Task 1: Estimate Rate at Which Phosphorus is Rendered No Longer Bioavailable in Sediments

- Data from Anderson (2001), Anderson and Oza (2003), Anderson et al. (2007) and Anderson (2010) were used to improve understanding of sediment diagenesis in Canyon Lake and Lake Elsinore
- Kinetic modeling conducted to define reactivity and persistence of sediment-bound nutrients available for release from sediments

Table 1. Median water column, particulate and sediment properties in lakes.

	Property	Canyon L.	L. Elsinore
Water Column	Total N	1.50	3.82
(mg L^{-1})	Total P	0.18	0.22
	N:P Ratio	8.3	17.4
Particulates(Sediment Trap)	Total N	11.1	8.5
(mg g^{-1})	Total P	2.73	1.29
	Organic C	46.5	64.8
	Inorganic C	17.8	14.0
	C:N Ratio	4.2	7.7
	N:P Ratio	4.1	6.6
Sediment (0-10 cm)	Total N	4.4	5.0
(mg g^{-1})	Total P	0.74	0.85
	Organic C	32.6	43.0
	Inorganic C	5.3	9.0
	C:N Ratio	7.4	8.6
	N:P Ratio	5.9	5.9
Loss from Particulates	Total N	6.7 (60%)	3.5 (41%)
(mg g^{-1})	Total P	1.99 (73%)	0.44 (34%)
	Organic C	13.9 (30%)	21.8 (34%)
	Inorganic C	12.5 (70%)	5.0 (36%)

- Median TN:TP values indicate weak N-limitation in Canyon Lake and co-limitation or weak P-limitation in Lake Elsinore when light not limiting
- Particles recovered in sediment traps in Canyon Lake had higher median N and P contents and lower organic C contents and TN:TP ratio than Lake Elsinore
- Lower N:P ratios in particles suggest preferential removal of N during settling and/or resuspension
- Sediments (0-10 cm) had much lower N and P contents that particles recovered in sediment traps, indicating significant loss through recycling and diagenesis
- Greater relative loss in surficial sediments of Canyon L. (60-70%) compared with L. Elsinore (~35-40%)

Table 2. Median particulate flux, internal recycling rate and difference in flux rates.

	Property	Canyon L.	L. Elsinore
Particulate Flux In	Total Mass	8,220	16,300
(mg m^{-2} d^{-1})	Total N	91	138
	Total P	22.4	21.0
	Organic C	382	1056
	Inorganic C	146	228
	N:P Ratio	4.1	6.6
Nutrient Flux Out	NH_4-N	29.1	86.0
(mg m^{-2} d^{-1})	SRP	9.1	10.2
	N:P Ratio	3.1	8.4
Difference	Total N	62	52
(mg m^{-2} d^{-1})	Total P	13.3	10.8
= storage	N:P Ratio	4.7	4.8

- Assuming sediments are ~80% water with a bulk density of 1.1 g cm^{-3}, these total particle flux rates correspond to sediment rates of 1.4 – 2.7 cm yr^{-1}

- Sediment trap data were used to calculate median particle-borne nutrient deposition rates to sediments
- Very similar particulate-P flux to sediments (~21 mg m^{-2} d^{-1}) in both lakes
- Higher particulate-N, organic C and inorganic C flux to bottom sediments in L. Elsinore
- Similar median rates of SRP flux out of bottom sediments in both lakes (9-10 mg m^{-2} d), but lower NH4-N flux from Canyon L.
- N:P ratio of median recycling/flux rates lower in Canyon L. than L. Elsinore (3.1 vs. 8.4, respectively).

- Differences between particle-borne nutrient flux to sediments and recycling/release from sediments reflect possible storage
- Based upon rates of nutrient flux, similar total N and total P concentrations and N:P ratios would be expected (and are seen) in the two lakes
- Results of all this indicate pronounced biogeochemical transformation occuring within water column and bottom sediments of these lakes
- Kinetic analyses were conducted using available sediment core data to determine rates of these transformations

- Mineralization of organic matter in sediments proceeds through a very complex set of physical, microbiological and chemical reactions

- The rate of mineralization can, in some cases, be represented as a simple 1^{st}-order process:

$$dC/dt = -kC$$

where *C* is the concentration, *k* is the decomposition rate constant and *t* is time

