Current Trends in Alum Treatment of Stormwater Runoff

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Characteristics of Alum

-Clear, light green to yellow solution, depending on Fe content

-Liquid is 48.5% solid aluminum sulfate

-Specific gravity = 1.34

-11.1 lbs/gallon

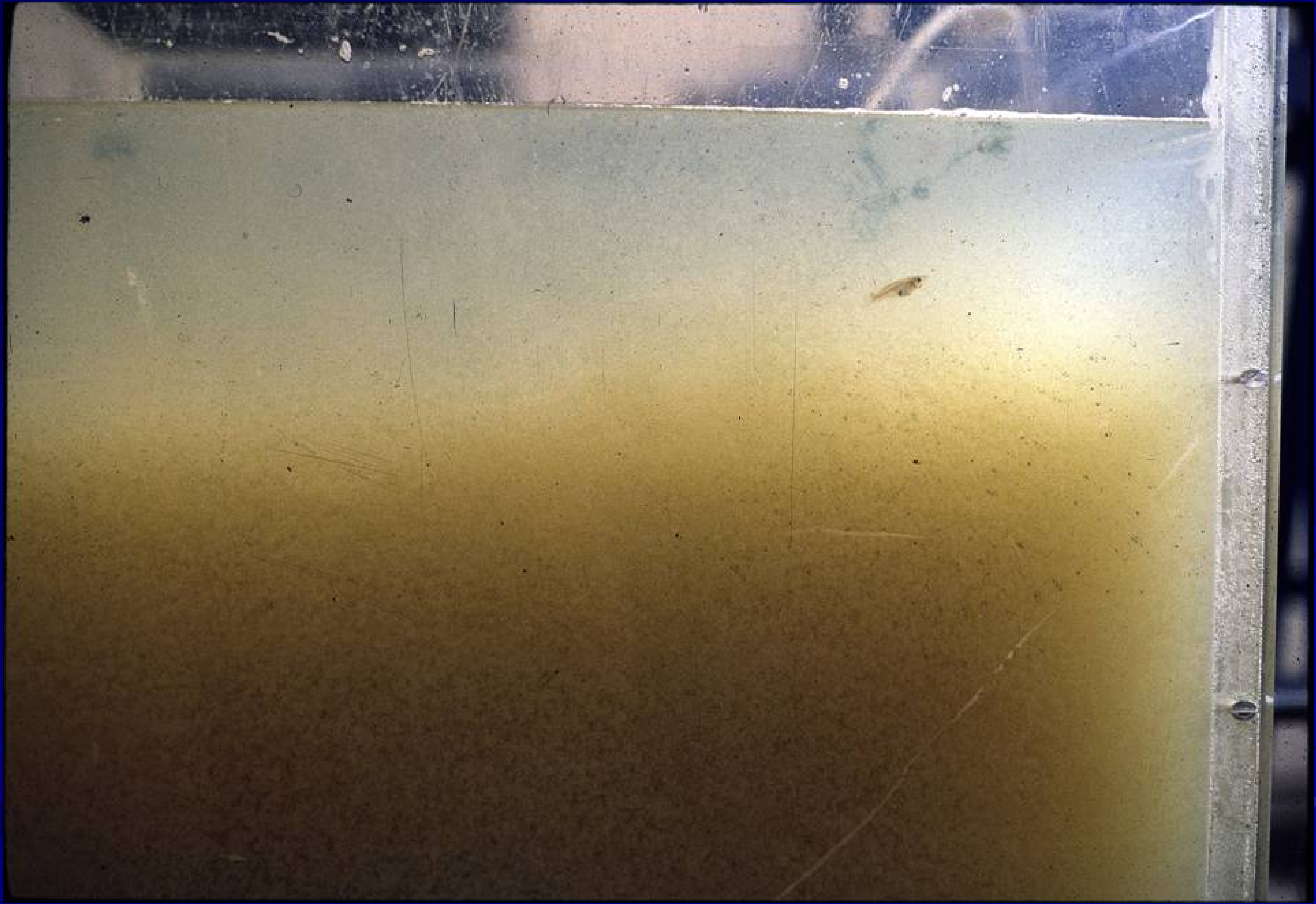
-Freezing point = -15° C

-Delivered in tanker loads of 4500 gallons each

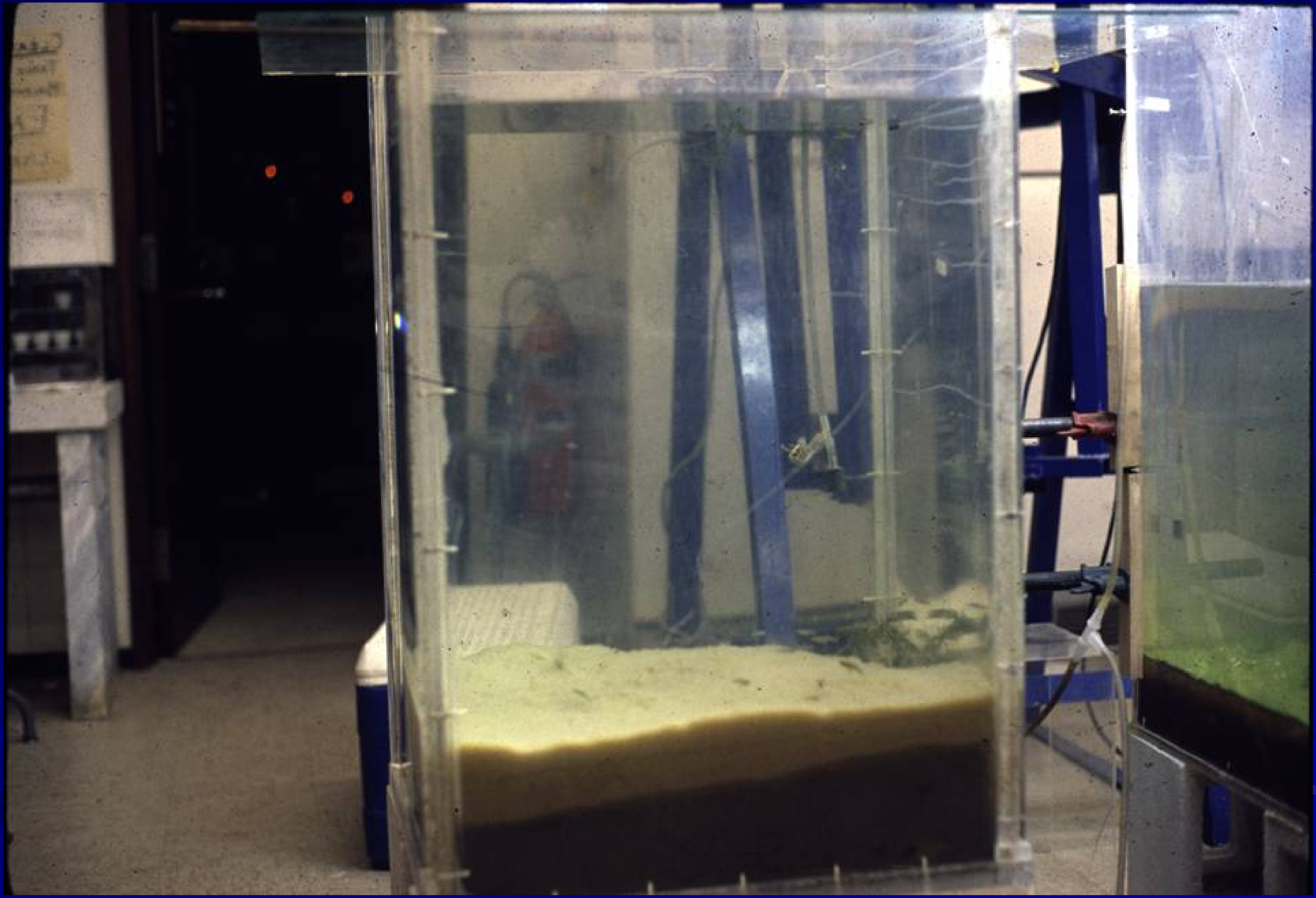
Alum is made by dissolving aluminum ore (bauxite) in sulfuric acid

