City of Lakewood

Waughop Lake Management Plan

November | 2016

Waughop Lake Has Long History of Cyanobacteria Blooms

Historic farming contributed substantial nutrient loads to lake

- Pigs and cattle
- Sediments used for fertilizer

Cyanobacteria concerns:

- >25,000 ug/L microcystin in 2011 (WA ECY); 2nd highest in WA
- Microcystin found in fish tissue

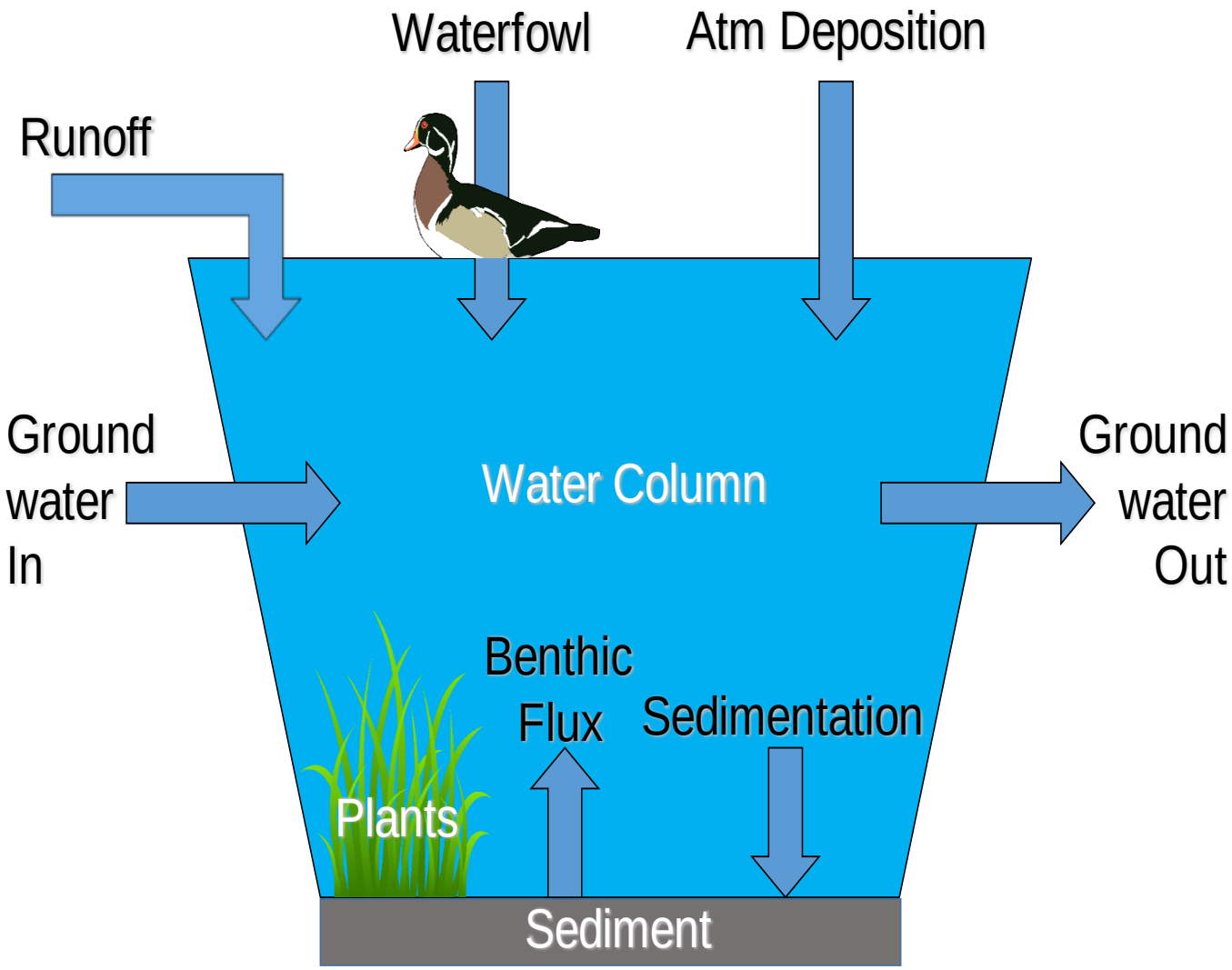
City of Lakewood applied for state grant to develop Waughop Lake Management Plan

Why Worry about Blue-Green Algae Blooms?

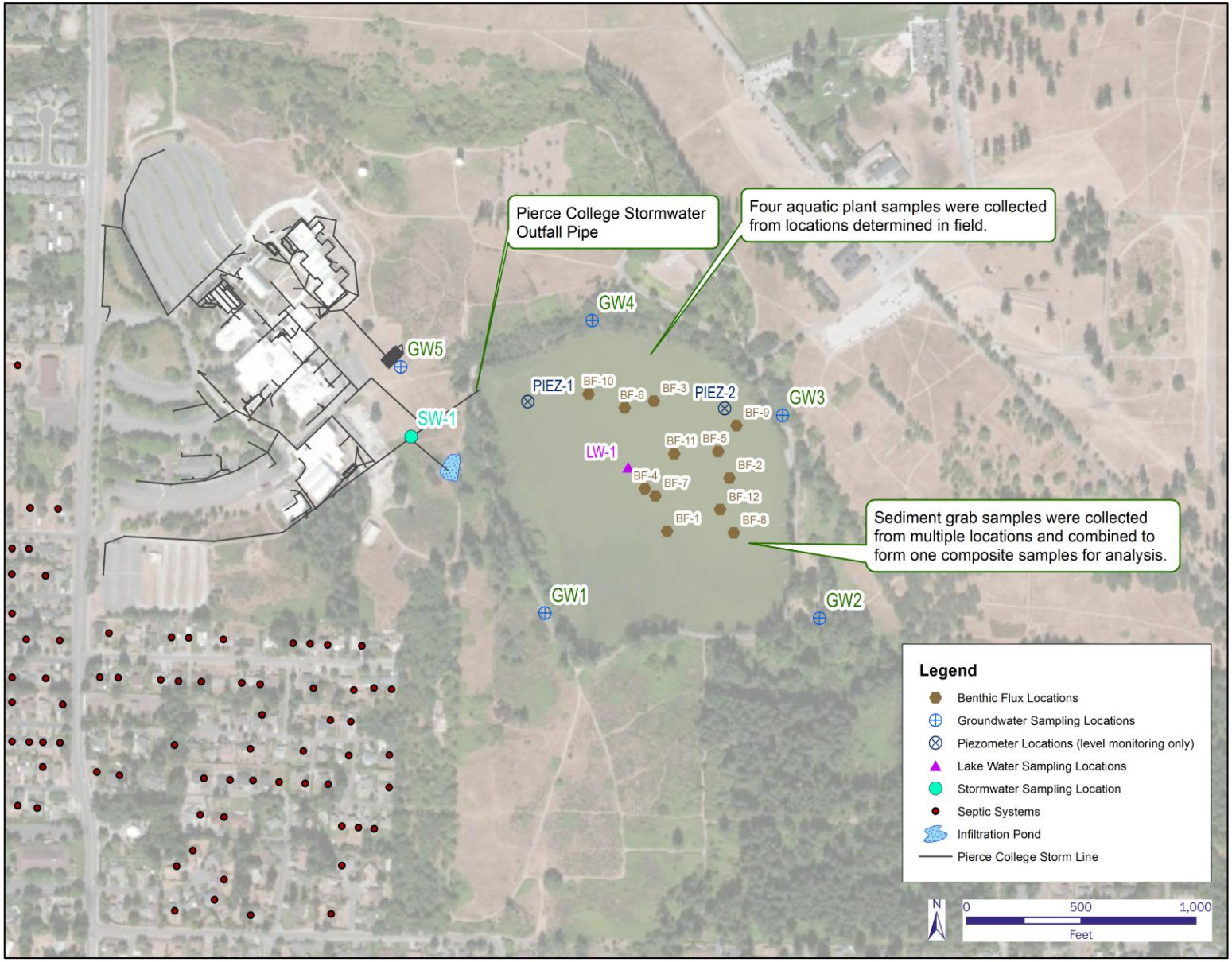
- Unsightly and noxious odors
- Can be toxic to wildlife, pets and swimmers
- Can affect lake water chemistry
- Dead algae can deplete oxygen from bottom waters

Algae bloom in Waughop Lake

Waughop Lake Conceptual Model



Waughop Lake Monitoring Program 2014-15



Waughop Monitoring Plan

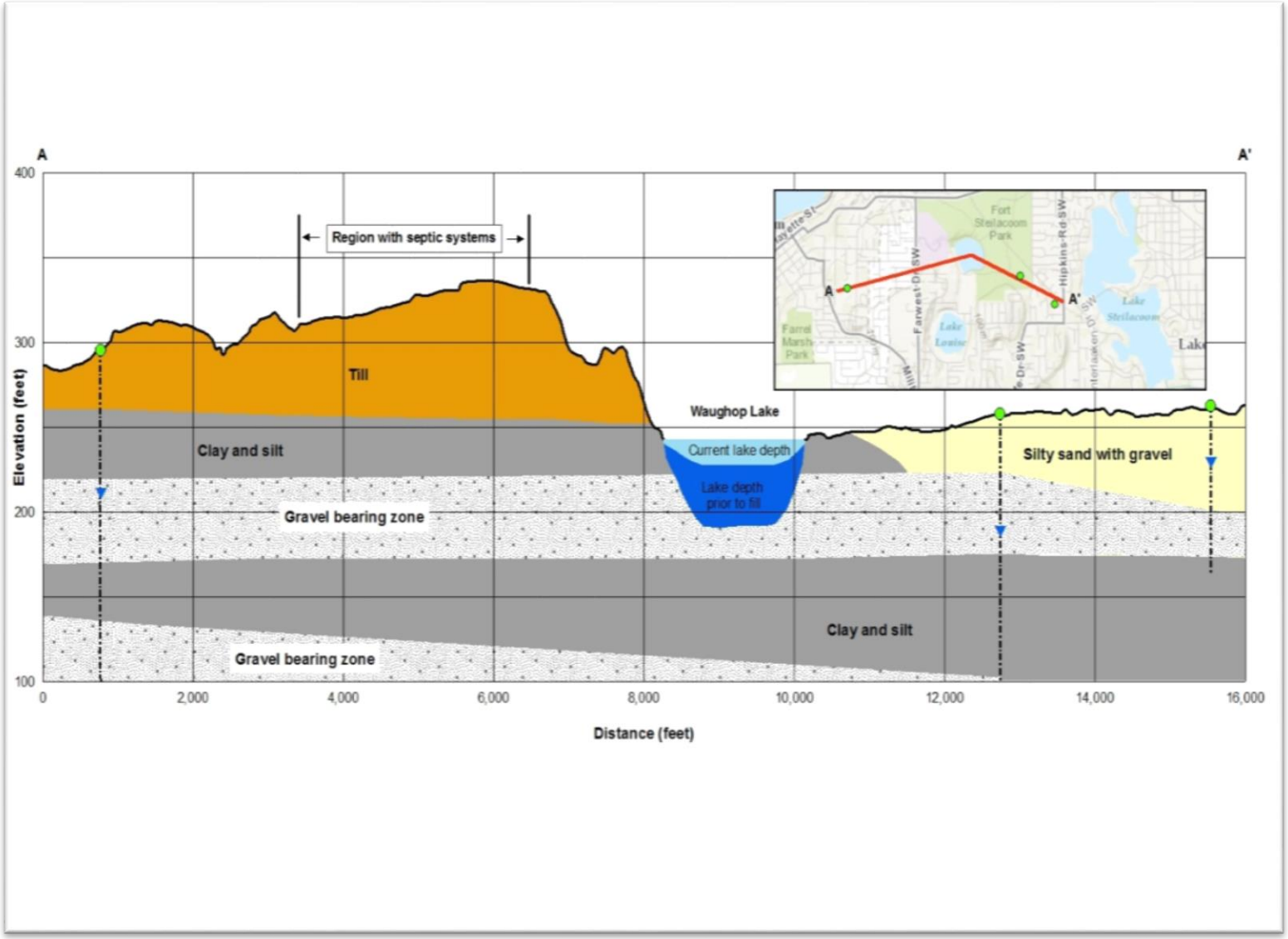
Table 2-1. Sampling Locations and Constituents

