Performance of the Pit Lake at Ridgeway Gold Mine, South Carolina, USA

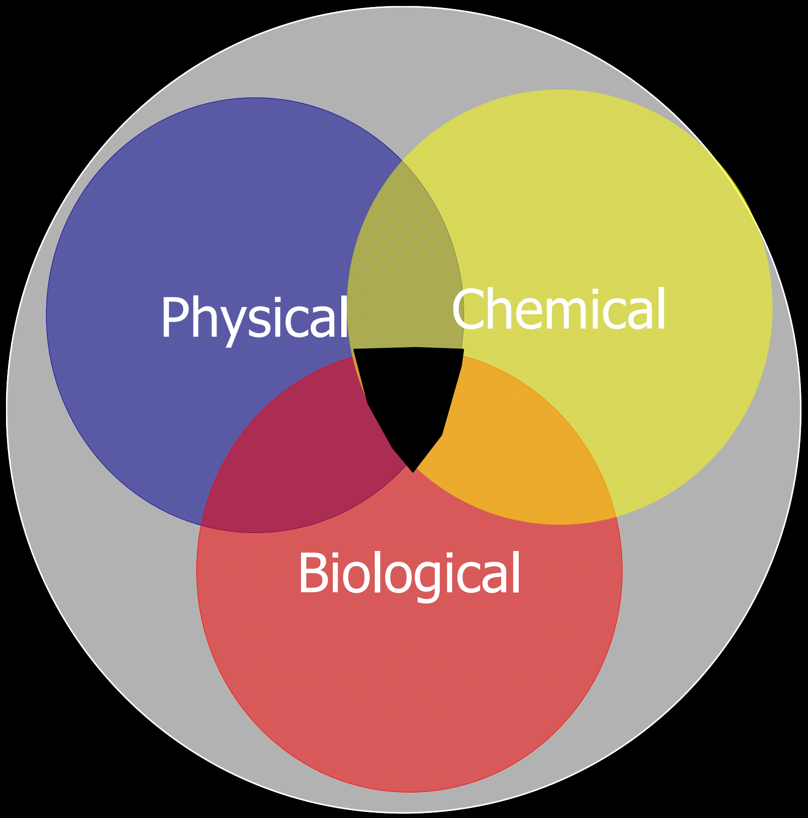
Oscar Flite and Roy Duckett

Reframing the big picture…

- Short-term goals
  - Increasing lake pH
  - Waste rock disposal
  - Removing metals from pit lake
  - Resource extraction
- Long-term goals
  - Titrating lake into carbonate buffer system
  - Strategic placement to optimize lake sustainability
  - Developing a sustainable ecosystem
  - Sustainable mining

What is the big picture for pit lakes? What should they look like?

- Many approaches to pit lake remediation
- Not all take a holistic approach
- Disregarding one or more domains often ends short of intended goal



Rio Tinto-Ridgeway Mining Company

Ridgeway, South Carolina

- Mining from 1988-1999
- Closure from 1996-2001 (included liming)
    - Clay cover on tailings facility
    - Site vegetation
    - Wetlands construction
    - Development of two fresh water lakes
        - Extensive Monitoring Program
            - Physical
            - Chemical
            - Biological

3.5 years of weekly data
3 years of monthly data
4 years of biannual-annual data

Pit lake monitoring program

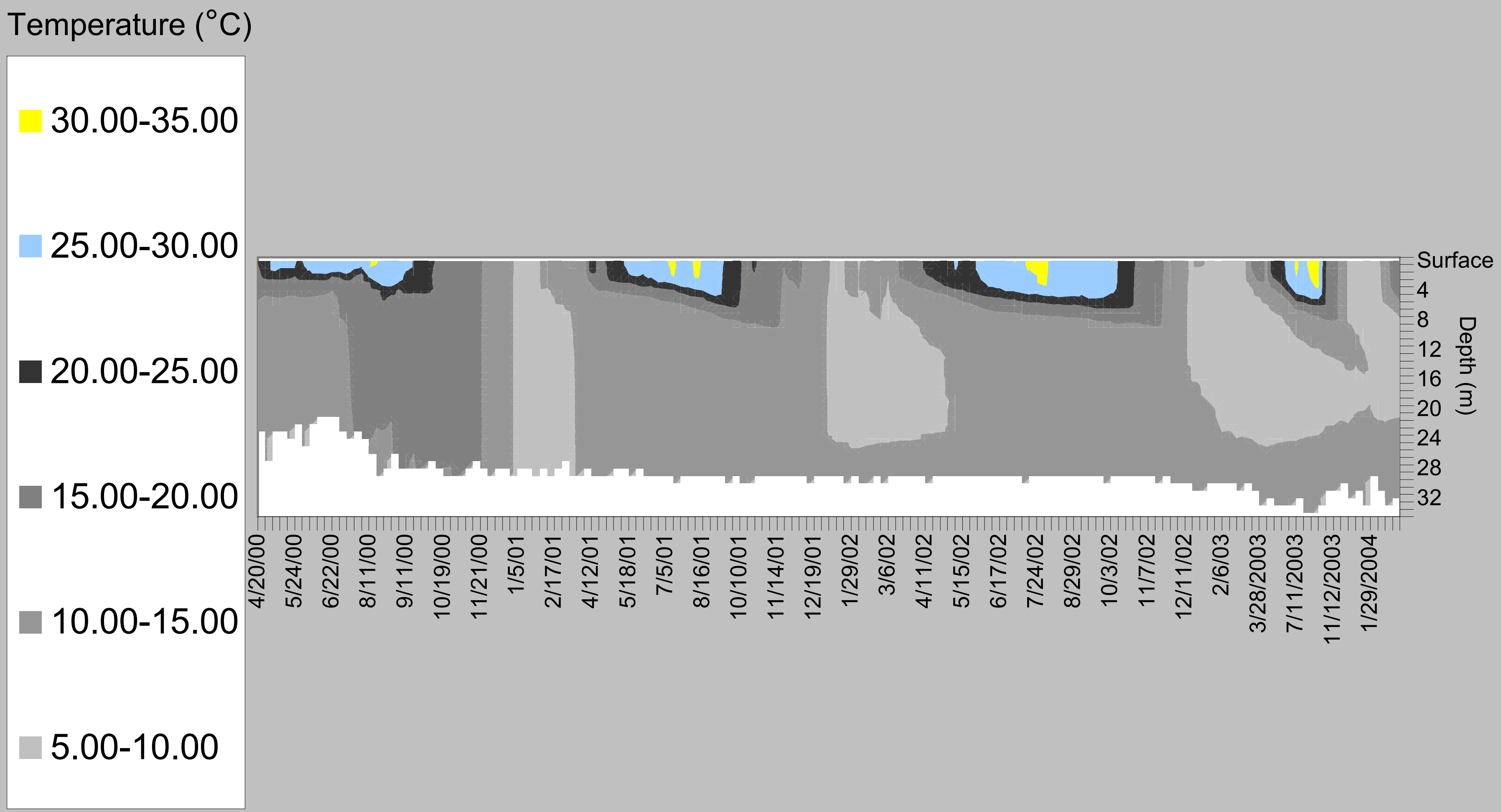
Continuous: thermistors
weather stations

Weekly: Hydrolab profile
Licor profile
phytoplankton
zooplankton
chlorophyll a

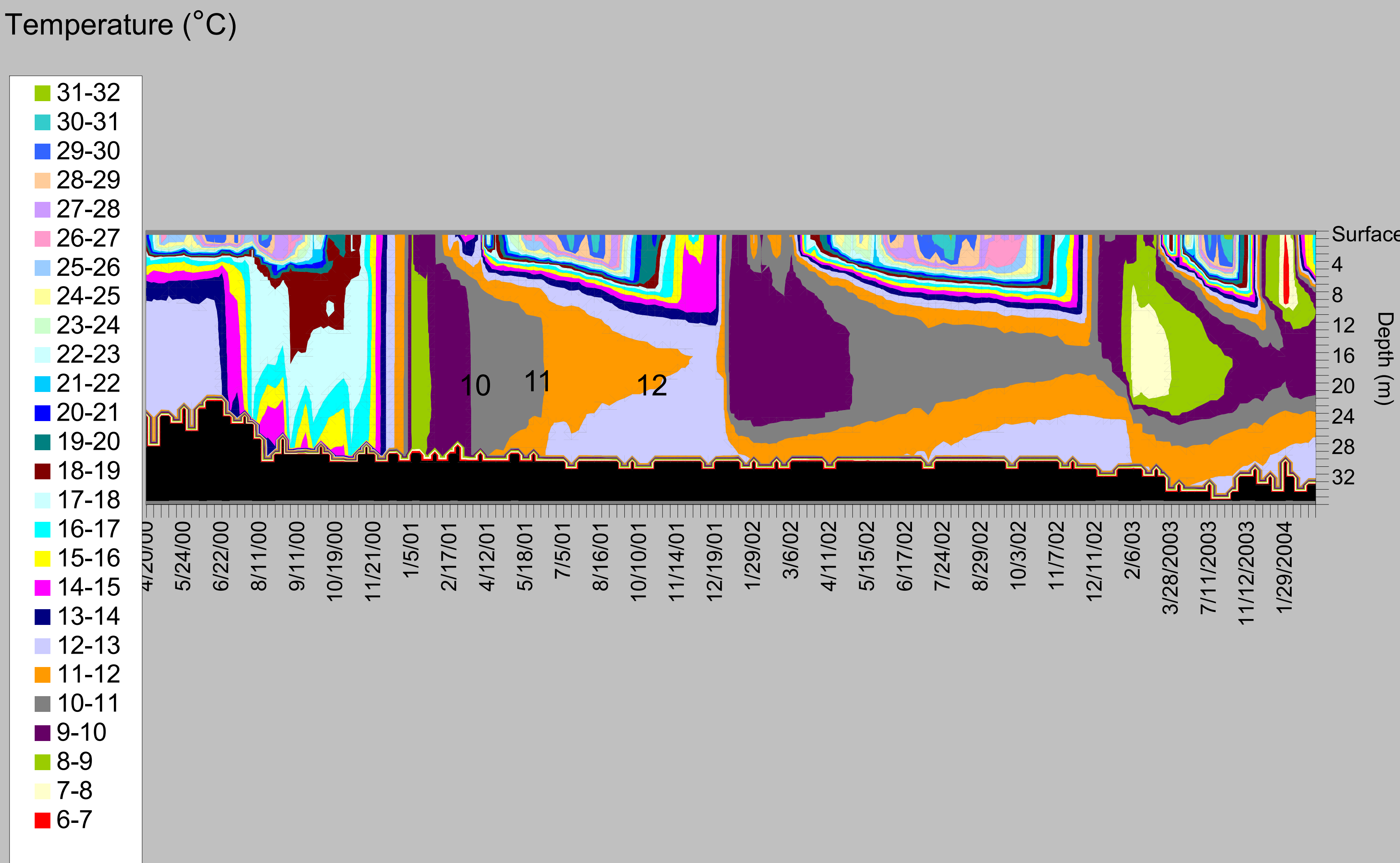
Monthly: primary productivity
macroinvertebrates

