Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

Tracking Sources of Phosphorus and the District's Action Plan for Sustainable Phosphorus Management

Kuldip Kumar

Associate Environmental Soil Scientist

Brett Garelli

Deputy Director of Maintenance & Operations

M&R SEMINAR

FEBRUARY 24, 2012

Overview

- Worldwide Phosphorus Budget
- Sources of Phosphorus in District Wastewater
- Chemical vs Biological Phosphorus Removal
  - Process footprint
  - Cost for removal at North Side, Calumet and Stickney WRPs
- Phosphorus Loading to District WRPs
- Phosphorus Removal Philosophy
- Results to-date

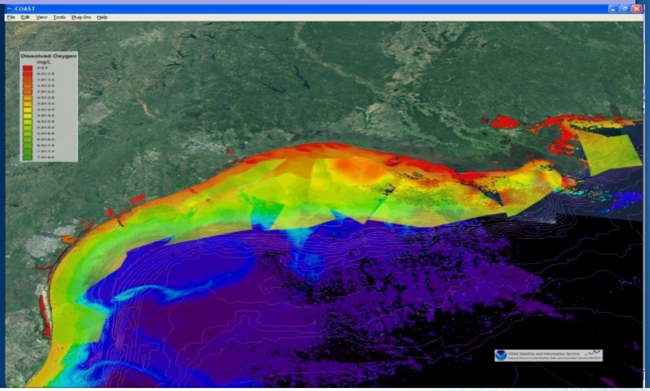
Acknowledgements

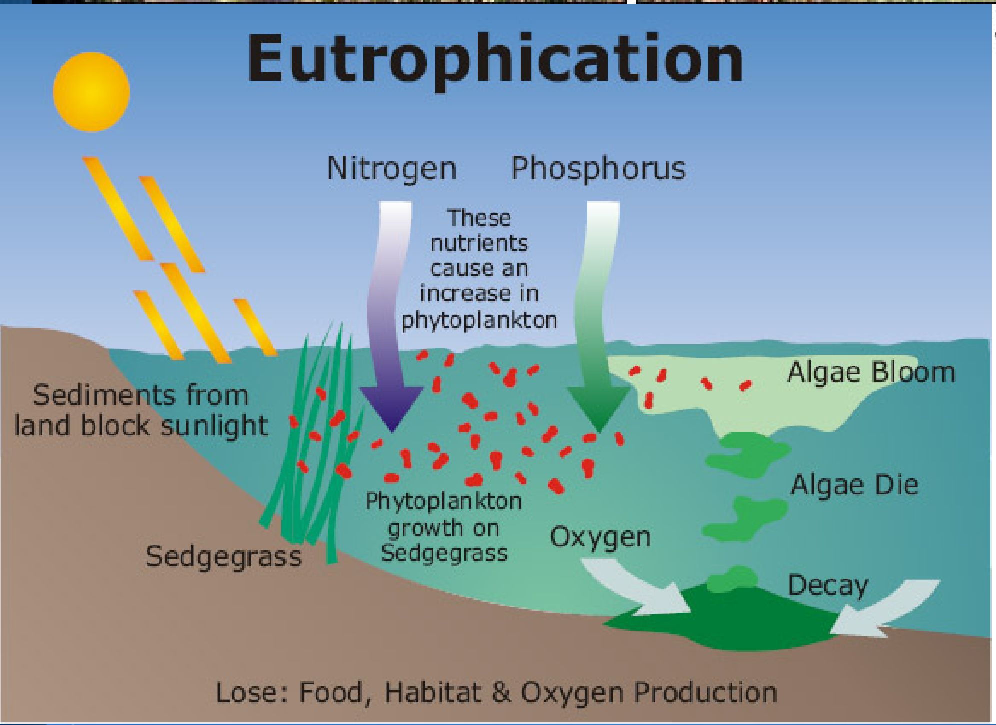
- Louis Kollias for Invitation to Talk at IWEA Govt Affairs Conference – June, 2011
- Catherine O’Connor
- Thomas Granato
- Bob Renaud, Greg Yarnik, Mathew Joseph and Staff
- Tom Liston and ALD Staff
- Lakhwinder Hundal
- Kamlesh Patel
- Joe Kozak
- Albert Cox
- Heng Zhang

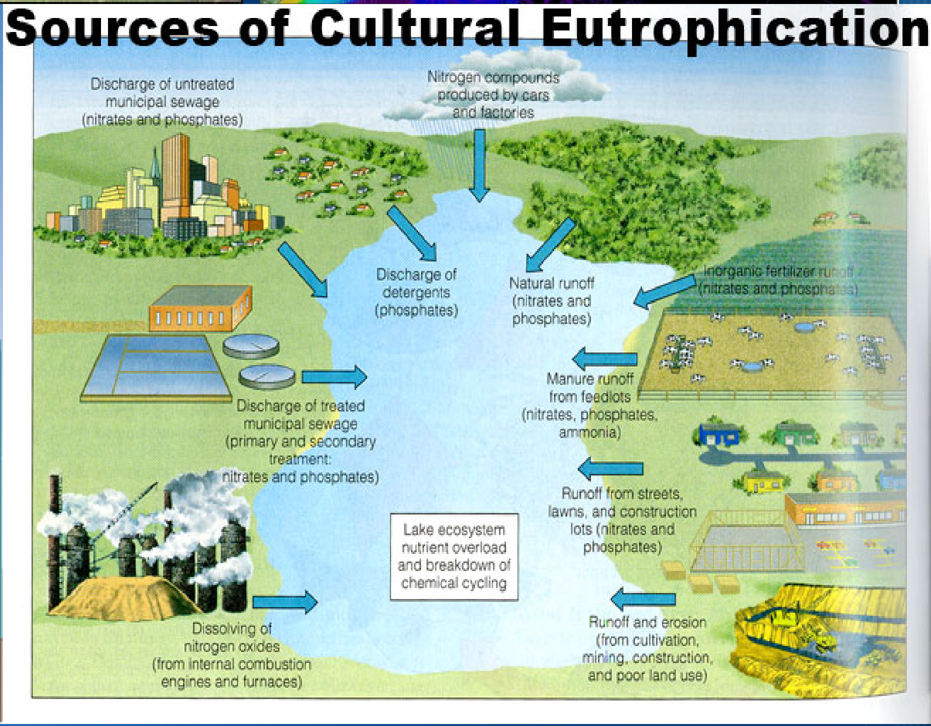
Outline

- Phosphorus (P) – A Resource and Pollutant
- P Cycle
- P in Excreta
- Sources of P – Mass Balance Calculations
- P Recovery / Source Control
- Recover Cost and Improve Effluent Quality
- Watershed P Loading
- Take Home Message

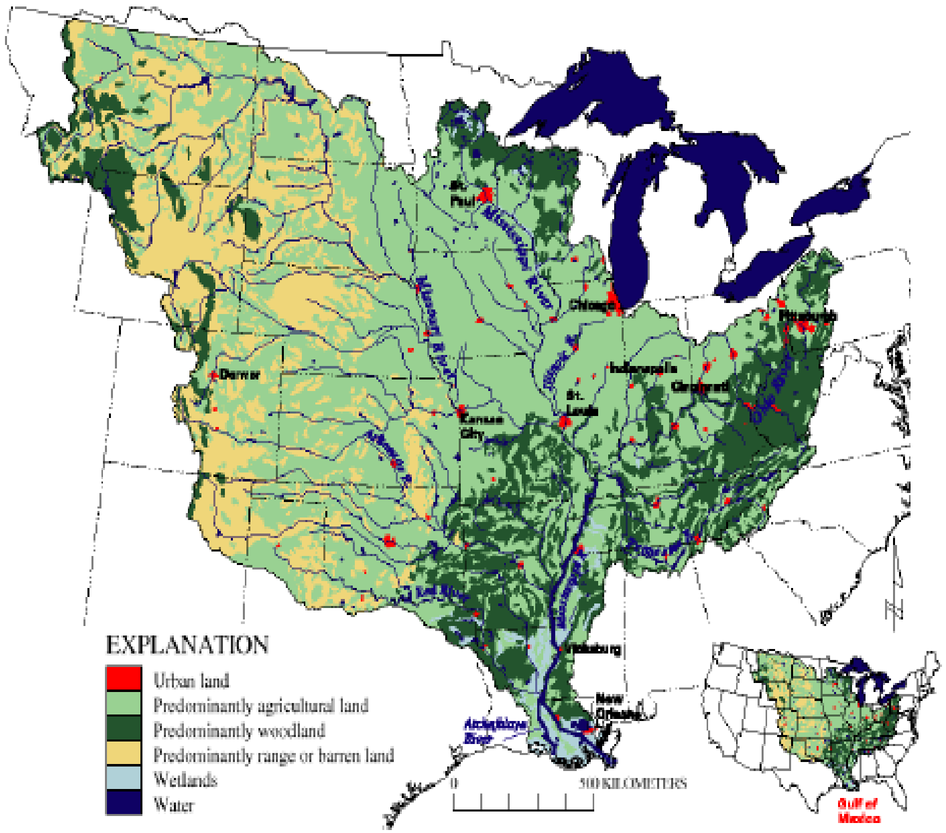
Eutrophication/Hypoxia







- More stringent requirements developing across the Mississippi Basin



USEPA Driving Regulations

1998 – USEPA announces National Strategy for Development of Regional Nutrient Criteria

http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/index.cfm

2001 – USEPA tasks IEPA with developing Water Quality Standards for Nutrients (Nitrogen and Phosphorus)

2002 – USEPA finalizes Ecoregional Nutrient Criteria

2004 to present – IEPA working to develop defensible basis for water quality standards

2006 – IEPA/IPCB promulgate the Interim Phosphorus Rule (1 mg/L TP limit for new and expanding WWTPs)

2008 – Illinois Requested Extension to Dec 2010

Dec 2010 – Illinois misses Dec 2010 deadline

USEPA Driving Regulations

January 2011 – USEPA Letter to IEPA demanding immediate action based on existing 303(d) list of impaired waterways

IEPA has agreed to work with its stakeholder group to develop a narrative standard as another "interim" standard while work continues on WQ standard.

