NEWMAN LAKE PHASE II AMENDED, 1992-1995

INTRODUCTION

The analytical and field work for the Phase II restoration of Newman Lake was completed September, 1992 in accordance with County Resolution contract no. 89 0542. The draft report was completed in December 1992 and forwarded to support agencies, institutions, and interested parties for review and comment. As discussed in the main body of the report, it was necessary to design a new type of aerator (oxygenator) for the next restoration procedure at Newman Lake. Despite widespread scientific interest in the effects of the first use of a downflow oxygenation system in a nutrient-rich lake, no study funds could be obtained from state or local sources. The State of Washington Water Research Center (WWRC) was able to shift some funding from other sources to partially fund additional analyses, with the assistance of several graduate students who took field (lake and inlet) measurements and analyzed water samples in the laboratory.

A modest program was carried out from late 1992 to 1995, largely on a volunteer basis. Several graduate students carried out field work at the lake and analyzed water samples in the WSU Environmental Engineering Water Laboratory. Members of the Newman Lake Property Owners Association (NLPOA) also contributed many hours in taking oxygen measurements, collecting water samples, and providing boats for the WWRC personnel. This effort would have been terminated in late 1995 but was continued to 1997 by a small grant through the Newman Lake Flood Control Zone District (NLFCZD) administered by the Spokane County Engineers office. Data for the 1996-97 period are included in WWRC Report No. 101 as part of the development of a stormwater plan for Newman Lake (Robison and Funk, 1997).

ANALYTICAL METHODS AND QUALITY CONTROL

Analytical methods and sampling status remained the same as those described in the body of the main report. Sample collection frequency was reduced to compensate for the lack of monies to pay for instrument analyses. Efforts were made, however, to sample as frequently as possible during the summer growing season.

Quality assurance/quality control (QA/QC) as described in Table 3 of the main report, were carried out according to the U.S. Environmental Protection Agency procedures. In 1994, the Washington State University’s Environmental Engineering laboratories were certified by the Washington State Department of Ecology (Worthington and Juel, 1994).

The major study effort was centered around the mid-lake station to determine the effects of oxygenation upon the deeper area of the lake. Inflowing streams were also sampled in conjunction
with the development of the stormwater plan for Newman Lake (Robison and Funk, 1997). Increased development activity in the immediate watershed around Newman Lake was also noted by field crews sampling the lake and inflowing streams.

**PHYSICOCHEMICAL RESULTS**

**Lake Stations**

**Alkalinity**

Alkalinity measurements expressed as mg·L⁻¹ CaCO₃ were carried out during the 1993-95 study period. Measurements ranged from 15 mg·L⁻¹ at mid depth levels to 37 mg·L⁻¹ at the mid lake station. At the north and south stations, alkalinity ranged from 18 to 22 mg·L⁻¹. These measurements indicate, as in previous studies, Newman Lake is moderately well buffered. Measurements are shown in Figures AM-1 and AM-2.

**Specific Conductance**

Specific conductivity measurements expressed as μmhos ranged from 20 to 75 μmhos but generally were ~ 45 μmhos at the mid lake station. At the north and south stations, measurements ranged from 35 to 55 μmhos (Figures AM-3 to AM-5).

**Light Transparency**

Secchi disk measurement ranged from 1.5 to 3.0 m at all three lake stations. Most measurements were near 2.0 m. This was an overall decrease of about 0.5 m from the previous four years due most likely to the reduced effectiveness of the 1989 alum treatment. Without reduction of sediment and phosphorus inflow to the lake, the longevity of a lakewide alum treatment was expected to be 4 years. With the operation of the oxygenation system, the longevity was extended and the 1995 algal biomass was only about half or less than pre-1989 measurements (algal numbers and biomass are discussed in the following section). Figure AM-6 shows Secchi disk measurements.
Newman Lake, Washington
Alkalinity Measurements at Mid-Lake: 1993-1995
Figure AM-1
Newman Lake, Washington
Alkalinity Measurements at North and South Sites: 1993-1995
Figure AM-2
Newman Lake, Washington
Specific Conductivity Measurements at Mid-Lake: 1993-1995
Figure AM-3
Newman Lake, Washington
Specific Conductivity Measurements at North Site: 1993-1995
Figure AM-4
Dissolved Oxygen

Oxygen levels have remained sufficiently high during the mid and late summers to allow desirable game fishes to enter and forage in the bottom areas of the lake. This extension of the habitat area is a direct result of oxygenation of the deeper areas by the installation of the Speece Cone oxygenation system, which has greatly improved hypolimnetic oxygen levels at the mid-lake station. On occasion, oxygen was decreased to less than 1.0 mg*L⁻¹, but anoxic conditions were no longer prevalent. Dissolved oxygen levels at the south and north station also range from less than 1.0 at night to greater than 12.0 mg*L⁻¹ during the day due to photosynthetic processes carried out by macrophyte beds that raise oxygen levels. Oxygen measurements during 1993-1995 are shown in Figures AM-7 to AM-9. The success of this system at Newman Lake was recently published (Doke et al. 1995).