Quarterly: chemistry profiles

Temperature (5° C resolution)



Temperature (1° C resolution)



Specific cond

Stochastic events (perturbations)

75 millio
nutrient lad
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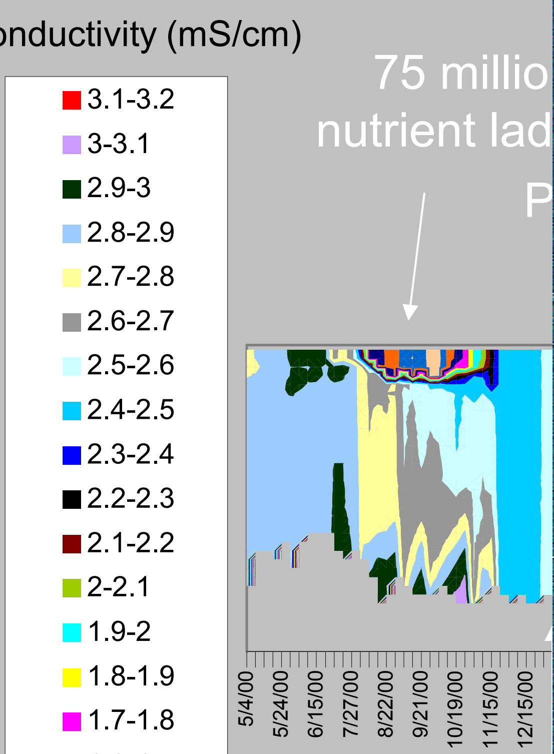

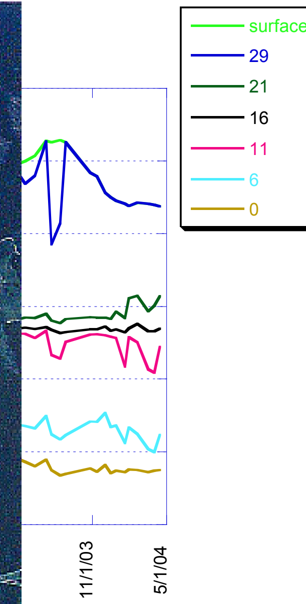

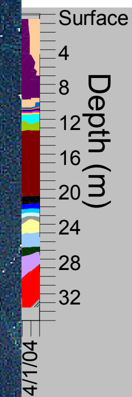

Winte

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Fa
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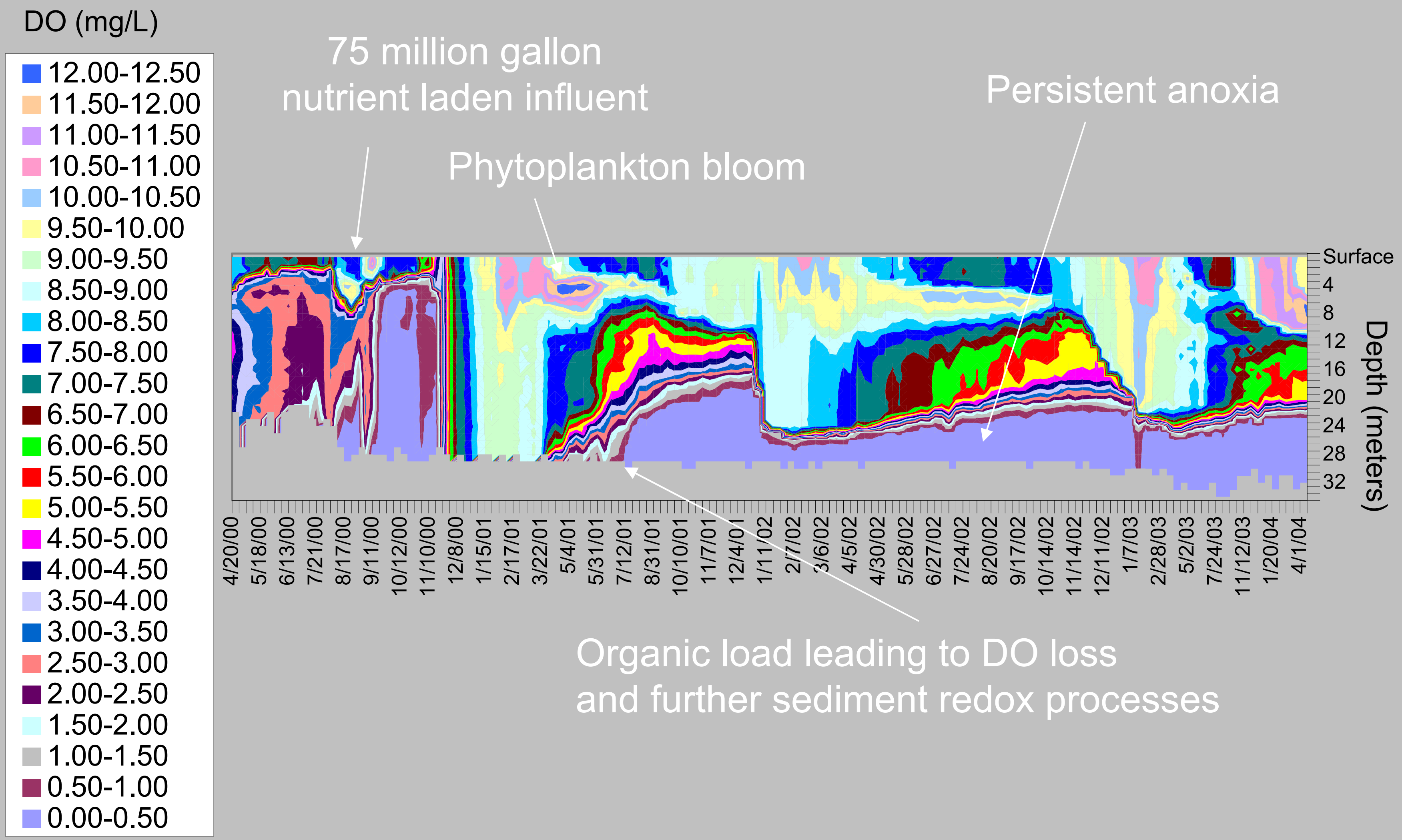
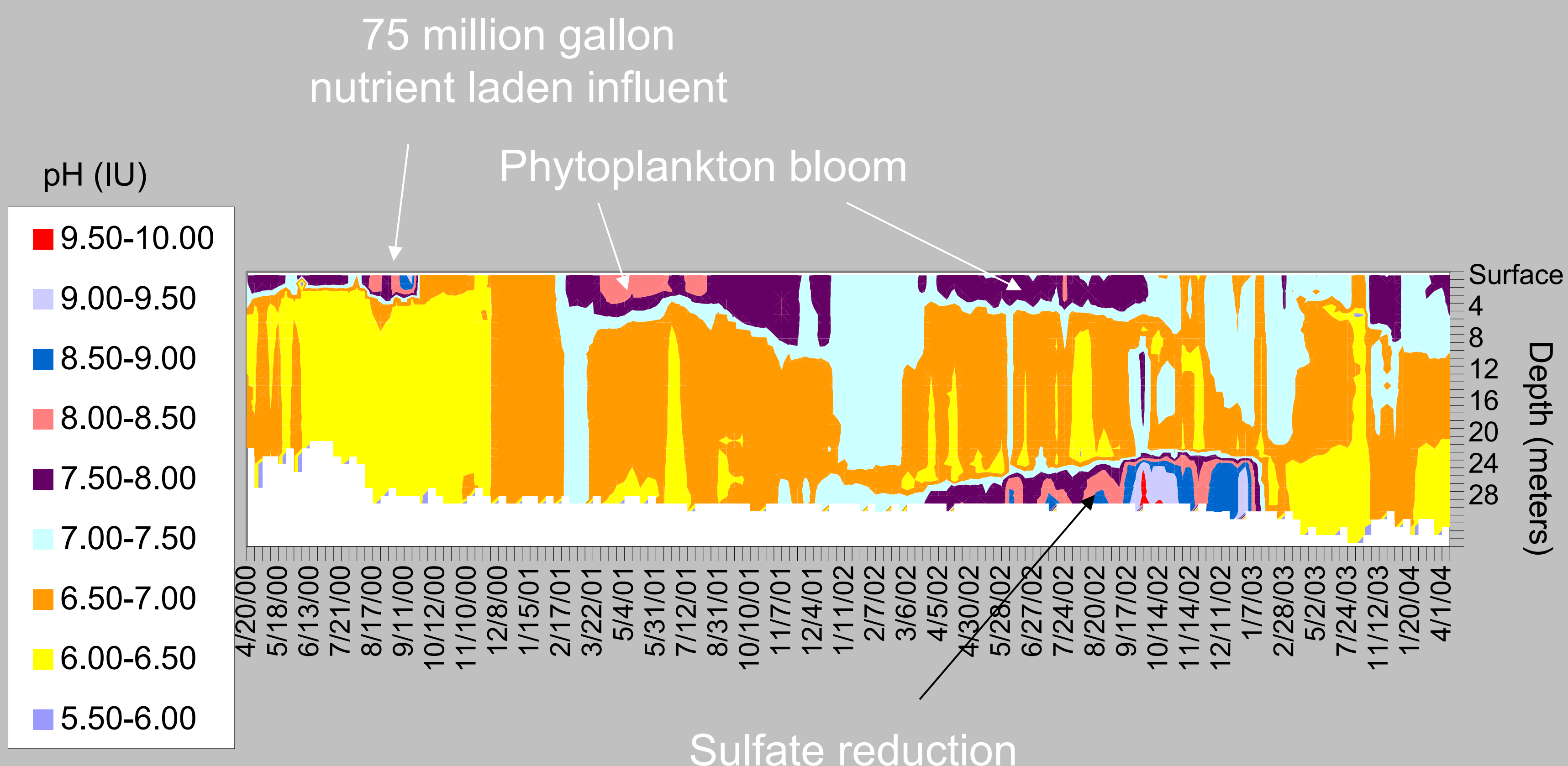
Dissolved oxygen

