RTRM

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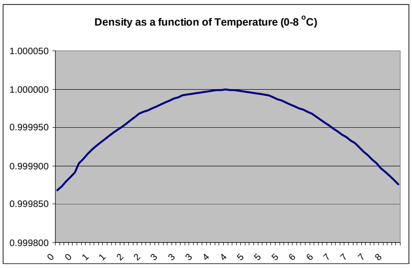
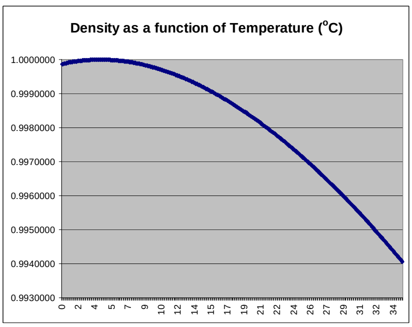
RTRM

Relative **T**hermal **R**esistance to **M**ixing





Water is a very interesting substance – but I guess I don't need to tell this audience that! It is polar, which confers some unique properties. It is (perhaps) the only substance (that I can think of) which has a solid state that is less dense than its liquid state. Ice floats on liquid water (imagine what our dimictic lakes would be like if that weren't the case). It is the universal solvent. It is the chemically reduced state of oxygen (the product of aerobic respiration using O_2 as the terminal electron acceptor; and the reactant in aerobic photosynthesis). **Perhaps the most important property of water is the density change as a function of temperature.** Water is most dense at 4° C. The further you deviate from that temperature (in either direction), the less dense water becomes. *Can ice form on a lake before all lake water has dropped to 4°C?* (I'll let you ponder that one for a while.)

Because lakes gain (and lose) heat primarily from the surface, and because density decreases as water warms, temperature layers develop. Everyone who works in lake management has looked at a temperature profile at one time or another to see if the lake became stratified. But was your conclusion correct? RTRM is a simple method for the quantitative evaluation of stratification due to temperature differences.

$$\textbf{RTRM} = \frac{\text{Density of Upper Layer} - \text{Density of Lower Layer}}{\text{Density at } 5^{\circ}\text{ C} - \text{Density at } 4^{\circ}\text{ C}}$$

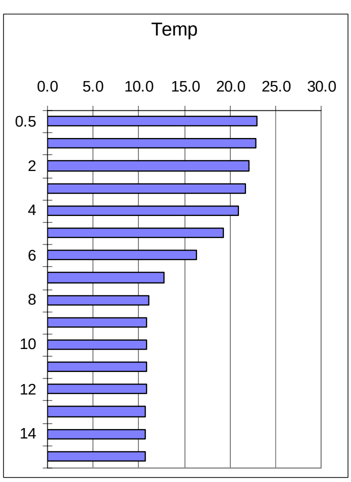
RTRM

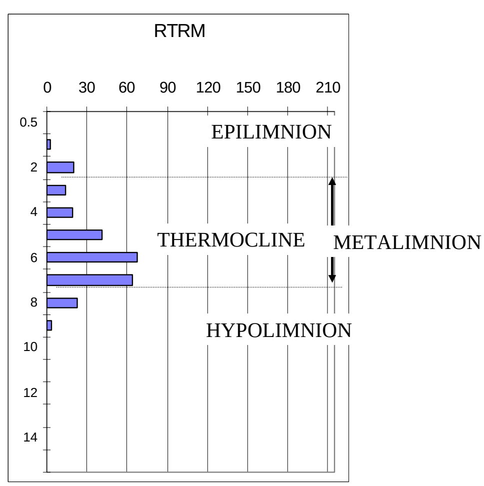
•…is a relative, non-dimensional, value which quantifies stratification as a function of temperature differential.

•…is independent of the units of depth used.

•…is additive (Σ RTRM indicates total stratification intensity).

•…the Peak RTRM identifies the location and intensity of the thermocline (steepest density gradient).



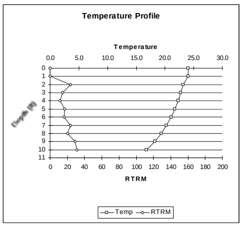


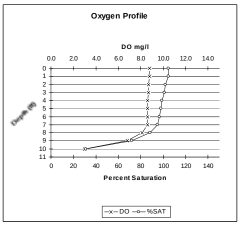
Long Hill Reservoir, CT 8/07/2000 The "classic stratification" found in a limnology textbook exhibits a well mixed surface layer to about 4-5 m deep (epilimnion), a depth zone where temperature decreases rapidly with depth (>1° C per m; metalimnion), and a uniformly cold hypolimnion (below about 8-9 m). RTRM quantifies how strong the density differences are (*relative* to the difference at 4°-5°) and where the peak is (the thermocline). RTRM>20 generally identifies the upper and lower metalimnion boundaries. However, you will rarely find this "classic example" in nature!

