonic species.

The diatoms in Foehn Lake are common in the Northwest calibration set and so provided a robust reconstruction. More than 90% of the diatoms identified in Foehn Lake were also members of the calibration set. However, the Foehn Lake core had a remarkably consistent assemblage throughout. The assemblage did not change appreciably in composition or in relative frequencies. The only noticeable change in the core was the peak in percentage of all three of the most common diatoms in the 2.0-2.5 cm interval. This was led by the high mark for *A. distans* at 60%. This is reflected by slight changes in the reconstructed water parameters, pH and total phosphorus (TP).

The pH reconstruction based on a 54 lake calibration set from the Northwest shows little change in pH, as the estimated pH varies slightly around pH of 6.0. This is not surprising as all three of the major diatoms have optima around 6.0 or just below. The 2.0-2.5 interval shows a very slight decrease in pH. This analysis and the graphs used the weighted average model incorporating tolerances [WA (tol)]. The root mean squared error of prediction for samples in the training set (combining bootstrap and prediction errors) was 0.50 pH units. An analysis of variance conducted when plotting observed versus predicted values has an adjusted R^2 of 0.833 and a standard error of 0.324. It is notable that the pH reconstruction is based on lakes of between 5 and 8.5 pH units. A pH of 6 is toward the mid-lower range of these lakes.

The total phosphorus (TP) reconstruction was based on 41 lakes for which TP values are known. The majority of these are in the Cascades region with most of the Sierra Nevada lakes eliminated. The TP values also vary little from around 10 mg/L (RMSE= 6.835; ANOVA R^2= 0.6705, s.e.=4.185). As previously noted and demonstrated by the statistics, the phosphorus reconstruction is not as reliable as the pH, although again the diatoms are extremely well represented in the calibration set. A TP concentration of 10 *u*g/L is near the median in the calibration set and greater than the measured concentrations in Foehn Lake. However, in this case, the information on trends is more relevant than the actual DI-value.

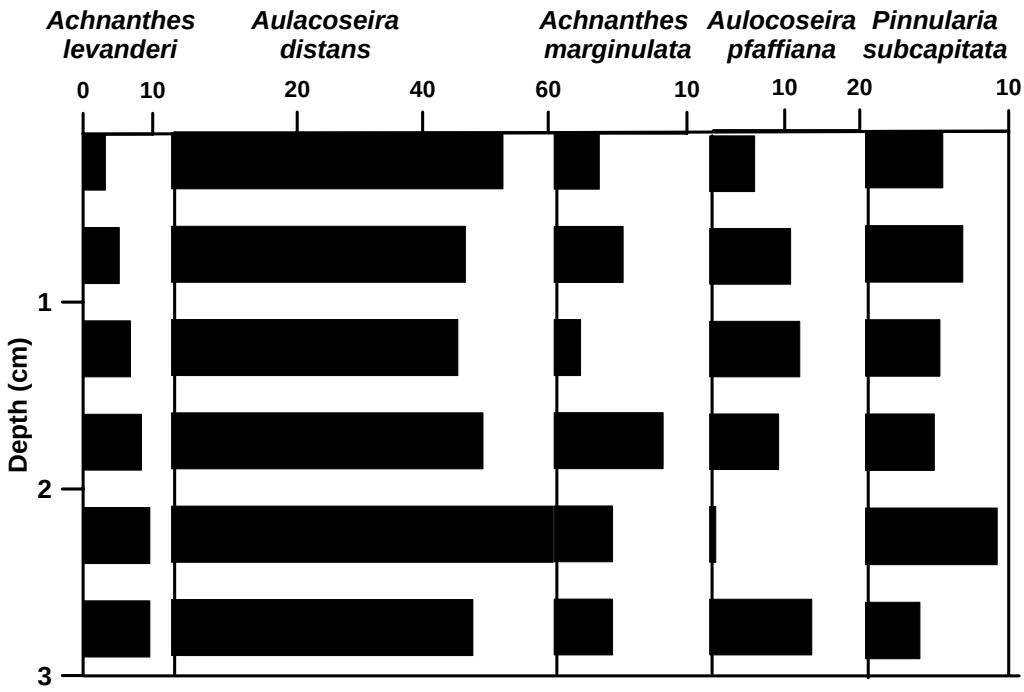

Figure 60. Relative abundance of dominant diatoms in the sediments of Foehn Lake.

Lake Model Simulations

Lake Notasha

The hydrodynamic simulation for Lake Notasha indicated the lake has a hydraulic residence time of about 1.4 years. The model indicates that the most stable thermal stratification occurs in the winter under ice cover (Figure 61). The calibration for the two-year period reproduces the increase the base cations during the summer as the lake stage declines and concentrations of ions increases as a consequence of evapoconcentration (Figure 62). The model calibration shows minor increases in algal and zooplankton abundance, the former of which causes a slight increase in surface pH. The model simulations indicate that Lake Notasha would not become acidic unless sulfur deposition increased nearly threefold over current levels. The model suggests that Lake Notasha is relatively insensitive to increases in nitrogen deposition (with regard to the effects of acidification).

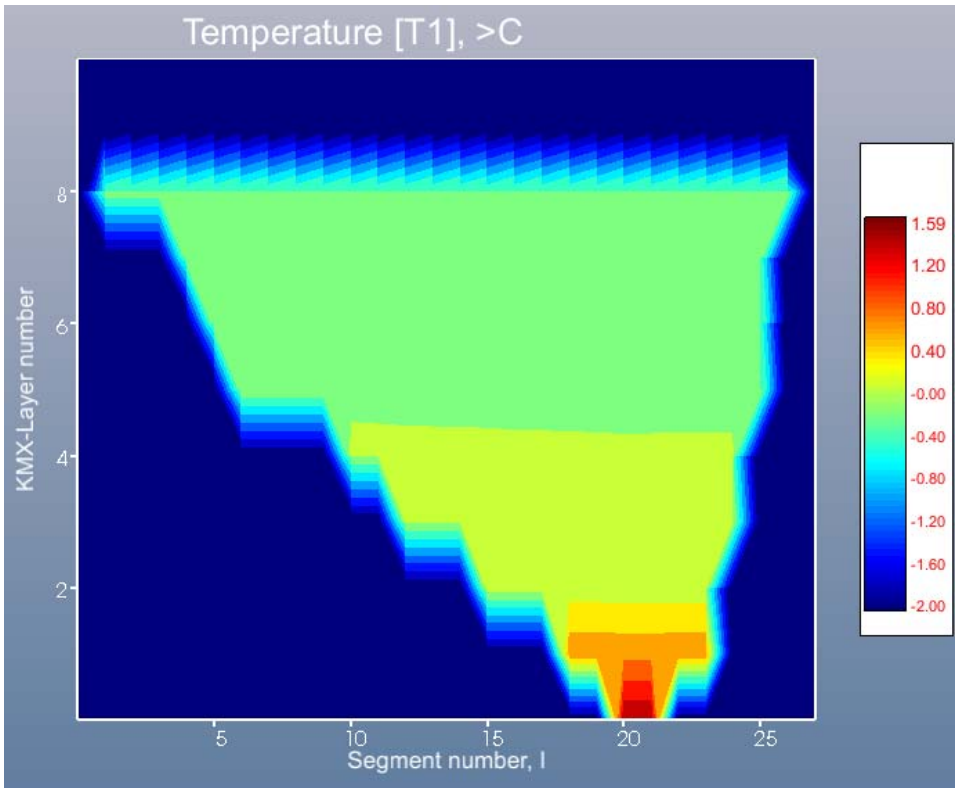

Figure 61. Lake Notasha simulated temperatures for Julian day 38 (February 7). Each segment is 10 m wide, each layer is 1 meter wide. The edge effect around the border of the system is an artifact of the classification methodology. It has no impact on model results.

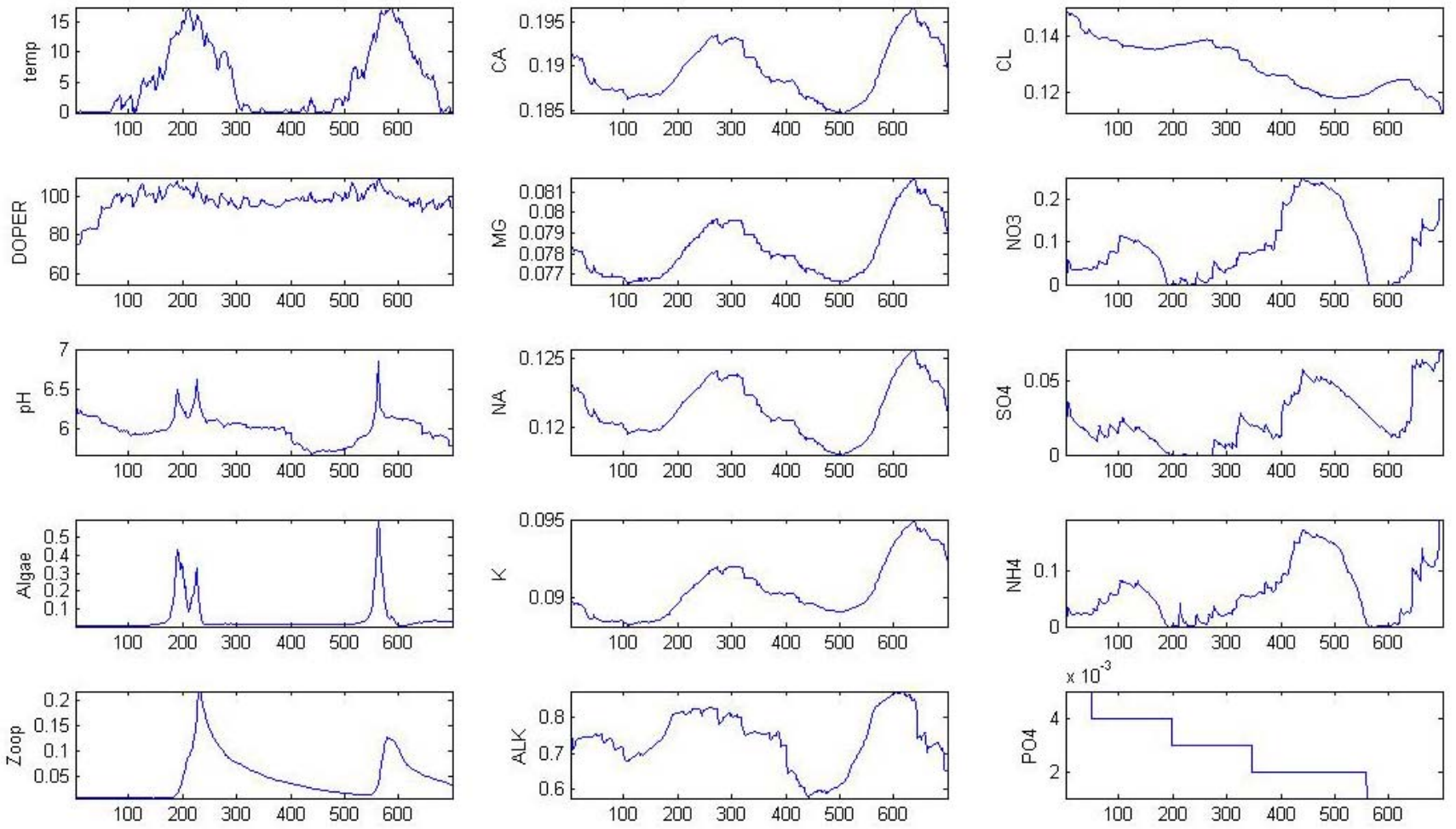

Figure 62. CE-QUAL-W2 model simulation for Lake Notasha under current deposition conditions.

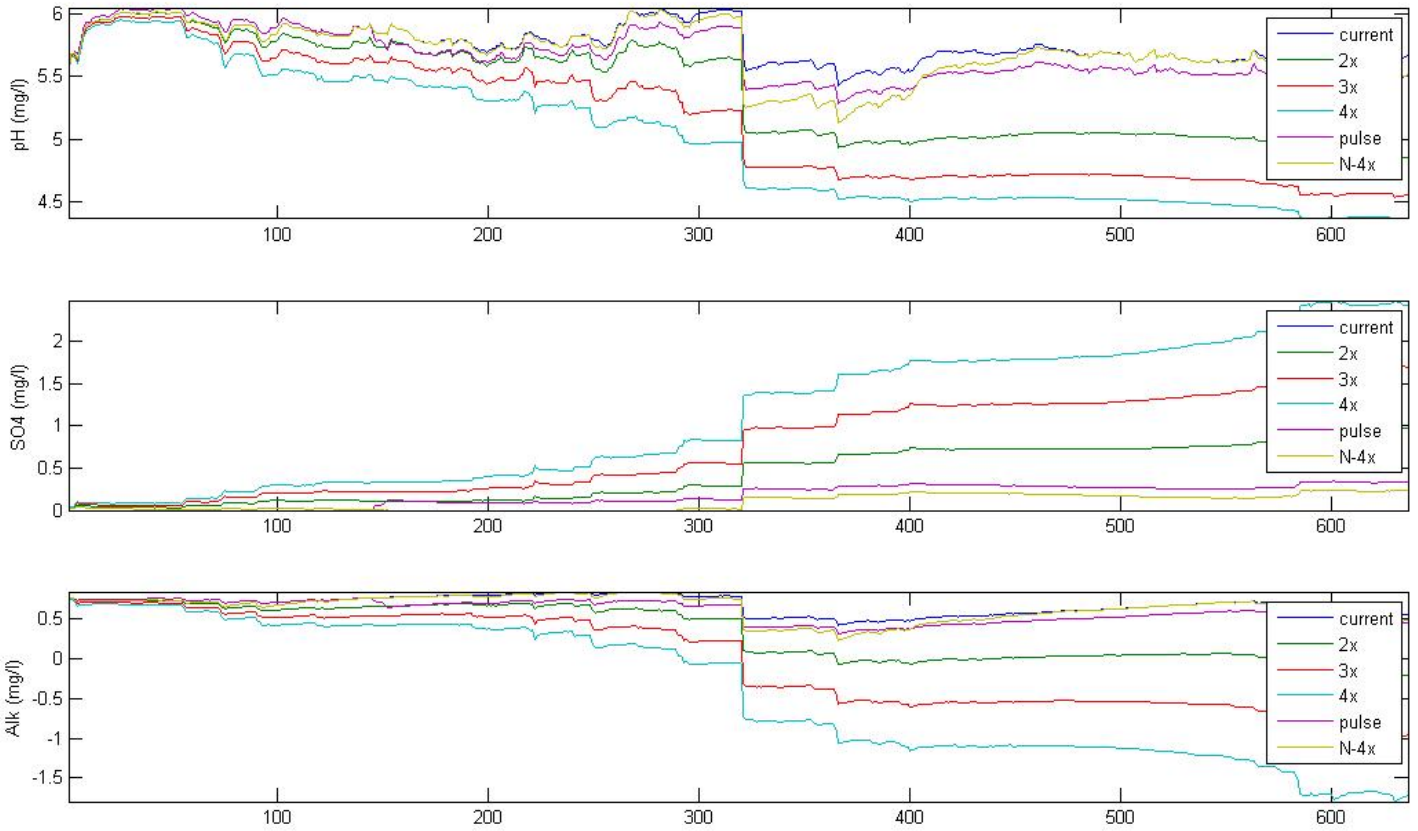

Figure 63. CE-QUAL-W2 model scenarios for increased levels of sulfur and nitrogen deposition for Lake Notasha.