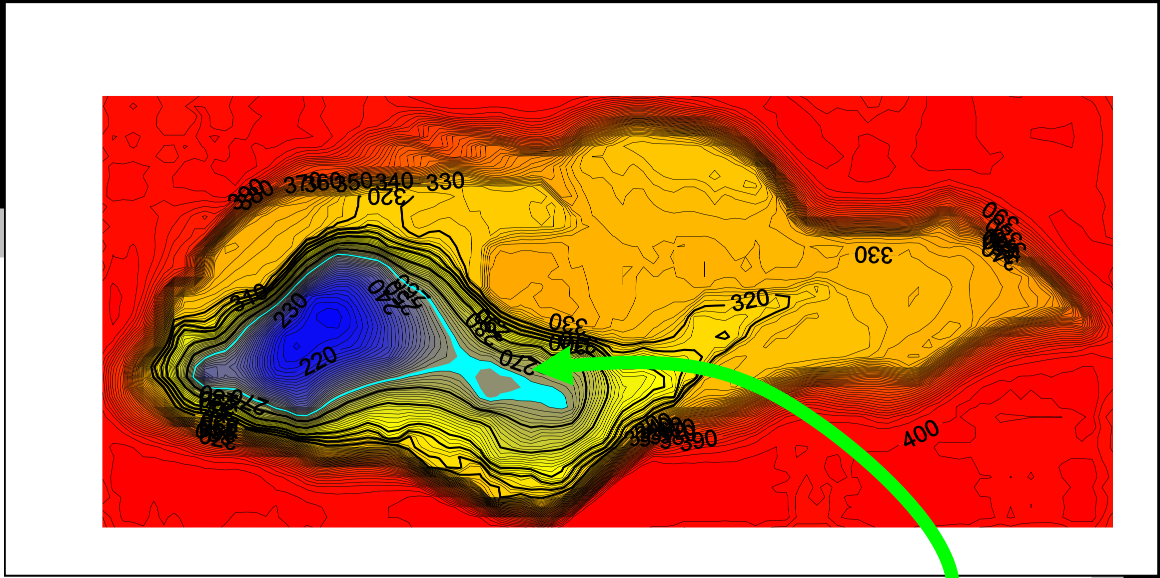


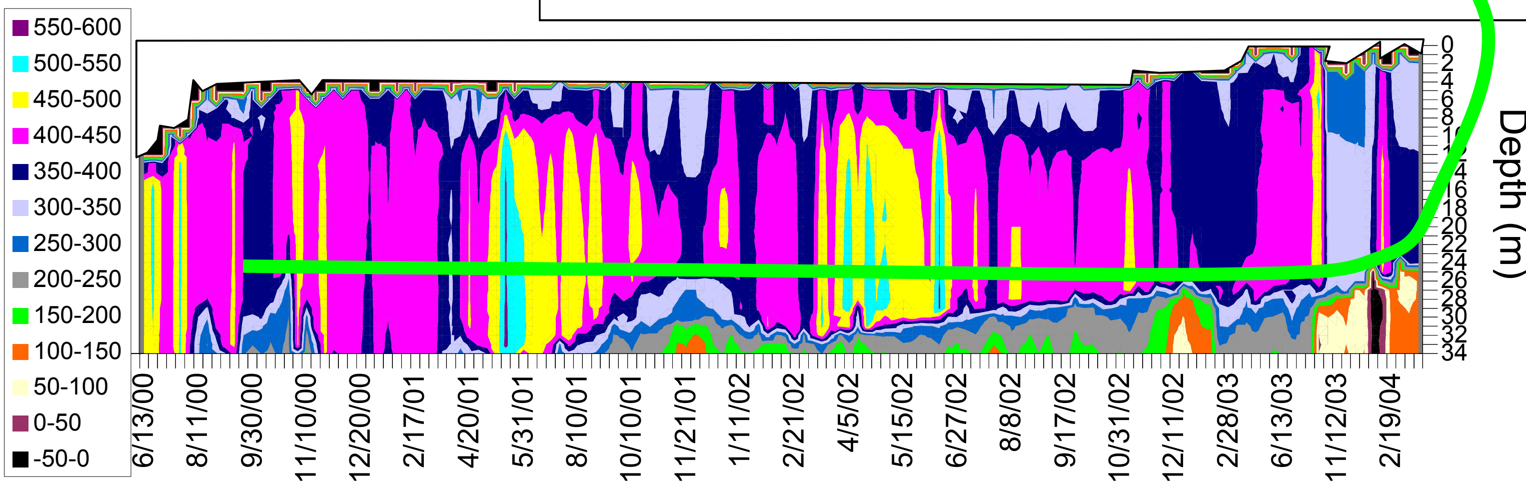
pH trends



$$SO_4^{2-} + 2(CH_2O) \rightarrow H_2S + 2CO_2 + 2OH^-$$

Redox trends



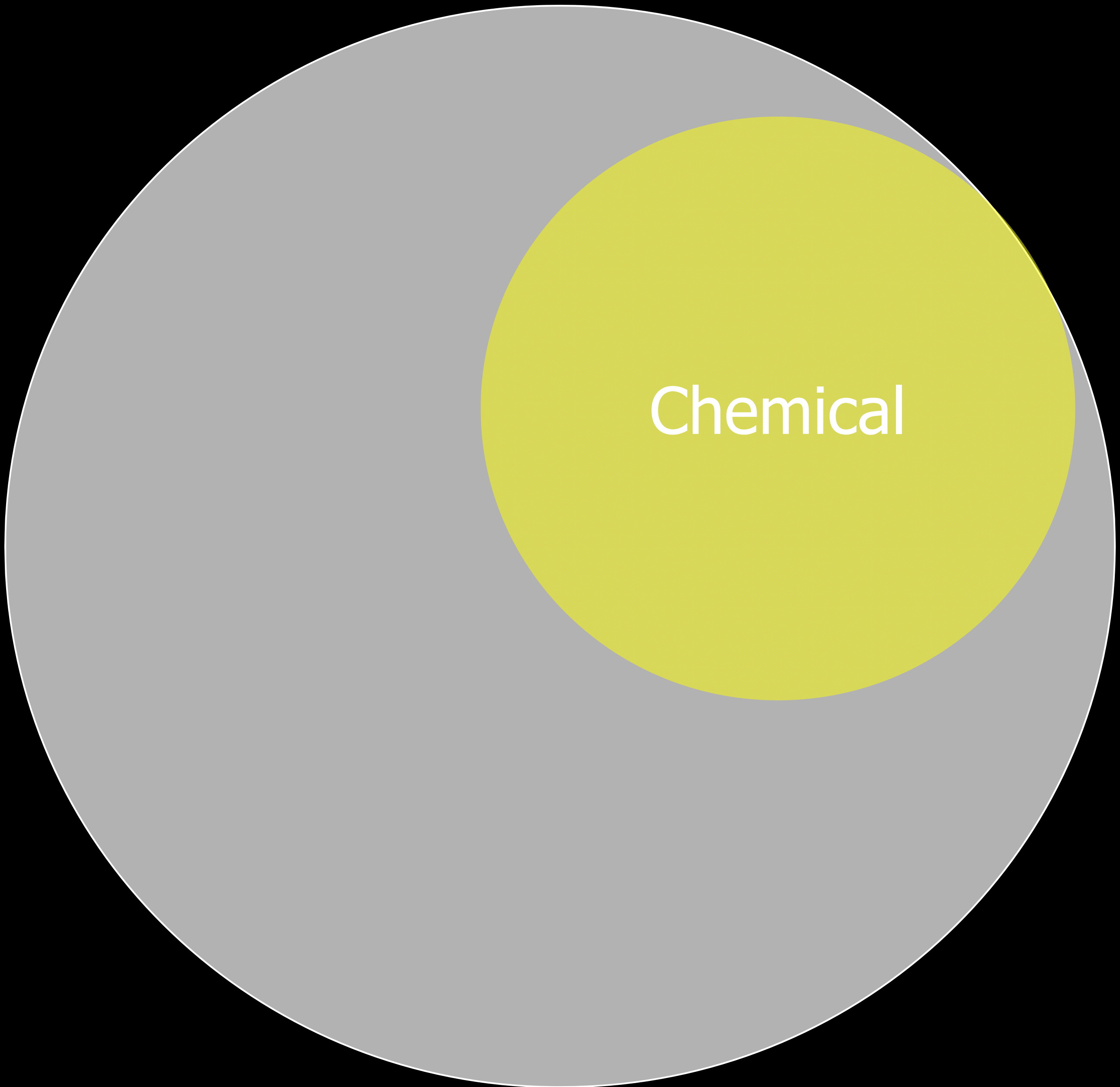


How important is the lake bathymetry for producing and/or MAINTAINING meromixis?

These systems are manmade!

Development of meromixis in South Pit Lake

1) Biogeochemical
2) Dilution



More than just dilution

2009 data

depth	**Na**
0	39
15	38
30	64
	1.641026

Chemistry profile-bottom water density dynamics

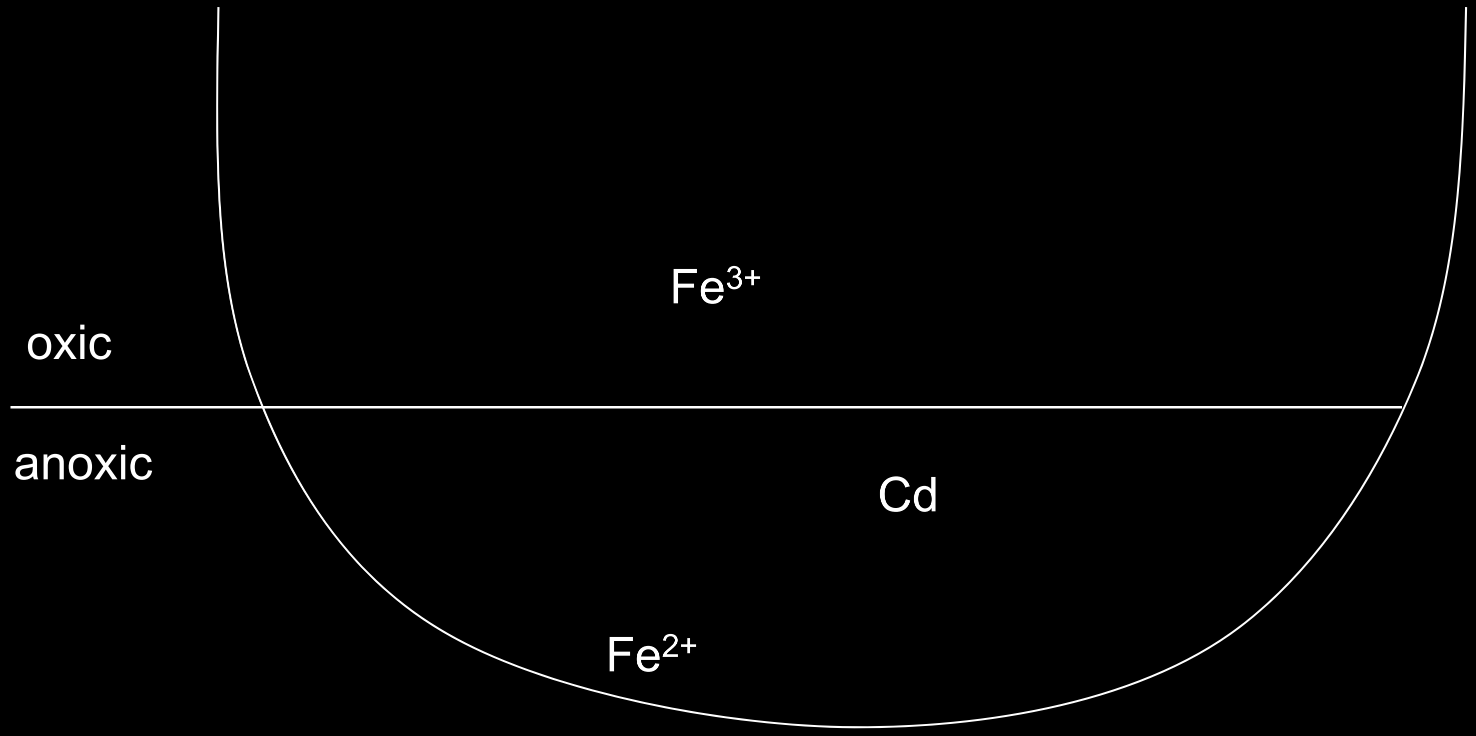
	South pit lake depth (m) - 2005							
Constituent (mg/L)	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**34**
Aluminum	0	0	0	0	0	0	0	0
Ammonia - N (phenate)	0.11	0	0	0.12	0.14	1	1.6	1.5
Antimony	0	0	0	0	0	0	0	0
Arsenic	0	0	0	0	0	0	0	0
Barium	0	0	0	0	0	0	0	0
Beryllium	0	0	0	0	0	0	0	0
Boron	0	0	0	0	0	0	0	0
Cadmium	0	0	0	0	0	0	0	0
Calcium	180	200	220	330	310	500	570	620
Chloride	5	5.4	5.6	6.2	6.7	7	7.5	7.5
