Thermal and Oxygen Dynamics in Four Drinking Water Reservoirs

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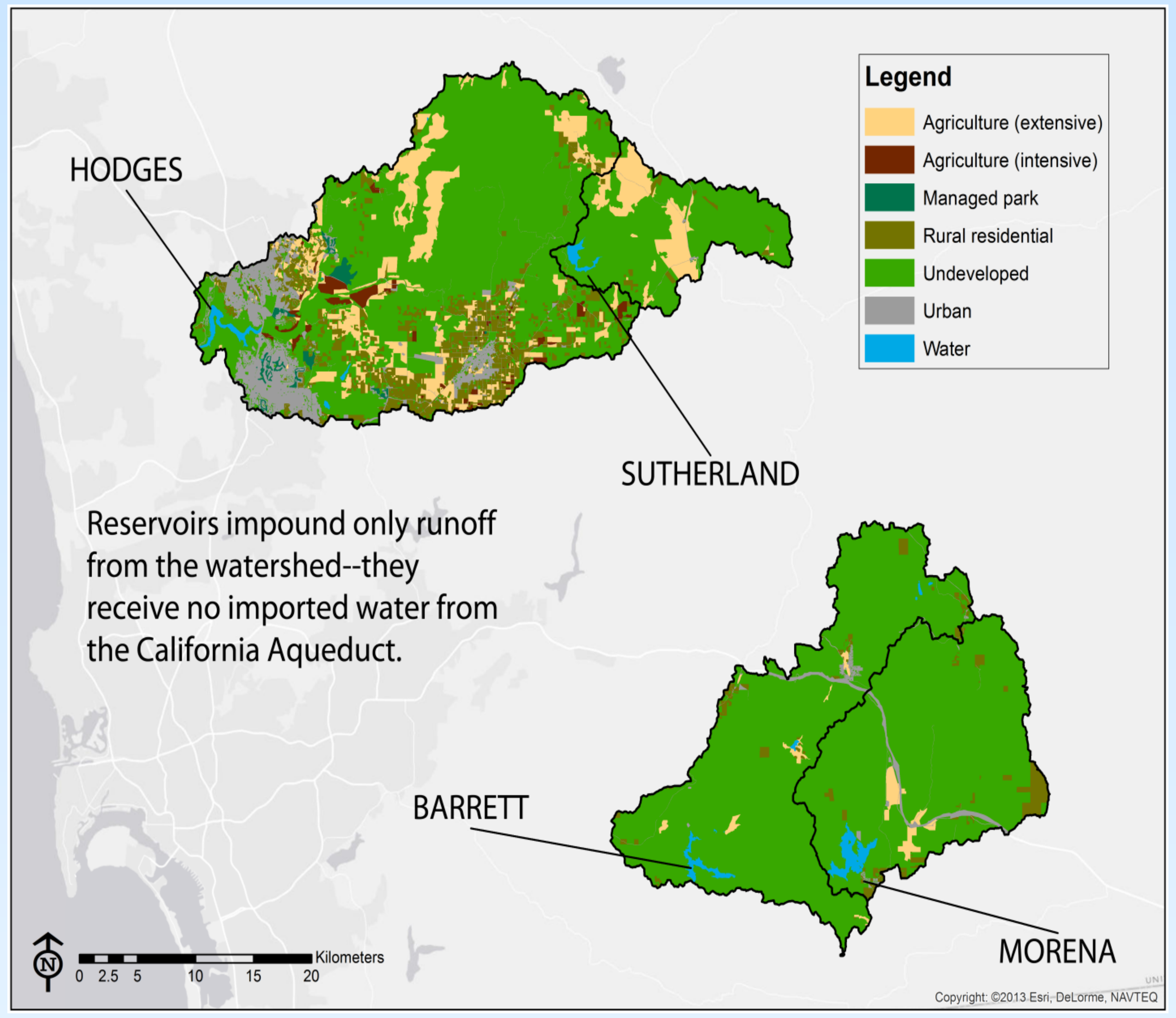
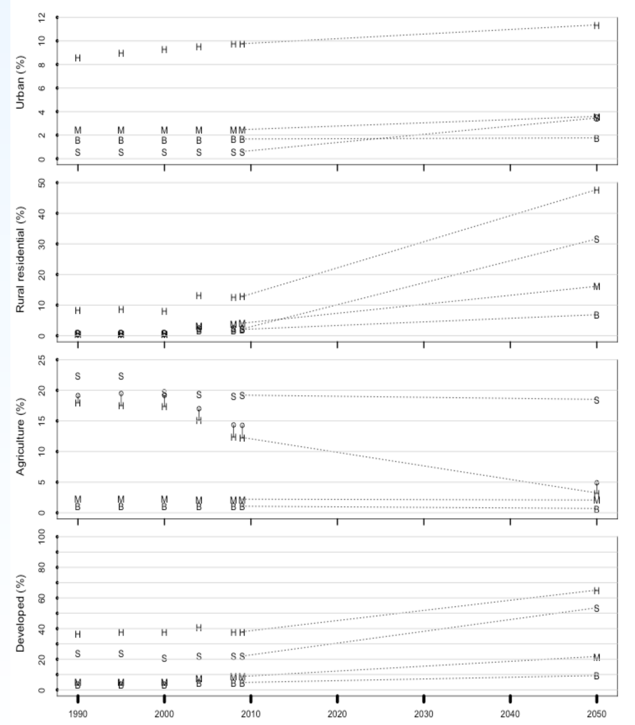
Abstract