- This differential equation can be integrated to:

$$C=C_0e^{-kt}$$

- Organic matter in sediments is being both mineralized through bacterial processes *and* buried at some sedimentation rate ω

- With information about the sedimentation rate, we can transform from time domain to depth and rewrite as:

$$C_z = C_0 e^{-\frac{k_r}{\omega} z}$$

where k_r is the rate constant for mineralization, and calculated from fit to sediment core nutrient concentrations with depth (k) and sedimentation rate

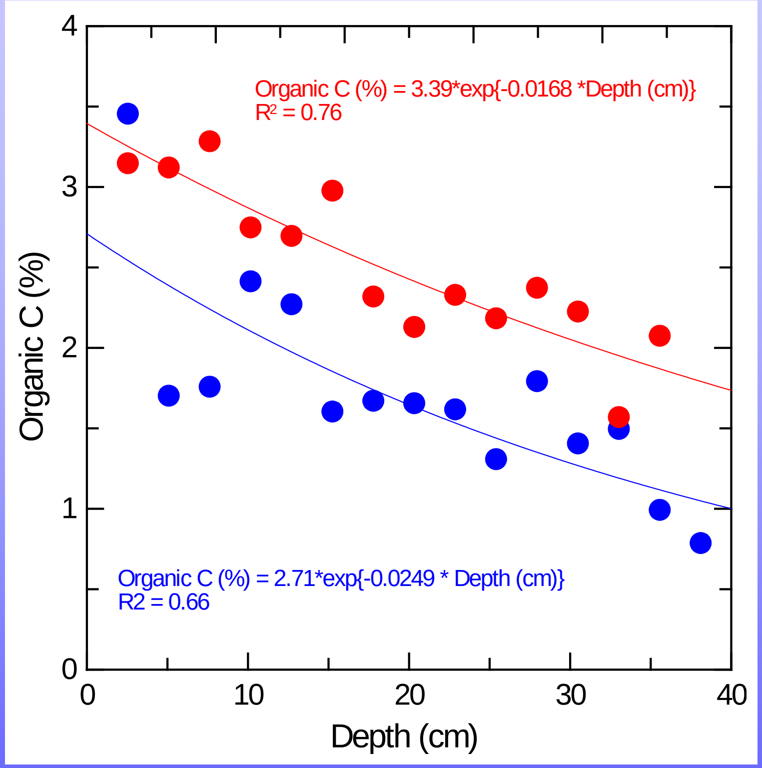
$$k_r = k\ \omega$$

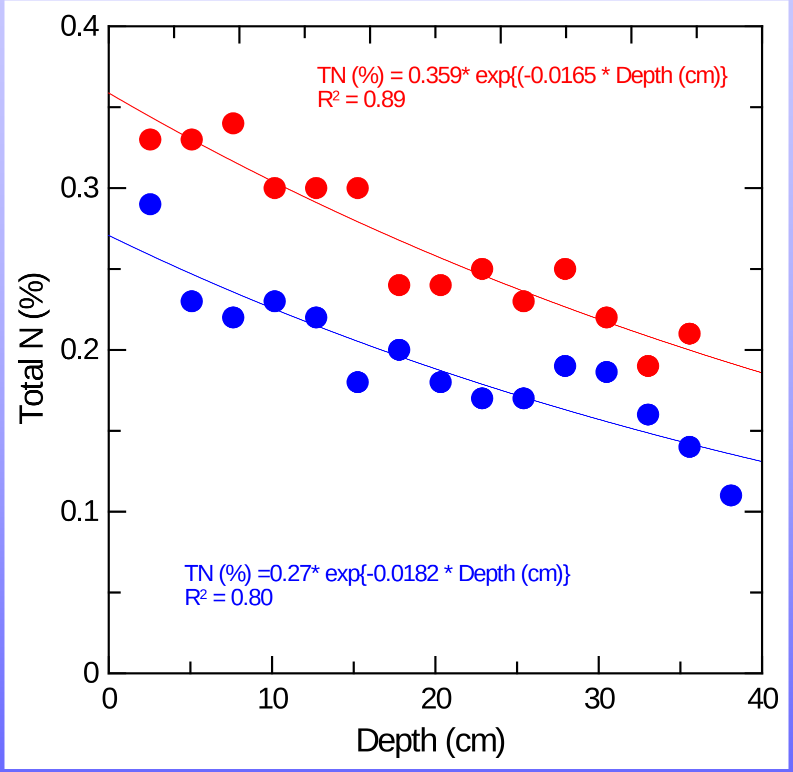
- The half-life for nutrients in the sediment can then be calculated for kr via:

$$t_{1/2} = 0.693/k_r$$

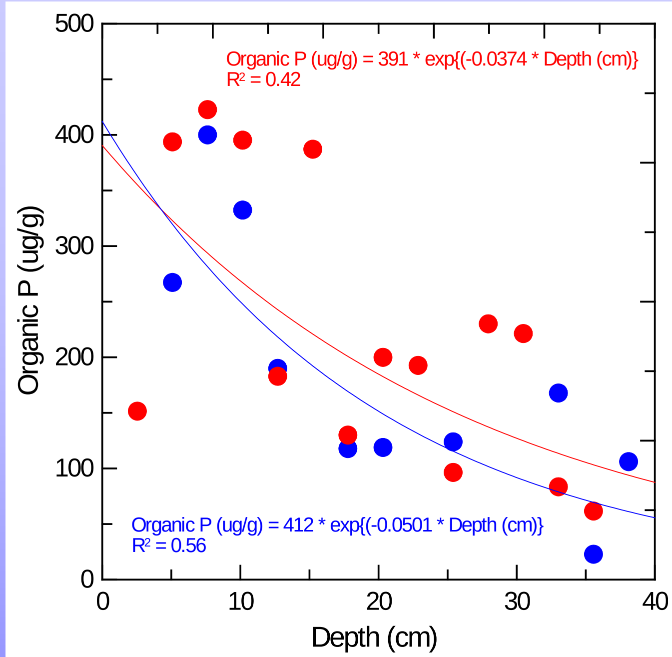
- Sedimentation rates of 2.4 cm yr^{-1} reported by USGS for Canyon L. and 1.35 cm yr^{-1} reported by Kirby et al.

Canyon Lake (East Bay cores, 2002)





- Organic C and total N contents decrease with depth in sediments
- Statistically significant (at $p=0.05$) for exponential model



- Organic P concentrations exhibited greater scatter and fits not statistically significant
- Half-lives were similar for organic C and N (~14-16 yrs), but lower for organic P (6.7 yrs)

Table 3. Mineralization rate and half-life for organic C, total N and organic P in East Bay, Canyon L.

	k (cm^{-1})	R^2 (n=15)	k_r (yr^{-1})	$t_{1/2}$
Organic C	0.0205 0.0040	0.71 0.05	0.050 0.010	13.9 2.9
Total N	0.0174 0.0008	0.85 0.05	0.042 0.002	16.5 0.8
Organic P	0.0438 0.0064	0.49 0.07	0.105 0.015	6.7 1.0

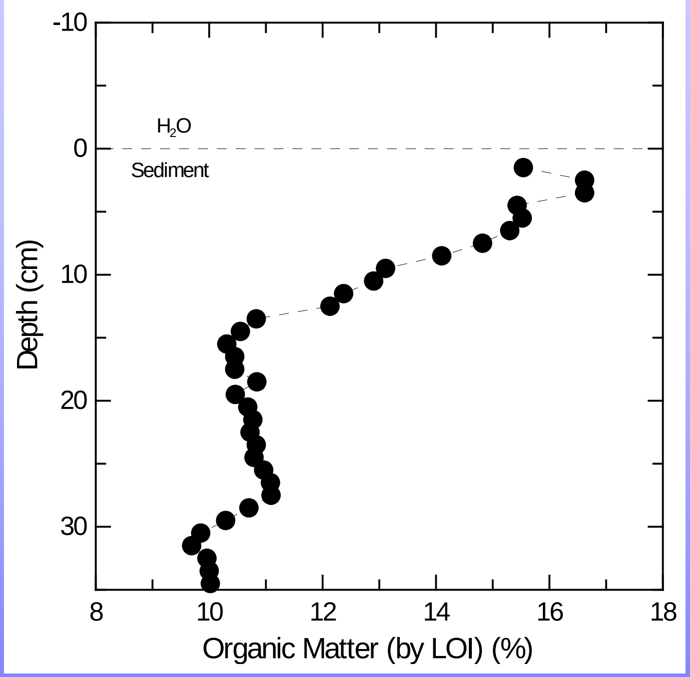
Lake Elsinore (2001)