- Rulemaking expected to be proposed within 1 year
- Limit for affected facilities expected to be between 0.6 and 1.0 mg/L
- Several outstanding questions:
  - Details of limits (may vary by size or type of facility)
  - Definition of impaired waterway
  - Determination of what facilities "contribute" to impairment

FDA Regulations?

Gross but True: FDA allows certain number of rodent hair in the food you eat. (A whole mouse, however, is not)

The FDA's action level for peanut butter is 30 or more insect fragments or one or more rodent hairs per 100 grams.

EPA is Worried about ppm level nutrients in water?

Wouldn't you love to have FDA as your regulator?

Phosphorus – Friend or Foe?

Sustaining Life: Friend as a "Nutrient":

- Necessary for agriculture and essential component for life

WWTPs - Foe as "Pollution":

- Recognized as leading cause of eutrophication in water bodies
  - *~365,000 tons/year of phosphorus in US sewage*

Result: Phosphorus is really a mismanaged resource.

A resource for the future of mankind

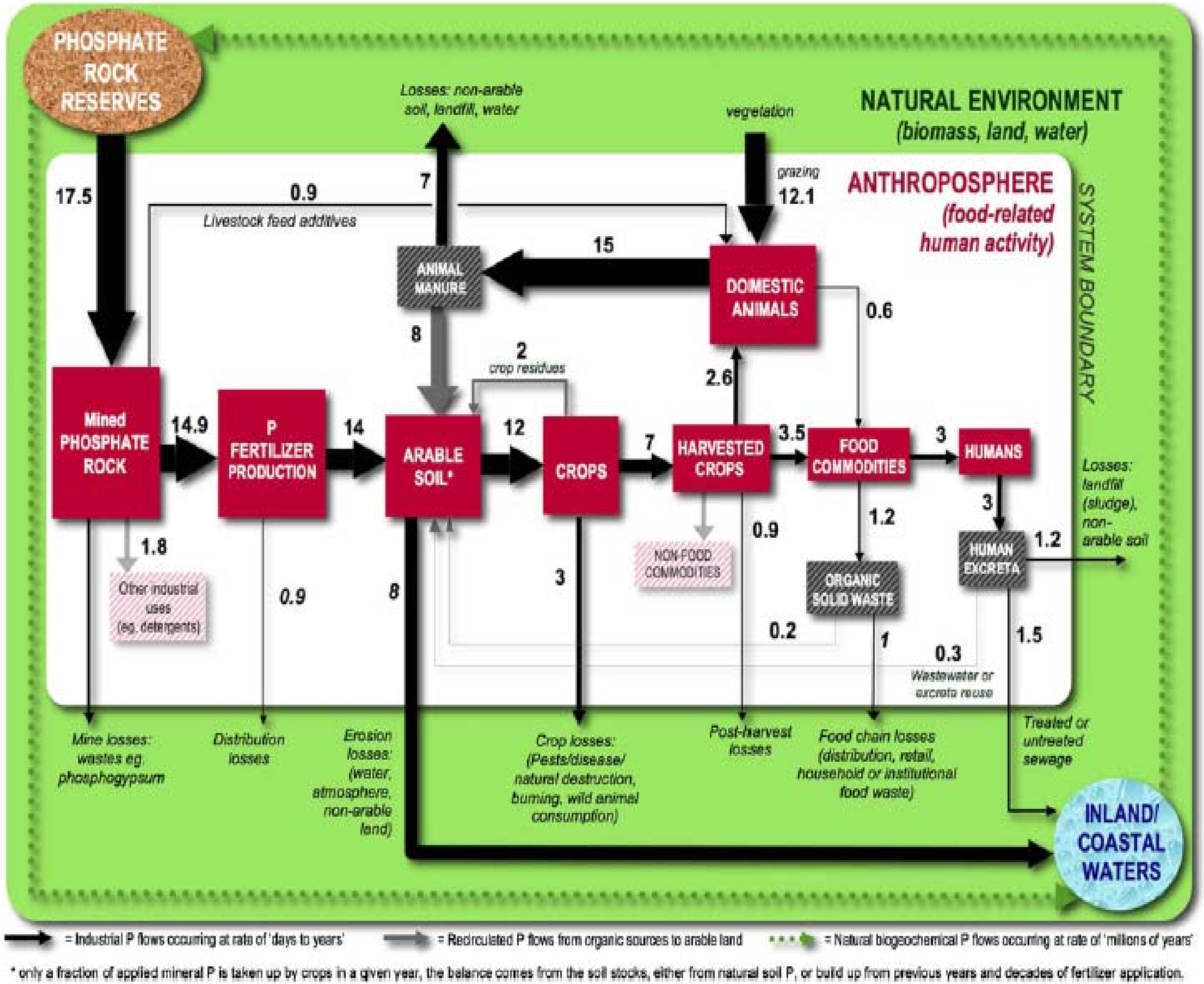
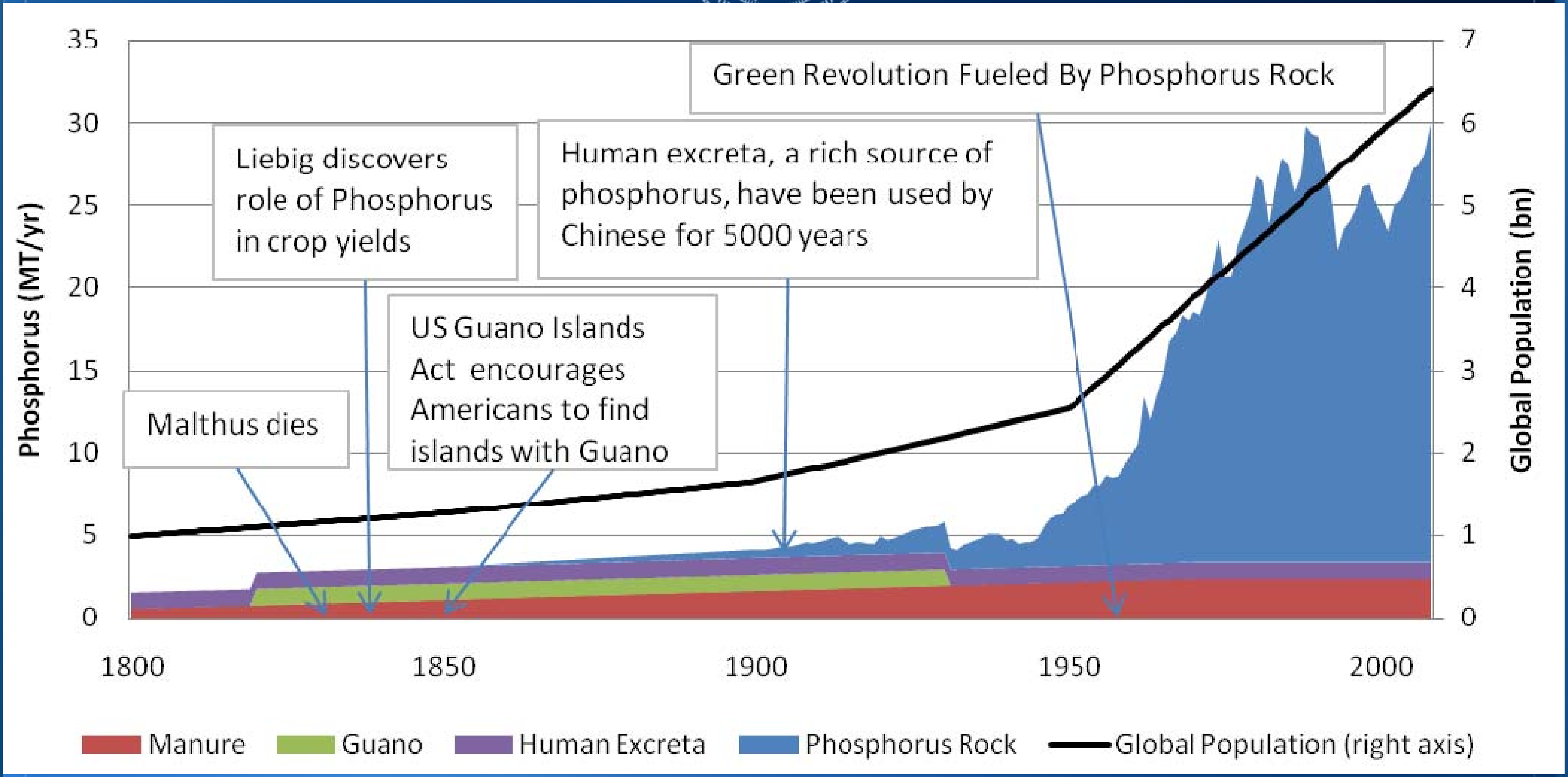


