Temporal and Spatial Patterns of Oxygen Depletion in Reservoirs

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The production and consumption of dissolved oxygen results in concentration fluctuations at both temporal and spatial scales. Temporal and spatial development of density gradients, due primarily to changes in vertical temperatures in the water column, results in vertical and longitudinal zonation in aquatic systems. Extinction of light with depth results in the establishment of two primary vertical zones. In the upper, photic zone net oxygen production typically exceeds consumption. In a lower zone where photosynthesis is limited and oxygen production is exceeded. This results in net consumption of dissolved oxygen often followed by the establishment of hypoxic or anoxic conditions. The extent and the rate of oxygen depletion can be used to evaluate the “health” of the aquatic system and provide information critical for design guidance for remediation. Factors contributing to the establishment of these zones will be presented for selected reservoirs, assessment methods will be described, and implications for in-lake management techniques will be discussed.

Temporal and Spatial Gradients In Dissolved Oxygen Concentrations Assessment Techniques

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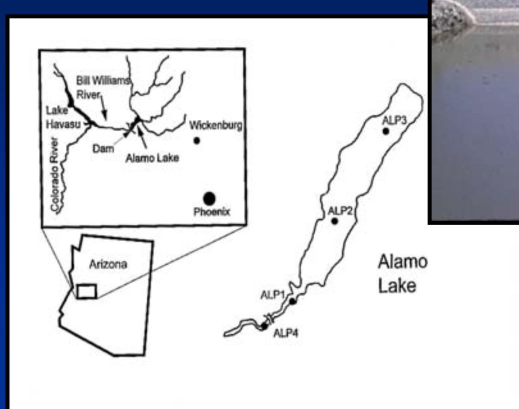
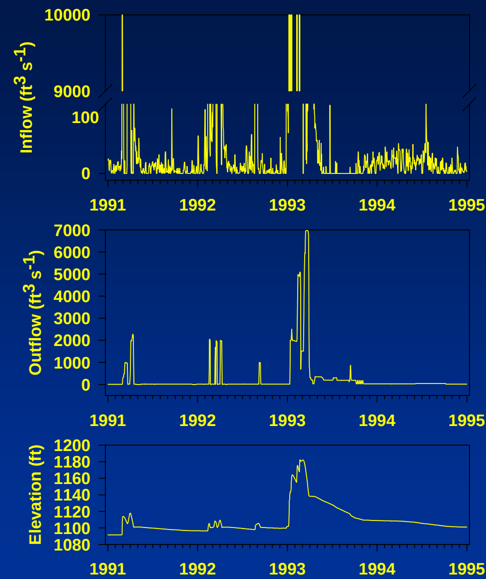
Alamo Lake, AZ

**Case Study:
Flood Control Project
in Arid Region**



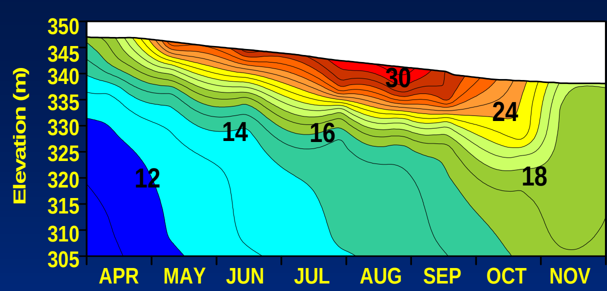
Hydrologic Information

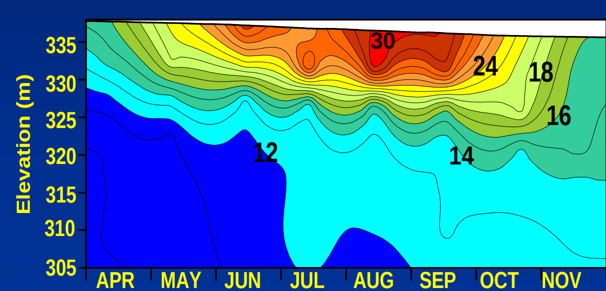
- 1993 was a very wet year with high surface elevation and discharge
- 1994 was a very dry year with low discharge



Thermal Structure

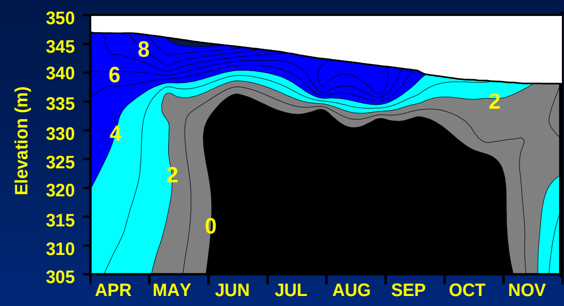
- 1993 (top)
- 1994 (bottom)

