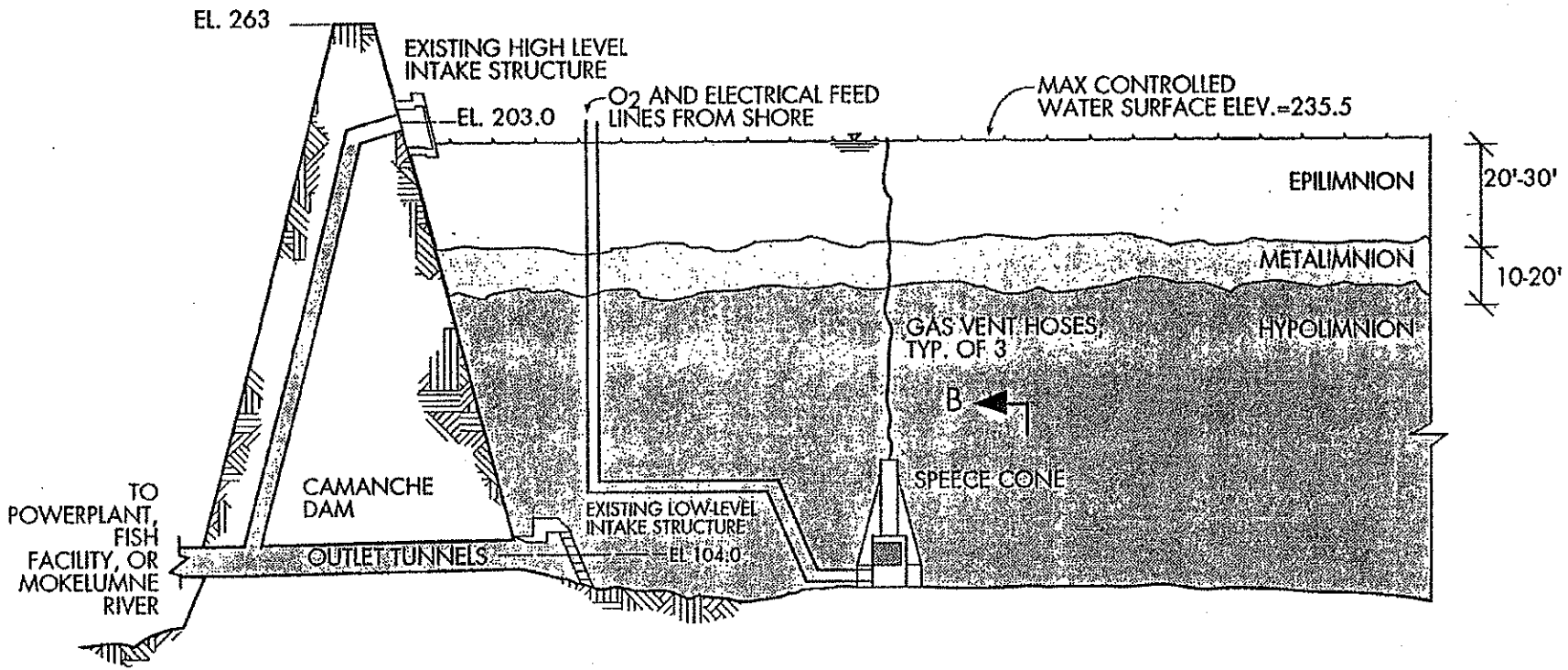
Figure 3

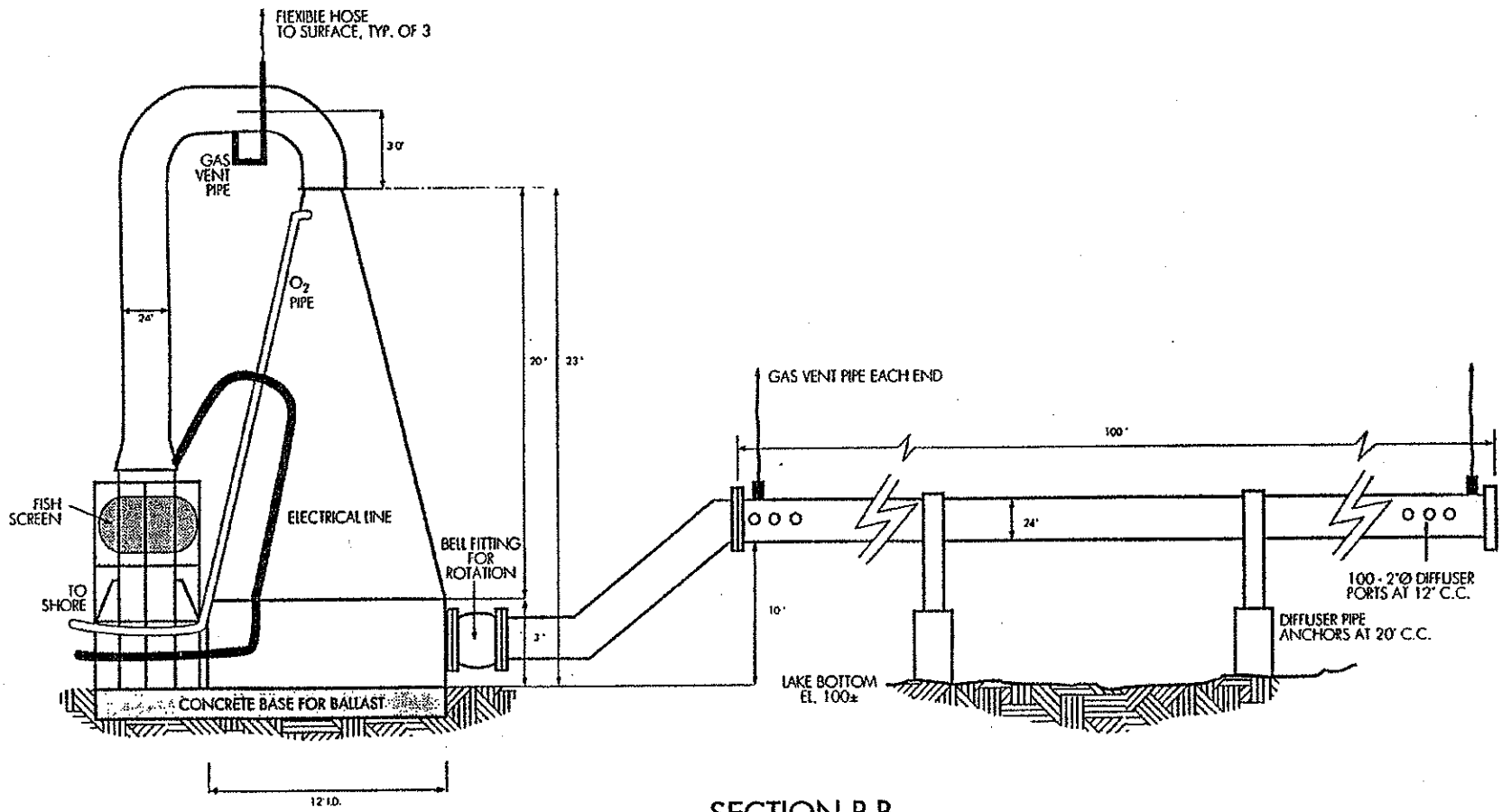
CAMANCHE HYPOLIMNETIC OXYGENATION DEMONSTRATION PROJECT
SECTION A-A



SECTION A - A B
(not to scale)

Figure 4

CAMANCHE HYPOLIMNETIC OXYGENATION DEMONSTRATION PROJECT
SECTION B-B



SECTION B-B
(not to scale)

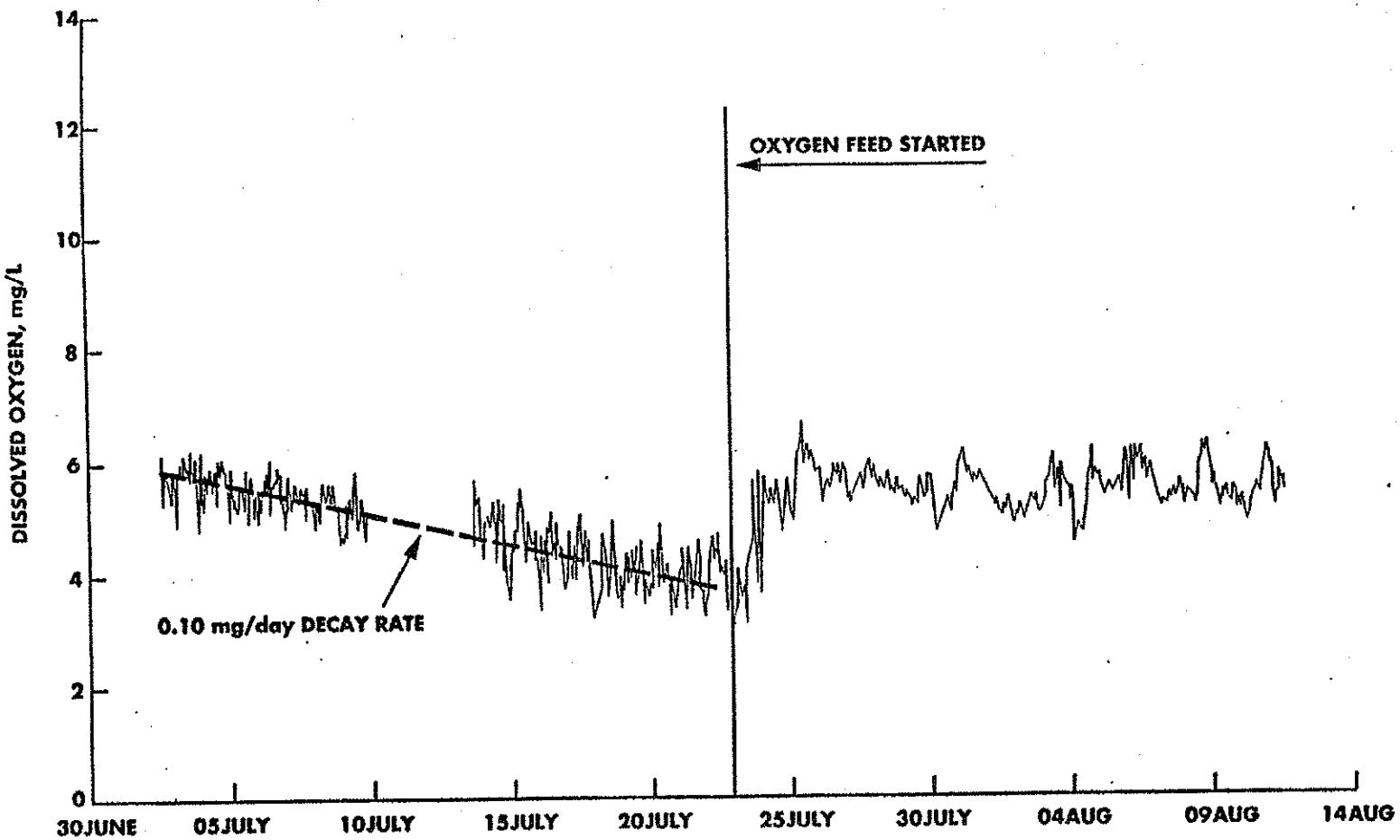


Figure 5 Initial effects of the oxygenation system on dissolved oxygen near the Speece Cone in 1993 (About 2m off the bottom).