Scout Lake

Scout Lake exhibits a temperature gradient of several degrees during the summer, a feature that is reproduced reasonably well here (Figure 64). In most other respects, Scout Lake behaves similarly to Lake Notasha, which again is reproduced in the model calibration (Figure 65). The model simulations show that even under a threefold increase in sulfur deposition, Scout Lake would still be able to maintain a pH of 5.9 or above (Figure 66). The lake is also expected to be able to absorb a large pulse input of acid or acid-precursors without becoming acidic.

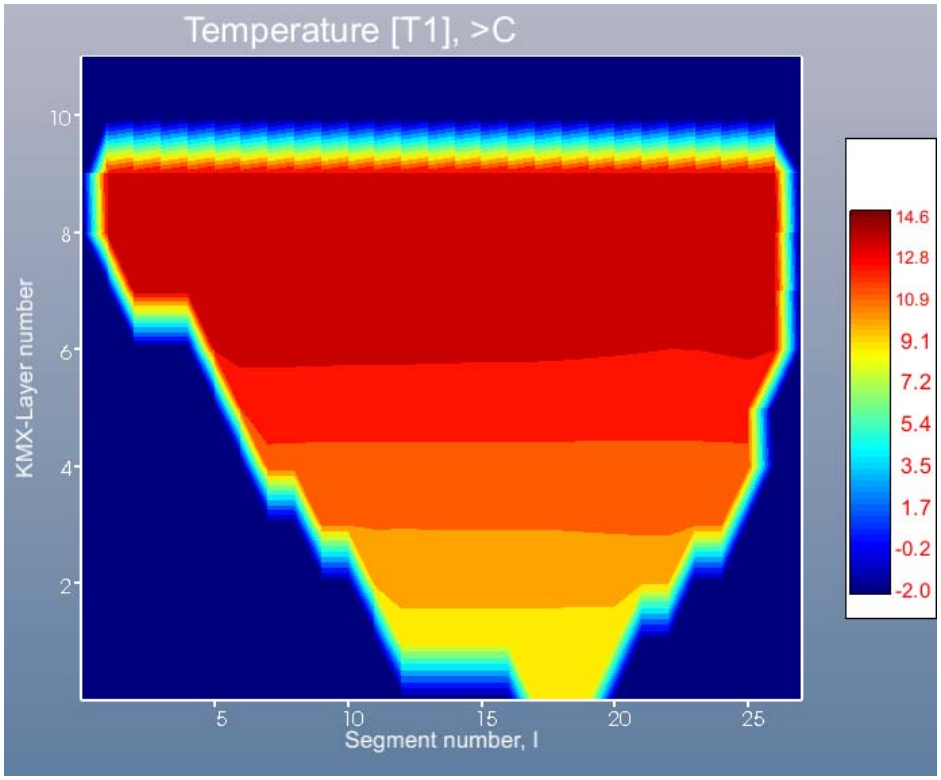

Figure 64. Scout Lake simulated temperatures for Julian day 179 (June 27). Each segment is 10 m wide, each layer is 1 meter wide. The edge effect around the border of the system is an artifact of the classification methodology. It has no impact on model results.

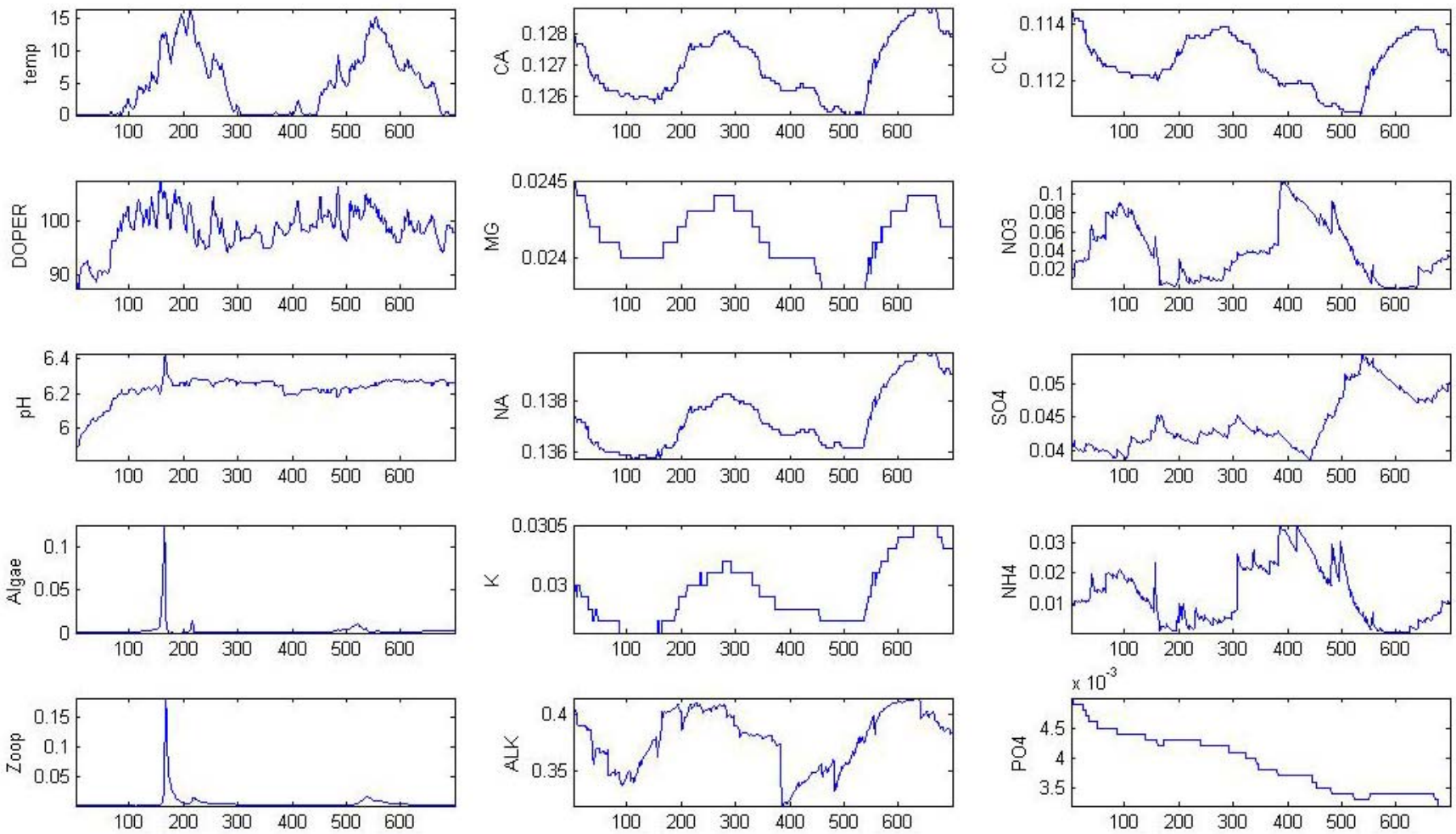

Figure 65. CE-QUAL-W2 model simulation for Scout Lake under current deposition conditions.

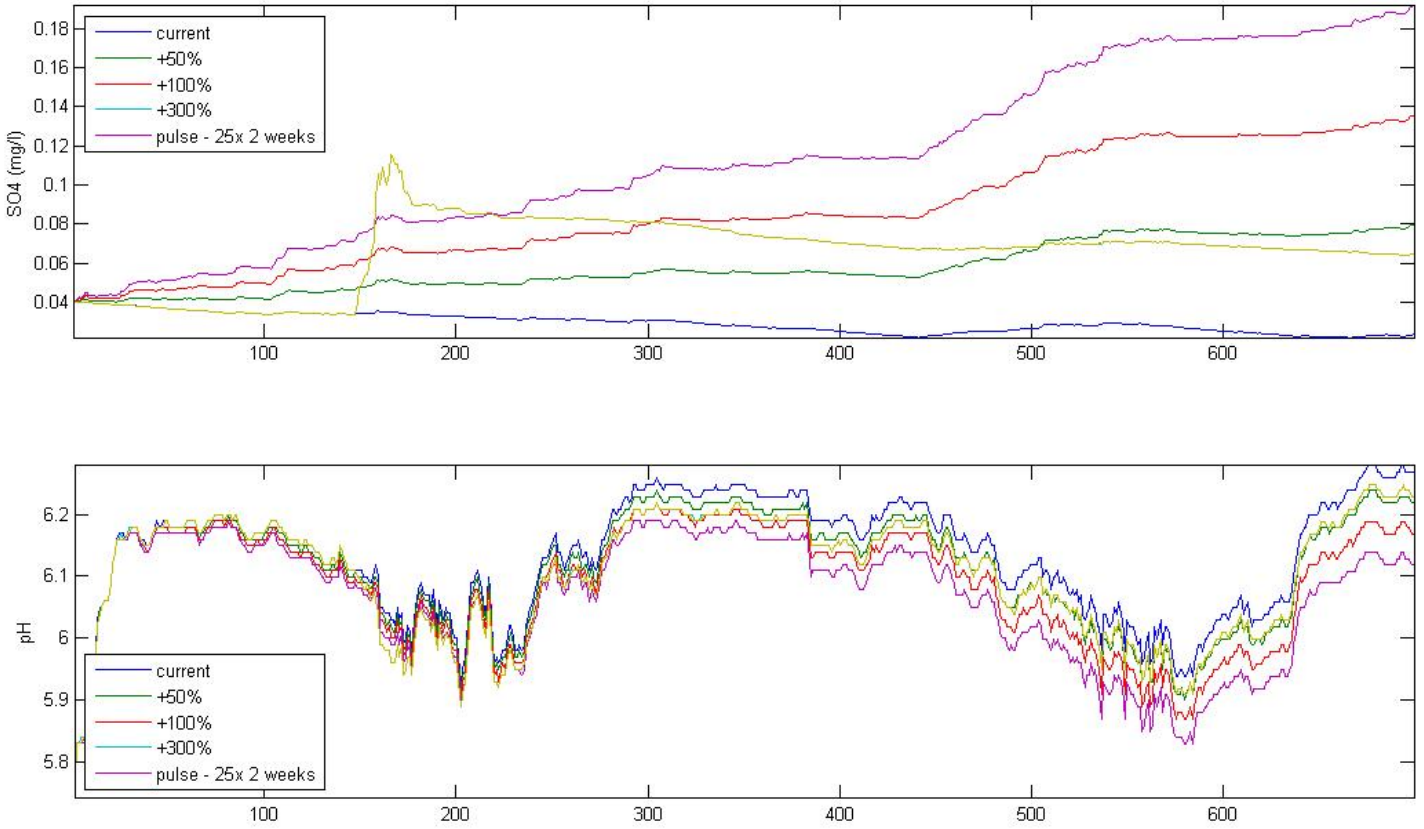

Figure 66. CE-QUAL-W2 model scenarios for increases in deposition of sulfur and nitrogen for Scout Lake.

Summit Lake

Summit Lake is the only lake among the four that establishes strong thermal stratification from spring to fall (Figure 67). Concentrations of most analytes show little seasonal variation in Summit Lake, a feature that is captured in the model calibration (Figure 68). Note that although the calibration plots show what appears to be considerable variation, the scales for the analytes are artificially exaggerated. The model simulations indicate that Summit Lake also would be highly resistant to changes in sulfur and nitrogen deposition. Again, it would require about a threefold increase in sulfur deposition to effect a measureable change in Summit Lake and again it appears highly resistant to inputs of nitrogen and pulse inputs of high loads over short durations (Figure 69).

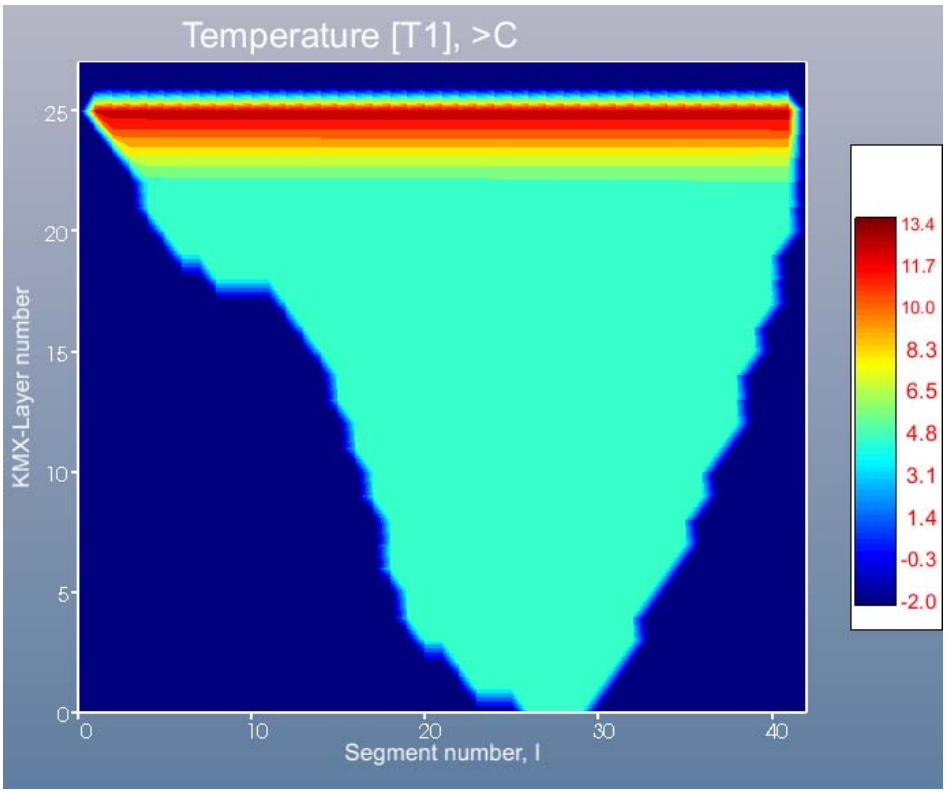

Figure 67.Summit Lake simulated temperatures for Julian day 203 (July 21). Each segment is 10 m wide, each layer is 2 meters wide. The edge effect around the border of the system is an artifact of the classification methodology. It has no impact on model results.