Water quality in San Diego drinking water reservoirs is compromised by seasonal algal production, which may lead to significant economic costs for municipalities that draw water from them. This study looks at temporal trends (1990-2011) in and controlling factors of thermal stability and anoxia in reservoirs whose watersheds are currently in varying degrees of agricultural and urban development. It compares how land use, particularly urbanization, compares with other controls, such as climate and lake water fluctuations, on water quality. Lake volume is a significant control of thermal processes. An increase in anoxia in Lakes Barrett and Hodges is most strongly correlated with land use.

Study Site

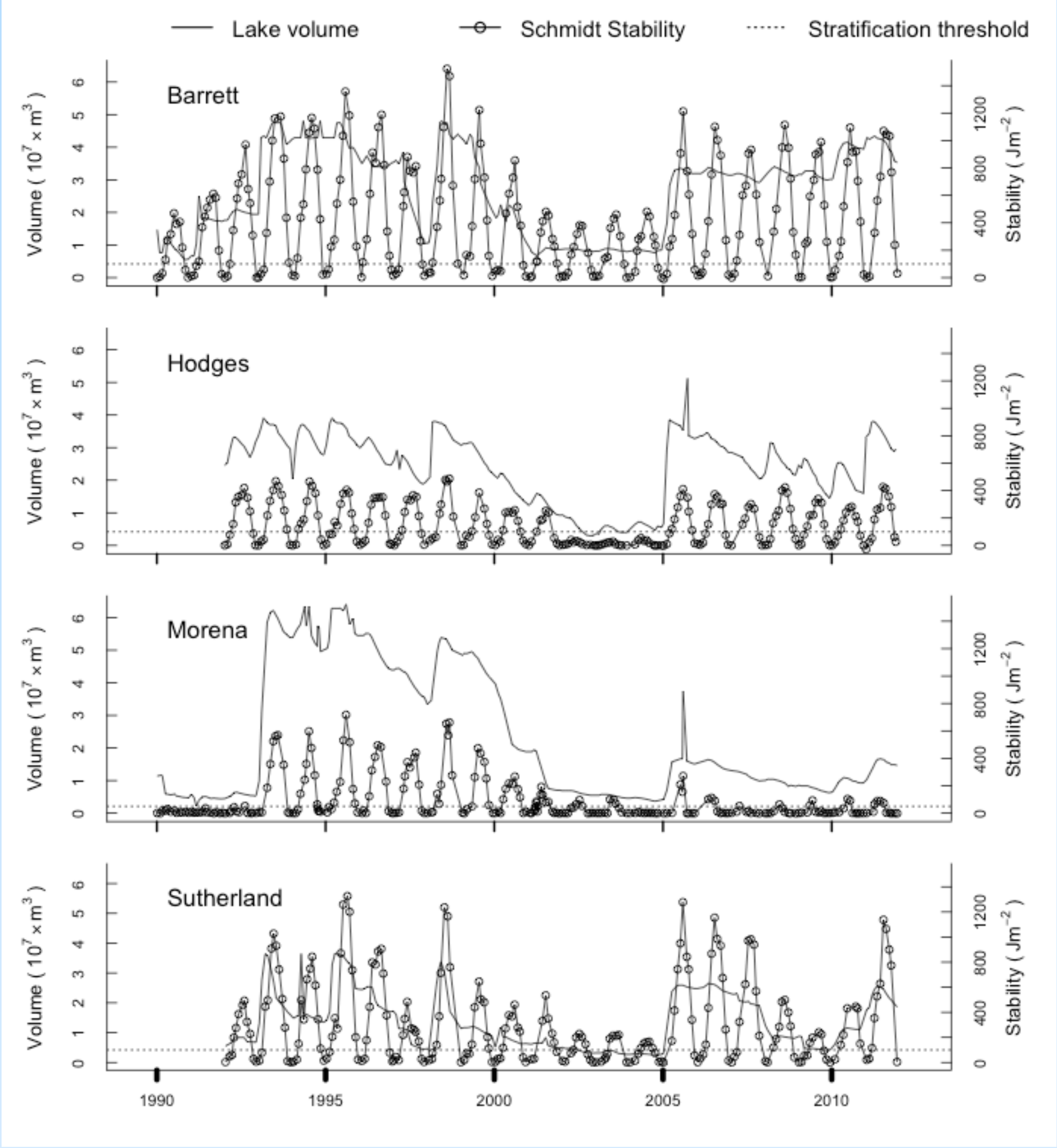