Fig. 3. Key phosphorus flows through the global food production and consumption system, indicating phosphorus usage, losses and recovery at each key stage of the process. Units are in Million Tonnes per year (Only significant flows are shown here, relevant to modern food production and consumption systems.). Calculations based on data in IFA (2006) and Smil (2000a,b).

History of Phosphorus-Based Fertilizers



Source: "The Story of Phosphorus: Global Security and Food For Thought", Cordell, et.al. *Global Environmental Change*, Volume 19, Issue 2, May 2009

World's Largest Producer, Consumer, & Importer? US

- Reserves of Phosphate rock in the US will be depleted in 25 years
- Most imports from Morocco and Morocco occupied Western Sahara
- Western Sahara Resource Watch claims that "Extracting and Trading with Phosphates from Western Sahara are contrary to international law
- Such trade is highly condemned by the UN
- Several European Countries have boycotted this trade in recent years

Peak Phosphorus – A Sequel to Peak Oil ?

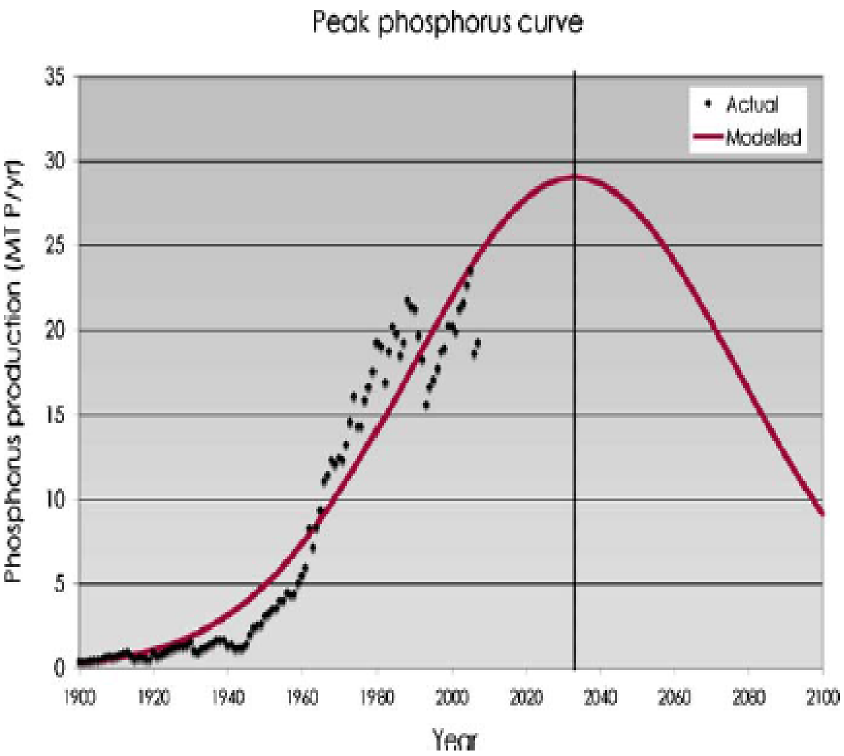
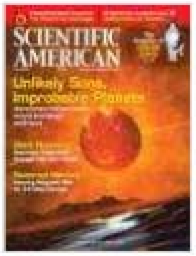


Fig. 4. Indicative peak phosphorus curve, illustrating that, in a similar way to oil, global phosphorus reserves are also likely to peak after which production will be significantly reduced (Jasinski, 2006; European Fertilizer Manufacturers Association, 2000).

- Oil can be replaced with other forms of energy once it is too scarce
- There is no substitute for P in food production
- Oil is unavailable once used
- Fortunately, P can be recovered from the food production & consumption chain and reused

Phosphorus as an "Emerging Issue"



From the June 2009 Scientific American Magazine | 28 comments

Phosphorus Famine: The Threat to Our Food Supply

This underappreciated resource--a key component of fertilizers--is still decades from running out. But we must act now to conserve it, or future agriculture could collapse

By David A. Vaccari

From The Times

June 23, 2008

Scientists warn of lack of vital phosphorus as biofuels raise demand

Leo Lewis, Asia Business Correspondent

NEWS SCAN

Scientific American – November 2009

Technology

Sewage's Cash Crop

How flushing the toilet can lead to phosphorus for fertilizers BY KATHERINE TWEED

TUCKED AWAY IN OREGON'S WILLAMETTE VALLEY, THREE MASsive metal cones could help address the world's dwindling supply of phosphorus, the crucial ingredient of fertilizers that has made modern agriculture possible. The cones make consistently high-quality, slow-release fertilizer pellets from phosphorus recovered at the Durham Advance Wastewater Treatment Facility, less than 10 miles from downtown Portland. By generating about one ton

WASTEWATER WONDER: Ostara's Crystal Green, a slow-release fertilizer, incorporates phosphorus retrieved from sewage streams.

Nature 461, October 2009

The Disappearing Nutrient

Phosphate-based fertilizers have helped spur agricultural gains in the past century, but the world may soon run out of them. Natasha Gilbert investigates the potential phosphate crisis.

Nutrients in Human Excreta could Produce 250 kg grain/yr (Wolgast, 1993)

Nutrients	Urine 500 L	Feces 50 L	Total	Fertilizer need for 250 kg grain
N	5.6 kg	0.09 kg	5.7 kg	5.6 kg
P	0.4 kg	0.19 kg	0.6 kg	0.7 kg
K	1.0 kg	0.17 kg	1.2 kg	1.2 kg
N+P+K	7.0 kg (94%)	0.45 kg (6%)	7.5 kg (100%)	7.5 kg

Lots of P in The Pee!

Phosphorus in Human Excreta of Vegetarian and Meat Eaters

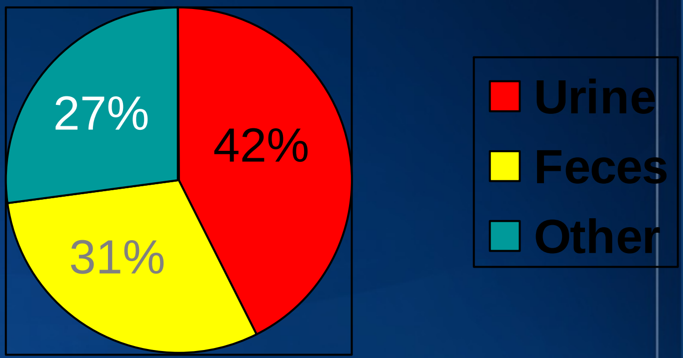
Consumption Type	P in Excreta (most in urine)
Vegetable-based diet	0.3 kg P/yr
Meat-based diet	0.6 kg P/yr

Diet? Meat-Based or Vegetarian

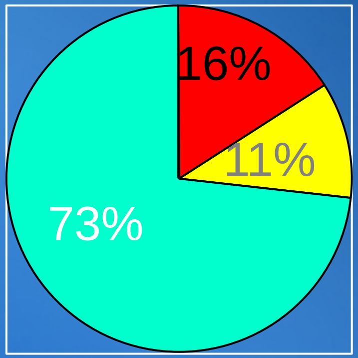
- Vegetarian diet demands significantly less P fertilizer (4.2 kg rock phosphate p.c p.a) than a meat-based diet (11.8 kg p.c p.a)
- A change in Chicago's residents diet to one with NO EXCESS P consumption (i.e. recommended daily intake per person) could decrease the total city's P load by 15%
- A switch in the current Indian Diet to meat would increase India's demand for P by 3-folds
- Need for SMART DIET which requires input of less P, water, & energy
  - Food preferences are generally more strongly correlated with taste, advertisement and price than they are with nutritional value