Chromium	0	0	0	0	0	0	0	0
Cobalt	0	0	0	0	0	0	0.32	0.35
Copper	0	0	0	0	0	0	0	0
DOC	3.2	4	3.3	2.3	2.2	2.1	1.9	2.1
Iron	0	0	0	0	0	14	68	75
Lead	0	0	0	0	0	0	0	0
Magnesium	39	42	46	60	53	89	140	150
Manganese	0	0	0	1.3	1.7	24	24	26
Molybdenum	0	0	0	0	0	0	0	0
Nickel	0	0	0	0	0	0	0	0.2
Nitrate - N	0	0	0	0.081	0.12	0.058	0	0
Ortho-phosphorus	0	0	0	0	0	0.054	0.091	0.049
Phosphorus	0.014	0	0	0	0	0.012	0.032	0.041
Potassium	0	0	0	0	0	0	29	32
Selenium	0	0	0	0	0	0	0	0
Silica (calculation)	0	0	0	0	0	0	12	15
Silicon	0	0	0	0	0	0	5.9	6.9
Silver	0	0	0	0	0	0	0	0
Sodium	26	30	32	46	44	51	66	73
Sulfate	730	640	740	1100	1300	1800	2000	2000
Thallium	0.091	0.052	0	0.056	0	0.1	0.064	0.071
Tin	0	0	0	0	0	0	0	0
Titanium	0	0	0	0	0	0	0	0
TKN	0	0	0.54	0.82	0	2.7	2.8	2
Vanadium	0	0	0	0	0	0	0	0
Zinc	0	0	0	0	0	0	0	0

Dilution factors

	5m	30m	30m/5m
Cl	5.4	7.5	1.39
Ca	200	570	2.85
Mg	42	140	3.33
SO4	640	2000	3.13
Na	30	66	2.20
Fe	0	68	
Mn	0	24	
Alk(2003)	30	239	7.97

Analysis does not answer how the system is stabilized!