Figure 6

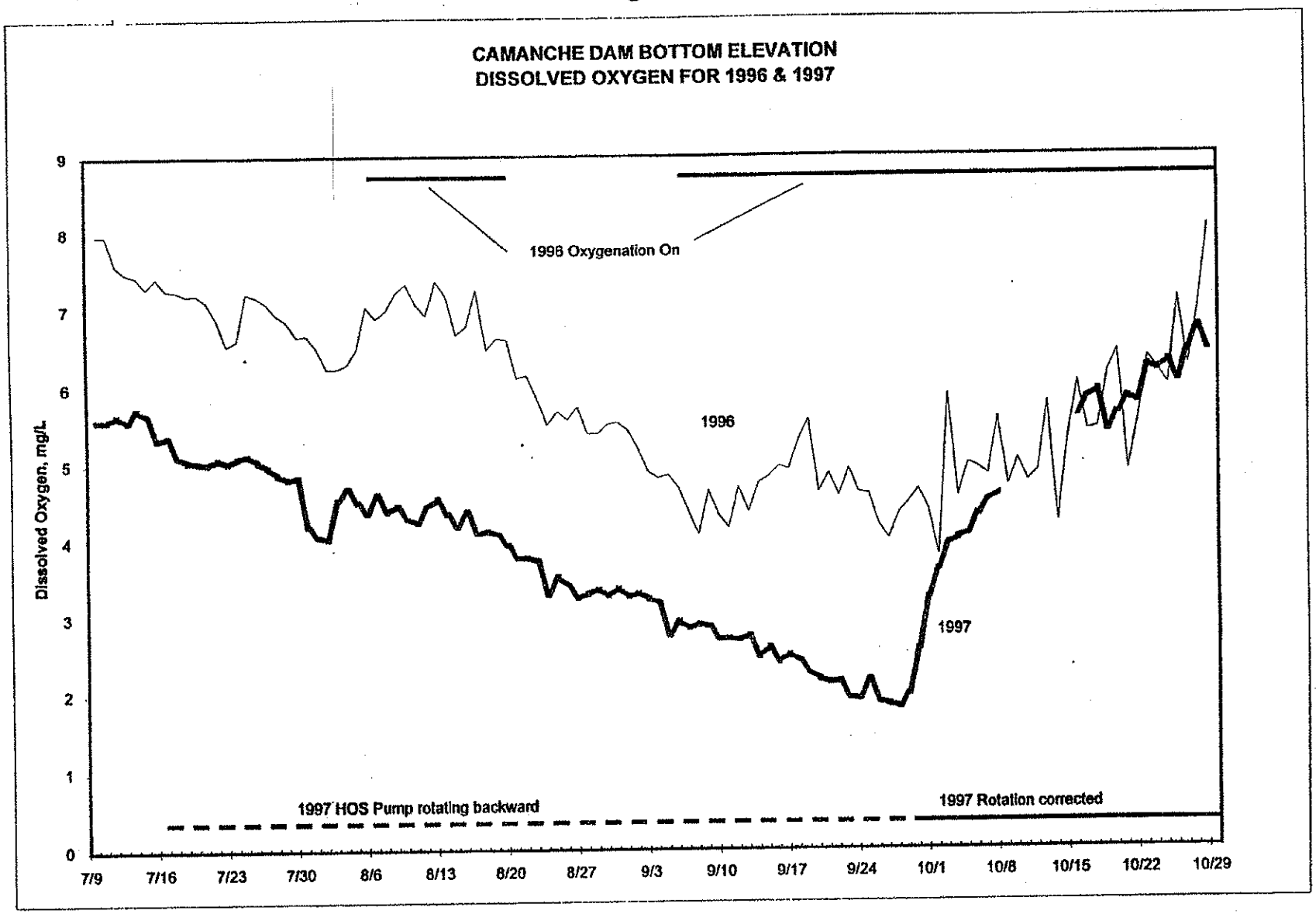
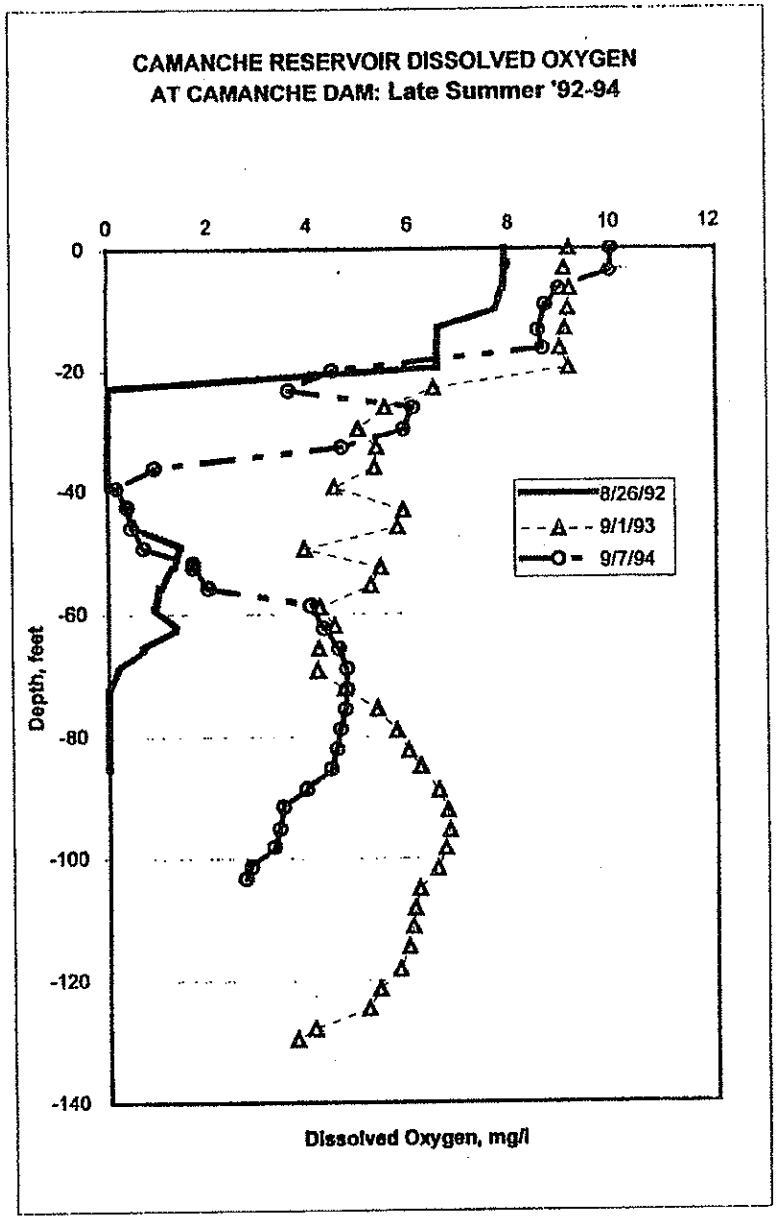
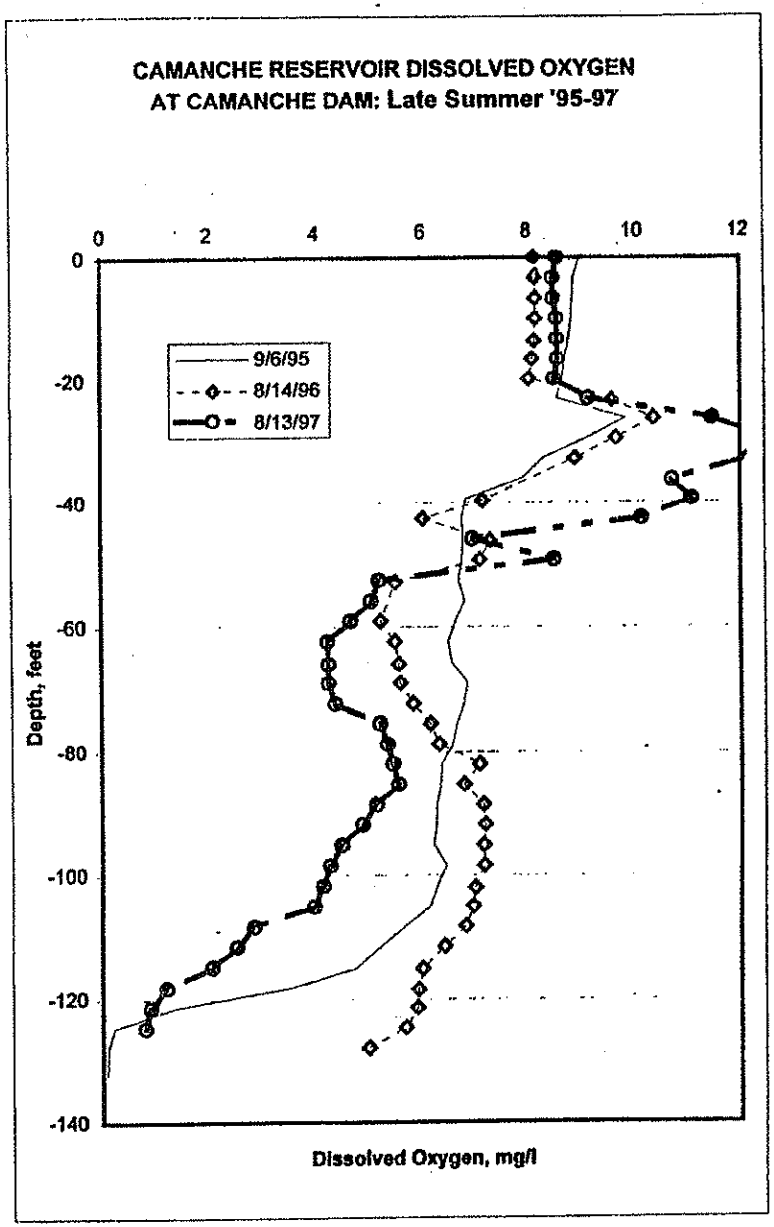

CAMANCHE DAM BOTTOM ELEVATION
DISSOLVED OXYGEN FOR 1996 & 1997
Dissolved Oxygen, mg/L
9
8
7
6
5
4
3
2
1
0
1996 Oxygenation On
1996
1997
1997 HOS Pump rotating backward
1997 Rotation corrected
7/9
7/16
7/23
7/30
8/6
8/13
8/20
8/27
9/3
9/10
9/17
9/24
10/1
10/8
10/15
10/22
10/29

Figure 7





Lines without symbols indicate no oxygen added.

Figure 8
Camanche Reservoir Dissolved Oxygen Profile: 07/13/94 (40 Days after Startup)

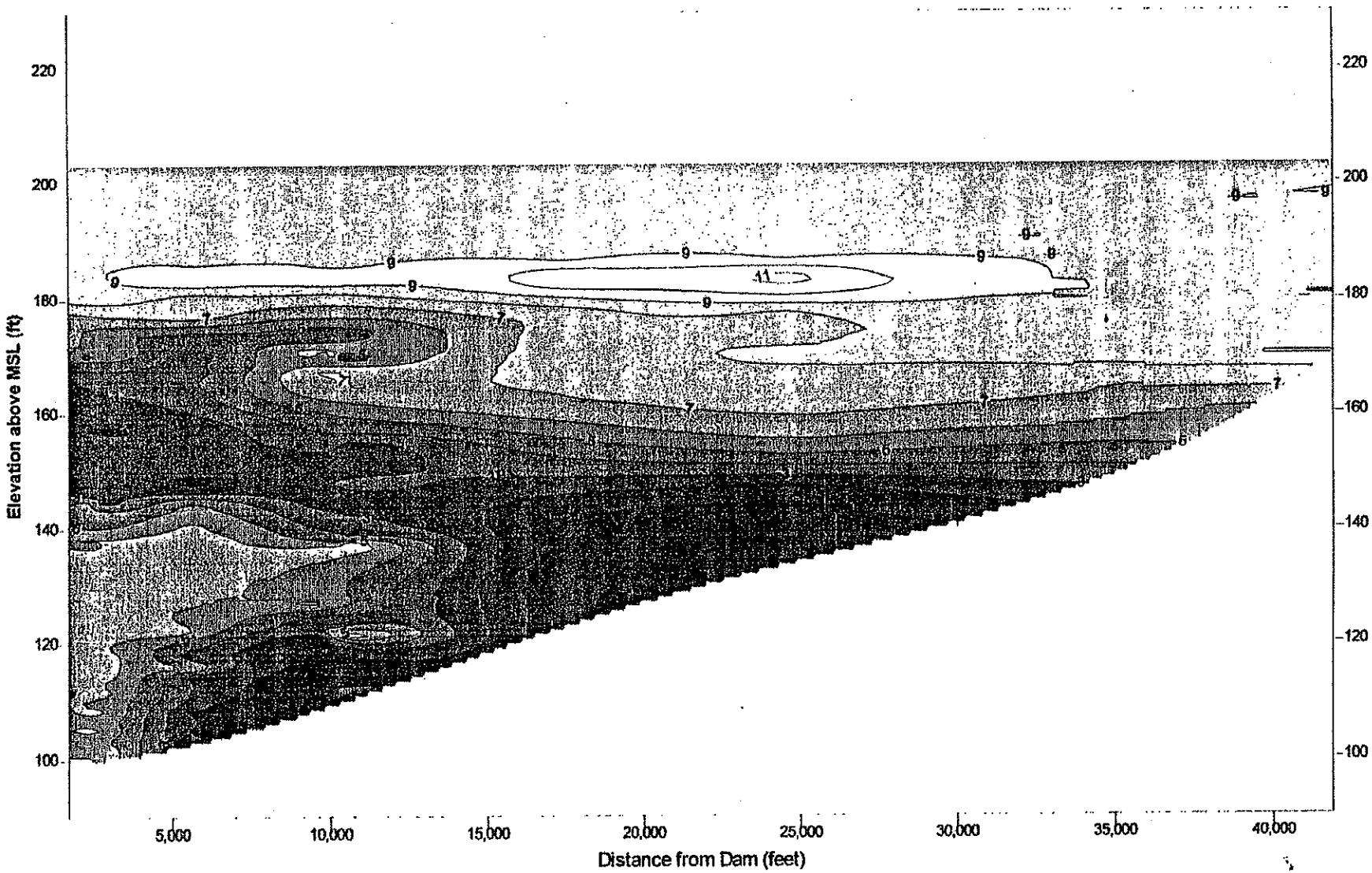
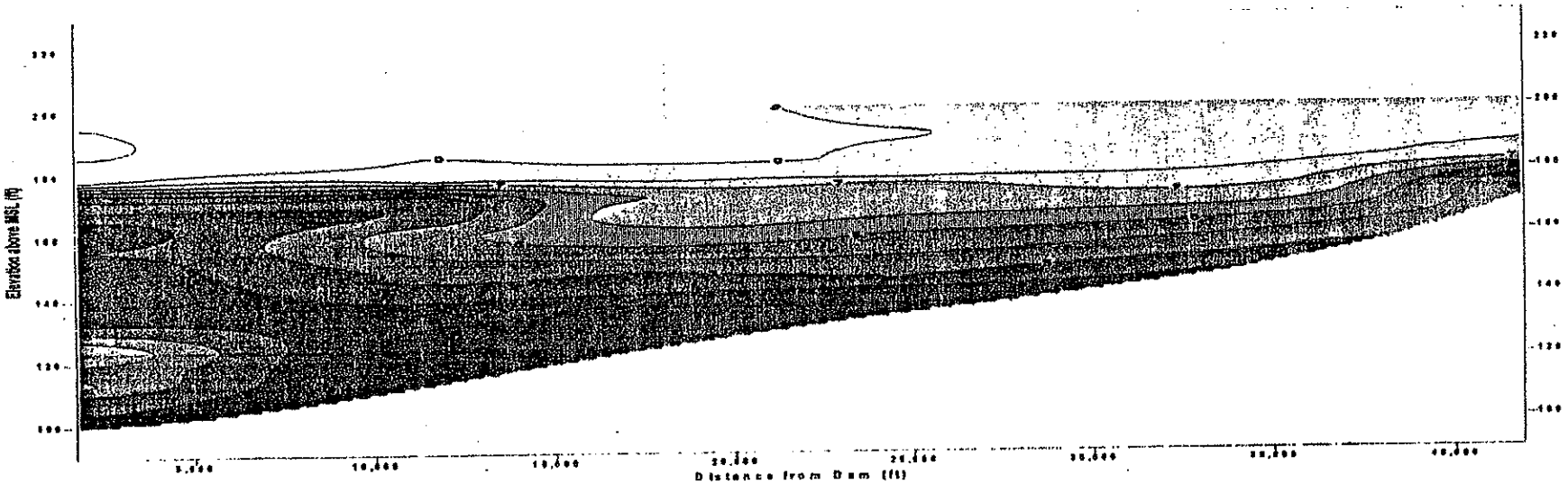