Contribution of Human Excreta to Total P Load in The Wastewater Stream

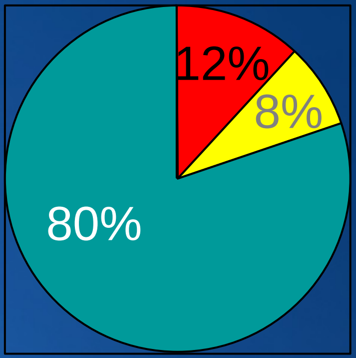
WRP	In. P mg/L	Flow MGD	Population million	P Load t
N. Side	3.39	238	1.349	1113
Cal.	6.64	246	1.025	2254
Stick.	7.06	686	2.276	6682



North side

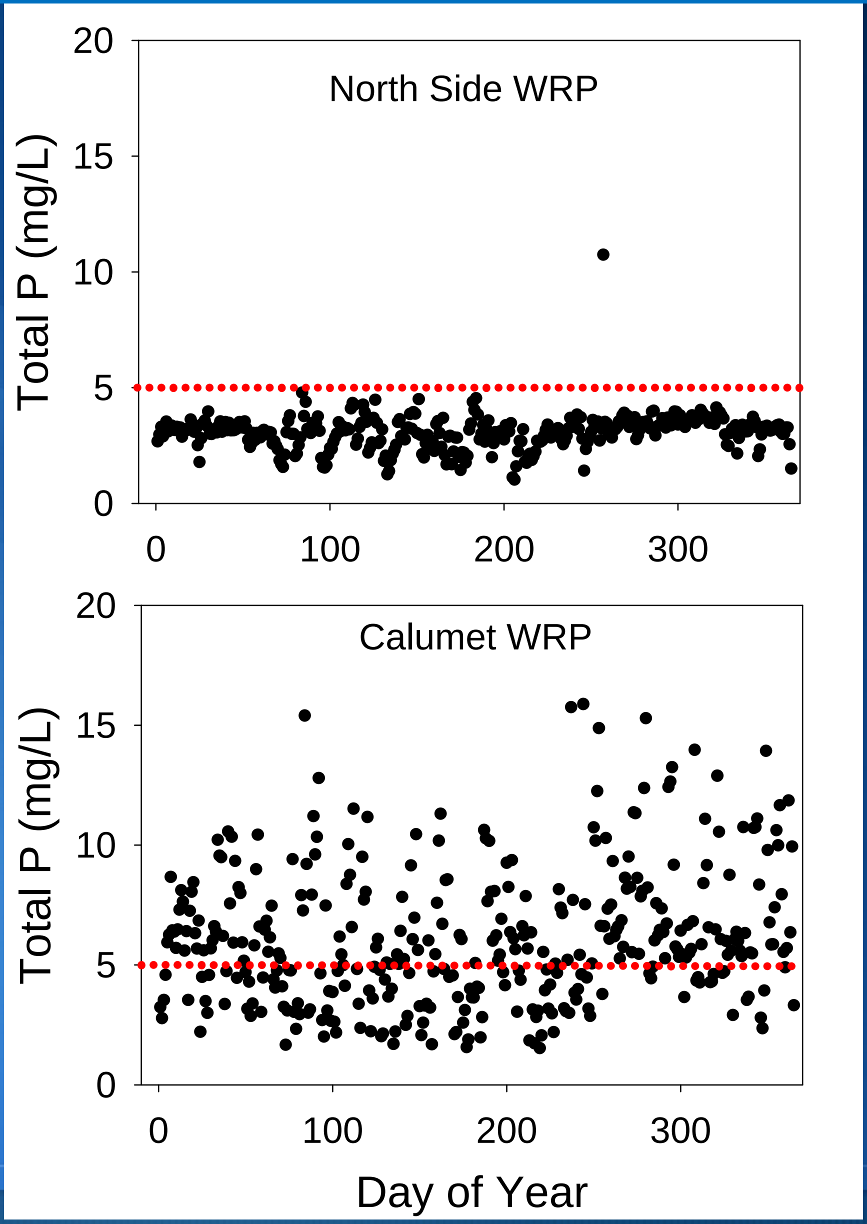


Calumet



Stickney

Total P Concentration in Raw Influent - 2010




IF YOU THINK
PICKING UP
DOG POOP IS
UNPLEASANT,
TRY SWIMMING IN IT.
Pet Waste Pollutes Our Rivers,
Lakes & Streams
CLEAN WATER
CAMPAIGN
WWW.CLEANWATERCAMPAIGN.COM

P (Pooh) Index (www.rockrivercoalition.org)

C7 =C6

	A	B	C	D	E	F
1			**Calculating Dog Pooh Runoff**			
2						***Click on the link below: select housing units under profile and then your city's name. You'll get a large chart, you'll find your total housing units in 2000 in the first full row.***
3						
4	City of (enter your city's name here)		Cook County			Wis Stat: 2000 Census Data
5	*Amount pooh using 35% **					
6	Number of Households in city		1722597			Replace # with number of households
7	Number of Households with dogs		1722597	x .35	602908.95	Equals X number of households with dogs
8	Number of dogs in the community		602908.95	x 1.5	904363.425	Equals Y number of dogs in the community
9	Number of dogs walked		904363.425	x .55	497399.8838	Equals Z number of dogs who are walked
10	after		497399.8838	x .35	174089.9593	Equals A amount of pooh for these dogs/day
11	pounds/dog/day (not picked up)		174089.9593	x .75	130567.4695	Equals B amount of pooh for these dogs/day
12	pounds/dog/year		130567.4695	x 365	47657126.36	Equals C amount of pooh in ton/year
13	tons/dog/year		47657126.36	/ 2,000	23828.56318	Equals P amount of pooh in ton/year
14						
15	*Amount pooh using 10%*					
16	Number of Households with dogs		1722597	x .35	602908.95	Equals X number of households with dogs
17	Number of dogs in the community		602908.95	x 1.5	904363.425	Equals Y number of dogs in the community
18	Number of dogs walked		904363.425	x .55	497399.8838	Equals Z number of dogs who are walked
19	after		497399.8838	x .10	49739.98838	Equals A amount of pooh for these dogs/day
20	dog pooh left/day in community		49739.98838	x .75	37304.99128	Equals B amount of pooh for these dogs/day
21	pounds of dog pooh left/year in community		37304.99128	x 365	13616321.82	Equals C amount of pooh in tons/year
22	tons of dog pooh left/year in community		13616321.82	/ 2,000	6808.160909	Equals P amount of pooh in tons/year