Alum Reacts Quickly to Remove Both Particulate and Dissolved Pollutants

Colloidal Runoff Sample Settled for 45 Days

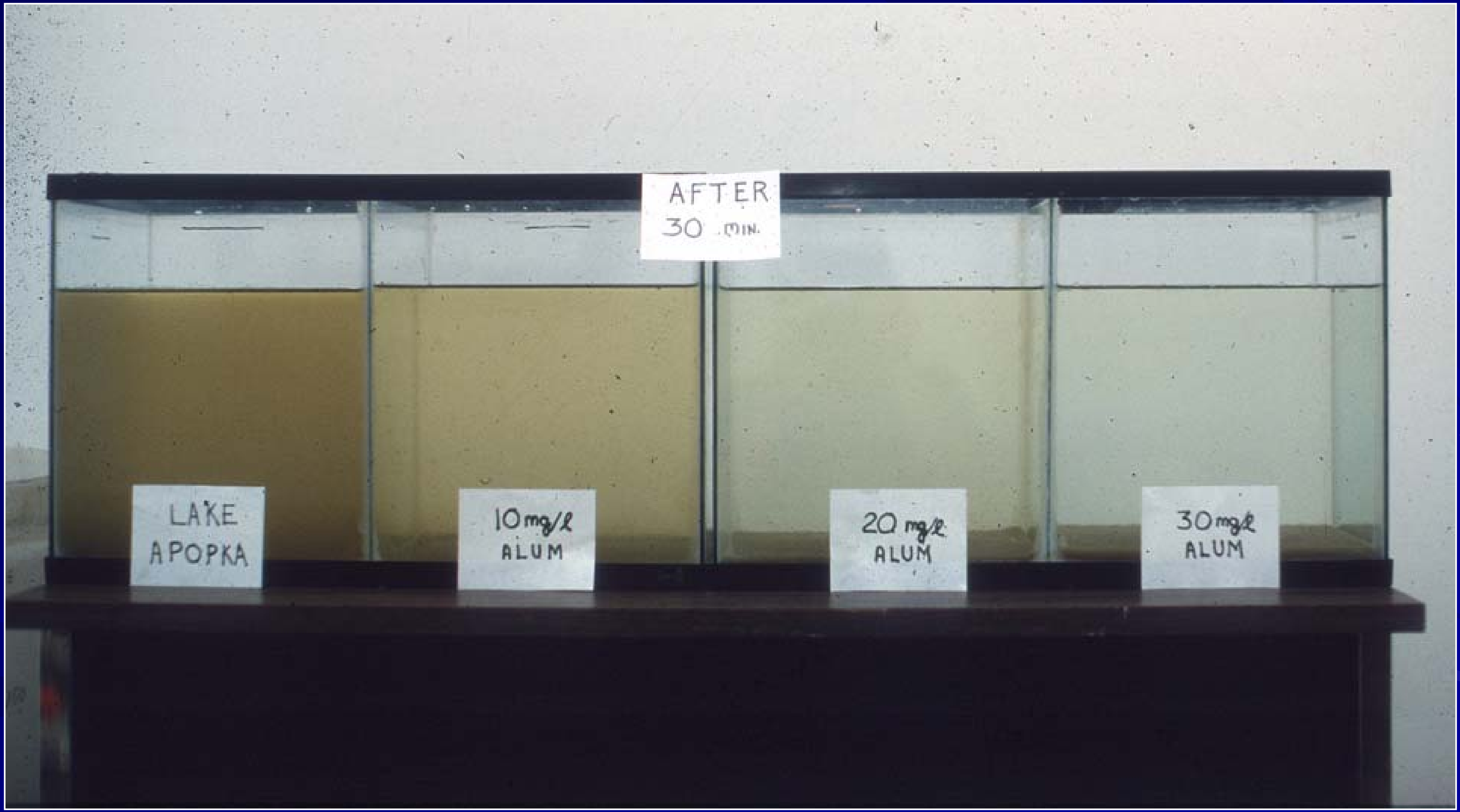


Immediately Following Alum Addition



Treated Sample 4 Hours After Alum Addition

The efficiency of alum treatment is a function of applied dose



Significant Alum Removal Processes

1. Removal of suspended solids, algae, phosphorus, heavy metals and bacteria:

$$Al^{+3} + 6H_2O \longrightarrow Al(OH)_{3(s)} + 3H_3O^{+}$$

2. Removal of dissolved phosphorus:

$$Al^{+3} + H_nPO_4^{n-3} \longleftrightarrow AlPO_{4(s)} + nH^{+}$$

Aluminum Coagulants

Aluminum Sulfate (alum)

Aluminum Chloride

Poly Aluminum Hydroxy-chloride

Alum/Polymer Blends (floc logs)

Alum Coagulation

Advantages

Rapid, efficient removal of solids, phosphorus, and bacteria

Inexpensive – approximately $0.60/gallon

Relatively easy to handle and feed

Does not deteriorate under long-term storage

Floc is inert and is immune to normal fluctuations in pH and redox potential

Floc also binds heavy metals in sediments, reducing sediment toxicity

Disadvantage

May result in lowered pH and elevated levels of Al^{+3} if improperly applied

Typical Analyses of Inorganic Coagulants

Metal Conc. (ppm)

Element	PACl	Alum	$Fe_2(SO_4)_3$	$FeCl_3$
Silver	< 0.4	< 0.4	2	12
Barium	< 0.2	0.15	0.08	130
Cadmium	<0.05	<0.05	4.9	2
Cobalt	<0.08	0.15	12	38
Chromium	0.6	40	1.4	460
Copper	< 0.1	0.5	110	17
Manganese	1.1	1.5	79	5700
Nickel	1.0	0.3	10	15
Titanium	1.5	10	9.3	6600
Vanadium	0.5	15	110	690
Zinc	5.5	1.0	12	100
Lead	< 1	< 2	33	51
Arsenic	< 1	< 2	3	2
Mercury	< 0.002	< 0.002	2	5

SOURCE: WATER/Engineering & Management (Feb. 1998)

History of Alum Usage

Drinking water – Roman Times

Wastewater – 1800s

Lake surface – 1970

Stormwater - 1986

History of Chemical Stormwater Treatment

- Initial research on chemical coagulation conducted in the late 1970s – Evaluated salts of Al, Fe, and Ca
- Chemical coagulation evaluated for several stormwater retrofit projects in the early 1980s
- First system constructed at Lake Ella in Tallahassee in 1986
- Since then, 37 systems have been designed and constructed
- 11 additional systems are currently being designed or evaluated

Winter Haven (3)
Orlando (4)
Ocala
Celebration
La Porte, IN
Cocoa Beach
Pinellas Co. (8)
Lake County

St. Petersburg (6)
Orange County
King County, WA
Polk County
Brevard County
Port Orange (2)
Theme Park (2)
Highlands Co.

Winter Park (5)
Tallahassee
Largo
SWFWMD (2)
Hillsborough County
Winter Garden
NWFWMD

Typical Percent Removal Efficiencies for Alum Treated Stormwater Runoff

Parameter	Settled Without Alum (24 hrs)	Alum Dose (mg Al/liter)		
		5	7.5	10
Diss. Organic N	20	51	62	65
Particulate N	57	88	94	96
Total N	20*	65*	71*	73*
Diss. Ortho-P	17	96	98	98
Particulate P	61	82	94	95
Total P	45	86	94	96
Turbidity	82	98	99	99
TSS	70	95	97	98
BOD	20	61	63	64
Total Coliform	37	80	94	99
Fecal Coliform	61	96	99	99

* Depending on the type of nitrogen species present

Comparison of Treatment Efficiencies for Common Stormwater Management Systems

Type of System	Estimated Removal Efficiencies (%)			
	Total N	Total P	TSS	BOD
Dry Retention (0.50-inch runoff)	40-80[1]	40-80	40-80	40-80
Wet Detention[2]	20-30	60-70	75-85	65-70
Wet Detention with Filtration	20-30	60	> 90	80
Dry Detention	0-30	0-40	60-80	0-50
Dry Detention with Filtration	0-30	0-40	60-90	0-50
Alum Treatment	30-70	> 90	> 95	60-75