Stratification is *not* a function of depth.

Stratification is a function of density change due to temperature differences.

If the density gradients are strong enough to resist the mixing action of wind the water body is stratified (whether it is 20 meters deep or 20 inches!). To the left are profiles from a lake that is 10 ft deep. Total RTRM was 186 units. That's 186 RTRM units in 3m of water – as much stratification as found in some deep dimictic lakes. Actually, this lake exhibits a metalimnion that extends from the surface to the bottom (not at all unusual for soft-water humic stained lakes). Stratification in this lake plays a very important role in governing biotic communities (via habitat).

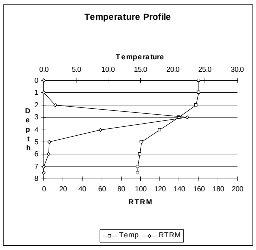


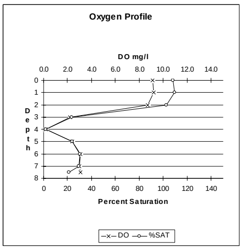


Barger Pond, NY 6/2/95 Depth in Feet
RTRMsum = 186 RTRM Units

Stratification Intensity and Duration Increases..as Latitude Decreases

This is a supply reservoir near the North Carolina border. It is usually (most years) monomictic. Only during very occasional winters does the entire waterbody lose enough heat to reach 4o C, allowing for the possibility for ice formation (there's your answer). Note how intense the stratification structure is in relatively shallow water. These data were collected while the "hypolimnion" was being aerated (to prevent iron problems in water treatment). Before the waters below 4m received hypolimnetic aeration (that's right below 13 ft in this lake) the metalimnion extended from 2m to the bottom. *There was no hypolimnion* (although all waters deeper than 3m became anoxic with upto 30 mg/L of iron). "Hypolimnetic aeration" created the "hypolimnion" by mixing bottom waters and overcoming the "resistance to mixing" in the deep layer.

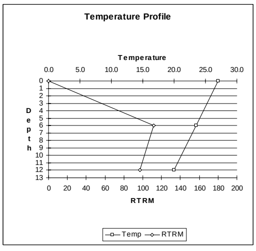


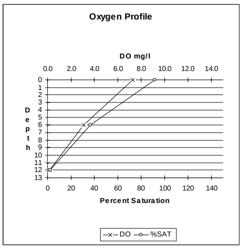


Reservoir in Southeastern Virginia 6/18/92
Depth in Meters RTRMsum = 229 RTRM Units

Stratification is exhibited by Tropical Lakes and Reservoirs

Do Tropical Lakes exhibit thermal stratification? Well, think about it. The warmer water becomes, the greater the density difference per degree Centigrade. The warmer the lake, the more subtle the temperature profile for an equivalent resistance to mixing due to density differences. Stratification does occur in tropical lakes – but often with very different periodicity (daily, seasonal, etc.). The profiles at left are from December in a water supply reservoir in Sao Paulo, Brazil (their summer). (A similar nearby reservoir exhibits only about 20% as intense RTRM most of the time. Why? Because 12 cubics (Brazilian slang for m^3/sec) are withdrawn continually from the bottom, (which dramatically weakens stratification structure.)



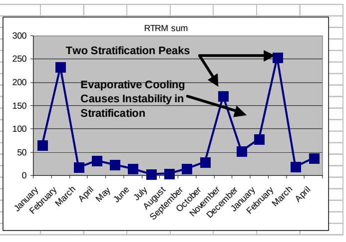


December 1993 (their summer)
Rio Grande Reservoir, Sao Paulo, Brazil
Depth in Meters RTRMsum= 209 RTRM Units

Stratification in Lakes and Reservoirs on the Tropic of Capricorn and Tropic of Cancer can become unstable due to evaporative cooling.