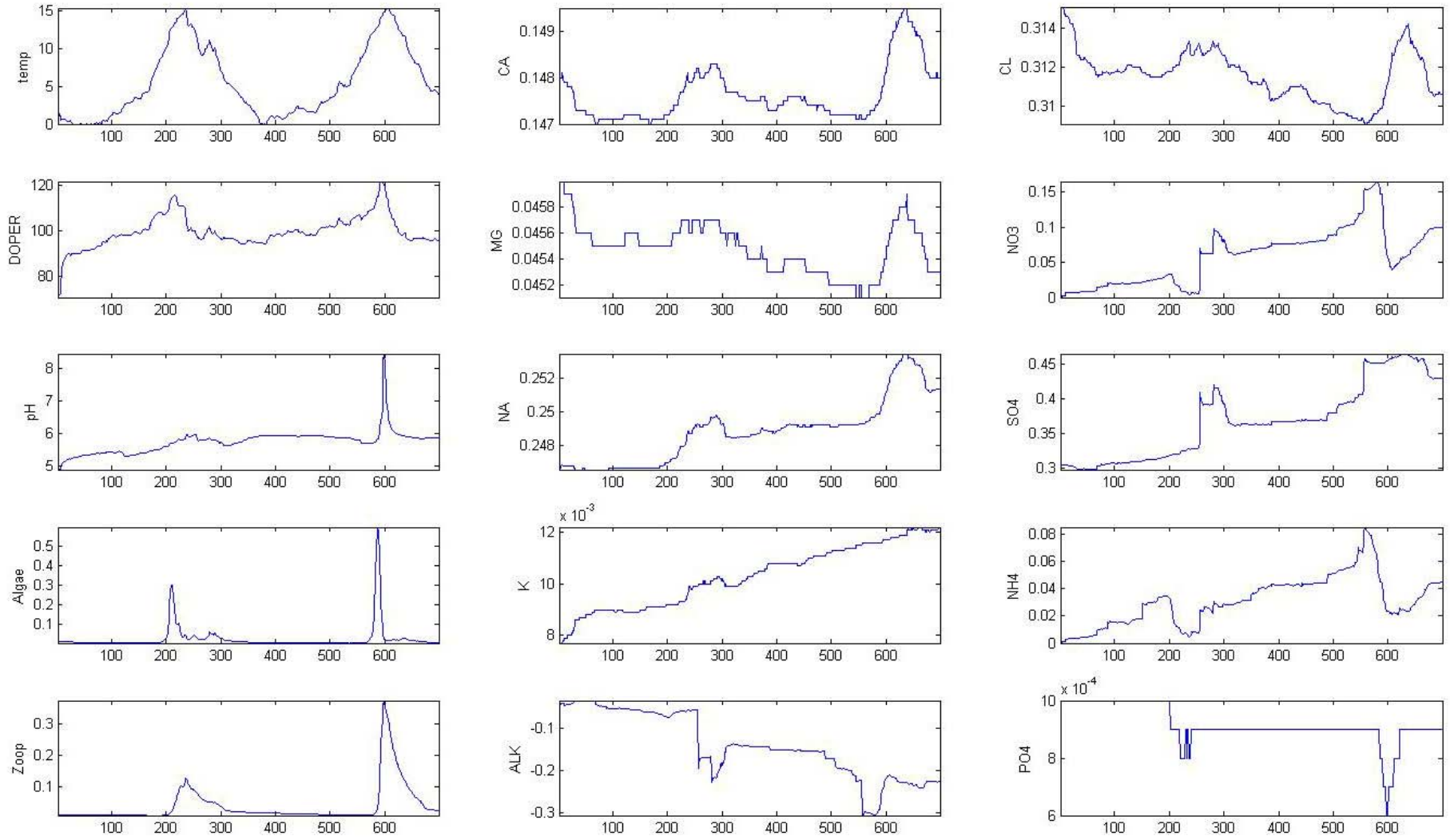

Figure 68. CE-QUAL-W2 model simulations for Summit Lake.

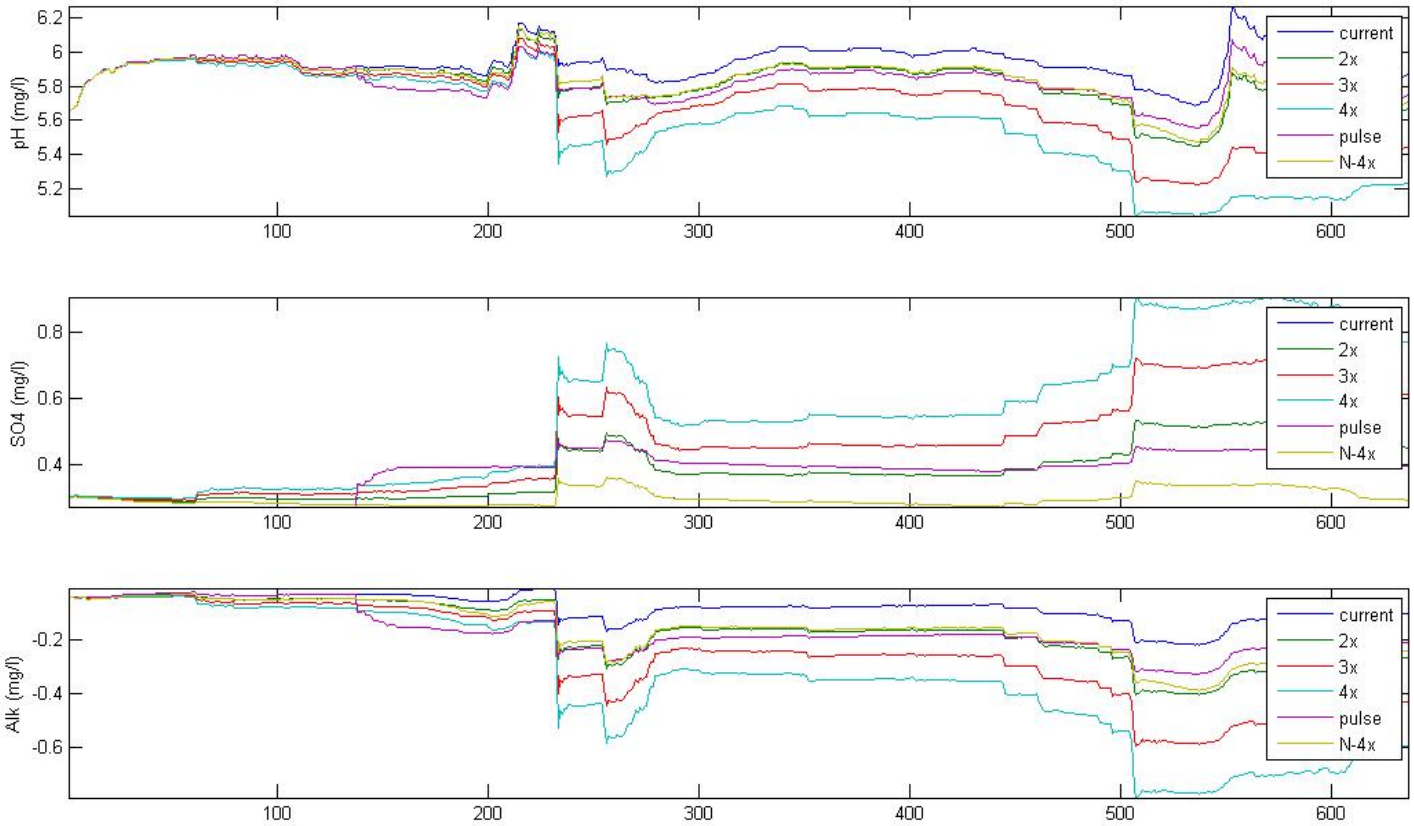

Figure 69 . CE-QUAL-W2 model scenarios for increased deposition of sulfur and nitrogen in Summit Lake.

Foehn Lake

Foehn Lake may set up short-term thermal stratification, but the shallow depth of the lake prevents these conditions from being maintained for any length of time (Figure 70). Because Foehn Lake is so shallow, it has the capability of responding rapidly to external forces. The model calibration under current deposition levels illustrates the short-term spikes that might occur with brief increases in algal populations (Figure 71). The model simulations for Foehn Lake under increasing deposition of sulfur and nitrogen show greater sensitivity than observed for lakes Notasha, Scout, and Summit (Figure 72).

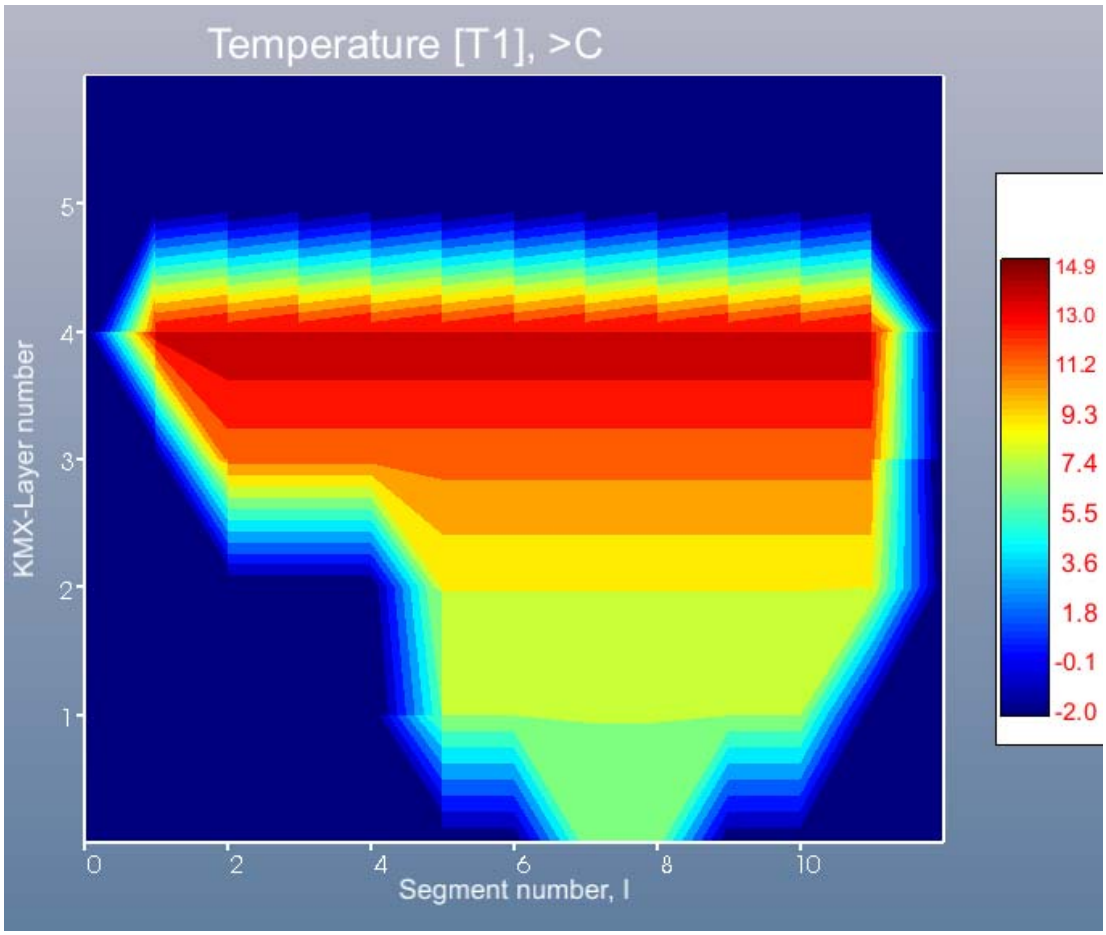

Figure 70. Foehn Lake simulated temperatures for Julian day 200 (July 18). Foehn is a small lake, which results in a more pronounced classification artifact. This is simply a function of the drawing procedures, and has no influence on the model results. Each layer is 0.5 meters deep, and the segments are 10 meters wide.

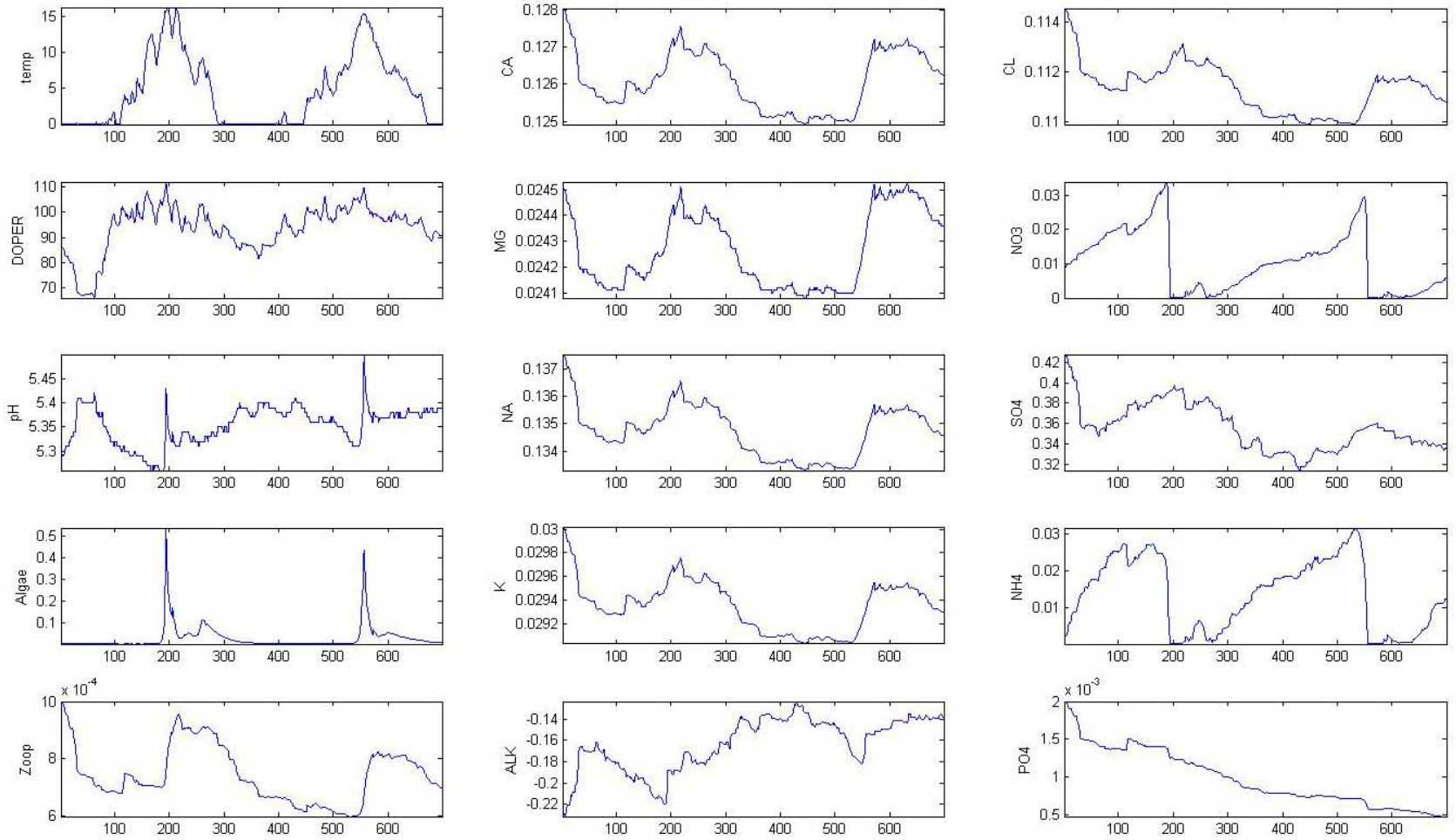

Figure 71. CE-QUAL-W2 model calibration for Foehn Lake under current levels of S and N deposition.