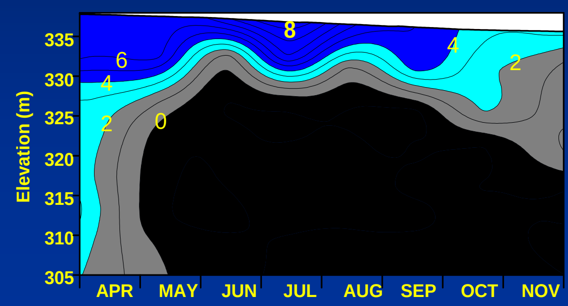




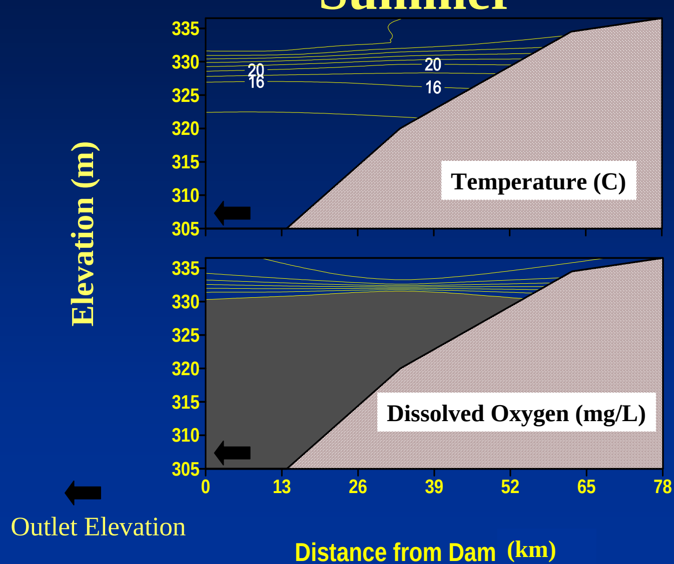
Dissolved Oxygen Distribution

- 1993 (top)
- 1994 (bottom)





Longitudinal Gradients - Late Summer



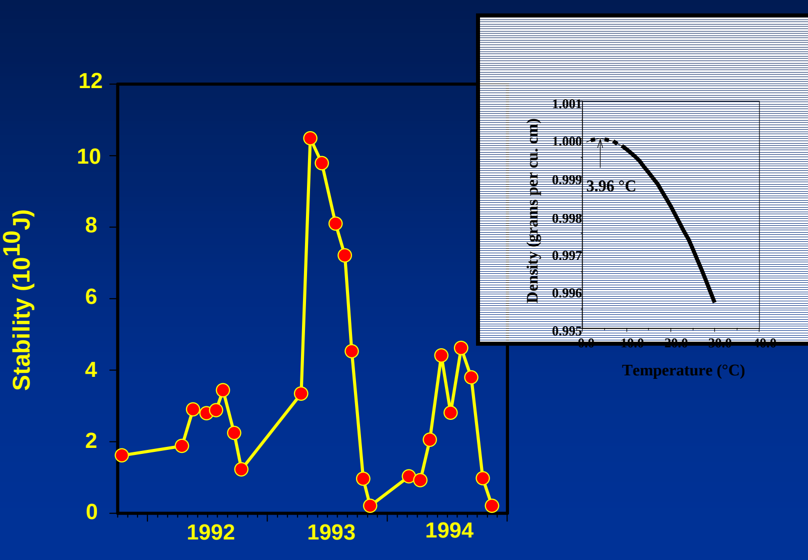
Stability

Stability (J) = *PEM* - *PES*

$$PE = g \sum_{i=1}^{n} p_i V_i h_i$$

Davis, J.M. 1980. Water Services, 84, 497-504.
Meyer, E.B. 1991. IEB, E-91-1, USAE, WES
Hutchinson, G.E. 1957 and Birge, E.A. 1915