Figure 9
Camanche Reservoir Dissolved Oxygen Profile: 8/03/94 (20 Days of no Oxygen)



Camanche Reservoir Dissolved Oxygen Profile: 8/12/94 (29 Days of no Oxygen)

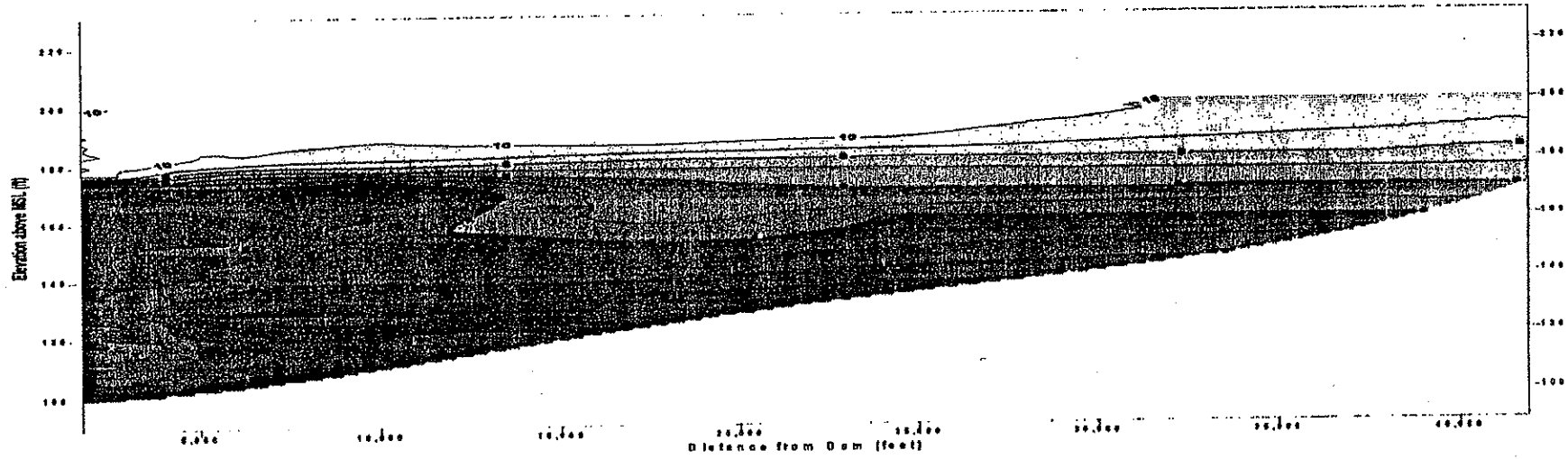


Figure 10

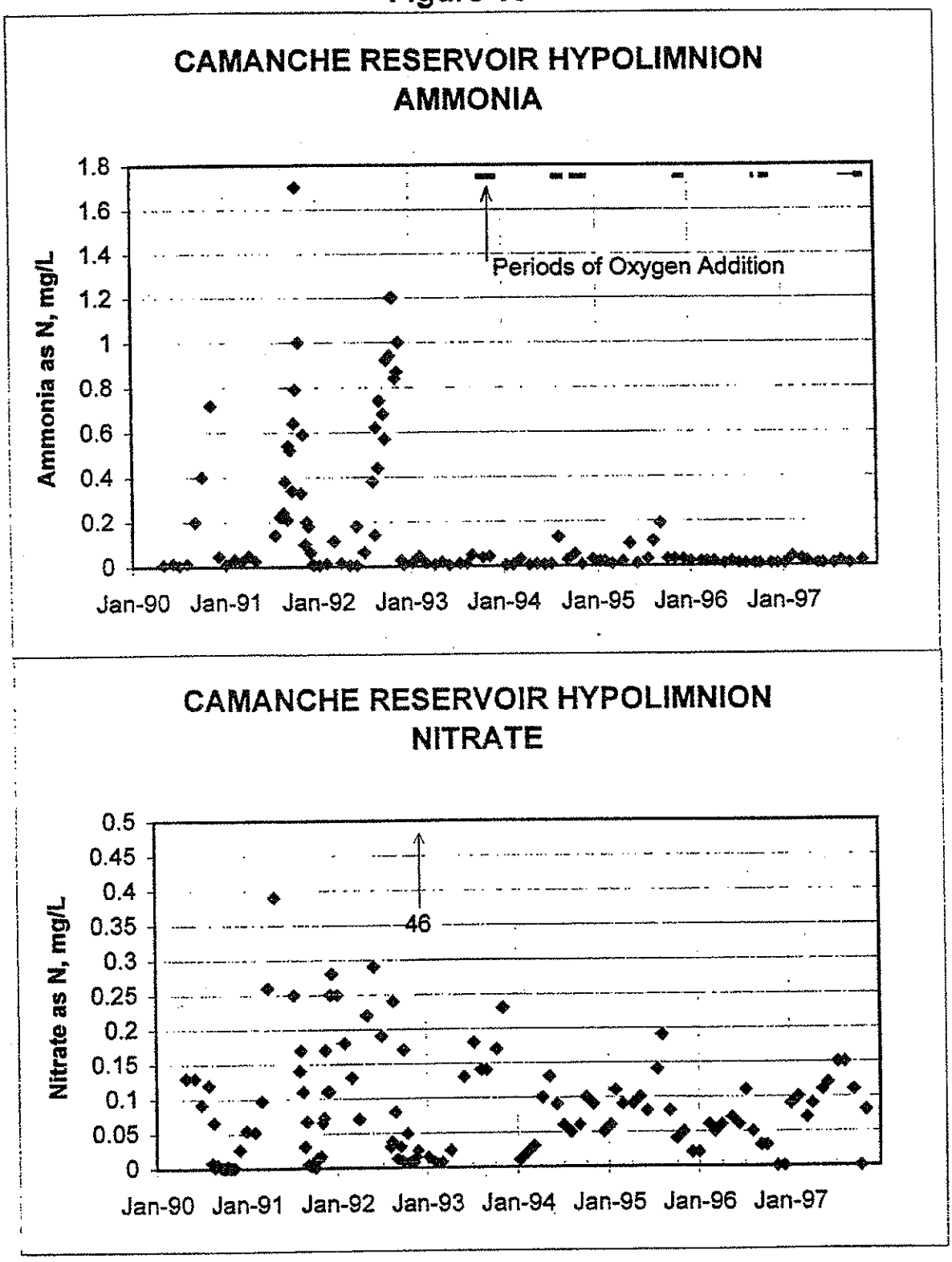
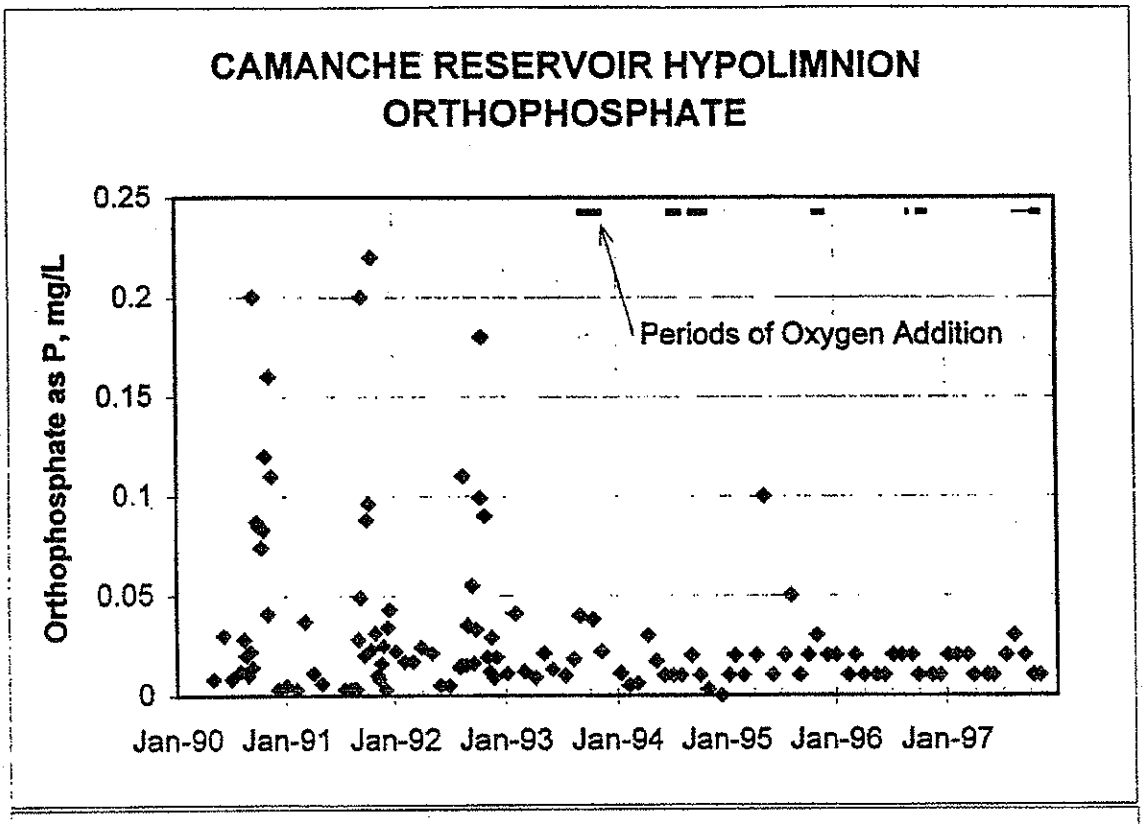