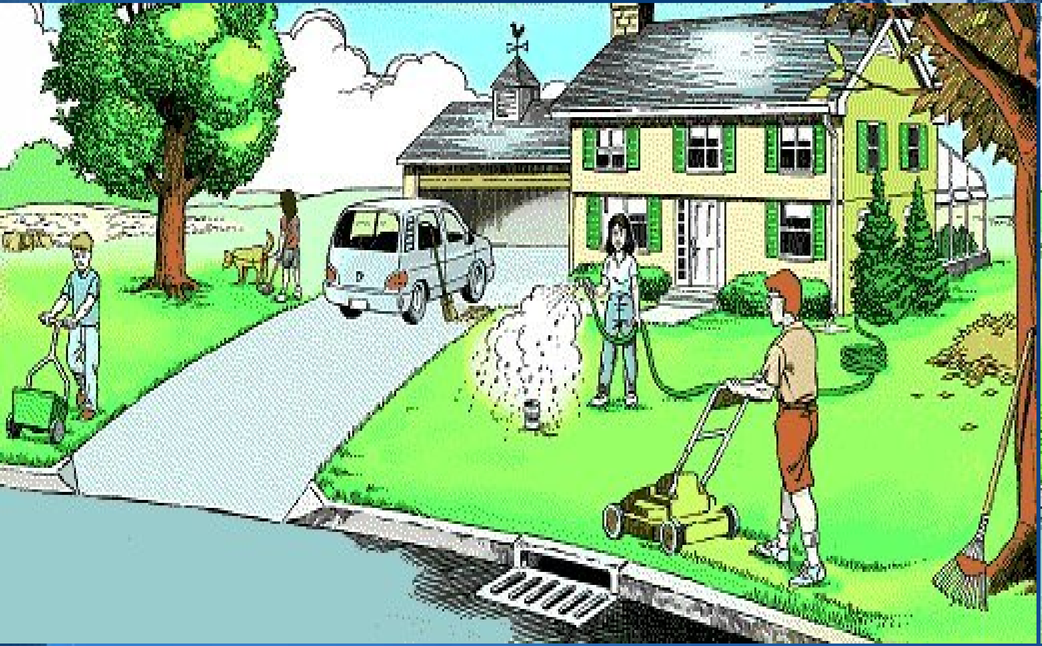
Calculator equations

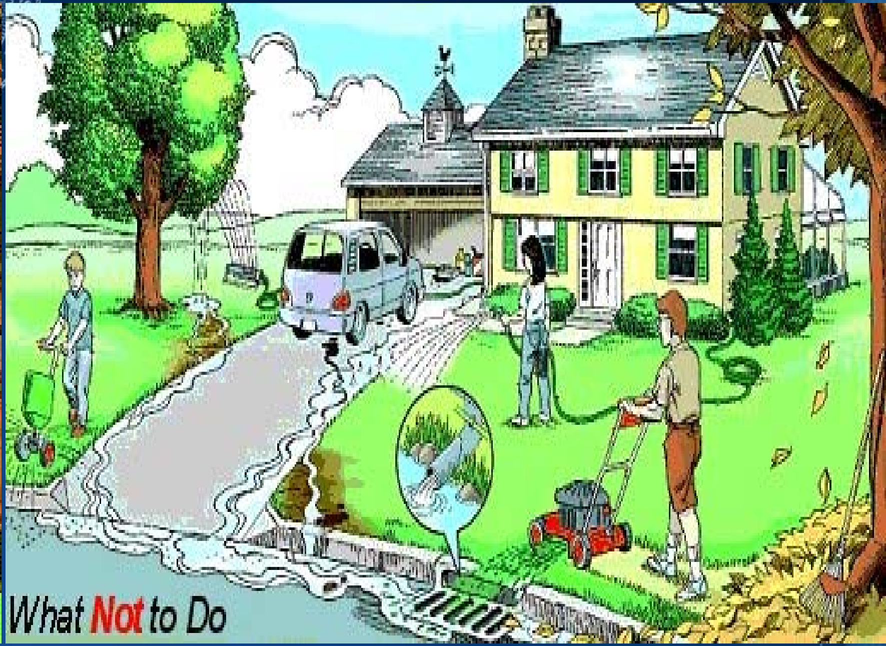
Number of households x .35 = X number of households with dogs
X x 1.5 = Y number of dogs in the community
Y x .55 = Z number of dogs who are walked
(40 - 50% of all dogs aren't walked, therefore you could use 50 - 60%)
Z x .35 = A Number of dogs who are walked and not picked up after
A x .75 = B amount of pooh for these dogs/day
B x 365 = C amount of pooh in pounds per year
C / 2,000 = P amount of pooh in tons/year
P = city's Pooh Index

Dogs Contribute ~250 t P

- 36.1 % households in US have on an average 1.6 dogs (Am. Vet. Med Assoc)
- 0.3-0.8 kg P /yr/dog in feces
- Disposal
  - 30% toilet
  - 20% not picked
  - 50% trash
- District system (All Toilet + 25% not picked via storm drains)

Lawn Management/Leaf Fall - P





Estimated P Loading from Autumn Leaf-Fall ~ 80 to 330 t

Trees: (4.1 m Chicago + 31.8 m Suburban Cook) = 35.8 m

Institutional Land (FP, GC, cemetery's) = 49%

Residential and Urban = 46%

Assumptions: Between 25-50% leaves end up in storm drains

Mass of leaves per tree between 10-20 kg

Average P concentration of leaves = 0.2 %

Annual P Loading from Autumn Leaf Fall ~ 80 to 330 t

PUBLIC AFFAIRS: Let us start a campaign - “ADOPT A STORM SEWER”

Cola's Contribute ~150 t P

- Population served by 3 WRP's = 4,651,011
- Soda consumption 54 gal/capita/yr
- 60% cola's (dark colored like pepsi, coke…)
- P concentration – 250 mg/L
- Body doesn't utilize any P from cola

Drinking Water Contributes ~200 t P

- Based on service population of 3 WRP's
- Water consumption – 150 gal/capita/d
- P conc. in finished water – 0.2 – 0.27 mg/L

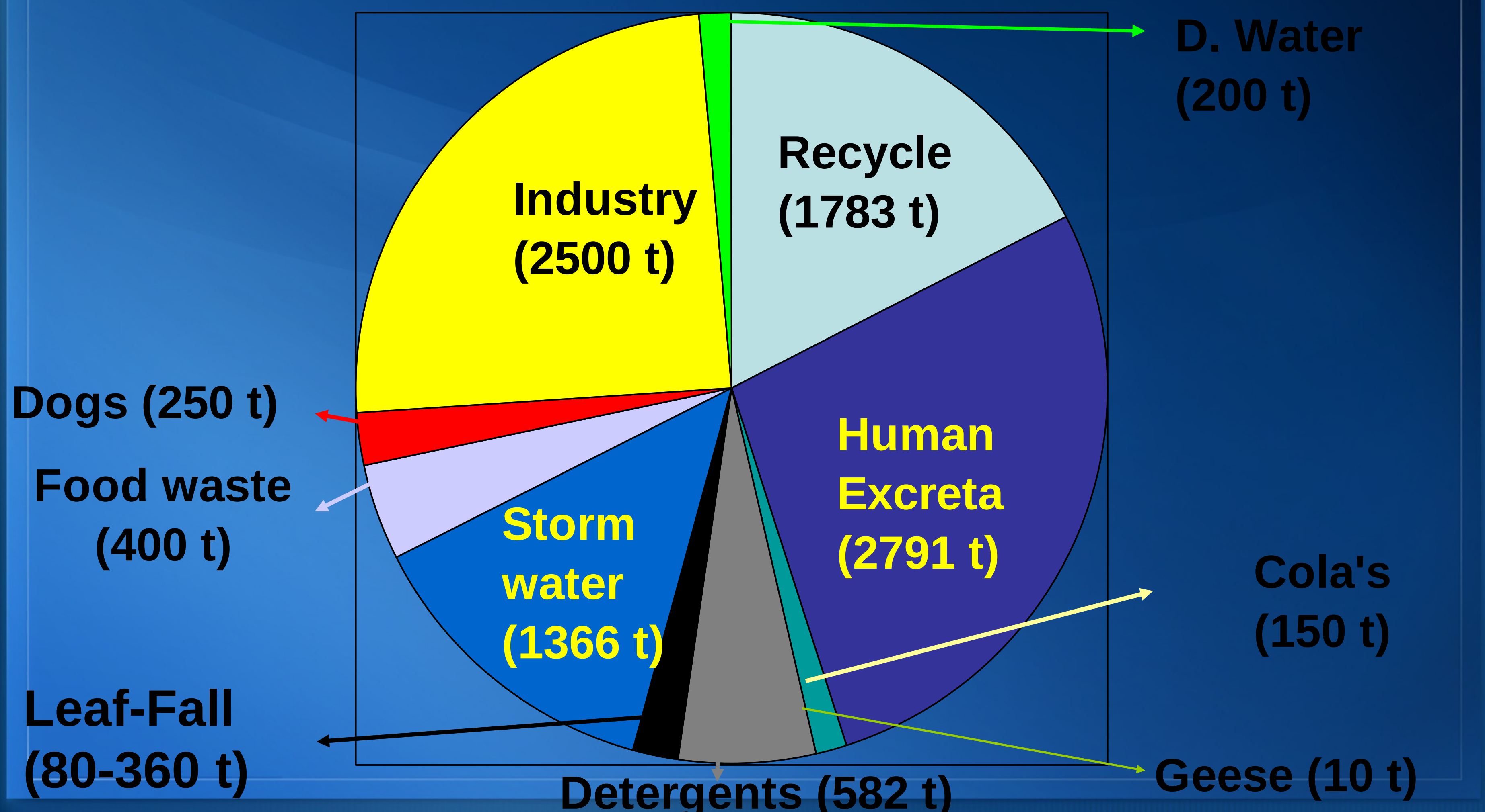
Food Waste Contributes ~400 t P

- Family of 4 wastes 2000 lbs food annually
- 50% US households have garbage disposals
- 10% food waste in disposal @ 0.075% P

Geese Contribute ~10 t P

- ~50,000 geese in service area
- 245 d/yr resident time
- 0.396 lbs feces/d/goose
- P – 1.87%
- Total P = 41 t
- Only 25% ends up in storm water

Annual Total P Load (10,049 t) For Three Major WRPs (Stickney, Calumet & Northside)



Annual Loading of total P and soluble P from industry at Stickney WRP (n=28 of

Industry No.	Total P, t	Soluble P, t	% Soluble P
1	45.89	33.81	74
2	23.90	23.47	98
3	22.10	16.37	74
4	9.76	9.60	98
5	8.50	7.14	84
6	6.52	6.32	97
7	6.25	6.01	96
8	4.42	2.58	58
9	1.54	1.47	96
10	1.45	1.33	92
11-28	<0.92	<0.66	80
Total (10)	130.33	108.1	83
Total (28)	135.84	111.68	82