Sample type	Site ID	Level	TP	TN	Alkalinity	SRP	% solids	Particle size	Phyto-plankton	Zoo-plankton	Chlorophyll *a*	Water temp	pH	DO	Conductivity	Transparency (Secchi depth)	Macro-phyte species ID	Biomass estimate
Groundwater	GW-1, GW-2, GW-3, GW-4, GW-5	✓	✓									✓ [a]	✓ [a]	✓ [a]	✓ [a]			
Lake/ groundwater	Piez-1, Piez-2	✓																
	LW-1	✓	✓ [b]	✓ [b]	✓	✓ [b]			✓	✓	✓	✓	✓	✓	✓	✓		
Aquatic plants	Plant-1, Plant-2, Plant-3		✓	✓													✓	✓
Lakebed sediment	Sed-1		✓	✓			✓	✓	!	!	!	!	!	!	!	!	!	!
Benthic flux	Flux-1 through Flux-12 [c]		✓	✓ [d]		✓						✓	✓	✓	✓			
Stormwater	SW-1		✓	✓		✓ [e]	!	!	!	!	!	!	!	!	!	!	!	!

Waughop Monitoring Plan

Table 2-2. Sampling Locations and Frequencies			
Media	Sampling location	Methods	Frequency
Groundwater	Five shoreline monitoring wells (GW-1, GW-2, GW-3, GW-4, and GW-5)	• Purge then collect grab sample using pump	• Quarterly
Waughop Lake water	LW-1: One location in the middle of the lake	• In-situ vertical (depth) profiling using datasonde • Grab sampling from surface and bottom [a]	• Twice per month during the summer months • Monthly during the remainder of the year.
Aquatic plant	Three locations throughout the lake (Plant-1, Plant 2, Plant 3)	• Visual, plant rake	• 1x during maximum plant growth (September 2015)
Lakebed sediment	Three grab sample locations combined to form one composite sample (Sed-1)	• Use clamshell sampler to collect one composite sample from each area	• Once during summer
Benthic flux	Twelve locations throughout lake (Benthic Flux-1 to Benthic Flux-12) [b]	• Datasonde and grab (pump)	• During July, August and September 2015
Stormwater	One location from the Pierce College storm drainage line (SW-1)	• Grab sample	• Four storm events [c]

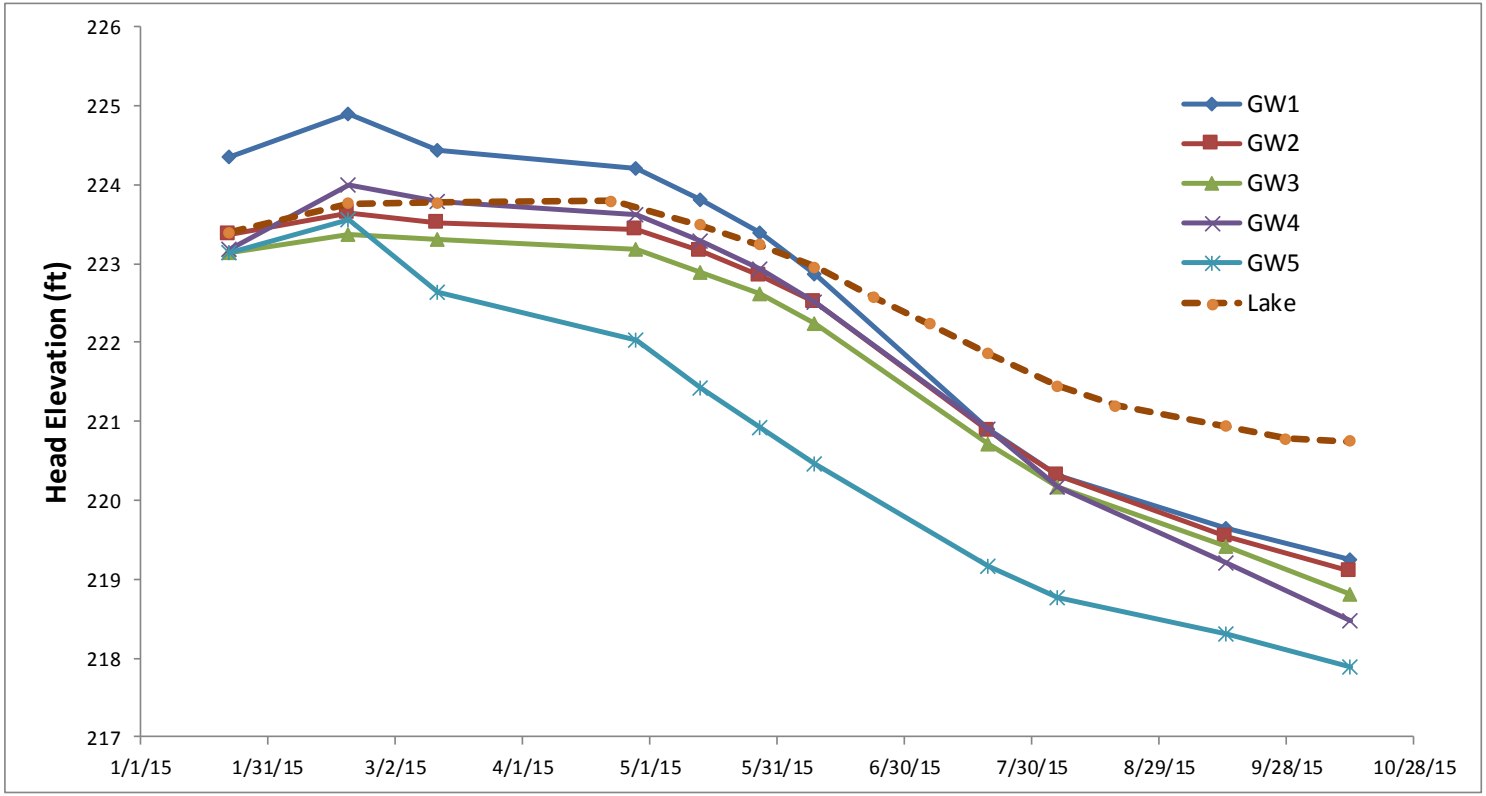
Waughop is a Natural "Kettle" Lake Fed by Rain, Groundwater, and Stormwater



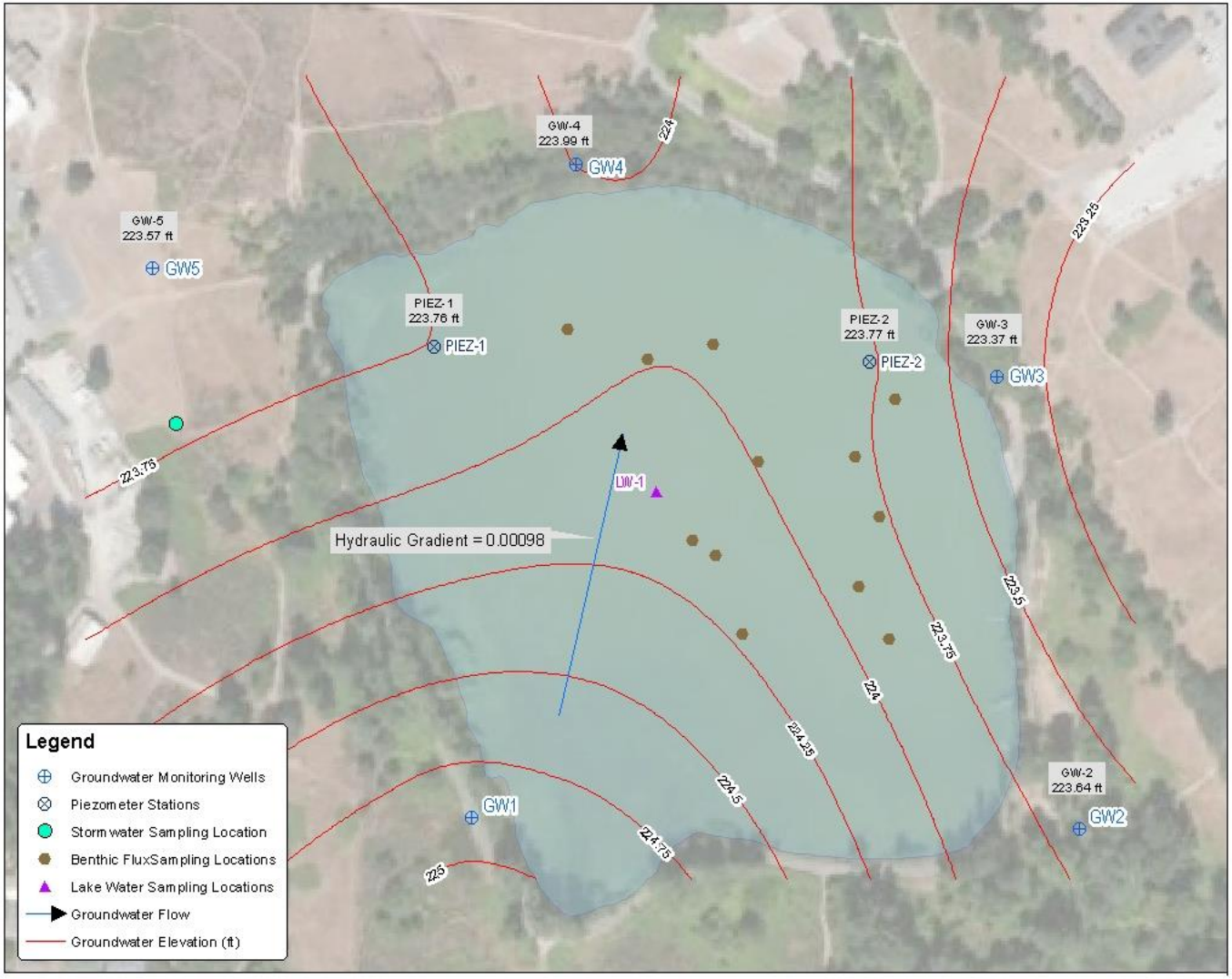
Waughop Lake Sediment Particle Size Distribution

