WATER QUALITY RESPONSE TO HYPOLIMNETIC OXYGENATION LAKE THUNDERBIRD, OKLAHOMA

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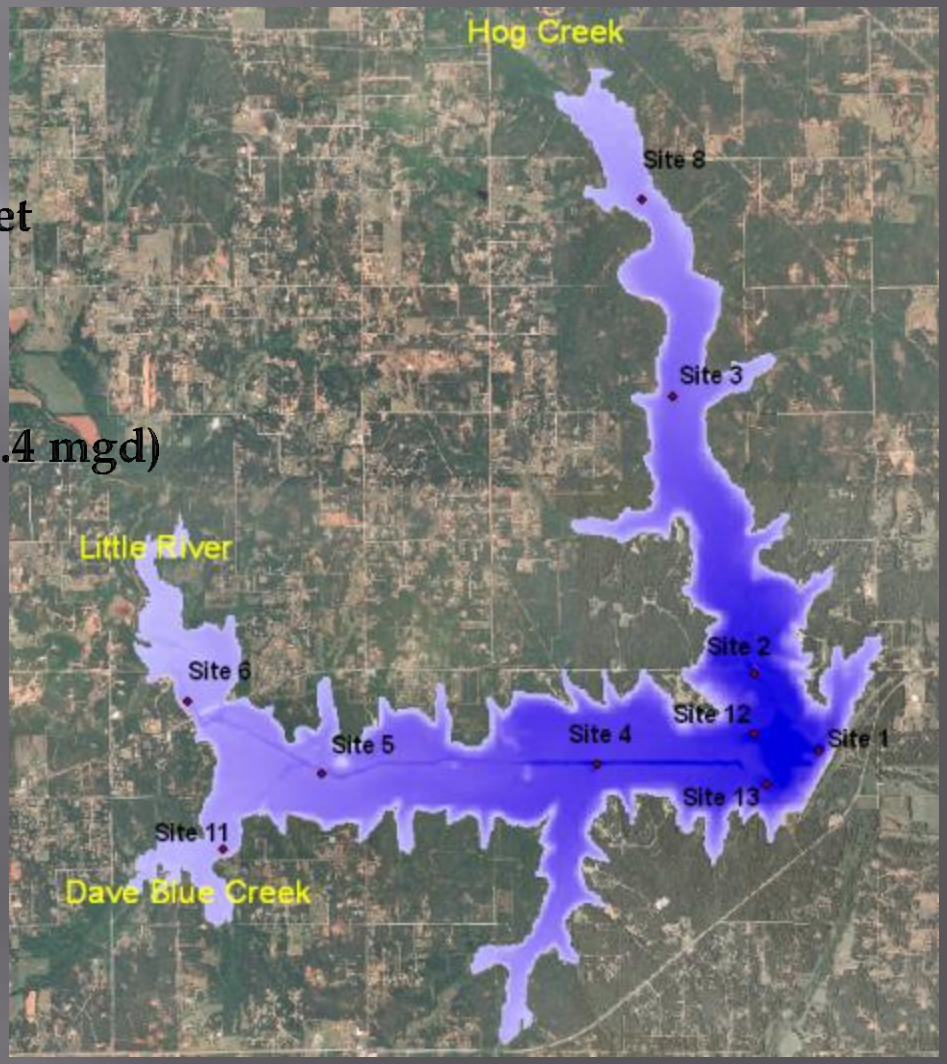
OWRB
the water agency

Lake Thunderbird, OK

Area	5,439 acres
Volume	105,838 acre-feet
Shoreline	96 km
Mean Depth	4.7 m (15.4 ft)
Max. Depth	17.7 m (58 ft)
Yield	21,700 af/yr (19.4 mgd)
Residence (tau)	0.5 – 7 yr^{-1}



Impaired Water Quality

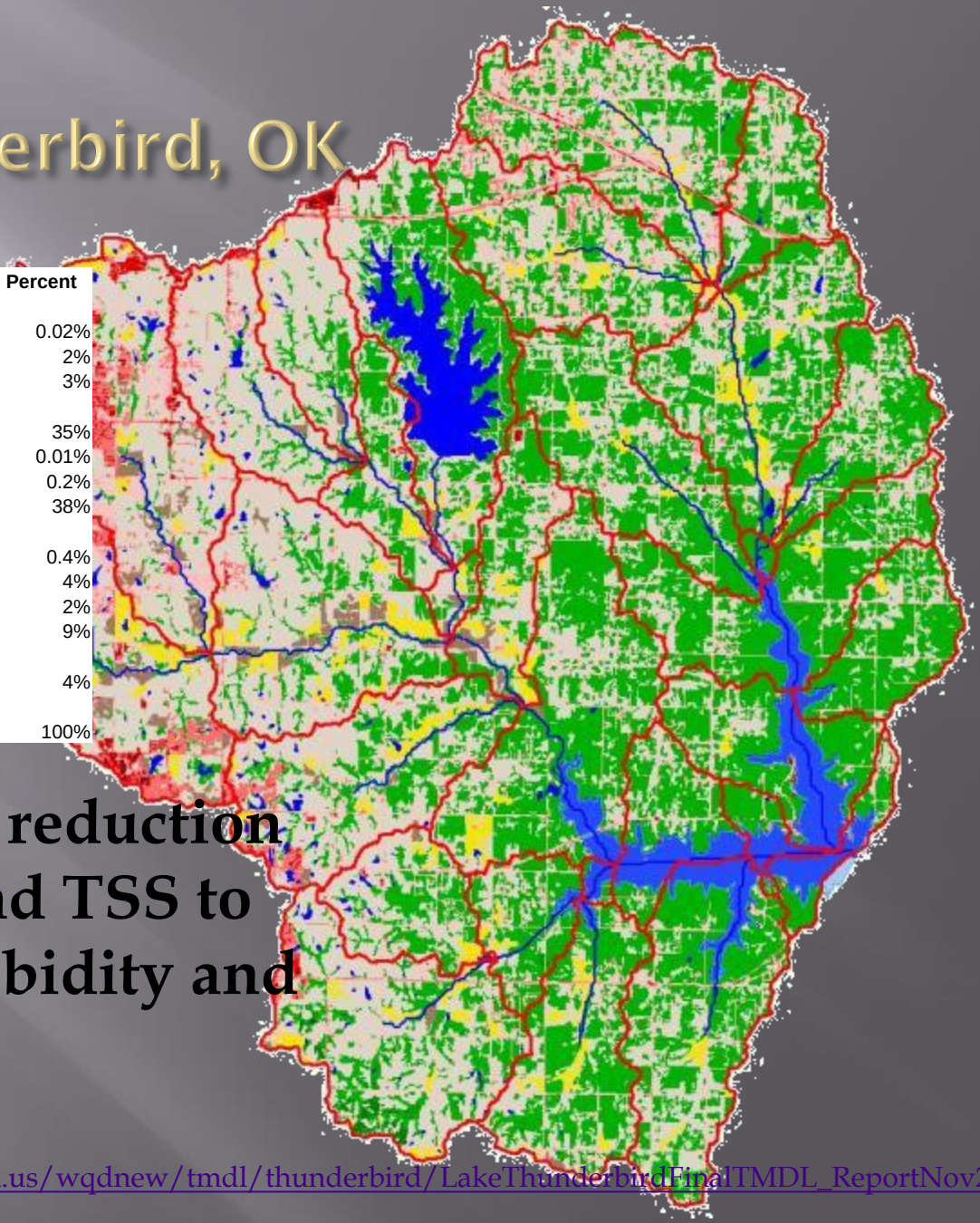
Category 5 (303d list) in the State's 2012 Integrated Report