CAMANCHE RESERVOIR HYPOLIMNION
AMMONIA
Ammonia as N, mg/L
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Periods of Oxygen Addition
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
CAMANCHE RESERVOIR HYPOLIMNION
NITRATE
Nitrate as N, mg/L
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
46
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97

Figure 11


CAMANCHE RESERVOIR HYPOLIMNION
ORTHOPHOSPHATE
Orthophosphate as P, mg/L
0.25
0.2
0.15
0.1
0.05
0
Periods of Oxygen Addition
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97

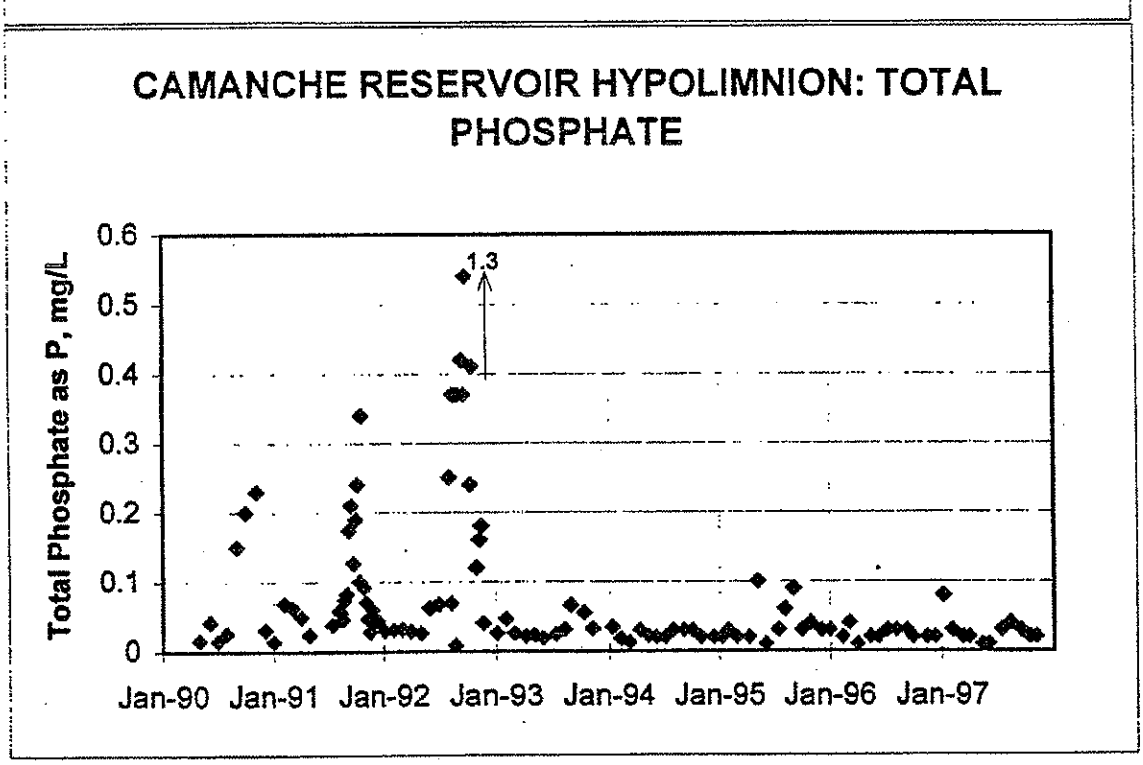
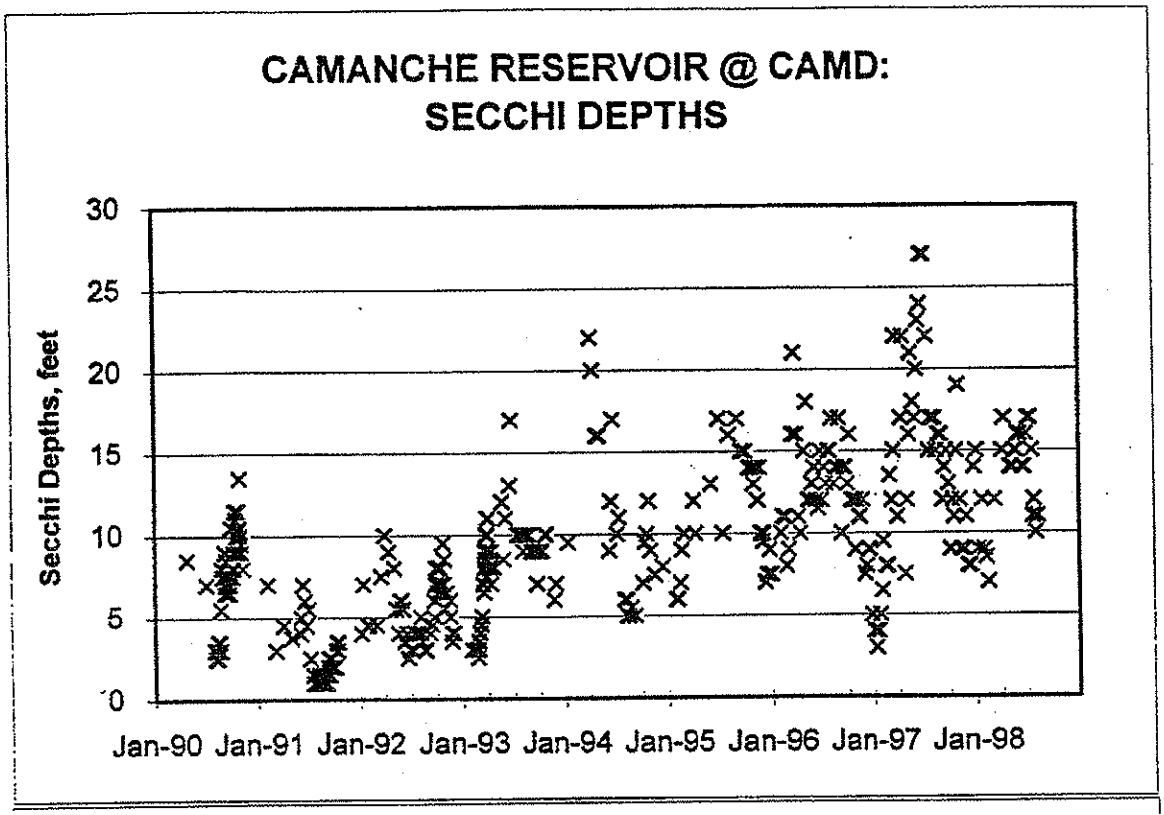

CAMANCHE RESERVOIR HYPOLIMNION: TOTAL
PHOSPHATE
Total Phosphate as P, mg/L
0.6
0.5
0.4
0.3
0.2
0.1
0
1.3
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97

FIGURE 12


CAMANCHE RESERVOIR @ CAMD:
SECCHI DEPTHS
Secchi Depths, feet
30
25
20
15
10
5
0
Jan-90 Jan-91 Jan-92 Jan-93 Jan-94 Jan-95 Jan-96 Jan-97 Jan-98

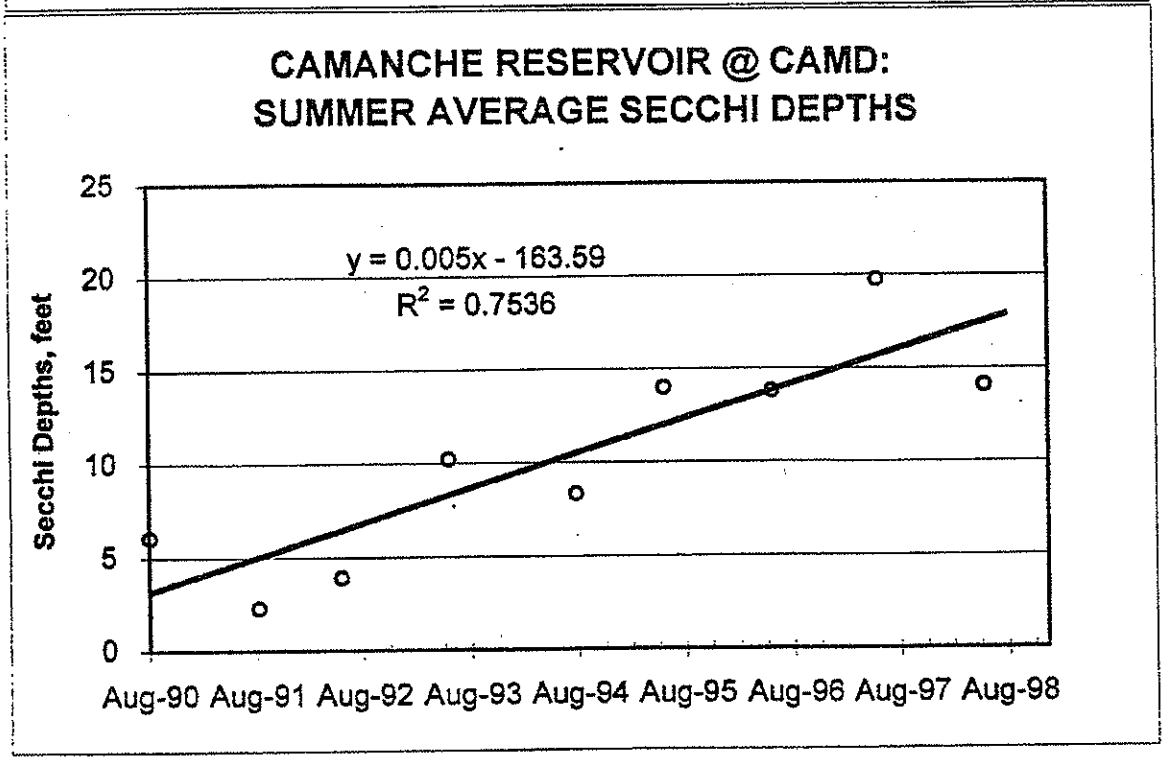
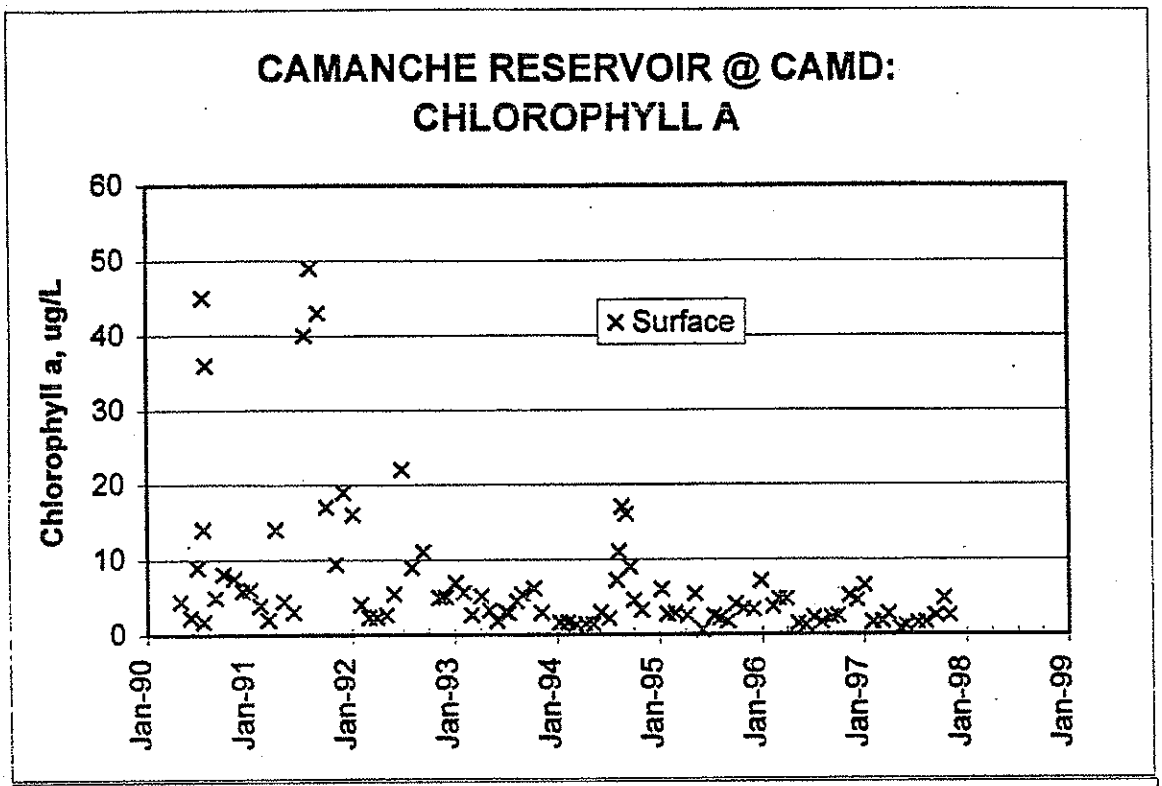