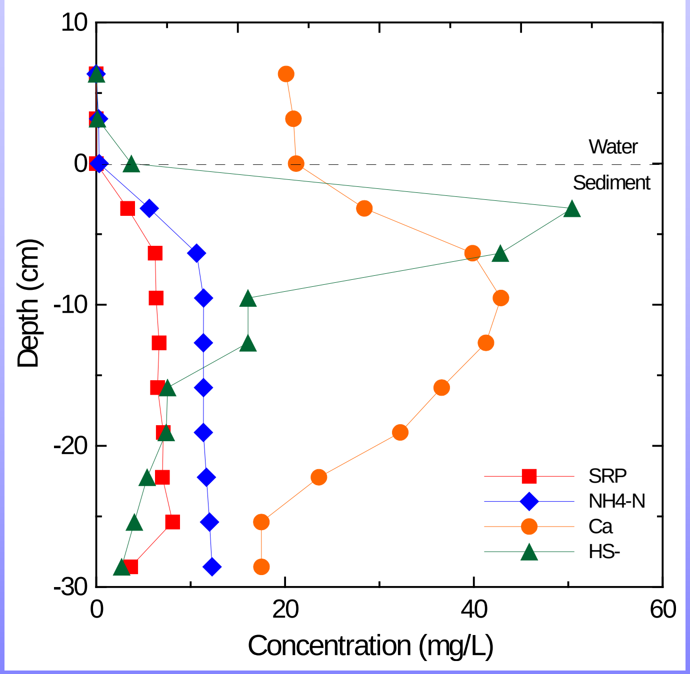
Table 4. Table 3. Mineralization rate and half-life for total organic C, total N and organic P from a single core from Lake Elsinore (Anderson, 2001).

	k (cm^{-1})	R^2 (n=10)	k_r (yr^{-1})	$t_{1/2}$ (yr)
Organic C	0.0218	0.59*	0.029	23.9
Total N	0.0166	0.68**	0.023	30.1
Organic P	0.0085	0.50	0.011	60.4

- Lake Elsinore was found to have a slower apparent mineralization rate constant and corresponding (2x) longer nutrient half-lives
- Organic C and N were estimated to have t1/2 values of 24-30 yrs (2x longer than Canyon L.)
- Organic P half-life was 60 yrs or 9x longer than Canyon L.

Two-phase model





- Zone of most rapid loss of organic matter coincides with sulfide in porewater, suggesting that sulfate serves as a 1º oxidant in sediments in L. Elsinore

- Core from Kirby et al. indicates organic matter (LOI) persists within buried sediment

- Organic matter often consists of or degrades to a recalcitrant phase that undergoes very slow further mineralization
- We can model the sediments as a 2-phase system with a rapidly reacting organic matter and slow or negligibly reactive phase as:

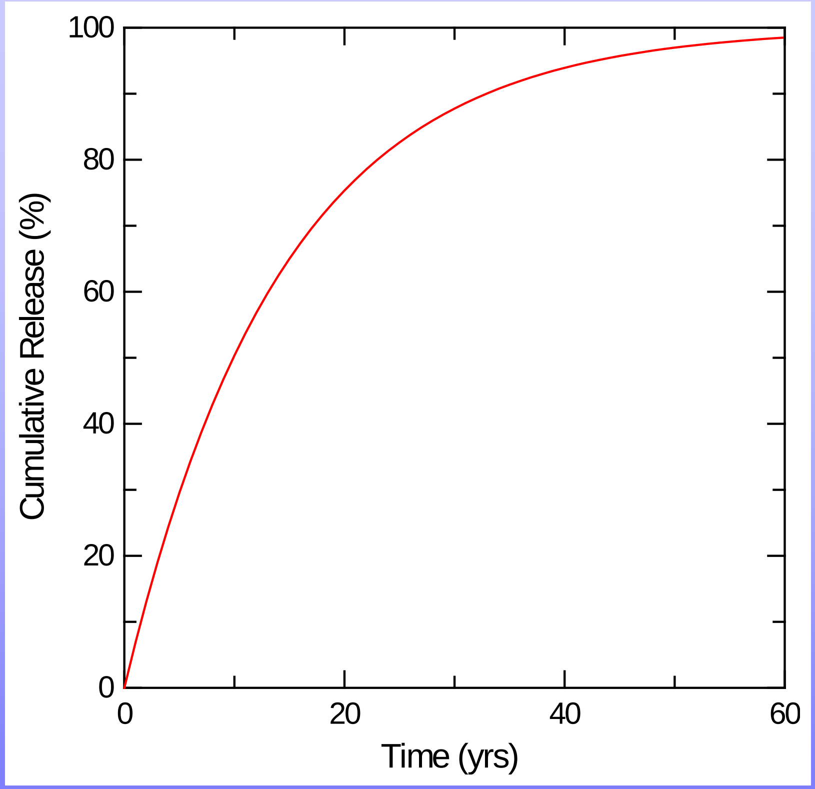
$$C_z = C_0 e^{-\frac{k_r}{\omega} z} + C_u$$