- excessive turbidity,
- low dissolved oxygen and
- excessive chlorophyll-*a*

http://www.deq.state.ok.us/wqdnew/305b_303d/2012_draft_integrated_report.pdf

Lake Thunderbird, OK

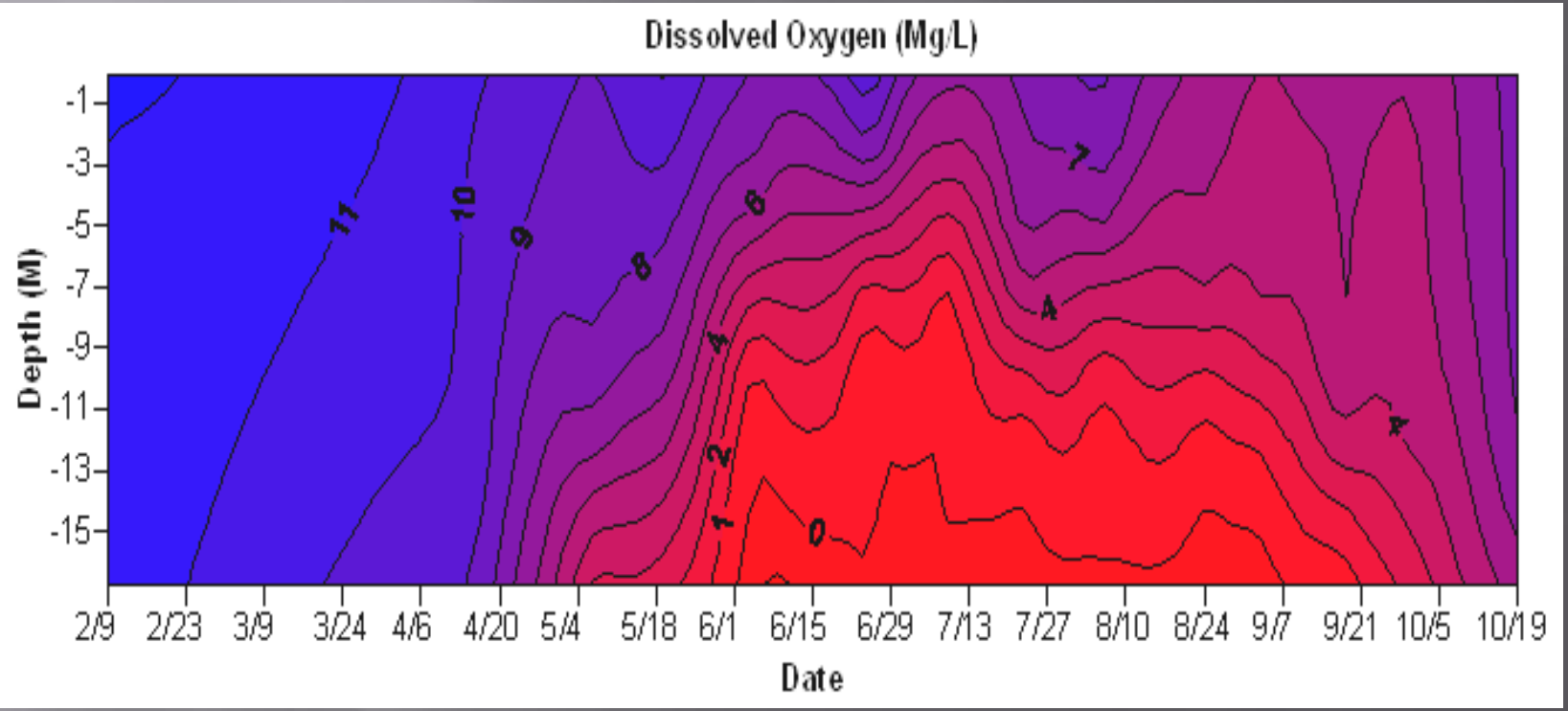
Land Use	Acres	Percent
Barren Land	30	0.02%
Cultivated Crops	3,341	2%
Pasture/Hay	5,452	3%
Deciduous Forest	55,010	35%
Emergent herbaceous wetlands	8	0.01%
Evergreen Forest	351	0.2%
Grassland/Herbaceous	59,765	38%
Developed, high intensity	661	0.4%
Developed, low intensity	6,769	4%
Developed, medium intensity	3,102	2%
Developed, open space	14,661	9%
Open water	6,738	4%
Total Watershed	155,888	100%



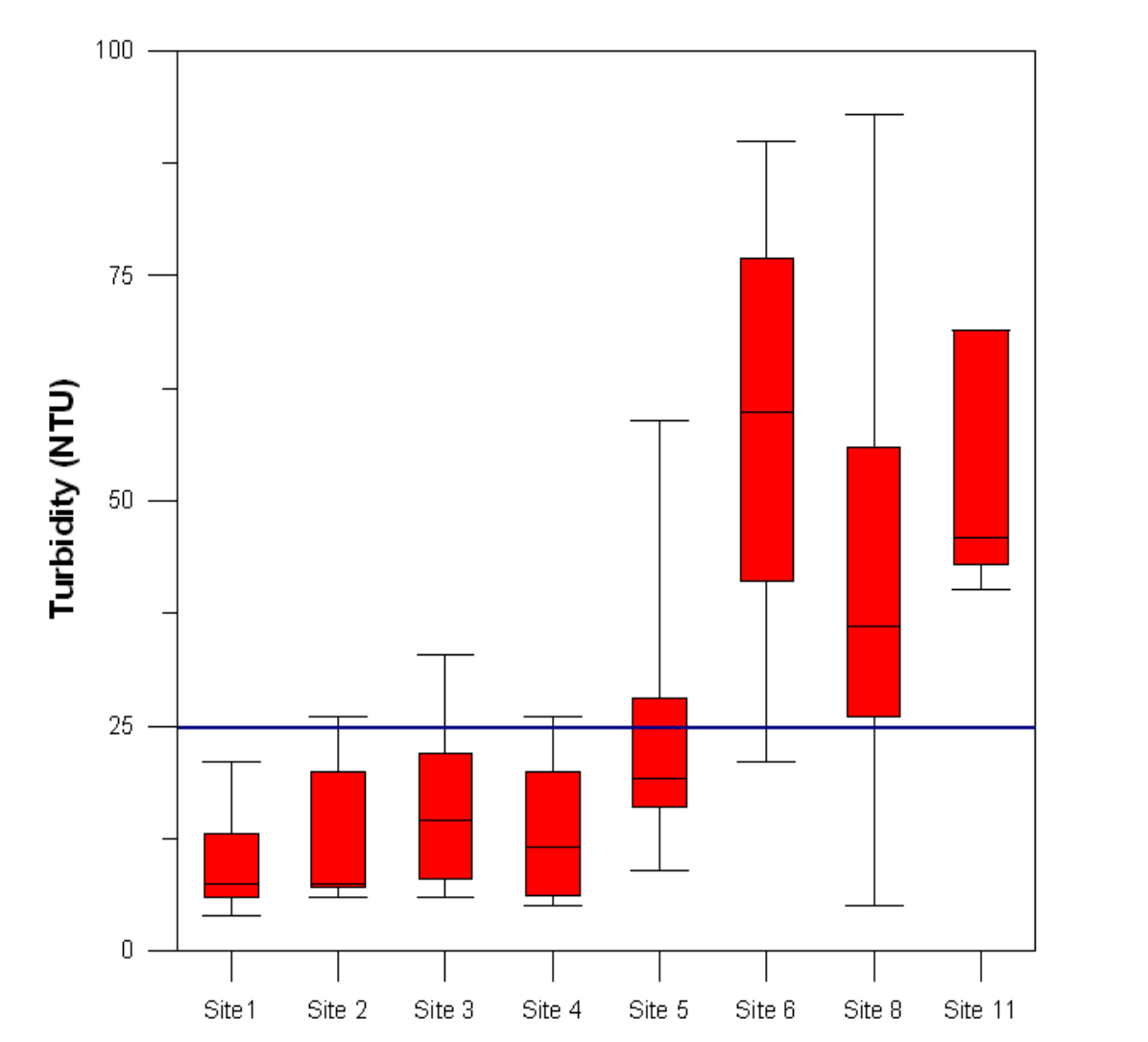
TMDL - 35% reduction of TN, TP and TSS to meet DO, turbidity and Chl-a WQS

http://www.deq.state.ok.us/wqdnew/tmdl/thunderbird/LakeThunderbirdFinalTMDL_ReportNov2013.pdf