- Barrett, Hodges, Morena and Sutherland are drinking water reservoirs that receive only surface runoff and no imported water
- warm monomictic lakes (stratify once in the summer)
- anoxic hypolimnia in the summer, though oxygen is depleted at varying rates

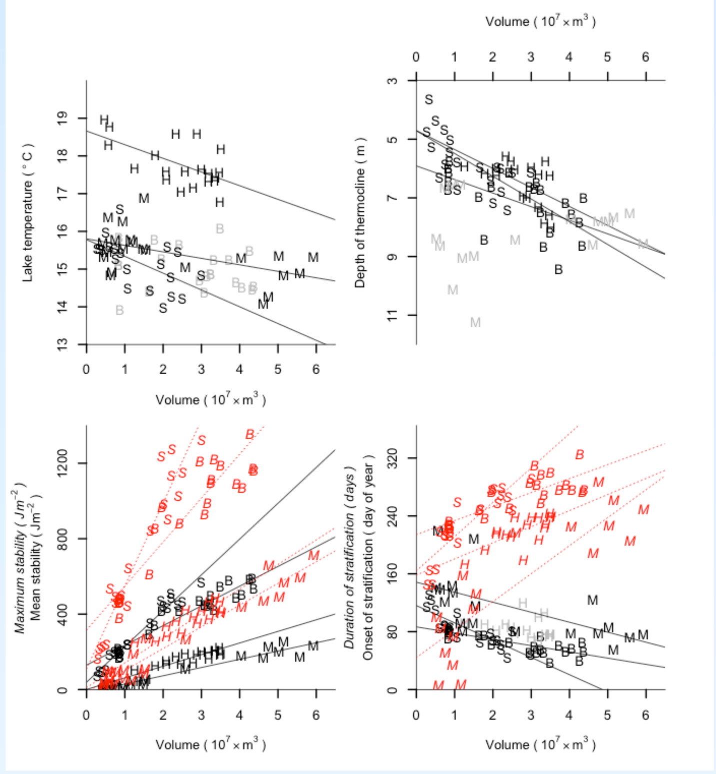


- nitrogen (N) and phosphorus (P) are the primary catalysts for algae growth
- different amounts of land use in their watersheds
- urbanization is expected to increase[1] across the county until 2050

Results



- lake volume is a major control of thermal processes:
  - lake temperature
  - thermocline depth
  - Schmidt stability[2]
  - stratification
- lake volumes fluctuate often
- few trends in lake thermal behavior were observed from 1990-2011