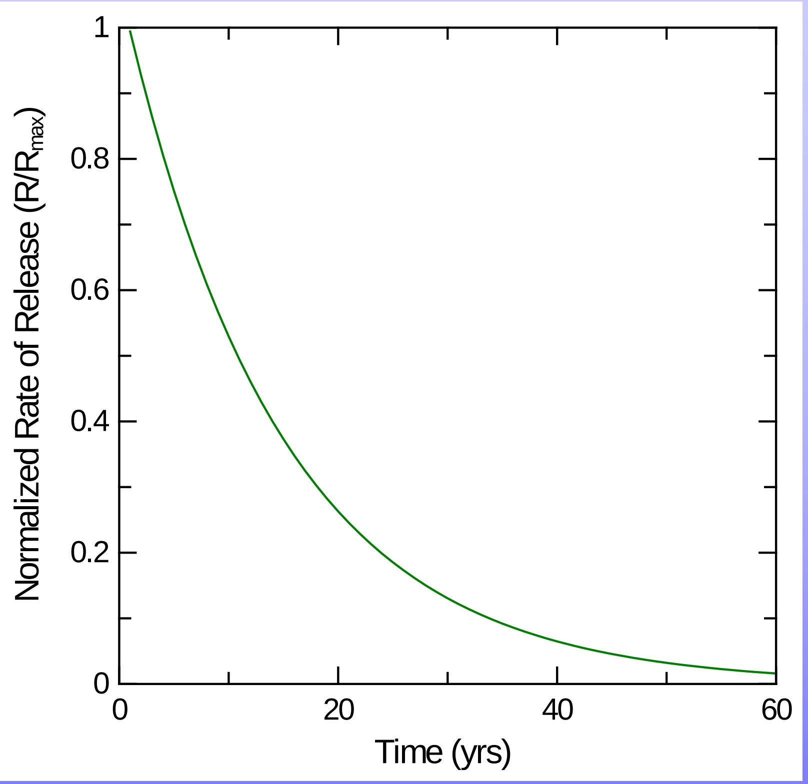
- It is assumed here than the unreactive phase at concentration C_u undergoes no reaction
- A nonlinear least-squares analysis for 3 unknowns (k_r, C_0 and C_u) was conducted

Table 5. Mineralization rate and half-life for total organic C, total N and organic P in Canyon Lake and Lake Elsinore.

	k_r (yr^{-1})		$t_{1/2}$	
	1-phase	**2-phase**	**1-phase**	**2-phase**
Canyon L.				
Organic C	0.050 0.010	0.113 0.081	13.9 2.9	8.2 5.9
Total N	0.042 0.002	0.065 0.018	16.5 0.8	11.1 3.1
Organic P	0.105 0.015	0.125 0.071	6.7 1.0	6.6 3.7
L. Elsinore				
Organic C	0.029 na	0.047 na	23.9 na	14.7 na
Total N	0.023 na	0.043 na	30.1 na	16.0 na
Organic P	0.011 na	0.023 na	60.4 na	29.7 na

- The 2-phase model yielded higher k_r values and shorter half-lives than the 1-phase model
- This indicates that half-lives of nutrients in Canyon L. and L. Elsinore are ~10 and 15 yrs, respectively





- With a half-life of ~10 yrs for Canyon L., by definition ~50% of the nutrients have been released from the sediments in 10 yrs
- After 30 yrs, only about 15% remain, with very slow rate of release