Lakebed Sediment Sample % by Particle Size (µm)										
Sample location	Particle Diameter									
	0.4	4	8	15	31	63	125	250	500	1,000
Subsample-1	0.82	1.6	4.7	15	28	29	16	3.5	0.27	0
Subsample-2	0.96	1.9	5.5	17	29	26	14	3.2	0.1	0
Subsample-3	1.0	2.1	6.0	18	30	25	13	2.2	0.92	0.01
Mean	**0.94**	**1.8**	**5.4**	**16**	**29**	**27**	**14**	**3.0**	**0.43**	**0.01**
Cumulative	**0.94**	**2.8**	**8.3**	**25**	**54**	**81**	**96**	**99**	**99**	**100**

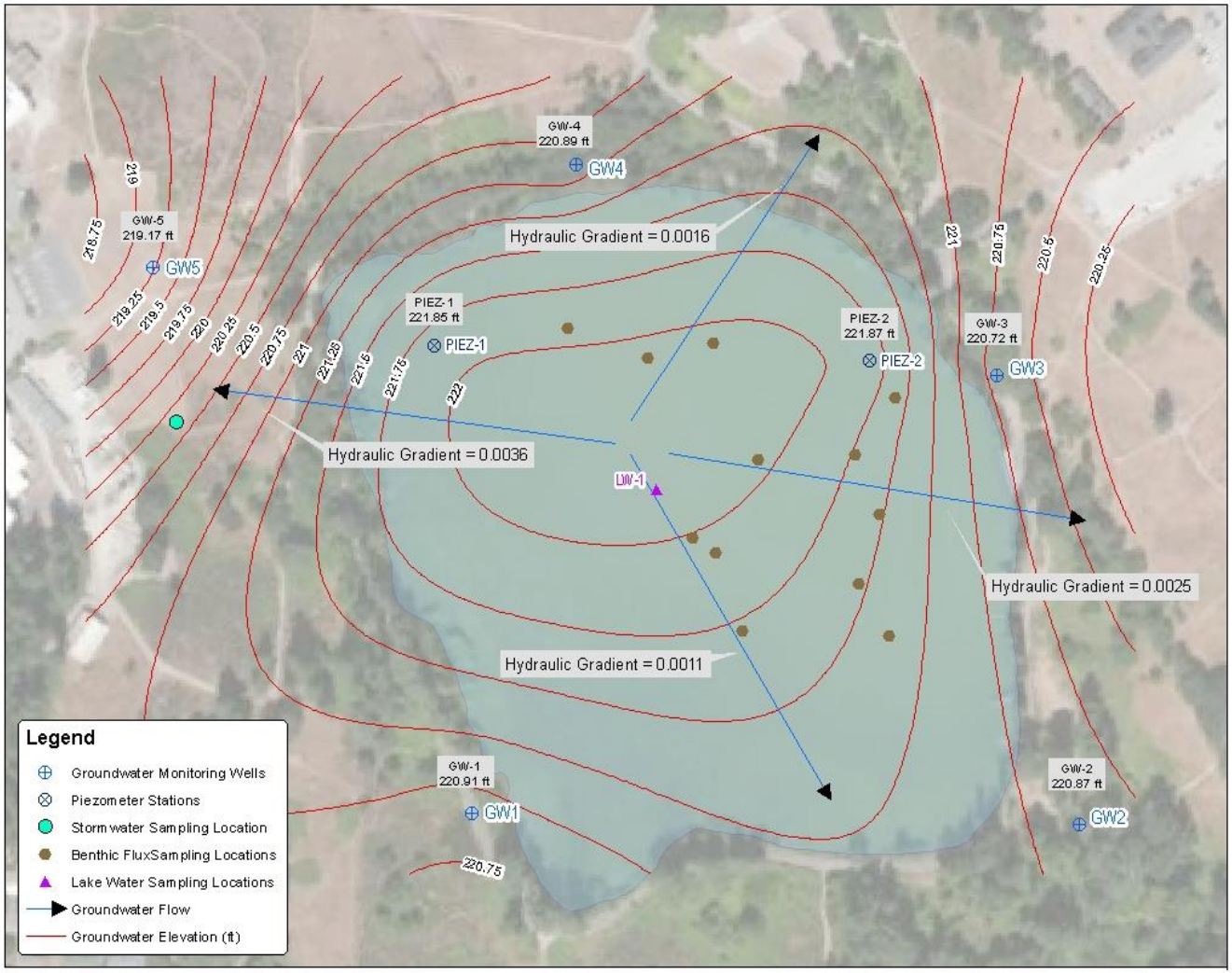
Mostly a losing lake
Poor aquifer connectivity