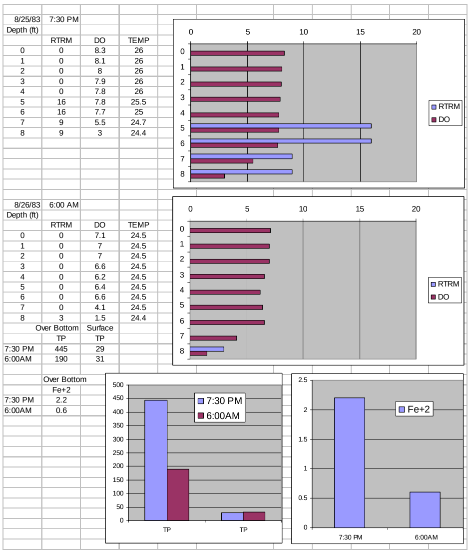
In several reservoirs lying on the Tropic of Capricorn, two primary stratification seasons were observed (along with two anoxia and P-release seasons). During late December, when the sun is directly overhead, evaporative cooling is adequate to cause instability in stratification. Recall that the warmer the water, the greater the density change per degree? Well, in very warm lakes it takes very little temperature decrease at the surface to cause a large density change. The two stratification and anoxia seasons were puzzling, until RTRM and temperature-density relationships were applied.

	RTRM sum
January	65
February	233
March	17
April	32
May	23
June	15
July	3
August	5
September	15
October	29
November	171
December	53
January	79
February	253
March	19
April	38



Guarapiranga Reservoir, Sao Paulo, Brazil

During the summer, two stratification peaks are observed (and result in two anoxia seasons, separated by a mixing episodes). The evaporative cooling during mid-summer represents enough temperature change (hence density change at the warm lake temperatures) to cause instability in stratification. The RTRM peaks during February and March are typically stronger because overall temperatures are higher (remember the higher the temperature, the stronger the resistance to mixing per degree difference). The reservoir typically exhibits bluegreen algae blooms in January-April.



8/25/83	7:30 PM		
Depth (ft)	RTRM	DO	TEMP
0	0	8.3	26
1	0	8.1	26
2	0	8	26
3	0	7.9	26
4	0	7.8	26
5	16	7.8	25.5
6	16	7.7	25
7	9	5.5	24.7
8	9	3	24.4

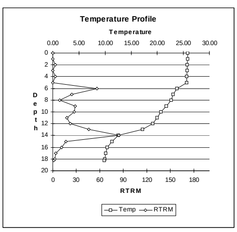
8/26/83	6:00 AM		
Depth (ft)	RTRM	DO	TEMP
0	0	7.1	24.5
1	0	7	24.5
2	0	7	24.5
3	0	6.6	24.5
4	0	6.2	24.5
5	0	6.4	24.5
6	0	6.6	24.5
7	0	4.1	24.5
8	3	1.5	24.4

	Over Bottom	Surface
	TP	TP
7:30 PM	445	29
6:00AM	190	31

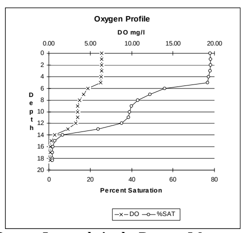
	Over Bottom
	Fe+2
7:30 PM	2.2
6:00AM	0.6

Diurnal and Light/Dark Cycles are not always as expected – Stratification plays an important role.

In a shallow lake in Northwestern New Jersey, we conducted several diurnal sampling rounds. The increment rate for TP through the summer exceeded what was possible for external loading. We had observed relatively high RTRM values – at least for an 8ft deep lake. We hypothesized that the "light-dark cycle" was creating a TP pump – that during the night oxygen loss would occur and sediment-P would be released in this eutrophic lake. What we found was exactly the opposite of what we expected! During the day, enough heat gain occurred to isolate the deep benthic boundary, and it was then (not at night) that iron and P was released from sediments. During the night, radiational cooling resulted in a mixed water column, oxic conditions over-bottom, and little Fe and P release.
Does this happen in other shallow lakes? Probably – if heat is gained during the day and lost at night.



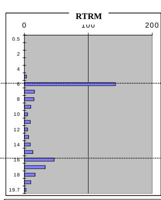
Stronger Stratification, Colder at Depth

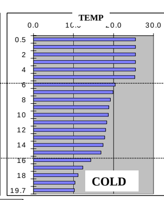


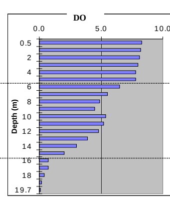
Oxygen Loss only in the Deepest Waters

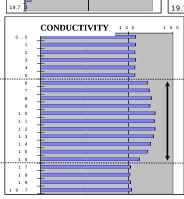
Hemlocks Reservoir August 12, 1997

Destratification (undersized) - Use was Abandoned









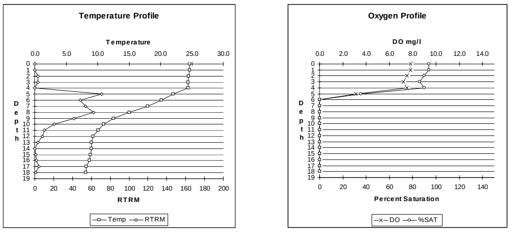
Hemlocks Reservoir August 19, 1998

Saugatuck Reservoir water, released from about 50 feet deep, flows through Aspetuck Reservoir as an "Underflow", and then it flows through Hemlocks Reservoir as an "Interflow" between thermoclines at 6 and 16 meters deep.

