LIMNOLOGICAL AND FISHERIES INVESTIGATIONS AT

VIRGINIA LAKE, SOUTHEAST ALASKA

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by

Glenn J. Hollowell
and
Timothy P. Zadina

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AUTHORS

Glenn J. Hollowell is a fishery biologist for the Alaska Department of Fish and Game, Division of Commercial Fisheries, 2030 Sea Level Drive, Suite 205, Ketchikan, Alaska 99901-6073.

Timothy P. Zadina is a fishery biologist for the Alaska Department of Fish and Game, Division of Commercial Fisheries, 2030 Sea Level Drive, Suite 205, Ketchikan, Alaska 99901-6073.

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ABSTRACT

The Virginia Lake nutrient enrichment program was continued in 2002. Fertilizer was applied at 65% of the critical phosphorus load, using 20-5-0 liquid fertilizer that was applied twice weekly from mid-May to early September and a new prototype solid, controlled-release fertilizer (CRF) 16-30-0 with an estimated 100-day dissolution rate. Limnological sampling showed that total phosphorus and chlorophyll a concentrations were at elevated levels throughout the 2002 growing season. Zooplankton density and biomass were below the 16-year average, but above levels observed during the 1999–2001 period. The fall rearing sockeye salmon *Oncorhynchus nerka* fry population was estimated at 32,000 fish on 20 September 2002. The ZB-EZD model predicted the lake could support an estimated 115,000 – 192,000 smolt dependent on either optimum or maximum production values. The 2002 rearing fry were progeny of the adults that returned naturally in 2000 and 2001 from the initial colonization program (1989 to 1996). Based on 12% marine survival, the predicted total return for 2003 is estimated at 10,000 adult sockeye.

KEY WORDS: sockeye salmon, *Oncorhynchus nerka*, Virginia Lake, Mill Creek, Porterfield Creek, Southeast Alaska, limnology, zooplankton, lake fertilization, nutrient enrichment, survival, rearing, hydroacoustics, mid-water trawl, fishpass

INTRODUCTION

Over the past 16 years, a great deal of fisheries work has been conducted at Virginia Lake. Historically, Virginia Lake had a flow-limiting natural barrier located just above tidewater that was size specific to the passage of fish, and allowed only a limited population of sockeye salmon *Oncorhynchus nerka* to utilize the lake (Zadina and Haddix 1993). In a cooperative effort, the U.S. Forest Service (USFS) installed a fishpass in 1988, and the Alaska Department of Fish and Game (ADFG) and Southern Southeast Regional Aquaculture Association (SSRAA) stocked the lake with sockeye salmon fry from 1989 to 1996 (Edmundson et al. 1991; Zadina and Haddix 1993; Zadina 1997). The nutrient enrichment program was added in 1991, two years after problems occurred stocking emergent sockeye salmon fry in April, prior to when the lake's food supply was ready for this introduction (Edmundson et al. 1991). The fertilizer was applied at 50–60% of the critical phosphorus load (after Vollenweider 1976) while sockeye salmon fry were planted in the lake, from 1991 to 1996. After a hiatus in 1997, the nutrient enrichment program was reimplemented in 1998, with the total phosphorus additions loaded at 50% of the critical loading rate (Zadina and Weller 1999). The intent of the lower loading rate was to increase lower trophic level production in Virginia Lake, primarily to the benefit of the resident cutthroat trout *Oncorhynchus clarki spp*. population. Increasing the forage base for rearing sockeye salmon fry was a secondary goal of the lake fertilization program.

In 1999, fertilizer was applied at 60% of the critical phosphorus load into Virginia Lake, only this time all of the phosphorus added to the lake was contained in solid, controlled-release fertilizer (CRF) that was primarily distributed in the littoral zone of the upper half of the lake (Zadina and Heinl 2000). The initial results were both promising and problematic as difficulties with the fertilizer application made it almost impossible to determine if solid CRF fertilizer could be successfully used to increase the nutrient levels in the lake. In 2000, the lake was again fertilized with a combination of liquid and solid CRF; again at 60% of the critical phosphorus load, with 25% of the solid fertilizer distributed in upper Porterfield Creek, approximately 6.4 km above the confluence with Virginia Lake. In 2001, the nutrient enrichment program returned solely to liquid fertilizer and the application amount was again lowered to 50% of the estimated critical loading rate. During the 2002 season, applications were raised back to 60% of the estimated critical loading range and again used 20-5-0 liquid fertilizer. In addition, a new prototype CRF was stocked in the lake raising the critical loading rate to 65%. This new CRF was also evaluated for dissolution rate and nutrient release timing.

Here, we report the results of continued limnological and fisheries studies at Virginia Lake during the 2002 field season. These studies included: (1) an assessment of the primary and secondary production in the lake; (2) an assessment of the nutrient enrichment program; (3) an estimate of the rearing sockeye fry population through hydroacoustic and mid-water trawl sampling; and (4) a forecast of the total adult return for 2003. The escapement and age structure of adult sockeye salmon returning to Virginia Lake were evaluated by USFS personnel and are not included in this report.

Study Site

Virginia Lake (56°20' N, 132°10' W) is located 16 km east of Wrangell on mainland Southeast Alaska at an elevation of 32 m (Figure 1). The lake is slightly organically stained with a surface area of 256.7 ha, mean depth of 27.5 m, maximum depth of 54 m, and volume of $70.7 \cdot 10^6$ m^3 (Figure 2). The lake empties into Eastern Passage via Mill Creek (<1 km). There are two inlet streams: Porterfield Creek (ADF&G stream number 10740-10070-0010-2010) flows southwest 11 km to the east end of Virginia Lake, and Glacier Creek (ADF&G stream number 10740-10070-0010-2006) flows west 13 km to the south side of Virginia Lake (Orth 1967). Mean annual precipitation is an estimated 280 cm, the lake watershed area encompasses approximately 83 km^2, and the hydraulic residence time or flushing rate is estimated at 4.2 months (Edmundson et al. 1991).

Project Sponsorship

The United States Forest Service through the Alaska Department of Fish and Game provided funding to evaluate the limnological and nutrient enrichment assessment program in 2002. This is the final report fulfilling contract obligations for Sikes Act Contract 43-0109-2-0167.

METHODS

Limnological Assessment

Sampling to evaluate the nutrient enrichment program was conducted on the lake at station A, with a replicate zooplankton sample collected at Station B (Figure 2). Physical data, water quality, and biological samples were collected on 7 May, 6 June, 3 July, 6 August, 6 September, and 8 October 2002. All samples were analyzed at the ADF&G, Division of Commercial Fisheries, Limnology Laboratory in Soldotna, Alaska.

Physical Parameters

Measurements of underwater light penetration (foot candles) were recorded at 0.5 m intervals, from the surface to a depth equivalent to one percent of the subsurface light reading, using an International Light[2] IL1350 submarine photometer. Vertical light extinction coefficients (K_d) were calculated as the slope of the light intensity (ln of percent subsurface light) versus depth. The euphotic zone depth (EZD), the depth to which 1% of the subsurface light (photosynthetically available radiation [400-700 nm]) penetrates the lake surface (Schindler 1971), was calculated from the equation: $EZD = 4.6205 \cdot K_d^{-1}$ (Kirk 1994). Euphotic volume (EV) is the product of the EZD and lake surface area and represents the volume of water capable of photosynthesis.

[2] Mention of trade names does not constitute endorsement by ADF&G but are included for scientific completeness.

Temperature and dissolved oxygen concentrations were recorded at 1 m depth intervals, from the lake surface to 50 m, using a Yellow Springs Instruments (YSI) model 58 meter, calibrated each sampling trip with a 60 ml Winkler field titration (Koenings et al. 1987).

Water Quality

A 4 L Van Dorn sampler was used to collect water samples from the epilimnion (1 m) and from the mid-hypolimnion. Ten liters of water were collected from each depth, stored in pre-cleaned polyethylene carboys, transported to Ketchikan, and then filtered or preserved for laboratory analysis. Separate subsamples from each carboy were: (1) refrigerated for general tests and metals; (2) frozen for nitrogen and phosphorus analysis; and (3) filtered through a 0.7 μm particle retention glass fiber filter and frozen for analysis of dissolved nutrients and primary production (Koenings et al. 1987). Samples were analyzed for general qualities, metals, nutrients, and primary production by methods detailed in the Alaska Department of Fish and Game Limnology Field and Laboratory Manual (Koenings et al. 1987).

Secondary Production

Zooplankton samples were collected using a 0.5 m diameter, 153 μm mesh, 1:3 conical net. Vertical zooplankton tows were pulled from a depth of 50 m to the surface at a constant speed of 0.5 m $\cdot$ sec^{-1}. The net was rinsed prior to removing the organisms, and all specimens were preserved in neutralized 10% formalin (Koenings et al. 1987). Samples were analyzed by methods detailed in the Alaska Department of Fish and Game Limnology Field and Laboratory Manual (Koenings et al. 1987).

Lake Fertilization

Nutrient additions to Virginia Lake were based on estimates of yearly phosphorus loading (P in mg $\cdot$ m^{-2} $\cdot$ yr^{-1}) calculated after Vollenweider (1976):

surface specific loading:

$$L_p = (P)_c^{sp} Q_s \left(1 + \sqrt{\bar{z}/Q_s}\right)$$; and

surface critical loading:

$$L_c = \left(10 \text{ mg P/m}^3\right) Q_s \left(1 + \sqrt{\bar{z}/Q_s}\right);$$

where: $(P)_C^{SP}$ = spring overturn total P (mg $\cdot$ m^{-3}),
Q_s = $\bar{z}/T_w$,
T_w = water residence time (0.35 yr),
$\bar{z}$ = mean depth (27.5 m), and
10 mg P/m^3 = lower critical phosphorus level.

