Science of BNR Optimization

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Ohio Water Environment Association

Plant Operations and Laboratory Analysis Workshop

September 1, 2010

Brown AND Caldwell

Workshop Overview

- Fundamentals of Biology and Chemistry
  - Respiration and Energy
  - Oxygen Uptake Rate
  - Alkalinity
  - ORP
- Nitrification
- Denitrification
- Aeration Basin Profiles

This Workshop is Interactive.
It is okay to say….

- I don’t understand
- I don’t know
- I disagree
- Let me share my experience

Energy and Respiration

- Source of Energy - Food
  - Heterotrophic
  - Autotrophic

- Means of Respiration – How they use or break down the food
  - Aerobic
  - aNO$_x$ic
  - Anaerobic
  - Facultative

Source of Energy

- Heterotrophic – organic carbon ($cBOD_5$)
  - $cBOD_5$ removal
  - Denitrification
  - Hydrogen sulfide production

- Autotrophic – inorganic carbon
  - Nitrification (NH_4^+-N)
  - Photosynthesis (Sunlight)
  - Sulfide oxidation - acid corrosion in sewers (H_2S)

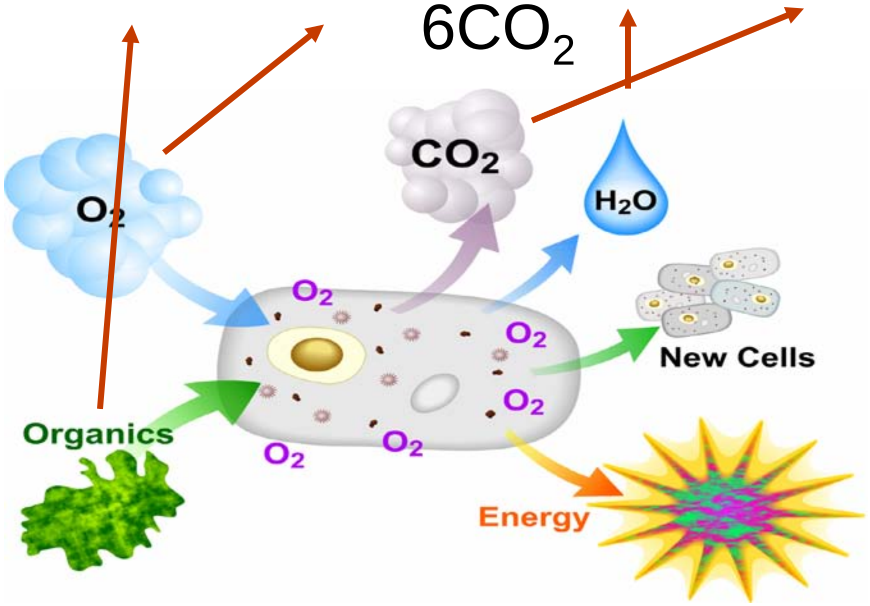
Means of Respiration

Aerobic	Oxygen (O_2), Nitrate (NO_3^-- N), Sulfate
aNO$_x$ic	Nitrate, ~~Oxygen~~
Anaerobic	~~Nitrate~~, ~~Oxygen~~, Sulfate
Facultative	Can use different acceptors
Fermentation	~~Nitrate~~, ~~Oxygen~~, Sulfate

cBOD$_5$ Removal

- Primary objective of TF/SC
- cBOD$_5$ removing organisms dominate
- This is what humans do

$$C_6H_{12}O_6 + 6O_2 \dashrightarrow 6H_2O + 6CO_2$$



What does this tell us?

$$C_6H_{12}O_6 \ + \ 6O_2 \ \text{--->} \ 6H_2O \ + \ 6CO_2$$

- Use organic carbon – Heterotrophic
- Use oxygen – Aerobic
- Produce water and carbon dioxide

OUR

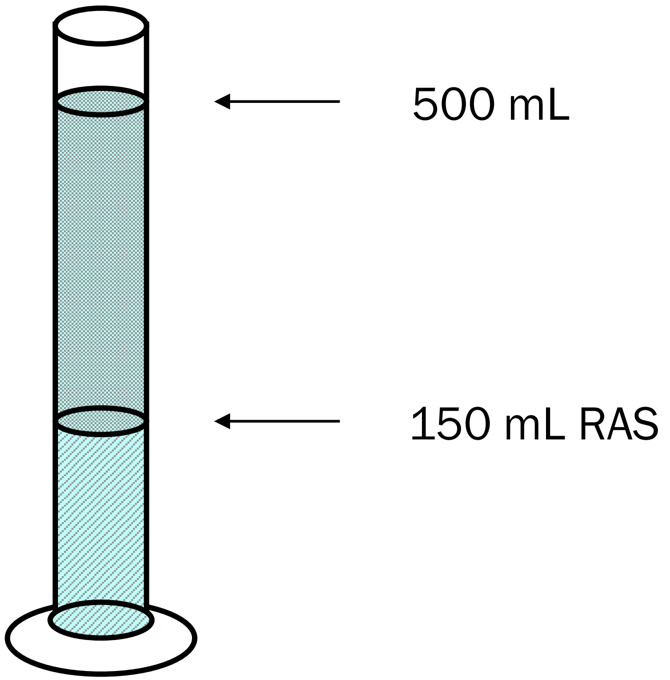
Method

- Simplified OUR
- Fill 1-gallon jug about 2/3 full with MLSS
- Cap and shake to aerate for 30 seconds
- Use field D.O. probe to measure oxygen depletion
- 10-second readings for one minute

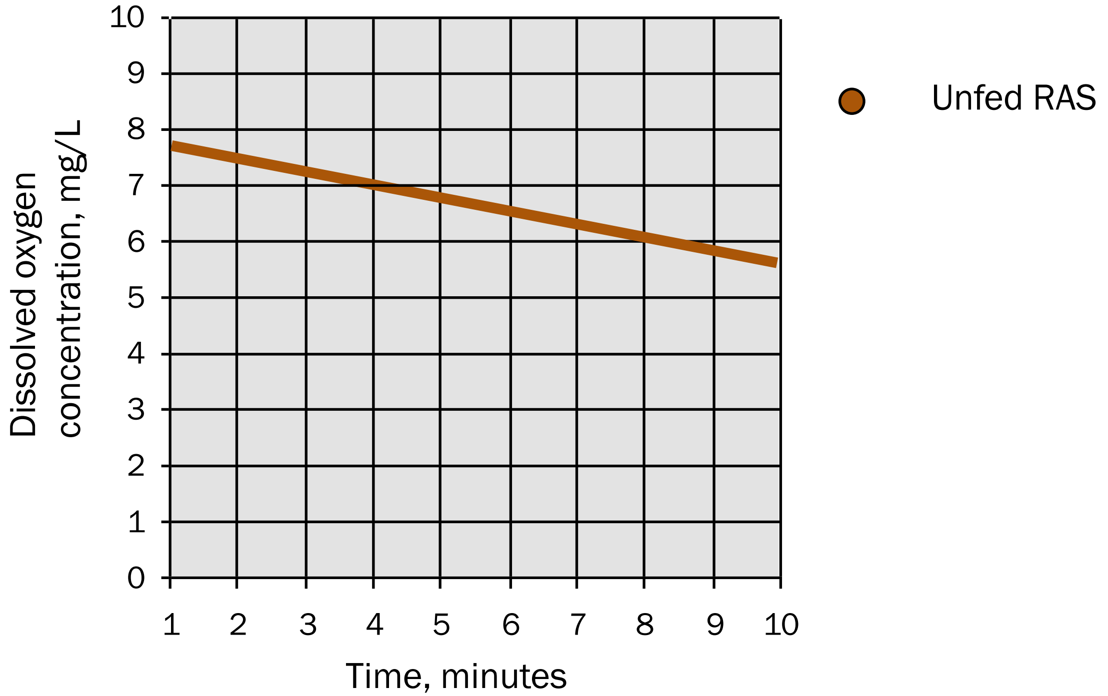
Load Fluctuations Affect Oxygen Uptake Rate (OUR)

- Unfed RAS
- RAS fed with primary effluent
- RAS fed with trickling filter effluent
- Slug organic load
- Toxic load

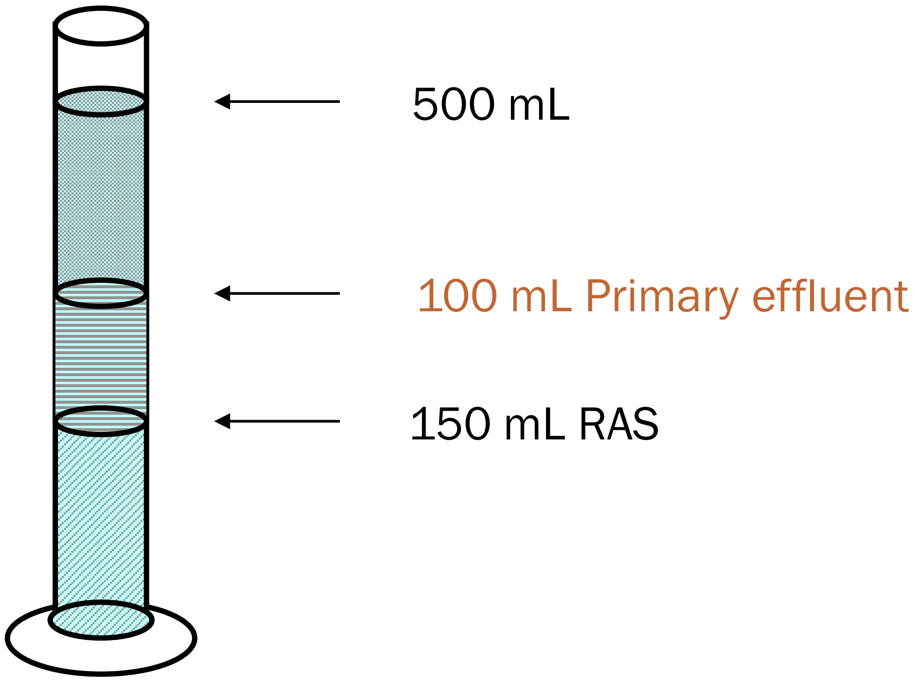
Oxygen Uptake Rate of Unfed Return Activated Sludge (RAS)