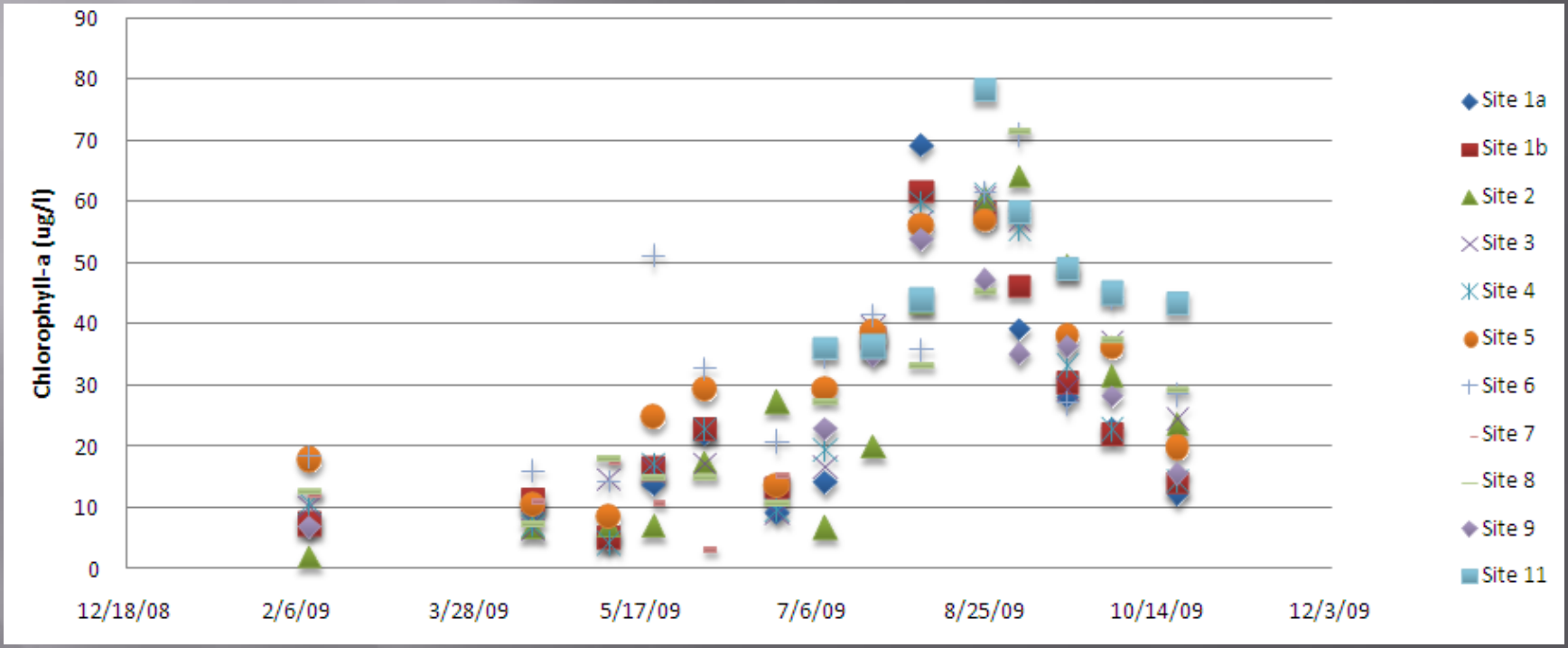
2009

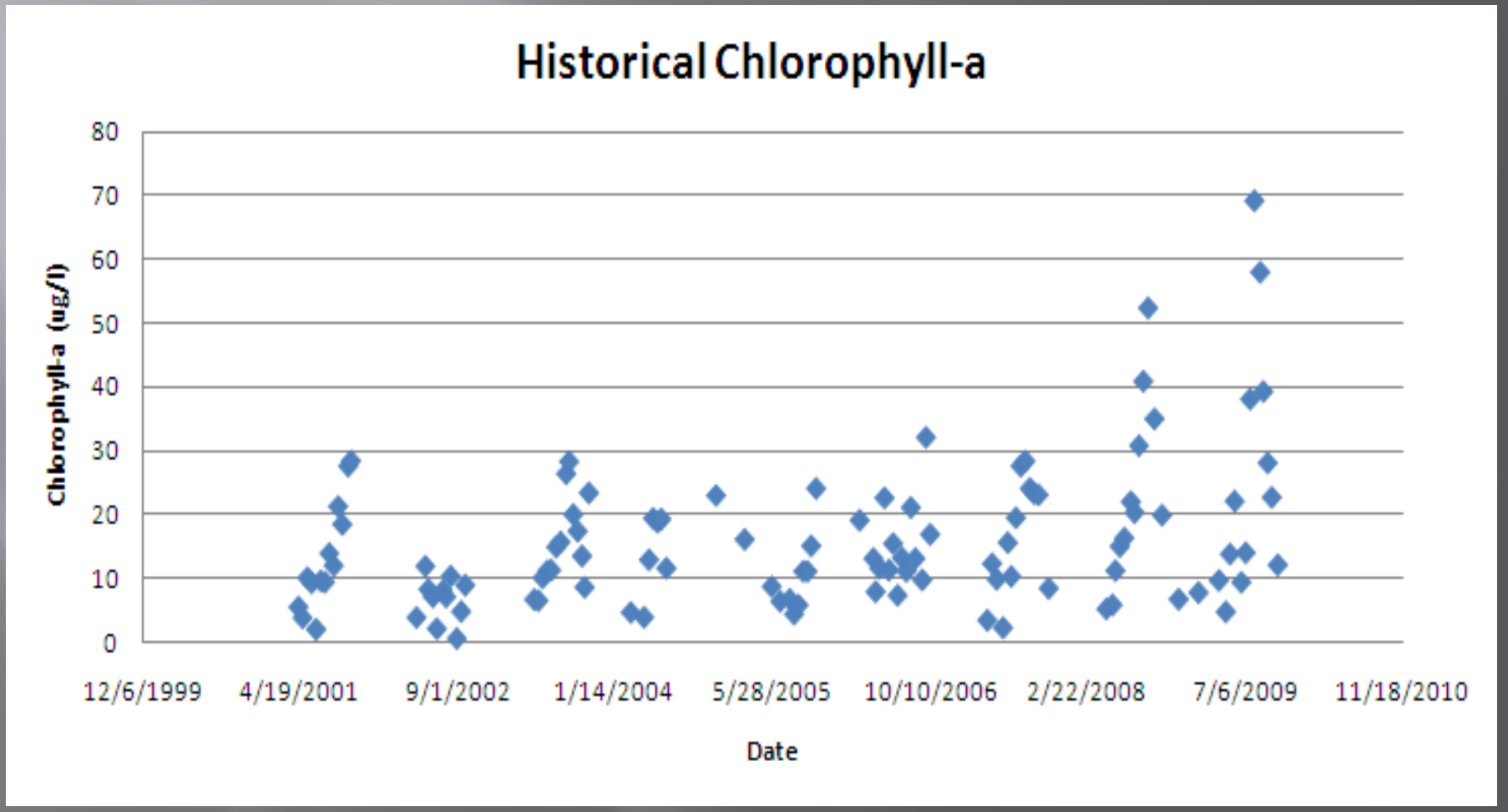

Dissolved Oxygen (Mg/L)
Depth (M)
-1
-3
-5
-7
-9
-11
-13
-15
11
10
9
8
6
4
2
1
0
7
4
4
2/9
2/23
3/9
3/24
4/6
4/20
5/4
5/18
6/1
6/15
6/29
7/13
7/27
8/10
8/24
9/7
9/21
10/5
10/19
Date