The addition of nutrients in 2002 was based on 60% of the critical load, and is equal to:

$$0.6L_c - L_p$$

Thus, the recommended quantity of fertilizer for application in 2002, based on a spring overturn total of 4.5 mg P $\cdot$ m^{-3}, was 8,430 gallons of 20-5-0 (Zadina and Hollowell 2002). This total amount was scheduled for twice-weekly applications over a 16-week period that equals approximately 270 gallons (9 barrels) per application. Liquid fertilizer was applied by the same methods as described by Zadina and Weller (1999).

In addition, a new, controlled-release fertilizer (CRF) was also distributed in 2002. The Lesco, Inc., Nutri-Stone® Aquatic Restoration Fertilizer Briquette 16-30-0 was a new, experimental CRF with a vegetable oil binder and a theorized nutrient dispersal time of 100 days. This fertilizer was stored in sealed buckets each containing 13 kg of individual 6 g pellets. The CRF was distributed in three lake areas. Area 1 (North logs) was located near the littoral area of the north lakeshore and consisted of an anchored log. Area 2 (East logs) was located near the littoral area of the east end lakeshore and consisted of an anchored log. Area 3 (float) was located adjacent to the Virginia Lake Island and consisted of an aluminum perforated box suspended by floats. The addition of 99 buckets (1,290 kg) of Nutri-Stone briquettes raised the loading rate to 65% of critical load in 2002.

Juvenile Sockeye Salmon Assessment

Rearing Fry Population

The distribution and abundance of rearing sockeye salmon fry was estimated by hydroacoustic and mid-water trawl sampling using the same methods described by Zadina and Weller (1999). Virginia Lake was divided into ten sampling areas based on surface area. Sample design consisted of a series of ten stratified, randomly chosen orthogonal transects across the lake, two from each sampling area. The two sets of ten transects were treated as independent surveys. Transect sampling was conducted during post-sunset darkness in one night. A constant boat speed of about 2.0 m sec^{-1} was attempted for all transects. A Biosonics DT-4000™ scientific echosounder (420 kHz, 6° single beam transducer) with Biosonics Visual Acquisition © version 4.0.2 software was used to collect data. Ping rate was set at 5 pings $\cdot$ sec^{-1} and pulse width at 0.4 ms. Data were analyzed using Biosonics Visual Analyzer © version 4.0.2 software after returning to the office. A 2 m $\times$ 2 m elongated trawl net was used for pelagic fish sampling. Trawl depths and duration were determined by fish densities and distributions throughout the lake based on observations during the hydroacoustic portion of the survey.

Lake Rearing Model

This report uses the ZB-EZD model (Stan Carlson, ADF&G Commercial Fisheries, Soldotna, personal communication, 1998) that utilizes zooplankton biomass and euphotic zone depth to estimate the potential sockeye fry rearing capability of the lake.

$$SB = 1.95(ZB) + 15.5(EZD) - 183.0;\ r^2 = 0.94,$$

where: SB = total smolt biomass (kg $\cdot$ km^{-2}),
ZB = weighted seasonal mean zooplankton biomass (mg $\cdot$ m^{-2}), and
EZD = seasonal mean euphotic zone depth (m).

The total potential smolt biomass is estimated by multiplying the calculated smolt biomass (SB) by the total lake area (km^2). Since sockeye salmon fry do not normally rear in water less than 5 m deep, it is logical to exclude the littoral zone from the total lake area when making this calculation. Virginia Lake has a surface area of 2.49 km^2 that covers depths greater than 5 m. Thus, the total potential smolt biomass of Virginia Lake will be the SB multiplied by 2.49 km^2. Maximum smolt production assumes an individual fish size of 2.4 g and optimum smolt production assumes an individual fish size of 4.0 g. Taking the estimated total smolt biomass and dividing by either 2.4 or 4.0 g, respectively, will calculate the potential number of smolt that could be produced from Virginia Lake.

This model, based on current physical and biological information, is only used for a comparison of the estimated potential to the actual sockeye salmon fry rearing population (estimated from hydroacoustic sampling). This basic examination allows us to see if the existing lake rearing environment may be a factor leading to any significant mortality of the existing population. The survival rate from fall rearing fry to smolt under normal, under capacity conditions is assumed to be 70% (Geiger and Koenings 1991). Therefore, the potential fall fry population (the number of fry the lake can support) can be estimated by taking the maximum or optimum smolt production and dividing by 70%.

Projected Returns and Marine Survival

Projected adult returns at Virginia Lake were calculated from the hydroacoustic estimate of the rearing fall fry population and based on standard fall fry-to-smolt and marine survival assumptions for sockeye salmon (Koenings et al. 1989; Geiger and Koenings 1991). The age at adult return assumptions derived from previous sockeye salmon work at Hugh Smith and McDonald Lakes (Zadina and Haddix 1989) are presented in Table 1. A matrix was constructed using multiple brood years to estimate adult returns by year.

RESULTS

Limnological Assessment

Physical Parameters

The euphotic zone depth (EZD) ranged from 4.4 m (6 September) to 14.9 m (6 August); with a seasonal mean depth of 8.74 m (Table 2). Euphotic volume (EV) was estimated at 22.46 $\cdot$ 10^6 m^3 or 22.46 EV units. This volume, capable of photosynthesis, represents 31.8% of the total lake volume. The thermocline depth ranged from 15 to 30 m throughout the growing season. Dissolved oxygen levels and seasonal temperature were normal and consistent with other years (Figure 3).

General Water Quality and Nutrient Concentrations

General water quality parameters and metal concentrations continued to be within the range regarded as normal for stained, oligotrophic, coastal Alaska lakes (Tables 3 and 4; see Edmundson et al. 1991; Zadina et al. 1992). The slightly acidic pH (mean 6.4), low conductivity, and low alkalinity indicated soft water; and the color (mean 13.2 Pt units) and iron concentrations (mean 143.8 $\mu g \cdot L^{-1}$) were characteristic of an organically stained lake.

Phosphorus is the primary element controlling lake productivity. It was the least abundant element of the nutrients required for algal growth in Virginia Lake. The concentration of total phosphorus varied from lows in May and October of 3.7 and 5.2 $\mu g \cdot L^{-1}$, respectively, to a high of 9.0 $\mu g \cdot L^{-1}$ in early July (Table 3). The concentrations of filterable reactive phosphorus (FRP), the most available form of phosphorus for algal uptake (Koenings et al. 1987), and total filterable phosphorus (TFP) while slightly above average, but within normal ranges found previously in Virginia Lake, and fairly stable through the season (Table 3).

Total nitrogen levels were fairly constant from May through September (175 - 185 $\mu g \cdot L^{-1}$), decreasing in October to a low of 133 $\mu g \cdot L^{-1}$ (Table 3). The atomic ratio of nitrogen to phosphorus varied from a high of 103:1 in May to a low of 23:1 in August, but still within the desired range for promotion of growth by the appropriate phytoplankton (Figure 4). This mid-summer nitrogen deficit has occurred regularly in McDonald and Virginia Lakes, where nutrient sampling has been done. The mean seasonal total nitrogen concentration was above average, but fell within the range of values previously observed at Virginia Lake (Table 4). Ammonia, which contains both the ammonium ion and ammonia, is the preferred form of nitrogen for uptake by phytoplankton (Koenings et al. 1987). Ammonia levels fluctuated significantly throughout the summer, though the overall mean seasonal concentration (7.5 $\mu g \cdot L^{-1}$) was within the range of measured seasonal values for this lake. The mean annual nitrate + nitrite concentration (90.7 $\mu g \cdot L^{-1}$) was lower than that observed in 2001 (103.8 $\mu g \cdot L^{-1}$). Last years level was the highest nitrate + nitrite recorded at Virginia Lake during the course of this study (Table 4). The total Kjeldahl nitrogen (TKN) concentration, while higher than average, was within the normal range of values previously observed at Virginia Lake.

Concentrations of reactive silicon (required for the formation of frustrule cell structure by diatoms) were highest in May, decreasing through early August and then showing significant increase in both the September and October samples (Tables 3 and 4). The silicon levels observed in July and August (88 and 103 $\mu g \cdot L^{-1}$) were the third and sixth lowest levels, respectively, observed in this lake in the last 16 years (Tables 3 and 4). The summer concentration of organic carbon, which estimates the amount and energy content of organic material in the lake (Koenings et al. 1987), was significantly higher than all of the previous 16 years, with the exception of 1992 where the organic carbon level was slightly higher (Table 4).

Primary and Secondary Production

The mean epilimnion concentration of chlorophyll a in 2002 was only slightly higher than average and relatively low when compared to levels documented during years when fertilization was conducted at a target level of 60% of critical load levels. The 2002 epilimnion concentrations ranged from 0.24 to 1.89 $\mu g \cdot L^{-1}$ with a seasonal mean 0.87 $\mu g \cdot L^{-1}$ (Table 5).

The macrozooplankton community of Virginia Lake in 2002 was again comprised of two species of Copepods (*Cyclops* sp. and *Diaptomus franciscanus*), the Cladoceran *Bosmina longirostris*, and unspecified Cladocerans of the subfamily Chydorinae (Table 6). Total zooplankton productivity by both density and biomass at Virginia Lake was below the 16-year average, but above the 1999–2001 period (Figures 5 and 6). The proportion of the total zooplankton density and biomass that were Cladocerans was also slightly below average but well within the normal range observed in the last 16 years (Figures 7 and 8). Cladocerans are the preferred prey of sockeye salmon fry (Koenings and Burkett 1987).