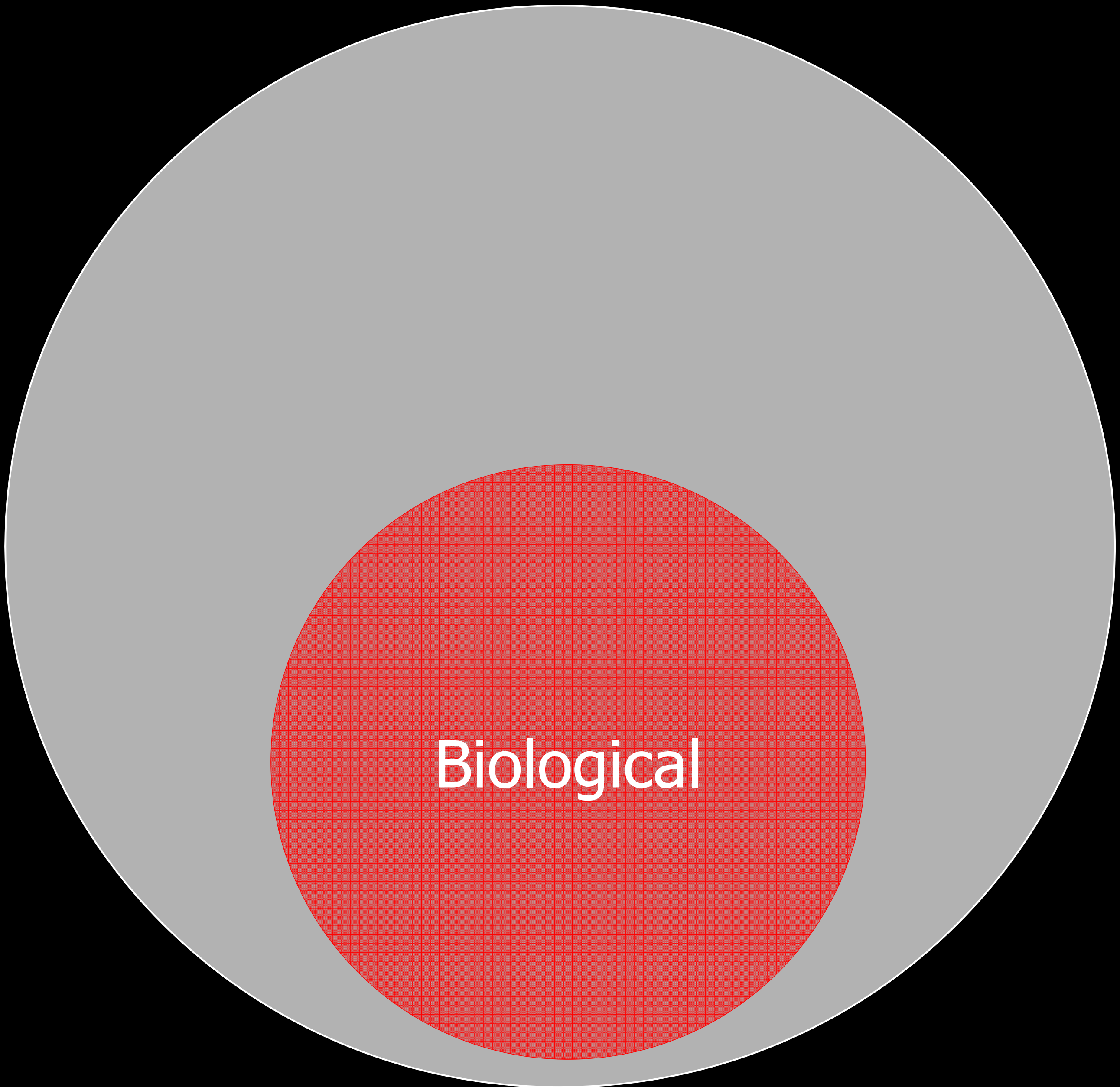
Controlling metals through the 2-layered system