1. Varies according to project characteristics and location
2. Based on 14-day wet season residence time

Alum treatment provides removal efficiencies similar to dry retention

Lake Dot – Pre-treatment Water Quality

5 ac. Lake Receiving Runoff from 305 ac. Urban Basin

108 inch Stormsewer Entering Lake Dot

Lake Dot – Post Treatment

Trends in Alum Treatment

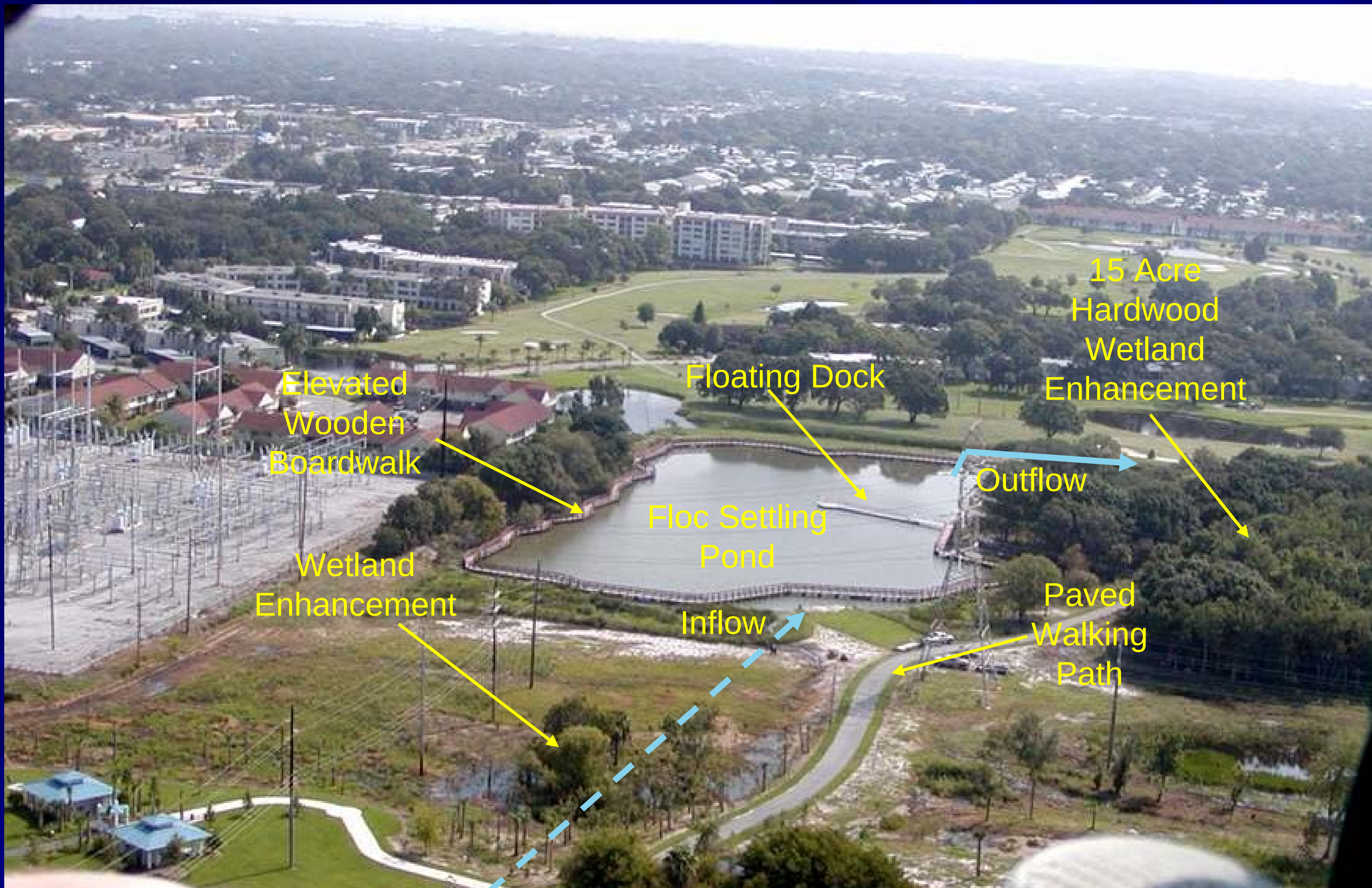
- Recent alum treatment systems are typically used to retrofit large watershed areas (>100 acres) where large pollutant mass removal is required within a small footprint

- Stormwater treatment systems in Florida have been permitted by a variety of agencies:
  - FDEP
  - FDEP (for NWFWMD)
  - SJRWMD
  - SWFWMD
  - SFWMD
- FDEP has indicated that floc collection is required for discharges to State waters by:
  - Federal Clean Water Act
  - Chapter 403, F.A.C. (prohibits treatment of stormwater in “Waters of the State”)
- Much of current and recent efforts has revolved around issues of floc collection and disposal