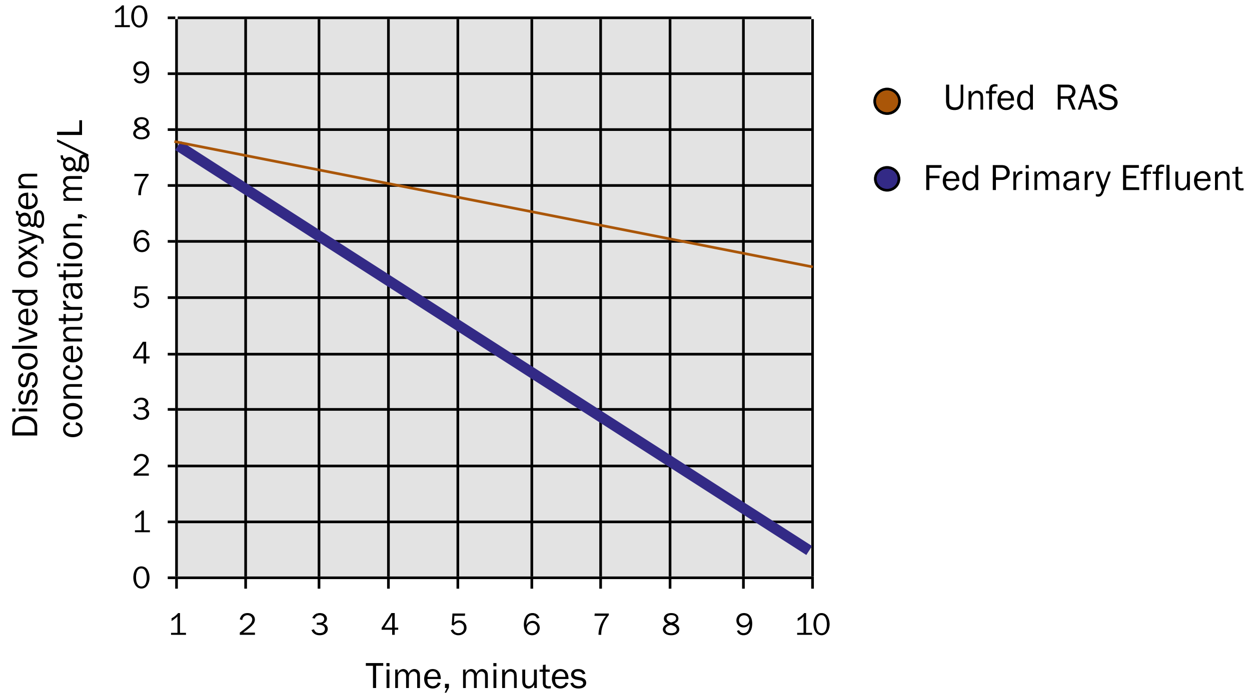
Unfed RAS Has A Low Oxygen Uptake



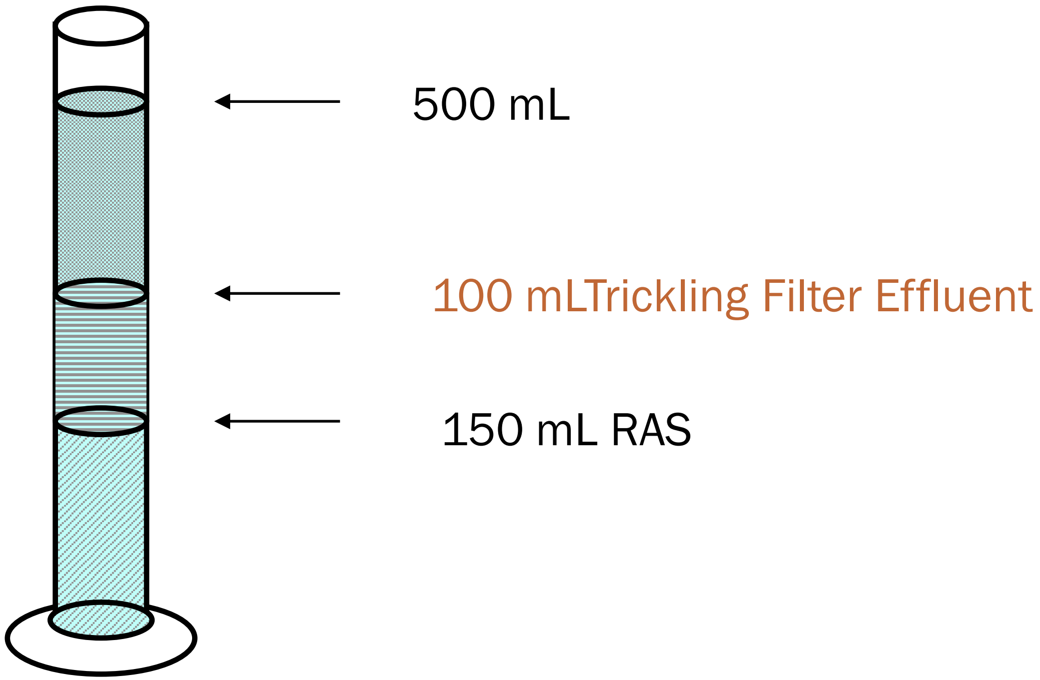
Effect of Primary Effluent on Oxygen Uptake Rate



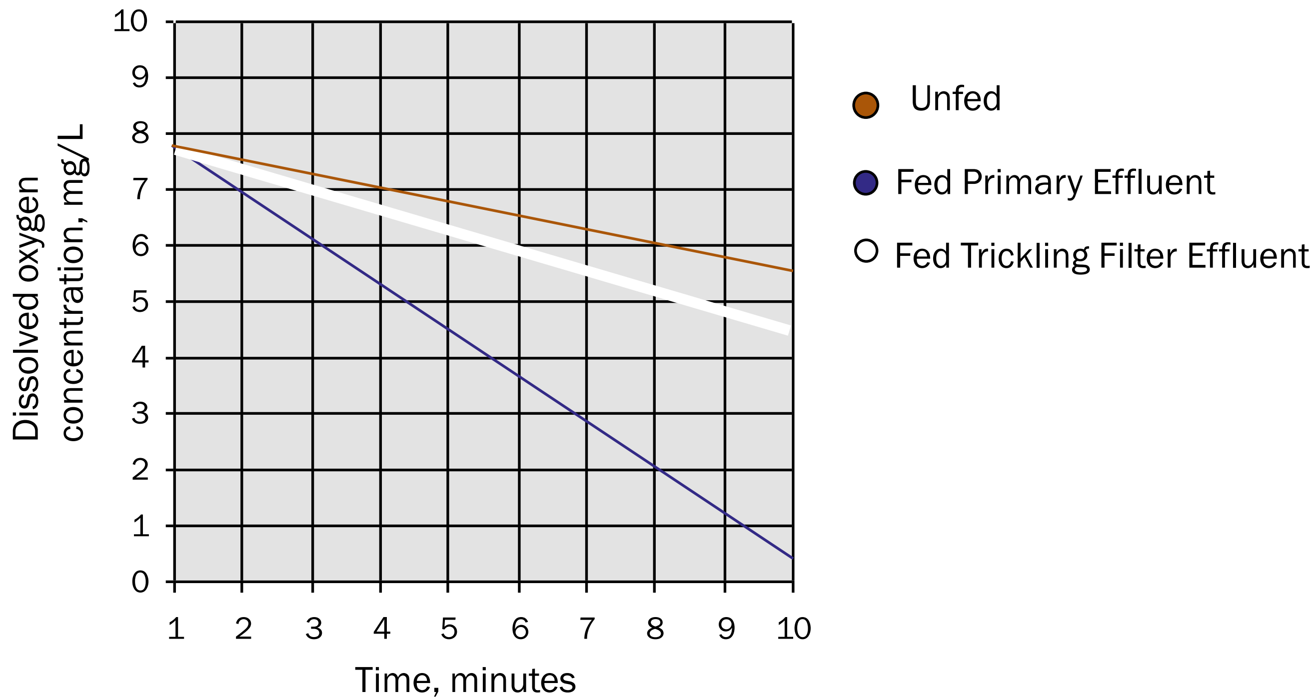
Primary Effluent Increases the Oxygen Uptake of RAS



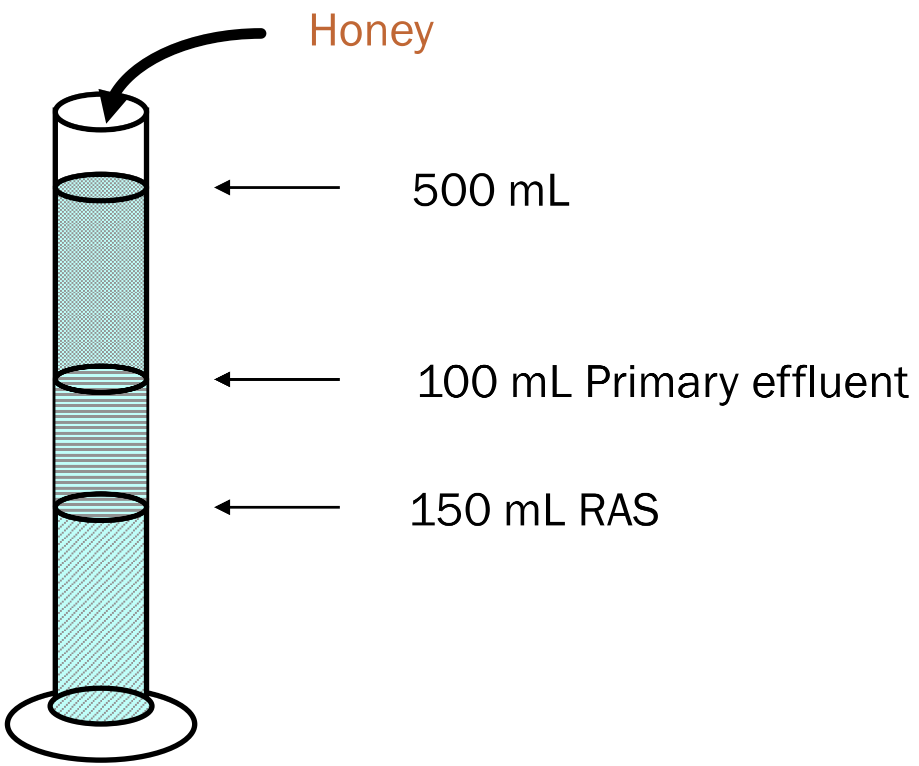
Effect of Trickling Filter Effluent on Oxygen Uptake Rate