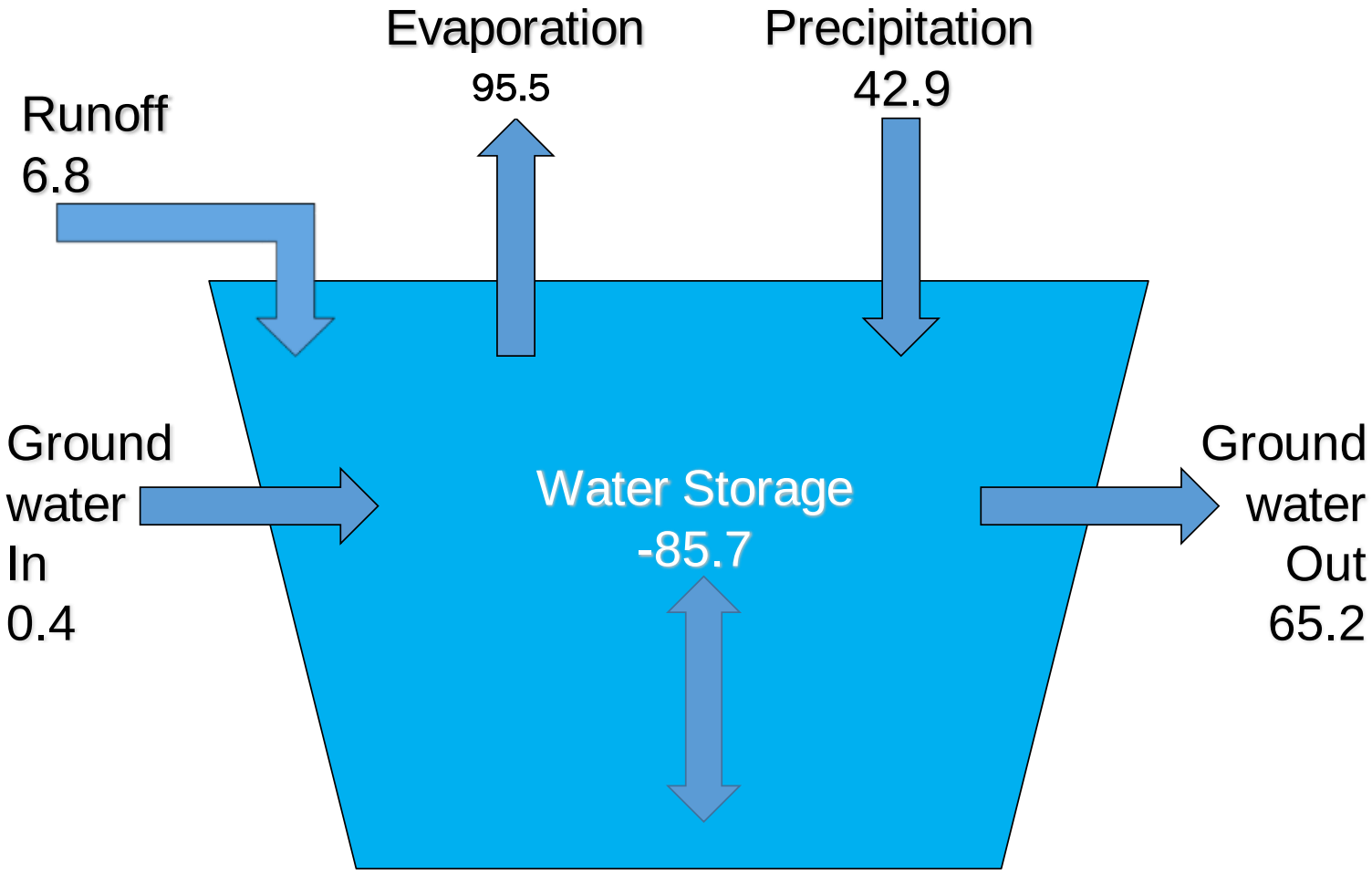
Groundwater Direction – February 2015



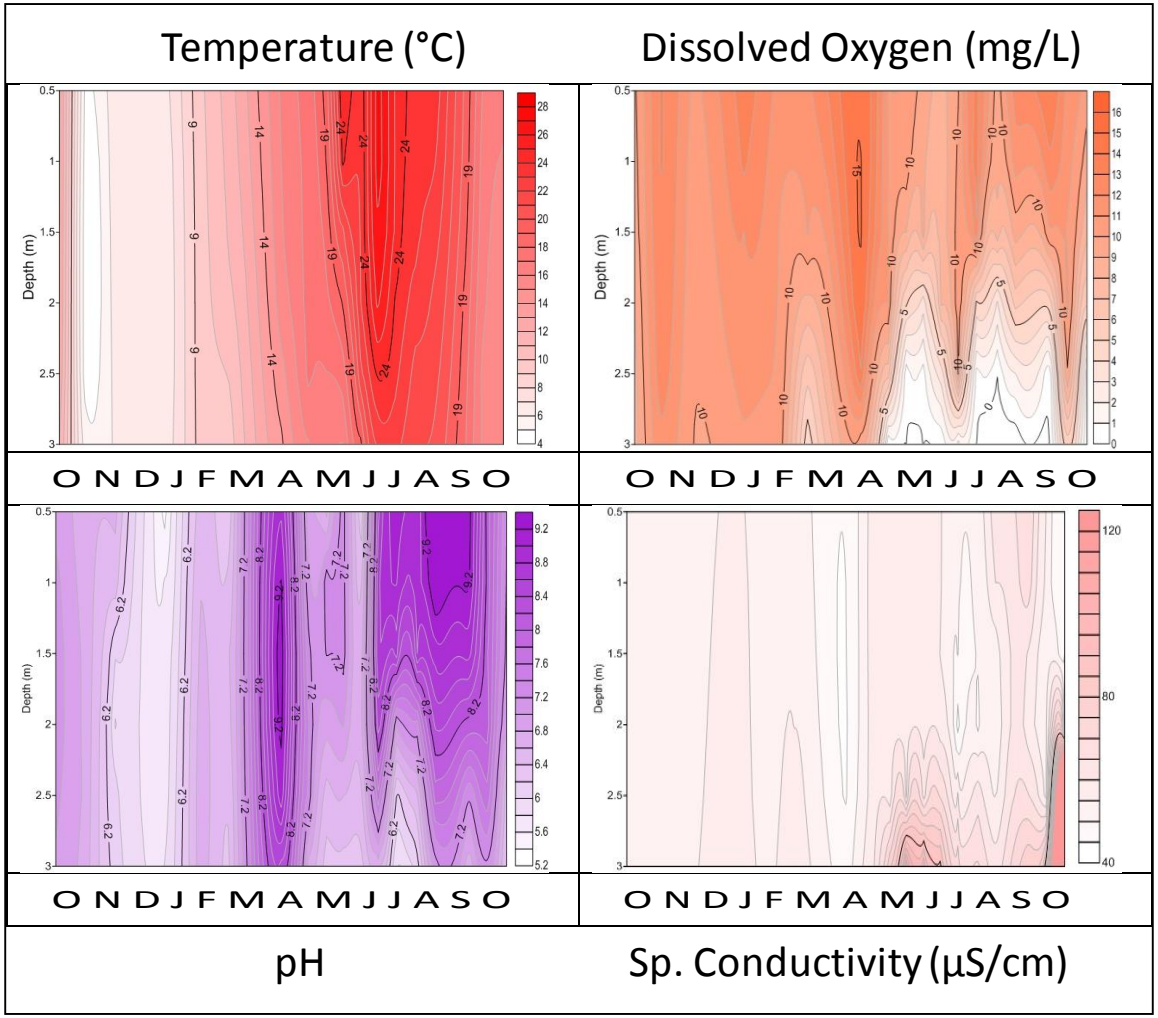
Groundwater Direction – July 2015



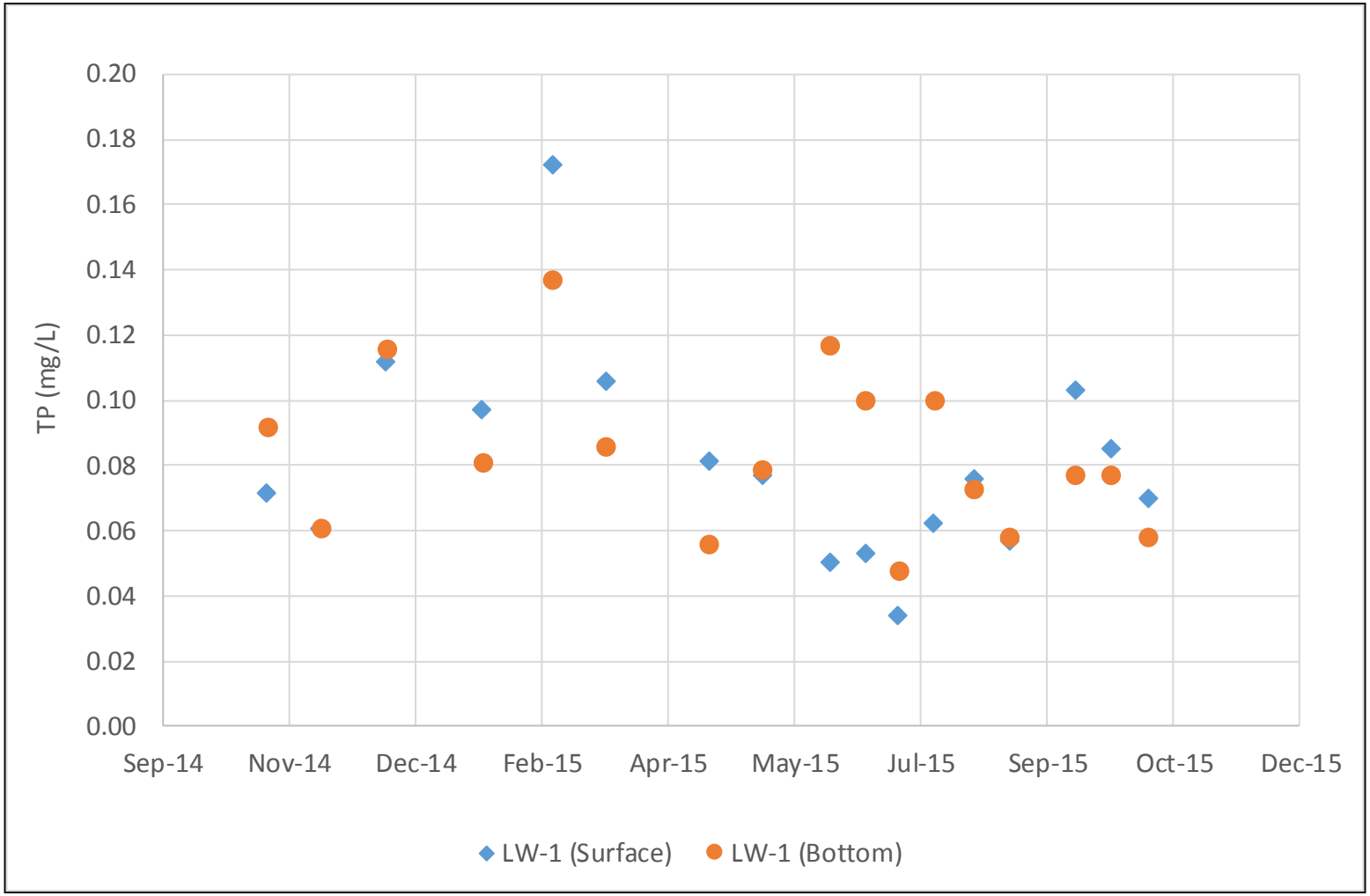
Hydrology Model Summary (ac-ft)



Waughop Lake Vertical Water Quality Profiles (10/14 to 10/15)



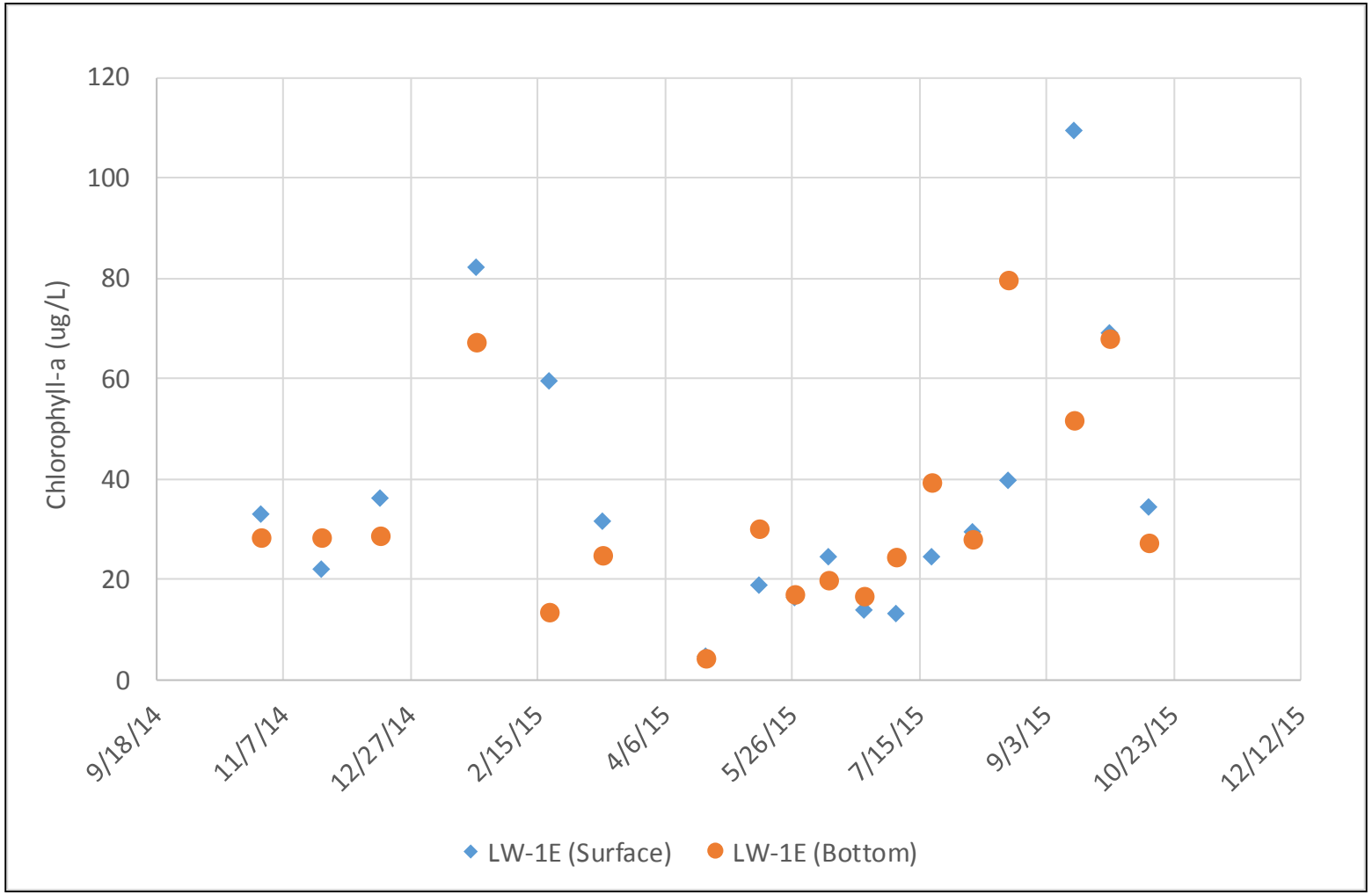
Total Phosphorus in Waughop Lake Water Samples



Phytoplankton Composition in Waughop Lake Water Samples

Percent abundance of phytoplankton in Waughop Lake		
	Cyanophyta	Other
October 2014	26%	74%
November 2014	17%	83%
December 2014	42%	58%
January 2015	64%	36%
February 2015	45%	55%
March 2015	53%	47%
April 2015	40%	60%
May 2015	43%	57%
June 2015	41%	59%
July 2015	87%	13%
August 2015	62%	38%
September 2015	81%	19%
October 2015	62%	38%