Stratification structure can be useful for lake or reservoir management.

For example, in this multiple reservoir system (in series), high quality cold water (hard water) is released from a large storage reservoir (from 50 ft deep) and is conveyed through the terminal supply reservoir to deep intakes, without mixing with ambient waters. This "thermal interflow" can be observed in the temperature, RTRM, and conductivity profiles (conductivity because it is hard water "interflowing" through a soft water reservoir).

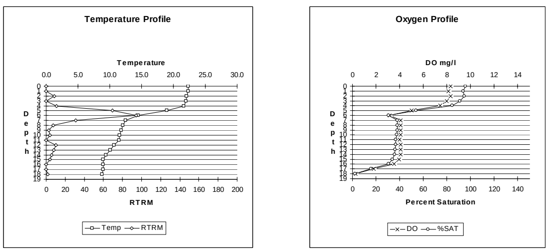
Stratification intensity increases as latitude decreases.



Lake Shenipsit 8/19/1985 (Before Multiple Layer Aeration)
SD= 1.5 m   RTRMsum= 333 RTRM Units

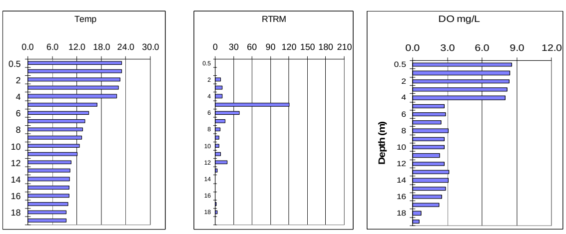
RTRM has been a useful diagnostic tool in the development of several new lake and reservoir management techniques over the past 20 years.

Several techniques have been developed, partly due to the diagnostic information provided by RTRM. During the early 1980's several hypolimnetic withdrawal and treatment projects were implemented. RTRM profiles were used to identify boundary conditions of the metalimnion, and where water would com from if a withdrawal were placed somewhere vertically in the water column. Similar analyses have since been used for depth-selective supply withdrawals from reservoirs. In one treatment system (Lake Waramaug, CT) the iron generated by anaerobic respiration in the deep hypolimnion is withdrawn, oxidized, and reinjected at the thermocline to strip P from the water column (kind of a continuous nutrient inactivation treatment using lake-generated coagulant). RTRM was used to identify design depths for the treatment.



Lake Shenipsit 8/2/2000 (with Multiple Layer Aeration)
SD= 4.0 m   RTRMsum= 258 RTRM Units

Another approach was developed in the 1980's called Layer Aeration (although it should probably be called heat budget and thermocline manipulation and redistribution). In that technique, a detailed heat budget is prepared (T x Volume = heat). By "iteration" the heat content of different mid-depth layer thicknesses are computed, divided by volume to estimate resultant temperature if the layer were to be mixed. Then RTRM is used to determine stratification structure and stability after the "depth-discrete mixing treatment".



Lake Shenipsit 2000 (During Multiple Layer Aeration)

RTRM is a simple and informative index for quantifying thermal stratification in lakes and reservoirs. It is easy to compute (once you have a spreadsheet with the density look-up table). It identifies the position of the thermocline, the width of the metalimnion, and stability of stratification. It works equally well for monitoring done in feet, meters, or any other depth measurement. RTRM accounts for the nonlinear change in density as a function of temperature (temperature alone can be very misleading). RTRM is additive, you can sum the RTRM values taken in feet or meters to estimate total water column resistance to mixing. RTRM has been applied to restoration of lakes in a variety of techniques.

RTRM has been around for a few years; Birge and Juday 1915-1920; Vallentyne 1957; Wetzel 1975; Kortmann and Henry *Lakeline* 1981). Yet, few in lake management are aware of the utility of RTRM, perhaps because they don't have a computation spreadsheet to easily calculate the index. If you are interested in using RTRM, a limited number of disks are available with the spreadsheet for your "enjoyment". If we've run out of disks – don't fret! Simply send me an email (eco.system@snet.net) and I will respond to you with an attached Excel file spreadsheet.

Thermal stratification properties exert a profound influence over lake ecosystems, setting the "habitat stage" for a diverse and desirable biotic community (or not). Try using RTRM instead of just looking at a subtle temperature profile. Try it…you'll like it! Bob Kortmann, Ph.D.