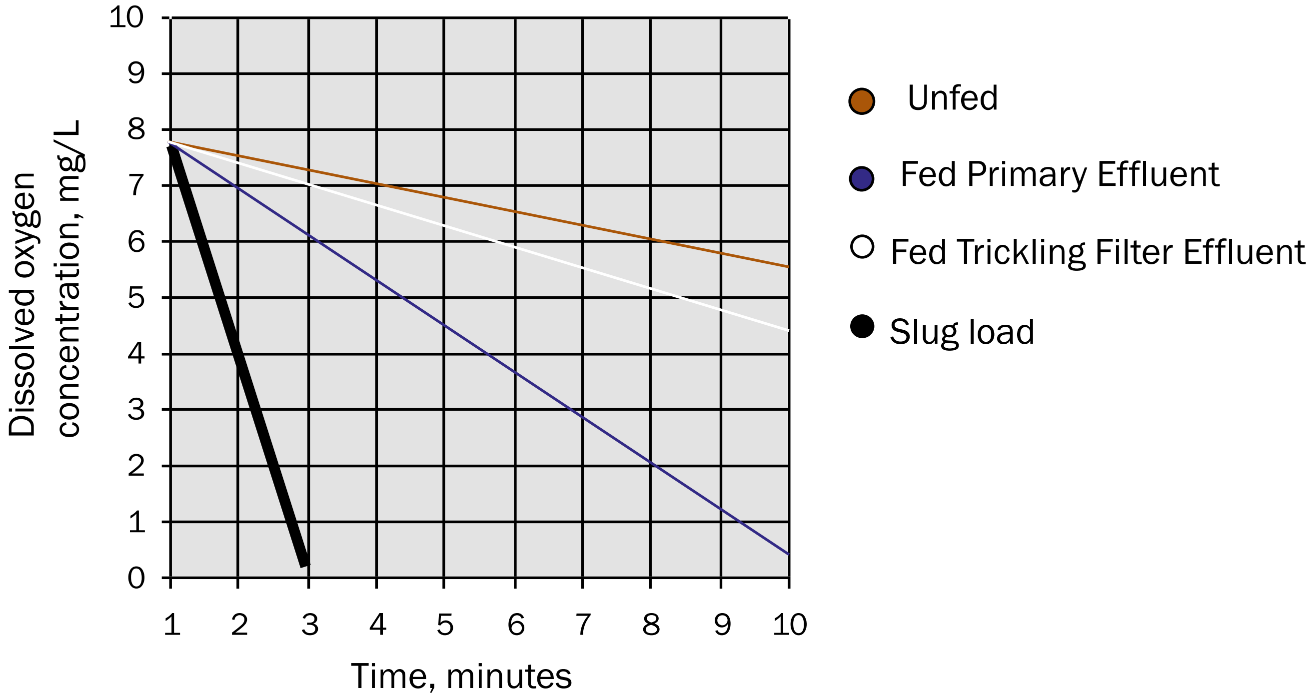
Trickling Filter Effluent Has A Lower OUR than Primary Effluent



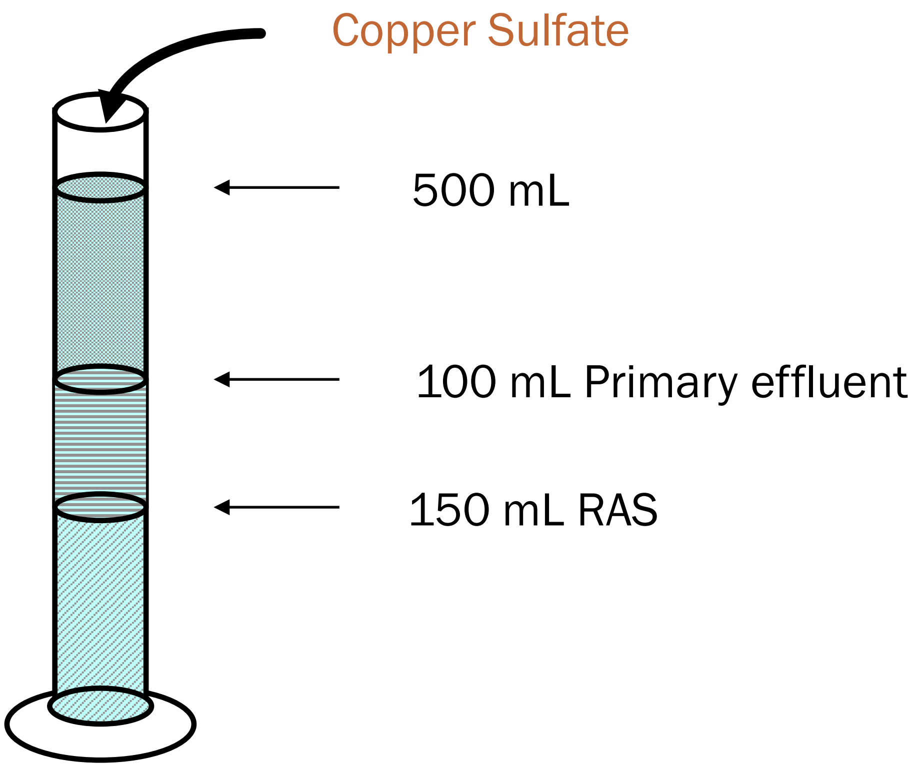
Effect of a Slug Organic Load on Oxygen Uptake Rate



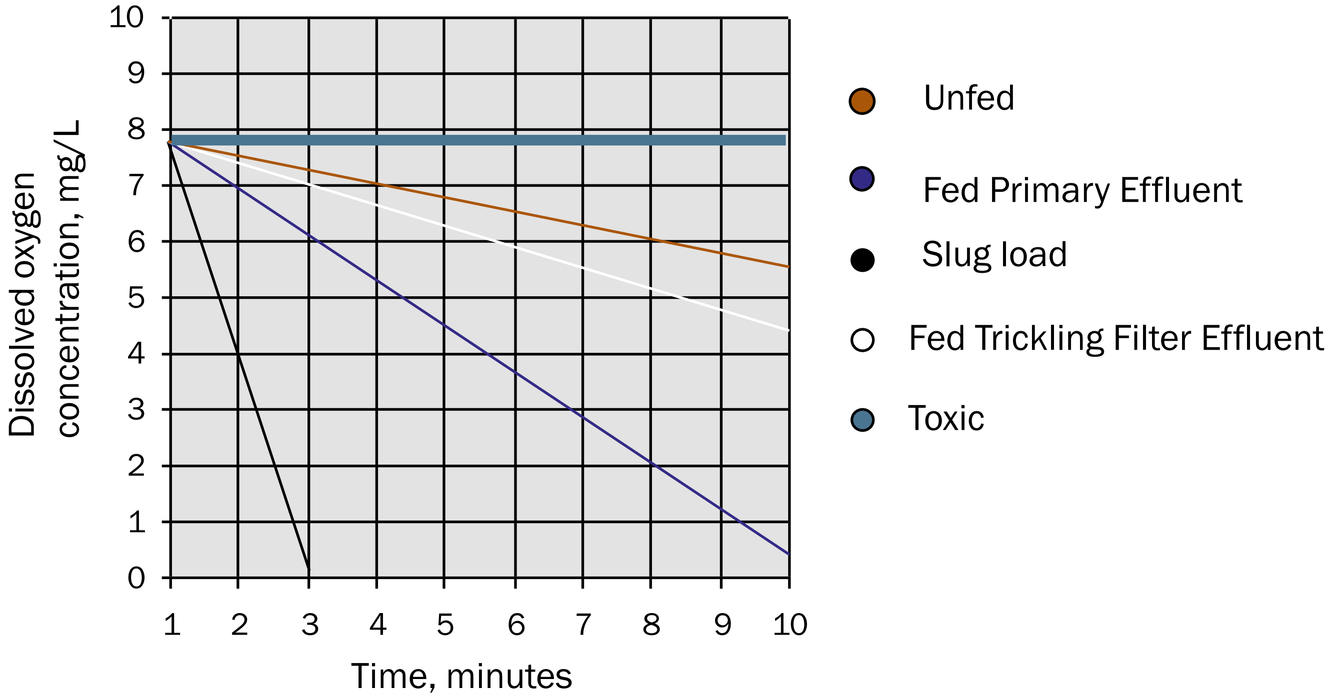
A Slug Organic Load Further Increases Oxygen Uptake of RAS



Effect of a Toxic Load on Oxygen Uptake Rate



A Toxic Load Inhibits or Stops Oxygen Uptake



Oxidation Relationship

1 mg/L of oxygen consumed

per

1 mg/L of cBOD oxidized

Alkalinity

Alkalinity is the buffering capacity of water; the ability of water to neutralize a strong acid.


Vinegar is an acid.
Baking soda is one type of alkalinity.
BAKING SODA


Add a little alkalinity.
HEINZ
BAKING
SODA


Add a little acid.
BAKING SODA


Buffering in action !
Eruption!
Wow !

Expressing Alkalinity

Regardless of the form of alkalinity, it is expressed as calcium carbonate ($CaCO_3$) equivalent

Alkalinity Species Include....

- Bicarbonate (HCO_3^-)
- Carbonate ($CO_3^=$)
- Hydroxide (OH^-)
- Phosphate (PO_4^{3-})
- Others

Alkalinity is Consumed or Produced by

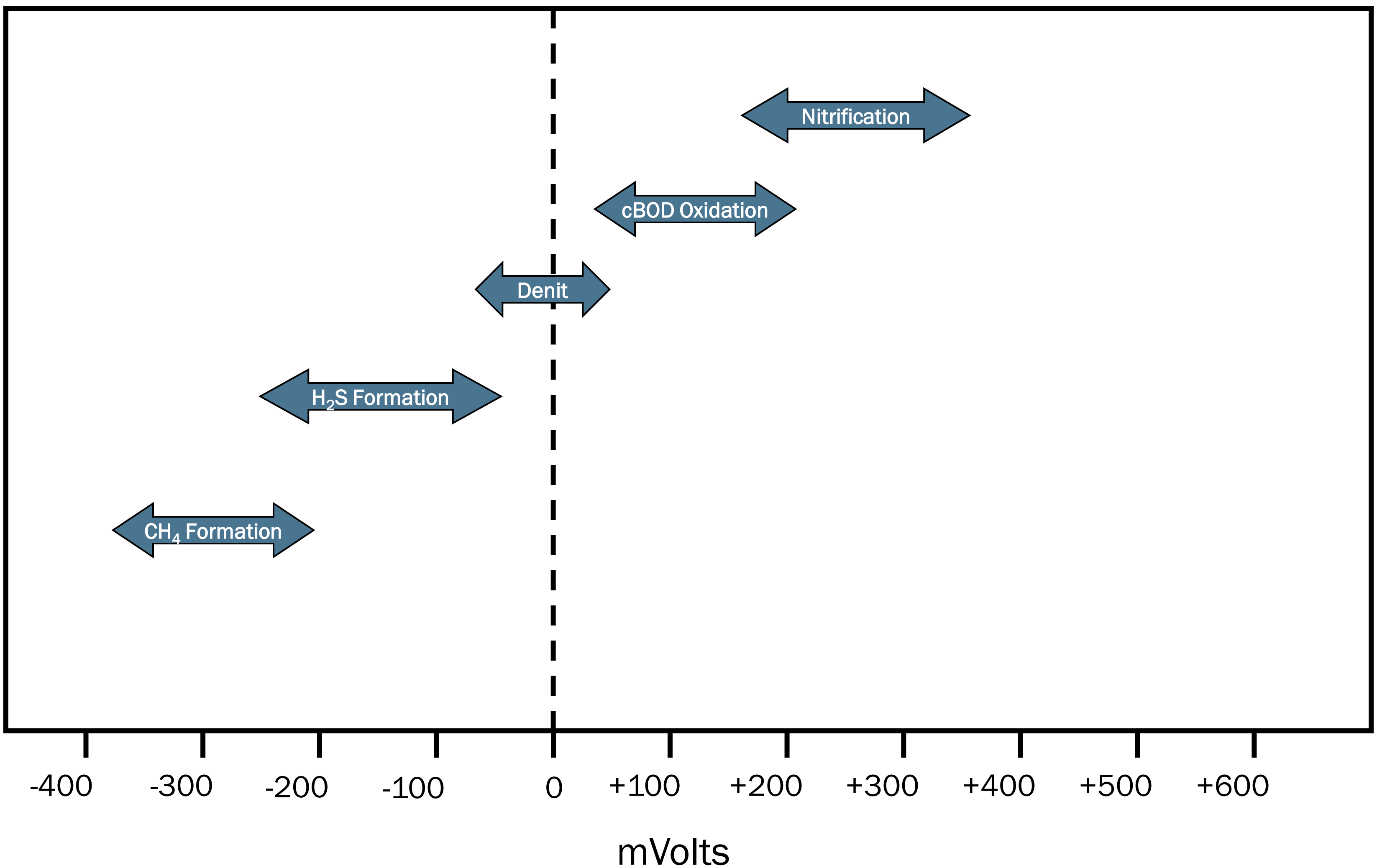
Process	Alkalinity Change, mg/L	Per mg/L of
Nitrification	-7.1	Ammonia-N oxidized
Denitrification	+3.6	Nitrate-N reduced
Chlorination	-1.4	Chlorine added
Breakpoint Chlorination	-1.4	Chlorine added
Dechlorination	-2.4	Sulfur dioxide added
Dechlorination	-1.4	Sodium bisulfite added
Phosphorus Removal	-5.6	Aluminum added
Phosphorus Removal	-2.7	Iron added