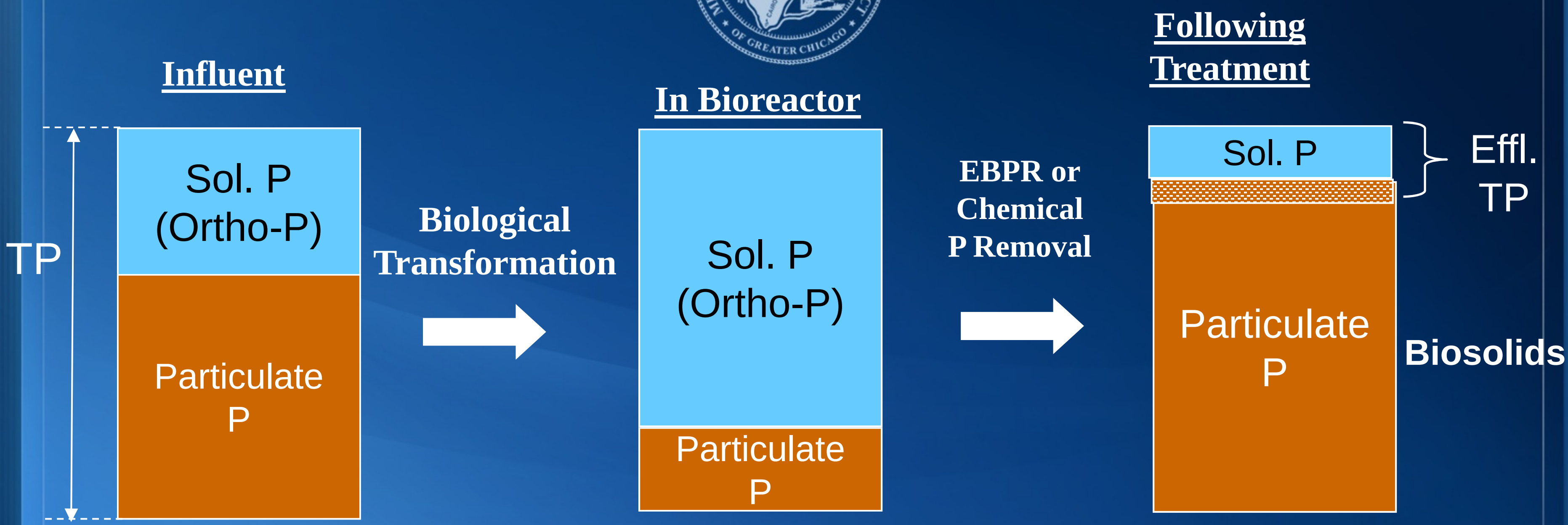
Annual Loading of total P and soluble P from industry at Calumet WRP (n=7 of 55)

Industry No.	Total P, t	Soluble P, t	% Soluble P
1	32.18	25.35	79
2	11.20	10.49	94
3	10.07	9.04	90
4	0.33	0.19	59
5	0.11	0.06	56
6	0.04	0.03	75
7	0.04	0.01	25
Total (3)	53.45	44.88	84
Total (7)	53.98	45.18	84

Annual Loading of total P and soluble P from industry at Northside WRP (n=8 of

Industry No.	Total P, t	Soluble P, t	% Soluble P
1	3.46	2.03	59
2	2.91	1.45	51
3	1.44	0.38	26
4	0.67	0.63	94
5	0.10	0.07	70
6	0.08	0.04	50
7	0.08	0.06	75
8	0.02	0.02	100
Total (3)	7.81	3.86	49
Total (28)	8.75	4.72	54

Fate of Phosphorus During Treatment



Process	Mechanism	Component Removed
EBPR	Biological P Uptake	Soluble P
Chemical P Removal	Chemical precipitation	Soluble P
	Coagulation, Flocculation	Particulate P
Solids Capture	Clarification, Filtration	Particulate P

What & How ?

Influent SP mg/L | **Effluent SP mg/L**

Reduction in influent SP loading to reduce effluent SP conc. by

Influent SP mg/L	Plant	Effluent SP mg/L	0.25 mg/L	0.50 mg/L
	N. Side (P Release Uptake)			
2010 – 1.40		1.30		
2009 – 1.29		1.17	82 t	164 t
2008 – 1.23		1.23	(7.5 %)	(15%)
	Calumet (P Release Uptake)			
2010 – 4.10		3.60		
2009 – 3.17		2.98		
2008 – 3.23		2.51		
	Stickney (P Release Uptake)			
2010 – 2.89		1.30	110 t	220 t
2009 – 2.14		1.13	(2%)	(4%)
2008 – 2.45		1.02		

Why P Source Control/Harvest?

- Cheaper than treating waste – much less volumes and much cleaner matrix.
- Harvested P could be sold locally as slow release fertilizer for urban market – Revenue
- Reduction in biosolids P concentration – 4:1 ideal N:P ratio.
- Sustainability – Triple Bottom Line of Social, Economical, & Environmental Benefits.

Concept of PPP (Polluters Pay for Pollution)

- Cola's @ 2¢/L: ~$11 m
- Dog Owners @$5/yr: $4.5 m
- Industry (User Charge + Sale of Harvested Fertilizer: ~$? m

Proportion of Total P loading as Phosphoric Acid

Upper IL River
P Load 4078 t
Phos. Acid 61%

IL River
P Load 7346 t
Phos. Acid 32%

Missouri River
P Load 26, 000 t
Phos. Acid 5%

Ohio River
P Load 39, 400 t
Phos. Acid 28%

MRB
P Load 136, 500 t
Phos. Acid 27%

Take Home Messages!

- Similar to metals, source control or industrial pre-treatment is the best solution to reduce point source P to meet the regulation without energy intensive and cost prohibitive biological or chemical P removal – not removal (from water to biosolids).
- P harvesting or recovery (for example stickney side-streams) may be viable and cost may be recovered from industry as User Charge and sale of recovered P as fertilizer.
- Convince EPA to include phosphoric acid in TCI program and find alternatives to phosphoric acid.

Phosphorus Species / Reactions

- Organic Phosphorus (P) – can be converted to orthophosphate
- Orthophosphate – most abundant species; reactive in chemical precipitation and consumed in biological growth
- Polyphosphates – condensed orthophosphates, can be used in biological growth, *may* react w/ metal salts

Phosphorus Removal From Wastewater

- Chemical Precipitation
  - Low capital expense (compared to biological removal)
  - High operating costs (chemical addition, price of consumables escalating)
  - Effective to very low concentrations (~ 0.1 mg/L)
- Biological Removal (Enhanced Biological Phosphorus Removal – EBPR)
  - Required aeration tank capacity
  - Under ideal conditions, may actually reduce operating costs
  - Effective to ~ 0.5 mg/L
- Membrane Filtration, Reverse Osmosis – extremely expensive

Phosphorus Removal from Wastewater

Chemical precipitation

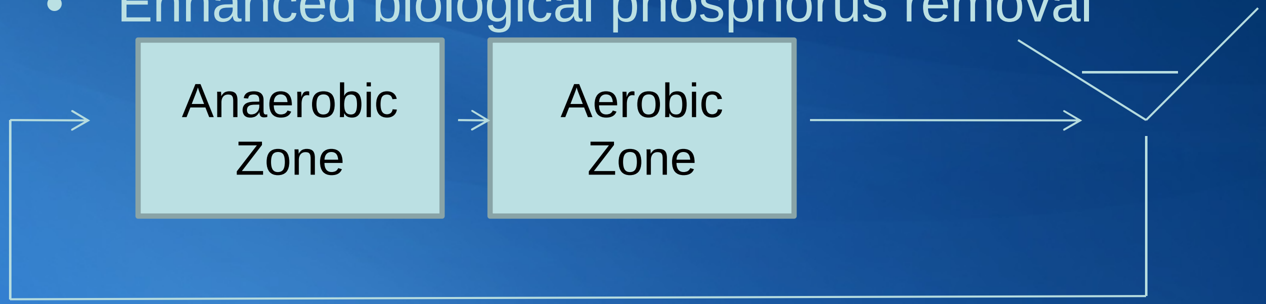
- FeCl3, Alum,
  - $Fe^{3+} + H_nPO_4^{3-n} \leftrightarrow FePO_4 + nH^+$
  - $Al^{3+} + H_nPO_4^{3-n} \leftrightarrow AlPO_4 + nH^+$
- Effective to very low concentrations ~ 0.1 mg/L
- Chemical dosing system relatively inexpensive (compared to expanding secondary treatment capacity)
- Design, Operating parameters
  - *Dose requirement*
  - *Minimum achievable phosphate concentration [f(permit)]*
  - *Effect of pH*
- Increases solids production
- Increases inert portion of MLSS, higher concentration of MLSS required for treatment

Enhanced Biological Phosphorus Removal

- Typical biomass ~2% w/w phosphorus/ volatile solids
- *Enhanced* Bio Uptake: 6-8% phosphorus
- A/O Process: anaerobic zone, aerobic zone
- Anaerobic zone
  - Fermentation to provide simply hydrocarbons as food for phosphate-accumulating bacteria (PAO)
  - Creates an environment that provides competitive edge for PAOs
- Aerobic zone
  - Additional phosphorus taken-up and stored in the PAO cell
  - PAO bacteria population increases