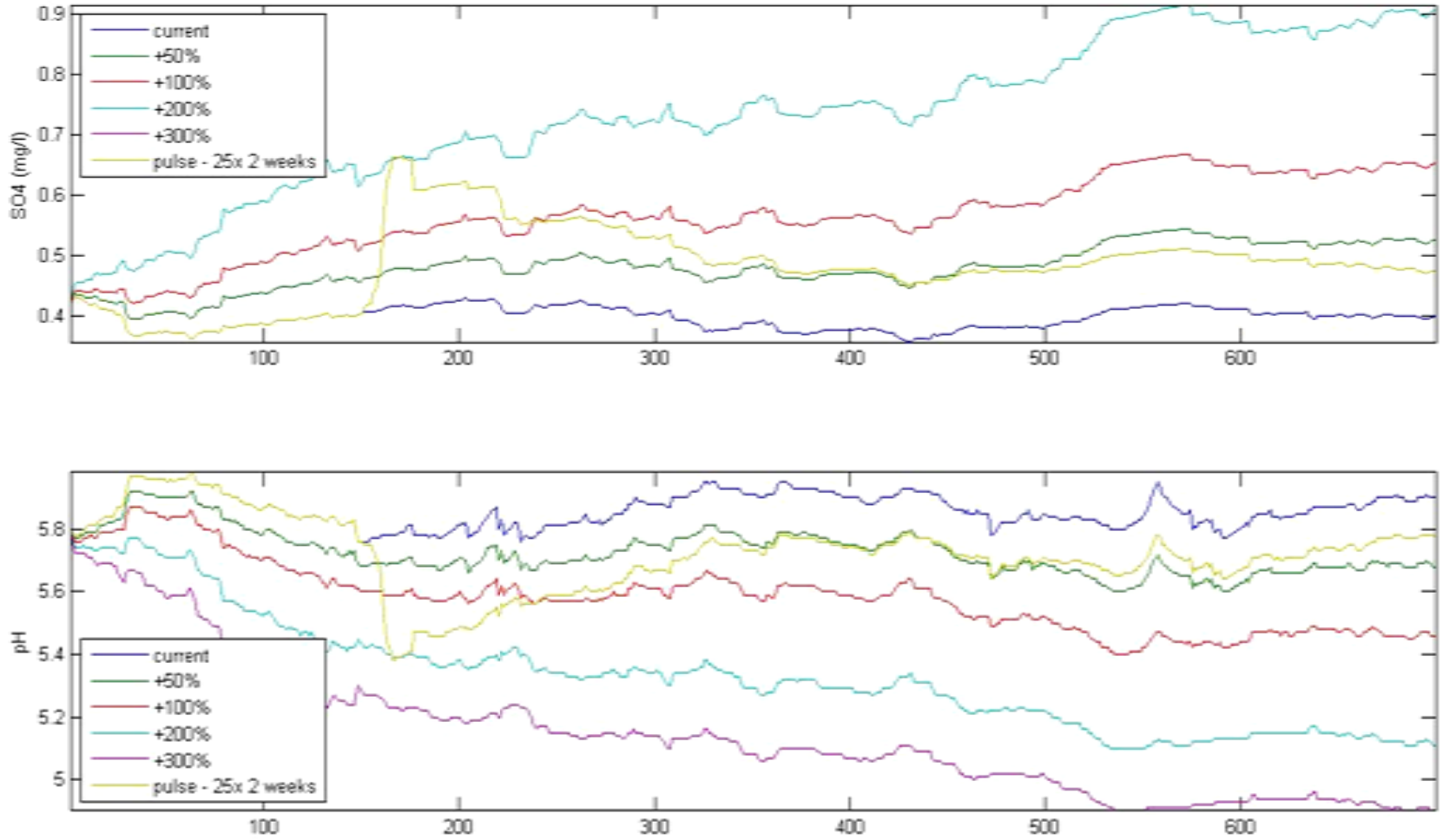

Figure 72. CE-QUAL-W2 model simulations for increased deposition of sulfur and nitrogen for Foehn Lake.

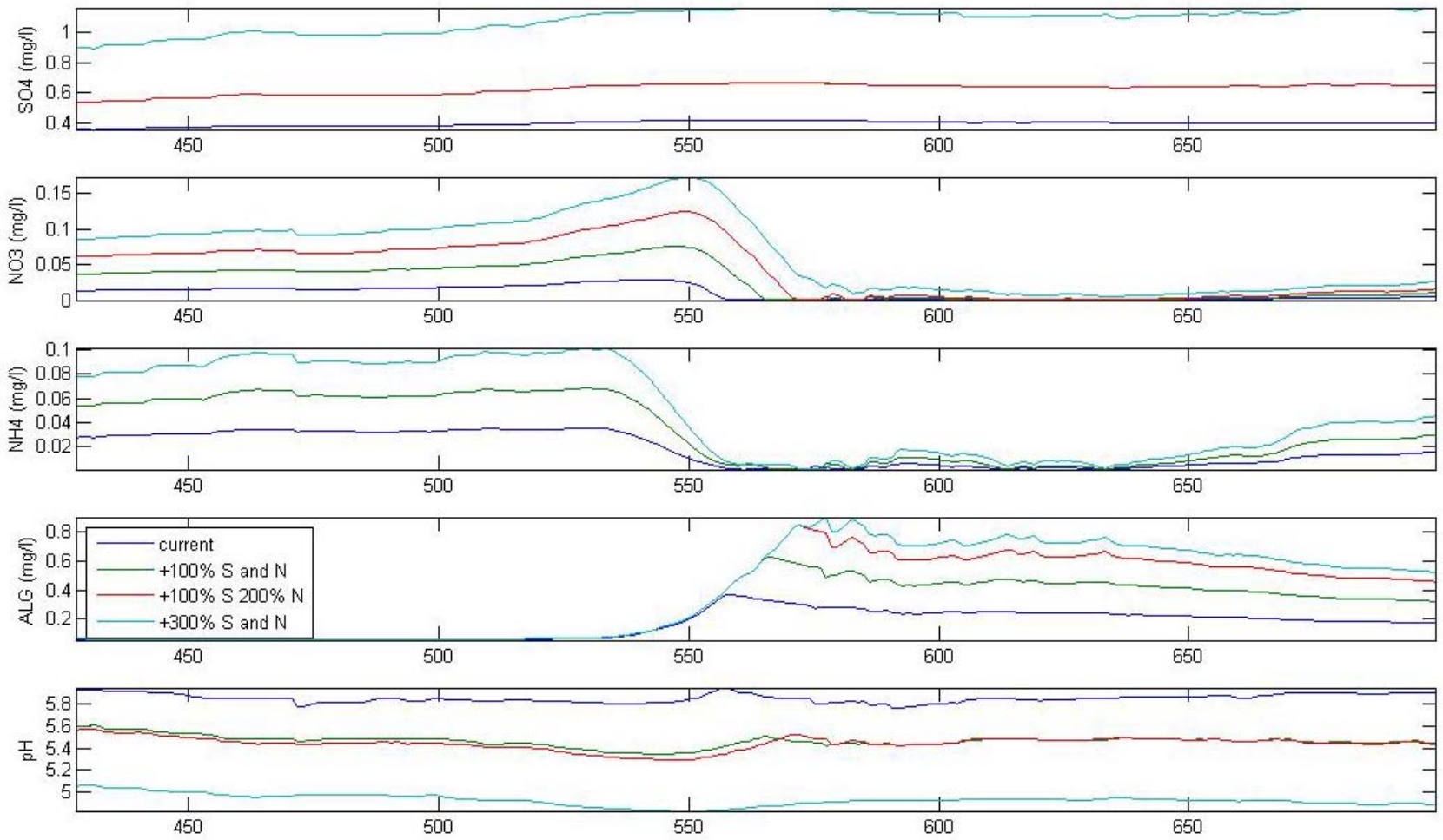

Figure 73. CE-QUAL-W2 model scenarios for increased levels of sulfur and nitrogen deposition for Foehn Lake. The simulation from Year 1 is omitted because of model artifacts in stabilizing.

DISCUSSION

Current Lake Status

All four lakes are extremely dilute systems, yet they vary in their current acid-base status. Lake Notasha and Scout Lake have low concentrations of major ions, yet sulfate and nitrogen concentrations are also low. Consequently, these two Oregon lakes have measureable ANC to buffer against acid inputs. Both Notasha and Scout lakes have reasonably diverse and abundant zooplankton populations. Phytoplankton populations are low, yet not unexpectedly low given the limited nutrient status of these two lakes. There is little in either the chemistry or biology of Notasha and Scout lakes to indicate that they have been significantly altered from their natural condition.

Summit and Foehn lakes differ from the Oregon study lakes in several respects. Both Summit and Foehn lakes exhibit concentrations of sulfate that appears elevated above natural conditions. The sulfate likely has neutralized several microequivalents of ANC, putting both lakes on the cusp of acidification. Most of this sulfate is non-marine in origin and in Summit Lake; it was demonstrated through isotopic analysis that the majority of the sulfur was derived from atmospheric deposition (Eilers et al. 1998a).

Summit Lake differs from the other study lakes in several respects. The lake is closest to marine waters, it is at the lowest elevation, it is deep, and it has a dense mat of bryophytes over much of the bottom. The proximity to marine waters makes it more likely that it will receive high concentrations of marine aerosols. This explains the comparatively high chloride levels in the lake and the higher proportion of marine-derived sulfate. However, marine-derived sulfate still accounts for only 15 percent of the sulfate concentrations in the lake. The lower elevation of Summit Lake also makes it more likely that it will receive more marine aerosols than the other study lakes. The considerable depth of Summit Lake increases the hydraulic residence time and thus increases the likelihood that in-lake processes can neutralize acid inputs (Baker et al. 1988). The long hydraulic residence time also has a dampening effect on short-term changes in external factors. The large biomass of bryophytes present in Summit Lake, most likely the dominant biological feature of the system, makes it possible that these plants have some influence on the acid-base chemistry of the lake. Bryophytes are known to act as ion-exchangers by assimilating divalent cations and releasing H^+ and organic anions (Clymo 1967; Glime et al. 1982).

Foehn Lake is slightly acidic (albeit within the error of the ANC analysis), shallow, and apparently very young. Sulfate ions may have neutralized several microequivalents of ANC. Given the extremely low concentrations of base cations in Foehn Lake, only modest levels of sulfur deposition are necessary to acidify the lake. Because Foehn Lake is shallow, it has a short hydraulic residence time and is more susceptible to short-term changes in external factors. The minimal accumulation of sediment offers relatively little buffering of external inputs. The apparent youth of the exposed watershed terrain results in low weathering rates, thus minimizing neutralization of incoming acids. The lake is extremely depauperate from a biological perspective, with few zooplankton crustaceans or benthic invertebrates present. The one sample of phytoplankton collected from Foehn Lake was dominated by two species of dinoflagellates.

Historic Lake Conditions

The paleolimnological data show that all four study lakes have been relatively stable over the last century. Diatom community composition in the sediment cores and the DI-inferred down-core values show no significant signs of change. Even Lake Notasha, which has a dense forest surrounding the lake that has likely experienced repeated forest fires showed no indication that the major ion chemistry had fluctuated to any measureable degree. Lake Notasha, Scout, and Summit had all experienced moderate to high rates of camping pressure as evidenced by trails, campsites, and damaged vegetation and yet had shown no effects on the lake. These same three lakes had also been stocked with trout during portions of the 20th century and whatever biological changes may have occurred is insufficient to be detected through the sediment data.

The absence of a measureable change in the diatom community composition in Foehn Lake may reflect the largely benthic habitat preferences of the diatom remains in the sediments. Few diatoms were present in the phytoplankton sample from Foehn Lake and use of diatom stratigraphy from such a shallow lake may limit the utility of this approach. Alternatively, sufficient sulfur deposition may have been present from the onset of the formation of Foehn Lake, resulting in a lake that initially began as slightly acidic and has remained so for its duration.

Forecasted Lake Response to Changes in Atmospheric Deposition

The model runs based on current deposition as provided through the deposition modeling were used to calibrate to current conditions in all four lakes. The inputs of sulfur and nitrogen were then increased for each lake as combinations of both sulfur and nitrogen and nitrogen alone. The forecasted lake responses for lakes Notasha, Scout, and Summit .showed relatively little change in lake pH until sulfur and nitrogen deposition had been increased by 300 percent. This is less surprising for Lake Notasha and Summit Lake where there still are modest concentrations of ANC (circa 10 μeq/L) present. An earlier modeling analysis by Baker et al. (1988) illustrated that seepage lakes can be highly resilient to inputs of sulfur and nitrogen because of internal lake processes associated with the relatively long-residence time systems. However, Summit Lake has virtually no measureable ANC and yet the model shows that it too is forecasted to remain stable under moderate increases in sulfur and nitrogen deposition. Again, this may be attributed largely to its considerable depth (50 m) and very long hydraulic residence time. Another factor is that there is a large population of bryophytes present in Summit Lake, and these plants may exert more control of the acid-base chemistry on this lake than those derived from external inputs.