2009 Turbidity

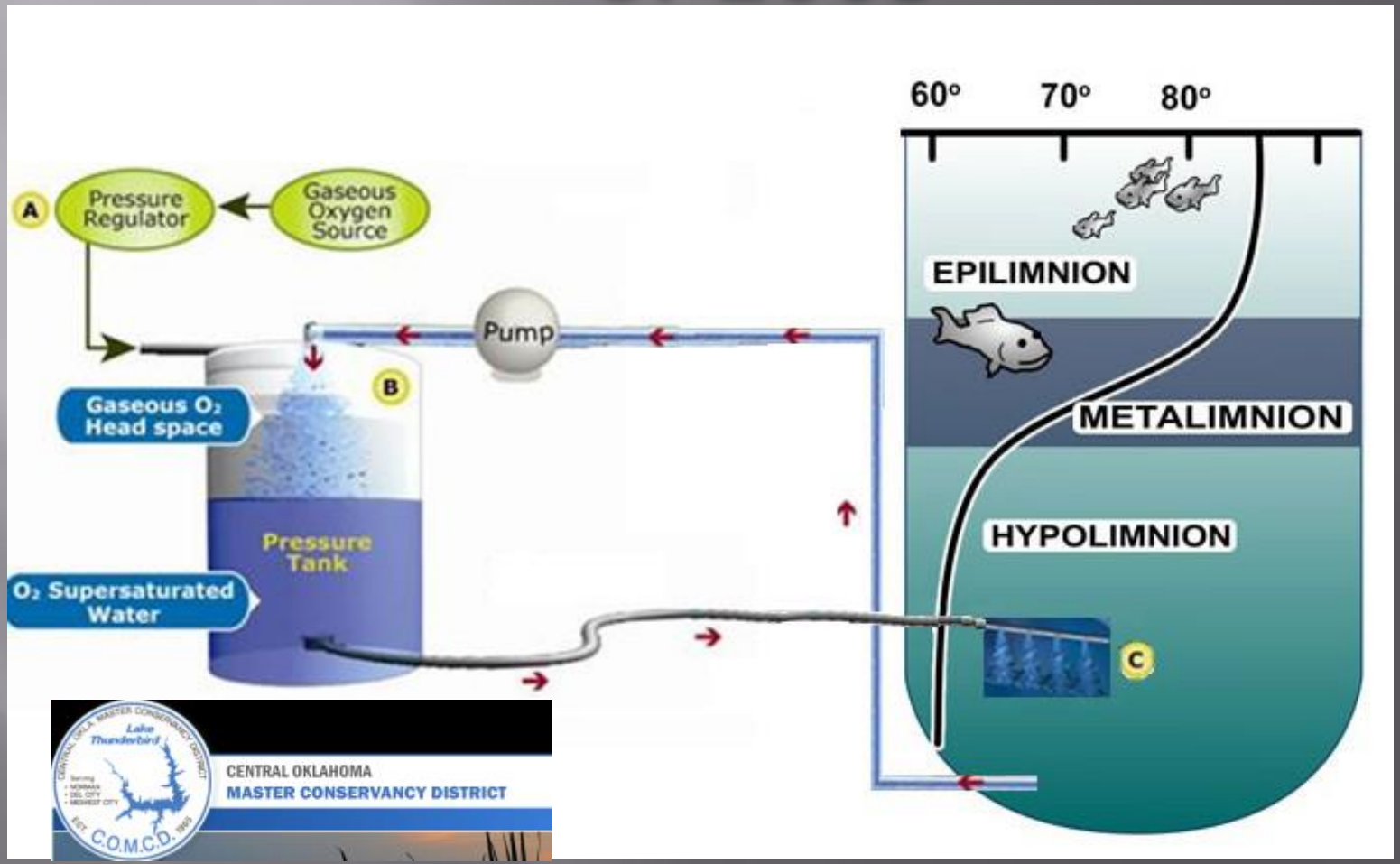


2009 Chlorophyll-*a* plot




Historical Chlorophyll-a
Chlorophyll-a (ug/l)
80
70
60
50
40
30
20
10
0
12/6/1999
4/19/2001
9/1/2002
1/14/2004
5/28/2005
10/10/2006
2/22/2008
7/6/2009
11/18/2010
Date

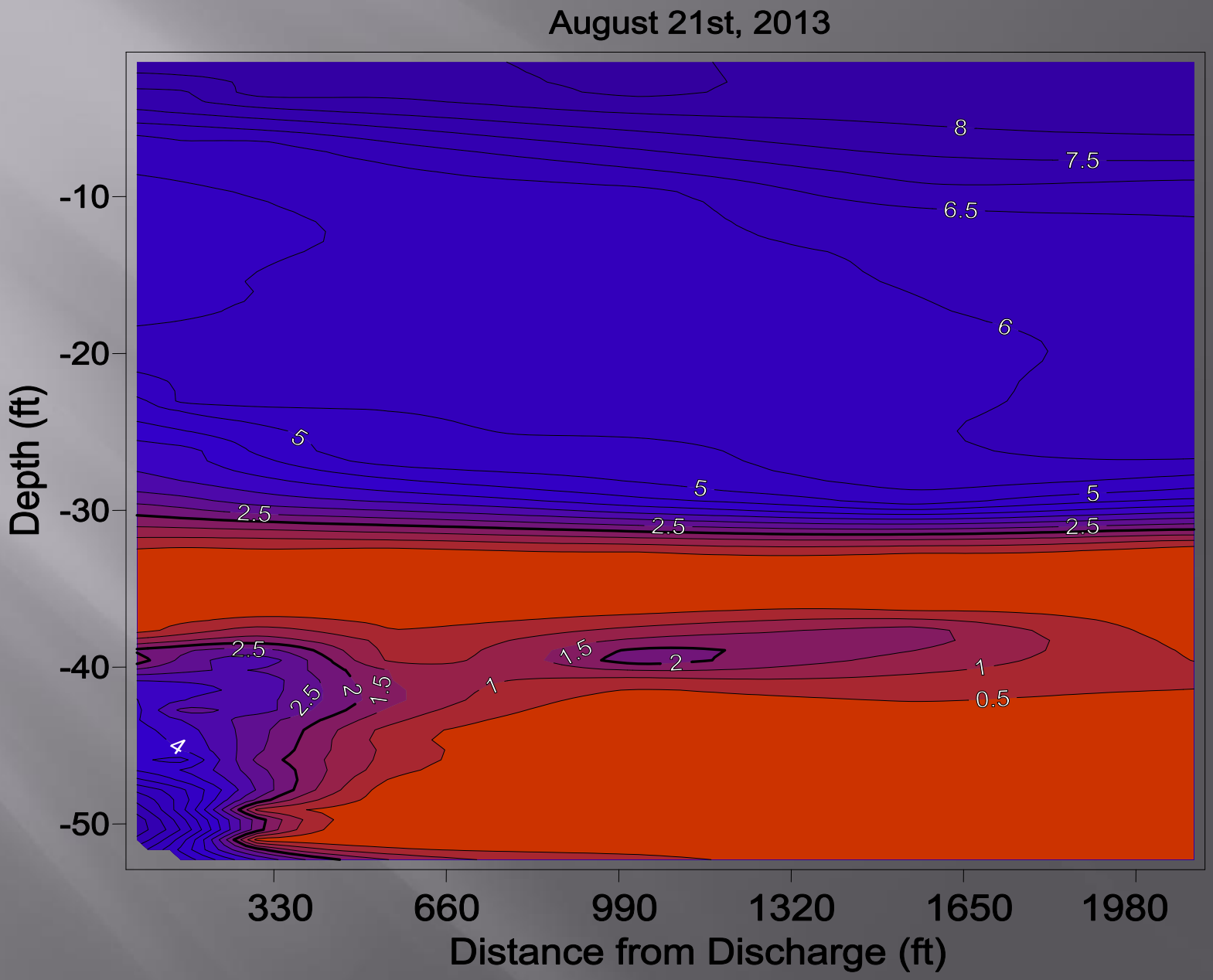
American Recovery and Reinvestment (ARRA) Act of 2009



SDOX Designed Functions:

- Direct effect:
  - Increase dissolved oxygen in hypolimnion without disruption of thermocline
  - Raise Oxidation-Reduction potential, as oxidant is provided to hypolimnion