CAMANCHE RESERVOIR @ CAMD:
SUMMER AVERAGE SECCHI DEPTHS
Secchi Depths, feet
y = 0.005x - 163.59
R2 = 0.7536
25
20
15
10
5
0
Aug-90 Aug-91 Aug-92 Aug-93 Aug-94 Aug-95 Aug-96 Aug-97 Aug-98

Figure 13


CAMANCHE RESERVOIR @ CAMD:
CHLOROPHYLL A
Chlorophyll a, ug/L
60
50
40
30
20
10
0
× Surface
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99

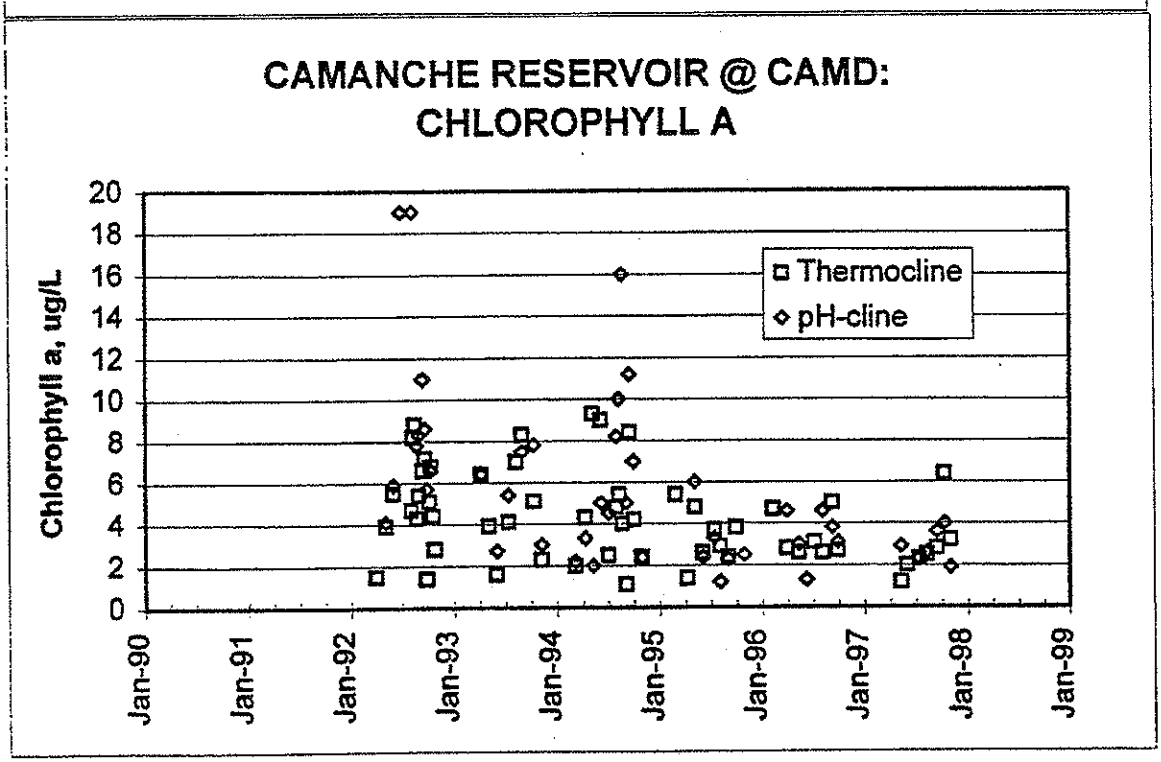

CAMANCHE RESERVOIR @ CAMD:
CHLOROPHYLL A
Chlorophyll a, ug/L
20
18
16
14
12
10
8
6
4
2
0
□ Thermocline
◇ pH-cline
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99

FIGURE 14

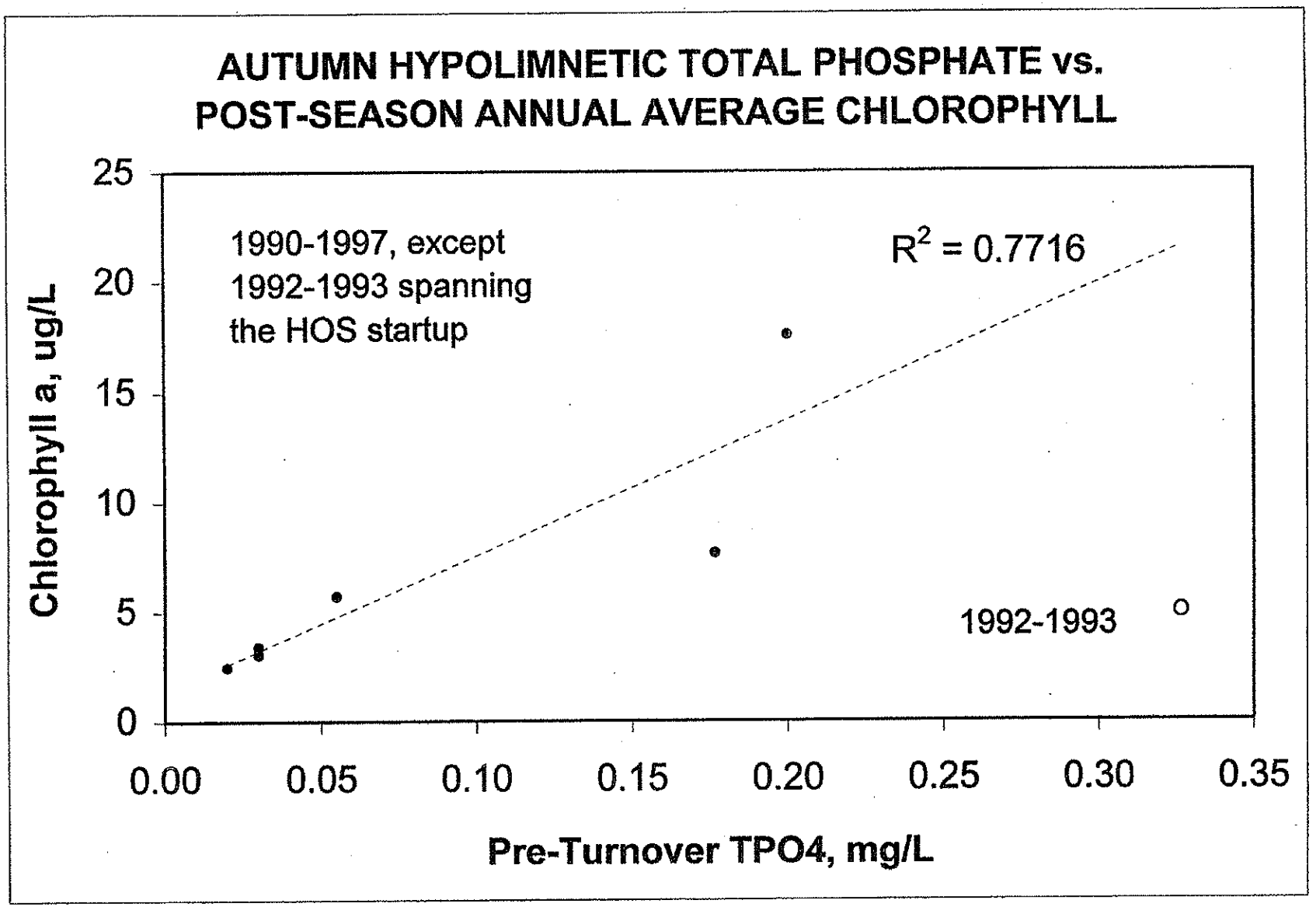

AUTUMN HYPOLIMNETIC TOTAL PHOSPHATE vs.
POST-SEASON ANNUAL AVERAGE CHLOROPHYLL
1990-1997, except
1992-1993 spanning
the HOS startup
R^2 = 0.7716
1992-1993
Chlorophyll a, ug/L
0
5
10
15
20
25
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Pre-Turnover TPO4, mg/L

