SUCCESS STORY:

20 YEARS

of HYPOLIMNETIC OXYGENATION of a RESERVOIR
Agenda

• EBMUD & Camanche Reservoir

• Water Quality Challenges

• Speece Cone Technology

• Effects of Hypolimnetic Oxygenation on Water Quality
East Bay MUD

East Bay Municipal Utility District in Oakland, CA

Supplies about 1.5 Million Residents in the East Bay of San Francisco with Drinking Water
East Bay MUD

In 1929 the Pardee Reservoir was built on the Mokelumne River.

In 1964 the Camanche Reservoir was built 10 miles downstream of Pardee Reservoir.
Lower Mokelumne River
Fishing in Lower Mokelumne River

The river supports several introduced and native fish:

• Chinook Salmon
• Steelhead Trout
• Largemouth Bass
• Stripers
Lower Mokelumne River Fish Hatchery

Built in 1964 at the base of the Camanche Dam to mitigate the loss of spawning habitat caused by the reservoir.
Camanche Reservoir

Used for:
- Flood Control
- Flow Regulation for downstream Irrigation Purposes
- Protection of In-stream Resources,
- Recreation
- Hydroelectric Power Generation

417,000 acre-feet max. volume
135ft max. depth
Camanche Lake Characteristics

Eutrophic

Summer Stagnation $\rightarrow$ Stratification

Droughts in 1987 and 1990 caused fish kills downstream

Cause: Seasonal Hypolimnetic Anoxia & $\text{H}_2\text{S}$ Generation in Sediment
Project Goals

• Prevent Fish Kills

• Eliminate H\textsubscript{2}S, Prevent Anaerobic Conditions

• Maintain Cold Water Fish Habitat

• No impact on EBMUD’s water supply needs

Balance Fishery Needs with Water Supply Needs
Alternatives Evaluated

• Hypolimnetic Oxygenation
  most cost-effective & feasible

• Multi-level intake structures

• Applying potassium permanganate plus aeration

• Diversion from Pardee Reservoir
Oxygen Gas

Water Side Stream From Hypolimnion

170HP Sidestream Pump

OTE: 90-95%

High Water Inlet Velocity

Low Discharge Velocity

In Lake: 8mg/L D.O. 7mg/L D.O. for WQ 1mg/L D.O. for H2S

Oxygenated Side Stream 100mg/L D.O.
150ft long 24" diffuser
Manifold with 100 2" openings

"Speece Cone" Detail

12ft diameter Speece Cone, 25ft high

Intake Screen & Submersible Pump
Speece Cone Installation, 1993

350ft from Dam @ approx. 100’ depth
70-200 scfm depending on depth  16,000 lb O2 / day

Cone D.O. Discharge 100 mg/L
Effects on Water Quality
D.O. Increase 2m off the Bottom

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

Baseline 1992 No Oxygenation

1993

1994

1995 & '97 No Oxygenation

1996
Oxygen Plume

Oxygen plume extended > 10,000ft
After 40 days of oxygen feed

H$_2$S Oxidation requires a minimum of 24 hours
→ Plume was large enough to provide this

Final plume extends 3 miles into the reservoir
Nutrient Levels

Oxygenation suppressed internal nutrient loading!

All nutrient levels decreased:

Soluble Phosphorous in the Hypolimnion declined three-fold from 123 to 38 μg P/L

Ammonia fell ~ 70 fold (706 to < 10 μg N/L)
Nutrient Levels - Phosphate

CAMANCHE RESERVOIR HYPOLIMNION: TOTAL PHOSPHATE

Graph showing the total phosphate levels from January 1990 to January 1997.
Nutrient Levels - Ammonia

CAMANCHE RESERVOIR HYPOLIMNION
AMMONIA

Ammonia as N, mg/L

Jan-90  Jan-91  Jan-92  Jan-93  Jan-94  Jan-95  Jan-96  Jan-97

Periods of Oxygen Addition
Later Winter Surface Conditions

Nutrients available for Spring algae bloom:

TP fell 58% (33 to 14 μg/L),

TIN was down 88% (190 to 23 μg/L) (Relative to pre-HOS conditions)

TIN : TP ratio fell from 6 to 1.6.
Chlorophyll A at the Surface

CAMANCHE RESERVOIR @ CAMD:
CHLOROPHYLL A

Chlorophyll a, µg/L

Jan-90  Jan-91  Jan-92  Jan-93  Jan-94  Jan-95  Jan-96  Jan-97  Jan-98  Jan-99

× Surface
Secchi Depth

CAMANCHE RESERVOIR @ CAMD:
SUMMER AVERAGE SECCHI DEPTHS

\[ y = 0.005x - 163.59 \]
\[ R^2 = 0.7536 \]
Algae Growth

After 12 years of Hypolimnietic Oxygenation:

Nitrate declined further (42 to 3 μg N/L)

Chlorophyll declined an additional 50% (88% overall).

Low inorganic nitrogen apparently forced algae to oligotrophic low levels despite the moderate TP values that indicate mesotrophy.
Algae Growth

Large blooms of the colonial blue-green algae, *Aphanizomenon* and *Anabaena*

dropped by over 93% in the first five years and over 99% thereafter

The common colonial diatom *Fragilaria* dropped 71%.
Conclusion

20 Years of Hypolimnetic Oxygenation

Switched the trophic stage of Camanche Reservoir from

Eutrophic → Mesotrophic

No more H$_2$S / Fish Kills

Due to the cold, dense and horizontally flowing blanket of high D.O. concentrations above the bottom sediment.
Questions?

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