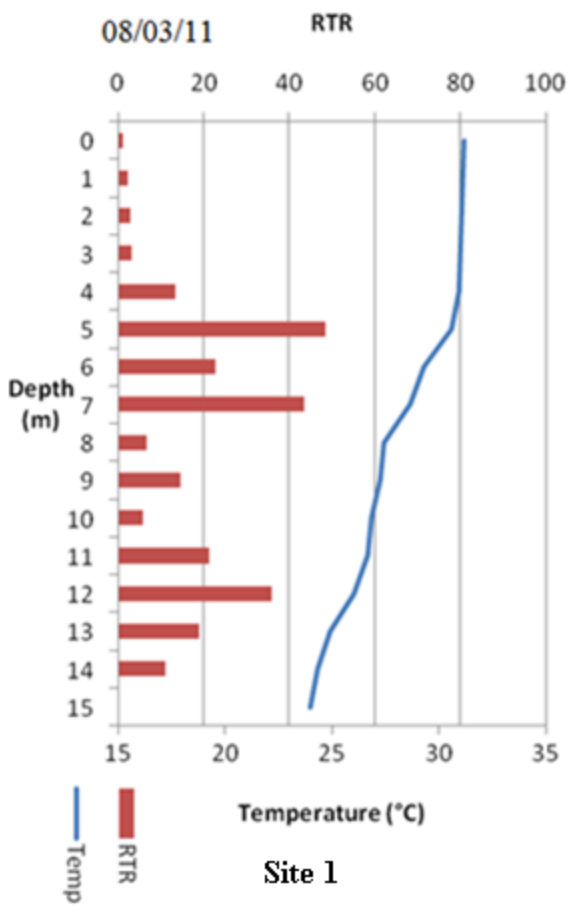
- Secondary effects
  - Reduce anaerobic mediated sediment phosphorous release (~20% total P load)
  - Reduce dissolved metals
  - Prevent turnover associated algae bloom, reduce TOC, lower drinking water treatment costs & T/O complaints


August 21st, 2013
Depth (ft)
-10
-20
-30
-40
-50
330
660
990
1320
1650
1980
Distance from Discharge (ft)
8
7.5
6.5
6
5
5
5
2.5
2.5
2.5
2.5
2
1.5
1
1.5
2
1
0.5
4