FIGURE 15

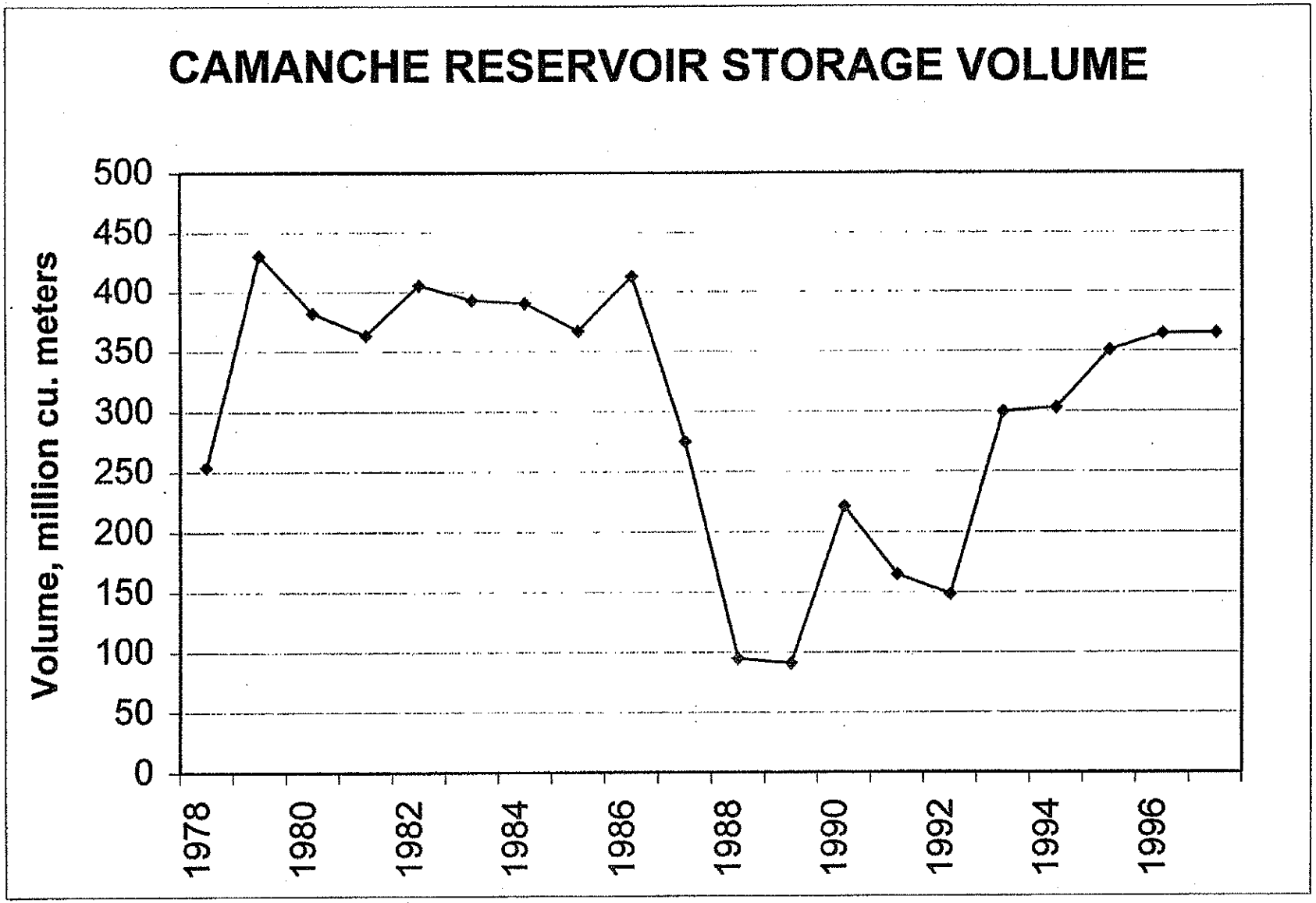
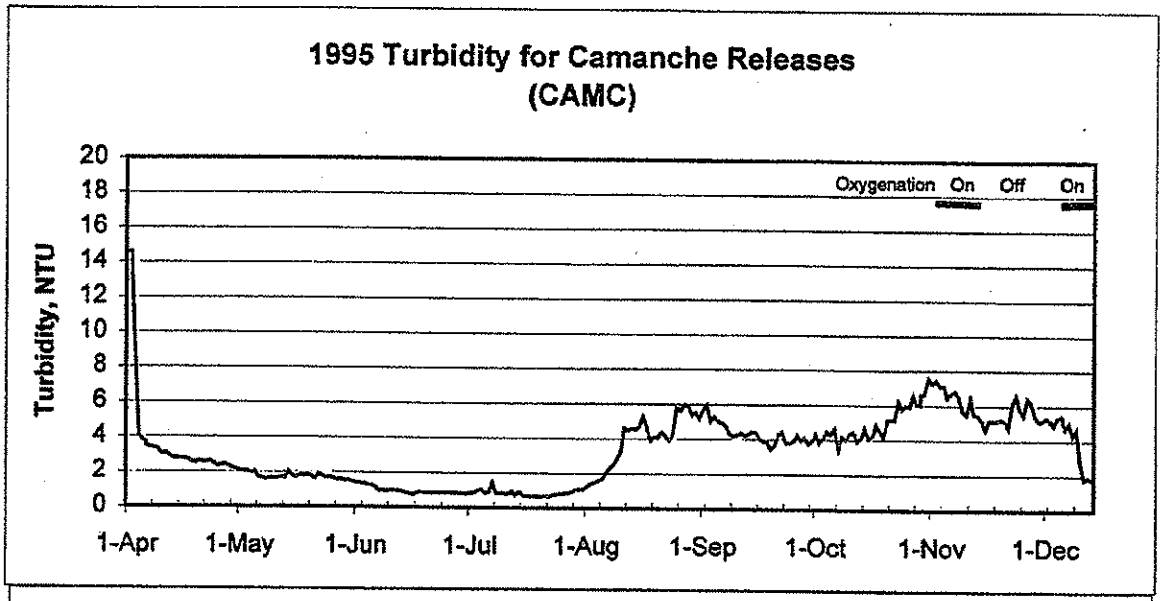
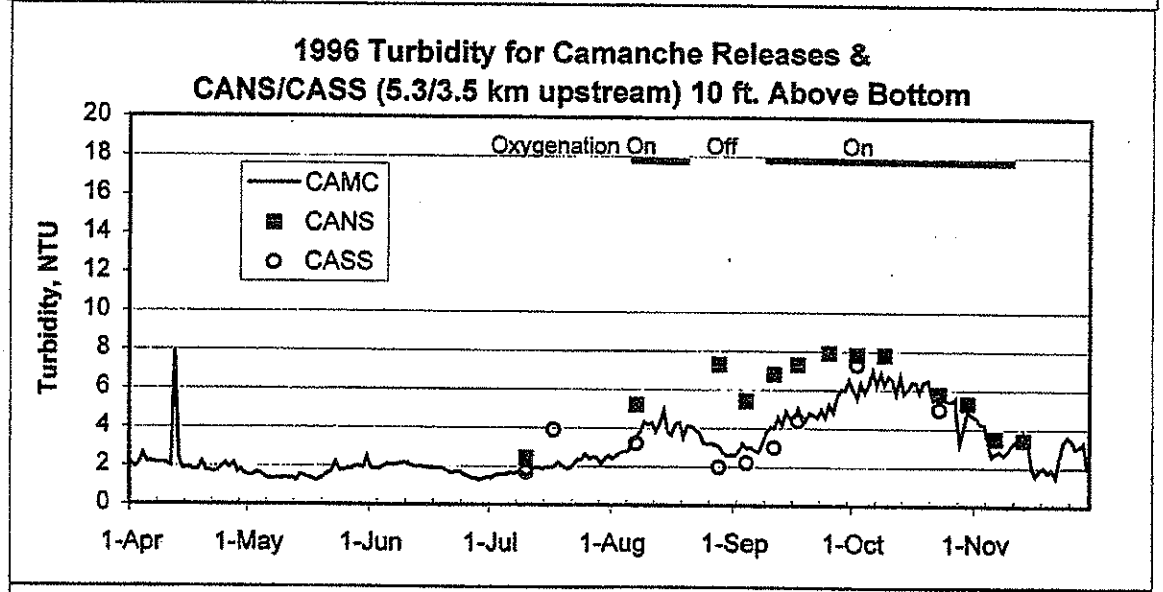
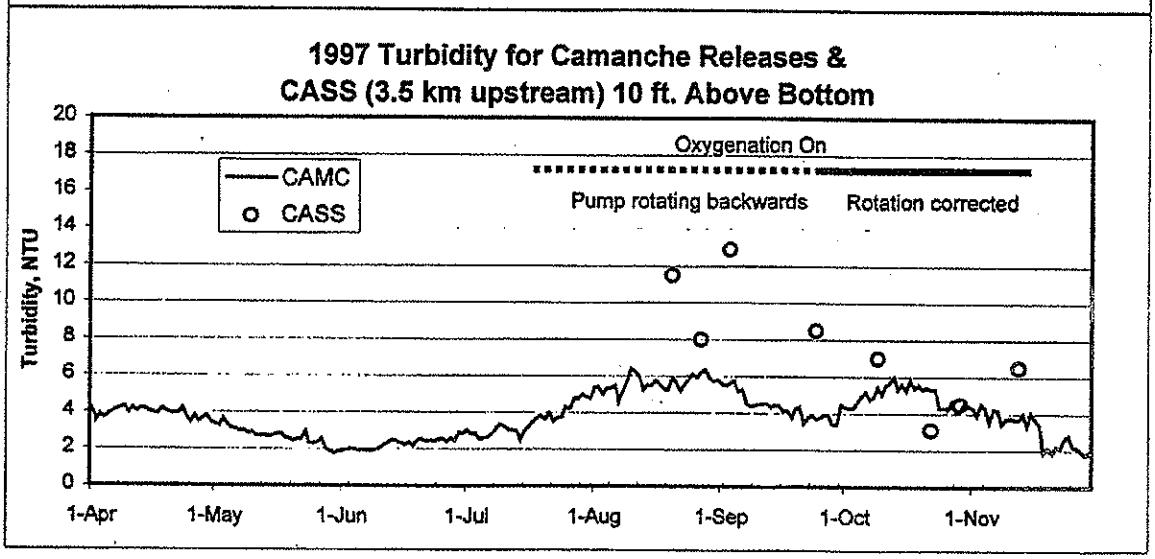

CAMANCHE RESERVOIR STORAGE VOLUME
Volume, million cu. meters
500
450
400
350
300
250
200
150
100
50
0
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996

FIGURE 16


1995 Turbidity for Camanche Releases
(CAMC)
Turbidity, NTU
Oxygenation On Off On
0
2
4
6
8
10
12
14
16
18
20
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec


1996 Turbidity for Camanche Releases &
CANS/CASS (5.3/3.5 km upstream) 10 ft. Above Bottom
Turbidity, NTU
Oxygenation On Off On
CAMC
CANS
CASS
0
2
4
6
8
10
12
14
16
18
20
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov


1997 Turbidity for Camanche Releases &
CASS (3.5 km upstream) 10 ft. Above Bottom
Turbidity, NTU
Oxygenation On
CAMC
CASS
Pump rotating backwards
Rotation corrected
0
2
4
6
8
10
12
14
16
18
20
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov

A Decade on the Bottom

Performance of the Speece Cone in Newman Lake.

Some Observations on:

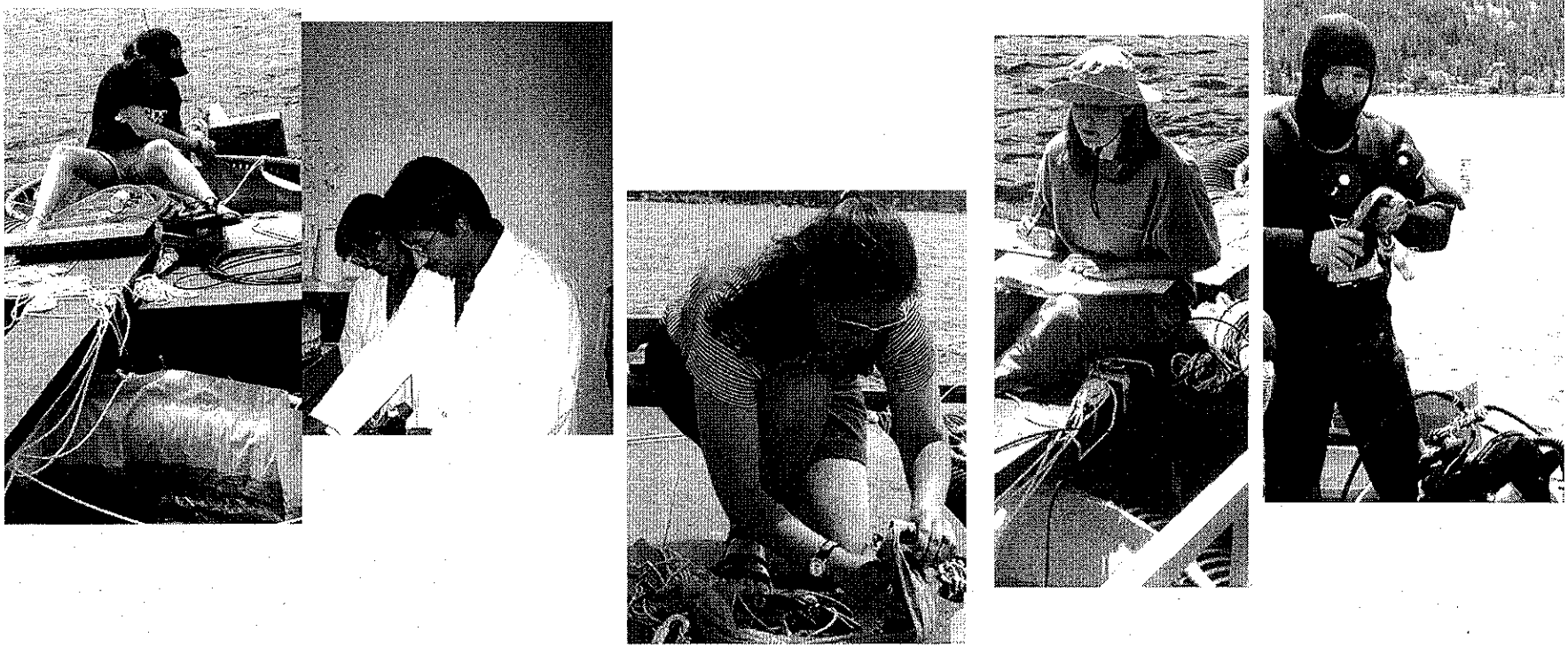
Design, operation, and data sets for hypolimnetic oxygenation systems