It was necessary to carefully evaluate the size and potential efficiency of oxygenation systems. This was carried out by Chen in 1992 and was reported by Moore et al. (1996). Data from those experiments were of great benefit in the design of the oxygen system placed in the lake.

Temperature

Lake temperature measurements mirror the 1989-1992 study with stratification occurring at the mid-lake station by mid July and ranged from 11-14°C in the lower layers to approximately 24°C in the near-surface waters. An exception occurred in early August 1994 when surface temperatures reached 27°C and temperatures in the lower depths reached 20°C. Temperature measurements for 1993-1995 are shown in Figures AM-10 to AM-12.

pH

Measurement of pH continued from January 1993 through July 1995 at the mid-lake station. On two occasions, in July and August 1993 and once in July 1995, pH was at or near 6.0 in lower depths. At all other levels, pH was near or above 7.0. On two occasions in mid June 1993 and in late May 1995, pH exceeded 8.4 during increased algal growth. No measurements approached pH 9.0 which was common during heavy algal growth prior to the aluminum sulfate treatment in 1989. Figures AM-13 to AM-15 shows pH measurements for 1993-1995.
Newman Lake, Washington

Dissolved Oxygen Measurements at Mid-Lake: 1993-1995

Figure A-M-7
Newman Lake, Washington
Dissolved Oxygen Measurements at North Site: 1993-1995
Figure AM-8
Newman Lake, Washington
Dissolved Oxygen Measurements at South Site: 1993-1995

Figure AM-9
Figure AM-10
Temperature Measurements at Mid-Lake: 1993-1995
Newman Lake, Washington

Temperature degrees Celsius

1.00
3.00
5.00
7.00
9.00
11.00
13.00
15.00
17.00
19.00
21.00
23.00
25.00
27.00

1/30/93
2/28/93
4/24/93
5/21/93
6/18/93
7/22/93
8/13/93
9/17/93
10/22/93
4/10/94
4/29/94
5/27/94
6/29/94
7/12/94
8/2/94
9/2/94
9/14/94
10/7/94
11/7/94
4/14/95
5/6/95
5/25/95
7/29/95
Newman Lake, Washington
Temperature Measurements at South Site: 1993-1995

Figure AM-12
Figure AM-13
pH Measurements at Mid Lake: 1993-1995
Newman Lake, Washington

- Date: 1/30/93
- pH: 5.8

- Date: 2/28/93
- pH: 6.5

- Date: 4/24/93
- pH: 6.2

- Date: 5/21/93
- pH: 6.0

- Date: 6/18/93
- pH: 6.3

- Date: 7/22/93
- pH: 6.1

- Date: 8/13/93
- pH: 6.2

- Date: 9/17/93
- pH: 6.4

- Date: 3/11/94
- pH: 6.3

- Date: 4/10/94
- pH: 6.1

- Date: 4/29/94
- pH: 6.2

- Date: 5/27/94
- pH: 6.1

- Date: 5/25/95
- pH: 6.3

- Date: 7/29/95
- pH: 6.2
Newman Lake, Washington
PH Measurements at North Site: 1993-1995
Figure AM-14
Inlet Stations

In 1996-97, more emphasis was placed on flowing streams as a part of the Newman Lake storm water plan (Robison and Funk, 1997). Some lake samples were included in this group. These stations were located at the Heylman and Balcom Dock stations in the most northern lobes of the lake. Heylman Dock is located in the northwest lobe and Balcom Dock is at the most northern area of the lake, 300 meters east of the Thompson Creek Inlet. These stations are shown in Figure 2 of the main report. Additional data included in this report show measurements from 1989 (1991 to 1993) and in some instances to 1995 (as constraints allowed) for comparative purposes. Data are shown in Figures AM 18-20, 22, 47-48, 50-51, 53-54 and 56-64.

Alkalinity

Alkalinity measurements generally ranged from 5 to 70 mg·L⁻¹ with an average near 15 mg·L⁻¹. The wide range in alkalinity for inlet (stream) flow is due to localized conditions: snow melt, rainstorms and human activities in the watershed. Results are shown in Figures AM-16 to AM-18.

Specific Conductance

Specific conductivity measurements expressed as umhos ranged from a low of 21 to a high of 120 umhos. The range of measurements also depend upon human activities in the watershed and precipitation events. The results are shown in Figures AM-19 to AM-21.

Dissolved Oxygen

Inlet and outlet streams were mostly at saturation levels or above due to considerable daytime photosynthesis by aquatic plant or algae growth at sampling stations. Exceptions were at the outlet station during ice over conditions in mid to late winter or after the demise of algal blooms or senescence of aquatic weeds. At those times oxygen levels dropped to below 5 mg·L⁻¹. Oxygen measurements for the inlet streams and the outlet are shown in figures AM-22 to AM-24.