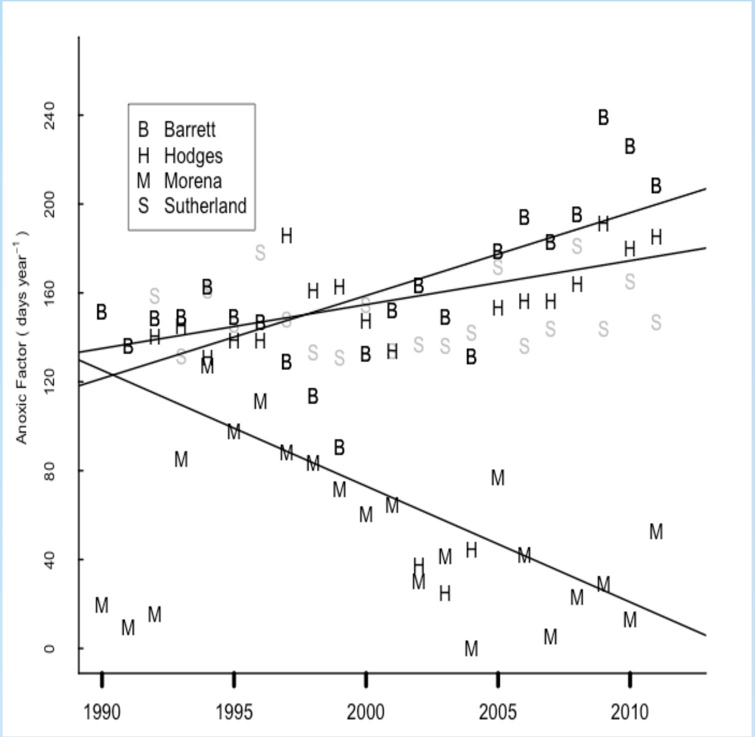
(Above) Linear regression lines show significant (α < 0.05) relationships. Points are annual means.

Reservoir	Elevation (m)	V (10^6 m^3)	A_0 (km^2)	z_{max} (m)	z (m)	$z/A_0^{0.5}$ ($m\ km^{-1}$)	S_{max} ($J\ m^{-2}$)	S ($J\ m^{-2}$)	Stratified season (days)	AF (days $year^{-1}$)
Barrett	490	48.0	3.5	41.9	13.8	7.4	944.5	411.0	266	161
Hodges	67	51.2	6.0	29.1	8.45	3.5	326.8	149.6	220	139
Morena	926	64.1	6.4	32.2	10.0	4.0	242.8	85.8	146	53
Sutherland	627	36.6	2.3	40.6	16.3	10.9	715.3	300.0	229	149

Characteristics of study reservoirs: Elevation; V—lake volume*; A_0 —lake surface area*; z_{max} —maximum depth; z —mean depth; S_{max} —mean maximum annual Stability; S —mean annual Stability; Stratified season —mean length of stratified season; AF —mean annual Anoxic Factor.

***largest value observed from 1990-2011.**

Results

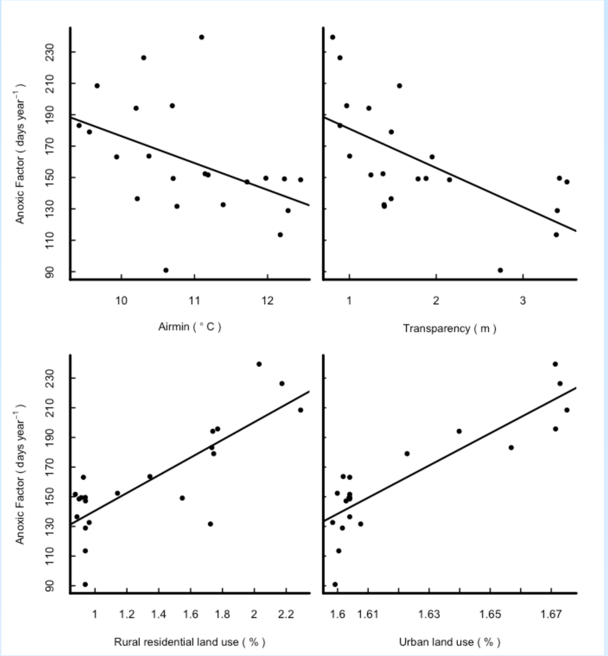


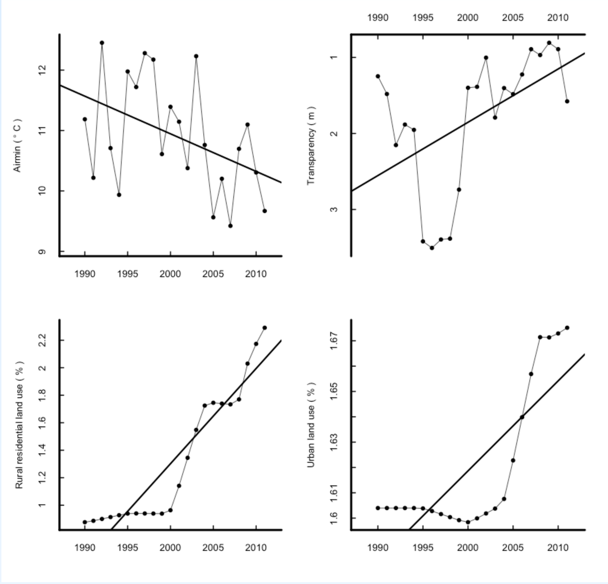
The Anoxic Factor[3] increased at Barrett (3.7 days $year^{-1}$) and Hodges (2.0 days $year^{-1}$).