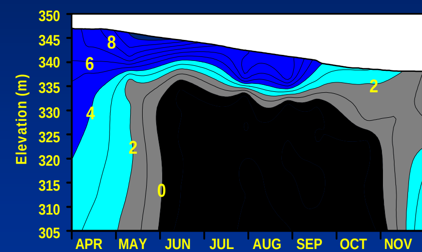
Stability



Dissolved Oxygen Dynamics

- Hypolimnetic Oxygen Deficit Rates
  Walker, W.W., 1987. TR EL-81-9, USAE

PROFILE



- Oxygen Consumption Rates
  Dark Bottle Respiration
  Measurement

PROFILE	Bottle Method
Areal or Volumetric Rates Valid for Oxic Conditions	Discrete Rate Applicable to Oxic or Anoxic Conditions
Requires Morphometry, Area/Volume Curves	Requires Multiple Sampling Depths

Dissolved Oxygen Consumption

PROFILE
0.04 - 0.11 mg L^{-1} day $^{-1}$

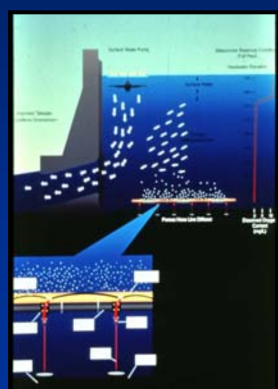
Oxygen Consumption Method
0.05 - 0.51 mg L^{-1} day $^{-1}$

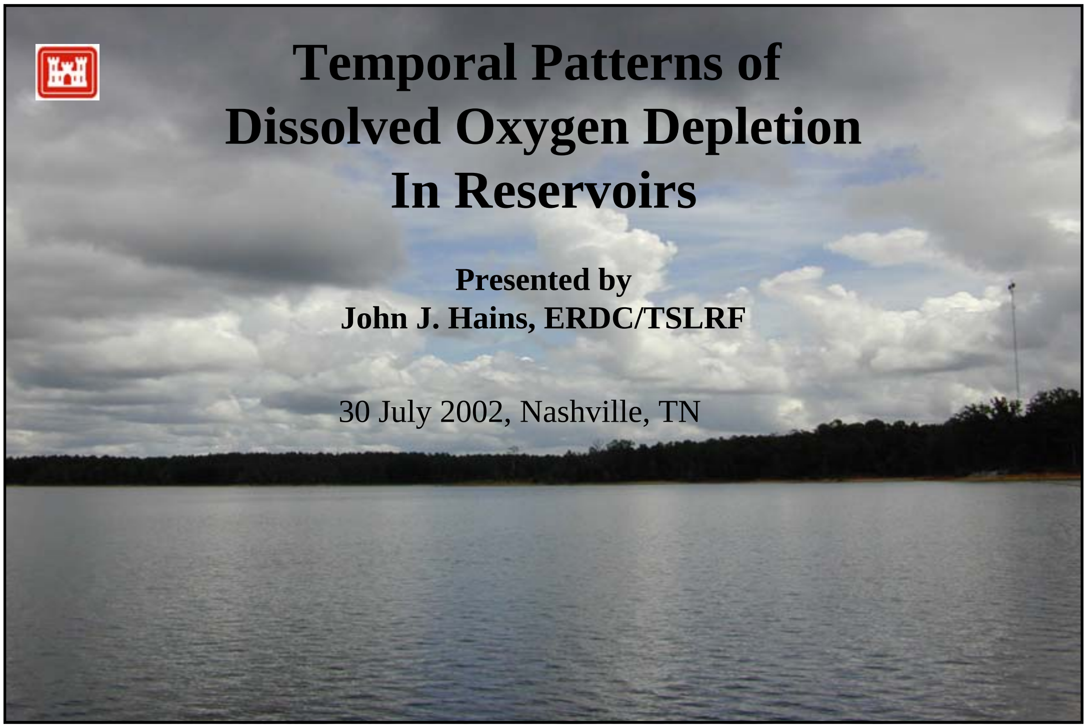
Recommended	**0.15 mg L^{-1} day $^{-1}$**

Recommendations

Alternate Low Level Release

Aeration System





Temporal Patterns of Dissolved Oxygen Depletion In Reservoirs

Presented by
John J. Hains, ERDC/TSLRF

30 July 2002, Nashville, TN

DISSOLVED OXYGEN

Very reactive, tends to oxidize reduced materials.
(redox, respiration, metabolism, decomposition, etc.)

Essential for aerobic organisms and therefore is one of the two most important habitat determinants (along with temperature).

DISSOLVED OXYGEN

Hutchinson’s Master Variables

pH and pε

Of these, pε cannot be directly measured. Greatly affected by presence of oxygen, in aerobic environments oxygen can be used as a surrogate for pε.