Foehn Lake, as expected, shows the greatest responsiveness to inputs of sulfur and nitrogen. Factors that likely contribute to this greater responsiveness are its shallow bathymetry, the high percentage of exposed bedrock in the lake, and its shallow sediments. This lake appears to be only a century old based on the ^{210}Pb dating. However, the diatom community composition in the sediments shows no indication of any significant change during this early period. Although there is the expectation that deposition of sulfur and nitrogen has increased in the last 100 years downwind of the Olympia-Seattle urban corridor, there is little indication in this first evaluation of the lake to suggest that the lake has responded significantly to whatever changes in deposition may have occurred. The average non-marine sulfate concentrations in Foehn Lake are indicative of some anthropogenic inputs, yet the sediment diatoms failed to signify that this has caused a measureable biological response. The modeling scenarios also indicate that one might not expect a measureable decline in pH for Foehn Lake unless sulfur and nitrogen deposition rates were increased by 100 percent or more over current levels. Thus, there seems to be a congruence of the paleolimnological data and the modeling forecasts for Foehn Lake.

Saros et al. (2005) observed increases in *Asterionella formosa* and *Fragilaria crotonensis* in the sediments of oligotrophic alpine lakes in the Beartooth Mountain Range (Montana-

Wyoming) which they attributed to increases in nitrogen deposition. We observed no similar changes in the sediment diatom composition in these Cascade lakes that would suggest there has been an early response to possible increases in deposition of nitrogen. In addition, all four lakes showed little change in acid-base chemistry to increases in simulated deposition of nitrogen only. Once again, it may be that these longer-residence time seepage lakes allow for sufficient internal processing to assimilate inputs of nitrogen without posing a major risk to either the acid-base status of the lakes or to their trophic status. An examination of the stoichiometry of the water chemistry in these four study lakes indicated that they were likely phosphorus-limited systems and therefore they may be relatively insensitive to moderate increases in nitrogen deposition.

Recommendations for Further Study

This study provides additional insight into the potential for lakes in the Pacific Northwest to be altered by atmospheric deposition. The two Washington lakes in the study, Summit and Foehn, both show possible evidence of having lost ANC through sulfur deposition. The two Oregon lakes show no evidence of effects from atmospheric deposition of sulfur or nitrogen. Our conclusion is that if additional resources are to be spent on this topic in the Northwest, those efforts should be focused on lakes in the Washington Cascades. Although the Alpine Lakes Wilderness presents difficult access challenges, there are strong indications that this area contains additional lakes which are highly sensitive to changes in atmospheric inputs. We recommend that additional research on this topic be focused in the Alpine Lakes Wilderness.

The deposition input provided by the Forest Service for representing inputs of sulfur and nitrogen to the study lakes was based on model output. The modeled deposition made it possible to conduct our lake model simulations, but this approach presents serious limitations. There is no way to assess the uncertainty in the modeled deposition because there are no data at these elevations to corroborate the modeled deposition. Second, the modeled deposition does not provide output on all other ions present in the deposition. Additionally, it is possible that the lakes could remain in their current condition, even with substantial increases in acidic deposition, if those increases in acid anions are balanced by dust associated with increased soil entrainment from land disturbance and a reduction in precipitation (cf Psenner 1999). Lakes respond to the sum of all inputs, not just sulfur and nitrogen. At some point, the appropriate land management agencies will have to address the lack of measured deposition data in the areas with sensitive resources.

The study design used for the Four Lakes Project attempted to assess the sensitivity of lakes in the region to changes in atmospheric deposition of sulfur and nitrogen using an approach that (1) characterized the present condition of the lakes through lake sampling, (2) defined the historical conditions of the lakes through use of paleolimnology, and (3) simulated future response of the lakes to changing atmospheric conditions with hydrodynamic modeling. Given the resources available, we think this was an efficient methodology to achieve the information gain realized in this study. However, additional methods are needed to better define the responsiveness of selected lakes to atmospheric deposition in addition to the need for collection of atmospheric deposition data at high elevation. This involves more detailed study of a single system, such as Foehn Lake, to better characterize processes that affect lake response. This additional study could include experimental manipulations. Whole lake or split-lake studies conducted over several years have the greatest potential to provide results that are robust and unambiguous in their findings (Schindler et al. 2008). Short-term manipulations or experiments involving use of microcosms have a greater potential to yield results that don't reflect how the lake system will respond to perturbations.

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ACKNOWLDEGEMENTS

This project was funded by the Air Program, Pacific Northwest (Region 6) under contract # 53-046W-4-0580/AG-046W-P-06-0144 to MaxDepth Aquatics, Inc. The technical contract representative for the Forest Service was Janice Peterson. Forest Service personnel responsible for contributing to the field sampling included Barry Gall and his assistants. We thank Ian Gunter and Ruth Arnold for assisting with the field efforts. We thank Dr. Jack Cornett and Janet Lardner, MyCore Scientific for conducting the ^{210}Pb dating for sediment cores from Scout and Foehn lakes. Analytical analysis of water samples was conducted by the Cooperative Central Analytical Laboratory, Oregon State University in Corvallis, Oregon (nutrients), the Forest and Range Experiment Station in Fort Collins, Colorado (major ions), and chlorophyll *a* by Aquatic Analysts, White Salmon, Washington. Taxonomic work on phytoplankton samples was conducted by Aquatic Analysts, benthic organisms were identified by staff with EcoAnalysts, Moscow, Idaho, and zooplankton samples were identified by Dr. Allan Vogel of ZP Taxonomic Services, Lakewood, Washington.

APPENDIX

A. Phytoplankton Taxonomic Methods

Aquatic Analysts
Algae Analytical and Quality Assurance Procedures

May 4, 2004

Sample Handling
Sample Collection and Preservation

Phytoplankton is collected by filling bottles with natural water samples. Samples are collected at either discrete depths, or integrated through the photic zone of lakes. A volume of 250 ml is sufficient for most samples.

These samples are preserved with 1% Lugol's solution immediately after collection. Refrigeration is not necessary, and holding times are a year or more.
Sample Tracking

All samples received in the laboratory are immediately logged into a Sample Receipt Log. All samples are stored in a dedicated area until they are processed. After samples are processed and analyzed and data reports have been submitted to clients, samples are placed in storage for at least one year.
Sample Preparation

Permanent microscope slides are prepared from each sample by filtering an appropriate aliquot of the sample through a 0.45 micrometer membrane filter (APHA Standard Methods, 1992, 10200.D.2; McNabb, 1960). A section is cut out and placed on a glass slide with immersion oil added to make the filter transparent, followed by placing a cover slip on top, with nail polish applied to the periphery for permanency. A benefit to this method is that samples can be archived indefinitely; we have over 18,000 slides archived.

Microscopic Analyses
Algae Identifications

Aquatic Analysts has an extensive library of algae literature, including journal reprints, standard reference books, and internet reference sites. We also maintain files, notes, and photographs of algae we've encountered during the past 29 years of identifying algae. Most algae are identified by cross-referencing several taxonomic sources.
Enumeration

Algal units (defined as discrete particles - either cells, colonies, or filaments) are counted along a measured transect of the microscope slide with a Zeiss standard microscope (1000X, phase contrast). Only those algae that were believed to be alive at the time of collection (intact chloroplast) are counted. A minimum of 100 algal units are counted. (Standard Methods, 1992, 10200.F.2.c.).

Average biovolume estimates of each species are obtained from calculations of microscopic measurements of each alga. The number of cells per colony, or the length of a filament, is recorded during sample analysis to arrive at biovolume per unit-alga. Average biovolumes for algae are stored in a computer, and measurements are verified for each sample analyzed.

Results of sample and data analyses are provided to the client in electronic format (email and/or CD disk), and in hard copies. Deliverables include individual sample reports, similarity indices, data summaries, combined species lists, and a brief narrative discussion of the results. Individual sample reports include sample identification, a trophic state index, total sample density, total sample biovolume, and a list of algae species with their absolute and relative densities and biovolumes. All data are reported in Excel format.

Data summaries include sample identification, total density, total biovolume, the trophic state index, and the top 5 most common algae species (codes) and their relative densities. The summary format (Excel) allows for easy calculations and graphs of algae sample data. Combined species lists of all species within related groups of samples allow greater sensitivity in comparing different lakes, sites, dates, or depth. Algae species are compiled according to their relative densities.

A Trophic State Index based upon phytoplankton biovolume has been developed from a data set of several hundred lakes located throughout the Pacific Northwest (Sweet, 1986, Report to EPA). The index was derived in a similar fashion as Carlson (1977) derived indices for Secchi depth, chlorophyll concentration, and total phosphorus concentration. The biovolume index ranges from 1 for ultra-oligotrophic lakes to 100 for hyper-eutrophic lakes. Values agree well with Carlson's indices.

The index is defined as:

TSI (biovolume) = (Log-base 2 (B+1)) * 5

Where B is the phytoplankton biovolume in cubic micrometers per milliliter divided by 1000.

A similarity index is useful in comparing phytoplankton communities between two samples. The index compares the relative abundances of each species present in two samples and yields a value ranging from 0 for totally dissimilar samples, to 100 for identical samples. The formula for the index (modified from Whittaker, 1967) is:

Similarity Index = 100 - (Sum of DIFFERENCE / 2)

Where DIFFERENCE is the absolute value of the difference of the percent density of a given species in two samples.

Aquatic Analysts use a Zeiss Standard phase-contrast microscope primarily with a 1000X magnification for identification and enumeration of algal samples. The diameter of the field of view at 1000X magnification is 0.182 mm. The effective area of a filter is 201 millimeters

square. Algae are enumerated along a measured transect, measured accurately to 0.1 mm with a stage micrometer. The algal densities are calculated from the area observed (transect length times diameter of field of view), the effective filter area, and the volume of sample filtered.
The microscope was calibrated using a standard concentration of latex spheres provided by EPA (Cincinnati, OH). The concentration of these spheres was 12,075 per milliliter. Duplicate preparations of the standard spheres were analyzed; the average result was 11,700 spheres per milliliter (96.9 percent). The computer program used to calculate algae densities compensates for this 3.1% error.

Replicate algae samples are analyzed at the client's request. We encourage blind replicates for approximately 10% of all samples collected. Replicates are assessed for algae abundance (relative mean difference of densities) and species composition (similarity indices, species lists). Aquatic Analysts has participated in the analyses of split algae samples on several occasions, with general agreement between samples in terms of algae density and algae species compositions.
A custom computer program handles all calculations and data analyses. Final sample reports are compared with laboratory bench sheets before releasing data. Data summaries, tables of similarity indices, abundance graphs, and combined species lists are searched for inconsistencies, outliers, and interrupted patterns that may indicate possible errors.

Aquatic Analysts maintains an herbarium of all microscope slides analyzed (over 18,000 to date). These may be reviewed if questions arise after data are reported. In addition, all computer data (sample tracking data, raw count data, final reported data, data analyses, narrative reports) are archived on CD's in permanent storage.

B. Zooplankton Taxonomic Methods

Standard Zooplankton Counting and Assessment Methodology Used by ZP's Taxonomic Services, Allan Hayes Vogel, sole prop.

The standard zooplankton sample enumeration uses the following methodology. Samples are first split with a Folsum plankton splitter until an approximate subsample size of 400 total individual arthropods and 100 individuals of the most abundant species are reached. If the initial split does not achieve both of these criteria, then increasingly larger splits are enumerated until both criteria were met, or until the entire sample is counted. All rotifers and protozoans in the split are completely enumerated as well unless their numbers significantly exceed 400 individuals; in which case, a separate rotifer subsplit is made, then counted for rotifers and protozoans. The statistical methodology for this approach is based upon Edmondson and Winberg (1971, p. 178), and assumes that the sampling methods (both in the field and during the splitting) follow a Poisson distribution. This assumption is violated for larger species such as *Chaoborus* and *Leptodora*; thus, all individuals of those taxa found in a sample are enumerated. The selected values of 400 and 100 individuals provide a maximum statistical standard error of the mean of 5 and 10 percent, respectively (The formula used is: $s = 1/\sqrt{N}$). While only the confidence limits for total numbers and most abundant species are set by this procedure, the standard error of the mean for each species can be determined from the original tallies, using the previous formula for the Poisson distribution. Results are

reported in numbers per cubic meter, along with the standard error for each value (also in units of numbers per cubic meter).

The standard zooplankton enumeration is done with a Wild M-3 microscope at 32X magnification. Samples are counted in an open counting chamber with six parallel channels following the procedures described in Edmondson and Winberg (1971, p. 131). Species identifications are made at higher levels of magnification under a compound microscope as needed. General taxonomic identifications follow Edmondson (1959), Pennak (1989), and Thorp and Covich (1991). Specific group references used include Berner (1994), Brooks (1957), Brandlova, et al. (1972), Deevey and Deevey (1971), DeMont and Hebert (1994), Dumont and Pensaert (1983), Hebert (2001), Korovchinsky (1992), Patterson (1996), Pontin (1978), Ruttner-Kolisko (1974), Stemberger (1979) and Taylor, et al. (2002). Identifications are to species for all adult and subadult crustaceans, excepting harpacticoid copepods and ostracods, and for most rotifers. Immature copepods through copepodite stage IV are identified as far as their developmental stage allows. Confirmation of the identifications is made using appropriate past local investigations.

For length-frequency studies, crustacean lengths are taken following the protocols described in Edmondson and Winberg (1971. Specifically, cladocerans are measured from the top of the head (helmet included) to the posterior edge of the carapace excluding any tail spine or mucro, and copepods are measured from the end of the cephalothorax to the end of the caudal rami, exclusive of the setae.

The basic quality control method used for enumerating zooplankton samples is the standard error value. Standard error is an estimator of within-sample variability; it is not a between-sample estimator of the population variance such as the statistical parameter, standard deviation, provides. Statistical analyses of past replicated counts have indicated that the standard error values adequately estimate between 90 and 98% of all within-sample variability. Since within-sample variability is <u>not</u> between-sample variability, it is recommended that several replicate samples be collected as part of any standard field research effort to assess between-sample variability. This recommendation is made because between-sample replicates taken at the same time and place have significantly higher variability due to plankton patchiness and species "swarms".