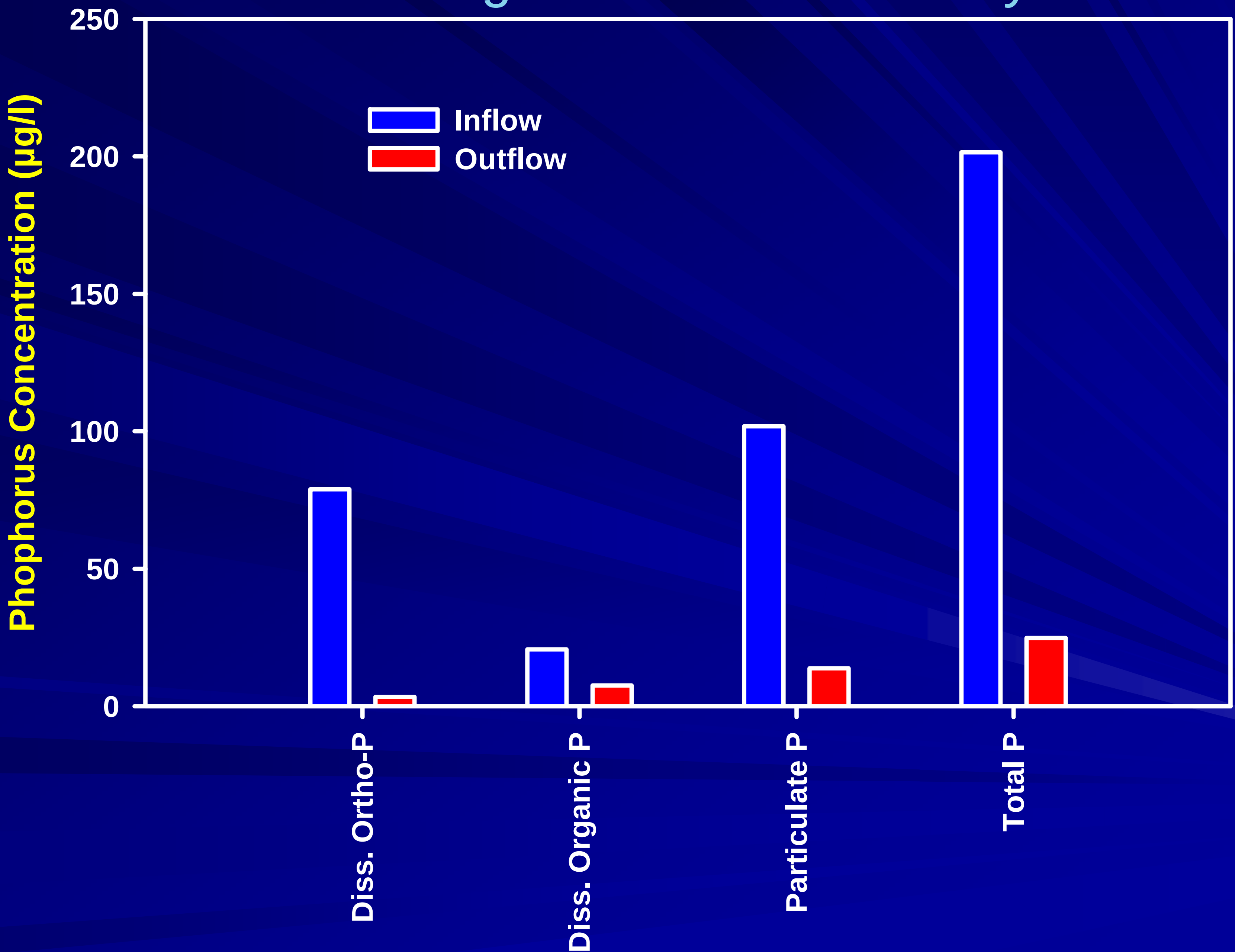
Largo Regional Alum Treatment System

Treated Watershed Area = 1500 acres

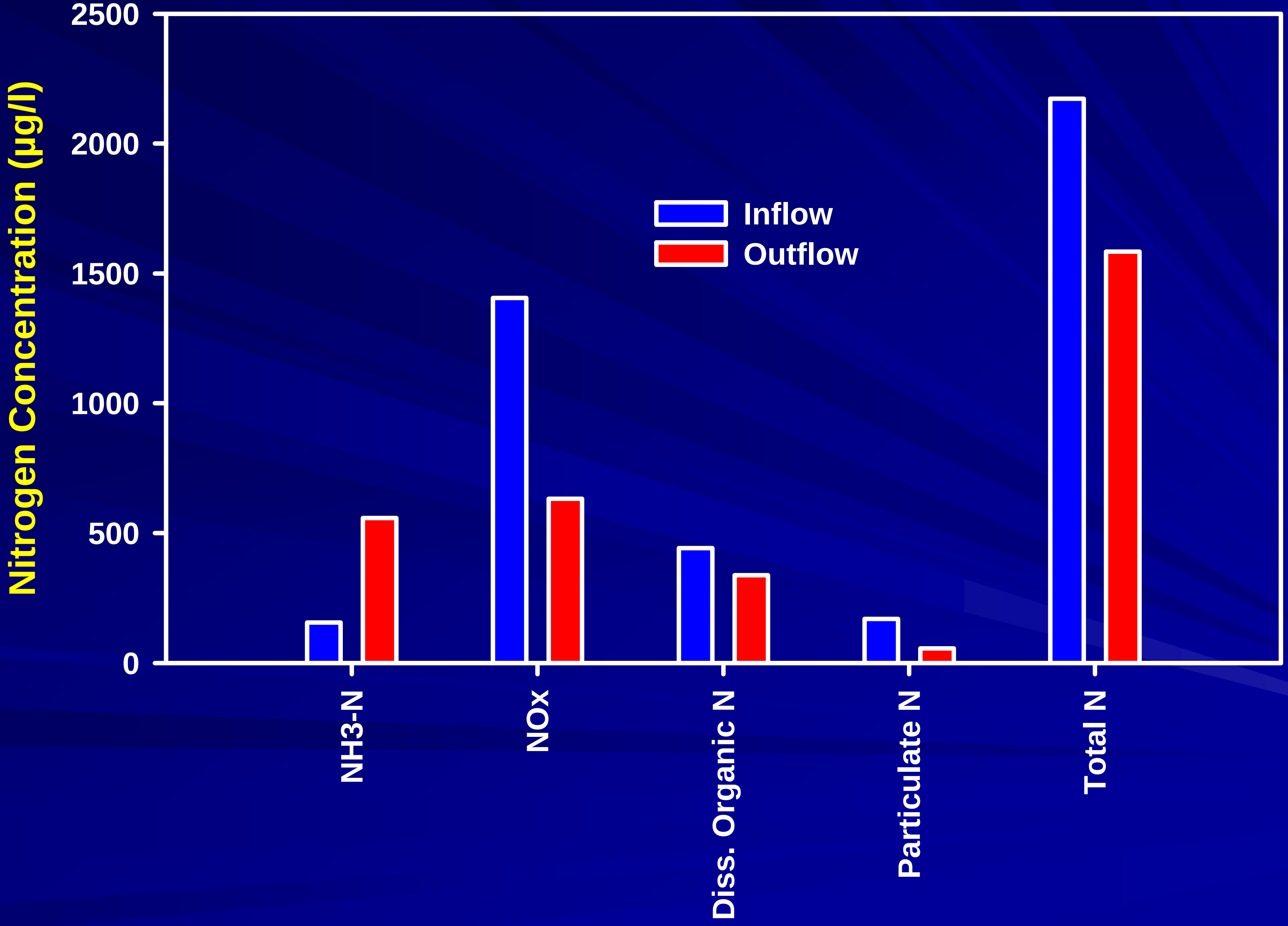
Largo Regional Alum Treatment System Components



Fate of Phosphorus Species in the Largo Stormwater Facility



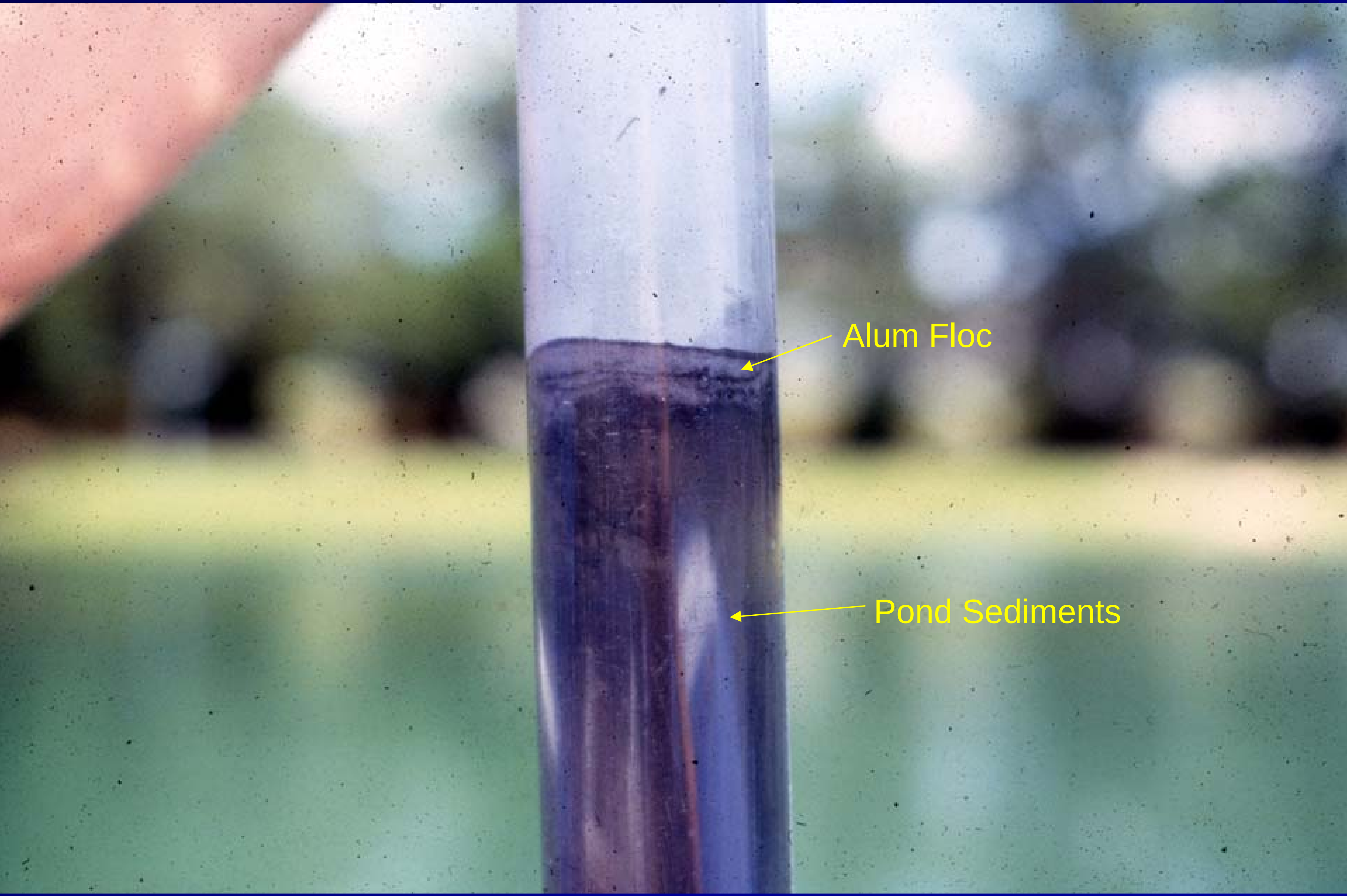
Fate of Nitrogen Species in the Largo Stormwater Facility



Comparison of Life Cycle Cost Per Mass Pollutant Removed for Typical Stormwater Retrofit Projects*

Project	20–Year Life Cycle Cost ($)	Cost per Mass Pollutant Removed ($/kg)		
		TP	TN	TSS
Alum Treatment				
Largo Regional STF	2,044,780	253	65	4
Lake Maggiore STF	4,086,060	200	71	2
Gore Street Outfall STF	1,825,280	87	12	1
East Lake Outfall TF	1,223,600	135	17	1
LCWA NuRF Facility	34,254,861	198	30	2
Wet Detention				
Melburne Blvd. STF	1,069,000	371	125	2
Clear Lake Ponds STF	1,091,600	658	237	2