Temperature

Inlet water temperatures ranged from near 0.0° to 24.9° C, and closely followed season changes in the water. Results are shown in Figures AM-25 to AM-27.
pH

Measurements of pH were generally between 6.5 to 7.5. Lower values occurred under ice cover (outlet) or algae bloom deterioration. Figure AM-28 shows results.
Fig. A-17

Alkalinity Measurements at North Inlets and Dock

Newman Lake, Washington

1991-1994

Balcony Dock □ Inlet #1 □ Inlet #1A □ Inlet #2 ■ Inlet #3 □ Inlet #6

Methyl Orange in mg/L

0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0

04/29/94 10/22/93 08/13/93 07/23/93 05/21/93 04/24/93 02/18/93 11/09/92 10/18/92 09/20/92 08/20/91 07/10/91 06/21/91 05/30/91 04/27/91 04/13/91 03/01/90

A-22
Newman Lake, Washington
1991-1993
Alkalinity Measurements at South Inlet, Outlet, and Docks
Figure AM-18
Newman Lake, Washington
1991-1993
Specific Conductivity Measurements at West Inlets and Dock
Figure AM-19
Specific Conductivity Measurements at Inlet 10 and Outlet: 1991-1993
Newman Lake, Washington
Dissolved Oxygen Measurements at West Inlets and Docks: 1989-93

Figure AM-22
Figure AM-23
Dissolved Oxygen Measurements at North Inlets and Dock: 1989-94
Newman Lake, Washington
Newman Lake, Washington

Temperature Measurements at West Intakes: 1989-1993

Figure AM-25
Figure AM-27

Temperature Measurements at South Inlet and Outlet: 1989-1994

Newman Lake, Washington

Outlet  ■  Inlet  □  Outlet  ■  Inlet  □
Figure AM-28  

pH Measurements at Inlets and Outlet: 1992-1994  
Newman Lake, Washington
CRITICAL NUTRIENTS

Inlake Stations

Ammonia

Ammonia levels were relatively high prior to the alum treatment and the installation of the oxygenation system, exceeding 1000µg•L⁻¹ in some instances, especially in lower depths of the lake where considerable organic degradation occurred. During 1993-1995, measurements reached .6mg•L⁻¹ only once under the ice at the 8m level. Ammonia ranged from .15 to .27mg•L⁻¹ at the three lake stations (Figures AM-29 to AM-31).

Nitrate Nitrogen

Nitrate/nitrogen levels are generally low because of rapid uptake by macrophytes and algae. Measurements were below .20mg•L⁻¹ for all depths at the three lake stations (Figures AM-32 to AM-34).

Total Nitrogen

Total nitrogen measurements includes all forms of nitrogen including that in microscopic animals and algae forms. Measurements at the mid lake station ranged from .30 to 1.23 mg•L⁻¹ during the study. The north and south lake stations ranged from .10 to .850 mg•L⁻¹. Figures AM-35 to AM-37 indicate these levels.

Total Soluble Phosphorus

Total soluble phosphorus at the mid-lake station has been consistently measured at low levels, ~.015mg•L⁻¹ since alum treatment and oxygenator installation. An exception was during mid winter under the ice when organic decomposition was occurring and the oxygenator was off (.138 mg•L⁻¹).

A different pattern was present at the north station. Soluble phosphorus exceeded .20mg•L⁻¹, except during some mid summer period when uptake was rapid during high algal growth periods. Figures AM-38 to AM-40 show soluble phosphorus.
Detection limit = 0.01 mg/L

Neumann Lake, Washington
Ammonia Concentrations at MiD-Lake: 1993-1995
Figure AM-29
Newman Lake, Washington

Ammonia Concentrations at North Site: 1990-1995

Figure AM-30
Newman Lake, Washington
Nitrate Concentrations at Mid-Lake: 1993-1995
Figure AM-32
Newman Lake, Washington
Nitrate Concentrations at North Site: 1991-1995
Figure AM-33
Newman Lake, Washington
Nitrate Concentrations at South Site: 1989-1995
Figure AM-34
Newman Lake, Washington

Total Nitrogen Concentrations at North Site: 1989-1995

Figure AM-36
Figure A.43

Newman Lake, Washington

Total Nitrogen Concentrations at South Site: 1989-1995

Detection Limit = 0.01

no data for South Mid Site
Newman Lake, Washington

Total Soluble Phosphorus Concentrations at Mid-Lake: 1993-1995

Figure AM-38
Newman Lake, Washington
Total Soluble Phosphorus Concentrations at North Site: 1989-1999
Figure A11-39

No North Mid data

Detection limit = 0.001
Newman Lake, Washington
Total Soluble Phosphorus Concentrations at South Site: 1989-1995
Figure AM-40
Orthophosphorus

Orthophosphorus measurements showed a similar pattern to that of soluble phosphorus. Higher measurements were recorded prior to oxygenation in the mid lake area and also during periods of ice cover at all stations and during periods of lake turnover and high winds. Most measurements were near .005 to .010mg*L⁻¹ and below except as noted (Figures AM-41 to AM-43).