Lake Fertilization

During the 2002 field season, a total of 8,640 gallons of 20-5-0 liquid fertilizer was applied to the lake at a rate of 540 gallons per week from 16 May–10 September (Appendix Table A.1), using the methods described by Zadina and Weller (1999). This translates into 54 kg per week of elemental phosphorus that were added to this lake. The amount of fertilizer was increased significantly this year in order to meet the recommended P loading rate of 60%. The liquid fertilizer was the primary nutrient additive in 2002.

A total of 1,290 kg of Lesco Nutri-Stone Aquatic Restoration Fertilizer Briquette 16-30-0 were dispersed on 19 June and left untouched for the remainder of the season (Table 7). This CRF addition raised the prescribed loading rate an additional 5% of the critical load from 60 to 65%.

Area 1 (North logs) consisted of 12 suspended bags of pellets; Area 2 (East logs) consisted of 26 suspended bags of pellets; and Area 3 (float) contained 55 buckets (715 kg) of pellets spread out in the submerged portion of the float with an additional 6 bags of pellets suspended from the floats in the water column. Each suspended bag contained one bucket of pellets. Samples were removed at 8, 31, 51, 60, 80, and 113 days, post-deployment for nutrient dispersal analysis. This dissolution analysis is not complete at this time.

Juvenile Sockeye Salmon Assessment

The fall hydroacoustic survey was conducted on 20 September 2002. The total lentic fish population estimate was 68,000 (s.d. = 6,500). Five midwater trawls were accomplished, all of 15 minute duration. One at the surface to 2m depth strata and four at the 10 to 12 m depth strata. A total of 42 fish were captured in these tows consisting of age-0 sockeye fry, three-spine stickleback (*Gasterosteus aculeatus*), and cottids that were not identified to species (Table 8). The sockeye fry comprised 48% (32,000) of the population and had a mean length of 62.1 mm and mean weight of 2.42 g. This population of sockeye fry is expected to produce approximately 22,000 smolt in spring 2003, based on an average 70% over-winter survival.

Using the ZB-EZD model, we estimate that Virginia Lake could potentially support an optimum to maximum smolt range of 115,000–192,000 fish, based on standard survival assumptions, at an average weight of 4.0 and 2.4 g, respectively. Assuming a 70% over winter survival this would calculate back to an equivalent 164,000–274,000 fall fry.

Adult Sockeye Salmon Forecast

The total adult return forecast for 2003 is estimated at 10,000 sockeye salmon based on 12% marine survival (Table 9). All of these fish are the progeny of naturally produced adults, as this lake was not stocked after 1996.

DISCUSSION

Once again, the primary intention of nutrient additions to Virginia Lake in 2002 was to increase all trophic levels in Virginia Lake to ultimately benefit the resident cutthroat trout population, with any increase to the sockeye salmon fry forage base a secondary result. Nutrient additions boosted trophic levels to some degree, but how the cutthroat trout populations have been affected by nutrient enhancement is not known.

While samples from the pelagic portion of Virginia Lake throughout 2002 showed that concentrations of total phosphorus (Table 3) and chlorophyll a (Table 5) were markedly higher than in recent years, both zooplankton density (Figure 5) and biomass (Figure 6) were slightly below the 16-year average. However, when compared with levels from 1999–2001, there was an increase in both zooplankton biomass and density. During those years (1999–2001), 21 to 30 kg of phosphorus was added weekly to Virginia Lake. From 1991 to 1995, 20 to 61 kg of phosphorus was added weekly. This resulted in a greater level of total phosphorus and increased primary production during the summer months from 1991–1995, compared with 1999 to 2001. During 2002, an average of 64 kg of phosphorus was added each week. This resulted in a total of 1,076 kg of phosphorus being added over the entire season. This was the highest amount introduced to Virginia Lake in the 11 years that this lake has been fertilized (Table 10). Even with this high phosphorus loading, the measured total phosphorus level in Virginia Lake only averaged 7.0 $\mu g \cdot L^{-1}$, the second highest since 1987.

A decline in the epilimnetic reactive silicon levels occurred during the summer months (Figure 4) indicating a possible high increase in nutrient uptake by phytoplankton.

While zooplankton production was sufficient for the number of sockeye salmon fry present. The estimated sockeye salmon fry population of 32,000, based on fall hydroacoustics, fell below the range of maximum (275,000) and optimum (165,000) numbers of fall fry that we estimate the lake could support. This was based on analysis of the 2002 light penetration and zooplankton biomass data (ZB-EZD model).

The original sockeye salmon production potential of Virginia Lake was estimated at 26,000–37,000 adult sockeye salmon (Edmundson et al. 1991). This estimate was based solely on the two original models. The EV model (Koenings and Burkett 1987), that only used physical characteristics of sockeye salmon nursery lakes and did not take into account the biological productivity of the study lake, and the ZB model (Koenings and Kyle 1997) that utilized the standing crop of zooplankton in sockeye salmon nursery lakes. The ZB model was driven by a few, very productive lakes in Southcentral Alaska and Idaho (Stan Carlson, biometrician, ADF&G, Soldotna, personal communication 1997). Thus, the two models predict an unrealistic productivity index for most coastal oligotrophic lakes in Southeast Alaska. In addition, the EV model also had a tendency to overestimate production in clear water lakes that may have lacked zooplankton production. However, these were the only models available when studies to estimate production at Virginia Lake were initiated. Analysis using the ZB-EZD model with zooplankton productivity data for the original pre-stocking (1987–1988), post-fertilizer (1997) and low loading rate fertilizer (1998–2001) years suggests the estimated adult sockeye salmon production potential of Virginia Lake may only reach a maximum annual return of 10,000–17,000 adult sockeye salmon. Virginia Lake is a naturally, nutrient poor system, with a rapid flushing rate (Edmundson et al. 1991). This is also compounded by a lack of returning adult salmon that would naturally provide needed nutrients to the Virginia Lake watershed. It is our opinion that the lake may never be as productive in its natural state as the original models predicted. There is a possibility that future runs could be higher than this level if either: a) the system receives increased salmon escapement leading to the increased marine derived nutrients required for good lake productivity; or b) with proper nutrient additions and further enhancement by planting sockeye salmon pre-smolt.

RECOMMENDATIONS

Suggested fertilizer quantities for 2003 are dependent on desired loading rates (Table 11). These suggested amounts are based on Vollenweider's (1976) loading equations and assume a 2003 spring overturn period total phosphorus level of 5.15 $\mu g \cdot L^{-1}$. This phosphorus level is estimated from water samples taken on 8 October 2002 (Table 3). We use the fall water sample because the collection of water samples and analysis of phosphorus concentrations in the spring cannot be accomplished in time to purchase and transport the fertilizer prior to the growing season. Should the goal of future nutrient additions to Virginia Lake be a clear and discrete boosting of limnetic zooplankton populations as forage for sockeye salmon fry and cutthroat trout, then we recommend continuing to fertilize at the current 60% of critical loading level. Specifically, we suggest applying an annual total of 270 kg of elemental phosphorus, or 2,600 gallons of liquid 20-5-0 fertilizer in the pelagic zone of Virginia Lake in 2003. This prescription does not include controlled-release fertilizer and should be reevaluated if the decision is made to add this type of fertilizer.

Limnological evaluation should continue if nutrient additions proceed at Virginia Lake or at least for one year after fertilization ceases. Evaluation of sockeye salmon juveniles, returning adult salmon, and resident salmonids is also strongly encouraged.

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TABLES

Table 1. Age distribution assumptions of adult sockeye salmon returning to Virginia Lake by brood years 1997–1999, with emphasis on returns in 2003

Brood Year	Smolt Years	Projected Adult Age Distribution	Adult Age Class	Return Year
1997	1999 or 2000	10.50%	1.2	2001
		65.10%	1.3	2002
		5.50%	2.2	2002
		18.00%	**2.3**	**2003**
1998	2000 or 2001	10.50%	1.2	2002
		65.10%	**1.3**	**2003**
		5.50%	**2.2**	**2003**
		18.00%	2.3	2004
1999	2001 or 2002	**10.50%**	**1.2**	**2003**
		65.10%	1.3	2004
		5.50%	2.2	2004
		18.00%	2.3	2005

Table 2. Virginia Lake monthly euphotic zone depth (EZD) based on light intensity profiles, 2002.

Date	EZD (m)
6 May	8.0
5 June	10.0
3 July	9.2
6 August	14.9
6 September	4.4
8 October	6.1
Mean	8.74

Table 3. Summary of general water quality parameters, metal concentrations, and nutrient concentrations within the epilimnion (Epi = 1 m) and mid-hypolimnion (Hypo) at Virginia Lake, Station A, 2002.