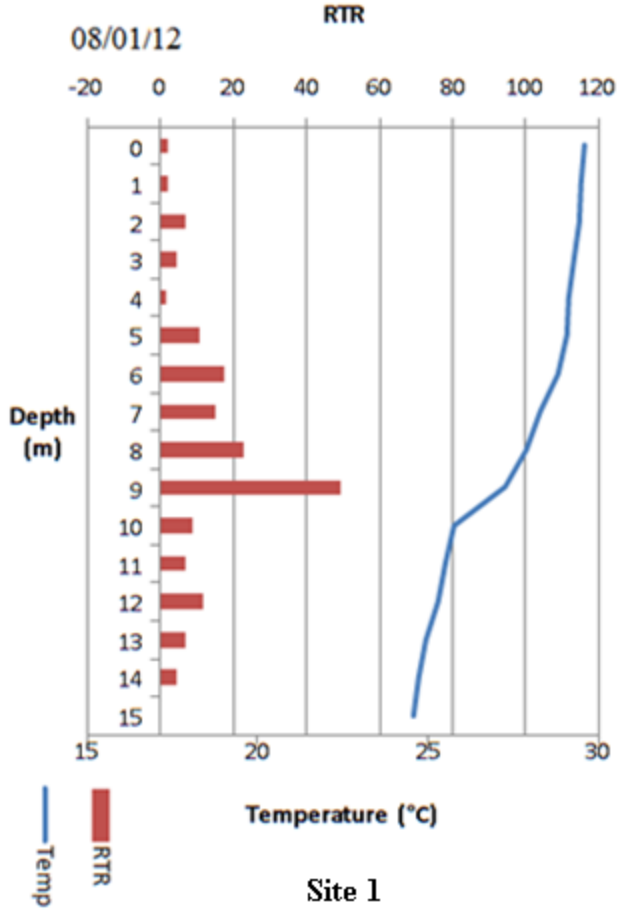
SDOX Impact Zone

Post Modification-Mixing confined to target zone

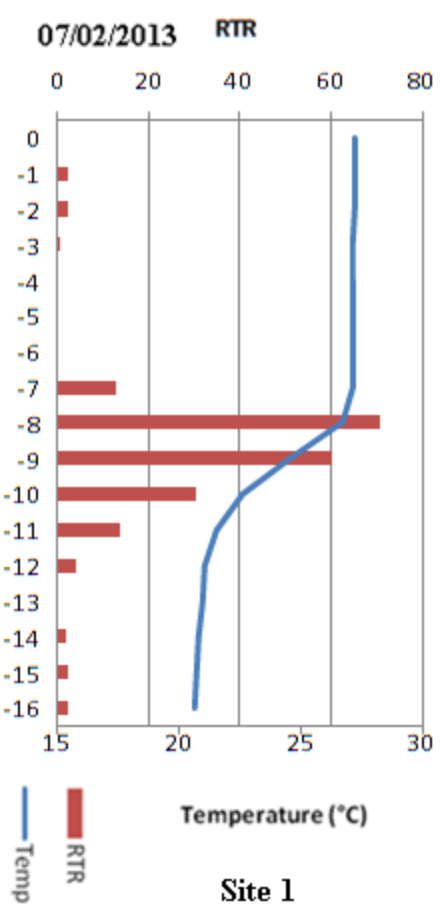
Old Set-Up



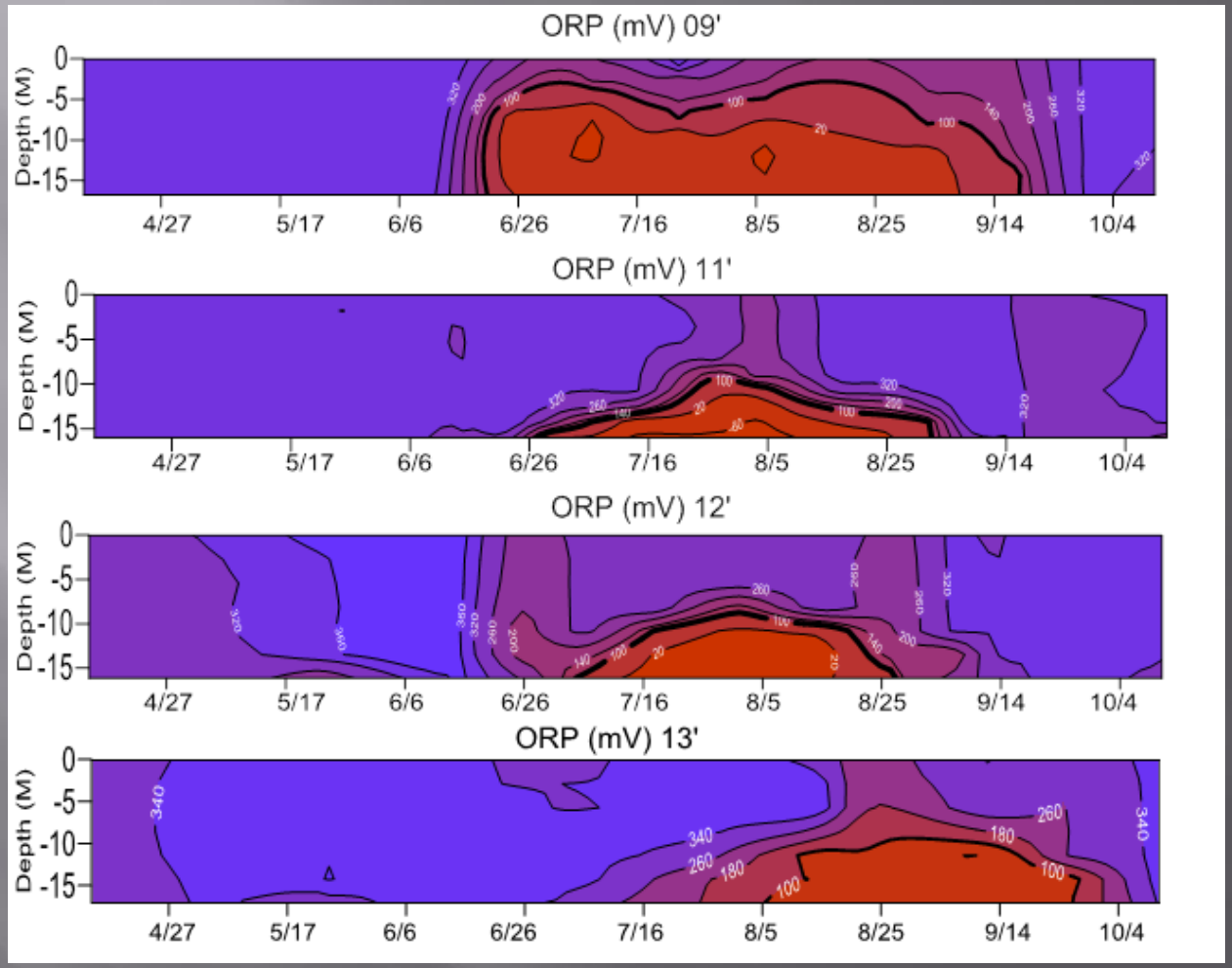
12’ New Set-Up



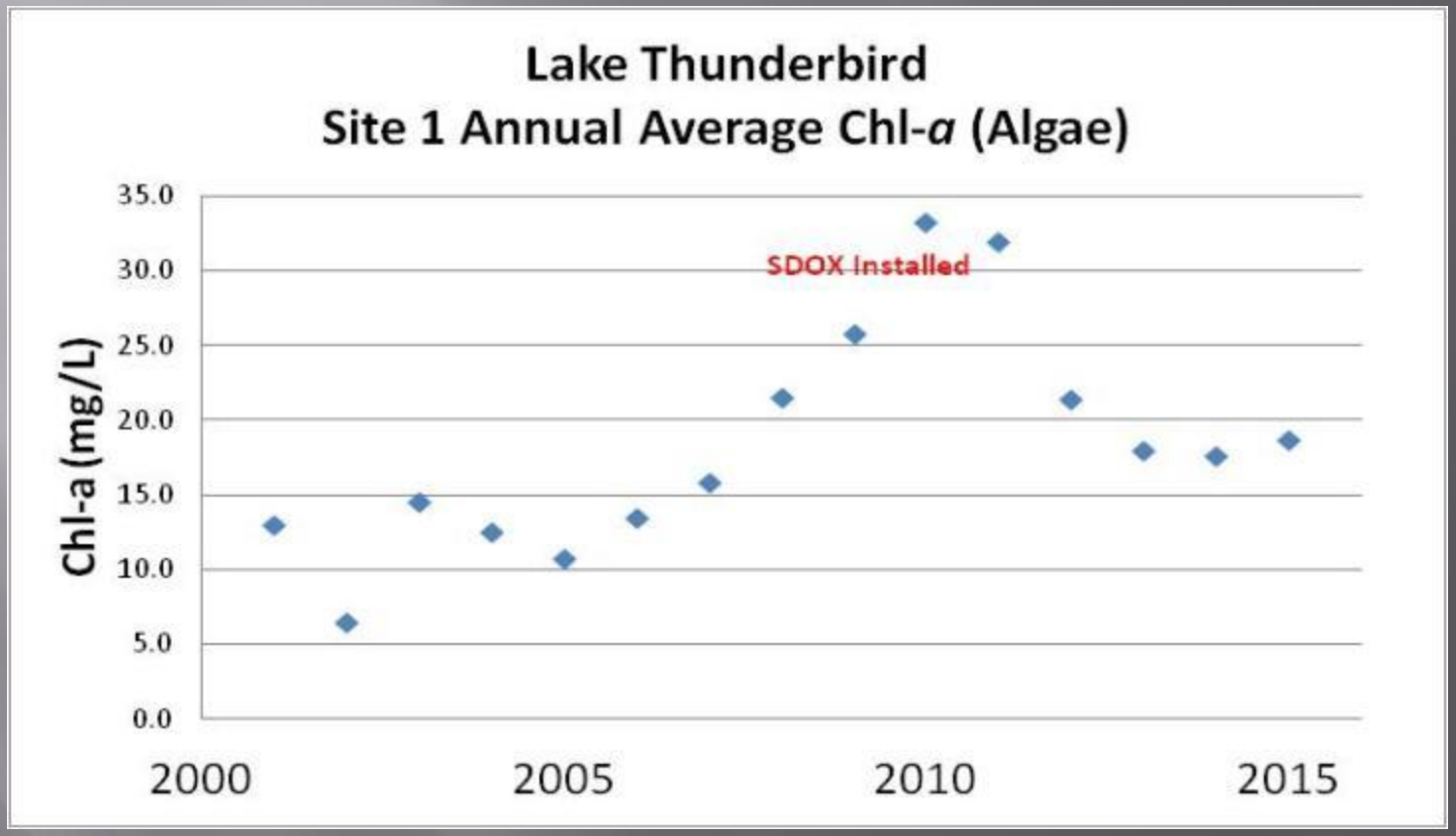
13’ New Set-Up



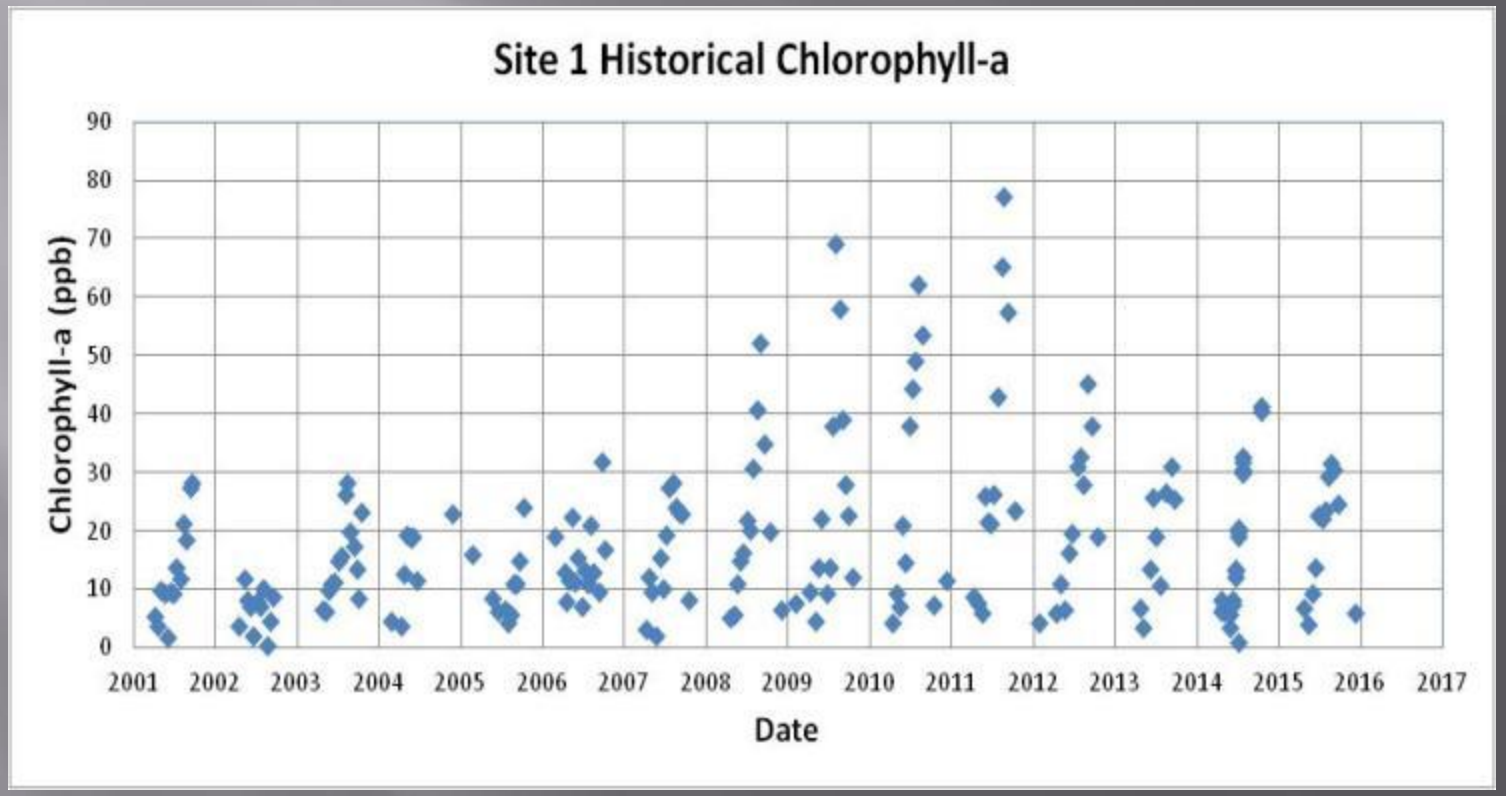
ORP most responsive to SDOX



SDOX Performance Measure



SDOX Performance Measure



SDOX Performance Measures

- % days operated (120 – 138 days)
- % capacity while in operation (5,200 lb/day)
- Sediment nutrient release (Nurnberg 1994)

$$\text{Load} = RR_{sed} * AF$$

$$Log(RR)_{sed} = 0.8 + 0.76 \log(TP_{sed})$$

$$AF = \sum_{i=1}^{n} (t_i * a_i) / A_o$$

Where
- n = number of time intervals
- t = time interval
- a = area of anoxic sediment within time
- A_o = area of lake