by Barry C. Moore

Lisa Audin Laurie Flaherty

Edward Martinez Ann Richter

Megan Rogers Louise Wold



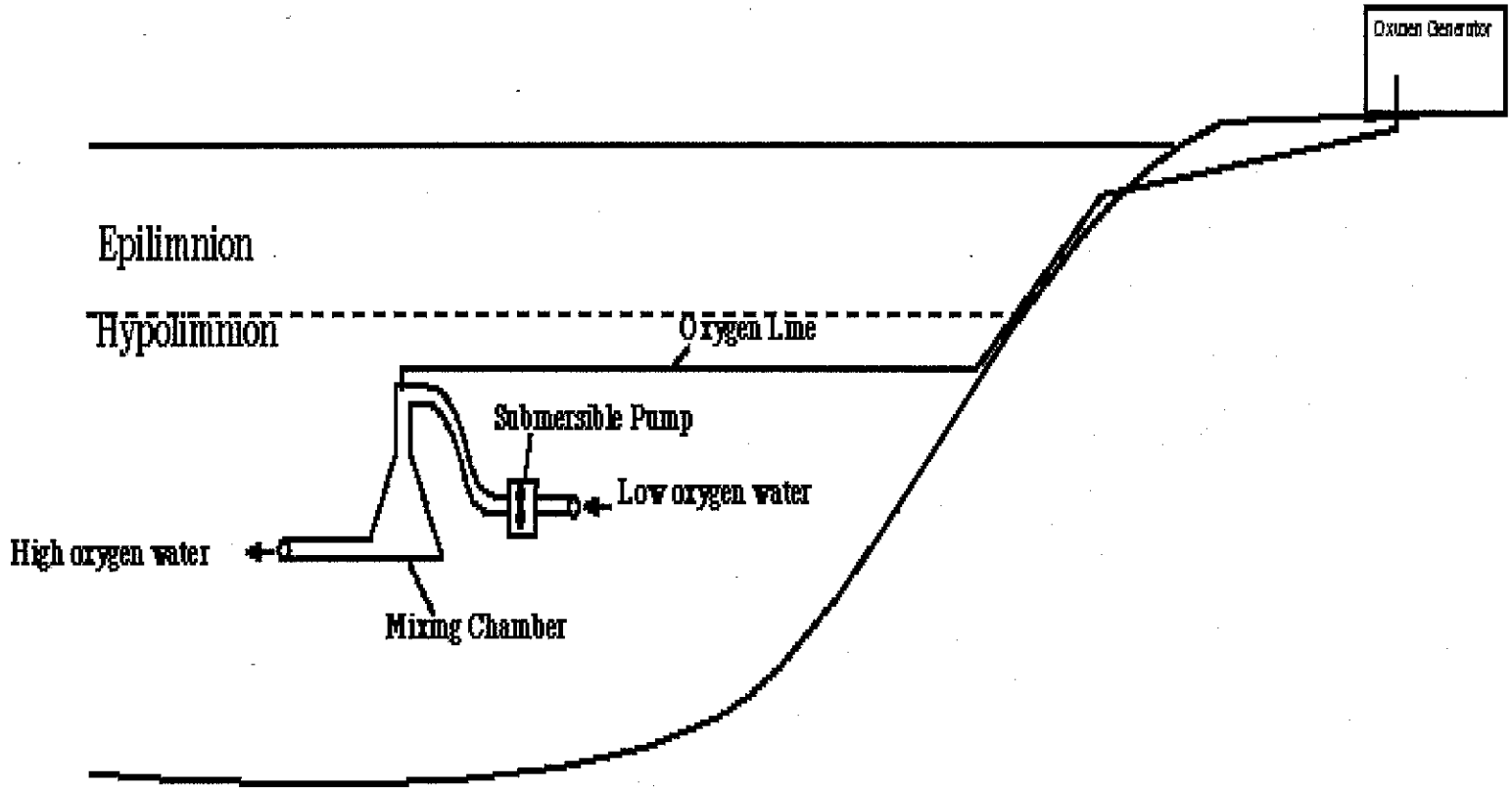
NEWMAN LAKE

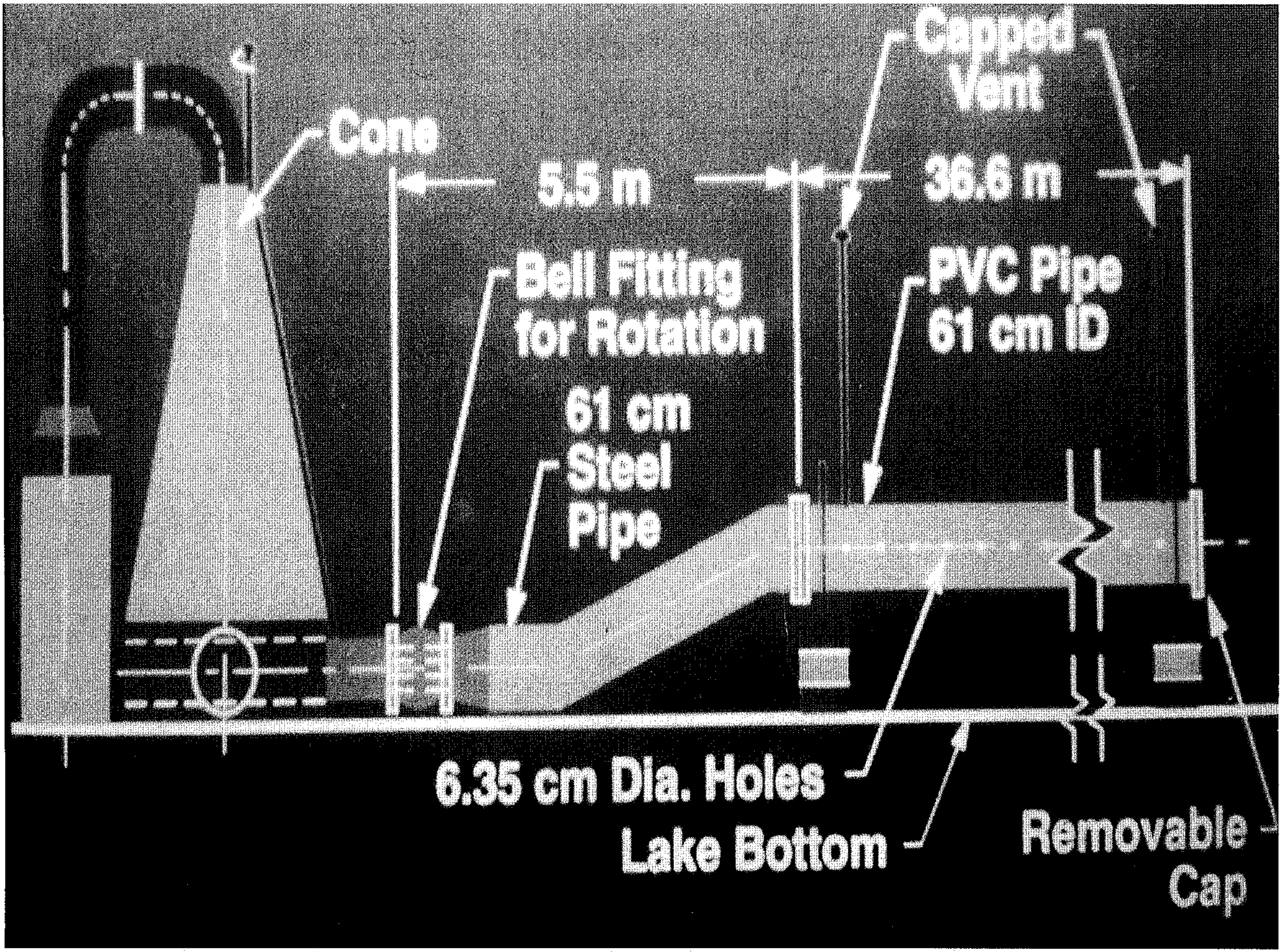
- Surface Area:
  1200 acres (480 ha)
- Mean Depth:
  19 ft (5.6m)
- Max Depth:
  30 ft (9 m)
- Lake Volume:
  25×10^6 m^3
  (883×10^6 ft^3)
- Dimictic
- Watershed Area:
  26,500 acres
  (10,700 ha)
- Land Use:
  Forestry 80%
  Agricultural
  Domestic Homesites

NEWMAN LAKE RESTORATION AND MONITORING ACTIVITIES

- 1975: Algae blooms prompt initial studies (Funk and others)
- 1985/86: Algae blooms worsen, Phase I study (Moore and Funk)
- 1989: Alum treatment
- 1992: Speece Cone installed
- 1989-1992: Water quality studies for Phase II (Moore, Funk, and others)
- 1990 - present: Watershed activities
- 1997: Alum injection system installed
- 1995- present: Ongoing water quality studies (Moore and others)

Downflow Contact Bubble Aerator (Oxygenator) or Speece Cone





Cone
5.5 m
Capped
Vent
36.6 m
Bell Fitting
for Rotation
PVC Pipe
61 cm ID
61 cm
Steel
Pipe
6.35 cm Dia. Holes
Lake Bottom
Removable
Cap

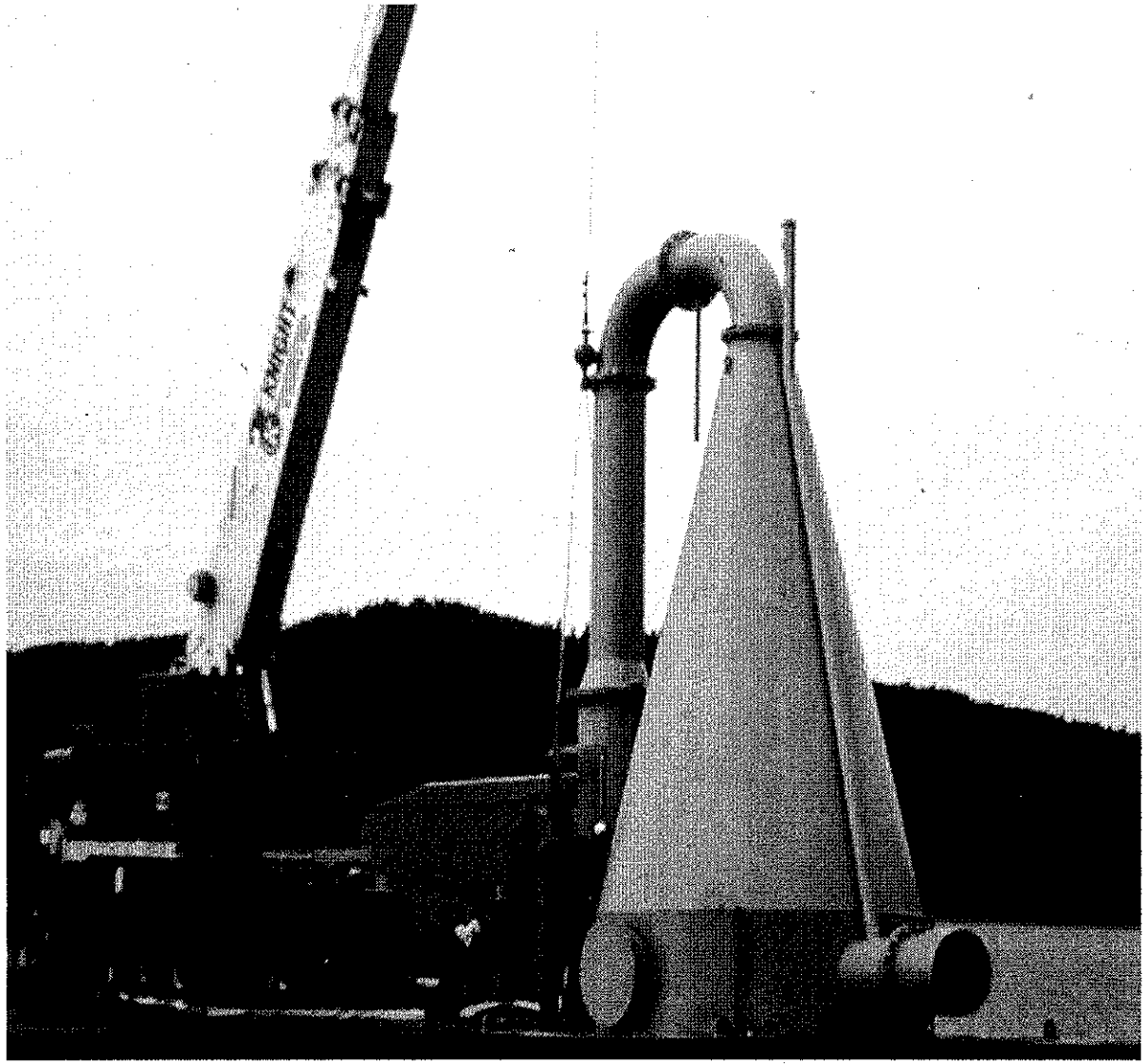
Significance of Speece Cone at Newman Lake

- First application of DCBA technology for hypolimnetic oxygenation (HO)
- Application of HO to relatively shallow lake
- Significant savings in equipment, capital costs, and operating expenses over traditional full-lift Bernhardt aerators
- Potential for widespread use in lake restoration, fisheries, and reservoir management