Quality assurance and control for within-sample variability is maintained by routine re-analysis of 2-3% of all samples examined. The samples re-analyzed are selected at random, using a random number generator and the unique sequence number of each sample analyzed. (Unless specifically requested, the results of these re-analyses are not provided.) For major projects (> 500 samples), 5-10% of the samples are re-enumerated and identified a second time “out house”.

An estimate as to the intensity of planktivory based upon the density and relative abundance of the edible species present index is normally made for each sample as well as Dodson's (1992) index calculated for each lake, provided all necessary background information is available. Evaluation of the availability of the different zooplankton species as food items for particular species of fish is derived from an ongoing literature review starting with Brooks (1969) and continuing with Kerfoot (1980), Zaret (1980), and Carpenter and Kitchell (1993). This evaluation is kept up-to-date by regular reviews of recently published zooplankton predation studies in Limnology and Oceanography and the Proceedings of the International Association of Theoretical and Applied Limnology (Verh. int. Ver. Limnol.) as well as the results of articles such as Eilers, et al. (2007). The earlier literature has been summarized in Canale, et al. (1975, 1976).

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C. Methods used by EcoAnalysts, Inc. for Identification and Enumeration of benthic macroinvertebrates

There are several steps involved in the successful completion of a macroinvertebrate project at EcoAnalysts. This section presents in detail the key technical steps associated with each project.

Step 1: Sample Check-In

The purpose of this process is to log samples in to our laboratory and document their condition when they arrive. The following procedure is followed to accomplish this purpose:

- Our receiving person opens up shipping containers and removes chain of custody forms or a packing list, if included.
- All sample containers are inspected for damage or leakage. If damage is found, the client is promptly contacted.
- Sample information is checked against custody forms and any discrepancies are

noted. Discrepancies are reported to the client in order to clarify and correct any errors.
• Samples are logged into our database and assigned a unique sample tracking number.
• Sample jars are labeled with this unique sample identifier and placed on a shelf until sorting begins.

Step 2: Sorting Benthic Macroinvertebrate Samples

The purpose of this step is to remove benthic macroinvertebrates from debris in the samples prior to identification. The steps detailed below accomplish this task:
• A sample is checked out using our custom laboratory information management system.
• A bench sheet is printed containing sample information from the database. The lab technician then removes the sample from the shelf and records the matrix type and beginning sample volume.
• The sample is emptied into a mesh sieve (this is usually 500µm, though can vary depending on the needs of the client) to remove preservative and fine sediment.
• The sample is then washed into a shallow pan of water where any large pieces of organic material are rinsed, inspected thoroughly by another technician for attached invertebrates, and retained in a separate container.
• The sample is agitated with water to separate any organic matter from inorganic sediments.
• After agitating the sample in water, the lighter organic material is poured back into the sieve.
• The inorganic portion of the sample remaining in the pan is repeatedly washed and decanted into the sieve until no more organic matter remains.
• After all organic material has been removed from the sample, the remaining inorganic sediments are inspected under a magnifying lamp (3X) to look for any invertebrates too heavy to have been decanted (e.g. mollusks, snails, stone-cased Trichoptera, etc.).
• Once it is determined there are no more invertebrates in the inorganic fraction of the sample, it is rechecked by a second specially designated tech and finally discarded. If there are significant numbers of invertebrates in the inorganic material, the sample is recombined.
• The organic material, which is retained in the sieve, is then evenly distributed in a Caton tray. These are essentially trays of various sizes consisting of gridded squares, each square being 2 inches per side. The bottom of the Caton is 250 micron mesh.
• A grid (or a standardized portion of a grid) is randomly selected and its contents transferred to a Petri dish.
• The material is sorted under a dissecting microscope (minimum magnification = 10X). The invertebrates are counted as they are placed into three vials containing 70% ethanol, one each for Chironomidae, Oligochaeta, and one for all other organisms.
• When the target count of organisms has been reached or the specified amount of material has been sorted (these specifications are determined by the client and the requirements of the study

design), a special large and rare protocol may be followed, with these organisms placed in an additional labeled vial.
• When the sample sorting has been completed, laser-printed labels with the appropriate sample tracking information are placed in the vials and the 3
sample jars. The total number of organisms removed (not including large and rare organisms), the number of grids sorted out of the total, the time spent sorting, and the final sample volume are all recorded on the sorting bench sheet.
• Sorted samples are placed on a shelf to await the quality assurance process. Once they have passed thorough QA testing, all sample residues are shelved and the invertebrates then taken to the taxonomy department for identification.

Step 3: Sorting Quality Assurance

The purpose of this step is to ensure **every** sample meets a standard minimum level of sorting efficacy. Instead of re-sorting 100% of every tenth sample, we have determined that a higher standard is maintained by re-sorting 20-25% of **every** sample that is processed in our lab. Based on our years of experience processing and sorting invertebrate samples and subsequent method and data comparisons, we are confident our internal procedures optimize sorting quality and efficiency.
To ensure all samples meet a 90% sorting efficacy level (or other specified by the client), we employ the following quality assurance method:
• Once primary sorting has been completed by a laboratory technician, each sample is put in queue to be processed by a specially trained and designated sorting quality control technician (this will **never** be the technician who originally sorted the sample).
• The sorting QC technician will redistribute the sorted portion of the sample into an appropriately-sized Caton sorting tray.
• The sorting QC technician removes randomly selected squares and re-sorts them until a minimum of 20% of the material has been thoroughly checked (e.g. 6 of 24 squares).
• The sorting QC technician then calculates an estimated percent efficacy by dividing the number of organisms found in the original sort by the total number of organisms estimated to be in the material, based on those found in the 20% quality assurance re-sort, using the following equation:
Where:
OriginalCount = the number of organisms picked by the first sorter
QACount = the number of organisms found in the Quality Assurance sort
QASquares = the number of squares **sorted** during the QA process
QTSquares = the total number of squares in the QA Caton
• Sorting efficacy is measured as the estimated percent of the total organisms found during the original sorting process. The QA process not only assures a high level of efficacy on every sample, it also serves to pull an even greater number of organisms than would be found in a primary sort alone.
• If the estimated percent sorting efficacy is 90% or greater, the sample passes the quality assurance check.
• If the estimate is less than 90%, the sample is re-sorted. When this happens, the sample undergoes the quality assurance process **again** until it passes the 90%

efficacy requirement.
• Sorting quality assurance data is recorded on the bench sheet and entered into the database for documentation.
• If requested, a quality assurance report is generated and provided to the client.

Step 4: Identification of Benthic Macroinvertebrates

The purpose of this process is to identify all benthic macroinvertebrates to the taxonomic level specified by the client. The following steps will be followed to accomplish this:
• A taxonomist will select a sample for identification and empty it into a Petri dish.
• Under a dissecting microscope the invertebrates are identified to the level specified.
• The taxonomist enters each taxon into the project database using a unique taxonomic code (this is done while at the microscope).
• The number of individuals of each taxon is counted and entered into the database.
• At least one specimen (preferably 3-5 specimens) of each taxon encountered is placed into a 1-dram vial containing 70% ethanol and is properly labeled with identity and sample number. These specimens will comprise the project synoptic reference collection.
• Depending on the needs of the client, organisms can be vouchered by the specified taxonomic level.
• The computer automatically prints out a taxonomic bench sheet for each sample, including taxa lists and counts.

Step 5: Taxonomic Data Entry and Quality Assurance

At EcoAnalysts, we have pioneered a new level of efficiency in the taxonomic process by incorporating a computer at each taxonomist's station. Our model has been adopted by other labs to retool and refine laboratory processes.
• As the sample is being identified, the taxonomist enters data directly into the computer using a custom built database and user interface.
– The data entry program has several features built into it, including steps for taxonomic identification of a specimen, the number of specimens in each taxon, life stage information, taxonomic notes, etc**.**
– There is a visual confirmation at each step which prompts for a user confirmation. The program makes it virtually impossible to make some of the most common data entry mistakes, such as duplicates, omissions, misspellings, typos, etc.
– A running tally of invertebrates, as well as the number of taxa in the sample, are displayed on the screen; therefore, a taxonomist can quickly look for low or high counts as a flag for major discrepancies.
– With this process, we have successfully eliminated the need for handwritten bench sheets, thereby doing away with a secondary step of data entry and the errors associated with it.
– We use the person most qualified to recognize potential data entry errors, the taxonomist, to enter the data.

Step 6: Internal Quality Assurance of Taxonomic Identifications

As with sample sorting, it is important to have strict quality assurance of taxonomic identifications. With our staff of highly skilled macroinvertebrate taxonomists, we have the ability to perform internal quality assurance checks that single operators cannot perform. The purpose of this step is to increase the integrity of your taxonomic data. The following steps will be taken to achieve this purpose:

• A second taxonomist will examine the project synoptic reference collection to verify the accuracy of all taxa identified in the project.
• Next, 10% of the samples will be randomly selected for re-identification by a QA taxonomist.
• Percent similarity is calculated to compare both sets of data.
• Both taxonomists meet and discuss any discrepancies, either by re-examining the specimens or discussion, depending upon the nature of the difference.
• The final data will be adjusted according to the recommendations of both taxonomists.
• Reconciliation reports are written and delivered to the client as part of the overall Quality Assurance Report.

Step 7: Data Compilation and Delivery

The purpose of this step is to compile the taxonomic data for each sample. This is accomplished in the following manner:

• Using our networked computer system, the appropriate data are combined for each sample to obtain the comprehensive taxa lists and counts.
• Data, including quality assurance reports, are delivered in an electronic format specified by the client. EcoAnalysts can deliver data in MS Access, Excel, or ASCII format on CD-ROM and via email, if required.
• The delivery schedule will be agreed upon by the client and EcoAnalysts in advance, specifying the sample lots, dates, and components. A hardcopy data package option can include all data, QA/QC reports, and copies of chain-of-custody forms.
• EcoAnalysts retains all raw data files used and derived in our projects, including bench sheets, reports, calculation records, and QA tests.

Step 8: Sample Residue Retention and Return

The purpose of this step is to specify the logistics of handling the sample materials after processing and data delivery is complete.

• Processed sample components may include:
– Sorted and unsorted residues in jars
– All identified organisms including reference collection specimens
– Client cooler(s)
• The standard retention period for these components at EcoAnalysts is at least 30 days after the data delivery date. We will store the sample components longer upon client request.
• After the retention period is over, the sample components specified for return by the

client are returned with the chain of custody forms and according to DOT and IATA rules and regulations for offering hazardous materials for shipment.
• Any components not requested to be returned to the client become the property of EcoAnalysts, Inc.

D. Methods for Analysis of Sediment Diatoms (Dr. P. Roger Sweets)

Sediment was sent and stored in sealed centrifuge tubes kept at low temperatures. After homogenization in the bags, a 1.0 ml sample was extracted either through use of a Beckman Pipetman. In each case the sample was digested by a 'cold digestion' method. The sediment is rinsed into a beaker with a minimal amount of distilled water. Typical volumes at this stage are about 10 ml. Two to three times that amount of concentrated sulfuric acid (H_2SO_4) is added to the beaker. A saturated solution of potassium permanganate is added at this stage resulting in rapid heating and digestion of organic matter. The permanganate is continually added until no digestion appears to take place. A saturated solution of oxalic acid is then added to 'clear' the solution. The digestate is replaced with water by removing the supernatant after settling through a lengthy series. The final volume of cleaned diatoms is brought to 15 ml. Battarbee (1973) trays placed on a slide warmer were used for settling diatoms on the cover slips. After a sufficient time for settling, the slide warmer was turned on for low heat until the water has evaporated. The cover slip is then fixed in Hyrax® medium on a slide.

The diatoms are counted using both phase and bright-field optics on an Olympus® BH-2 microscope. For this study, a count of 500 valves was performed by the transect method. Broken frustules are counted by the protocol of a single identifiable point for each valve. Both valve and girdle views are enumerated. All valves in colonies are counted, however, only one colony was observed from the Foehn Lake sediments (*Fragilaria construens)*. Because of the dominance of *Aulacoseira distans,* qualitative observations of a slide area equal to that required for 500 valves were made to establish whether diversity was well established after the 500 valve count.

Information on diatom taxonomy is drawn from a variety of texts, much of which resides on the counters extensive photographic documentation. Principal texts referred to are Patrick and Reimer (1966), Krammer and Lange-Bertalot (1986-1991), Hustedt (1959), and Camburn *et al*. (1986) and Camburn and Charles (2000). In this report a traditional taxonomy is employed that does not include some of the proposed genera of the last 20 years, principally to provide clarity with comparison with a diatom core investigation predating these texts by Whiting, other paleoecological investigations from the same region, and also because ecological and paleoecological investigations are performed with slightly different goals than taxonomic investigations that require SEM techniques. Further discussion of the most important of these nomenclatural choices are provided below. In the low diversity paleolimnological diatom flora of Foehn Lake, these differences are minimal as the major changes in the traditional taxa of *Navicula* and *Fragilaria* that began with Williams and Round (1987) are not important here.

The paleolimnological reconstructions are based on a calibration set of 55 lakes that combines lakes concentrated mainly in the Cascades mountains, but also in other areas of Washington and Oregon, with lakes from the Sierra Nevada region collected as part of the PIRLA project (Charles et al. 1986). Most of the Cascade lakes diatoms were identified by Sweets and most of the Sierra Nevada diatoms by Mark Whiting (Whiting et al. 1989) while Whiting and Sweets were located in the same laboratory; there is good harmony between these two diatom data sets. Fifty-four of these lakes have pH values associated with them and 41lakes have total phosphorus data. Analyses using canonical correspondence analysis (CANOCO: ter Braak and Smilauer 1998) have demonstrated that pH and total phosphorus are two parameters that explain the greatest amount of variance in the surface sediment diatom assemblages of these lakes.The reconstructions were performed with WACALIB 3.1 (Line *et al.* 1994) using the weighted averaging methodology and bootstrapping statistical techniques.