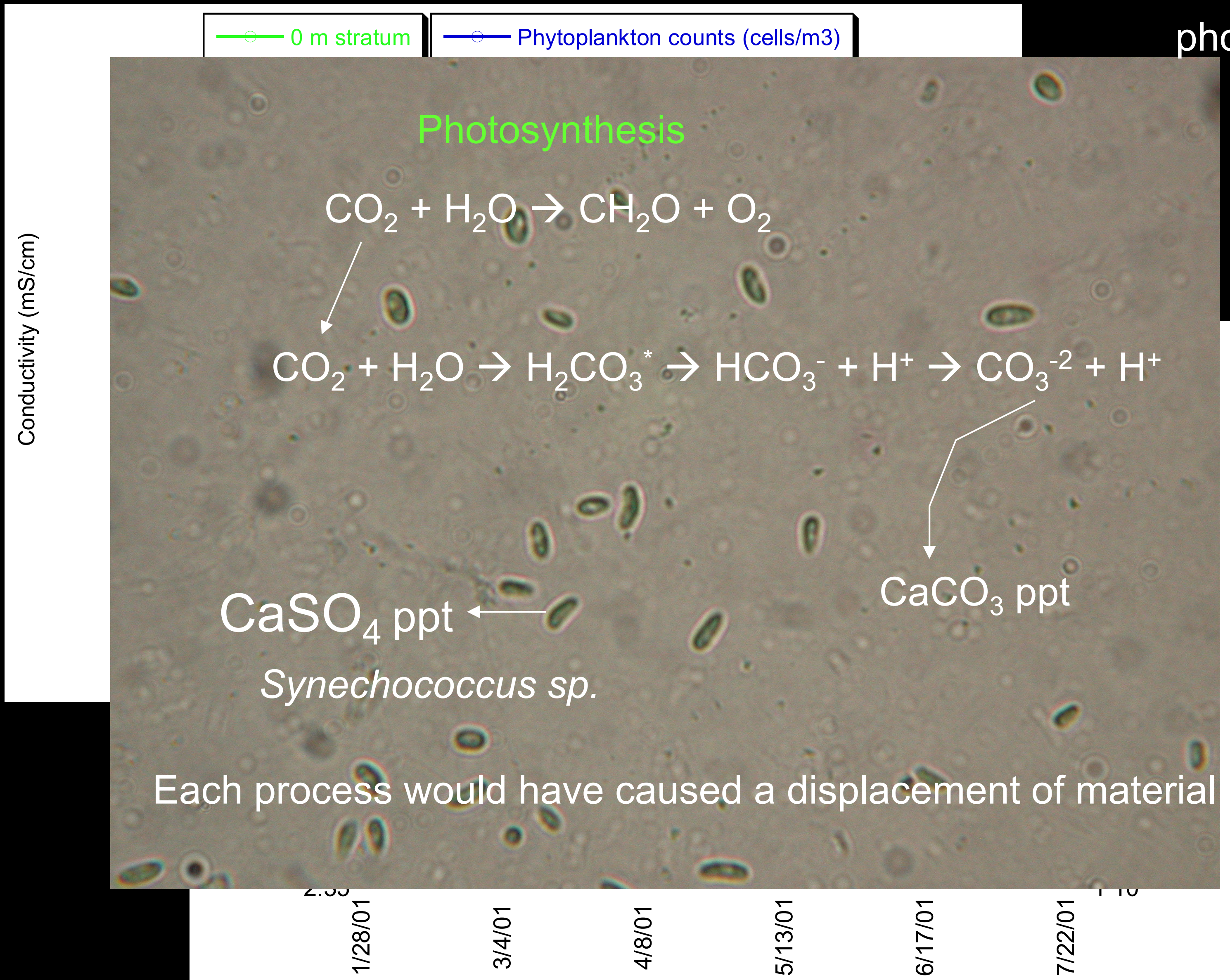
In-lake reaction chamber

Development of meromixis in South Pit Lake

1) Photosynthesis
2) Respiration



Evidence of phytoplankton facilitated meromixis



photosynthesis

↓

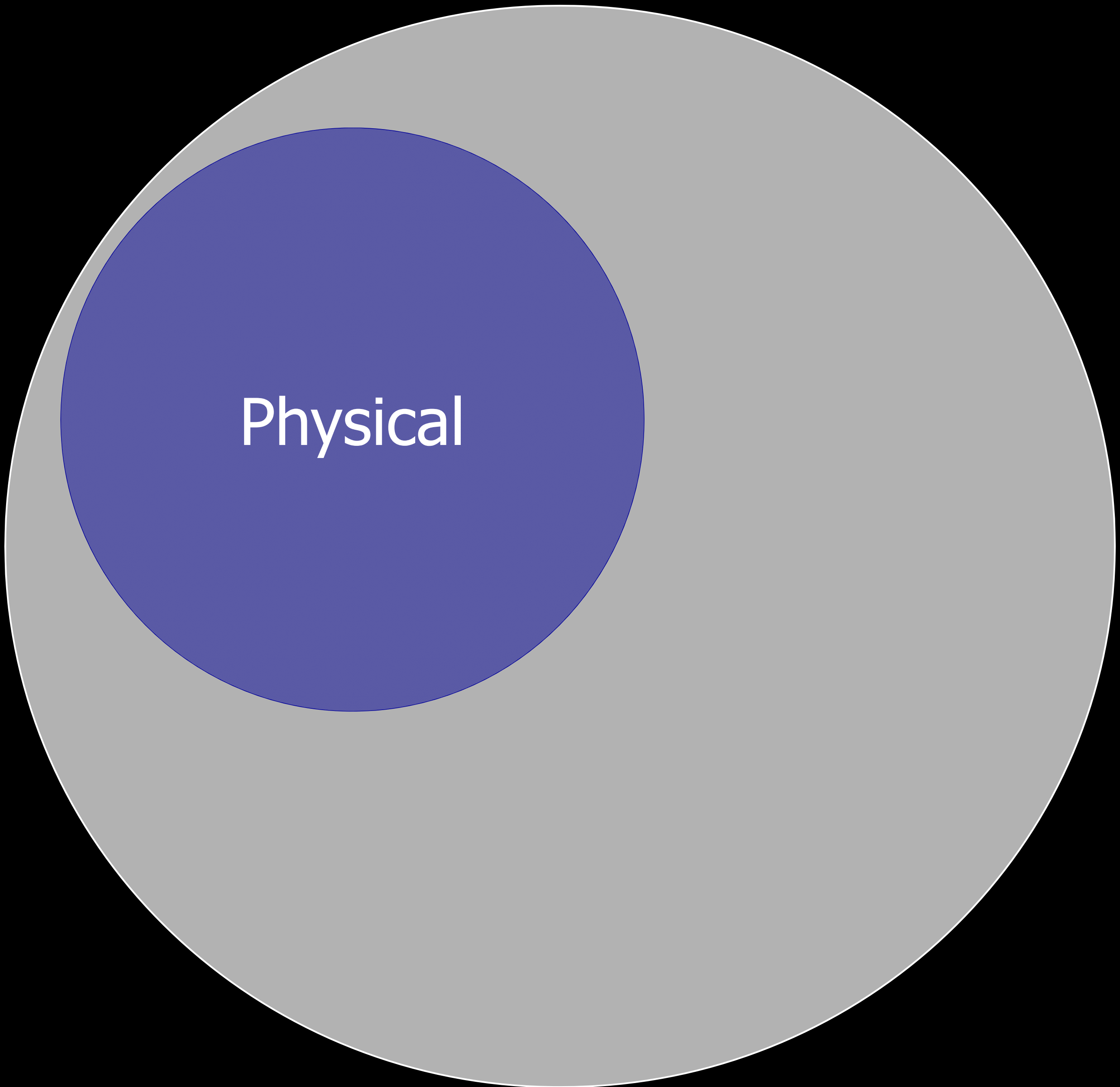
respiration

↓

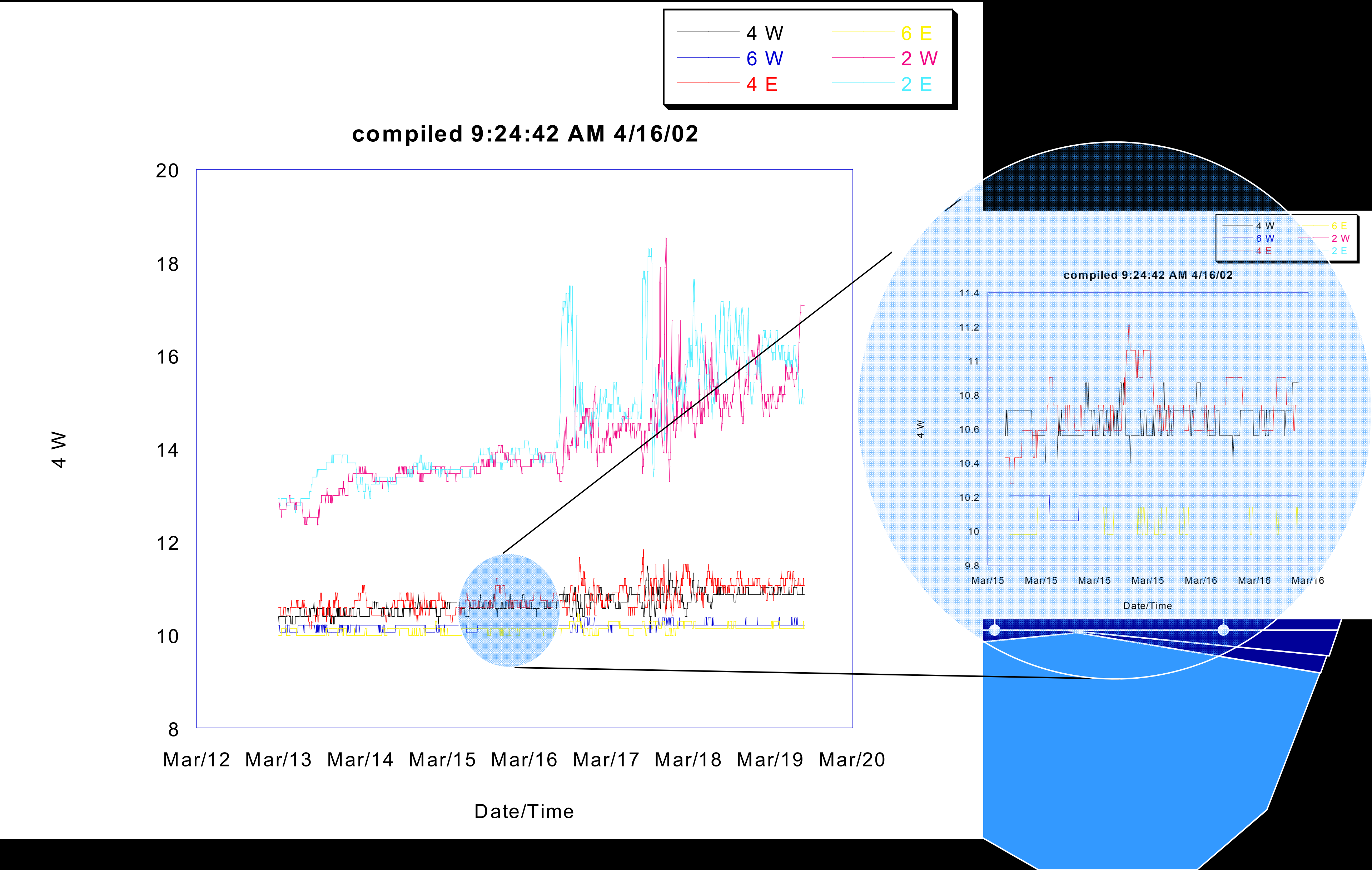
increase in sed. flux and diss.

Development of meromixis in South Pit Lake

1) Lake bathymetry
2) Wind mixing
3) Energy dissipation

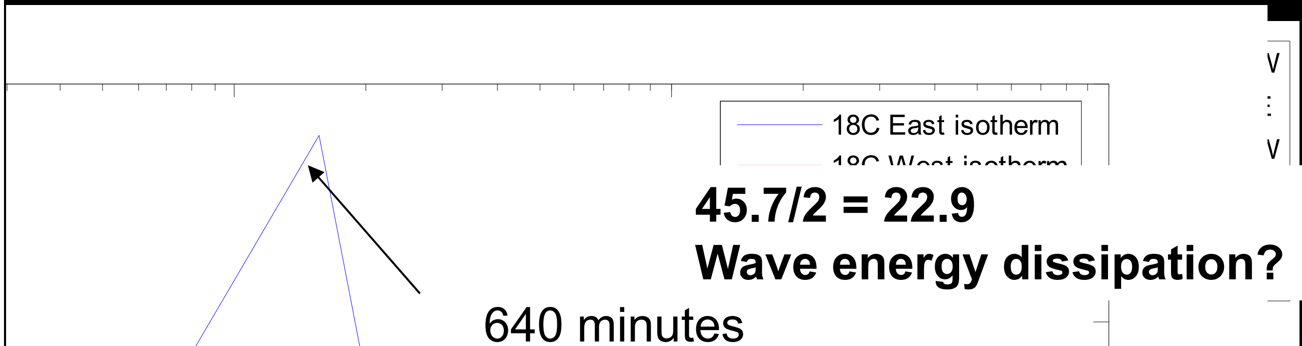


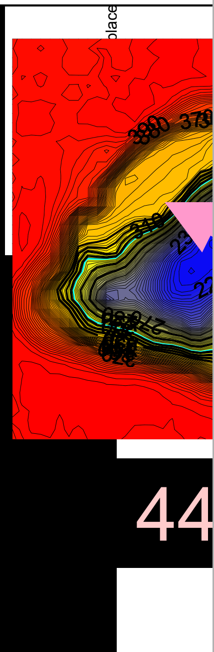
Using lake signatures to understand physical dynamics