* Does not consider cost of land purchase


Alum Floc
Pond Sediments

Anticipated Production of Alum Sludge from Alum Treatment of Urban Stormwater at Various Doses

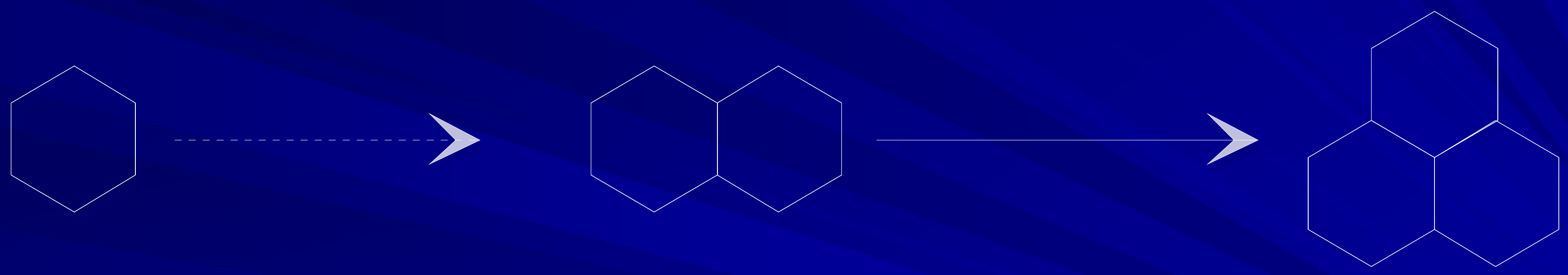
Alum Dose (mg/l as Al)	Sludge Production[1]	
	As Percent of Treated Flow	Per ac-ft of Runoff Treated
5	0.16	70 ft^3
7.5	0.20	87 ft^3
10	0.28	122 ft^3

1. Based on a minimum settling time of 30 days

Freshly Collected Alum Floc

Alum Floc Drying Process

$$\frac{OH}{Al} = 0.3\text{-}2.1$$

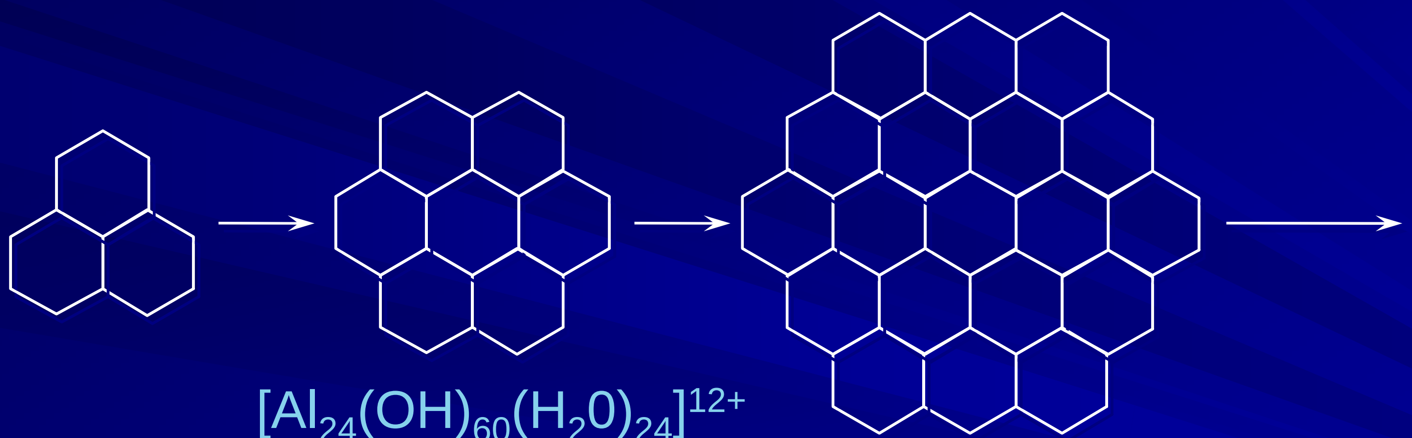


$[Al_6(OH)_{12}(H_20)_{12}]^{6+}$

$[Al_{10}(OH)_{22}(H_20)_{16}]^{8+}$

$[Al_{13}(OH)_{30}(H_20)_{18}]^{9+}$

$\longrightarrow \frac{OH}{Al} = 2.2\text{-}2.7 \longrightarrow \frac{OH}{Al} = 3.0\text{-}3.3$



Aluminum trihydroxide solid phase

$[Al_{13}(OH)_{30}(H_20)_{18}]^{9+}$ $\quad$ $[Al_{24}(OH)_{60}(H_20)_{24}]^{12+}$ $\quad$ $[Al_{54}(OH)_{144}(H_20)_{36}]^{18+}$ $\quad$ $[Al_n(OH)_{3n}$

Conclusions: 1. Aged alum floc is exceptionally stable under a wide range of pH and redox conditions