ORP

Method

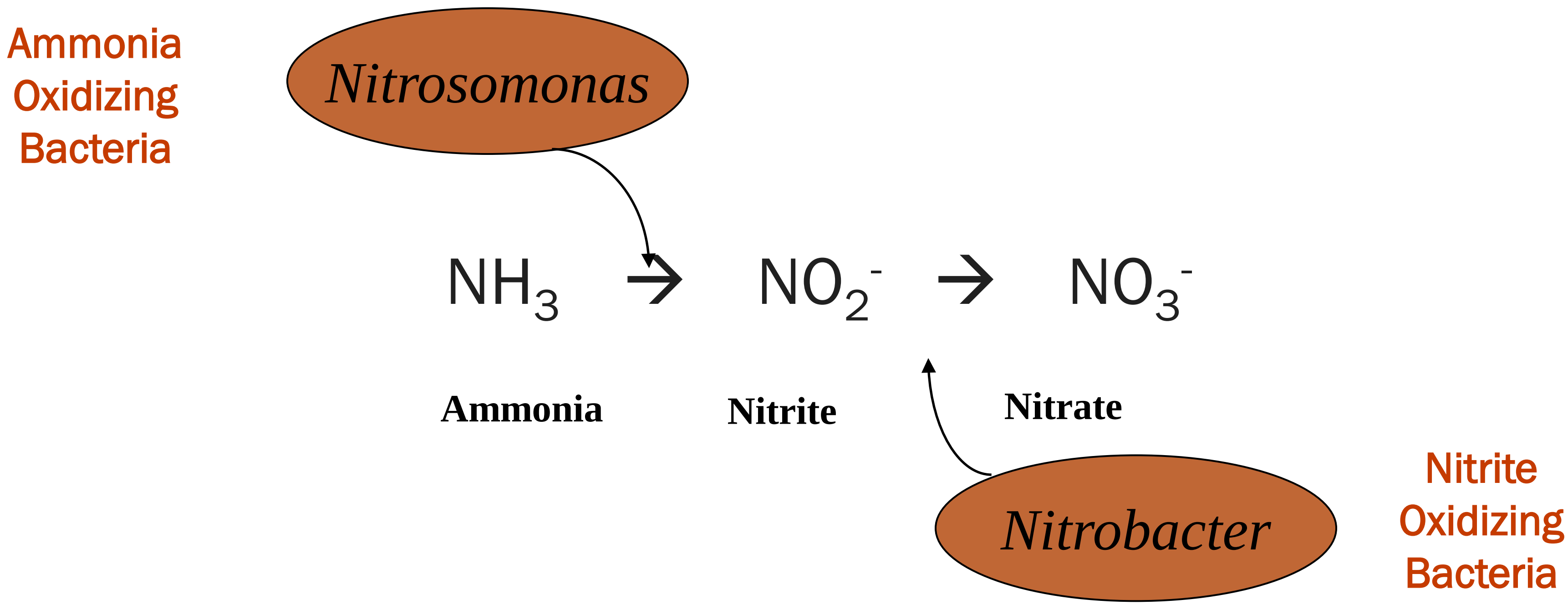
- Field measurement
- Orion Model 230 pH/ORP meter (old)
- Sensorex ORP probe

Biological impacts on ORP



Nitrification

Oxidation of Ammonia to Nitrate



Characteristics of Nitrifying Organisms

- Autotrophic
- Aerobic
- Slow growing
- Non-floc forming
- More sensitive to environmental changes than heterotrophs

What do these tell us?

- Use inorganic energy sources – Autotrophic
- Use oxygen – Aerobic
- Produces acid – consumes alkalinity