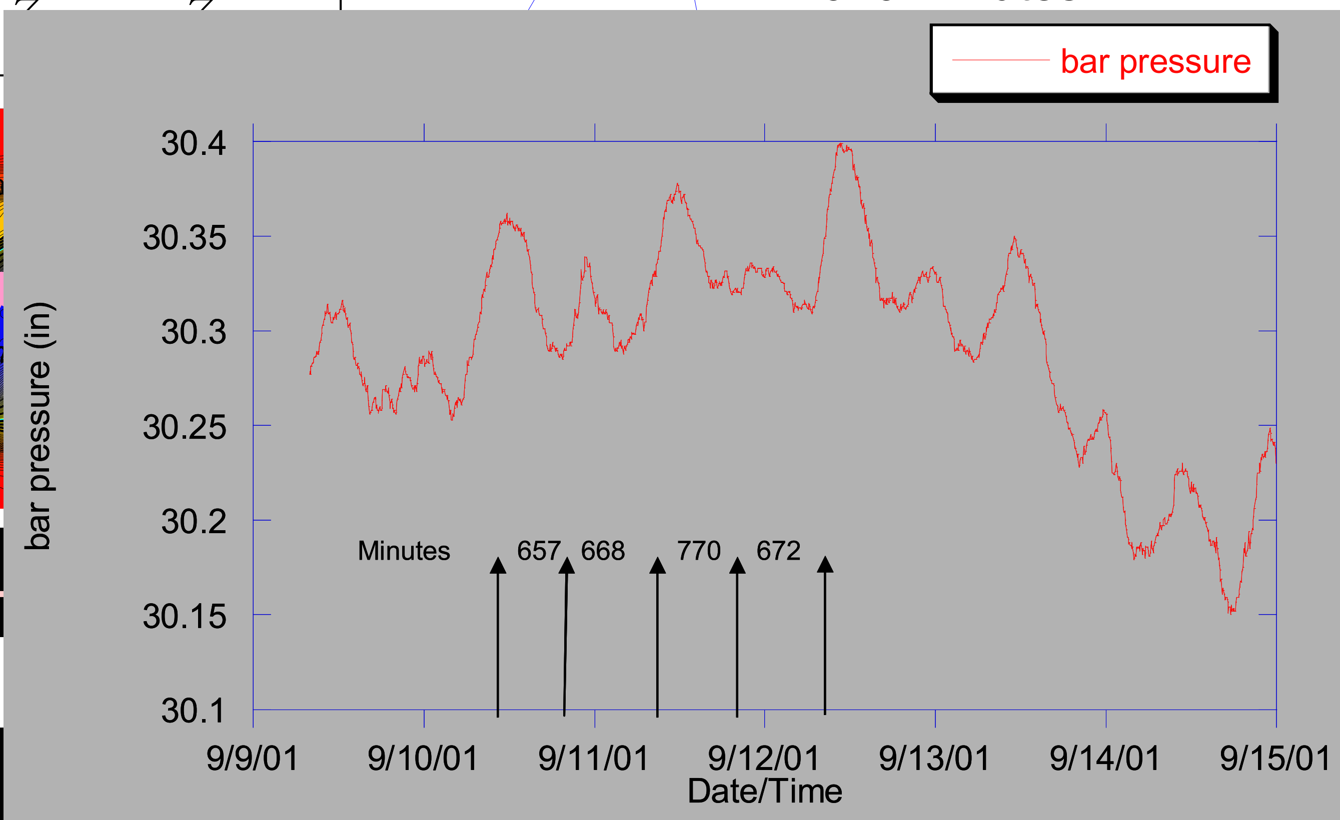


Did the bathymetry of SP help to dissipate the wind energy? Two approaches…

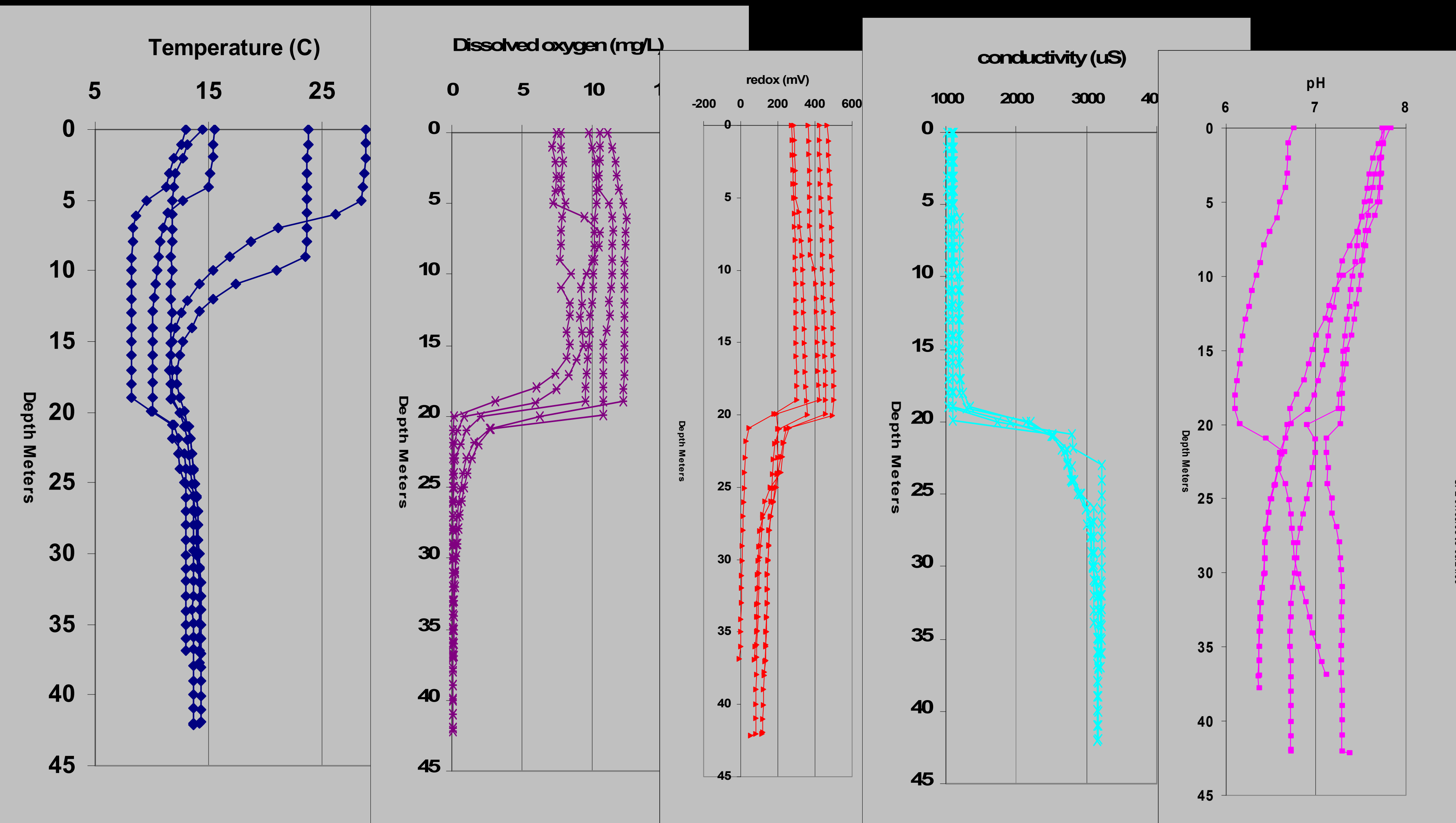
$$t = \frac{2l}{\sqrt{\frac{g(\rho_h - \rho_e)}{\frac{\rho_h}{\dots} + \frac{\rho_e}{\dots}}}}$$







2008-2010


Temperature (C)
5
15
25
Depth Meters
0
5
10
15
20
25
30
35
40
45
Dissolved oxygen (mg/L)
0
5
10
redox (mV)
-200
0
200
400
600
conductivity (uS)
1000
2000
3000
pH
6
7
8

Further research

- physical
  - determine extent of turbulent kinetic energy dissipation on sloping boundaries
- chemical
  - determine dynamics surrounding meromictic stability (is the chemical stability stabilized by either top-down or bottom-up flux?)
- biological
  - determine role of the biota in maintaining anoxia and meromixis and in sediment flux rates (algal biomass production in upper water and bacterial respiration rates in lower water)

Further research

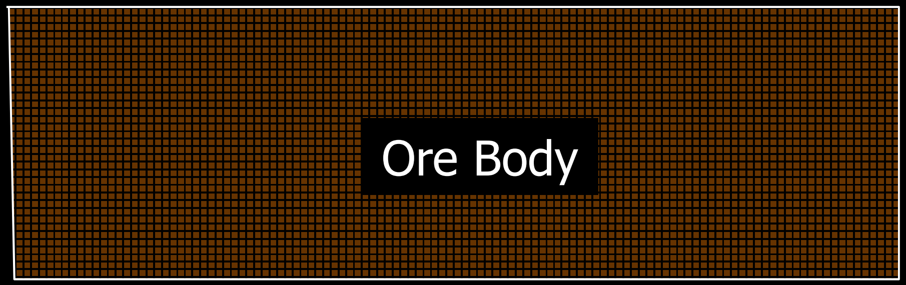
- This method has been proven in two pit lake systems in South Carolina, can it be done:
  - In colder climates?
  - For coal mining?
- Are there more applications for this type of treatment system?
  - Can the reaction chamber be done as a pass-through treatment system?

Final summation

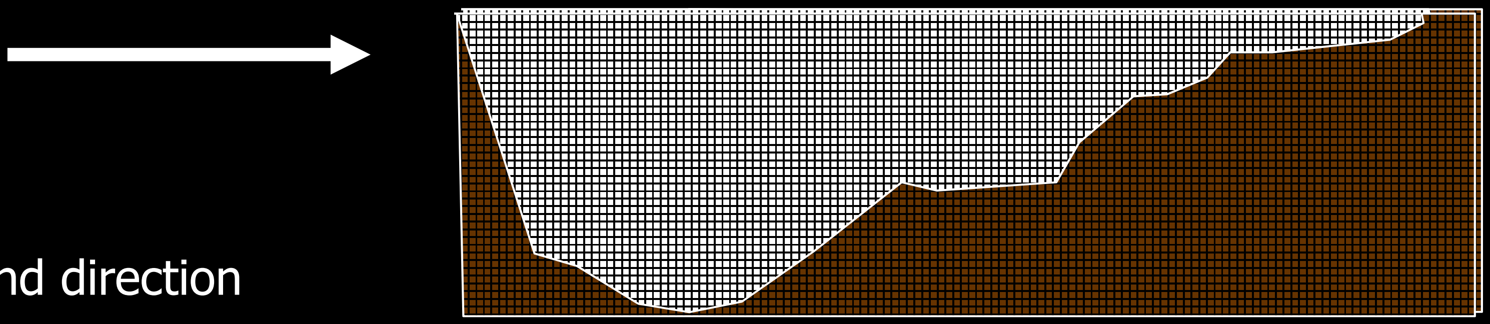
- physical
  - lake shape helped minimize impact of wind by dissipating wind energy at boundaries
- chemical
  - system was in the carbonate system
  - precipitation and resolubilization of gypsum, carbonate, manganese, and iron established meromixis
  - iron and manganese oxides coprecipitated heavy metals from the water column
- biological
  - phytoplankton induced an environment conducive for gypsum, iron, manganese, and carbonate precipitation from the upper water to lower water
  - benthic bacteria induced an environment conducive for resolubilization and sediment flux in the lower water