2. Constituents bound into the floc are inert and have virtually no release potential

Lake Howard

Equipment Building

Underground Alum Storage Tank

Alum Injection Equipment

Merritt Ridge

Equipment Building

In-line Floc Settling Pond

Alum Injection Equipment

pH Control Equipment

Webster Avenue

Equipment Vault

In-lake Floc Trap

In-lake Floc Trap

Gore Street

Equipment Building

Floc Disposal System

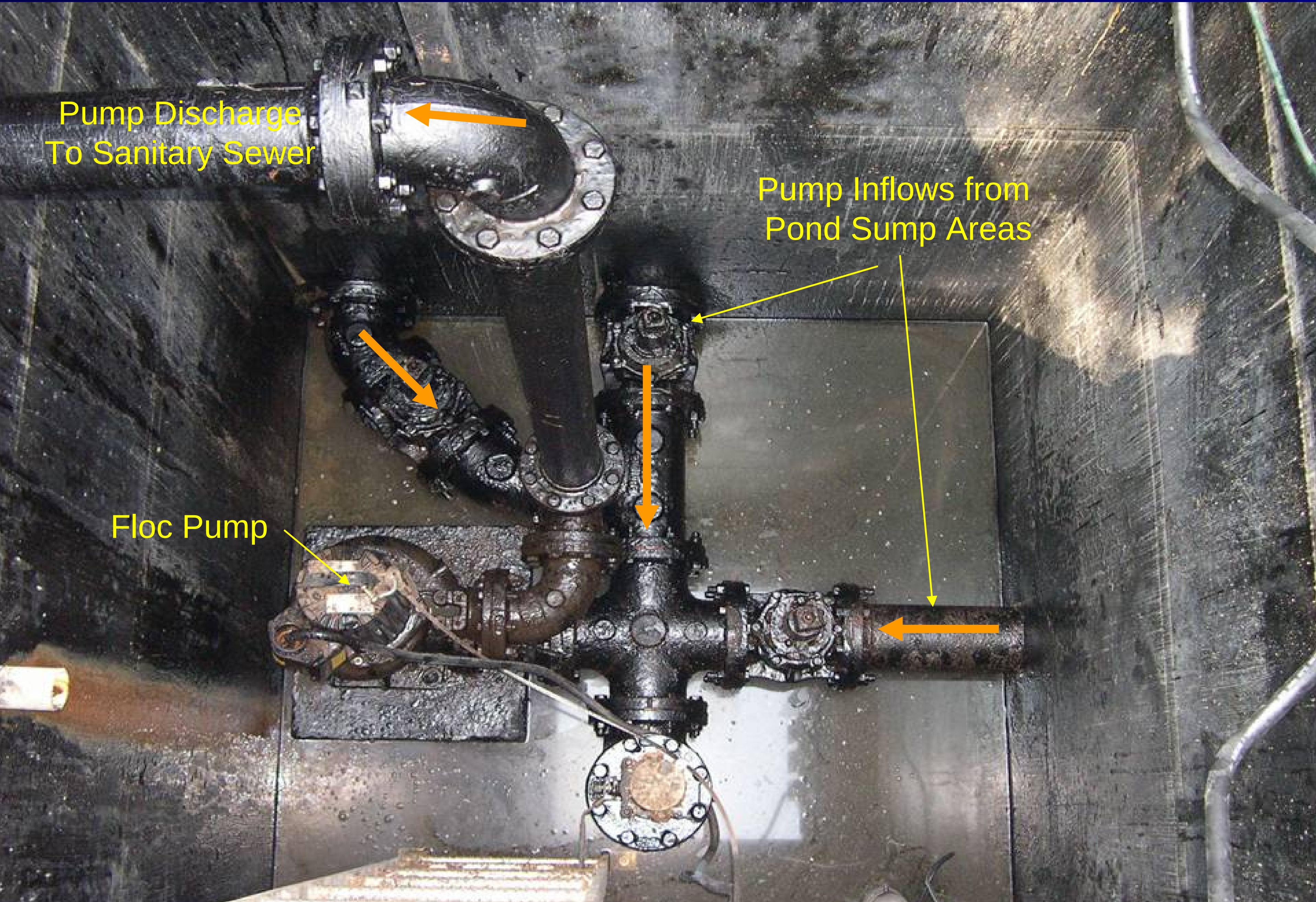
In-line Floc Trap

In-line Floc Trap

Port Orange B-23 Canal Equipment Building

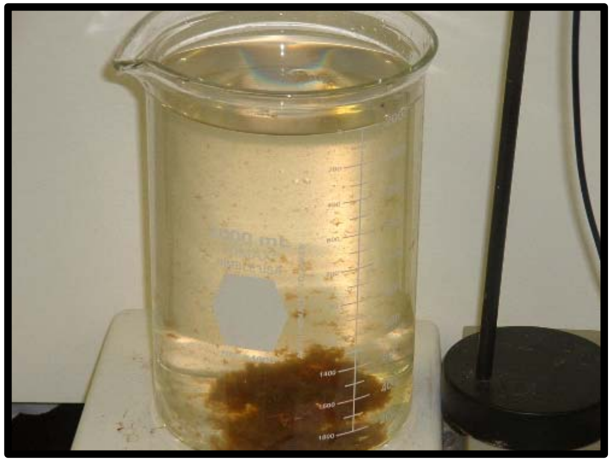
Port Orange B-23 Canal Floc Settling Pond

Port Orange Floc Collection Sump and Valves

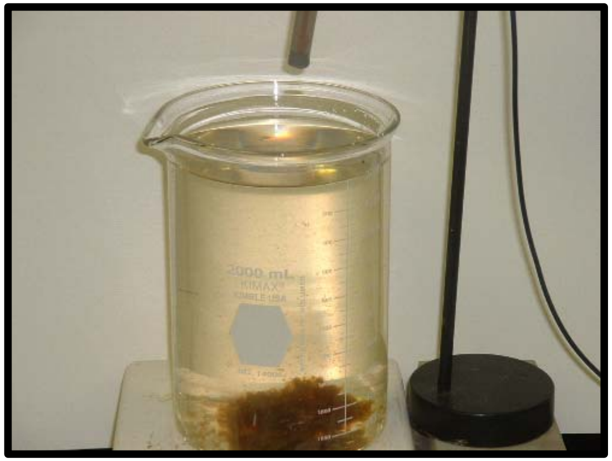


Immediately after alum / polymer addition

30 seconds following alum / polymer addition



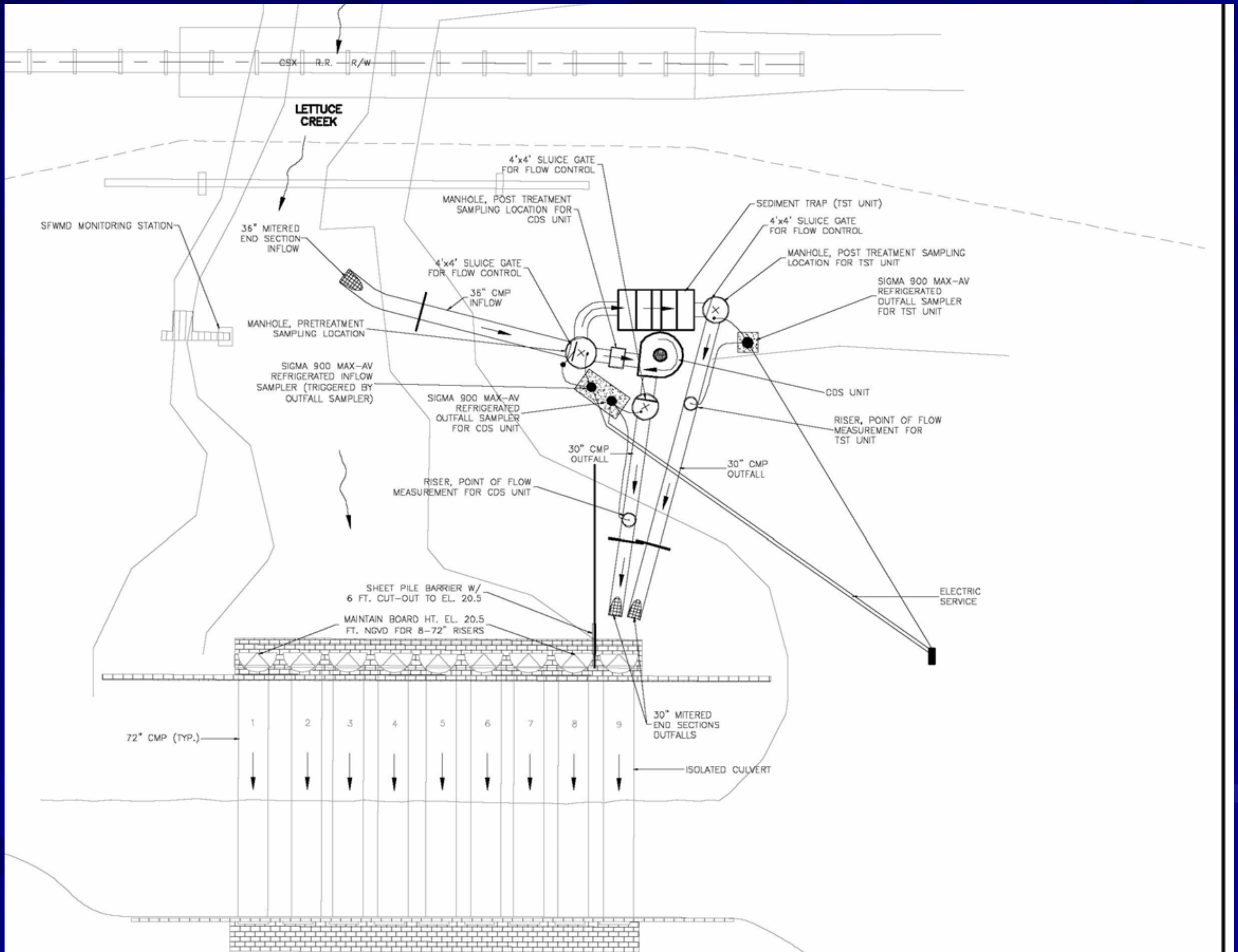
60 seconds following alum / polymer addition



3 minutes following alum / polymer addition

Lettuce Creek Floc Settling at an Alum Dose of 12.5 mg Al/liter and a Polymer Dose of 10 ppm