Total Phosphorus

Total phosphorus ranged from < .010mg*L⁻¹ to .28mg*L⁻¹ at the three lake stations. Higher levels were associated with heavy spring and fall growth of diatom populations and midsummer growth of blue-green algae. Figures AM-44 to AM-46 show 1993-1995 measurements.
Newman Lake, Washington
Orthophosphate Concentrations at Mid-Lake: 1993-1995

Figure AM-41
Newman Lake, Washington
Orthophosphate Concentrations at North Site: 1989-1995

Figure AM-42
Newman Lake, Washington
Total Phosphorus Concentrations at Mld-Lake: 1993-1995
Figure AM-44
Figure AM-45

Newman Lake, Washington
Total Phosphorous Concentrations at North Site: 1989-1995

No data for North Mid site
Newman Lake, Washington Total Phosphorus Concentrations at South Site: 1989-1995

Figure AM-46
Inlet Systems

Ammonia

Ammonia levels in the inflowing streams were considerably lower than lake levels largely due to lesser accumulation of deteriorating organic matter, release of volatile compounds by roiling action of streams movement and uptake by photosynthesizing organisms. Ammonia levels ranged from trace amounts in rapidly flowing inlets to a high of 45 mg L\(^{-1}\) at the outlet stream. Figures AM-47 to AM-49 show the levels.

Nitrate Nitrogen

Nitrate nitrogen is the more soluble form of nitrogen and leaches through soils readily. Higher levels are measured in winter months when plants are not assimilating it as fast or after ice out in the spring or following an algal bloom, if sufficient oxygen is present. Figures AM-50 to AM-52 show nitrate measurements. Levels were generally under .30 mg L\(^{-1}\) from Thompson Creek, most likely as the result of the flushing of a pasture to the creek. It should be noted that there has been a conscientious effort by most ranchers to reduce nutrient flow to the lake. These sources have been reduced from the mid-1970 period. Overall loading to the lake has remained about the same due to road and home building as well as recreational traffic in the stream drainage.

Total Nitrogen

Total nitrogen includes all forms of nitrogen including plant material being washed into the inflowing streams. There have been a number of instances where total nitrogen has exceeded 1.0 mg L\(^{-1}\). Generally those values have been during periods of high precipitation. Measurements are shown in figures AM-53 to AM-55.

Total Soluble Phosphorus

Soluble phosphorus showed no major reduction in loading to Newman Lake, varying from a low of .05 to a high of .168 mg L\(^{-1}\) at Inlet 9 (Figures AM-56 to AM-58).
Figure A.M-48

Ammonia Measurements at North Inlets and Dock: 1989-1993

Newman Lake, Washington

Detection Limit = 0.01

NH₃ mg/L
Neuvin Lake, Washington

Ammonia Measurements at Inlet 10 and Outlet: 1989-1994

Figure AM-49
Newman Lake, Washington

Nitrate Measurements at West Inlets and Docks: 1989-1993

Figure AM-50
Nitrate Measurements at North Inlets and Dock: 1989-1995
Newman Lake, Washington

Nitrate Measurements at Inlet 10 and Outlet: 1989-1994

Figure AM-52
Figure AM-53

Total Nitrogen Measurements at West Inlets and Docks: 1989-1993

Newman Lake, Washington

Detection Limit = 0.1

Heymann Dock * Lindgren Dock * * Inlet 7 * Inlet 9
Newman Lake, Washington

Total Nitrogen Measurements at Inlet 10 and Outlet: 1989-1994

Figure A.M-55
Total Soluble Phosphorus Measurements at West Inlets and Docks
Figure AM-56
Newman Lake, Washington
1989-1994
Total Soluble Phosphorus Measurements at North Inlets and Dock:

Figure AM-57
Orthophosphorus

Orthophosphorus ranged from a low of .001 mg•L⁻¹ at Thompson Creek to a high of .151 mg•L⁻¹ at Inlet 3. No reductions were noted from earlier studies (Figures AM-59 to AM-61).

Total Phosphorus

Total phosphorus measurements showed a similar pattern as in earlier studies. Higher measurements were taken at Inlet 9 and ranged from .05 to .427 mg•L⁻¹ (Figures AM-62 to AM-64).
figure AM-59

Newman Lake, Washington

Orthophosphate Measurements at West Inlets and Docks: 1989-1993

Detection Limit = 0.01
Orthophosphate Measurements at North Inlets and Dock: 1989-1993

Figure AM-60
Orthophosphate Measurements at South Inlet, Outlet, and Docks:
Newman Lake, Washington
1989-1995

Figure AM-61

A 70
Figure AM-63
Total Phosphorus Measurements at North Inlets and Dock: 1989-94
Newman Lake, Washington
Newman Lake, Washington
1989-1995
Total Phosphorus Measurements at South Inlet, Outlet, and Docks:
Figure AM-64
BIOLOGICAL RESULTS

Chlorophyll-α

A description of the value of chlorophyll-α as an indicator of lake conditions is contained in the body of the main report. Collection, preservation, and analyses were carried out in accordance with QA/QC procedures described in the main body of the report and the WSU Environmental Engineering Certified Laboratory Procedures Manual.

Chlorophyll-α data for 1992-1995 are presented in Figures AM-65 to AM-67 for comparative purposes. As previously described, the mid-lake station was consistently sampled. Samples were also collected, when possible, at the north and south stations.