Therefore, presence (or absence) of oxygen is critical for the biogeochemical state of the aquatic ecosystem.

Oxygen dynamics are therefore important for setting the limits of the environment for chemical reactions such as those involved with sulfides.

Great Lies

Mark Twain – Statistics

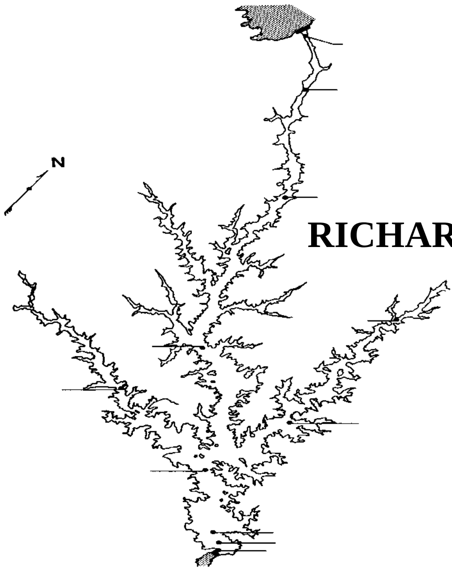
Championship Wrestling – is real (sorry Steve)

Dams – don’t inherently add anything to streams

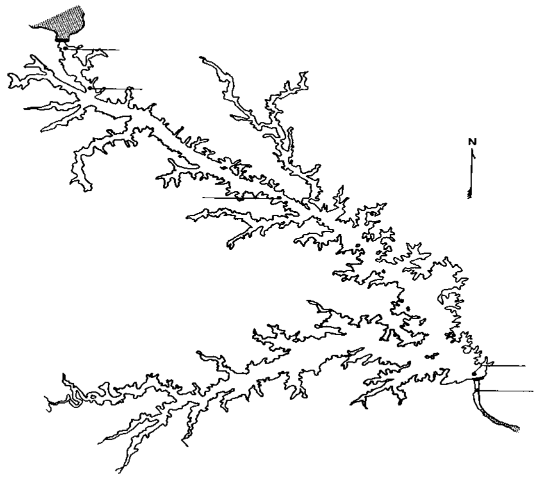
DAMS DO ADD (REMOVE) FROM THE STREAM

Or, properly, they change the energetic status of the water during the conversion of lotic to lentic systems.
Kinetic energy is altered and converted to potential energy which is sometimes converted to electricity.

In a stream, this loss of kinetic energy results in a loss of aeration during stream flow (among other effects).



RICHARD B. RUSSELL LAKE



J. STROM THURMOND LAKE
(formerly Clarks Hill Lake)

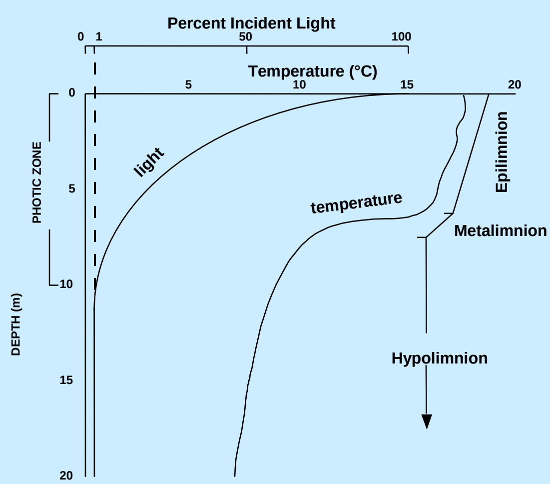


Diagram illustrating thermal patterns typical of a stratified monomictic lake.

What's a monomictic lake?

Lake Classification
Based on Mixing Processes

Monomictic = one period or season of mixing per year. Common in south-temperate lakes. Example: Lake Lanier

Dimictic = two periods or seasons of mixing per year. This is common in north-temperate lakes, especially those that have winter ice cover. Example: Lake Michigan

Meromictic = never mix completely, but always have an unmixed deep density layer (the monimolimnion). Example: Carter's Lake.

Other types include polymixis, atelomixis, etc.