LAKE SHAPE------CARBONATE SYSTEM-------PHYTOPLANKTON-----RESPIRATION

- Prospecting results in ore body model
- Model partitions ore body into blocks
- Removal of blocks based upon:
  - costs of handling, processing, and recovery of that block
  - ore grade within that block
  - values of adjacent or lower blocks
  - current market price



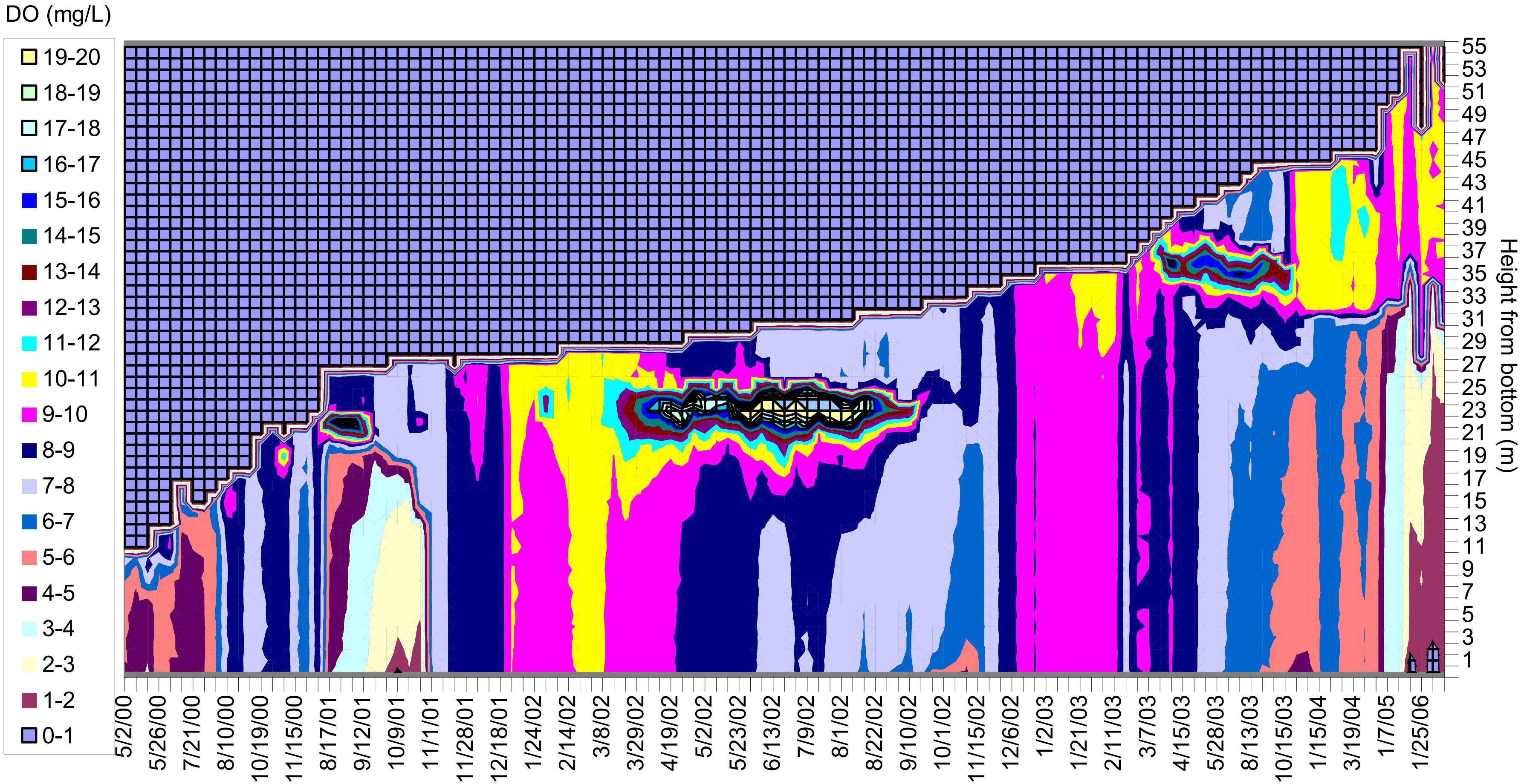
•Ultimately, pit lake shape is determined by mining economics

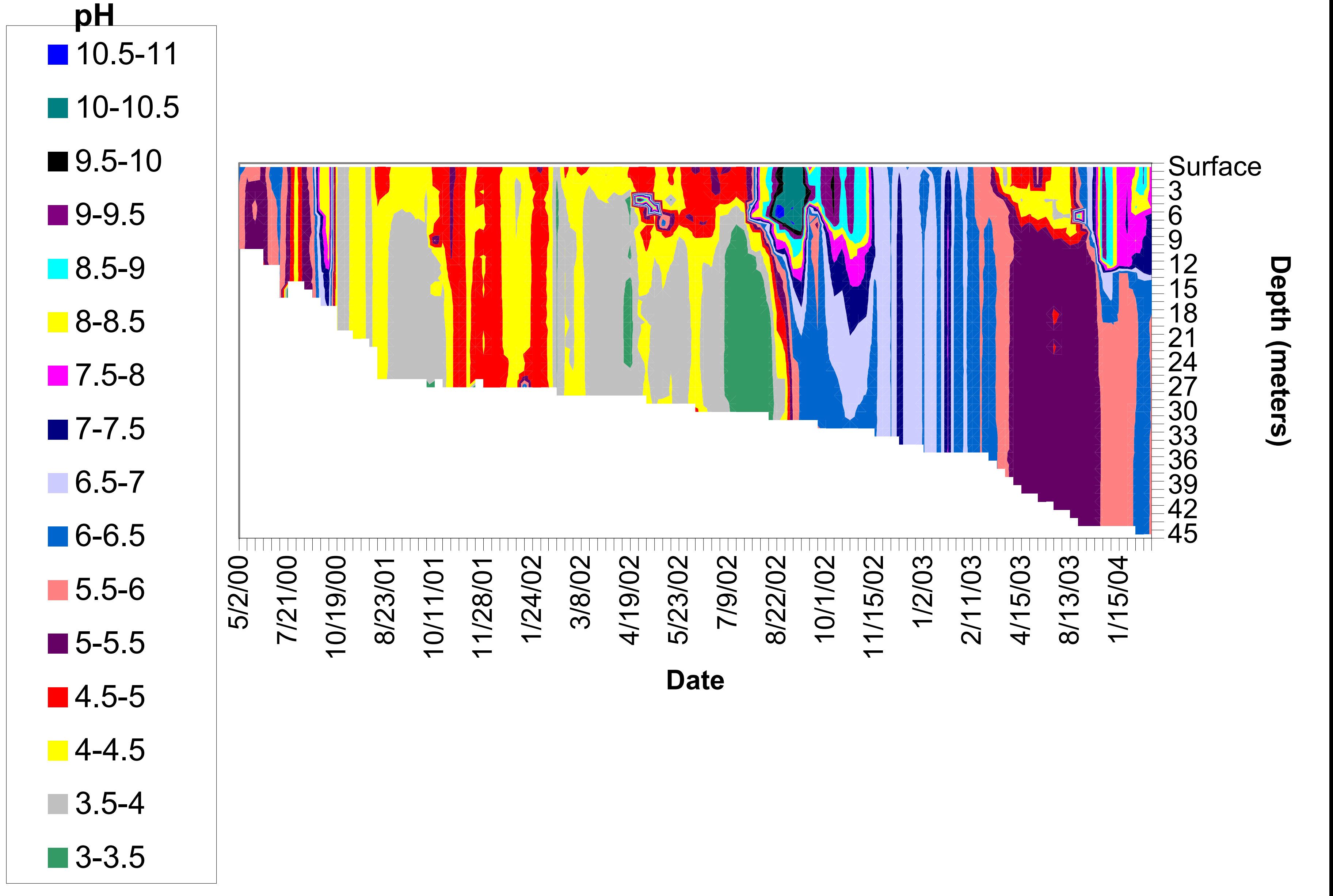


- Predominant wind direction
- Pit lake orientation optimized
- Placement of backfill optimized
- Alkalinity titration

Maximize pit lake sustainability

North Pit Lake





pH
10.5-11
10-10.5
9.5-10
9-9.5
8.5-9
8-8.5
7.5-8
7-7.5
6.5-7
6-6.5
5.5-6
5-5.5
4.5-5
4-4.5
3.5-4
3-3.5
Surface
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
Depth (meters)
5/2/00
7/21/00
10/19/00
8/23/01
10/11/01
11/28/01
1/24/02
3/8/02
4/19/02
5/23/02
7/9/02
8/22/02
10/1/02
11/15/02
1/2/03
2/11/03
4/15/03
8/13/03
1/15/04
Date