(Left, below) Linear regression lines show significant (α < 0.05) relationships. For Hodges, data points were excluded for years when the lake did not stratify. Points are annual means.

At Barrett, the Anoxic Factor is correlated with:

- **minimum air temperature**
- (r = -0.44; p-value < 0.05)
- **transparency**
- (r = -0.62; p-value < 0.001)
- **urban land use**
- (r = 0.87; p-value < 0.001)
- **rural residential land use**
- (r = 0.80; p-value < 0.001)

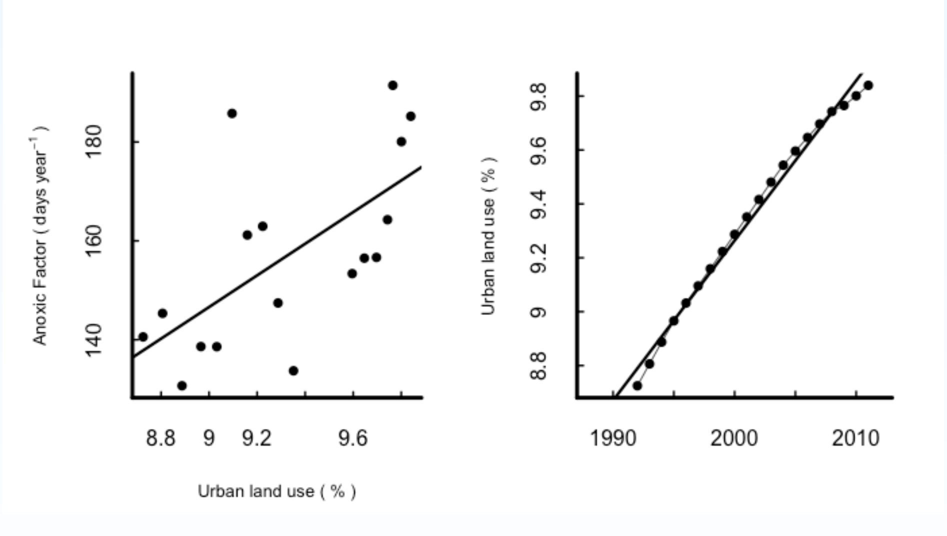




At Hodges, the Anoxic Factor is correlated with:

- **urban land use**
- (r = 0.63; p-value < 0.01)

(Above, below) Timeseries of independent variables.



Conclusions

- **This study looked at temperature and oxygen profile data at 4 reservoirs from 1990 – 2011. The reservoirs receive only surface runoff and no imported water. Water quality in the lakes reflects the water quality of runoff, which is related to human activity in the watershed.**
- **Lake volume has a large influence on lake temperature, stability and stratification in all of the study lakes. This has implications for reservoir management.**
- **Water temperature is not warming and is not significantly correlated with the Anoxic Factor at any of the study lakes.**
- **There are no trends in mean annual stability or the duration of stratification at Barrett, Hodges and Sutherland. The length of summer stratification is decreasing at Morena, due to a significant drop in lake volume. There is no trend, after controlling for lake volume.**
- **The Anoxic Factor increased at Barrett (3.7 days $year^{-1}$) and Hodges (2.0 days $year^{-1}$).**
- **Factors contributing to increased anoxia include air temperature, transparency and land use.**
- **Land use (urbanization) shows the strongest statistical relationship to the increase in the Anoxic Factor.**

References

1. San Diego Association of Governments (SANDAG) Land use Maps. <http://www.sandag.org/index.asp?subclassid=100&fuseaction=home.subclasshome>. Accessed 20 Apr. 2012.
2. Hutchinson, G E. (1957) A treatise on limnology. Volume 1. Geography, physics and chemistry. 1015 PP. Wiley, New York.
3. Nurnberg, G. K. (1995) Quantifying anoxia in lakes. *Limnology and Oceanography*, 40, 1100-1111.

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