Date	7 May		6 June		3 July		6 August		6 September		8 October		Means		
Depth (m)	Epi	Hypo	Epi	Hypo	Epi	Hypo	Epi	Hypo	Epi	Hypo	Epi	Hypo	Epi	Hypo	Total
pH	6.6	6.5	6.4	6.4	6.9	6.2	6.8	6.2	6.4	6.2	6.3	6.3	6.6	6.3	6.4
Conductivity (µmhos · cm^{-1})	36	30	24	28	21	29	20	28	20	29	23	29	24.0	28.8	26.4
Alkalinity (mg · L^{-1})	14.9	12.0	10.5	14.3	9.7	12.9	10.6	12.6	8.3	11.8	10.0	11.3	10.7	12.5	11.6
Turbidity (NTU)	1.2	0.8	0.5	0.5	0.8	0.5	1.4	0.5	0.9	1.0	0.6	0.5	0.9	0.6	0.8
Color (Pt units)	15	13	12	13	9	12	11	12	19	12	18	12	14.0	12.3	13.2
Calcium (µg · L^{-1})	4.1	5.0	3.6	4.2	3.4	4.2	3.4	4.2	3.1	4.4	3.5	4.2	3.5	4.4	3.9
Magnesium (mg · L^{-1})	0.9	0.6	0.5	0.6	0.5	1.0	0.4	0.7	0.4	0.6	0.8	0.5	0.6	0.7	0.6
Iron (µg · L^{-1})	163	237	91	205	51	247	75	184	75	180	73	144	88.0	199.5	143.8
Total-P (µg · L^{-1} P)	3.5	3.9	4.8	4.4	8.0	10.1	12.9	4.1	8.2		5.8	4.5	8.6	5.4	6.4
Total filterable-P (µg · L-1 P)	3.0	2.9		3.0	2.3	6.5	7.8	2.6	3.2	2.4	2.8	5.2	3.8	3.8	3.8
Filterable reactive -P (µg · L^{-1} P)	2.1	2.2	8.8	2.1	0.8	4.3	4.0	2.0	2.1	2.1	1.9	3.4	3.3	2.7	3.0
Total Kjeldahl N (µg · L^{-1} N)	65.3	69.7	69.7	55.7	105.2	123.6	131.1	51.3	105.2		86.8	55.7	112.7	71.2	83.6
Ammonia (µg · L^{-1} N)	3.7	1.7	7.1	4.9	10.9	13.4	25.8	14.7	9.1	13.7	14.9	18.6	11.9	11.2	11.5
Nitrate+nitrite (µg · L^{-1} N)	97.7	117.5	121.4	123.0	6.9	124.6	3.3	167.9	40.9	160.9	38.1	85.7	51.4	129.9	90.7
Total - N (µg · L^{-1} N)	163.0	187.2	191.1	178.7	112.1	248.2	134.4	219.2	146.1		124.9	141.4	174.3	194.9	167.8
Reactive silicon (µg · L^{-1} Si)	1,365	1,394	1,044	1,317	88	1,371	103	1,357	883	1,372	1,123	1,476	767.7	1,381.2	1,074.4
Carbon (µg · L^{-1} C)	122	137	157	88	332	142	240	85	131	85	134	88	186.0	104.2	145.1

Table 4. Comparison of the seasonal mean general water quality parameters, metal concentrations, and nutrient concentrations, at Virginia Lake, Station A, all depths, 1987–2002.

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Mean
pH	6.5	6.4	6.6	6.6	6.6	6.4	6.5	6.3	6.4	6.3	6.8	6.8	6.5	6.4	6.4	6.4	6.5
Conductivity (µmhos · cm^{-1})	24	24	26	25	25	23	24	26	29	29	27	26	26	26	24	26	25.7
Alkalinity (mg · L^{-1})	9.3	7.0	9.0	9.0	9.6	6.8	9.0	8.6	10.9	10.0	11.7	11.1	10.8	9.9	9.3	11.6	9.58
Turbidity (NTU)	0.4	1.1	0.8	1.1	1.0	1.0	2.2	1.1	1.3	0.9	0.7	0.7	0.9	0.9	0.8	0.8	0.98
Color (Pt units)	19	19	15	17	19	13	12	16	13	16	15	14	14	15	16	13	15.24
Calcium (mg · L^{-1})	5.5	3.9	4.3	4.1	4.1	3.9	4.0	4.1	4.4	4.1	4.0	3.9	4.1	4.0	3.7	3.9	4.12
Magnesium (mg · L^{-1})	0.6	0.2	0.2	0.4	0.3	0.7	0.5	0.6	0.7	0.4	0.4	0.3	0.4	0.4	0.5	0.6	0.44
Iron (µg · L^{-1})	91	138	130	175	146	121	257	152	161	146	87	67	123	101	110	144	134.2
Total-P (µg · L^{-1} P)	2.2	4.9	4.4	5.1	4.1	5.0	9.5	5.5	4.6	5.4	2.6	4.2	5.3	3.5	4.2	6.4	4.80
Total filterable-P (µg · L^{-1} P)	5.2	1.9	3.1	3.3	2.8	2.5	3.2	4.3	2.9	3.5	2.6	3.0	3.2	2.7	3.8	3.8	3.24
Filterable reactive -P (µg · L^{-1} P)	4.9	1.6	2.5	2.6	2.6	1.1	1.8	2.2	1.4	2.3	2.5	2.1	3.0	1.6	2.1	3.0	2.33
Total Kjeldahl N (µg · L^{-1} N)	45.5	57.5	53.3	54.5	67.4	68.4	134.3	79.2	67.6	97.9	65.8	69.9	78.3	106.0	58.3	83.6	74.22
Ammonia (µg · L^{-1} N)	50.0	1.5	6.6	4.2	4.8	9.1	11.9	6.8	3.3	9.9	7.7	4.2	10.2	12.5	7.5	11.5	10.10
Nitrate+nitrite (µg · L^{-1} N)	3.4	67.2	75.0	76.7	78.8	64.4	65.6	60.6	82.9	71.0	68.7	59.3	73.0	101.2	103.8	90.7	71.40
Total - N (µg · L^{-1} N)	48.9	124.8	128.2	131.3	127.0	132.8	199.9	139.8	150.5	168.9	134.5	129.2	151.4	207.2	162.1	167.8	144.02
Reactive silicon (µg · L^{-1} Si)	1,199	966	1,124	843	1,073	883	1,029	976	1,073	834	1,159	1,082	1,209	1,188	1,144	1,074	1,053
Carbon (µg · L^{-1} C)		92		136	120	151						111	129	101	110	145	121.7
Total Average of Chlorophyll a (µg · L^{-1})	0.23	0.14	0.15	0.20	0.45	0.60	0.91	1.02	1.89	3.47	0.33	0.74	0.27	0.39	0.36	0.88	0.75
Total Average of Phaeophytin a (µg · L^{-1})	0.24	0.13	0.12	0.12	0.21	0.41	0.42	0.34	0.64	0.50	0.24	0.34	0.10	0.14	0.14	0.17	0.26

Table 5. Summary of algal pigment concentrations (μg · L^{-1}) of chlorophyll a (Chl a) and phaeophytin a (Phaeo a) at Virginia Lake, Station A, 1992–2002.