The first 1993 measurements at mid-lake were taken in January and were low, <0.01 to 1.8 μg*L⁻¹. With the advent of considerable diatom growth, chlorophyll-α reached 2.5 μg*L⁻¹ at the 0.5 m depth in February. Mid depth (4.0 m) and lower depth (8.0 m) remained at low levels (~1.00 μg*L⁻¹).

In April 1993, 0.5 m measurements were 24.0 μg*L⁻¹ while at 4.0 m and 8.0 m chlorophyll-α was 19.7 and 10.0 μg*L⁻¹, respectively. May 1993 measurements varied between 9.0 to 10.0 μg*L⁻¹ at the mid and upper depths.

June 1993 measurements were lower (4.9 μg*L⁻¹) at the 0.5 m depth, while mid (4.0 m) and lower depths (8.0 m) were 10.0 and 8.9 μg*L⁻¹, respectively. July 1993 measurements indicated lower values at the near surface (0.5 m) of 3.0 μg*L⁻¹, higher at mid depth (4.0 m) at 8.0 μg*L⁻¹, and 18.00 μg*L⁻¹ at the 8.0 m depth. This trend continued through August 1993 with 0.5 m and 4.0 m depths measured at 3.0 and 5.0 μg*L⁻¹, respectively. The 8.0 m depth increased to 26.00 μg*L⁻¹, largely due to colonies of blue-greens remaining at lower depths.

September 1993 measurements dropped to 5.0 μg*L⁻¹ at the 0.5 m depth and to ~9.0 μg*L⁻¹ at the mid and lower depths. October measurements increased at all depths due to increased diatom and blue-green algae growth. Chlorophyll-α measurements at that time ranged from 13.0 to 17.0 μg*L⁻¹.

1994 measurements began in March with ~4.0 μg*L⁻¹ measured at the 0.5 m depth, ~20.0 μg*L⁻¹ measured at 4.0 m, and ~8.0 μg*L⁻¹ measured at 8.0 m. Diatoms, mostly Melosira granulata and the large green form, Staurastrum paradoxum, accounted for the higher chlorophyll-α at the 4.0 and 8.0 m depths. Large numbers of M. granulata and the green forms, S. paradoxum and Sphaerocystis Schroeteri, resulted in measurements of chlorophyll-α at ~14.0 μg*L⁻¹ at all depths at the mid-lake station. A slight reduction to levels at 7.0 to 10.0 μg*L⁻¹ was observed later in month. May 1994 analyses indicated a larger reduction at the 0.5 m depth to 5.3 μg*L⁻¹ with the
Newman Lake, Washington
Chlorophyll-a Measurements at North-Lake Site: 1992-1995
Figure AM-66
Chlorophyll-a Measurements at South-Lake Site: 1992-1995

Newman Lake, Washington

Figure AM-67
4.0 m depth at 16.0 μg·L⁻¹, and 10.0 μg·L⁻¹ at the 8.0 m depth. Algae populations in this case were more diverse with similar biovolumes of diatoms, greens, and Pyrrhophytes.

June 1994 measurements and algal populations were similar with the 0.5 m depth reduced to 1.8 μg·L⁻¹, but at 4.0 m chlorophyll-α was measured at 15.0 μg·L⁻¹ and at 8.0 m chlorophyll-α was measured at 18.0 μg·L⁻¹. August samples indicated high algal counts but low chlorophyll-α measurements indicated the onset of the senescence of a summer algal bloom. Chlorophyll-α was measured at 1.8 μg·L⁻¹ at 0.5 m, 0.5 μg·L⁻¹ at 4.0 m, and <1.0 at the 8.0 m depth.

September 1994 chlorophyll-α measurements increased as high as 18.0 μg·L⁻¹ largely due to resurgent increase in diatoms, especially *M. granulata*. A decrease occurred later in the month at the 8.0 m depth to <1.00 μg·L⁻¹. Increased *M. granulata* numbers in October resulted in chlorophyll-α increases up to 21.0, 27.0, and 24.0 μg·L⁻¹ at the 0.5, 4.0, and 8.0 m depths, respectively.

Chlorophyll-α measurements in November were ~15.0, 16.0, and 16.0 μg·L⁻¹ at 0.5, 4.0, and 8.0 m depths. *M. granulata* remained the dominant algal form until ice cover.

A short time after ice-out in March 1995, algae samples collected showed high numbers of *Asterionella formosa* and *Tabellaria fenestrata* as well as a considerable number of *Oscillatoria sp.* filaments. This algal growth continued through April. Chlorophyll-α measurements were 17.8, 14.7, and 15.6 μg·L⁻¹ at the 0.5, 4.0, and 8.0 m depths, respectively. *M. granulata* was the prominent algal form in May with the Pyrrhophyte, *Peridinium sp.*, representing about half the biomass.

Chlorophyll-α samples were collected and measured only through July 1995 due to lack of sufficient funding for this parameter. Algal biovolume and other measurements throughout the summer indicated continuation of a moderate algal bloom through September. Algae counts during this latter month indicated two blue-green forms, *Anabaena flos-aquae* and *Microcystis aeruginosa* dominated.

Chlorophyll-α measurements have been considerably less (31.0 μg·L⁻¹) since implementation of measures (alum treatment in 1989 and oxygenation in 1993). In prior years, chlorophyll-α measurements exceeded 50.0 μg·L⁻¹ many times each summer.