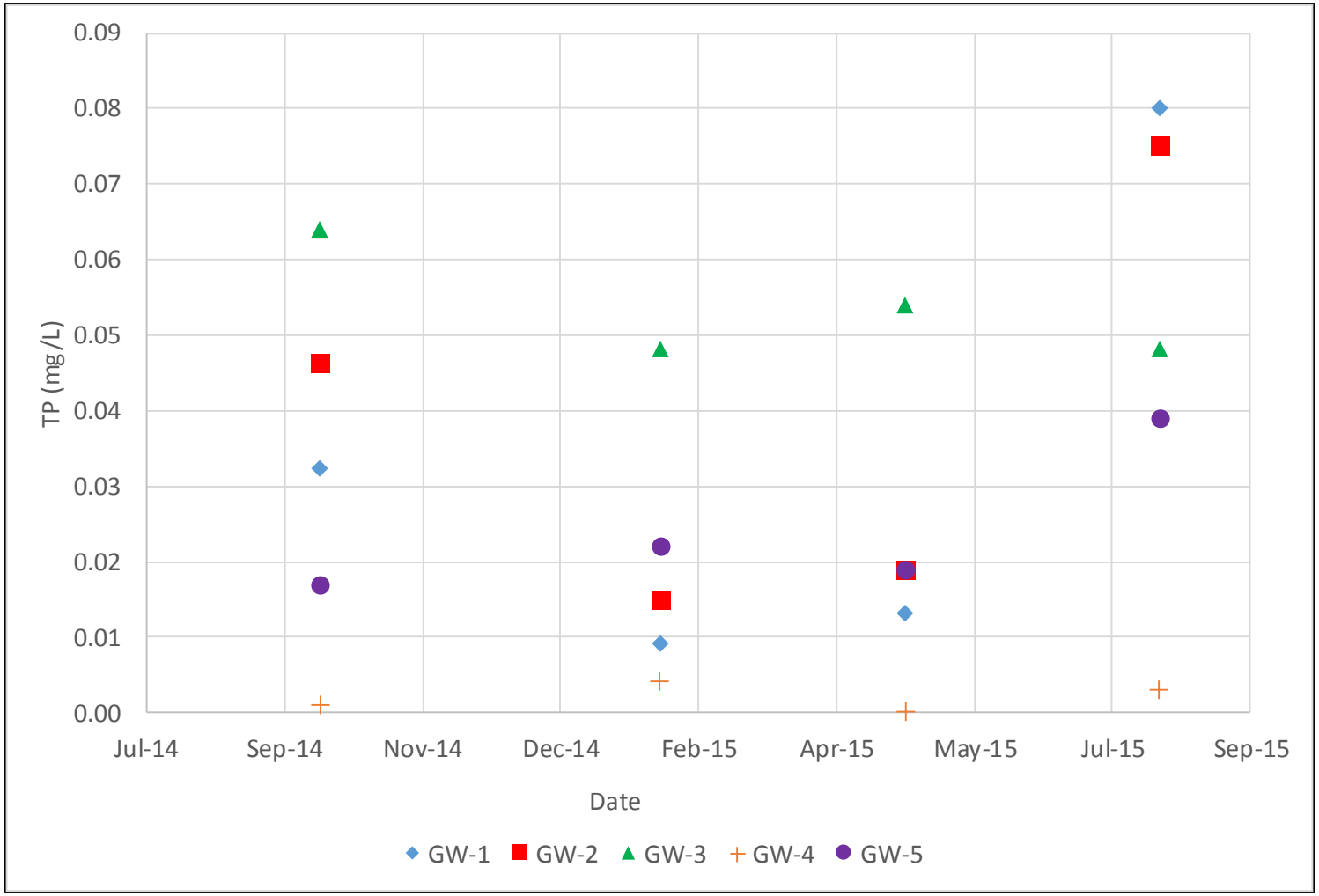
Chlorophyll-a Concentrations in Waughop Lake Water Samples



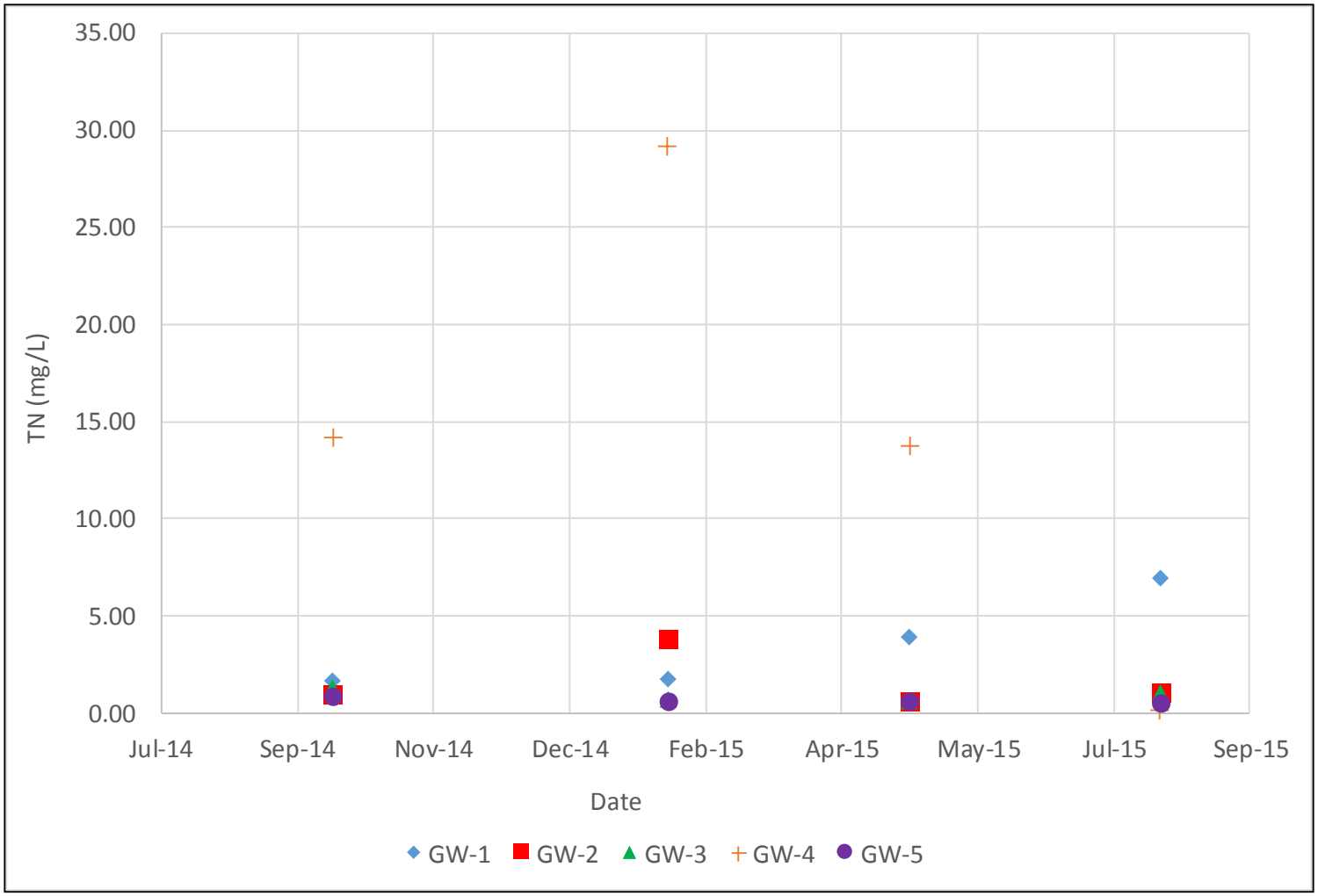
Waughop Lake is Eutrophic to Hypereutrophic

TSI Calculated for Waughop Lake using Chlorophyll-a, TP, TN and Secchi Depth				
Date	TSI (using chlorophyll-a)	TSI (using TP)	TSI (using TN)	TSI (using secchi depth)
10/29/2014	65	66	57	57
11/22/2014	61	63	60	56
12/15/2014	66	71	64	55
1/22/2015	74	70	64	59
2/19/2015	71	77	66	63
3/12/2015	64	71	66	58
4/22/2015	46	66	57	52
5/13/2015	59	67	60	61
6/9/2015	62	61	65	56
6/23/2015	56	62	59	50
7/6/2015	56	55	54	55
7/20/2015	62	64	60	58
8/5/2015	64	67	63	63
8/19/2015	67	62	62	62
9/14/2015	77	71	67	72
9/28/2015	72	68	64	68
10/13/2015	65	65	61	61

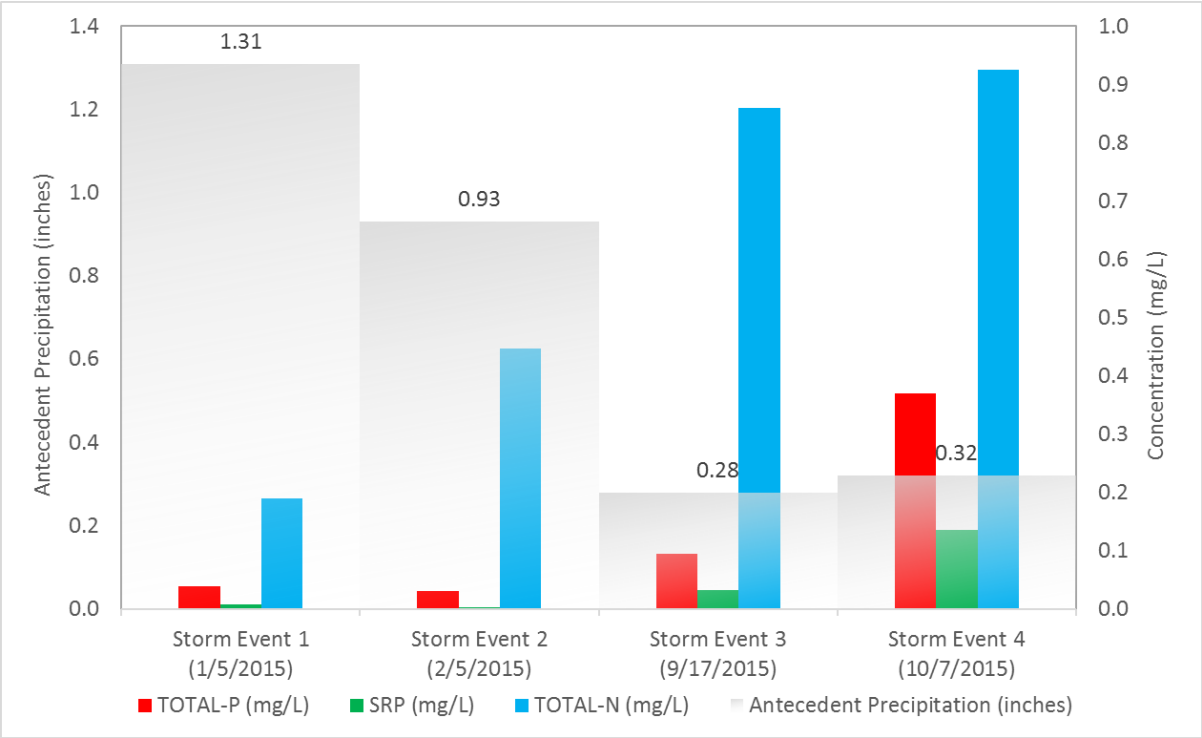
Total Phosphorus Concentrations in Monitoring Wells around Waughop Lake