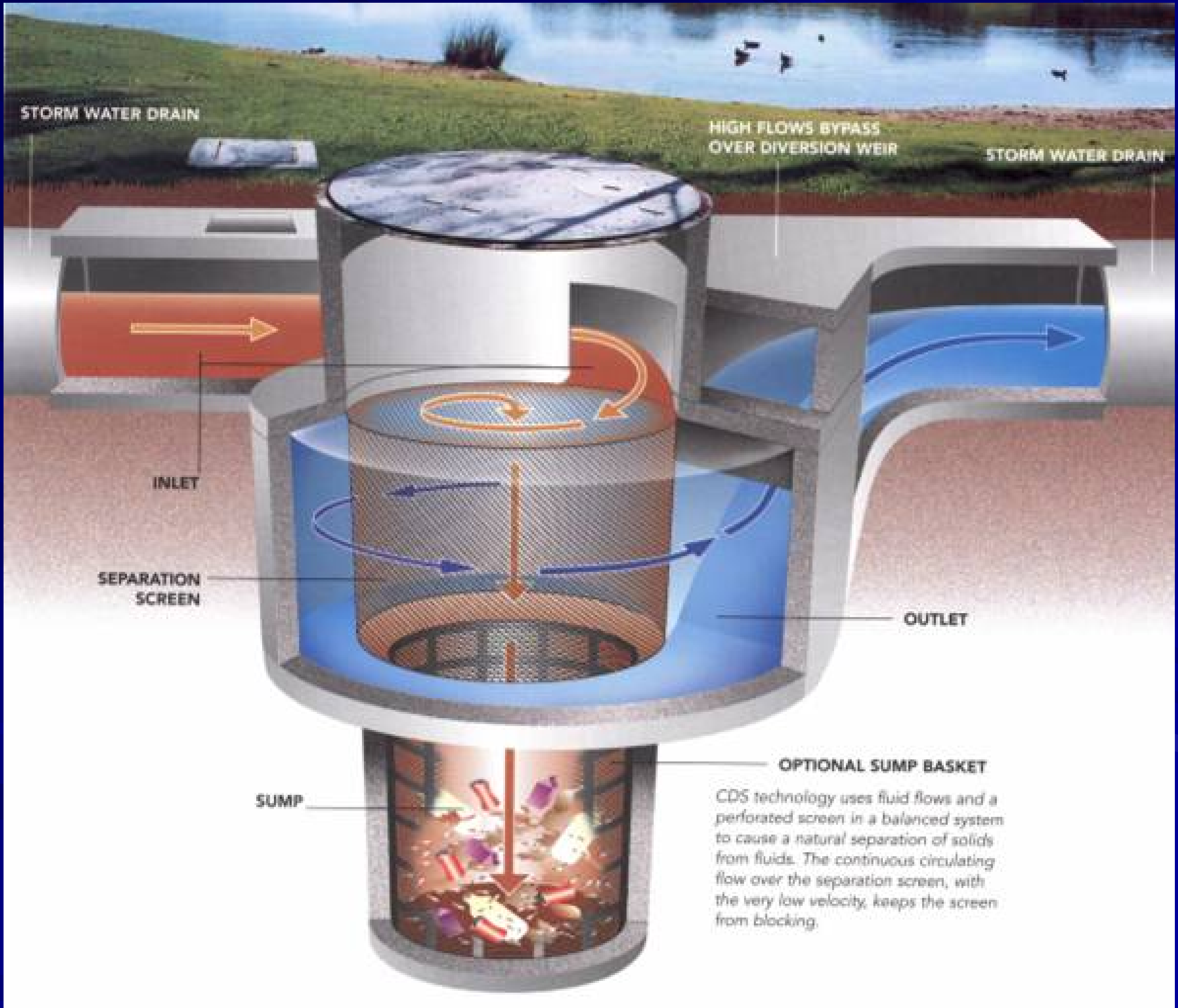
Schematic of Lettuce Creek Test Site



Monitoring System for Evaluation of CDS and TST Performance.

Lettuce Creek Between the CSX Railroad and the L-63S Canal

CDS Unit



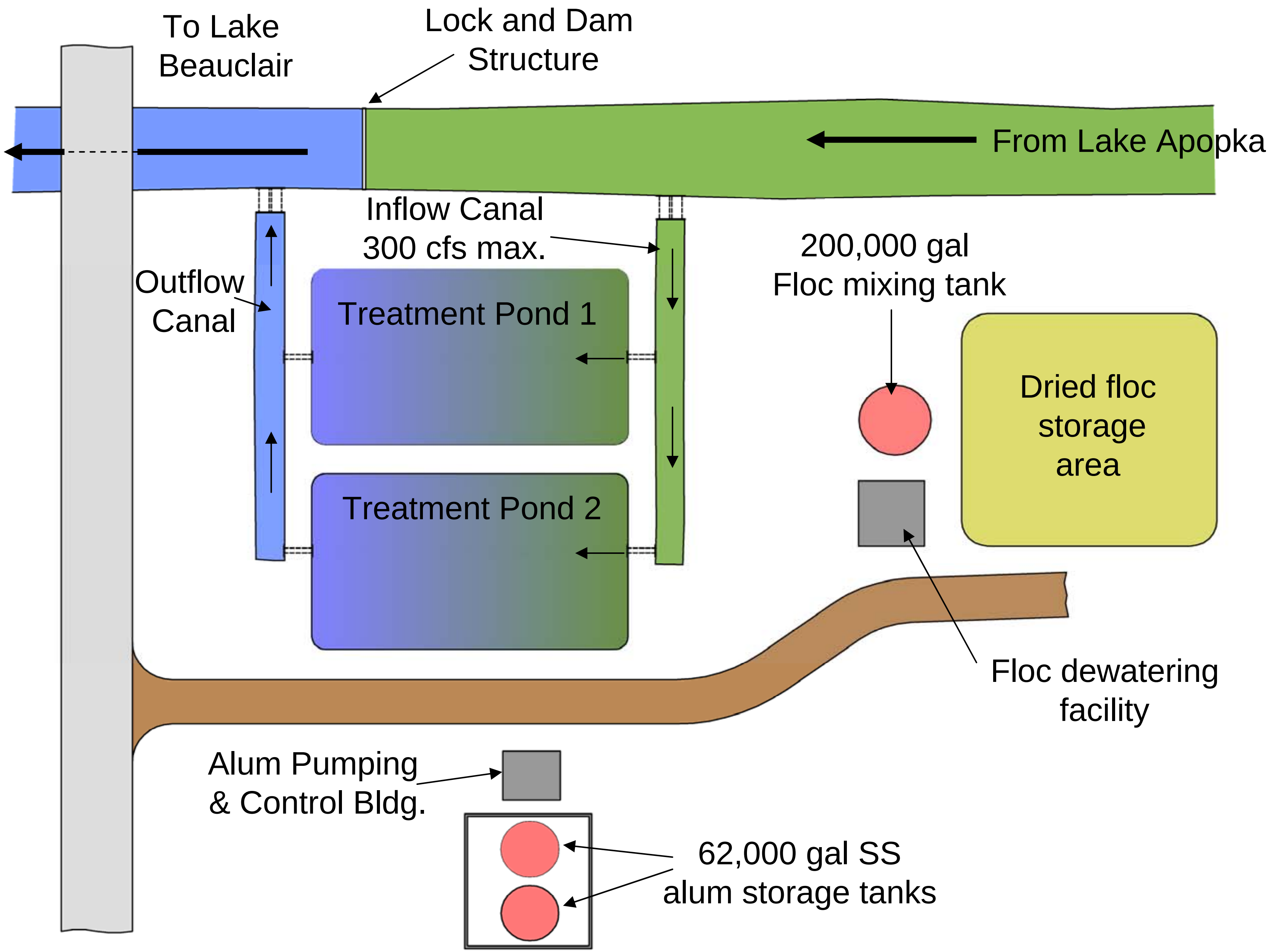
STORM WATER DRAIN
HIGH FLOWS BYPASS
OVER DIVERSION WEIR
STORM WATER DRAIN
INLET
SEPARATION
SCREEN
OUTLET
OPTIONAL SUMP BASKET
SUMP
CDS technology uses fluid flows and a perforated screen in a balanced system to cause a natural separation of solids from fluids. The continuous circulating flow over the separation screen, with the very low velocity, keeps the screen from blocking.

Construction of CDS and Baffle Box Units

Storage Tanks for Alum and Polymer

Conclusions – 1. CDS unit did not provide significant removal of alum floc
2. Turbulent conditions inside unit prevented floc from settling.