Dissolved Oxygen Distributions in Lakes

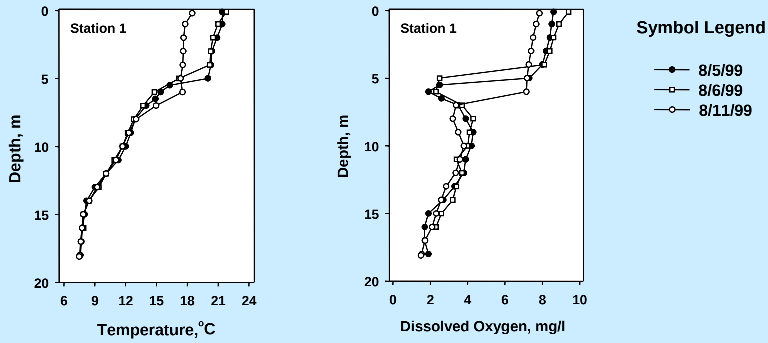
Orthograde – little, if any, gradient

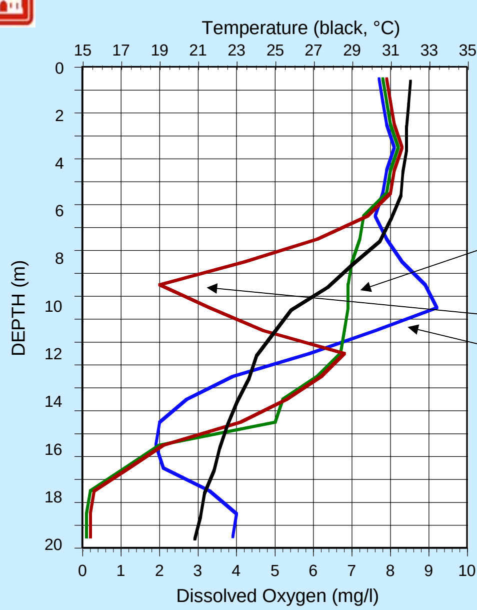
Clinograde – gradient of declining concentration