Month	Depth	1992		1993		1994		1995		1996		1997		1998		1999		2000		2001		2002		Monthly Mean	
		Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a	Chl a	Phaeo a
April	1 m	0.43	0.16			0.3	0.13																	0.37	0.15
	MEU	0.38	0.13			0.28	0.15																	0.33	0.14
	EZD	0.26	0.14			0.18	0.1																	0.22	0.12
	HYP		0.04			0.02	0.05																	0.02	0.05
May	1 m			0.17	0.12			0.31	0.12	0.28	0.17	0.45	0.26			0.16	0.02	0.32	0.21	0.13	0.02	0.33	0.11	0.27	0.13
	2 m							0.32	0.12	0.24	0.17	0.45	0.29			0.54	0.09	0.33	0.22					0.38	0.18
	MEU			0.19	0.09			0.34	0.12	0.27	0.17	0.45	0.26			0.36	0.15	0.27	0.14	0.19	0.07	0.07	0.04	0.27	0.13
	EZD			0.09	0.05			0.31	0.11	0.03	0.09	0.35	0.26			0.19	0.05	0.11	0.09	0.14	0.08	0.06	0.04	0.16	0.10
	HYP			0.02	0.03			0.03	0.04	0.25	0.18	0.33	0.24			0	0.02	0.02	0.05	0.01	0.09	0.05	0.04	0.09	0.09
June	1 m	0.84	0.47	1.2	0.38	3.57	0.03	1.8	0.47	6.36	1.26	0.16	0.09	0.19	0.2	0.54	0.24	0.38	0.12	0.93	0.11			1.60	0.34
	2 m					2.58	0.15							0.38	0.33									1.48	0.24
	MEU	1.01	0.46	0.76	0.43	2.56	0.54	0.96	0.46	6.91	1.44	0.41	0.2	0.88	0.71	0.57	0.15	0.56	0.11	0.81	0.15			1.54	0.47
	EZD	0.66	0.35	0.48	0.37	2.76	0.56	0.93	0.36	7.09	1.16	0.48	0.27	2.06	1.5	0.48	0.12	0.27	0.15	0.28	0.07			1.55	0.49
	HYP	0.01	0.08			0.03	0.06	0.03	0.05	0.09	0.07	0.23	0.15	0.04	0.08	0.02	0.04	0.02	0.06	0.10	0.47			0.06	0.12
July	1 m	1.06	0.52	6.24	1.73	0.47	0.64	1.63	0.35	2.8	0.95	0.26	0.17	1.81	0.6	0.19	0.12	0.59	0.17	0.64	0.12	1.89	0.05	1.60	0.49
	2 m							1.56	0.39			0.23	0.17	2.23	0.32	0.34	0.2					1.81	0.37	1.23	0.29
	MEU	1.24	0.85	0.99	0.61	0.47	0.5	1.97	0.88	1.99	0.83	0.29	0.25	3.14	0.05	0.23	0.09	0.79	0.13	0.43	0.12	1.92	0.15	1.22	0.41
	EZD	0.72	1.21	3.59	0.62	1.04	1.04	3.93	3.3	1.55	1.05	0.52	0.46	0.63	0.46	0.43	0.09	1.53	0.36	0.25	0.14	0.90	0.07	1.37	0.80
	HYP	0.08	0.14	0.09	0.12	0.13	0.15	0.23	0.24	0.39	0.23	0.15	0.08	0.1	0.17	0.05	0.08	0.03	0.07	0.02	0.07	0.02	0.03	0.12	0.13
August	1 m	1.13	0.99	1.14	0.87	2.15	0.73	1.83	0.44	3.59	0.7	0.38	0.27	0.29	0.19	0.12	0.11	0.76	0.16	0.03	0.09	1.37	0.11	1.16	0.42
	2 m					1.86	0.59	2.09	0.57	3.35	0.6			0.55	0.4	0.1	0.03	0.69	0.12	0.56	0.14	1.24	0.16	1.31	0.33
	MEU	1.25	1.11	0.76	0.69	1.82	0.51	1.9	0.7	2.87	0.63	0.52	0.39	0.25	0.23	0.35	0.09	0.63	0.14	0.41	0.18	1.66	0.05	1.13	0.43
	EZD	1.71	1.34	1.48	0.77	1.47	0.49	1.37	0.71	2.26	1.29	0.62	0.47	0.24	0.16	0.29	0.28	0.48	0.16	0.33	0.19	6.08	1.64	1.48	0.68
	HYP	0.05	0.23	0.22	0.27	0.55	0.39	0.1	0.22	0.35	0.31	0.12	0.14	0.03	0.09	0.04	0.05	0.14	0.32	0.70	0.17	0.17	0.11	0.22	0.21
September	1 m	0.5	0.19	0.37	0.21	0.82	0.34	6.3	1.33	9.82	0.01	0.34	0.29	0.55	0.32	0.49	0.1	0.13	0.09	0.62	0.17	0.51	0.05	1.86	0.28
	2 m					0.88	0.36			12.71	0.21	0.31	0.28	0.69	0.38	0.51	0.12			0.76	0.16			2.64	0.25
	MEU	0.63	0.31	0.34	0.19	1.06	0.2	7.2	0.42			0.43	0.31	0.43	0.31	0.68	0.16	0.51	0.1	1.04	0.25	0.63	0.16	1.30	0.24
	EZD	0.48	0.29	0.48	0.36	1.76	0.74	9.21	3.06	11.23	0.5	0.21	0.26	0.28	0.11	0.24	0.11	0.39	0.26	0.40	0.20	0.23	0.13	2.26	0.55
	HYP	0.05	0.19	0.01	0.4	0.16	0.19	0.42	0.46	0.17	0.12	0.05	0.07	0.04	0.09	0.02	0.03	0.01	0.03	0.03	0.10	0.03	0.05	0.09	0.16
October	1 m	0.19	0.15	0.23	0.35	0.24	0.13	2.36	0.87	5	0.28					0.23	0.06	0.56	0.13	0.18	0.09	0.24	0.06	1.03	0.24
	2 m							2.15	0.77							0.19	0.12							1.17	0.45
	MEU	0.22	0.14			0.23	0.13	1.8	0.76	5.05	0.36					0.14	0.09	0.31	0.13	0.22	0.08	0.14	0.10	1.01	0.22
	EZD	0.19	0.13	0.18	0.31	0.16	0.14	1.69	0.62	0.24	0.1					0.18	0.1	0.16	0.11	0.19	0.09	0.09	0.06	0.34	0.18
	HYP	0.03	0.12	0.08	0.24	0.04	0.07	0.17	0.15	5.22	0.01					0.02	0.04	0.03	0.06	0.07	0.10	0.02	0.05	0.63	0.09
Annual Mean	1 m	0.69	0.41	1.56	0.61	1.26	0.33	2.37	0.60	4.64	0.56	0.32	0.22	0.71	0.33	0.29	0.11	0.46	0.15	0.42	0.10	0.87	0.08	1.23	0.32
	2 m					1.77	0.37	1.53	0.46	5.43	0.33	0.33	0.25	0.96	0.36	0.34	0.11	0.51	0.17	0.66	0.15	1.53	0.27	1.45	0.27
	MEU	0.79	0.50	0.61	0.40	1.07	0.34	2.36	0.56	3.42	0.69	0.42	0.28	1.18	0.33	0.39	0.12	0.51	0.13	0.52	0.14	0.88	0.10	1.10	0.33
	EZD	0.67	0.58	1.05	0.41	1.23	0.51	2.91	1.36	3.73	0.70	0.44	0.34	0.80	0.56	0.30	0.13	0.49	0.19	0.27	0.13	1.47	0.39	1.21	0.48
	HYP	0.04	0.13	0.08	0.21	0.16	0.15	0.16	0.19	1.08	0.15	0.18	0.14	0.05	0.11	0.03	0.04	0.04	0.10	0.16	0.17	0.06	0.06	0.18	0.13

Table 6. Seasonal mean macrozooplankton density and weighted mean biomass distribution at Virginia Lake, 2002.

Species		Date						Mean Density		Weighted Mean Biomass	
		7 May	6 June	3 July	6 August	6 September	8 October	No. · m^{-2}	Percent	(mg · m^{-2})	Percent
Copepoda											
Diaptomus	Density (No. · m^{-2})	14,476	12,940	1,630	68	2,700	985	5,466	8.6%	27.0	22.6%
	Size (mm)	0.78	1.11	1.35	0.87	1.78	1.82				
Diaptomus-ovig.	Density (No. · m^{-2})					1,291	433	287	0.5%	8.0	6.7%
	Size (mm)					1.96	1.89				
Cyclops	Density (No. · m^{-2})	1,019	6,046	23,468	8,830	24,283	27,560	15,201	23.9%	31.9	26.7%
	Size (mm)	0.75	0.59	0.69	0.64	0.90	0.83				
Cyclops-ovig.	Density (No. · m^{-2})		102	43		119	204	78	0.1%	0.2	0.2%
	Size (mm)	1.07	0.42	0.60		1.13	1.03				
Total Copepoda	Density (No. · m^{-2})	15,495	19,087	25,140	8,898	28,392	29,182	21,032	33.0%	67.0	56.3%
Cladocera											
Bosmina	Density (No. · m^{-2})	5,969	7,947	14,306	87,180	101,308	30,073	41,130	64.6%	49.7	41.8%
	Size (mm)	0.46	0.40	0.33	0.34	0.39	0.37				
Bosmina-ovig.	Density (No. · m^{-2})			637	4,551	2,140	518	1,308	2.1%	2.1	1.8%
	Size (mm)		0.20	0.42	0.38	0.50	0.43				
Chydorinae	Density (No. · m^{-2})					595	620	202	0.3%	0.2	0.2%
	Size (mm)					0.34	0.35				
Chydorinae-ovig.	Density (No. · m^{-2})					170	51	37	0.1%	0.0	0.0%
	Size (mm)					0.37	0.21				
Total Cladocera	Density (No. · m^{-2})	5,969	7,947	14,943	91,730	104,212	31,262	42,677	67.0%	52.1	43.7%
Total Plankters	Density (No. · m^{-2})	21,463	27,034	40,083	100,628	132,604	60,443	63,709		119.1	

Table 7. Nutri-Stone® 16-30-0 controlled-release fertilizer application quantities for Virginia Lake, 2002.

Location	North Logs [a/]	East Logs [b/]	Float [c/]	Total
Buckets	12	26	61	99
Total lbs	344	745	1,748	2,837
Total kg	156	339	795	1,290

Bucket weight (kg) = 13

Table 8. Pelagic fish population estimates and size data by species from the hydroacoustic survey and mid-water trawl sampling at Virginia Lake on 20 September 2002.

Species	n	Percent	Population	Mean Length (mm)	Length (Std. Dev.)	Mean weight (g)	Weight (Std. Dev.)
Sockeye	20	48%	32,000	62.1	6.48	2.42	0.70
Stickleback	16	38%	26,000	66.4	25.28	3.79	2.87
Cottid	6	14%	10,000	81.0	14.42	6.50	3.70

Total Hydroacoustic Population 68,000

Table 9. The 2003 forecasted adult return of Virginia Lake sockeye salmon by age class and hatchery and wild components based on the projected smolt population.

Brood Year	Age Class	Stocked	%	Wild	%	Total Adult Return
1997	2.3	0	0%	1,500	100%	1,500
1998	1.3	0	0%	6,200	100%	6,200
1998	2.2	0	0%	600	100%	600
1999	1.2	0	0%	1,700	100%	1,700
	Total	0	0%	10,000	100%	10,000

Table 10. Historical phosphorus applications and levels at Virginia Lake, 1987–2002.