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E. CE-QUAL-W2 Project Input File for Foehn Lake

X. The project file for the Foehn Lake model. Similar project files are used in the simulations for the other lakes.

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 PSU W2 Model Version 3.6

TITLE C .....................TITLE.....................
      Foehn Lake

GRID       NWB    NBR    IMX    KMX
          1      1     13      7

IN/OUTFL    NTR    NST    NIW    NWD    NGT    NSP    NPI    NPU
          0      0      0      1      0      0      0      0

CONSTITU    NGC    NSS    NAL    NEP   NBOD    NMC    NZP
          6      0      1      0      0      0      1

MISCELL    NDAY
         100

TIME CON  TMSTRT   TMEND    YEAR
       1.00000 700.000    2004

DLT CON     NDT  DLTMIN
          1 1.00000

DLT DATE    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD    DLTD
       1.00000

DLT MAX   DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX  DLTMAX
DLTMAX
       3600.00

DLT FRN    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF    DLTF
       0.90000
```

```
DLT LIMI    VISC    CELC
WB 1         ON      ON

BRANCH G     US     DS    UHS     DHS     UQB     DQB   NLMIN   SLOPE
BR1          2     12      0      0       0       0       1 0.00000

LOCATION    LAT    LONG    EBOT     BS     BE    JBDN
WB 1     34.2000 93.3000 1730.00      1      1      1

INIT CND     T2I    ICEI  WTYPEC
WB 1     1.00000 0.00000   FRESH

CALCULAT     VBC     EBC     MBC     PQC     EVC     PRC
WB 1         ON      ON      ON     OFF      ON      ON

DEAD SEA   WINDC    QINC   QOUTC   HEATC
WB 1         ON      ON      ON      ON

INTERPOL   QINIC   DTRIC    HDIC
BR1          ON     OFF     OFF

HEAT EXCH  SLHTC    SROC  RHEVAP   METIC  FETCHC     AFW     BFW     CFW   WINDH
WB 1        TERM      ON     OFF      ON     OFF 9.20000 0.46000 2.00000 2.00000

ICE COVE    ICEC  SLICEC  ALBEDO   HWICE    BICE    GICE  ICEMIN   ICET2
WB 1         ON  SIMPLE 0.25000 10.0000 0.60000 0.07000 0.05000 3.00000

TRANSPOR   SLTRC   THETA
WB 1    ULTIMATE 0.00000

HYD COEF      AX      DX    CBHE    TSED      FI   TSEDF   FRICC
WB 1     0.10000 0.10000 0.30000 10.0000 0.01000 0.10000   CHEZY

EDDY VISC    AZC   AZSLC   AZMAX
WB 1         W2     EXP .10E-05

N STRUC     NSTR
BR1           0

STR INT    STRIC   STRIC   STRIC   STRIC   STRIC   STRIC   STRIC   STRIC   STRIC
BR 1

STR TOP    KTSTR   KTSTR   KTSTR   KTSTR   KTSTR   KTSTR   KTSTR   KTSTR   KTSTR
BR1

STR BOT    KBSTR   KBSTR   KBSTR   KBSTR   KBSTR   KBSTR   KBSTR   KBSTR   KBSTR
BR1

STR SINK   SINKC   SINKC   SINKC   SINKC   SINKC   SINKC   SINKC   SINKC   SINKC
BR1

STR ELEV    ESTR    ESTR    ESTR    ESTR    ESTR    ESTR    ESTR    ESTR    ESTR
BR1
```

STR WIDT WSTR WSTR WSTR WSTR WSTR WSTR WSTR WSTR WSTR
BR1

PIPES IUPI IDPI EUPI EDPI WPI DLXPI FPI FMINPI WTHLC

PIPE UP PUPIC ETUPI EBUPI KTUPI KBUPI

PIPE DOWN PDPIC ETDPI EBDPI KTDPI KBDPI

SPILLWAY IUSP IDSP ESP A1SP B1SP A2SP B2SP WTHLC

SPILL UP PUSPC ETUSP EBUSP KTUSP KBUSP

SPILL DOWN PDSPC ETUSP EBUSP KTDSP KBDSP

SPILL GAS GASSPC EQSP AGASSP BGASSP CGASSP

GATES IUGT IDGT EGT A1GT B1GT G1GT A2GT B2GT G2GT WTHLC

GATE WEIR GTA1 GTB1 GTA2 GTB2 DYNVAR

GATE UP PUGTC ETUGT EBUGT KTUGT KBUGT

GATE DOWN PDGTC ETDGT EBDGT KTDGT KBDGT

GATE GAS GASGTC EQGT AGASGT BGASGT CGASGT

PUMPS 1 IUPU IDPU EPU STRTPU ENDPU EONPU EOFFPU QPU WTHLC

PUMPS 2 PPUC ETPU EBPU KTPU KBPU

WEIR SEG IWR IWR IWR IWR IWR IWR IWR IWR IWR

WEIR TOP KTWR KTWR KTWR KTWR KTWR KTWR KTWR KTWR KTWR

WEIR BOT KBWR KBWR KBWR KBWR KBWR KBWR KBWR KBWR KBWR

```
WD INT    WDIC   WDIC   WDIC   WDIC   WDIC   WDIC   WDIC   WDIC   WDIC
          ON

WD SEG    IWD    IWD    IWD    IWD    IWD    IWD    IWD    IWD    IWD
          12

WD ELEV   EWD    EWD    EWD    EWD    EWD    EWD    EWD    EWD    EWD
       1734.00

WD TOP    KTWD   KTWD   KTWD   KTWD   KTWD   KTWD   KTWD   KTWD   KTWD
          2

WD BOT    KBWD   KBWD   KBWD   KBWD   KBWD   KBWD   KBWD   KBWD   KBWD
          3

TRIB PLA  PTRC   PTRC   PTRC   PTRC   PTRC   PTRC   PTRC   PTRC   PTRC


TRIB INT  TRIC   TRIC   TRIC   TRIC   TRIC   TRIC   TRIC   TRIC   TRIC


TRIB SEG  ITR    ITR    ITR    ITR    ITR    ITR    ITR    ITR    ITR
          0

TRIB TOP  ELTRT  ELTRT  ELTRT  ELTRT  ELTRT  ELTRT  ELTRT  ELTRT  ELTRT
       0.00000

TRIB BOT  ELTRB  ELTRB  ELTRB  ELTRB  ELTRB  ELTRB  ELTRB  ELTRB  ELTRB
       0.00000

DST TRIB  DTRC   DTRC   DTRC   DTRC   DTRC   DTRC   DTRC   DTRC   DTRC
BR 1      OFF

HYD PRIN  HPRWBC  HPRWBC  HPRWBC  HPRWBC  HPRWBC  HPRWBC  HPRWBC  HPRWBC
HPRWBC
NVIOL     OFF
U         OFF
W         OFF
T         ON
RHO       OFF
AZ        OFF
SHEAR     OFF
ST        OFF
SB        OFF
ADMX      OFF
DM        OFF
HDG       OFF
ADMZ      OFF
HPG       OFF
GRAV      OFF

SNP PRINT  SNPC   NSNP   NISNP
WB 1       ON     1      1
```

```
SNP DATE   SNPD   SNPD   SNPD   SNPD   SNPD   SNPD   SNPD   SNPD   SNPD
WB 1    1.00000

SNP FREQ   SNPF   SNPF   SNPF   SNPF   SNPF   SNPF   SNPF   SNPF   SNPF
WB 1    100.000

SNP SEG    ISNP   ISNP   ISNP   ISNP   ISNP   ISNP   ISNP   ISNP   ISNP
WB 1         6

SCR PRINT  SCRC   NSCR
WB 1        ON     1

SCR DATE   SCRD   SCRD   SCRD   SCRD   SCRD   SCRD   SCRD   SCRD   SCRD
WB 1    1.00000

SCR FREQ   SCRF   SCRF   SCRF   SCRF   SCRF   SCRF   SCRF   SCRF   SCRF
WB 1    1.00000

PRF PLOT   PRFC   NPRF   NIPRF
WB 1       OFF     1      1

PRF DATE   PRFD   PRFD   PRFD   PRFD   PRFD   PRFD   PRFD   PRFD   PRFD
WB 1    505.000

PRF FREQ   PRFF   PRFF   PRFF   PRFF   PRFF   PRFF   PRFF   PRFF   PRFF
WB 1    1.00000

PRF SEG    IPRF   IPRF   IPRF   IPRF   IPRF   IPRF   IPRF   IPRF   IPRF
WB 1         5

SPR PLOT   SPRC   NSPR   NISPR
WB 1       OFF     1      1

SPR DATE   SPRD   SPRD   SPRD   SPRD   SPRD   SPRD   SPRD   SPRD   SPRD
WB 1    274.700

SPR FREQ   SPRF   SPRF   SPRF   SPRF   SPRF   SPRF   SPRF   SPRF   SPRF
WB 1    100.000

SPR SEG    ISPR   ISPR   ISPR   ISPR   ISPR   ISPR   ISPR   ISPR   ISPR
WB 1         26

VPL PLOT   VPLC   NVPL
WB 1       OFF     1

VPL DATE   VPLD   VPLD   VPLD   VPLD   VPLD   VPLD   VPLD   VPLD   VPLD
WB 1    64.0000

VPL FREQ   VPLF   VPLF   VPLF   VPLF   VPLF   VPLF   VPLF   VPLF   VPLF
WB 1    0.01000

CPL PLOT   CPLC   NCPL
WB 1        ON     1
```

```
CPL DATE   CPLD   CPLD   CPLD   CPLD   CPLD   CPLD   CPLD   CPLD   CPLD
WB 1    1.00000

CPL FREQ   CPLF   CPLF   CPLF   CPLF   CPLF   CPLF   CPLF   CPLF   CPLF
WB 1    10.0000

FLUXES     FLXC   NFLX
WB 1         ON      1

FLX DATE   FLXD   FLXD   FLXD   FLXD   FLXD   FLXD   FLXD   FLXD   FLXD
WB 1    1.00000

FLX FREQ   FLXF   FLXF   FLXF   FLXF   FLXF   FLXF   FLXF   FLXF   FLXF
WB 1    0.40000

TSR PLOT   TSRC   NTSR   NITSR
          ON      1      1

TSR DATE   TSRD   TSRD   TSRD   TSRD   TSRD   TSRD   TSRD   TSRD   TSRD
       1.00000

TSR FREQ   TSRF   TSRF   TSRF   TSRF   TSRF   TSRF   TSRF   TSRF   TSRF
       1.10000

TSR SEG    ITSR   ITSR   ITSR   ITSR   ITSR   ITSR   ITSR   ITSR   ITSR
           6

TSR LAYE   ETSR   ETSR   ETSR   ETSR   ETSR   ETSR   ETSR   ETSR   ETSR
       1.00000

WITH OUT   WDOC   NWDO   NIWDO
          OFF      0      0

WITH DAT   WDOD   WDOD   WDOD   WDOD   WDOD   WDOD   WDOD   WDOD   WDOD


WITH FRE   WDOF   WDOF   WDOF   WDOF   WDOF   WDOF   WDOF   WDOF   WDOF


WITH SEG   IWDO   IWDO   IWDO   IWDO   IWDO   IWDO   IWDO   IWDO   IWDO


RESTART    RSOC   NRSO   RSIC
          OFF      0    OFF

RSO DATE   RSOD   RSOD   RSOD   RSOD   RSOD   RSOD   RSOD   RSOD   RSOD


RSO FREQ   RSOF   RSOF   RSOF   RSOF   RSOF   RSOF   RSOF   RSOF   RSOF


CST COMP    CCC   LIMC    CUF
          ON     ON      1
```

CST ACTIVE CAC
TDS OFF
Gen1 ON
Gen2 ON
Gen3 ON
Gen4 ON
Gen5 ON
Gen6 ON
PO4 ON
NH4 ON
NO3 ON
DSI OFF
PSI OFF
FE OFF
LDOM OFF
RDOM OFF
LPOM OFF
RPOM OFF
ALG1 ON
DO ON
TIC ON
ALK ON
ZOO1 ON
LDOM-P OFF
RDOM-P OFF
LPOM-P OFF
RPOM-P OFF
LDOM-N OFF
RDOM-N OFF
LPOM-N OFF
RPOM-N OFF

CST DERI CDWBC CDWBC CDWBC CDWBC CDWBC CDWBC CDWBC CDWBC CDWBC
DOC OFF
POC OFF
TOC OFF
DON OFF
PON OFF
TON OFF
TKN OFF
TN OFF
DOP OFF
POP OFF
TOP OFF
TP OFF
APR OFF
CHLA OFF
ATOT OFF
%DO ON
TSS OFF
TISS OFF
CBOD OFF
pH ON

```
CO2          ON
HCO3         OFF
CO3          OFF

CST FLUX   CFWBC   CFWBC   CFWBC   CFWBC   CFWBC   CFWBC   CFWBC   CFWBC   CFWBC
TISSIN       OFF
TISSOUT      OFF
PO4AR        OFF
PO4AG        OFF
PO4AP        OFF
PO4ER        OFF
PO4EG        OFF
PO4EP        OFF
PO4POM       OFF
PO4DOM       OFF
PO4OM        OFF
PO4SED       OFF
PO4SOD       OFF
PO4SET       OFF
NH4NITR      OFF
NH4AR        OFF
NH4AG        OFF
NH4AP        OFF
NH4ER        OFF
NH4EG        OFF
NH4EP        OFF
NH4POM       OFF
NH4DOM       OFF
NH4OM        OFF
NH4SED       OFF
NH4SOD       OFF
NO3DEN       OFF
NO3AG        OFF
NO3EG        OFF
NO3SED       OFF
DSIAG        OFF
DSIEG        OFF
DSIPIS       OFF
DSISED       OFF
DSISOD       OFF
DSISET       OFF
PSIAM        OFF
PSINET       OFF
PSIDK        OFF
FESET        OFF
FESED        OFF
LDOMDK       OFF
LRDOM        OFF
RDOMDK       OFF
LDOMAP       OFF
LDOMEP       OFF
LPOMDK       OFF
LRPOM        OFF
RPOMDK       OFF
```

```
LPOMAP       OFF
LPOMEP       OFF
LPOMSET      OFF
RPOMSET      OFF
CBODDK       OFF
DOAP         OFF
DOAR         OFF
DOEP         OFF
DOER         OFF
DOPOM        OFF
DODOM        OFF
DOOM         OFF
DONITR       OFF
DOCBOD       OFF
DOREAR       OFF
DOSED        OFF
DOSOD        OFF
TICAG        OFF
TICEG        OFF
SEDDK        OFF
SEDAS        OFF
SEDLPOM      OFF
SEDSET       OFF
SODDK        OFF