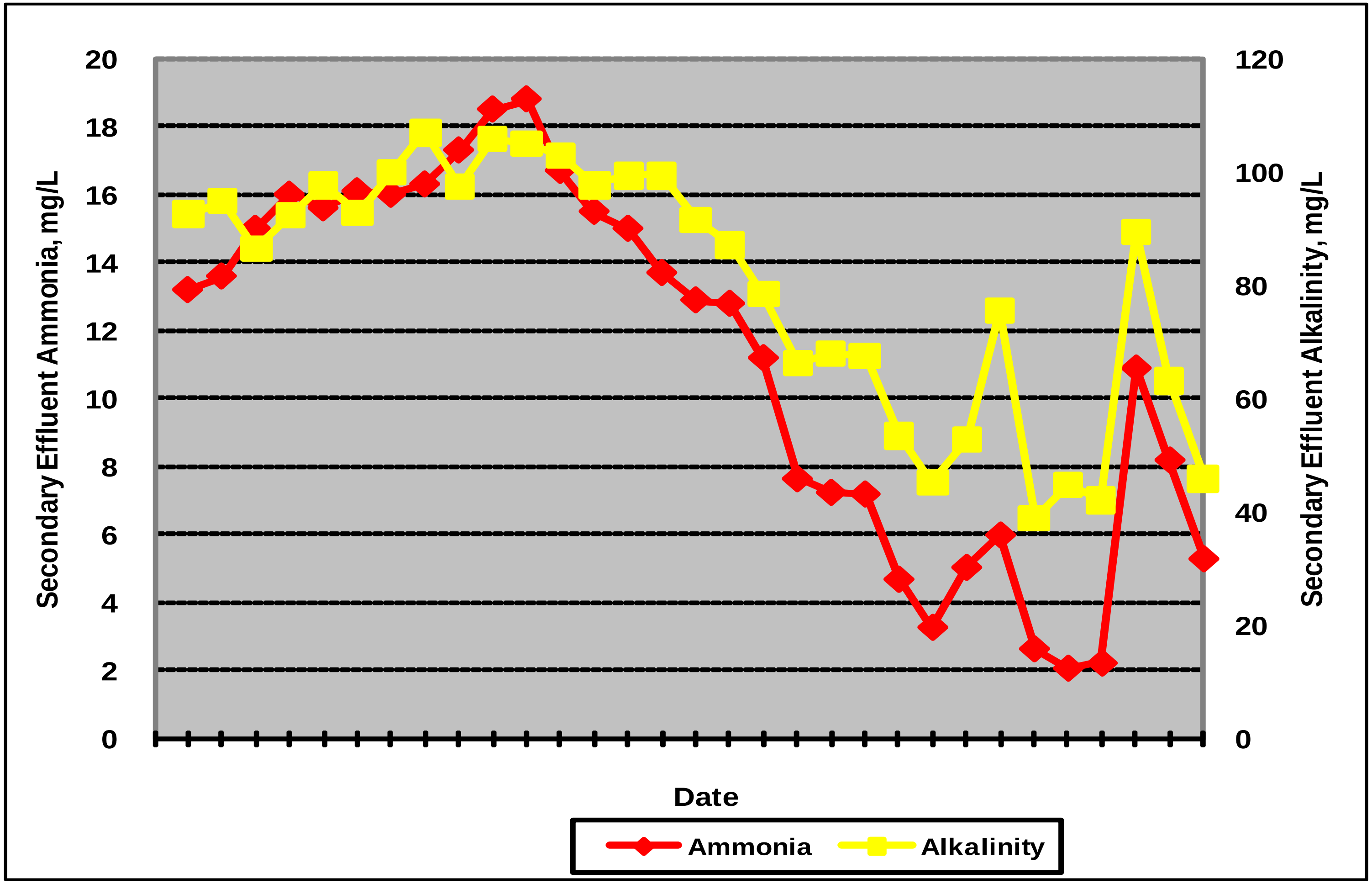
Nitrosomonas

$$2NH_4^+ + 3O_2 = 2NO_2^- + 2H_2O + 4H^+$$

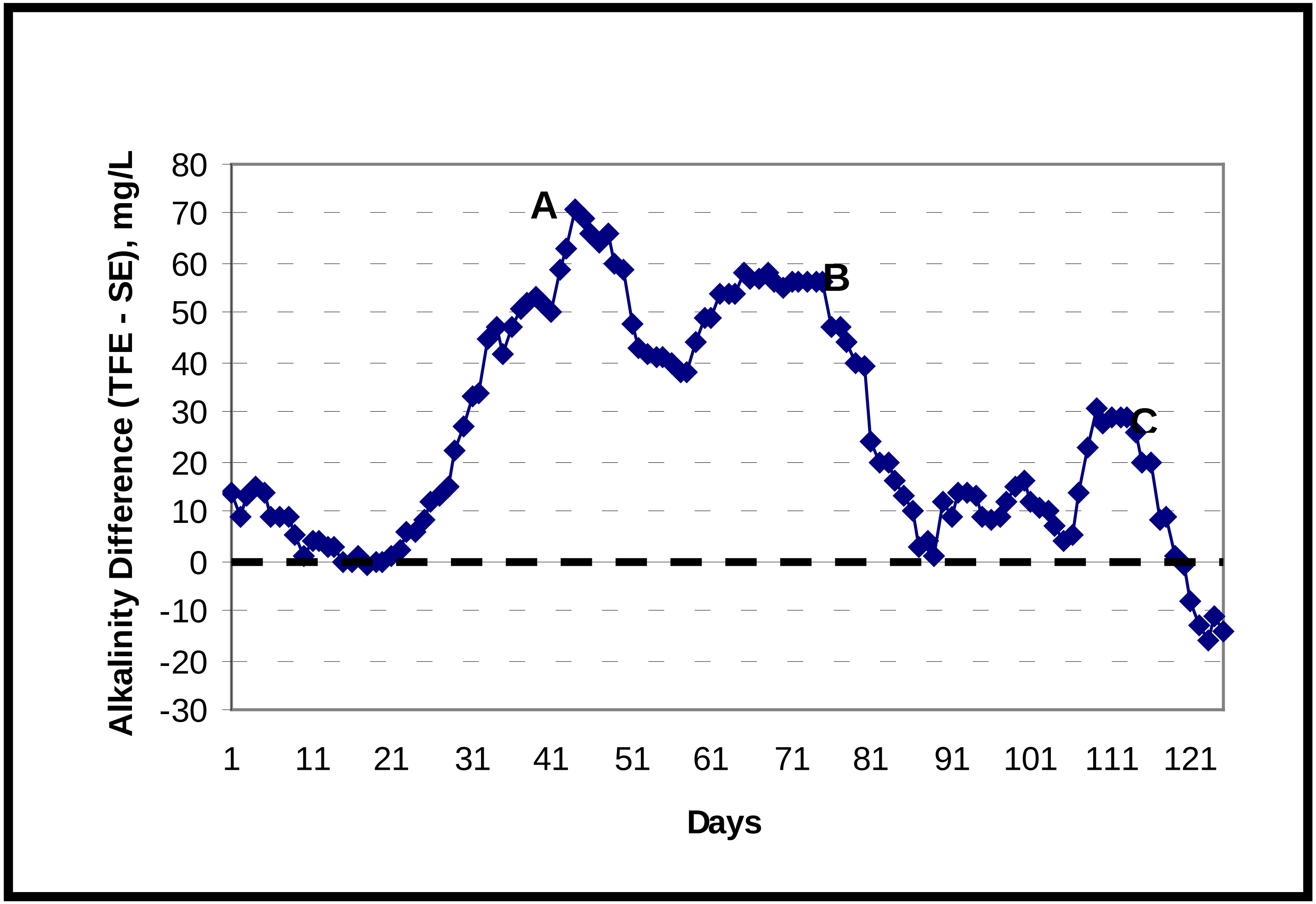
Nitrobacter

$$2NO_2^- + O_2 = 2NO_3^-$$

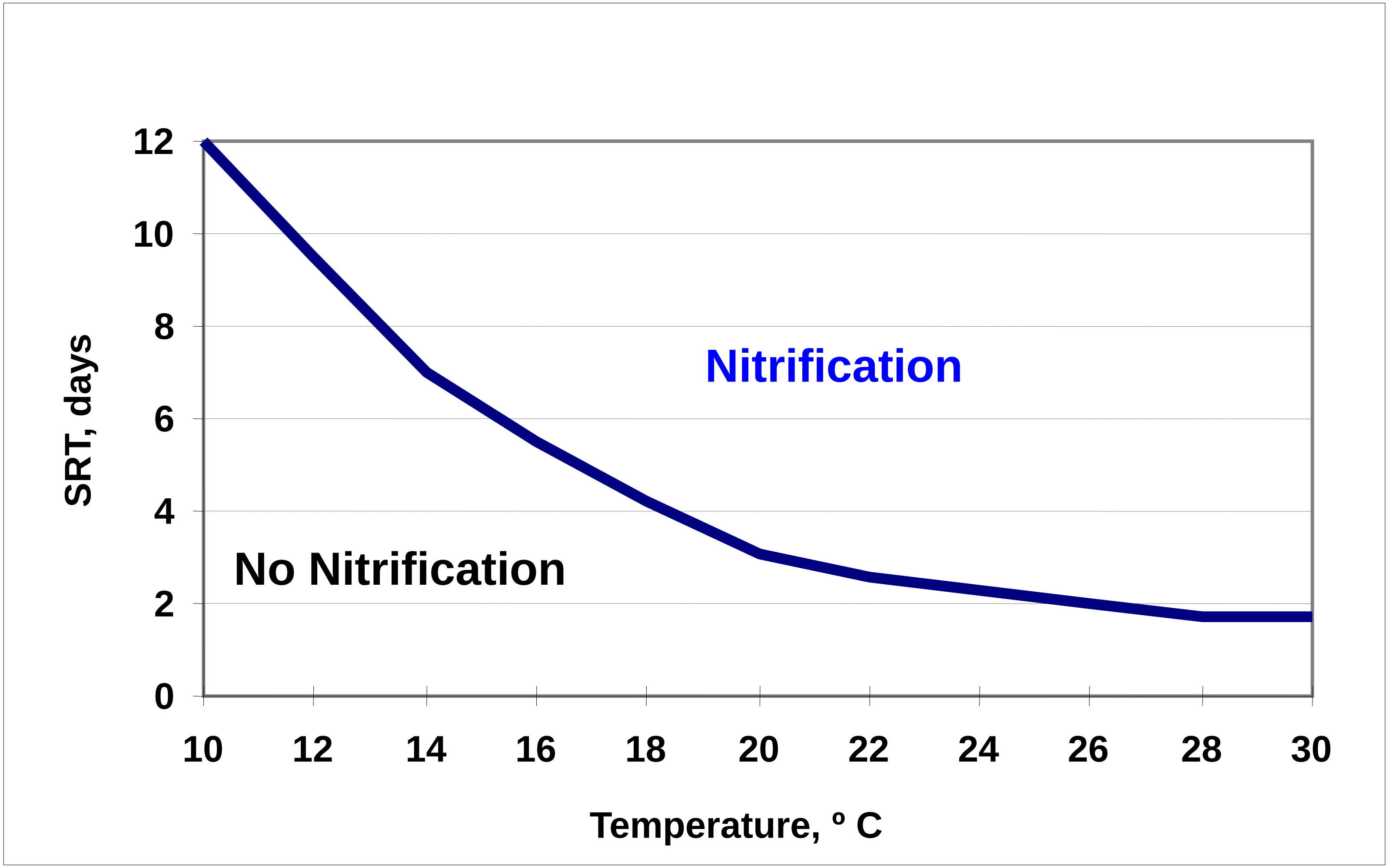
Monitoring Nitrification with Alkalinity