**Phytoplankton**

A modest program to sample, identify, and determine algal numbers and biovolume was carried out from 1993 to 1995 through the more active biological period (spring through fall). Methods were the same as described in the main report. The mid-lake station was considered to be representative of the lake. The north and south sites were sampled when possible.
In April 1993, cells were nearly 1000 cells·mL\(^{-1}\). The biovolume ranged from 3.8 \(\mu m^3\cdot 10^6\) in the surface area to 11 \(\mu m^3\cdot 10^6\) near the bottom. The high cell counts and biovolume were largely due to the diatoms \textit{M. granulata} and the Pyrrhophyta.

By May 1993, the diatoms \textit{Fragilaria crotonensis}, \textit{Asterionella formosa}, \textit{Stephanodiscus sp.}, and \textit{Tabellaria} were becoming more numerous. \textit{M. granulata} and Pyrrhophyta populations continued to make up a large portion of the biovolume. Cell numbers were over 1000 cells·mL\(^{-1}\) and biovolume reached 8.1 \(\mu m^3\cdot 10^6\) at the 8.0 m depth.

In June 1993, the diatoms \textit{T. fenestrata}, \textit{Stephanodiscus}, and \textit{Asterionella formosa} became prominent forms (~500 cells·mL\(^{-1}\)) with some large green forms, such as \textit{S. paradoxum}, also increasing in numbers. Some blue-green forms also made an appearance throughout the lake. Biovolume was approximately 2.5 \(\mu m^3\cdot 10^6\) at the three depths sampled.

In July 1993, about 67% of the algal populations at the 0.5 depth were diatoms. The blue-green form, \textit{M. aeruginosa}, made up about 18%. Green algae followed making up 16% of the total biovolume which was 4.2 \(\mu m^3\cdot 10^6\). At the 4.0 m depth, similar populations were present with a total biovolume of 1.5 \(\mu m^3\cdot 10^6\). \textit{M. aeruginosa} dominated the 8.0 m depth at approximately 84% of the total biovolume of 8.6 \(\mu m^3\cdot 10^6\).

August 1993 algae populations sharply declined. Diatoms were still dominant with \textit{M. granulata} making up 60% of the diatom biovolume (1.1 \(\mu m^3\cdot 10^6\)) and the blue-green, \textit{M. aeruginosa}, and \textit{A. flos-aquae} about 30% of the total biovolume of 2.1 \(\mu m^3\cdot 10^6\) at the 0.5 m depth. Algal biovolume were 0.9 \(\mu m^3\cdot 10^6\) at 4.0 m and 1.9 \(\mu m^3\cdot 10^6\) at the 8.0 m depths. At the 4.0 m depth, \textit{M. aeruginosa} made up 43% of the total biovolume and \textit{S. paradoxum} at 32%. Diatoms were 17%. At the 8.0 m depth the diatom, \textit{M. granulata}, made up 63% and the blue-green, \textit{A. flos-aquae}, 26% of the total biovolume of 1.9 \(\mu m^3\cdot 10^6\).

In September 1993, diatoms, especially \textit{M. granulata}, became the most numerous algal forms and accounted over 95% of the total biovolume of 10.7 \(\mu m^3\cdot 10^6\) at the 0.5 m depth. \textit{Tabellaria fenestrata} was the most numerous form at lower depths, making up 85% of the biovolume (6.3 \(\mu m^3\cdot 10^6\)).

October 1993 algal populations at the 0.5 m depth were mostly blue-green algal forms such as \textit{M. aeruginosa} and \textit{Coelosphaerium} which made up 55% of the total biovolume of 1.3 \(\mu m^3\cdot 10^6\). Diatoms, mostly \textit{M. granulata}, made up 43% of the population. At the 4.0 m level, \textit{M. granulata} was the dominant form with \textit{Stephanodiscus sp.} accounting for about 40% of the biovolume. Green forms such as \textit{Pediastrum} and \textit{S. paradoxum} made up 26% of the biovolume. Blue-green form, \textit{M. aeruginosa}, accounted for 31% of the total biovolume of 2.6 \(\mu m^3\cdot 10^6\). At the 8.0 m depth, \textit{M. granulata} accounted for 80 \(\mu m^3\cdot 10^6\) and \textit{Stephanodiscus sp.} 10 \(\mu m^3\cdot 10^6\) of the total biovolume. Blue-green forms such as \textit{Gomphosphaeria sp.} and the Pyrrhophyta \textit{Glenodinium quadridens} accounted for the remainder.
Figures AM-68, AM-69, and AM-70 show the 1993 biomass determinations.