Heterograde – gradient with discontinuity

Negative – discontinuity is negative

Positive – discontinuity is positive





Dissolved Oxygen Distributions in Lakes

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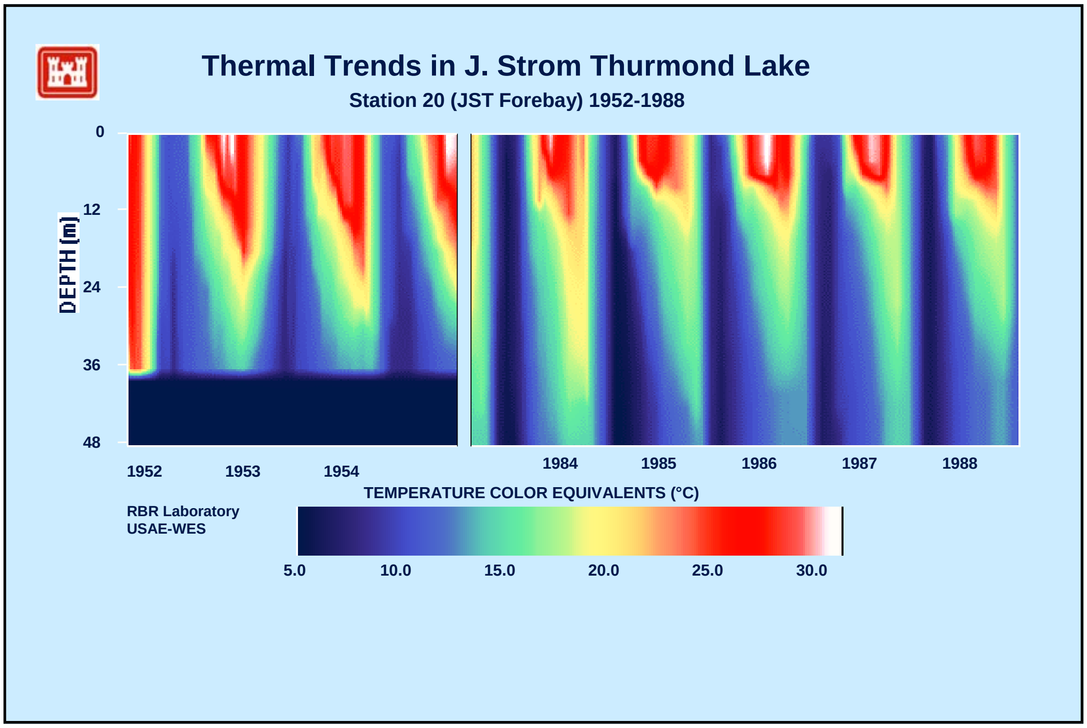
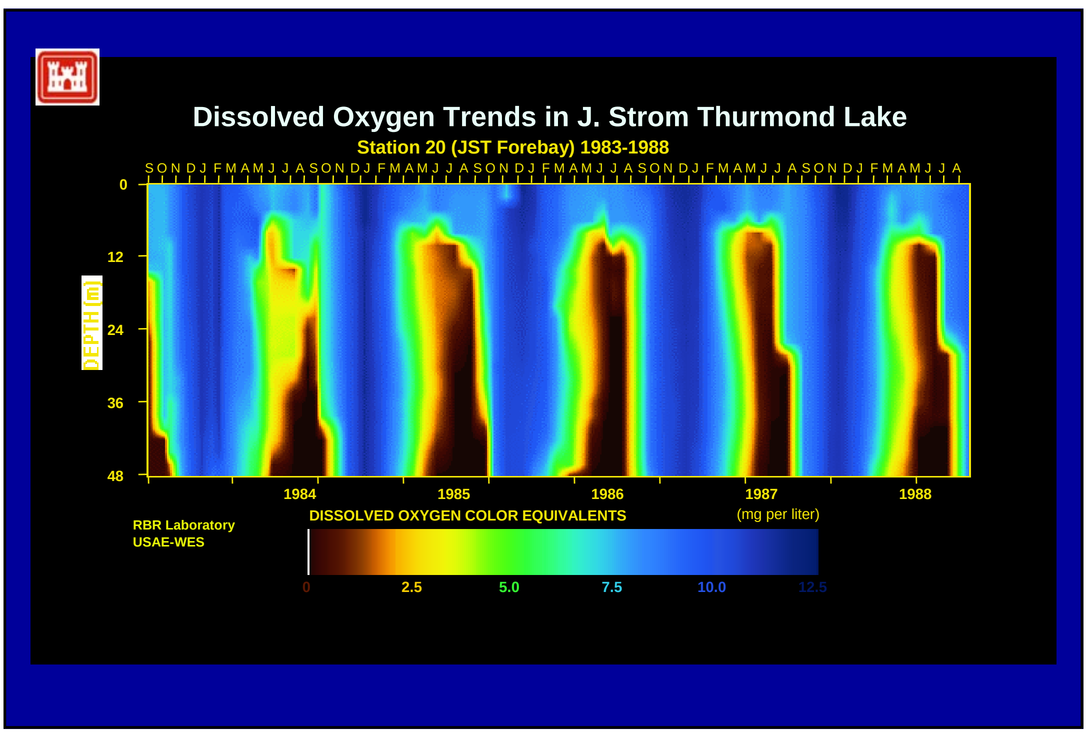
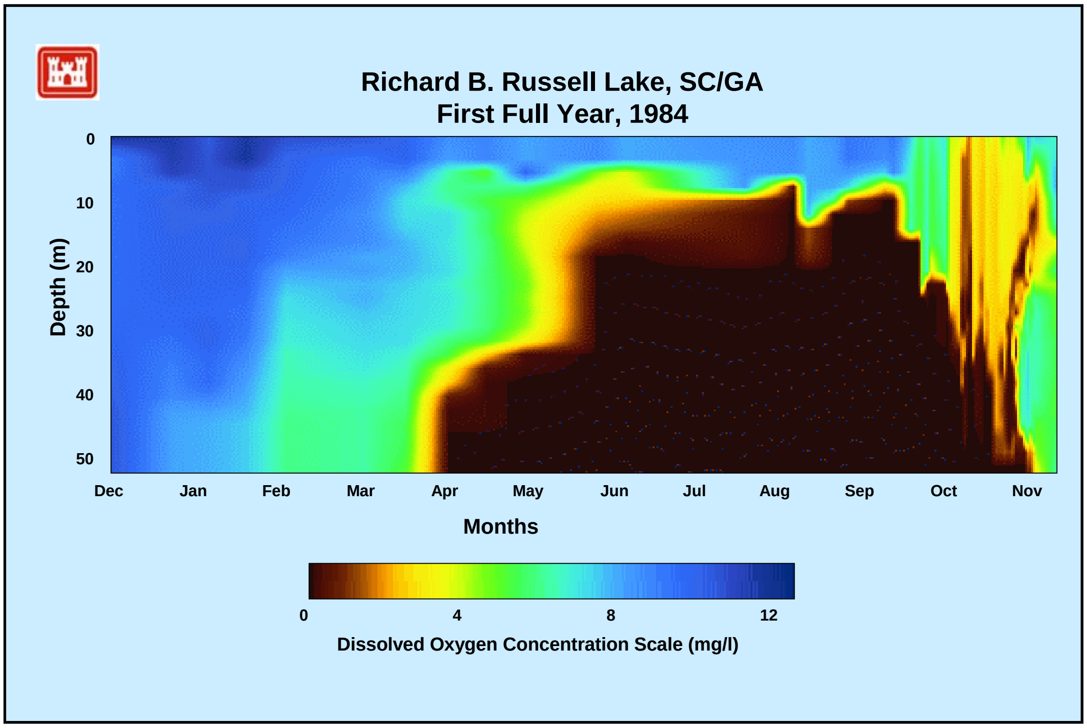
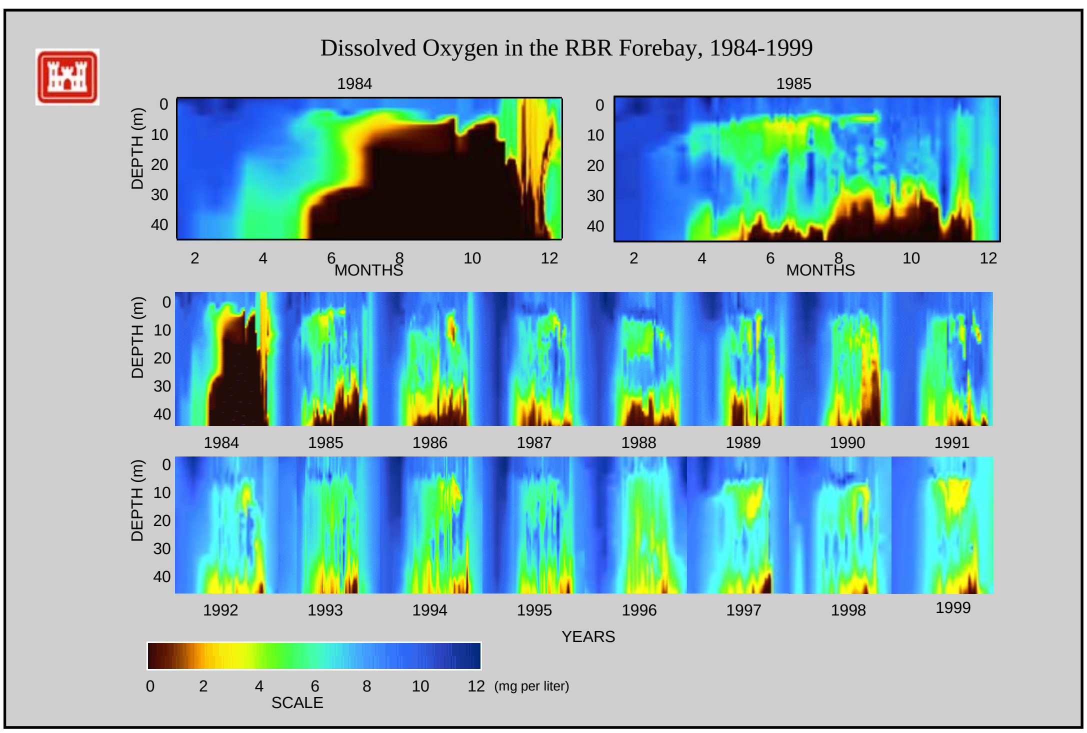
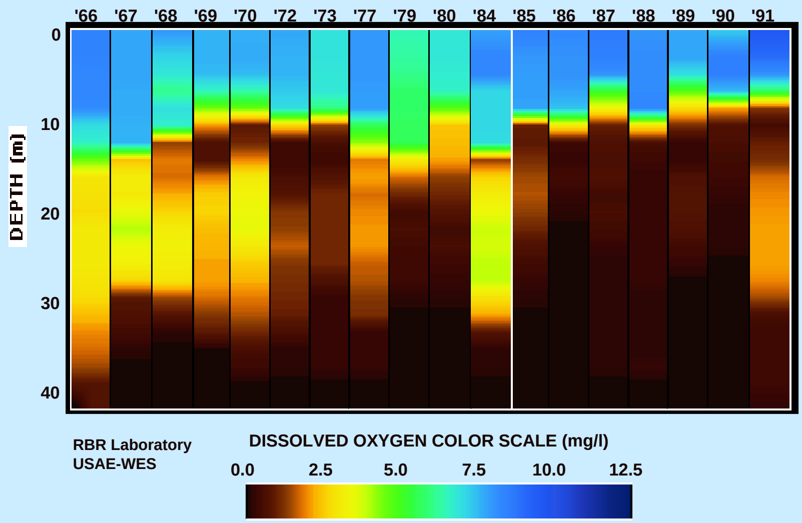