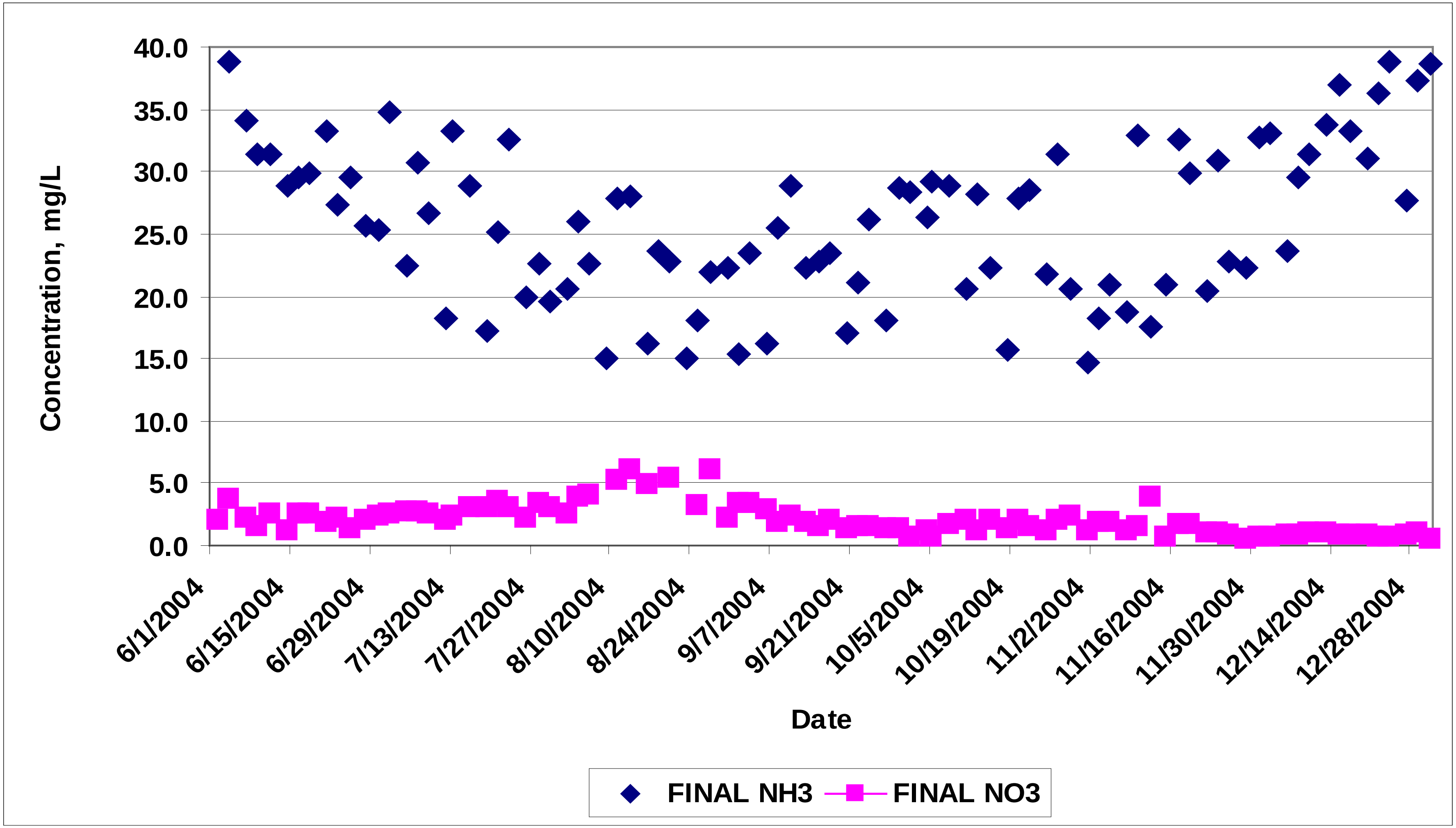
Case Study: Medford TF/SC Start-up



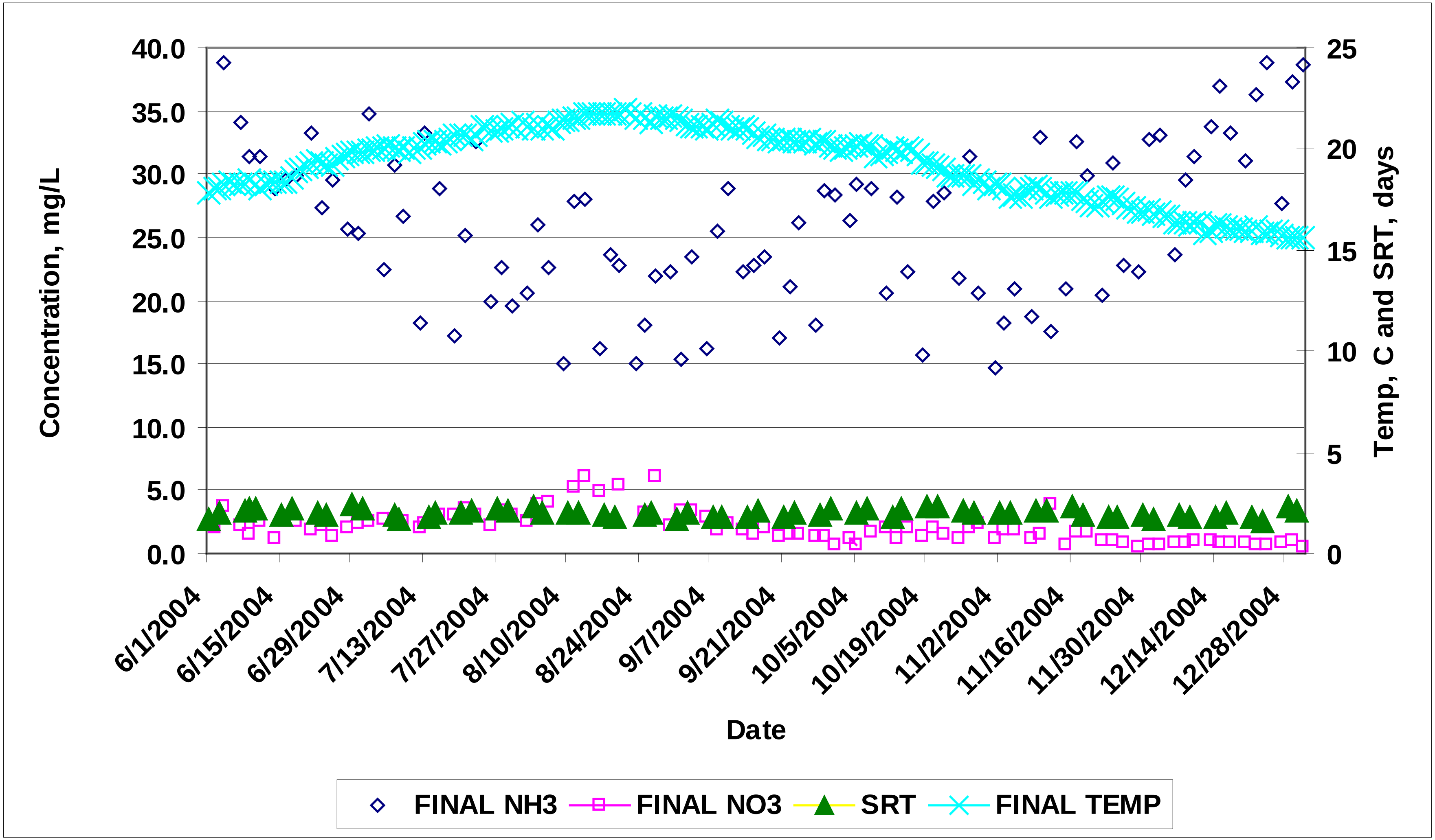
SRT drives nitrification..........
Temperature drives SRT



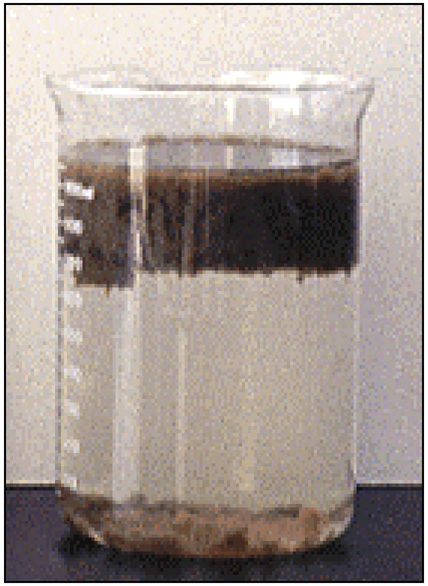
Using SRT to control nitrification



Using SRT to control nitrification



Denitrification



Reduction of nitrate to nitrogen gas

$NO_3^- \dashrightarrow NO_2^- \dashrightarrow N_2$

Nitrate **Nitrite** **Nitrogen Gas**

All within a single organism.

Anoxic

Anoxic = without oxygen

aNO_xic

Presence of nitrate (or nitrite)

Biology of Denitrification

$$NO_3^- + CH_3OH + H_2CO_3 \dashrightarrow N_2 + H_2O + HCO_3^-$$

- Use nitrate – Anoxic
- Use organic carbon energy source – Heterotrophic
- Consume acid/Produce alkalinity
- Produce nitrogen gas

(Note: Equation not balanced)

What the equation doesn't tell us...

Denitrifying organisms are facultative.
Give them oxygen....

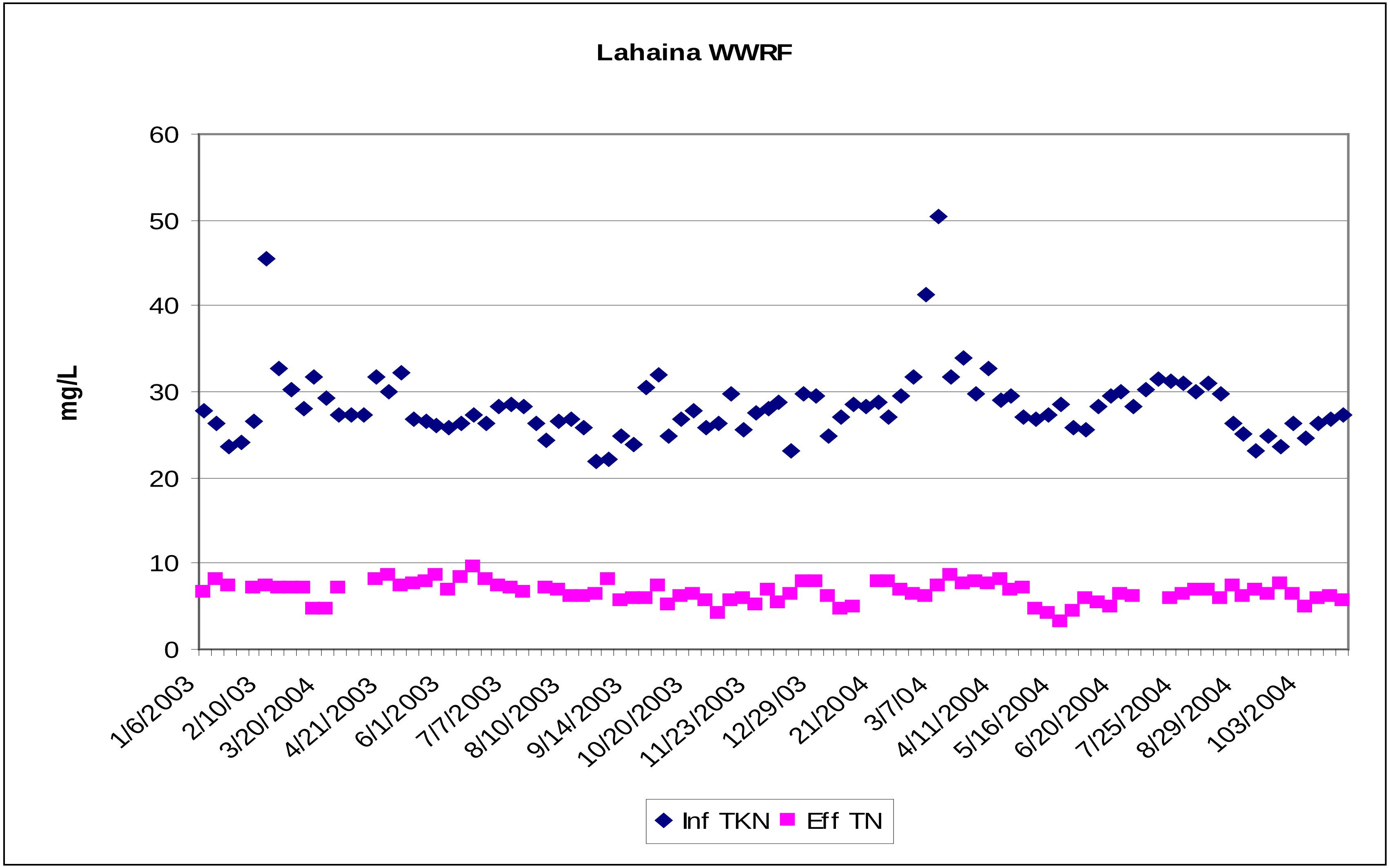
$$CH_3OH + 1.5\ O_2 \rightarrow 2H_2O + CO_2$$

They will not reduce nitrate to nitrogen gas, and nitrogen will not be removed.