Total Nitrogen Concentrations in Monitoring Wells around Waughop Lake



Stormwater Was Minor P Source



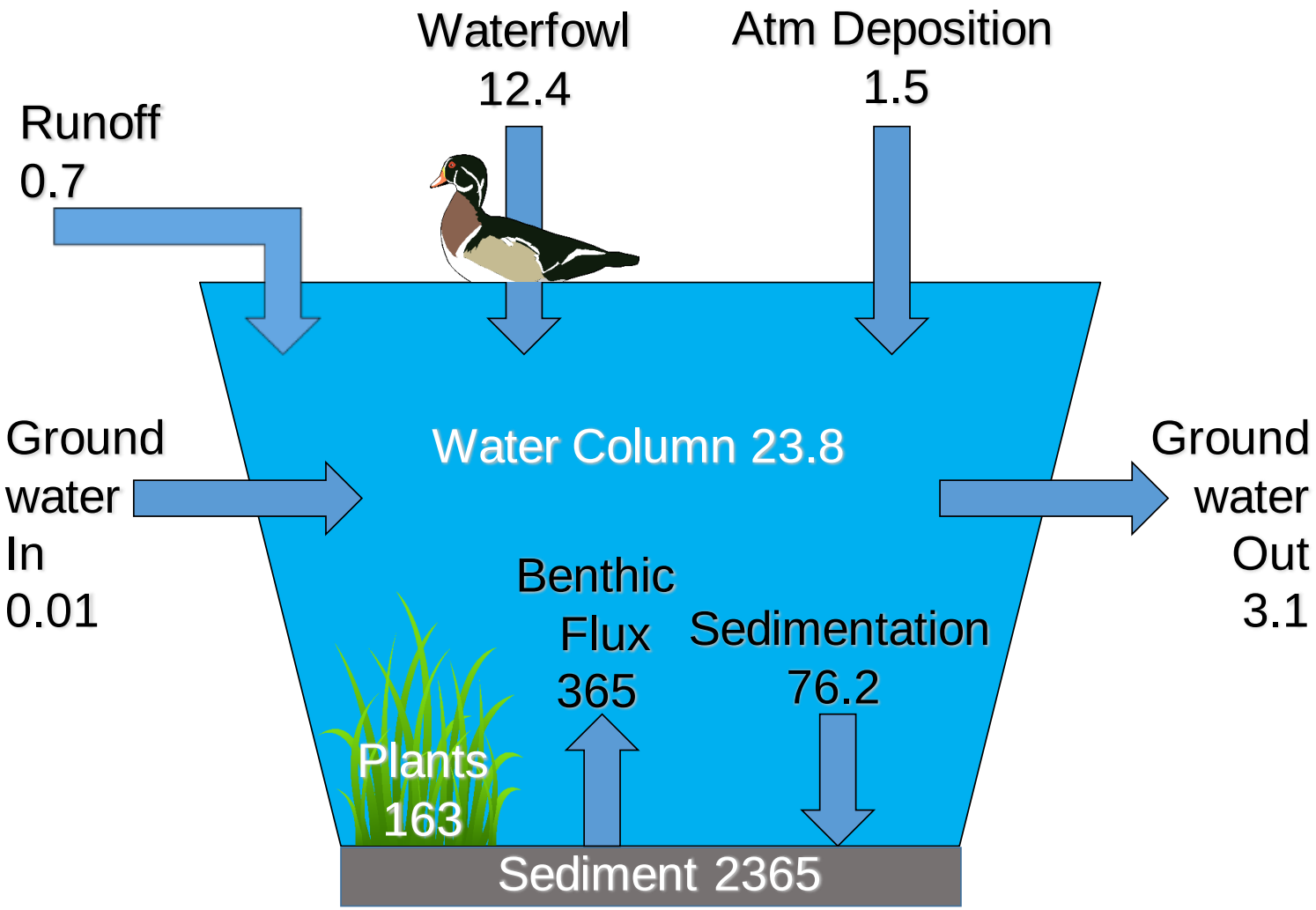
- PCC pond infiltrated all flow sampled during study period
  - Monitoring period was dryer than normal
  - Small area of PCC bypasses pond
- Lake receives small amount of direct runoff

Estimated N and P Loads from Waterfowl

Waterfowl contributions of P and N per month to Waughop Lake		
	Total Waterfowl P (kg/month)	Total Waterfowl N (kg/month)
October 2014	0.767	2.422
November 2014	3.814	12.079
December 2014	6.979	22.034
January 2015	2.515	7.941
February 2015	2.860	9.029
March 2015	3.707	11.704
April 2015	0.139	0.438
May 2015	0.173	0.550
June 2015	0.393	1.256
July 2015	0.691	2.190
August 2015	0.378	1.193
September 2015	0.795	2.513
October 2015	0.724	2.286

- Based on bird counts
- Probably overestimates N & P loads because it assumes all waterfowl feed in upland and poop in lake (ignores “recycling” of P from food in lake)

Phosphorus Model Summary (kg)



Waughop Lake Monitoring Results

- Direct rainfall was main water source to lake
- Phosphorus is limiting nutrient for aquatic plants
- Lake is eutrophic to hypereutrophic
- Water near lake bottom becomes anoxic
- When anoxic, bottom sediments release large amount of phosphorus into the lake water
- Septics and stormwater appear minor sources
- Bottom sediment is rich in phosphorus and internal loading is the primary source of P to lake

Potential Lake Management Measures – Initial Screening

Watershed	In-Lake		
Stormwater treatment/removal	Hypolimnetic aeration or oxygenation	Mechanical removal (algae/plants)	Nutrient input reduction
Septic system improvement or sewering	Vigorous epilimnetic mixing	Selective water withdrawal	Enhanced grazing (fish, zooplankton)
Waterfowl management	Circulation and destratification	Algaecides	Bottom-feeding fish removal
Public education	Dilution and flushing	Phosphorus inactivation	Fungal/bacterial/ viral pathogens
	Drawdown	Sediment oxidation	Competition and allelopathy
	Dredging	Settling agents	Floating wetlands
	Light-limiting dyes and surface covers	Selective nutrient addition	Pump and treat system

Measures that Passed Initial Screening

Watershed	In-Lake		
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Table 5-2. Management Measures that Passed Initial Screening - Options for Control of Harmful Algae								
Option	Planning Level Cost Estimates		20-Yr Costs (Capital+ Ongoing)	Water Quality Benefit	How Soon Will WQ Benefit Occur?	How Long Will WQ Benefit Last?	Other Potential Benefits?	Other Potential Impacts/Costs?
	Initial	Ongoing						
Lake aeration and mixing	$1.9M	$20K	$2.3M	High. Reduce P release from sediment, disrupt blue greens, increase DO for fish. Could be configured to include an alum emitter.	2 years	Long-term	Few conflicts with other uses. Increased DO should improve fish habitat.	Blower building and energy use. Addition of alum emitter would increase capital costs by about 100k and operating costs by about 30k/yr.
Dredging	Costs vary based on dredging and disposal methods. On-site disposal ranges from $2.7M to $12.0M Off-site disposal ranges from: $8.5M to $15.0M	None	$2.7 to $15M	Highest. Would remove ~100 years of P enriched sediment	<1 year	Long-term	Increased lake depth, more groundwater inflow, more fish habitat.	Habitat disturbance during dredging. Greater impacts if lake is dewatered prior to dredging. Odor from dredge spoils. On-site dewatering/ disposal would require large area. Equipment staging on shoreline.
Phosphorus inactivation	$210K for prep and initial treatment	$120K every 3 to 10 yrs	$0.45M to $0.93M	High initially, slow decline over time	Immediate	3-10 years	Minimal infrastructure, no conflicts with other lake uses.	Could increase macrophyte growth. Would need to be repeated every 3-10 yrs.
Pump and treat – chemical treatment	$1.5M	$80K/yr	$3.1M	Medium	1 year	Long-term	Flexible operation. Higher treatment capacity than wetland treatment system. Learning opportunity for college students.	Would require ~3 acres of land. Temporary impacts during construction.
Pump and treat – constructed wetlands	$3.1M	$100K/yr	$5.1M	Medium	1 year	Long-term	Flexible operation. Increased habitat for birds and other wildlife. Learning opportunity for college students.	Would require ~9 acres of land. Temporary impacts during construction.

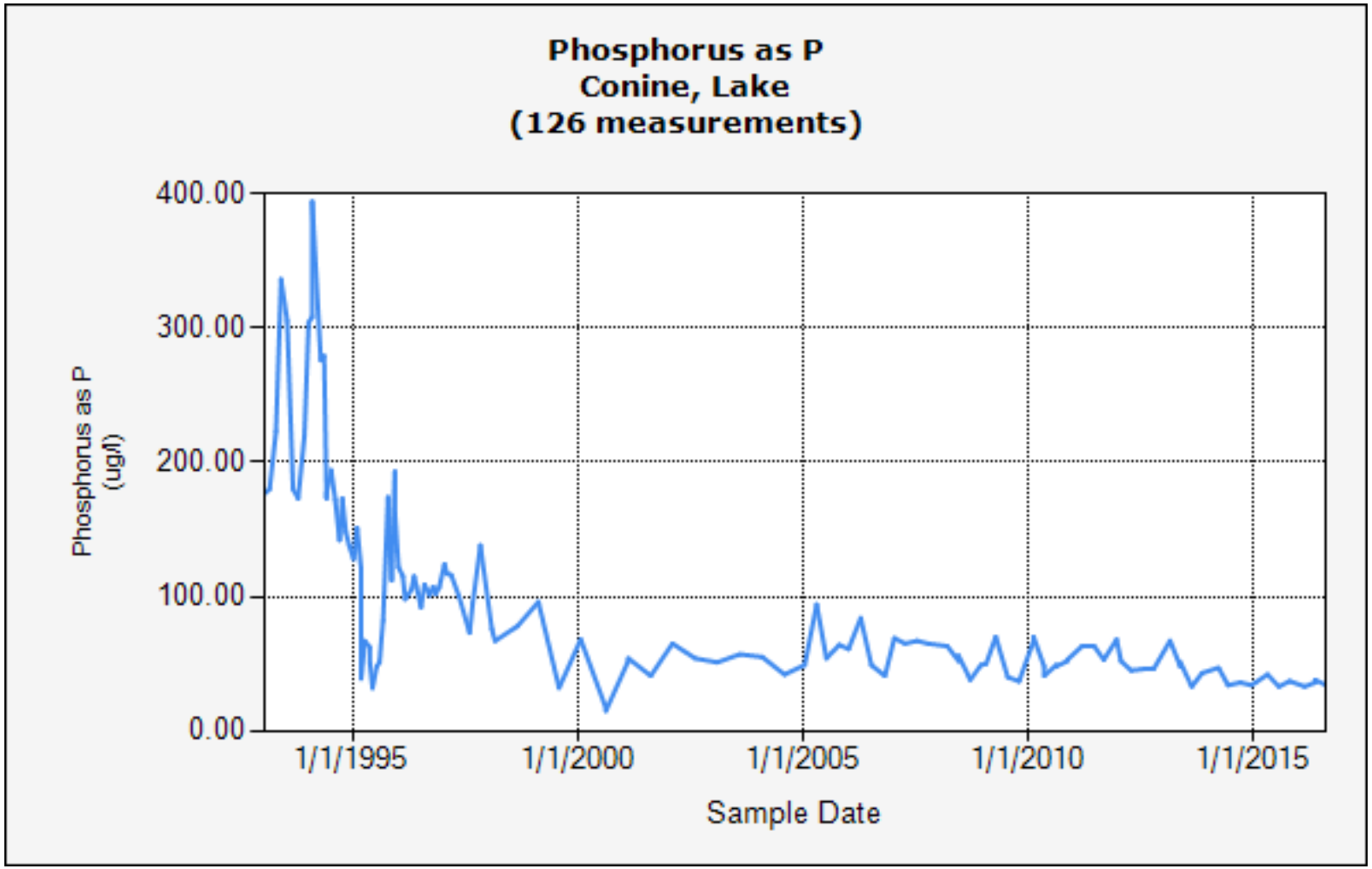
Mechanical Dredging

Hydraulic Dredging

Alum Treatment - Surface Application

- Mix lake water with chemical before applying
- Apply to surface or slightly below surface of lake
- Monitor water quality
- Completed in 1995 (125,000 gallons)