Phosphorus Removal from Wastewater

- Enhanced biological phosphorus removal



Return Activated Sludge : Fully de-nitrify

- Phosphorus accumulating bacteria (PAO) are ‘selected.’
- In anaerobic zone, PAO assimilate volatile fatty acids
- In aerobic zone, enhance phosphorus uptake
- Anaerobic zone ~ 1-2 hours HRT (capital intensive if secondary capacity is limited)

Annual Average Phosphorus Loading to Stickney , Calumet and North Side WRPs

Year	Stickney (million lbs)	Calumet (million lbs)	North Side (million lbs)	Total (million lbs)	Percentage of Total		
					Stickney	Calumet	North Side
2005	15.95	4.05	2.13	22.13	72	18	10
2006	16.44	3.85	2.08	22.37	73	17	9
2007	22.83	3.26	2.00	28.09	81	12	7
2008	17.09	4.26	2.07	23.42	73	18	9
2009	13.52	3.95	1.99	19.46	69	20	10

ANNUAL AVERAGE PERCENT REMOVAL OF POUNDS OF TOTAL PHOSPHORUS: STICKNEY, CALUMET, AND NORTH SIDE WRPs

	Stickney	Calumet	North Side
2005	84	40	63
2006	85	45	52
2007	87	48	53
2008	83	46	52
2009	82	37	53

ANNUAL AVERAGE TOTAL PHOSPHORUS DISCHARGE (MILLION POUNDS) BY THE STICKNEY, CALUMET, AND NORTH SIDE WRPs

	Stickney	Calumet	North Side	Total Loading to Lockport			
	(million	(million	(million	(million	Percentage of Total		
Year	lbs)	lbs)	lbs)	lbs)	Stickney	Calumet	North Side
2005	15.95	4.05	2.13	22.13	72	18	10
2006	16.44	3.85	2.08	22.37	73	17	9
2007	22.83	3.26	2.00	28.09	81	12	7
2008	17.09	4.26	2.07	23.42	73	18	9

Cost of Ferric Chloride to Meet Target Effluent Limits

	Target: 1.0 mg/L Effluent TP		Target: 0.5 mg/L Effluent TP	
WRP	Sludge Cost (K$/yr)	Chemical Cost (K$/yr)	Sludge Cost (K$/yr)	Chemical Cost (K$/yr)
Stickney	$ 2,083	$ 13,549	$ 3,876	$ 25,214
Calumet	$ 1,189	$ 7,736	$ 1,903	$ 12,378
North Side	$ 144	$ 937	$ 649	$ 4,221

Assumptions: 10.5 mg $FeCL_3$/ mg Sol –P
Sludge transport $132/DT
$FeCl_3$ $1.40/gal

District’s Approach – Sustainable Phosphorus Management

- Biological Phosphorus Removal w Existing Infrastructure
- Sidestream Recovery
- Benefits:
  - Energy Savings in Secondary Aeration (Anaerobic Zone)
  - Fully de-Nitrify RAS (Additional energy savings)
  - Recover phosphorus for use in agriculture

North Side, Stickney and Calumet Average/ Peak Flow Secondary Capacity

Aeration	North Side		Stickney		Calumet		
	Qave HRT (hr)	Qpeak HRT (hr)	Qave HRT (hr)	Qpeak HRT (hr)		Qave HRT (hr)	Qpeak HRT (hr)
Batteries A,B,C	7.4	4.0	7.5	3.5	Btty A,B	9.3	5.6
Battery D	5.2	2.5	7.0	3.4	Btty C	8.3	3.5
					Btty E1,E2	7.4	3.4

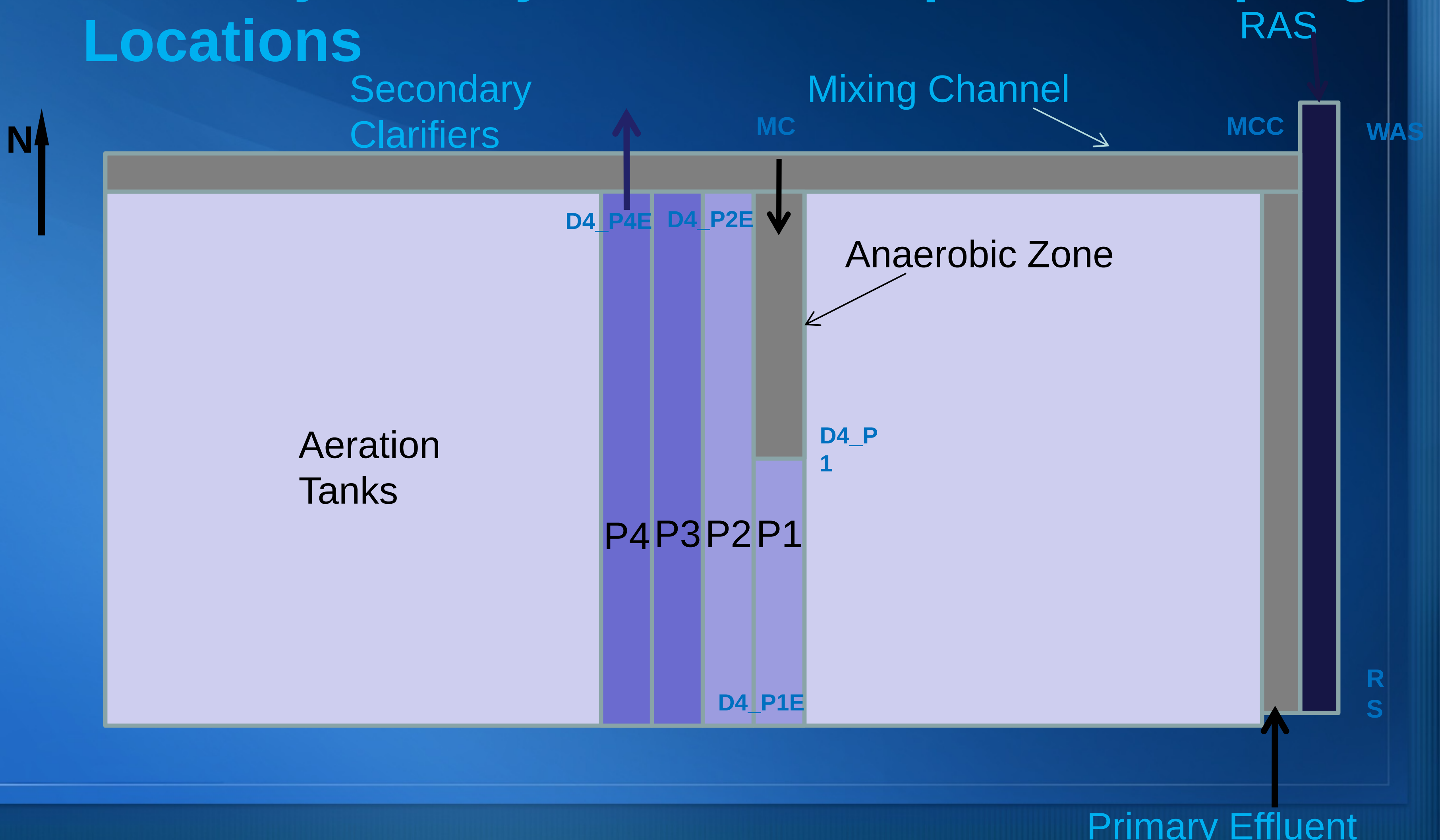
Bio-P Test at Battery D of the Stickney WRP

- Commenced in October 2011
- Turn air down to just enough for mixed liquor suspension to create anoxic zone in the mixing channel (de-nitrify RAS)
- Turn down air in first half of Pass 1 to create an anaerobic zone
- Luxury P uptake requires P release in anaerobic zone with plenty of easily biodegradable carbon present

Bio-P Test at Battery D of the Stickney WRP

- Phase I
  - Compare control Battery A to EBPR convert Battery D
- Phase II
  - Look at EBPR Battery efficiency under different stress conditions
    - *low flow, high flow, low P loads, and high P loads*
  - Look at diurnal variation of bio P removal in Battery D
- Phase III
  - Modify length of anaerobic zone
  - Look into modifying how RAS flow affects P Removal
- Phase IV
  - Use past and Phase I-III data to evaluate the effect of EBPR on nitrification
  - Run nitrification rate tests on EBPR mixed liquor and control mixed liquor
  - Install NH_3 probe at end of Battery D tank to get real time and continuous information on nitrification in tank