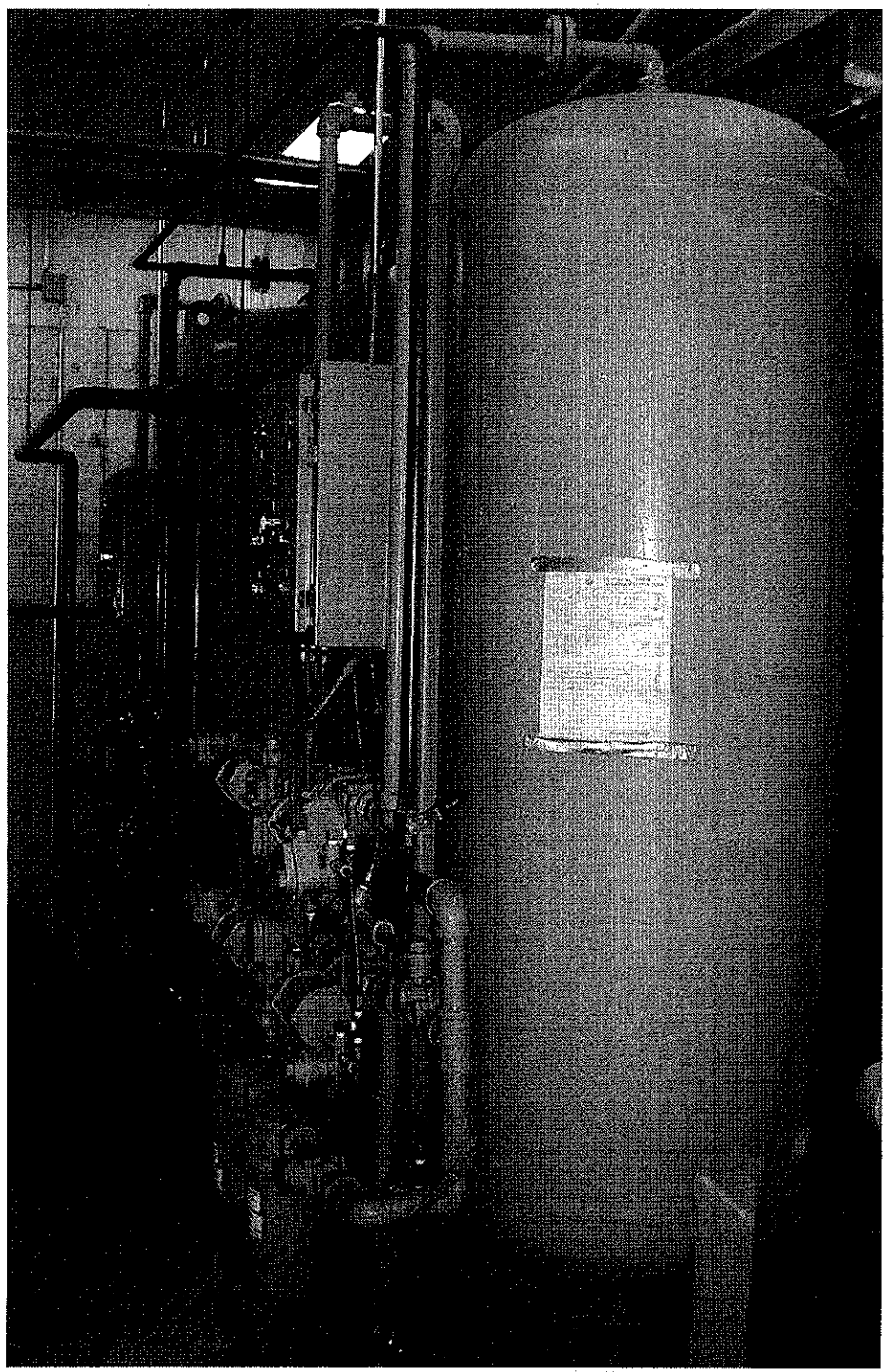
Other Innovations

- On-site oxygen generation (Air-Sep)
- Distribution manifold engineered to minimize sediment entrainment
- Operational flexibility and redundancy (dual compressors)

Unit Installation



Oxygen Generators



Speece Cone Specifications

- Oxygen Delivery: 3,000 lbs/day (1,360 kg/day)
- Cone Volume: 315 ft^3 (9 m^3)
- Cone Height: 15 ft (4.6 m)
- Water Flow Rate: 21 ft^3/sec (0.6 m^3/sec)

Other System Components

- Dual Air-Sep Oxygen Generators
  (each w/ 1500 lb/day capacity)
- Dual 50 hp Rotary Screw Compressors
- In-lake Water Pump: 9450 gpm @ 40 hp
- Distribution Manifold: 100 ft long, 2 ft diameter, w/ 2" ports on 2 ft spacing

Operation at Newman Lake

- 1992: Speece Cone installed (June)
- 1993 to 1996: Partial operation
  (start up at 50%, variable 50 or 100%
  for remainder of season)
- 1997 to present: 100% all season except 2000 (equipment breakdown and repairs)

Some Unusual Environmental Events Impacting Newman Lake

1992 Very cool July (lake looses ~ 5_o C. from June 30 to July 15) followed by large storm (sustained winds > 30 mph for over 20 hrs)

1997 Heavy mid-April rain on above-average snowpack accompanied by warming temperatures cause rapid snowmelt on saturated soils. > 30 yr runoff event in Newman Lake watershed. After winter ice storm, widespread erosion with heavy sediment load in cold inlet streams.

So what lessons have we learned from operating the Newman Lake Speece cone?

Anoxic Factor =

(duration of anoxia in days times anoxic sediment area in meters^2)

divided by lake surface area in meters^2

Ref: G. Nurnberg, 1995. Quantifying anoxia in lakes. *Limnol. Oceanogr. 40(6)1100-1111.*

Anoxic Factor quantifies persistence and extent of low oxygen conditions.

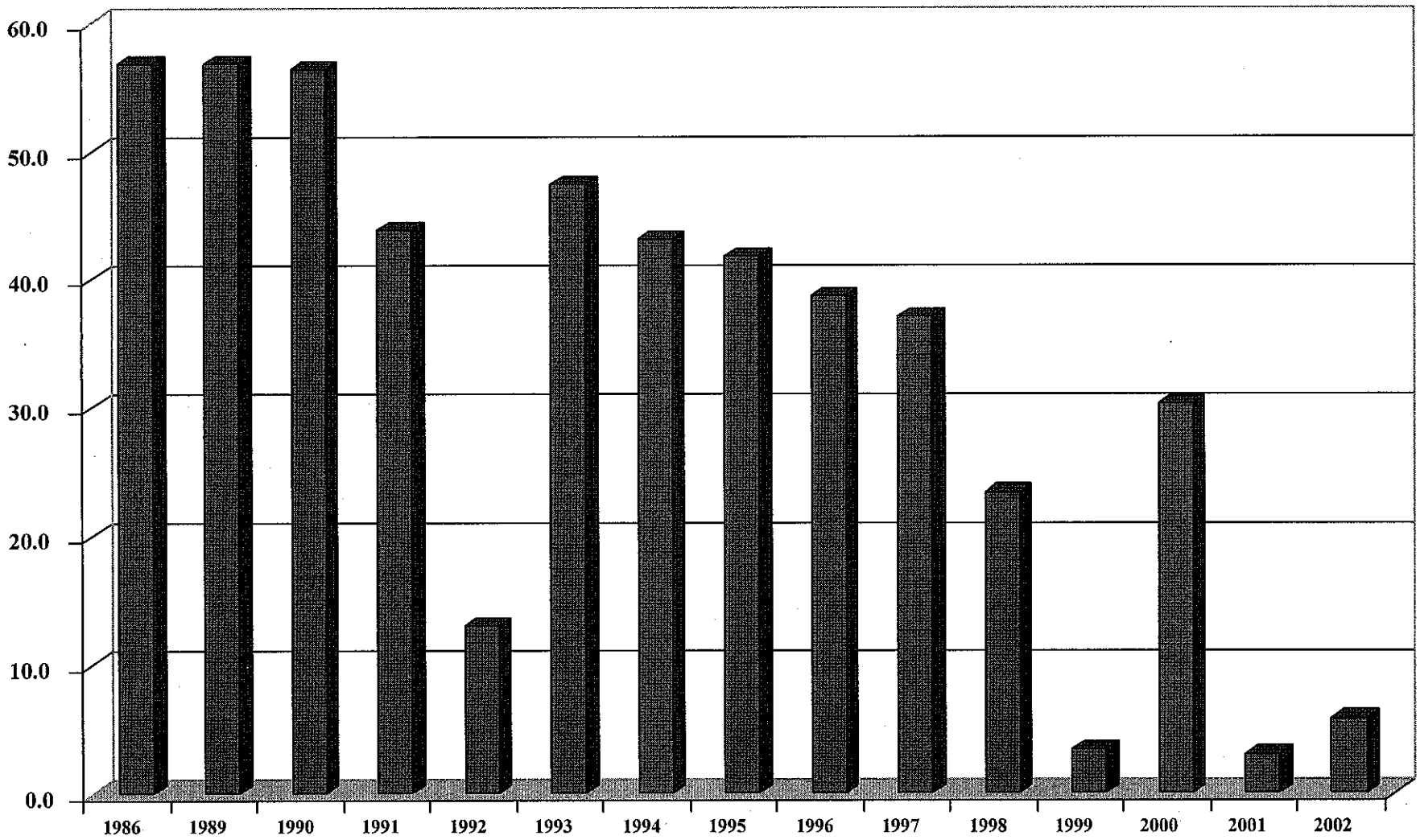
Criteria: O2 < 1 mg/L

Range in values from 0 to 365

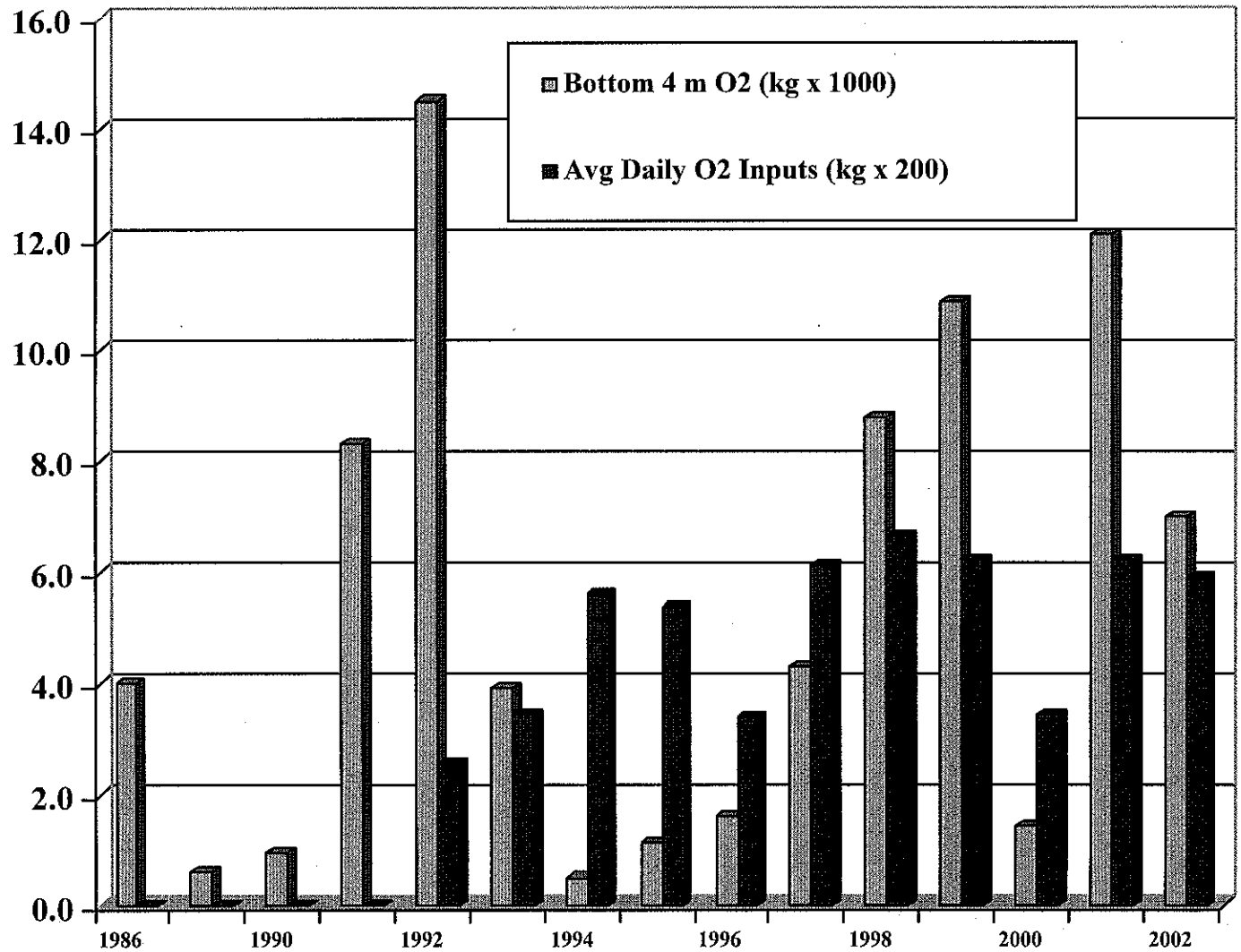
Most from ~ 1 to 80

Units: days per season (or year)

Summer Anoxic Factors for Newman Lake



Oxygen Mass in Bottom 4 meters vs. Average Daily Oxygenator Inputs



Lesson 1: Run the system at full design capacity

i.e. Power savings at lower delivery rates do not provide commensurate levels of O_2 or water quality benefits