SDOX Performance Measures

2014

- Operated 89% of time (120 of 135 days)
- 35% capacity (1,820 lb O_2/day avg.)
- 217,627 lb O_2 added to Lake Thunderbird

2015

- Operated 66% of time (87 of 132 days)
- 66% capacity (3,433 lb O_2/day avg.)
- 297,245 lb O_2 added to Lake Thunderbird

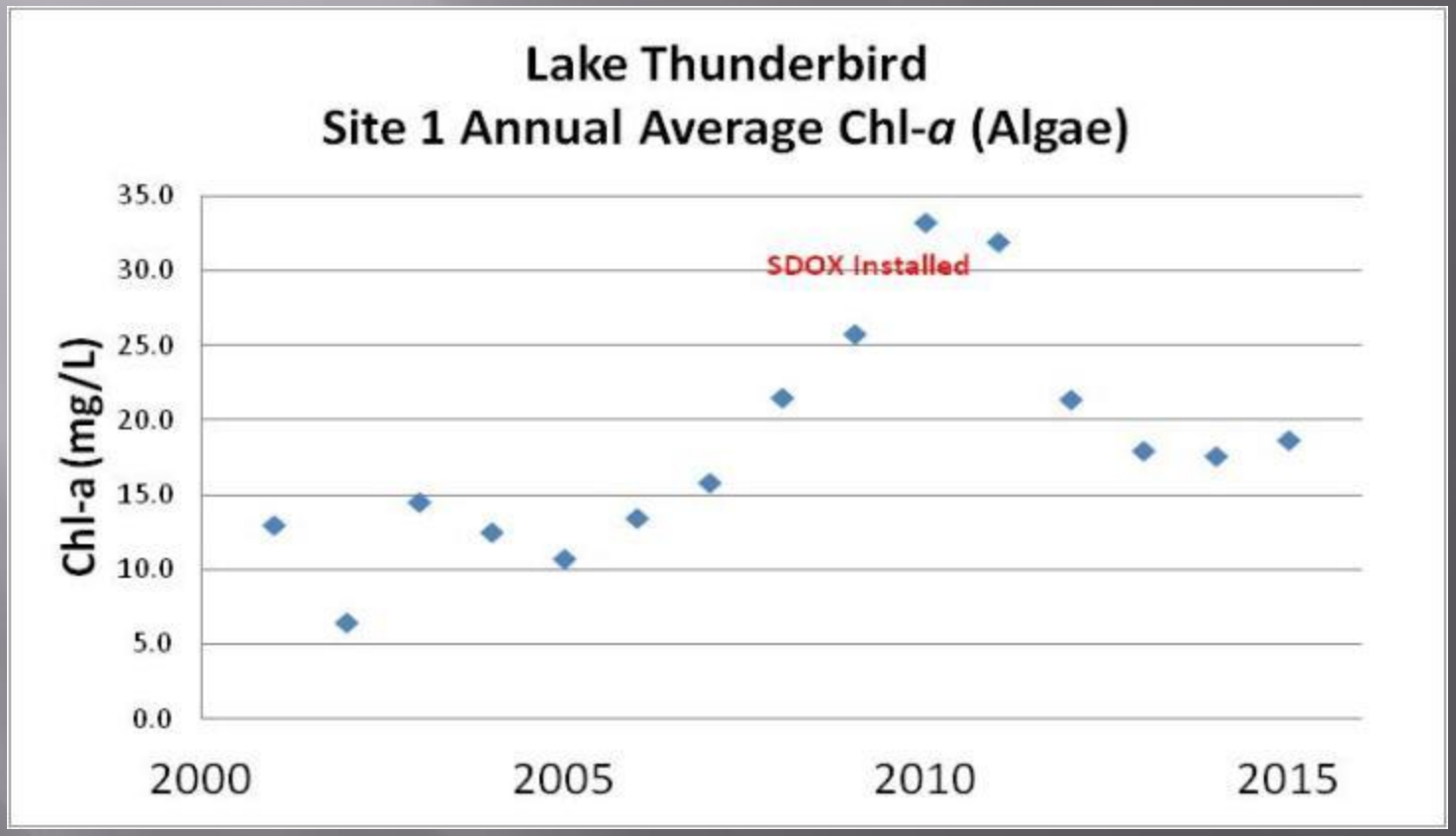
SDOX Performance Measure

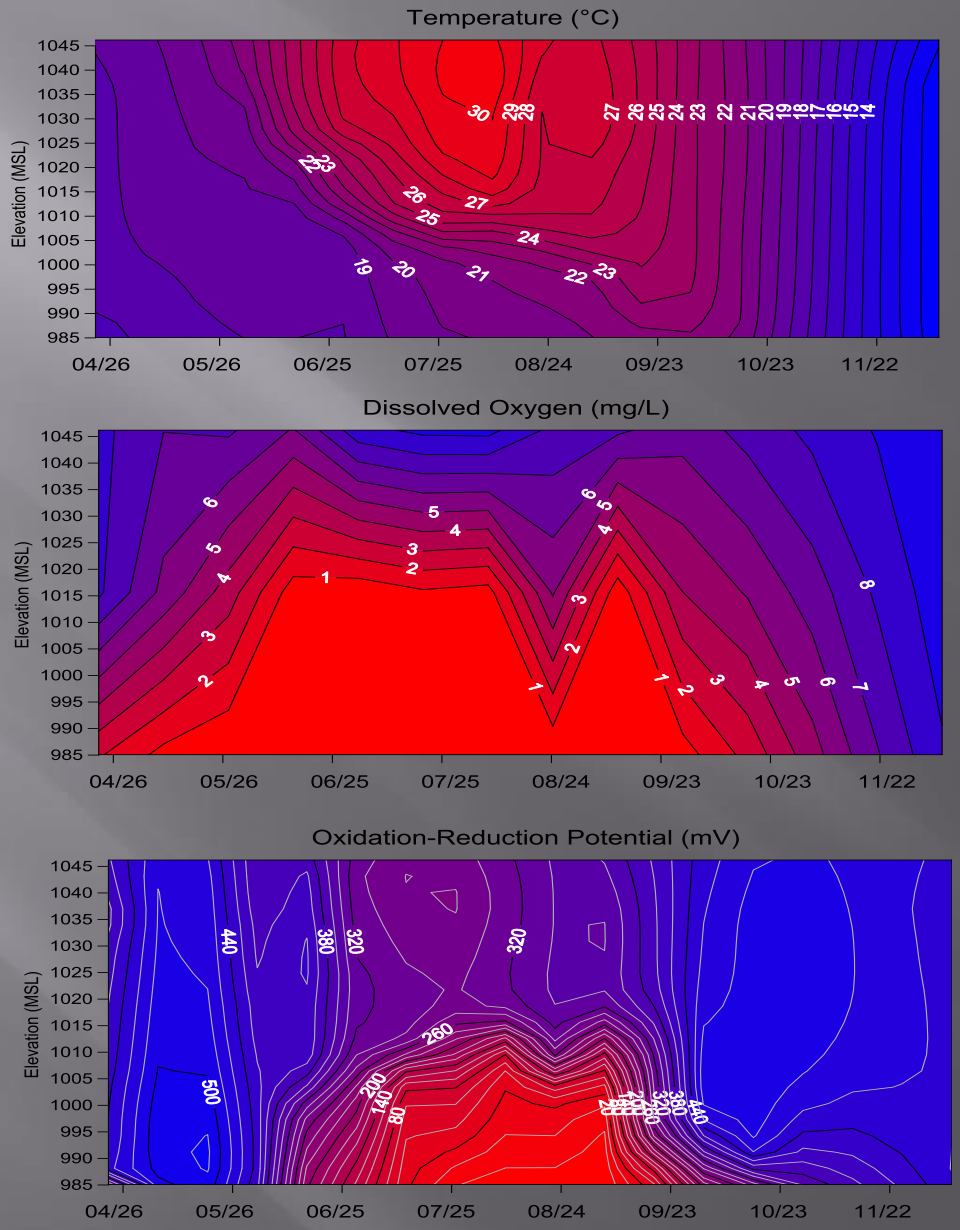
Anoxic Factor (AF)