Lake sampling began with ice-out in March 1994. Three diatoms dominated the surface layers (0.5 m): *A. formosa* in numbers of 300 cells mL\(^{-1}\), *Stephanodiscus* *sp.* with numbers over 156 cells mL\(^{-1}\) and *M. granulata* with large filaments in excess of 6-10 filaments mL\(^{-1}\). The large green alga, form *S. paradoxa*, was also present in numbers of ~25 cells mL\(^{-1}\). A blue-green form, *Gomphosphaeria sp.*, was present at 46 cells mL\(^{-1}\). The Pyrrhophyte, *Glenodinium quadridens*, was also present at 6-12 cells mL\(^{-1}\). Total biomass was near 1 \(\mu m^3\times10^6\). The same algal groups were present at great numbers (>1500 cells (filament) \(\times\) mL\(^{-1}\)) and biomass 4.7 \(\mu m^3\times10^6\) at the 4.0 m depth. At 8.0 m depth, the algal assemblage was similar to the surface 0.5 m depth at ~500 cells mL\(^{-1}\) and a biomass of ~1 \(\mu m^3\times10^6\).

April 1994 algal biomass was considerably higher near 8.0 \(\mu m^3\times10^6\) due largely to the larger diatom *M. granulata* filaments at ~360 filaments mL\(^{-1}\) and green forms *S. paradoxa* and *S. schroeteri*. These forms account for about 60% of the biomass. *G. quadridens* made up about 2.2 \(\mu m^3\times10^6\) of the biomass. Algal populations at lower depths of 4.0 and 8.0 m were proportionally similar but with fewer cells (filaments) and biomass. The mid depth numbers were ~700 cells (filaments) mL\(^{-1}\) with a biomass of 3.4 \(\mu m^3\times10^6\). The 8.0 m depth counts were also about 700 cells (filaments) mL\(^{-1}\). Algal samples collected near the end of April show higher cell numbers with the emergence of smaller diatoms at 1244 cells mL\(^{-1}\) but the biovolume of ~2.7 \(\mu m^3\times10^6\) was largely due to the Pyrrhophyte, *G. quadridens*, that contributed ~2.6 \(\mu m^3\times10^6\) to the total.

There was a decrease in the May 1994 cell numbers and biovolume. *M. granulata* filaments in the overlying water columns became fewer in number near the end of May as water temperature rose and circulation of the lake decreased. Diatoms such as *T. fenestrata* and *Fragilaria crotenensis* increased. *S. paradoxa* was fewer in number. The blue-green, *M. aeruginosa* was present in most samples. *G. quadridens* was still present and another large Pyrrhophyte, *Ceratium hirundinella*, was present. Cell numbers ranged between 100 to 500 cells mL\(^{-1}\) but with mostly smaller algae. Total biovolume at the three depths ranged from 1.5 to 2.6 \(\mu m^3\times10^6\).

August 1994 algae counts and biovolume increased slightly over May-June numbers. Higher biovolume was due largely to increased larger green forms and more blue-green algae. The diatom, *M. granulata*, was also prominent most likely due to wind action. Total cell (filament) counts were near 600 cells mL\(^{-1}\) and biovolumes ranged from 1.6 to 3.3 \(\mu m^3\times10^6\).

September/October algae counts and biovolume increased sharply most likely due to lake overturn which distributed more *M. granulata* filaments from the bottom to the overlying waters and increased *M. granulata* filaments in the lake. *M. granulata* counts were near 300 filaments mL\(^{-1}\) with a biovolume near 3.0 \(\mu m^3\times10^6\). Some large green forms, mostly *S.*
Newman Lake, Washington

1993 Algae Bioluminescence at Mid-Lake Station, 5 m

Figure AM-68
Newman Lake, Washington
1993 Algae Biovolume at Mid-Lake Station, 8 m
Figure AM-70
paradoxum, were still present. Blue-greens such as *Coelosphaerium sp.* were present but made up less than 0.2 \( \mu m^3 \cdot 10^6 \) of the biovolume. Total biovolume ranged from 3.6 to 5.1 \( \mu m^3 \cdot 10^6 \).

Algae counts and biovolume in November 1994 were mostly diatoms with a few blue-greens. *M. granulata* made up 90% of the diatom population at all depths through the lake. *A. formosa* made up about 5%. The remaining forms were *Stephanodiscus sp.*, *Cyclotella sp.*, *F. crotonensis*, and *T. fenestrata*. A few blue-greens were present in the samples, chiefly *M. aeruginosa* and *Gomphosphaeria sp.* Total biovolume ranged from 0.4 to 2.4 \( \mu m^3 \cdot 10^6 \).

The algal biomass data for March through November 1994 mid-lake station are shown in Figures AM-71, AM-72, and AM-73.

Algae sampling began in 1995 in mid March. *T. fenestrata* made up 90% of the cell (filament) counts and 95% of the total biovolume 1.6 \( \mu m^3 \cdot 10^6 \). Other diatoms accounted for about 3% of the population. The green form, *S. paradoxum*, and the blue-green form, *Oscillatoria sp.*, were present. Pyrrhophytes *Glenodinium sp.* and *C. hirundinella* were also present in few numbers.

April 1995 algae counts and biovolume were down. *A. formosa* made up 80% of the cell counts and about half of the biovolume at 0.9 \( \mu m^3 \cdot 10^6 \). Other diatoms were *F. crotonensis*, *M. granulata*, *T. fenestrata*, and *Stephanodiscus sp.* The blue-greens, *Oscillatoria sp.* and *Merismopedia sp.*, made up about 1% of the cell (filament) count and about 5% of the biovolume. Two Pyrrhophytes, *Peridinium sp.* and *G. quadridens*, were present in few numbers but made up 30% of the biovolume. About twice the number of algae cells and biomass were present at the 0.5 m depth than at the lower 4.0 m and 8.0 m depths.