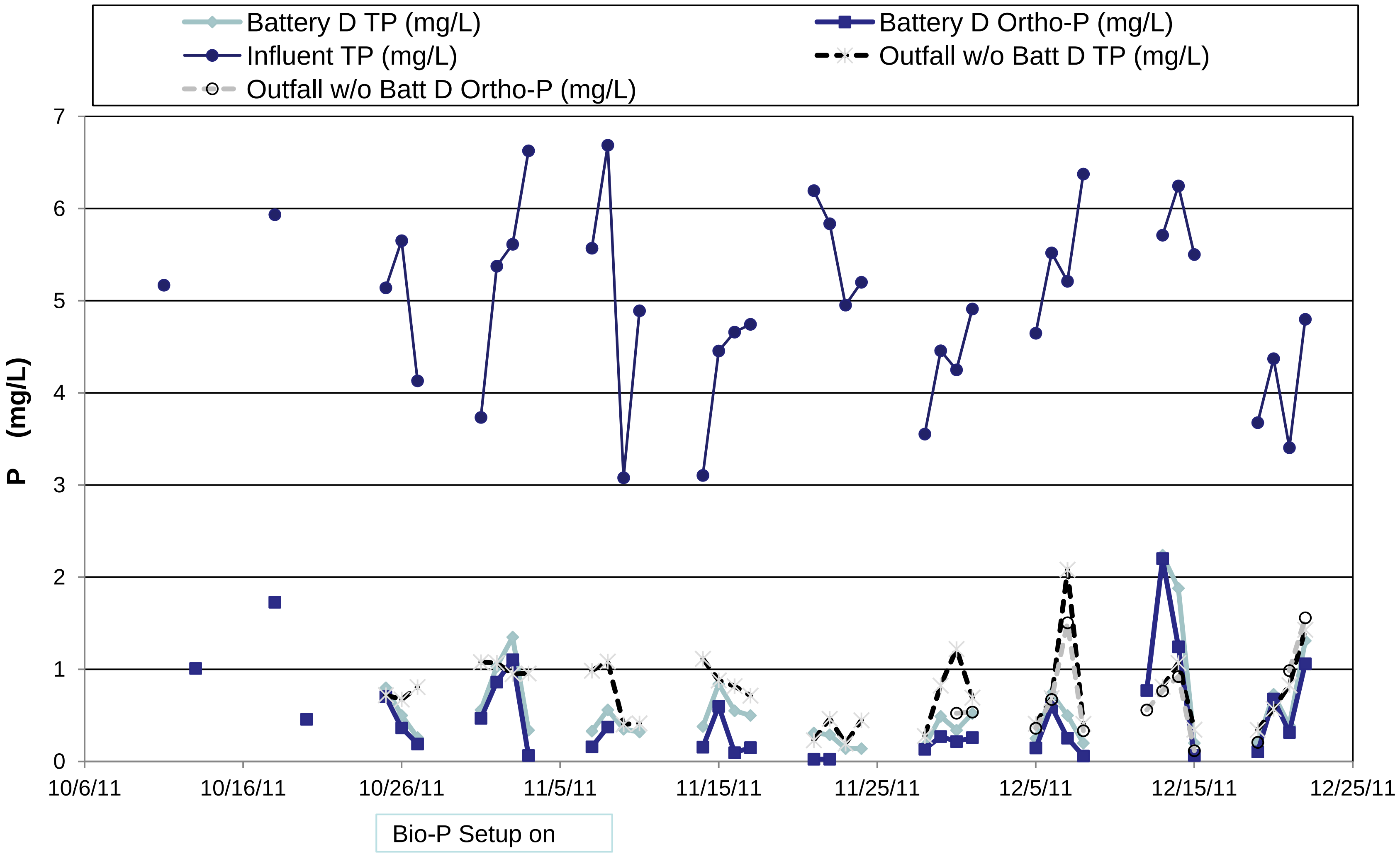
Stickney Battery D Bio-P Setup And Sampling Locations

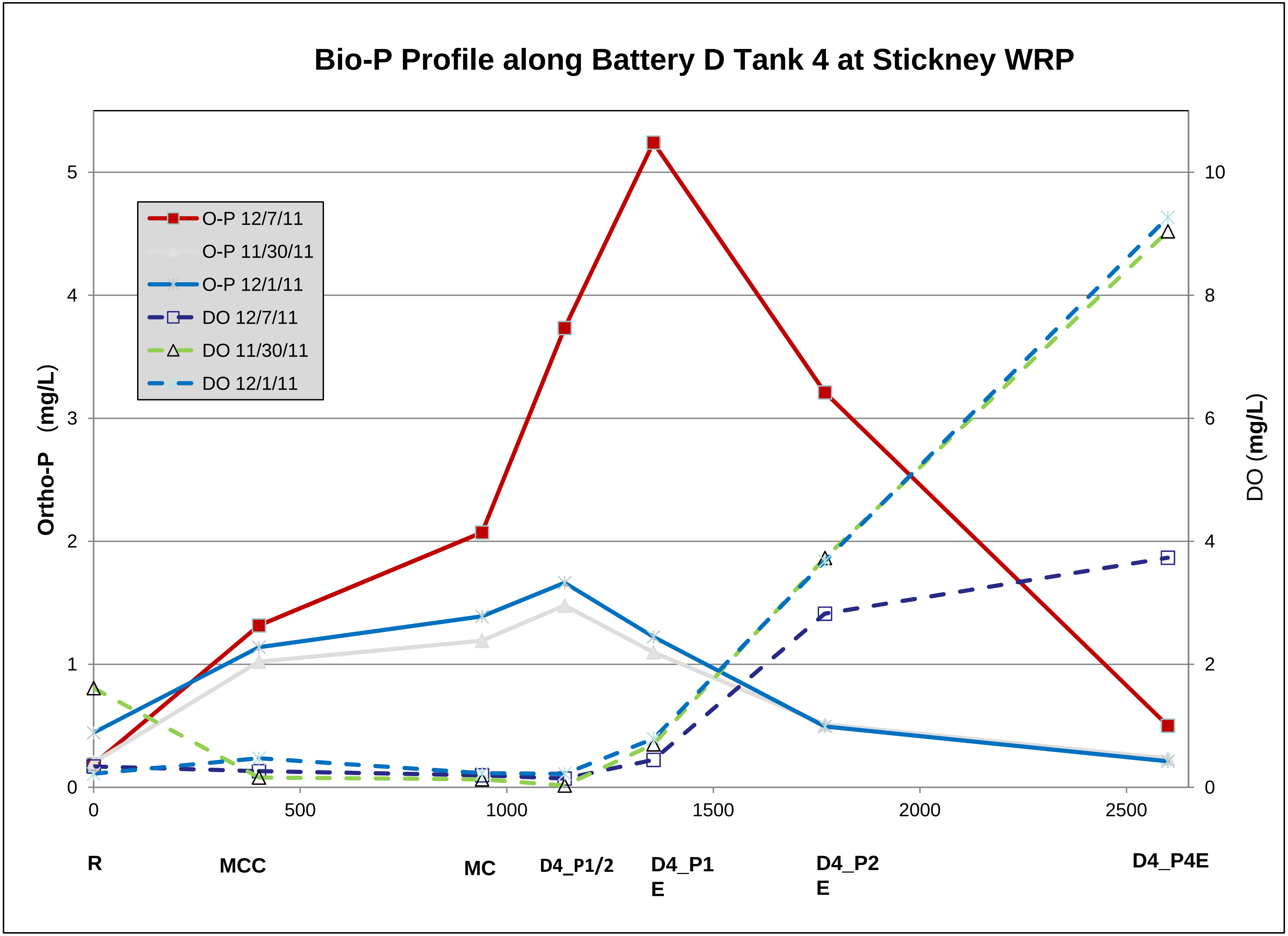


Bio-P Test at Battery D of the Stickney WRP

- Side by side comparisons w/ control battery
- Longitudinal plots of parameters throughout battery
- Check that operational data and influent data relative to EBPR design data
- Check that not compromising NPDES permits

Daily Average TP and Ortho-P (24-h Composites), Battery D and Stickney Outfall Excluding Battery D




Bio-P Profile along Battery D Tank 4 at Stickney WRP
O-P 12/7/11
O-P 11/30/11
O-P 12/1/11
DO 12/7/11
DO 11/30/11
DO 12/1/11
Ortho-P (mg/L)
DO (mg/L)
0
1
2
3
4
5
0
2
4
6
8
10
0
500
1000
1500
2000
2500
R
MCC
MC
D4_P1/2
D4_P1 E
D4_P2 E
D4_P4E

Preliminary Conclusions of Battery D EBPR

- EBPR was likely occurring at Battery D (lower effluent Ortho-P)
- Significant denitrification in mixing channel
- SRT of 5.9 days appears to be sufficient for Bio-P.
- Battery air shutdown (12/13/11) caused a spike of P in effluent.
- Accumulation of P in WAS was not detected (sampled after 12/13/11; 1.8% TP/TSS in Batt D vs. 1.7% TP/TSS in Batt B)
- HRT seems to have little impact on Bio-P, and further testing to confirm is required.
- Nitrification may have been compromised, but could be affected by SRT or short HRT in aerobic zone or both. Further test is required to verify.