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Target fertilization critical loading rate percent based on previous years October P level					64%	60%	50%	49%	66%	64%	0%	47%	69%	60%	50%	61%
Actual fertilizer critical loading rate percent based actual May P level					34%	38%	59%	62%	50%	49%	0%	51%	77%	48%	46%	65%
October P level ($\mu g \cdot L^{-1}$) [a/]			3.6	5.5	4.6	3.2	2.9	4.2	4.0	3.5	3.0	5.4	4.5	3.9	3.3	5.2
May P level ($\mu g \cdot L^{-1}$) [b/]			5.8	5.2	2.5	2.4	4.1	4.2	2.6	2.5	3.5	3.4	6.1	3.3	3.5	3.7
Liquid 20-5-0 applied (gallons)					2,640	4,320	5,490	6,060	7,440	7,290	0	5,280	0	0	3,360	8,640
Liquid 32-0-0 applied (gallons)					1,080	0	2,000	2,220	0	0	0	0	2,700	2,590	0	0
Solid CRF applied (kg) [c/]					0	0	0	0	0	0	0	0	2,818	2,727	0	1,290
Total phosphorus applied (kg)					276	452	574	634	778	762	0	552	499	483	351	1,076
Number of weeks applied					14.0	13.3	13.3	13.0	12.9	15.9	0	16.1	16.6	17.0	16.4	16.9
Mean kg per wk of phosphorus applied					20	34	43	49	61	48	0	34	30	28	21	64
Mean summer P level ($\mu g \cdot L^{-1}$)	2.2	4.9	4.4	5.1	4.1	5.0	9.5	5.5	4.6	5.4	2.6	4.2	5.3	3.5	4.2	7.0

[a/] All October P values were collected in October except in 1993, 1997, and 1998 which were collected in early September.

[b/] All May P values were collected in May except 1992 and 1994 which were late April and 1998 which was collected in June.

[c/] 1999 and 2000 consisted of 8-24-8 fertilizer and 2002 consisted of 16-30-0 fertilizer.

Table 11. Suggested fertilizer application amounts, based on two phosphorus loading rates, for the 2003 field season at Virginia Lake.

Percent of Critical P Load	Kg of elemental phosphorus required	30-gal barrels of 20-5-0 liquid required to meet this level
50%	0 [a/]	0 [a/]
60%	270	82

[a/] Fall phosphorus level exceeds 50% of critical load, no fertilizer required.

FIGURES

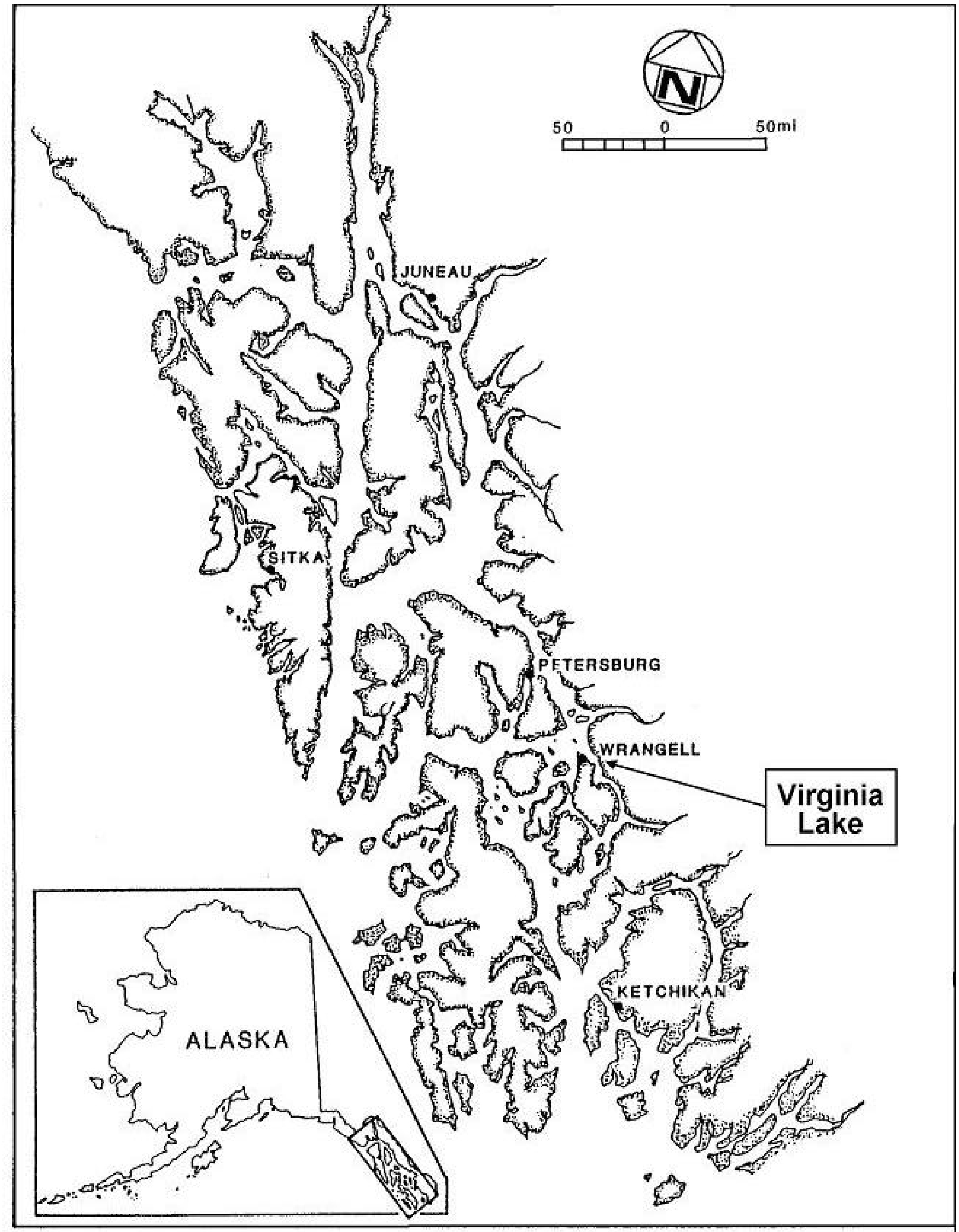

Figure 1. The geographic location of Virginia Lake, within the State of Alaska, and relative to cities within Southeast Alaska.

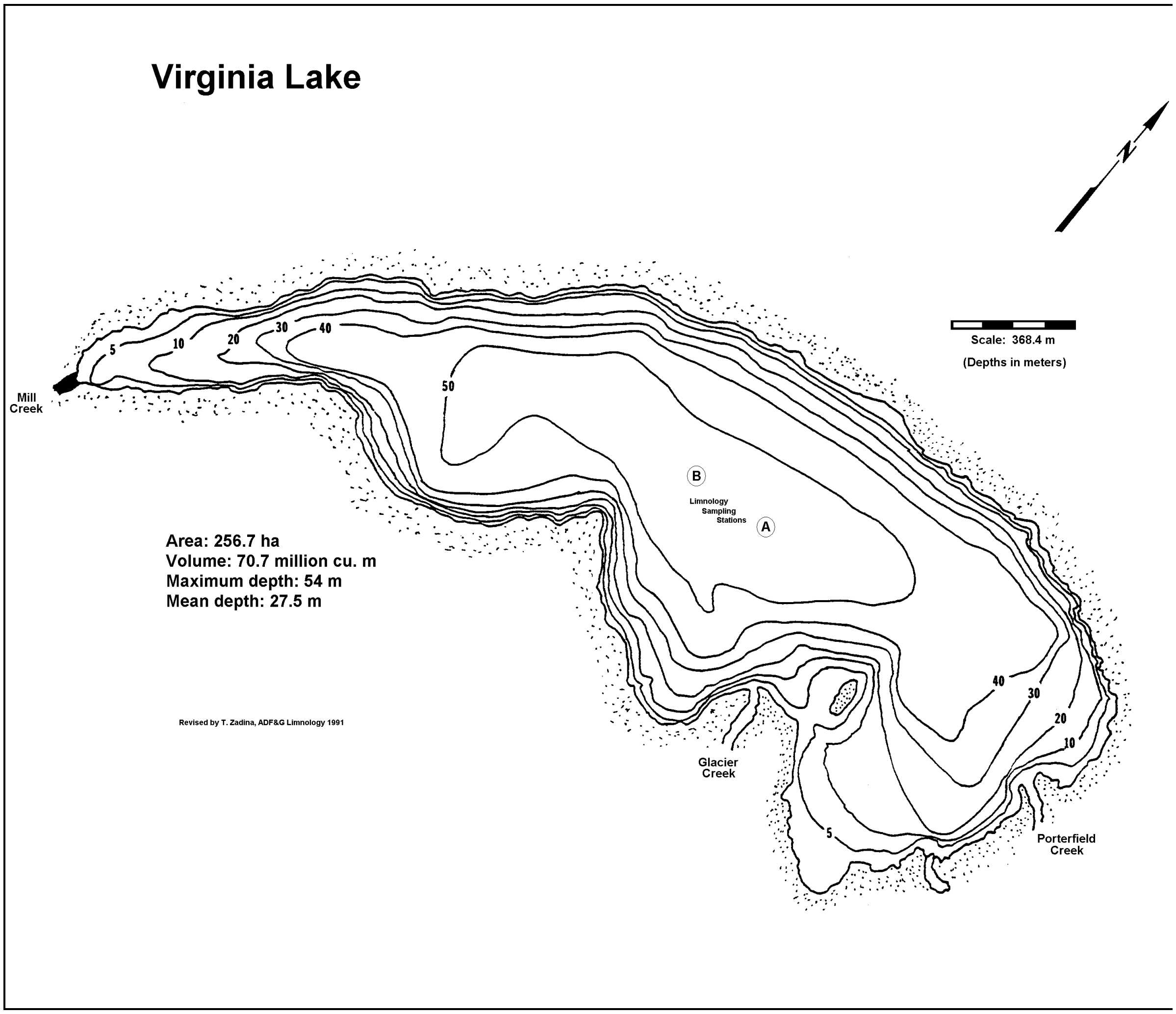

Figure 2. Bathymetric map of Virginia Lake, Southeast Alaska with limnology sampling stations.