Total algal biomass in May 1995 was similar to April but with more diversity. *T. fenestrata* was the dominant diatom followed by *F. crotonensis*. These two forms made up 94% of the biomass. *Peridinium sp.* of the Pyrrhophyte group was the only other significant other algae group and represented 9% of the biomass.

July 1995 algae count and biomass were relatively diverse. Biomass was almost evenly divided between diatoms and larger green forms. Together they made up 44% and 37%, respectively, of the total biomass of 1.1 \( \mu m^3 \cdot 10^6 \). *F. crotonensis* was the dominant diatom making up about 32% of the 44% biomass. *M. fenestrata* and *Cyclotella sp.* were the other two prominent diatoms. The green forms were mostly *S. paradoxum* and *Dictyosphaerium sp.* *M. aeruginosa* of the blue-greens made up 45% of the blue-green biomass followed by *Gomphosphaeria sp.* and *A. flos-aquae*. The blue-green forms represented 18% of the total algal biomass.

September algae counts and biomass dropped to the lowest point measured at the lake for the past 5 years at the mid-lake station with cell counts (filaments) of fewer than 400 cells\textbullet mL\(^{-1}\)
Newman Lake, Washington
1994 Algae Biovolume at Mid-Lake Station, 5 m
Figure AM-71
Newman Lake, Washington
1994 Algae Biovolume at Mid-Lake Station, 4 m
Figure AM-72
and biomass of $0.1 \mu m^3 \times 10^6$. However, cell counts and biomass at the northern and southern stations remained relatively the same as in previous years.

1995 algae counts and biovolumes are shown in Figures AM-74, AM-75, and AM-76. Phytoplankton biomass expressed in percent composition is shown in Figure AM-77.

Trophic State Index

Based upon chlorophyll $a$, Secchi disk, and total phosphorus measurements the mid-lake station appears to be in a mesotrophic state. Productivity has been reduced through alum treatment and oxygenation of the hypolimnion waters. However, as shown in Figure AM-78, this condition is borderline. Continued nutrient addition to the lake will increase algal growth and subsequently result in oxygen deficient waters. These events could overwhelm the oxygenation system and cause the return of eutrophic condition.

Figures AM-79 and AM-80 indicate trophic conditions at the north and south stations.
Newman Lake, Washington
1995 Algae Biovolume at Mid-Lake Station, 5 m
Figure AM-74
Newman Lake, Washington
Phytoplankton Biomass Percent Composition at Millelake 1990-1995
Figure AM-77
Newman Lake, Washington
Trophic State Indices for Mid-lake Since 1989-1996

Figure A4-78
Newman Lake, Washington
Trophic State Indices for North-Lake Since 1989-1996

Figure AM-79
Trophic State Indices for South Lake since 1989-1996

Newman Lake, Washington

Figure AM-80
SUMMARY AND CONCLUSION

The continuation of studies at Newman Lake has been very useful in extending the understanding and longevity of restoration effects. Extensive data gathered in the nutrient analyses of inflowing streams as well as the water quality of lake waters help to give an insight for additional measures that will be necessary to improve the water conditions of Newman and similar shallow lakes. Due to increased house building, road construction and other activities in the watershed, there has been little decrease in nutrient inflow for the past 5 years. A strong educational program will be required in order to raise awareness and explain to the public the relationship between phosphorus carried by the sediment into the lake and resultant algae blooms.

After 5 years, the effectiveness of the alum treatment has greatly diminished and increase in blue-green algae growth has been observed. The oxygenation system has been successful and has prevented large-scale release of phosphorus from the bottom sediment. Other steps must be taken, however, to prevent a return to the rapid cycling of phosphorus that was occurring in the years prior to 1989. Chlorophyll a values are 40 to 50% of those measured prior to 1989. The phytoplankton biovolume is considerably less, but blue-green blooms still occur although smaller in numbers and biovolume. The time period (months, days) that the oxygenation system should be operated for maximum benefit is still not fully understood.

Investigations carried out by Thomas et al. (1993) and Doke et al. (1995) have shown that oxygenation of the hypolimnion at Newman Lake has made a much larger habitat available for fishes. This action has in turn reduced and modified the benthic invertebrate populations largely due to fish predation. The present study indicates that blue-green algal numbers and biovolume remained much lower than those measured in pre-restoration studies.

In addition to the recommendations that watershed education be continued, it is also recommended that additional in-lake measures be implemented. Under present economic conditions, alum injection utilizing the oxygenator systems is the most viable. Other measures, justification, and costs are presented in Robison and Funk (1997).

If measures, as suggested in the main body of this report and the addendum, are carried out—and if a cooperative spirit is maintained within the Newman Lake community (including the large number of visitors that utilize the lake)—then the lake can be maintained in a reasonably good state for the benefit of all users.
CITATIONS