LCWA Nutrient Reduction Facility (NuRF)


To Lake Beauclair
Lock and Dam Structure
From Lake Apopka
Inflow Canal 300 cfs max.
Outflow Canal
200,000 gal Floc mixing tank
Treatment Pond 1
Treatment Pond 2
Dried floc storage area
Floc dewatering facility
Alum Pumping & Control Bldg.
62,000 gal SS alum storage tanks

Characteristics of NuRF Project

- Designed to reduce TP loadings from Lake Apopka to Harris Chain-of-Lakes
- Capable of treating up to 300 cfs from Apopka-Beauclair canal
- Opinion of construction cost = $5,000,000
- Floc collected in 2 settling basins
- Floc removal to occur using dedicated dredge system
- Floc generation = 239 ac-ft/yr
- Floc dewatered using centrifuge system
- Floc residual to be used as landfill cover or as soil amendment by SJRWMD

Estimated Annual Discharges Through the Apopka-Beauclair Canal

Condition	Annual Canal Discharge (ac-ft/yr)	Estimated Annual Mass Load (kg/yr)			
		Total N	Total P	TSS	BOD
Existing 1959-2000	54,092	193,972	13,328	2,465,472	339,836
Post Treatment[1]	54,092	137,002 (-29%)	4,669 (-65%)	1,434,165 (-42%)	209,781 (-38%)

1. Assumes that the system will treat 89% of water on an annual basis

Estimated Average Annual Total Phosphorus Loadings to Lake Beauclair from 1991-2000

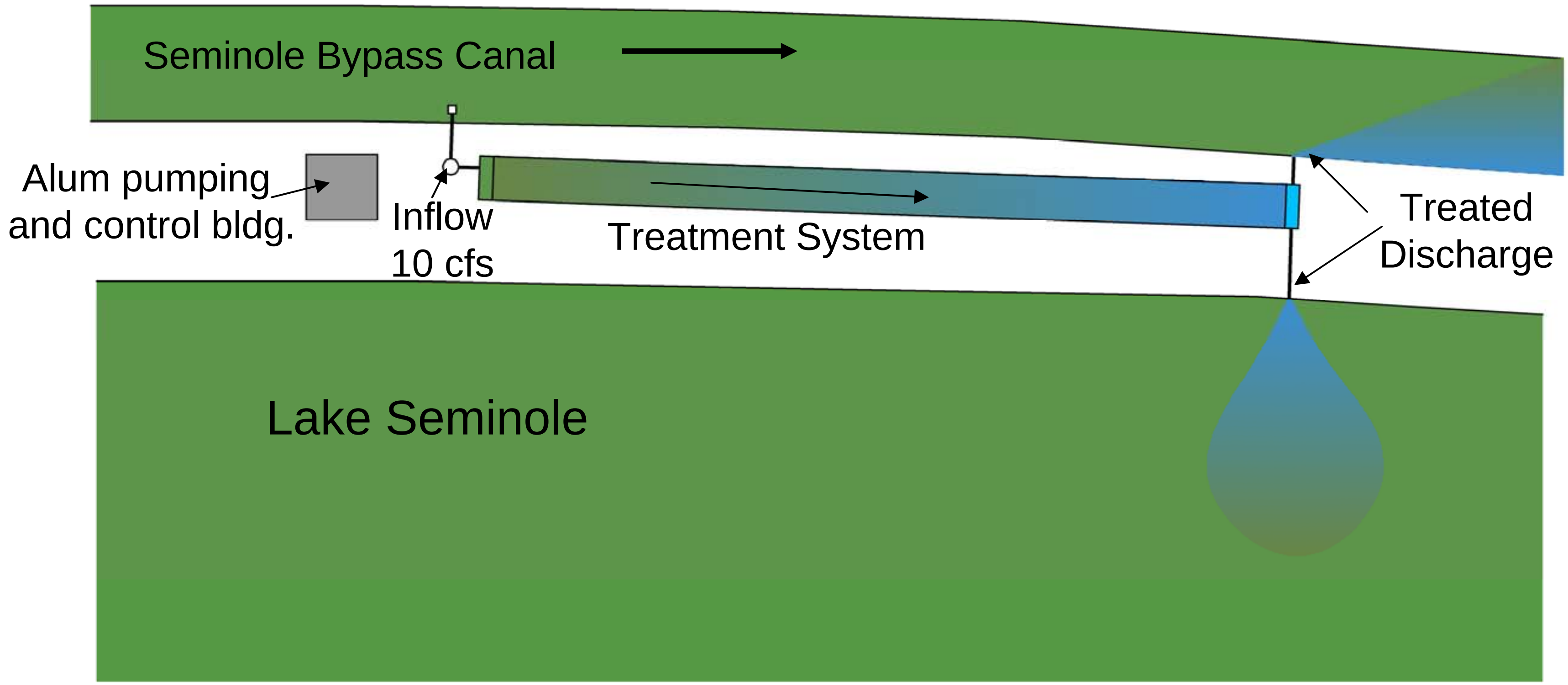
NUTRIENT SOURCE	MEAN TP LOAD	
	kg/yr	%
Low-Density Residential	46.5	0.22
Medium-Density Residential	42.2	0.20
High-Density Residential	0.0	0.00
Low-Density Commercial	4.9	0.02
High-Density Commercial	15.2	0.07
Industrial	10.0	0.05
Mining	0.0	0.00
Open Land / Recreational	1.1	0.01
Hurley Muck Farm	771.8	3.64
Pasture	59.6	0.28
Cropland	49.9	0.24
Tree Crops	38.5	0.18
Feeding Operations	0.0	0.00
Other Agriculture	20.8	0.10
Forest / Rangeland	29.7	0.14
Water	25.1	0.12
Wetlands	97.4	0.46
Septic Tanks	87.5	0.41
Precipitation	58.9	0.28
Dry Deposition	82.2	0.39
Apopka-Beauclair Canal Discharge	19,744.1	93.17
Lake Dora Discharge	6.8	0.03
TOTAL:	**21,192.3**	**100.00**

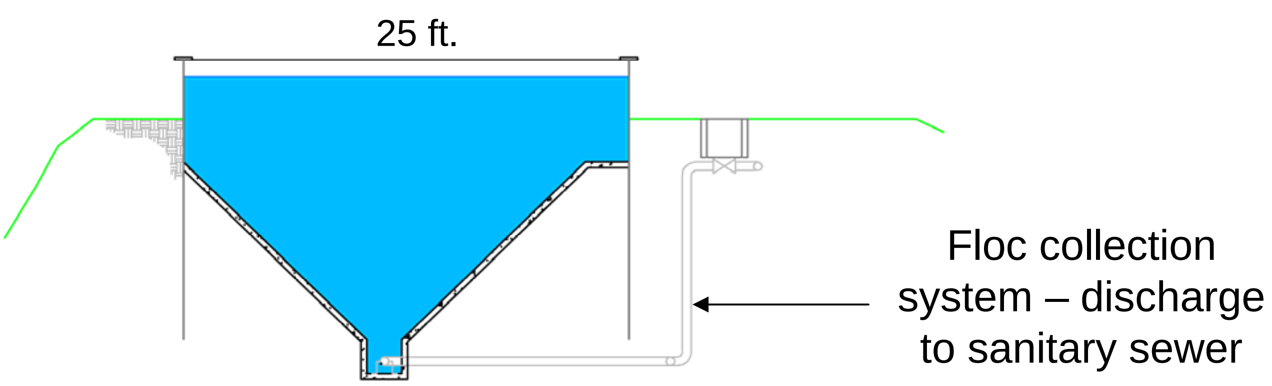
Chemical Characteristics of Dried Alum Residual from the NuRF Pilot Studies[1]

Parameter	Units	Value	Clean Soil Criteria[2] (Chap. 62-777 FAC)
Aluminum	µg/g	51,096	72,000
Antimony	µg/g	< 6.3	26
Barium	µg/g	< 21	110
Beryllium	µg/g	< 0.53	120
Cadmium	µg/g	0.5	75
Calcium	µg/g	1,564	None
Chromium	µg/g	65.0	210
Copper	µg/g	31.6	110
Iron	µg/g	764	23,000
Lead	µg/g	0.7	400
Magnesium	µg/g	96.8	None
Manganese	µg/g	12.3	1,600
Mercury	µg/g	< 0.091	3.4
Nickel	µg/g	2.3	110
Zinc	µg/g	50.6	23,000
NO_x	µg/g	0.773	120,000
Total N	µg/g	2,054	None
SRP	µg/g	< 1	None
Total P	µg/g	166	None
pH	s.u.	6.17	None

1. Residual sample air-dried and screened using an 0.855 mm sieve
2. Based on residential direct exposure criteria.

Lake Seminole Bypass Canal Treatment System





Cross-section of Treatment System

First system which is totally automated

Issues and Concerns

- System reliability
  - Early systems had reliability problems with flow monitoring equipment
  - Flow monitoring equipment has improved over the years and current systems are designed with redundant equipment
- Floc collection
  - Early floc collection systems have been inefficient in collecting floc
  - Recent modifications have improved the reliability
- Operation and maintenance
  - Many of the early systems were not properly maintained
  - Maintenance personnel typically had primary assignments other than the alum systems
  - A commitment to maintenance is necessary

Conclusions