Load = RR_{sed} * AF

Year	AF (day-^{1})	RPD
2005	41.99	-27%
2006	26.87	19%
2007	33.66	-2%
2008	31.89	3%
2009	30.76	7%
05 - 09 Average	***33.03***	**0%**
2011	21.47	35%
2012	25.50	23%
2013	13.07	60%
2014	38.26	-16%
2015	56.28	-70%

SDOX Performance Measure



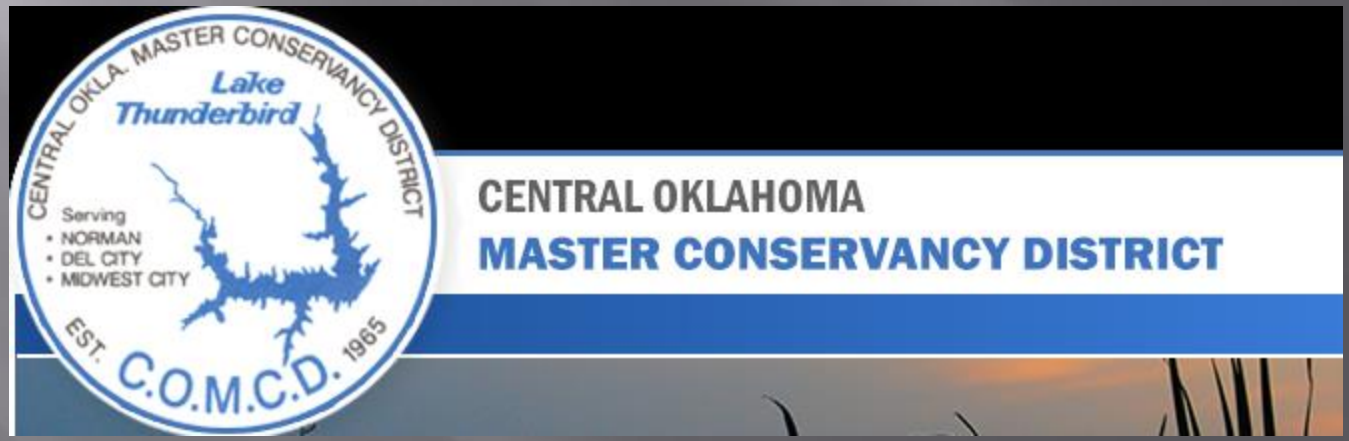

Temperature (°C)
Elevation (MSL)
1045
1040
1035
1030
1025
1020
1015
1010
1005
1000
995
990
985
04/26
05/26
06/25
07/25
08/24
09/23
10/23
11/22
Dissolved Oxygen (mg/L)
Oxidation-Reduction Potential (mV)

Conclusions

- No one metric “best” to describe SDOX performance
- 2015 was “epic” in terms of loading
- 2015 could have been much worse
- Lots –O-work to do to “fix” this lake

QUESTIONS

Thank you to the COMCD for caring not just about raw water quality but also Lake Thunderbird



Recommendations

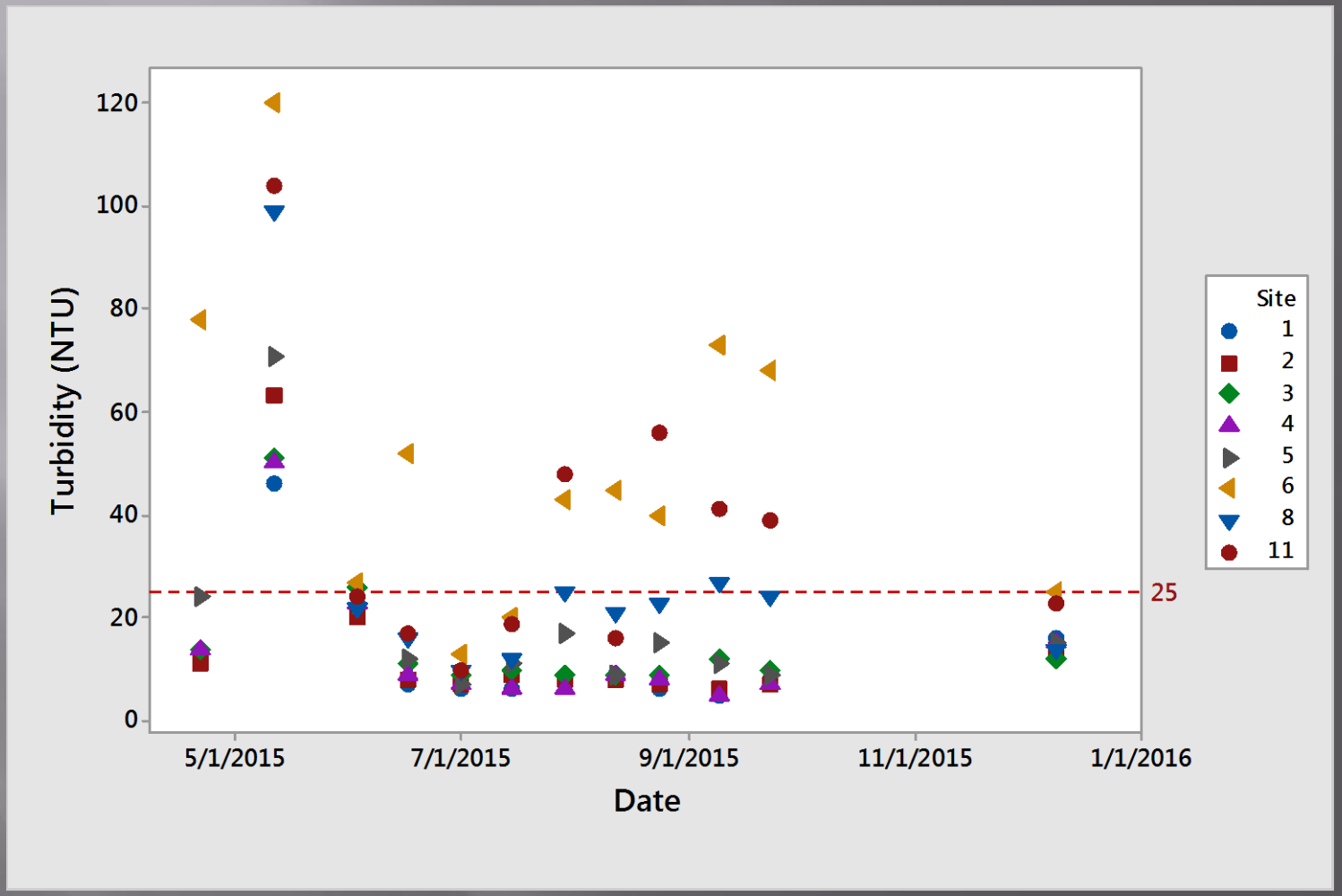
In-lake Measures

- Assess ability of SDOX to deliver O_2
- Assess sediment oxygen demand
- ID areas of sediment suspension (shore and lake)

Watershed Measures

- Adopt Low Impact Development (LID) practices as part of how the COMCD does business
- Encourage municipalities within the watershed to retrofit when possible and implement new LID
- Apply for BoR funds as a clearinghouse to foster LID within the watershed (http://www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=52996)

http://lid-stormwater.net/index.html
http://www.lowimpactdevelopment.org/index.htm


Turbidity (NTU)
120
100
80
60
40
20
0
5/1/2015
7/1/2015
9/1/2015
11/1/2015
1/1/2016
Date
25
Site
1
2
3
4
5
6
8
11