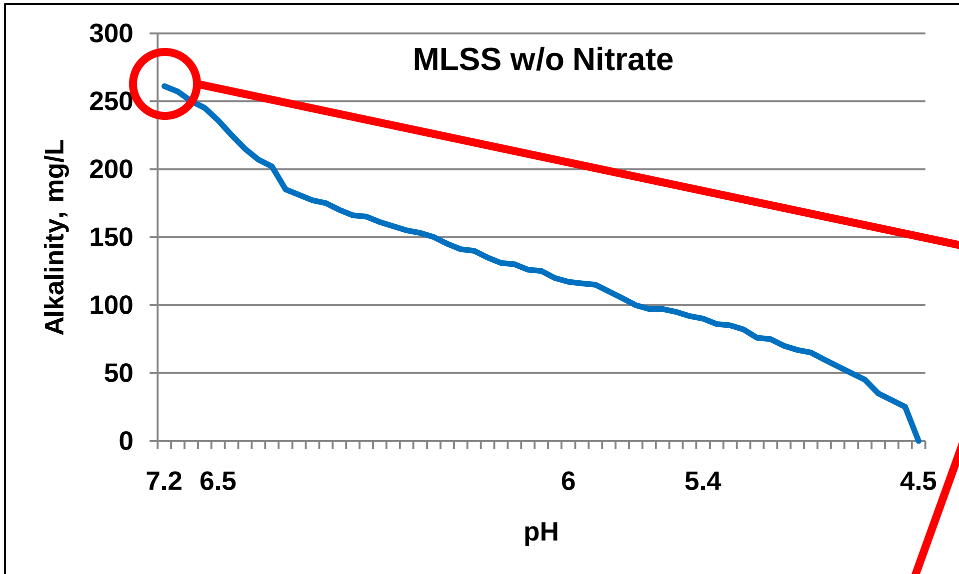
Benefits of Denitrifcation

- Removes nitrogen
- Recovers alkalinity
- Removes cBOD
- Serves as a selector

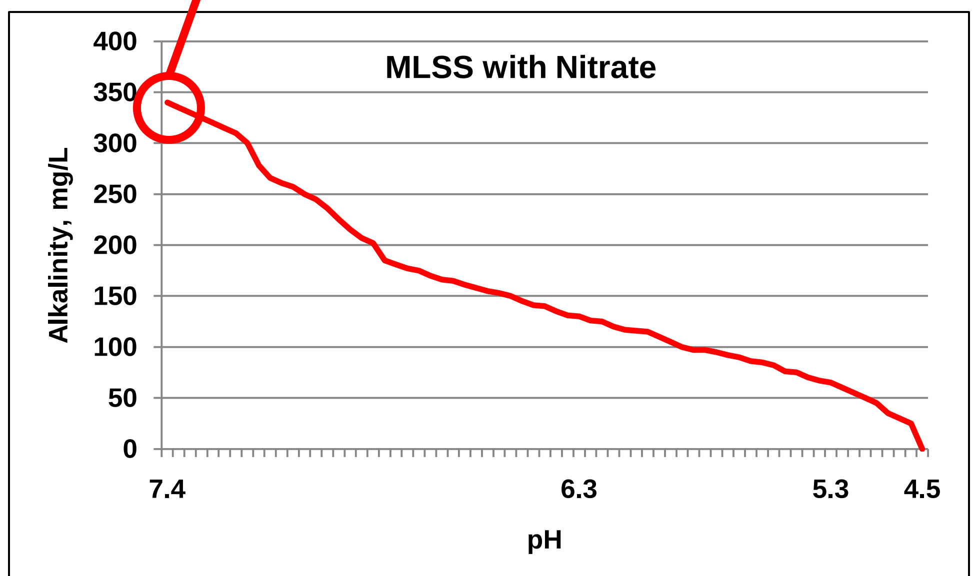
Removes Nitrogen



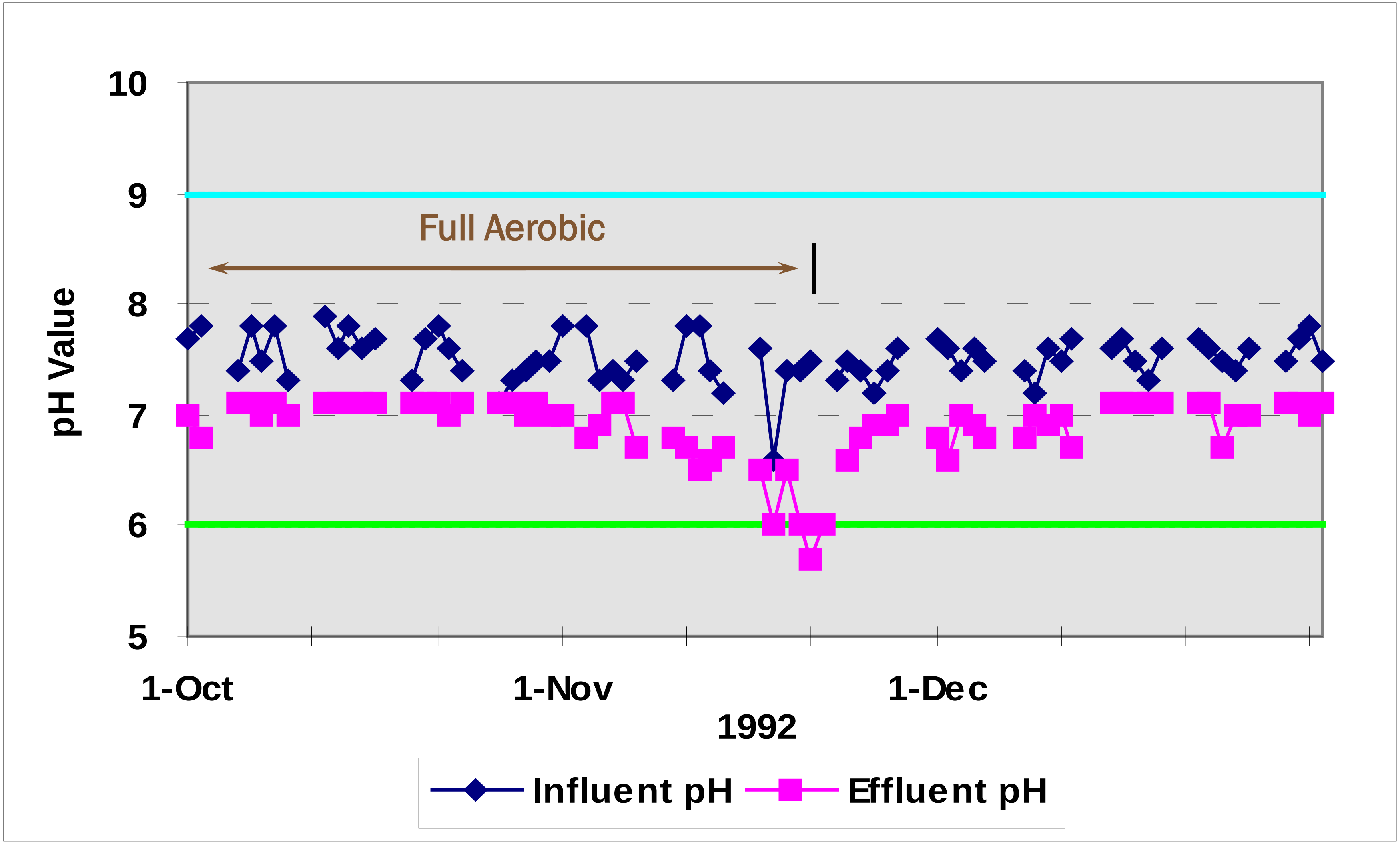
Recovers Alkalinity



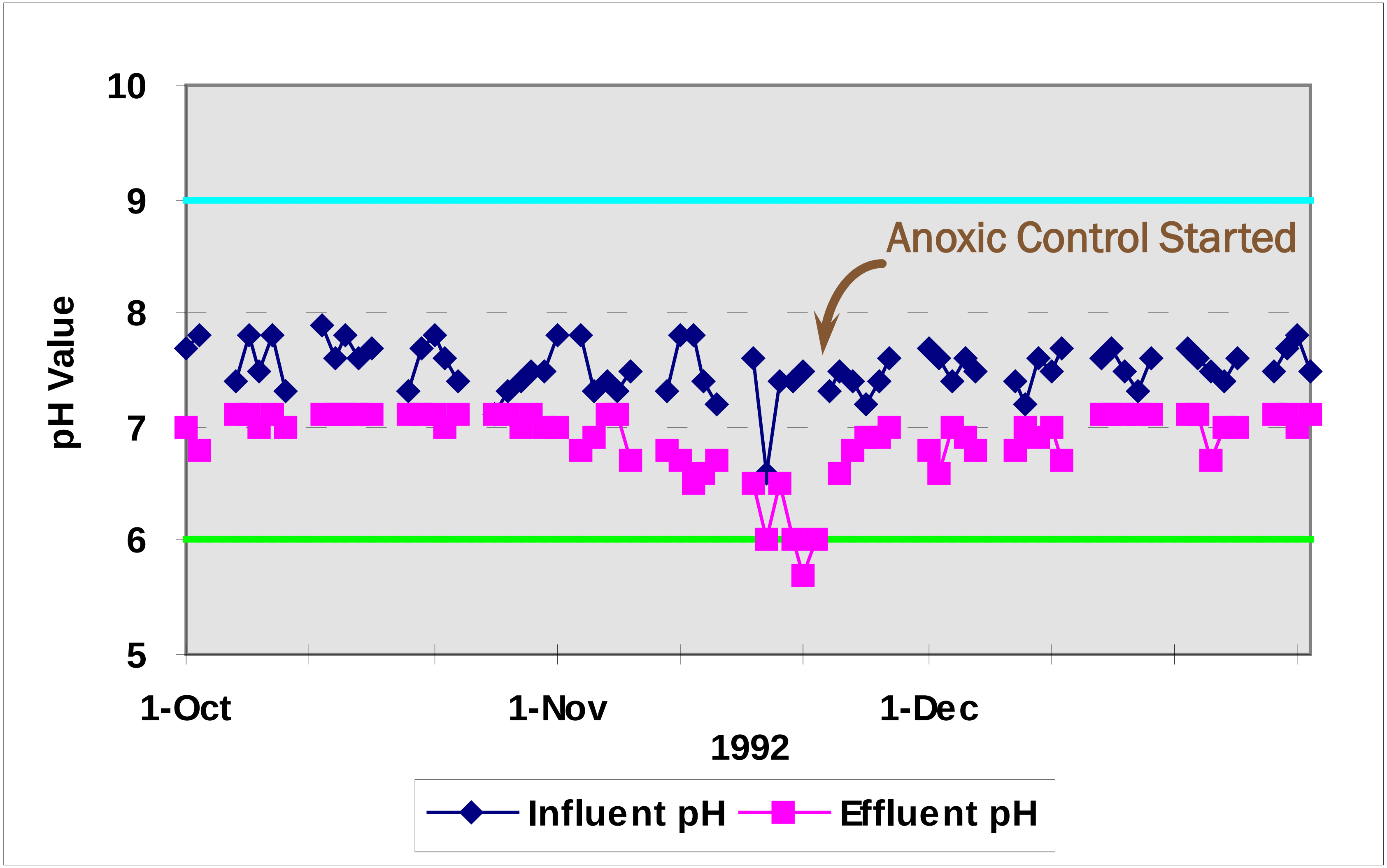
Denitrification increased Alkalinity approximately 80 mg/L