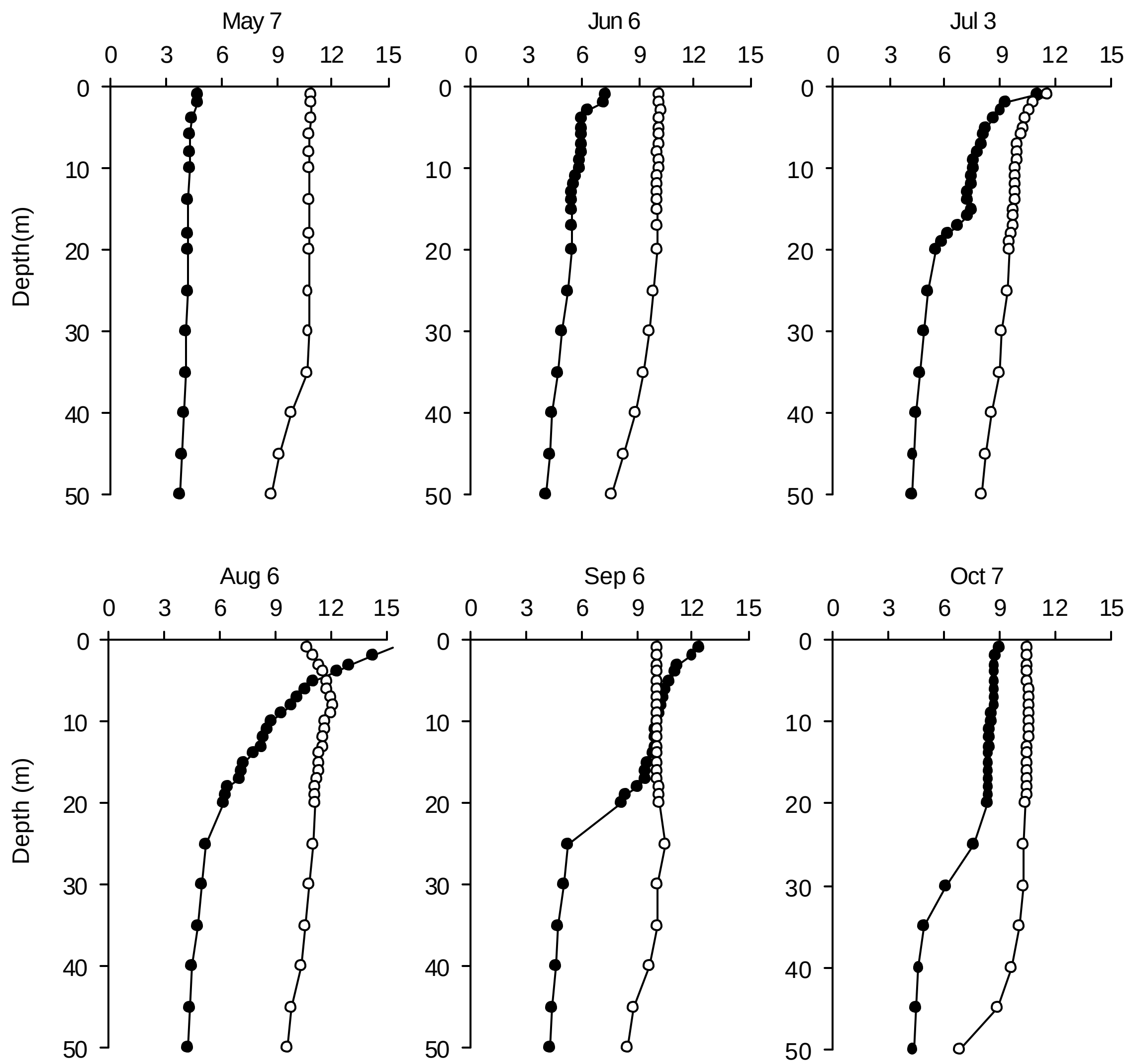

Figure 3. Seasonal temperature (°C; closed circles) and dissolved oxygen (mg · L^{-1}; open circles) profiles in Virginia Lake, 2002.

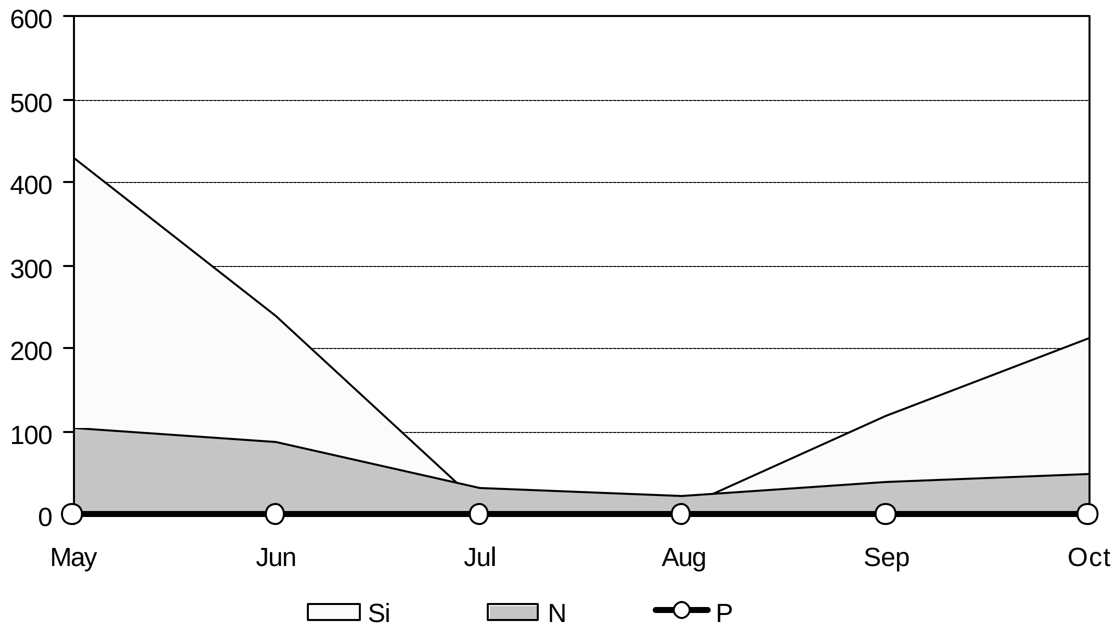

Figure 4. Monthly atomic concentration ratios of nitrogen (N), phosphorus (P; where the level of P is scaled to the value of 1), and reactive silicon (Si) in the epilimnion at Virginia Lake, 2002.

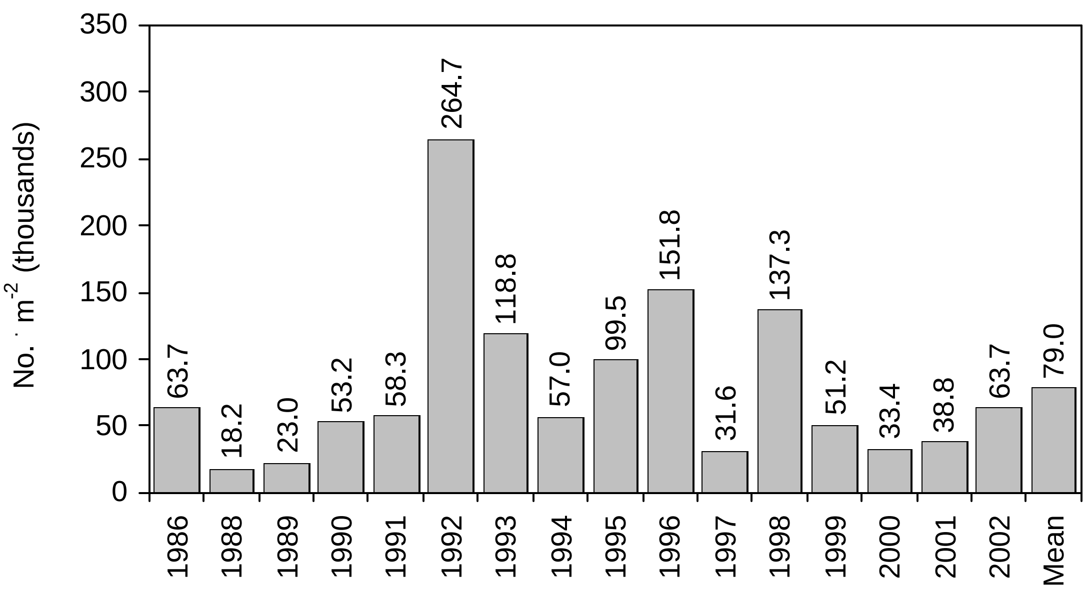

Figure 5. Mean seasonal macrozooplankton density at Virginia Lake, from 1986 to 2002, with the 16-year mean.