Thermal Trends in J. Strom Thurmond Lake
Station 20 (JST Forebay) 1952-1988
DEPTH (m)
0
12
24
36
48
1952
1953
1954
1984
1985
1986
1987
1988
TEMPERATURE COLOR EQUIVALENTS (°C)
RBR Laboratory
USAE-WES
5.0
10.0
15.0
20.0
25.0
30.0


Dissolved Oxygen Trends in J. Strom Thurmond Lake
Station 20 (JST Forebay) 1983-1988
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A
DEPTH (m)
0
12
24
36
48
1984
1985
1986
1987
1988
RBR Laboratory
USAE-WES
DISSOLVED OXYGEN COLOR EQUIVALENTS
(mg per liter)
0
2.5
5.0
7.5
10.0
12.5


Richard B. Russell Lake, SC/GA
First Full Year, 1984
Depth (m)
0
10
20
30
40
50
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Months
0
4
8
12
Dissolved Oxygen Concentration Scale (mg/l)

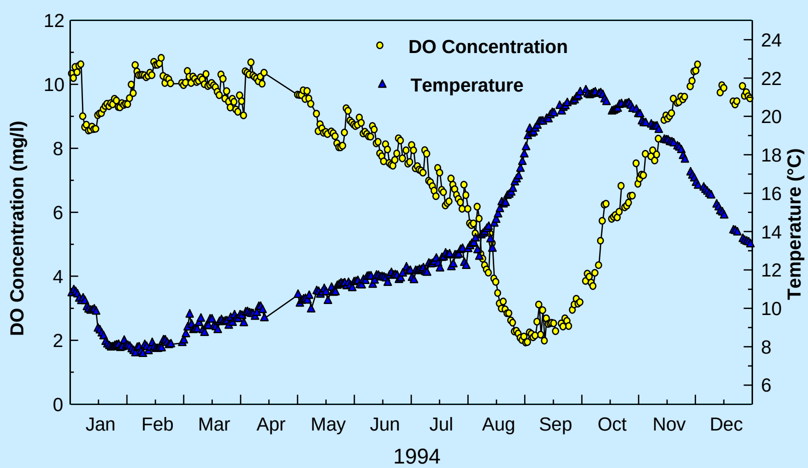

Dissolved Oxygen in the RBR Forebay, 1984-1999
1984
1985
DEPTH (m)
0
10
20
30
40
2
4
6
8
10
12
MONTHS
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
YEARS
0
2
4
6
8
10
12
(mg per liter)
SCALE

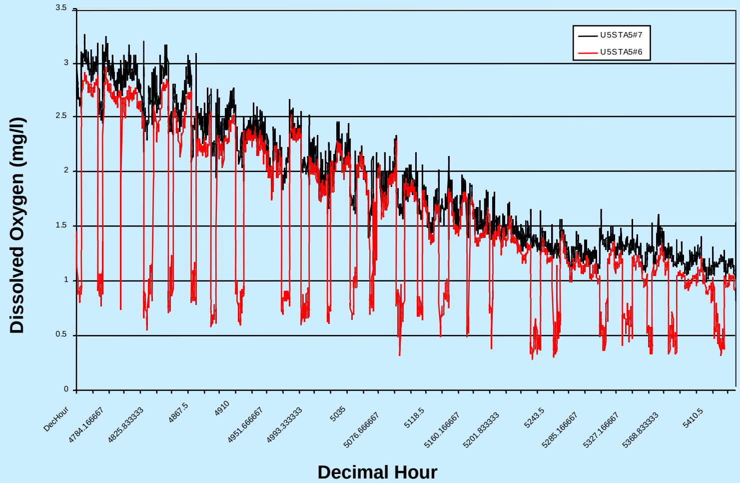
HISTORICAL SEPTEMBER DISSOLVED OXYGEN CONCENTRATIONS
J.STROM THURMOND FOREBAY



RBR Laboratory
USAE-WES

1994 Hartwell Dam Releases





Comparison of water quality from taps 6 and 7, penstock piezometer taps. Data collected during declining water quality conditions. Note periodic departures of tap #7 from #6 due to generation cycles.

Summary and Questions