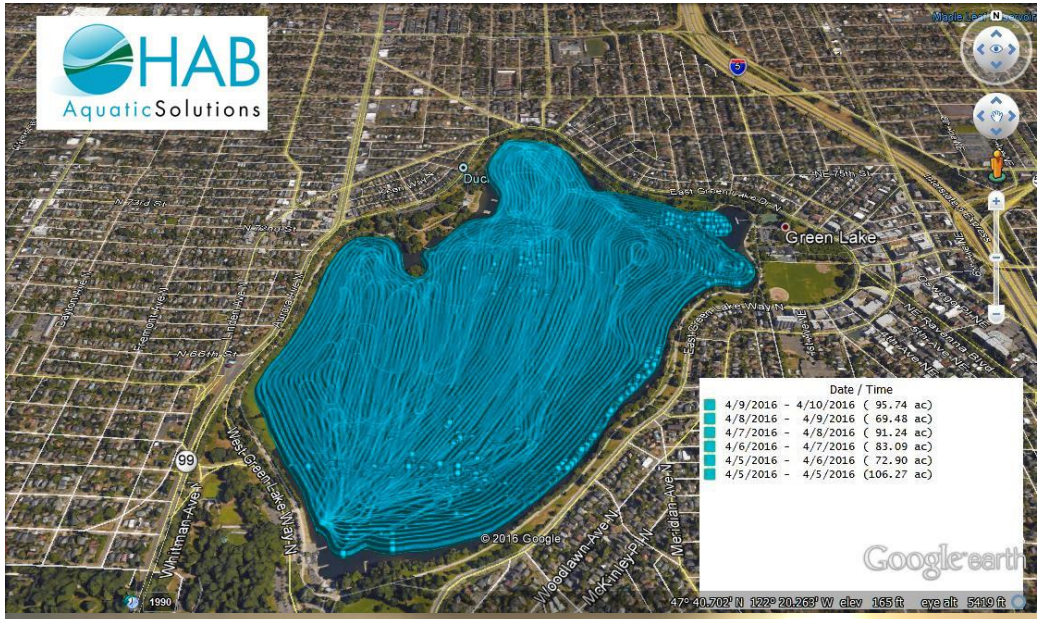
Lake Conine TP after Alum Treatment

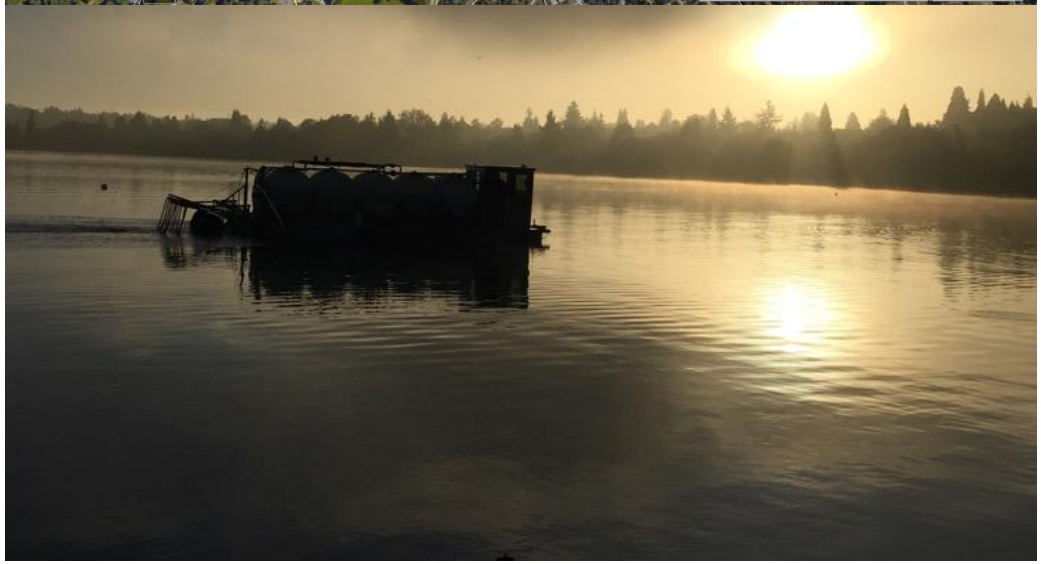


Green Lake, Seattle

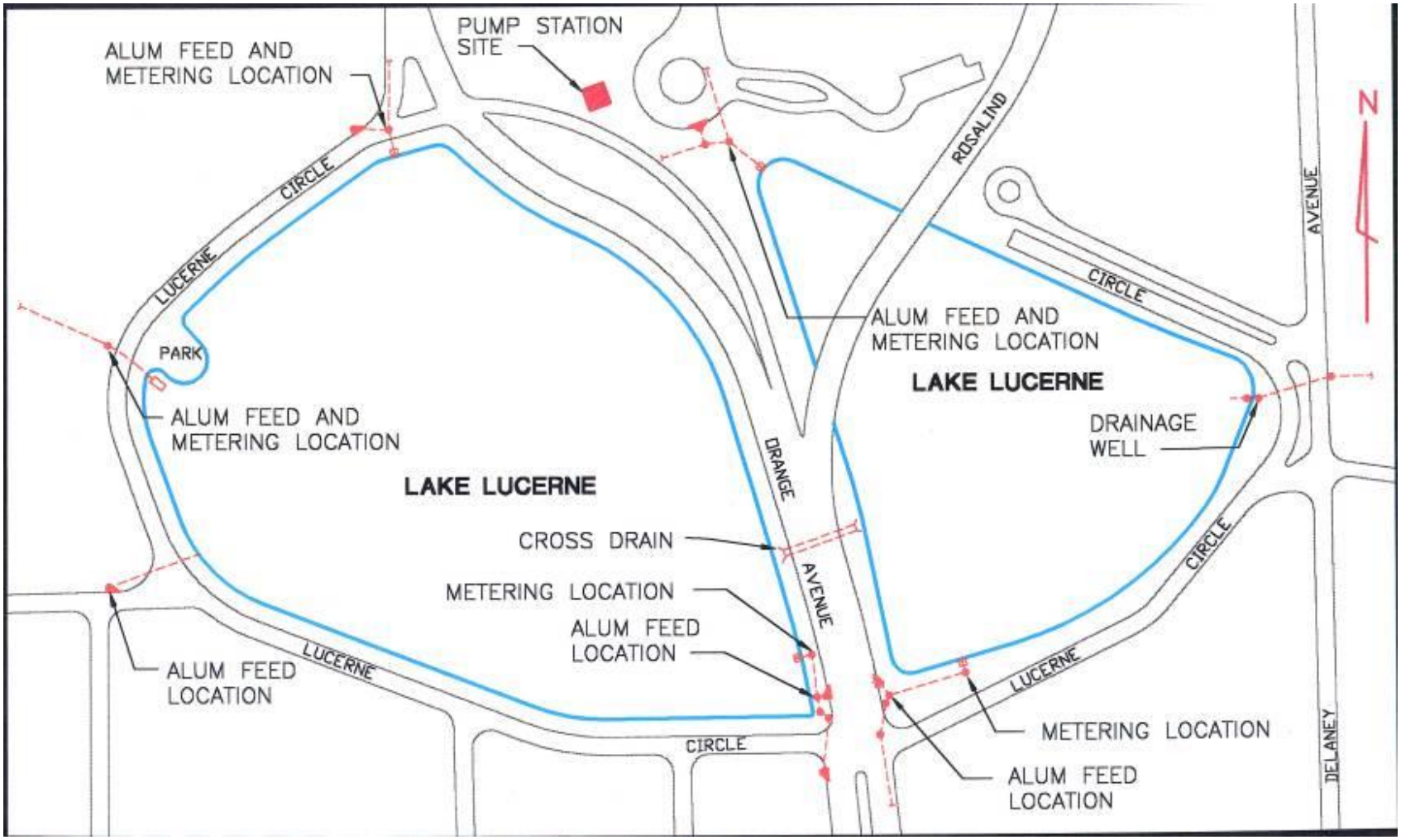
- 259 acres (117 ha)
- Average depth = 13ft
- Max depth = 30ft
- Urban lake with stormwater inputs
- Two previous applications in 1991 & 2004