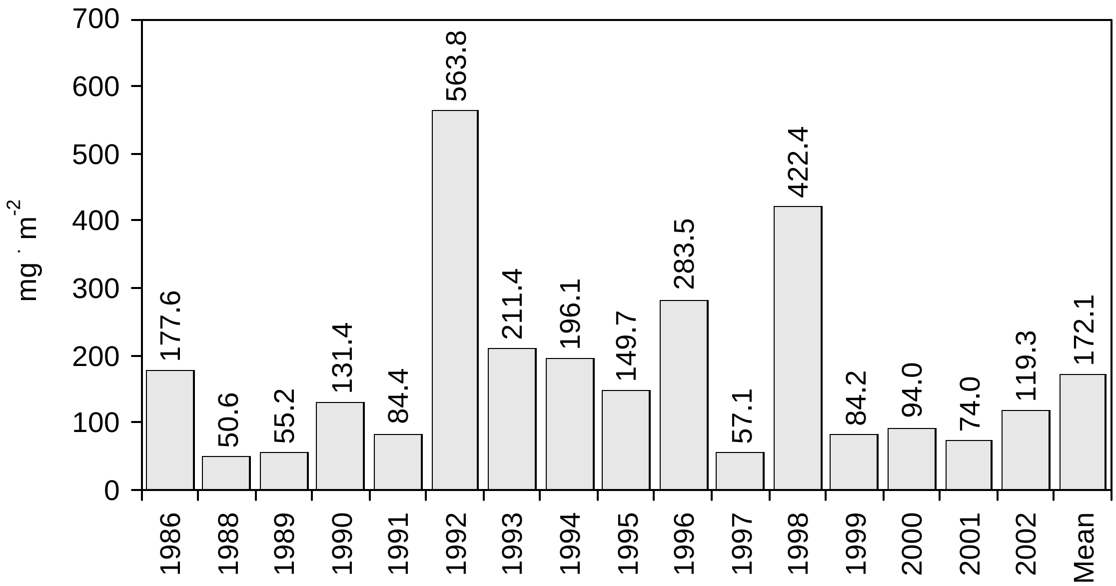

Figure 6. Mean seasonal macrozooplankton biomass at Virginia Lake from 1986 to 2002, with the 16-year mean.

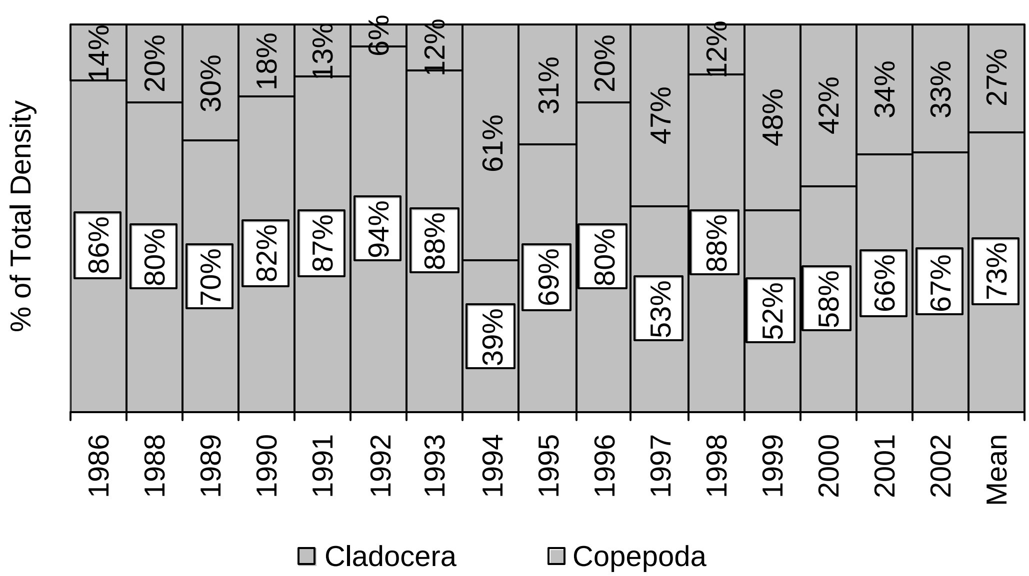

Figure 7. Mean seasonal macrozooplankton density distribution by plankter order at Virginia Lake, from 1986 to 2002, with the 16-year mean.

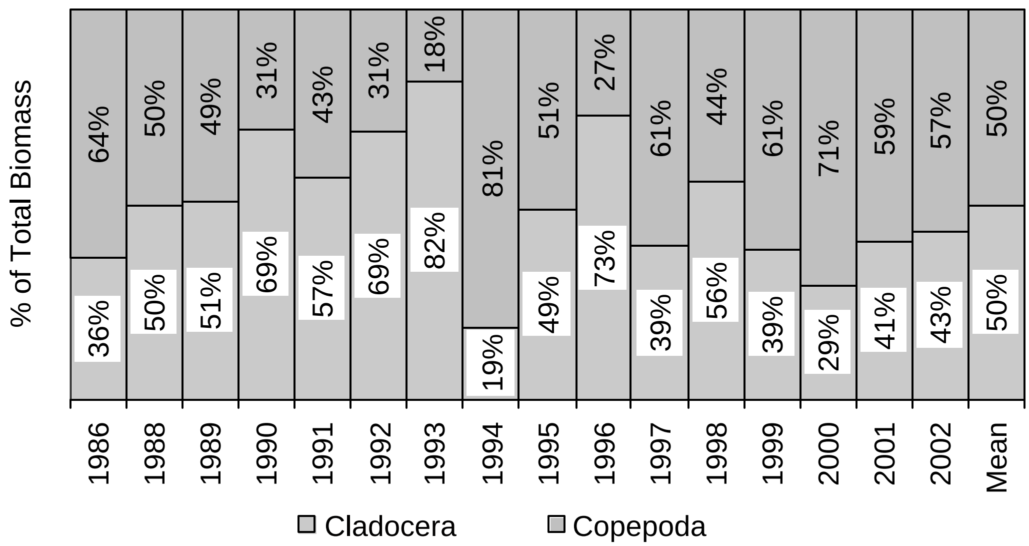

Figure 8. Mean seasonal macrozooplankton biomass distribution by plankter order at Virginia Lake, from 1986 to 2002, with the 16-year mean.

APPENDIX

Appendix Table A.1. Weekly fertilizer applications at Virginia Lake, 2002.

Application Number	Scheduled Date	Application Date	Time Start Applied	Time Elapsed (hours)	Application Amount (gals)	Rate (gal · hr^{-1})	Water Level	Weather	Applicator
1	5/12--5/18	5/16	1200	3.0	270	90.0	high	partly cloudy	J. Robinson
2	5/12--5/18	5/18	1200	3.5	270	77.1	high	partly cloudy	J. Robinson
3	5/19--5/25	5/20	1300	2.5	270	108.0	high	sunny	J. Robinson
4	5/19--5/25	5/25	1230	3.5	270	77.1	high	sunny	J. Robinson
5	5/26--6/01	5/28	1200	3.5	270	77.1	high	partly cloudy	J. Robinson
6	5/26--6/01	6/1	1300	2.5	270	108.0	high	overcast	J. Robinson
7	6/02--6/08	6/5	1230	3.5	270	77.1	high	overcast	J. Robinson
8	6/02--6/08	6/8	1200	3.5	270	77.1	normal	sunny	J. Robinson
9	6/09--6/15	6/13	1200	3.5	270	77.1	normal	sunny	J. Robinson
10	6/09--6/15	6/15	700	3.5	270	77.1	high	sunny	J. Robinson
11	6/16--6/22	6/18	1300	2.5	270	108.0	normal	overcast	J. Robinson
12	6/16--6/22	6/22	1300	2.0	270	135.0	normal	partly cloudy	J. Robinson
13	6/23--6/29	6/24	1200	3.5	270	77.1	normal	overcast	J. Robinson
14	6/23--6/29	6/28	1130	3.0	270	90.0	normal	partly cloudy	J. Robinson
15	6/30--7/06	7/3	900	3.5	270	77.1	normal	partly cloudy	J. Robinson
16	6/30--7/06	7/6	1100	3.0	270	90.0	normal	partly cloudy	T. Robinson
17	7/07--7/13	7/8	1000	3.5	270	77.1	normal	partly cloudy	J. Robinson
18	7/07--7/13	7/12	1200	2.5	270	108.0	high	partly cloudy	J. Robinson
19	7/14--7/20	7/17	1600	2.5	270	108.0	normal	overcast	J. Robinson
20	7/14--7/20	7/20	1200	4.0	270	67.5	normal	rain	J. Robinson
21	7/21--7/27	missed scheduled application							
22	7/21--7/27	7/26	900	2.5	270	108.0	normal	overcast	J. Robinson
23	7/28--8/03	missed scheduled application							
24	7/28--8/03	8/3	1100	3.0	270	90.0	low	sunny	J. Robinson
25	8/04--8/10	8/5	1100	2.5	270	108.0	low	sunny	J. Robinson
26	8/04--8/10	8/10	1030	2.5	270	108.0	high	partly cloudy	J. Robinson
27	8/11--8/17	missed scheduled application							
28	8/11--8/17	8/16	1100	2.5	270	108.0	normal	partly cloudy	J. Robinson
29	8/18--8/24	8/20	930	3.0	270	90.0	normal	partly cloudy	J. Robinson
30	8/18--8/24	8/24	not recorded		270	not	high	partly cloudy	J. Robinson
31	8/25--8/31	8/27	1300	2.5	270	108.0	high	rain	J. Robinson
32	8/25--8/31	8/31	1400	2.5	270	108.0	high	rain	J. Robinson
33	9/1--9/7	9/3	1000	3.0	270	90.0	high	rain	J. Robinson
34	9/1--9/7	9/7	1300	2.5	270	108.0	normal	overcast	J. Robinson
35	9/8--9/14	9/10	1000	4.5	270	60.0	normal	rain	J. Robinson
	Yearly			**93.5**	**8,640**				
	Yearly Mean			**2.92**	**270.0**	**89.7**			