CST ICON   C2IWB   C2IWB   C2IWB   C2IWB   C2IWB   C2IWB   C2IWB   C2IWB   C2IWB
TDS      1.00000
Gen1     0.12800
Gen2     0.02450
Gen3     0.13750
Gen4     0.03000
Gen5     0.42000
Gen6     0.11450
PO4      0.00200
NH4      0.01000
NO3      0.01000
DSI      0.00000
PSI      0.00000
FE       0.00000
LDOM     0.10000
RDOM     0.70000
LPOM     0.10000
RPOM     0.10000
ALG1     0.10000
DO       10.0000
TIC      0.10000
ALK      -0.2000
ZOO1     0.00100
LDOM-P   0.00500
RDOM-P   0.00050
LPOM-P   0.00050
RPOM-P   0.00050
LDOM-N   0.00050
RDOM-N   0.00800
```

LPOM-N 0.00800
RPOM-N 0.00800

CST PRIN CPRWBC CPRWBC CPRWBC CPRWBC CPRWBC CPRWBC CPRWBC CPRWBC CPRWBC
TDS OFF
Gen1 ON
Gen2 ON
Gen3 ON
Gen4 ON
Gen5 ON
Gen6 ON
PO4 ON
NH4 ON
NO3 ON
DSI OFF
PSI OFF
FE OFF
LDOM OFF
RDOM OFF
LPOM OFF
RPOM OFF
ALG1 ON
DO ON
TIC ON
ALK ON
ZOO1 ON
LDOM-P OFF
RDOM-P OFF
LPOM-P OFF
RPOM-P OFF
LDOM-N OFF
RDOM-N OFF
LPOM-N OFF
RPOM-N OFF

CIN CON CINBRC CINBRC CINBRC CINBRC CINBRC CINBRC CINBRC CINBRC CINBRC
TDS OFF
Gen1 OFF
Gen2 OFF
Gen3 OFF
Gen4 OFF
Gen5 OFF
Gen6 OFF
PO4 OFF
NH4 OFF
NO3 OFF
DSI OFF
PSI OFF
FE OFF
LDOM OFF
RDOM OFF
LPOM OFF
RPOM OFF

ALG1 OFF
DO OFF
TIC OFF
ALK OFF
ZOO1 OFF
LDOM-P OFF
RDOM-P OFF
LPOM-P OFF
RPOM-P OFF
LDOM-N OFF
RDOM-N OFF
LPOM-N OFF
RPOM-N OFF

CTR CON CTRTRC CTRTRC CTRTRC CTRTRC CTRTRC CTRTRC CTRTRC CTRTRC CTRTRC
TDS OFF
Gen1 OFF
Gen2 OFF
Gen3 OFF
Gen4 OFF
Gen5 OFF
Gen6 OFF
PO4 OFF
NH4 OFF
NO3 OFF
DSI OFF
PSI OFF
FE OFF
LDOM OFF
RDOM OFF
LPOM OFF
RPOM OFF
ALG1 OFF
DO OFF
TIC OFF
ALK OFF
ZOO1 OFF
LDOM-P OFF
RDOM-P OFF
LPOM-P OFF
RPOM-P OFF
LDOM-N OFF
RDOM-N OFF
LPOM-N OFF
RPOM-N OFF

CDT CON CDTBRC CDTBRC CDTBRC CDTBRC CDTBRC CDTBRC CDTBRC CDTBRC CDTBRC
TDS OFF
Gen1 OFF
Gen2 OFF
Gen3 OFF
Gen4 OFF

Gen5 OFF
Gen6 OFF
PO4 OFF
NH4 OFF
NO3 OFF
DSI OFF
PSI OFF
FE OFF
LDOM OFF
RDOM OFF
LPOM OFF
RPOM OFF
ALG1 OFF
DO OFF
TIC OFF
ALK OFF
ZOO1 OFF
LDOM-P OFF
RDOM-P OFF
LPOM-P OFF
RPOM-P OFF
LDOM-N OFF
RDOM-N OFF
LPOM-N OFF
RPOM-N OFF

CPR CON CPRBRC CPRBRC CPRBRC CPRBRC CPRBRC CPRBRC CPRBRC CPRBRC CPRBRC
TDS OFF
Gen1 ON
Gen2 ON
Gen3 ON
Gen4 ON
Gen5 ON
Gen6 ON
PO4 OFF
NH4 ON
NO3 ON
DSI OFF
PSI OFF
FE OFF
LDOM OFF
RDOM OFF
LPOM OFF
RPOM OFF
ALG1 OFF
DO OFF
TIC OFF
ALK OFF
ZOO1 OFF
LDOM-P OFF
RDOM-P OFF
LPOM-P OFF
RPOM-P OFF

```
LDOM-N      OFF
RDOM-N      OFF
LPOM-N      OFF
RPOM-N      OFF

EX COEF   EXH2O   EXSS   EXOM   BETA    EXC   EXIC
WB 1    0.45000 0.01000 0.20000 0.45000    OFF    OFF

ALG EX     EXA    EXA    EXA    EXA    EXA    EXA
      0.20000

ZOO EX     EXZ    EXZ    EXZ    EXZ    EXZ    EXZ
      0.20000

MACRO EX   EXM    EXM    EXM    EXM    EXM    EXM
      0.01000

GENERIC   CGQ10  CG0DK  CG1DK   CGS
CG 1    0.00000 0.00000 0.00000 0.00000
CG 2    0.00000 0.00000 0.00000 0.00000
CG 3    0.00000 0.00000 0.00000 0.00000
CG 4    0.00000 0.00000 0.00000 0.00000
CG 5    0.00000 0.00000 0.00000 0.00000
CG 6    0.00000 0.00000 0.00000 0.00000

S SOLIDS    SSS   SEDRC   TAUCR
SS# 1   1.00000    OFF 0.00000

ALGAL RATE   AG    AR    AE    AM    AS   AHSP   AHSN  AHSSI   ASAT
ALG1    2.00000 0.01000 0.10000 0.05000 0.10000 0.00100 0.00500 0.00000 100.000

ALGAL TEMP  AT1   AT2   AT3   AT4   AK1   AK2   AK3   AK4
ALG1    5.00000 30.0000 35.0000 40.0000 0.10000 0.99000 0.99000 0.10000

ALG STOI   ALGP   ALGN   ALGC  ALGSI  ACHLA  ALPOM  ANEQN   ANPR
ALG1    0.00020 0.08000 0.20000 0.00000 65.0000 1.00000      2 0.01000

EPIPHYTE   EPIC   EPIC   EPIC   EPIC   EPIC   EPIC   EPIC   EPIC   EPIC
EPI1       OFF

EPI PRIN   EPRC   EPRC   EPRC   EPRC   EPRC   EPRC   EPRC   EPRC   EPRC
EPI1       OFF

EPI INIT   EPICI  EPICI  EPICI  EPICI  EPICI  EPICI  EPICI  EPICI  EPICI
EPI1    0.00000

EPI RATE    EG    ER    EE    EM    EB   EHSP   EHSN  EHSSI
EPI1    1.50000 0.05000 0.02000 0.10000 0.00001 0.00200 0.00200 0.00000

EPI HALF   ESAT   EHS  ENEQN   ENPR
EPI1    150.000 15.0000      2 0.00100

EPI TEMP    ET1   ET2   ET3   ET4   EK1   EK2   EK3   EK4
EPI1    1.00000 3.00000 20.0000 30.0000 0.10000 0.99000 0.99000 0.10000
```

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EPI STOI     EP     EN     EC     ESI   ECHLA    EPOM
EPI1     0.00500 0.08000 0.45000 0.00000 65.0000 0.80000

ZOOP RATE    ZG     ZR     ZM    ZEFF   PREFP  ZOOMIN   ZS2P
Zoo1     1.00000 0.05000 0.20000 0.50000 0.25000 0.01000 0.08000

ZOOP ALGP  PREFA   PREFA   PREFA   PREFA   PREFA   PREFA   PREFA   PREFA   PREFA
Zoo1     0.80000

ZOOP ZOOP  PREFZ   PREFZ   PREFZ   PREFZ   PREFZ   PREFZ   PREFZ   PREFZ   PREFZ
Zoo1     0.20000

ZOOP TEMP    ZT1    ZT2    ZT3    ZT4    ZK1    ZK2    ZK3    ZK4
Zoo1     5.00000 15.0000 20.0000 36.0000 0.10000 0.90000 0.98000 0.10000

ZOOP STOI    ZP     ZN     ZC
Zoo1     0.00100 0.08000 0.25000

MACROPHY  MACWBC  MACWBC  MACWBC  MACWBC  MACWBC  MACWBC  MACWBC
MACWBC  MACWBC
Mac1         ON

MAC PRIN  MPRWBC  MPRWBC  MPRWBC  MPRWBC  MPRWBC  MPRWBC  MPRWBC
MPRWBC  MPRWBC
Mac1         ON

MAC INI  MACWBCI MACWBCI MACWBCI MACWBCI MACWBCI MACWBCI MACWBCI
MACWBCI MACWBCI
Mac1     0.00000

MAC RATE     MG     MR     MM    MSAT    MHSP    MHSN    MHSC    MPOM  LRPMAC
Mac1     0.30000 0.05000 0.05000 30.0000 0.00000 0.00000 0.00000 0.90000 0.20000

MAC SED    PSED    NSED
Mac1     0.50000 0.50000

MAC DIST    MBMP    MMAX
Mac1     40.0000 500.000

MAC DRAG  CDDRAG    DMV    DWSA   ANORM
Mac1     3.00000 70000.0 8.00000 0.30000

MAC TEMP     MT1    MT2    MT3    MT4    MK1    MK2    MK3    MK4
Mac1     7.00000 15.0000 24.0000 34.0000 0.10000 0.99000 0.99000 0.01000

MAC STOICH    MP     MN     MC
Mac1     0.00500 0.08000 0.45000

DOM      LDOMDK  RDOMDK   LRDDK
WB 1     0.30000 0.00100 0.01000

POM      LPOMDK  RPOMDK   LRPDK    POMS
WB 1     0.08000 0.01000 0.00100 0.50000
```

```
OM STOIC   ORGP   ORGN   ORGC   ORGSI
WB 1     0.00500 0.08000 0.45000 0.18000

OM RATE    OMT1   OMT2   OMK1   OMK2
WB 1     4.00000 30.0000 0.10000 0.99000

CBOD       KBOD   TBOD   RBOD   CBODS
BOD 1    0.25000 1.01500 1.85000 0.00000

CBOD STOIC  BODP   BODN   BODC
BOD 1    0.00500 0.08000 0.45000

PHOSPHOR   PO4R   PARTP
WB 1     1.00000 1.20000

AMMONIUM   NH4R   NH4DK
WB 1     0.15000 0.15000

NH4 RATE   NH4T1   NH4T2   NH4K1   NH4K2
WB 1     5.00000 25.0000 0.00500 0.99000

NITRATE    NO3DK   NO3S
WB 1     0.15000 1.00000

NO3 RATE   NO3T1   NO3T2   NO3K1   NO3K2
WB 1     5.00000 25.0000 0.00500 0.99000

SILICA     DSIR   PSIS   PSIDK  PARTSI
WB 1     0.10000 0.10000 0.30000 0.20000

IRON       FER    FES
WB 1     0.50000 2.00000

SED CO2    CO2R
WB 1     0.10000

STOICH 1   O2NH4   O2OM
WB 1     4.57000 1.40000

STOICH 2   O2AR   O2AG
ALG1     1.10000 1.40000

STOICH 3   O2ER   O2EG
EPI1     1.10000 1.40000

STOICH 4   O2ZR
Zoop1    1.10000

STOICH 5   O2MR   O2MG
Mac1     1.10000 1.40000

O2 LIMIT   O2LIM
       0.00000
```

```
SEDIMENT    SEDC SEDPRC   SEDCI    SEDS    SEDK    FSOD    FSED
WB 1         OFF      ON 0.00000 0.08000 0.10000 1.00000 1.00000

SOD RATE   SODT1   SODT2   SODK1   SODK2
WB 1     4.00000 30.0000 0.10000 0.99000

S DEMAND    SOD     SOD     SOD     SOD     SOD     SOD     SOD     SOD     SOD
       0.30000 0.30000 0.30000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000
       0.00000 0.30000 0.30000 0.30000

REAERATION  TYPE    EQN#   COEF1   COEF2   COEF3   COEF4
WB 1        LAKE       2 0.00000 0.00000 0.00000 0.00000

RSI FILE.....RSIFN.....
      rsi.npt - not used

QWD FILE.....QWDFN.....
      qwd.npt

QGT FILE.....QGTFN.....
      qgt.npt - not used

WSC FILE.....WSCFN.....
      wsc.npt

SHD FILE.....SHDFN.....
      shade.npt

BTH FILE.....BTHFN.....
WB 1    bth.npt

MET FILE.....METFN.....
WB 1    greenridge.npt

EXT FILE.....EXTFN.....
WB 1    ext_1.npt - not used

VPR FILE.....VPRFN.....
WB 1    vprStrat.npt

LPR FILE.....LPRFN.....
WB 1    lpr.npt - not used

QIN FILE.....QINFN.....
BR1     qin_br1.npt

TIN FILE.....TINFN.....
BR1     tin_br1.npt

CIN FILE.....CINFN.....
BR1     cin_br1.npt

QOT FILE.....QOTFN.....
```

BR1 qot_br1.npt

QTR FILE.....QTRFN.....
TR1 qtr_tr1.npt - not used

TTR FILE.....TTRFN.....
TR1 ttr_tr1.npt - not used

CTR FILE.....CTRFN.....
TR1 ctr_tr1.npt - not used

QDT FILE.....QDTFN.....
BR1 qin_br1.npt - not used

TDT FILE.....TDTFN.....
BR1 tdt_br1.npt - not used

CDT FILE.....CDTFN.....
BR1 cdt_br1.npt - not used

PRE FILE.....PREFN.....
BR1 foehn.pcp

TPR FILE.....TPRFN.....
BR1 foehn.ptm

CPR FILE.....CPRFN.....
BR1 foehndep.prn

EUH FILE.....EUHFN.....
BR1 euh_br1.npt - not used

TUH FILE.....TUHFN.....
BR1 tuh_br1.npt - not used

CUH FILE.....CUHFN.....
BR1 cuh_br1.npt - not used

EDH FILE.....EDHFN.....
BR1 edh_br1.npt - not used

TDH FILE.....TDHFN.....
BR1 tdh_br1.npt - not used

CDH FILE.....CDHFN.....
BR1 cdh_br1.npt - not used

SNP FILE.....SNPFN.....
WB 1 snp.opt

PRF FILE.....PRFFN.....
WB 1 prf.opt

VPL FILE.....VPLFN.....

WB 1 vpl.opt

CPL FILE.....CPLFN.....
WB 1 cpl.opt

SPR FILE.....SPRFN.....
WB 1 sprAnth.opt

FLX FILE.....FLXFN.....
WB 1 flx.opt

TSR FILE.....TSRFN.....
tsr.opt

WDO FILE.....WDOFN.....
wdo.opt - not used