- 6-day application (4/16)
- 81,744 gal of alum
- 40,905 gal of sodium aluminate

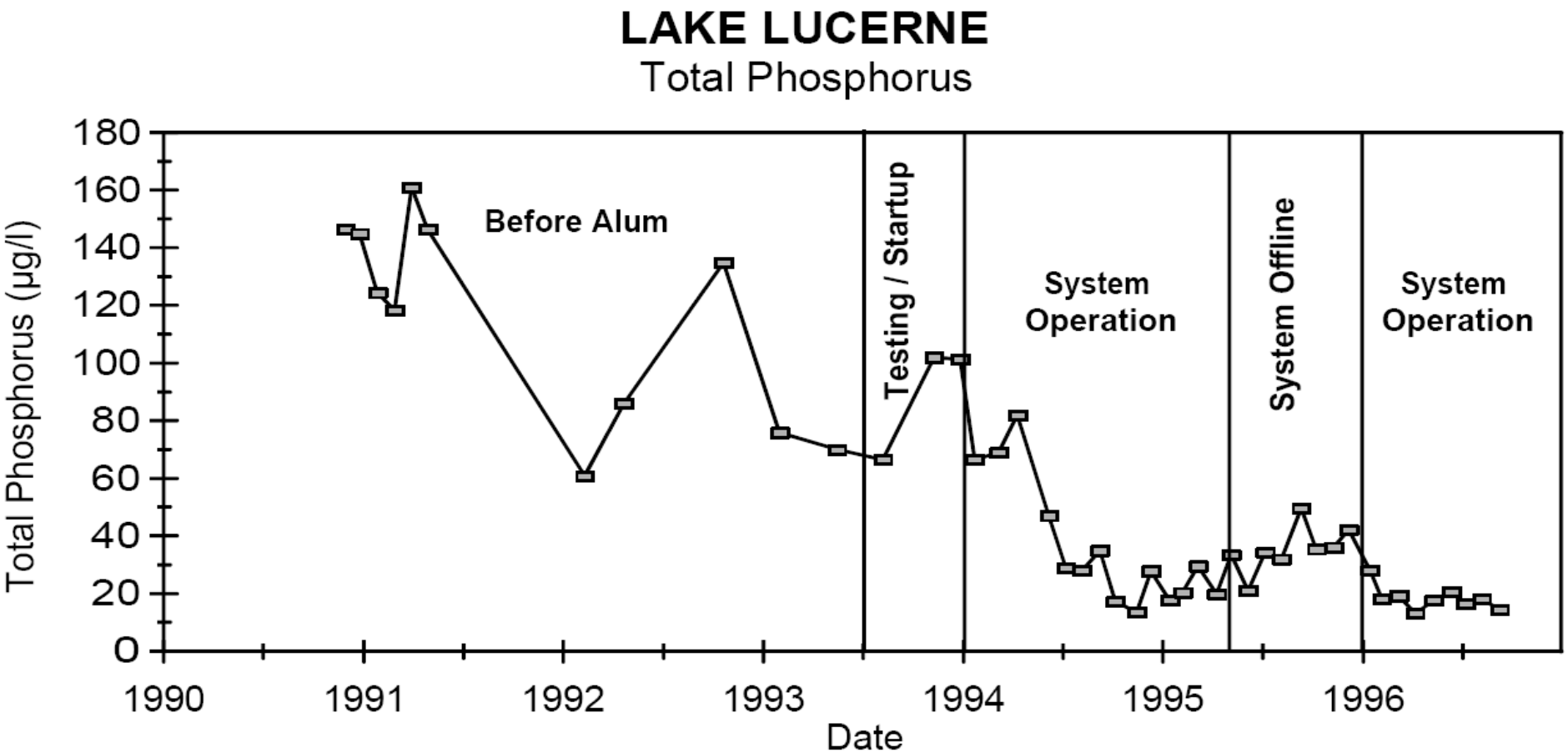




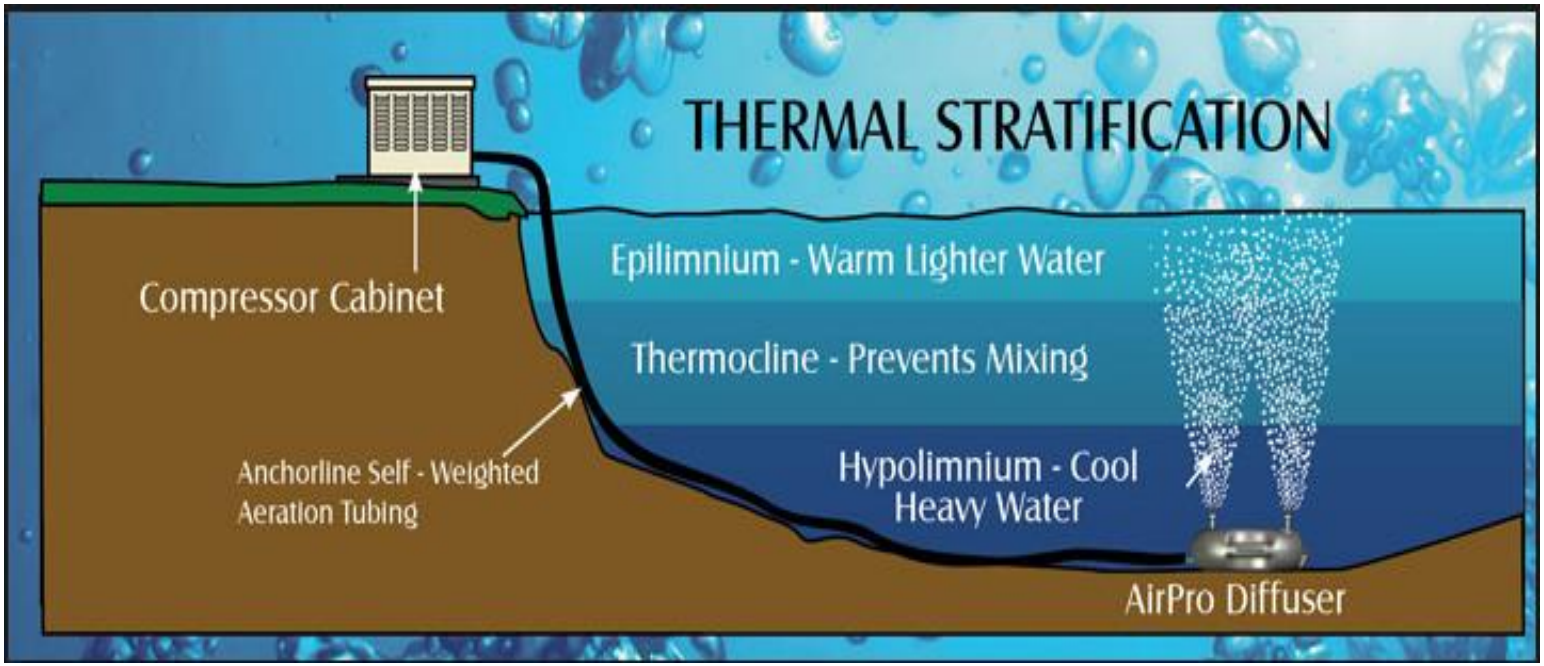
Alum Emitters



Significant Improvement in Lake Water Quality Following System Installation

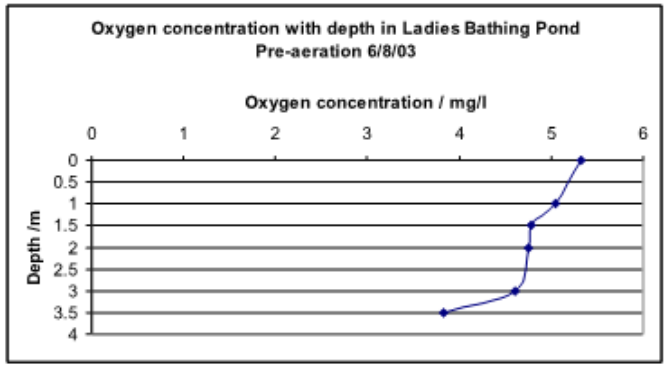


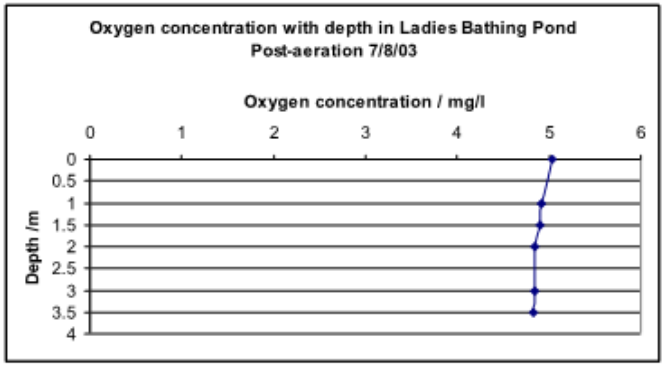
Aeration/Vigorous Epilimnetic Mixing

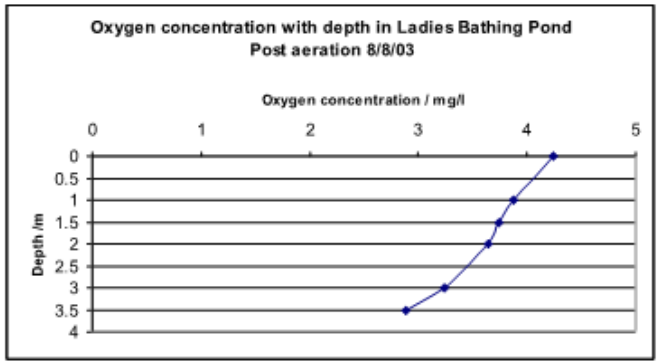


Hampstead Heath Ladies Pond, London

© National Pictures / Nick Edwards







Ladies Bathing Pond

Dixie Drain Treatment Facility, Boise, ID

Potential Funding Sources

- State budget allocation
- Grants
- Special purpose district
  - Lake management district
  - Local improvement district
- Flood Control Zone Management District

Questions?

Waughop Lake TP Mass Balance

TP Mass Balance Model for Waughop Lake									
Date	Groundwater Input (kg-TP) [a,c]	Groundwater Output (kg-TP) [b,c]	Precipitation (kg-TP) [d]	Waterfowl (kg-TP) [e]	Benthic Flux (kg-TP) [f]	Runoff (kg-TP) [g]	Sedimentation (kg-TP) [h]	TP In (kg)	TP Out (kg)
January 2015	0.002	0	0.26	2.51	0	0.11	7.62	2.89	7.62
February 2015	0.001	0	0.32	2.86	0	0.13	7.62	3.31	7.62
March 2015	0.001	0	0.27	3.71	0	0.10	7.62	4.08	7.62
April 2015	0.002	0	0.12	0.14	0	0.05	7.62	0.31	7.62
May 2015	0.002	0	0.04	0.17	73.70	0.02	7.62	73.93	7.62
June 2015	0	0	0.02	0.39	71.32	0.01	7.62	71.74	7.62
July 2015	0	0.62	0.01	0.69	73.70	0.00	7.62	74.40	8.24
August 2015	0	0.68	0.12	0.38	73.70	0.06	7.62	74.26	8.31
September 2015	0	0.96	0.07	0.80	35.66	0.04	7.62	36.56	8.58
October 2015	0	0.86	0.30	0.72	36.85	0.16	7.62	38.03	8.48

Waughop Water Budget

Waughop Lake Water Budget Summary										
			Inflow	Outflow	Inflow	Inflow	Outflow			
Month & Year	Lake Stage (ft) [a]	Change in Lake Storage (ac-ft) [b]	Groundwater Inflow (ac-ft)	Discharge to Groundwater (ac-ft) [c]	Precipitation (ac-ft)	Inflow-Runoff (ac-ft)	Evaporation (ac-ft)	Total Inflows (ac-ft)	Total Outflows (ac-ft)	Net Flux (Inflows-Outflows)
Jan-15	223.4	-	0.14	-	8.87	1.29	4.69	10.30	4.69	5.61
Feb-15	223.8	12.19	0.12	-	10.90	1.53	6.01	12.55	6.01	6.54
Mar-15	223.8	0.33	0.09	-	9.04	1.27	9.00	10.41	9.00	1.41
Apr-15	223.8	0.65	0.10	-	4.08	0.55	11.42	4.73	11.42	-6.68
May-15	223.2	(18.13)	0.12	-	1.38	0.20	13.67	1.70	13.67	-11.97
Jun-15	222.8	(15.44)	-	0	0.60	0.09	15.60	0.69	15.60	-14.91
Jul-15	222.0	(23.24)	-	11.90	0.31	0.05	14.48	0.36	26.38	-26.02
Aug-15	221.3	(23.48)	-	13.22	4.21	0.74	11.80	4.95	25.02	-20.07
Sep-15	220.9	(15.11)	-	18.51	2.32	0.43	0.84	2.75	19.36	-16.60
Oct-15	220.8	(3.49)	-	21.60	10.09	1.89	5.83	11.98	27.42	-15.44

Waughop Lake Monitoring Results

Depth (m)	TSI (CHL)	TSI (TP)	TSI (TN)	TSI (SD)
10/29/14	65	66	57	57
11/22/14	61	63	60	56
12/15/14	66	71	64	55
1/22/15	74	70	64	59
2/19/15	71	77	66	63
3/12/15	64	71	66	58
4/22/15	46	66	57	52
5/13/15	59	67	60	61
6/9/15	62	61	65	56
6/23/15	56	62	59	50
7/6/15	56	55	54	55
7/20/15	62	64	60	58
8/5/15	64	67	63	63
8/19/15	67	62	62	62
9/14/15	77	71	67	72
9/28/15	72	68	64	68
10/13/15	65	65	61	61