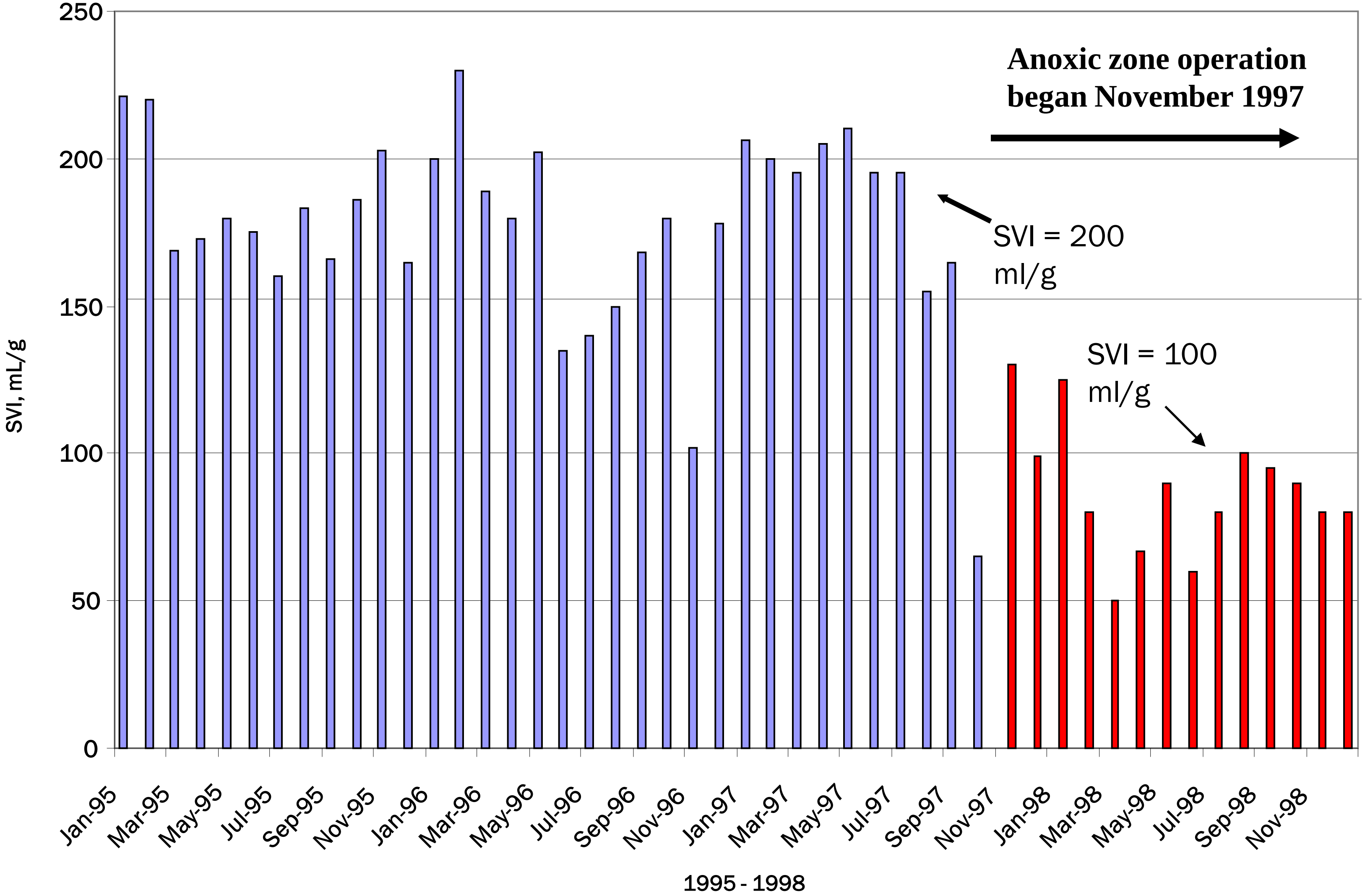
Recovers Alkalinity



Recovers Alkalinity



Acts as a Selector



Benefits Summary

- Removes nitrogen
- Removes organic carbon
- Produces alkalinity
- Serves as a selector

- Nitrate produced during denitrification is reduced to nitrogen gas
- Approximately 2.8 pounds BOD oxidized per pound of Nitrate-N reduced
- Recovers about half the alkalinity lost during nitrification (3.6 mg/L per mg/L Nitrate-N reduced)
- Uses readily biodegradable cBOD that filamentous organisms want – lower SVI

Environmental Conditions for Denitrification

- Presence of denitrifying organisms
- Absence of dissolved oxygen
- Presence of nitrate (nitrite)
- Presence of readily biodegradable organic carbon

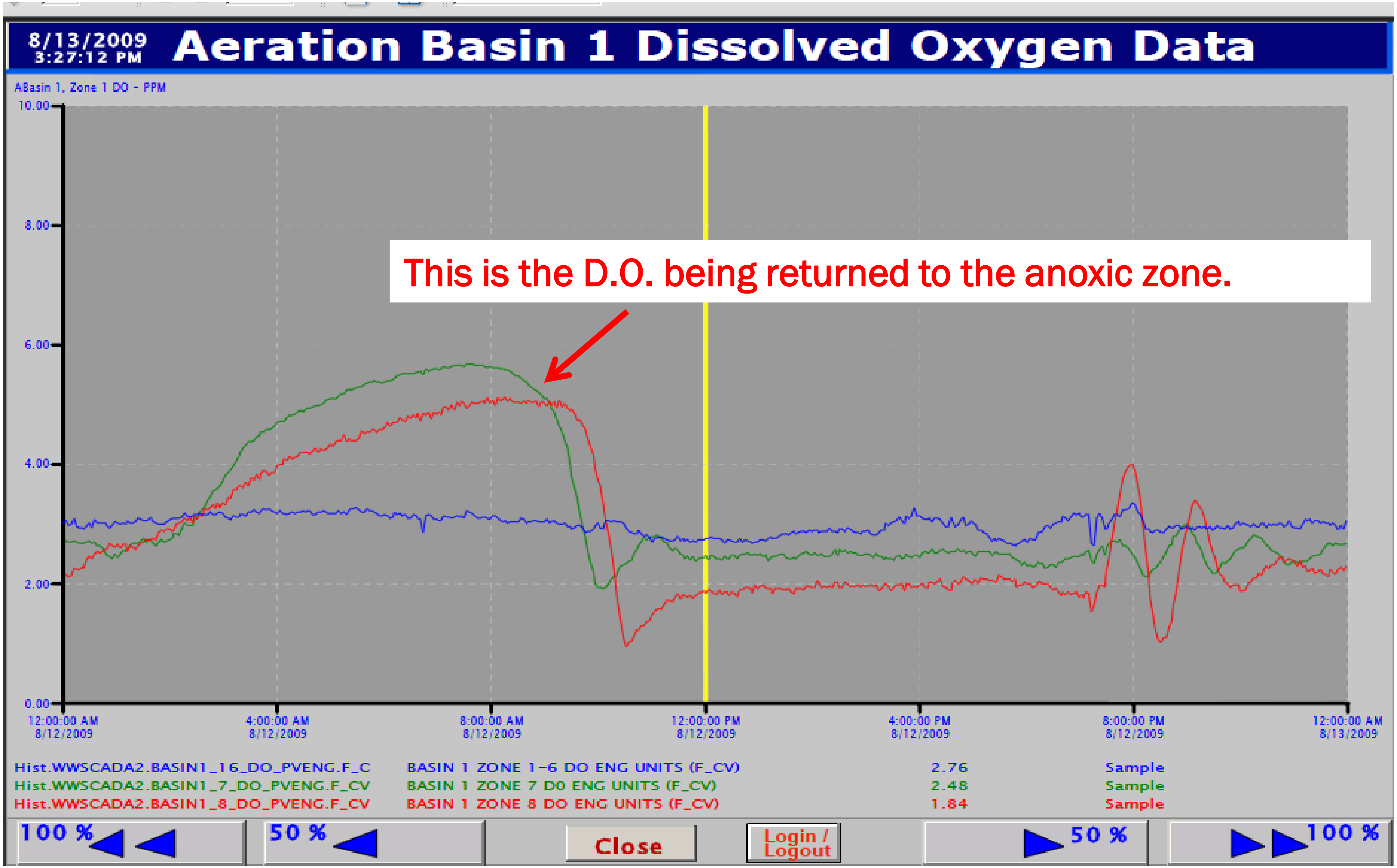
How do we ensure these environmental conditions are achieved?

• Denitrifying organisms	• Don't worry, they are present
• Low dissolved oxygen	• Optimize aerobic zone D.O. • Minimize introduced sources
• Nitrates	• Use nitrates produced during nitrification
• Organic carbon	• Locate anoxic zone at influent end of basin • Direct feed to anoxic zones • Add supplemental carbon • Endogenous respiration

How can dissolved oxygen enter an anoxic zone?

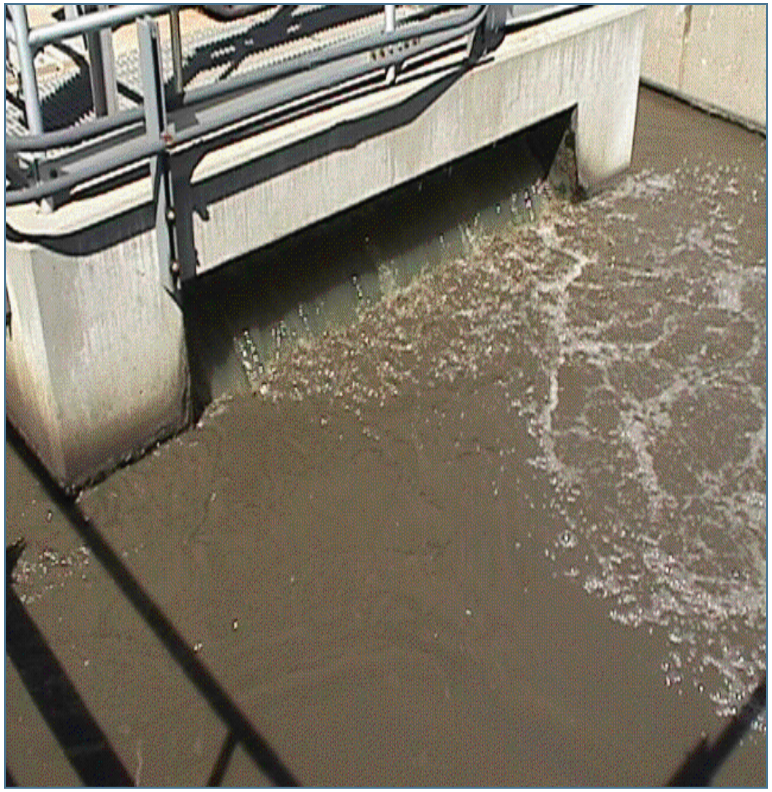
- Mixed Liquor Recycle
- Primary effluent entrainment
- Cascading feed
- Mixer vortex
- Back mixing
- Surface discharges
- MBR example
- Denitrification filter

Mixed Liquor Recycle

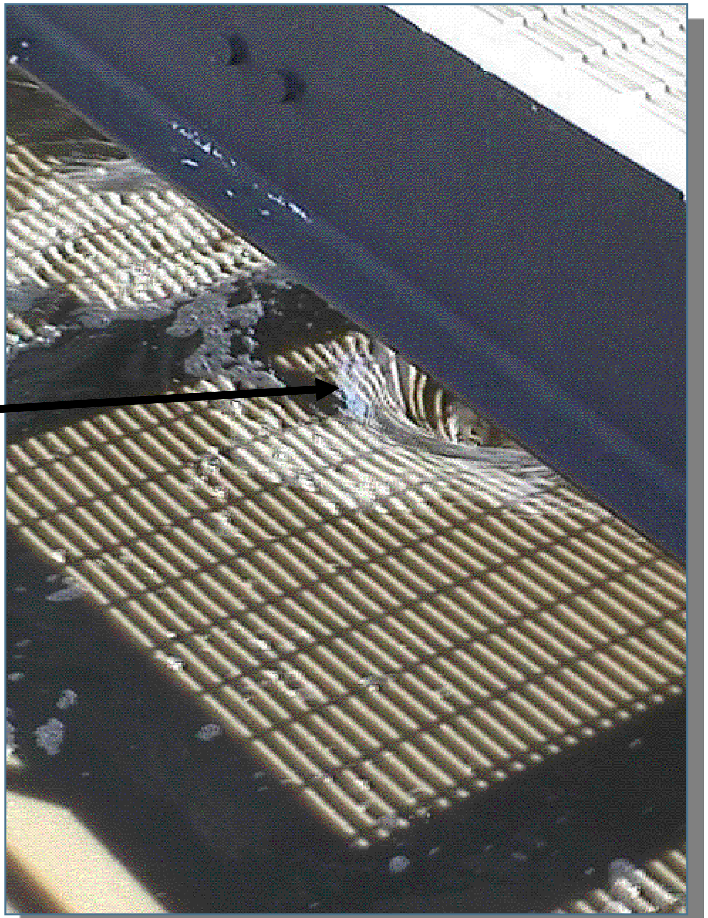


Primary Effluent Entrainment

Cascading Feed

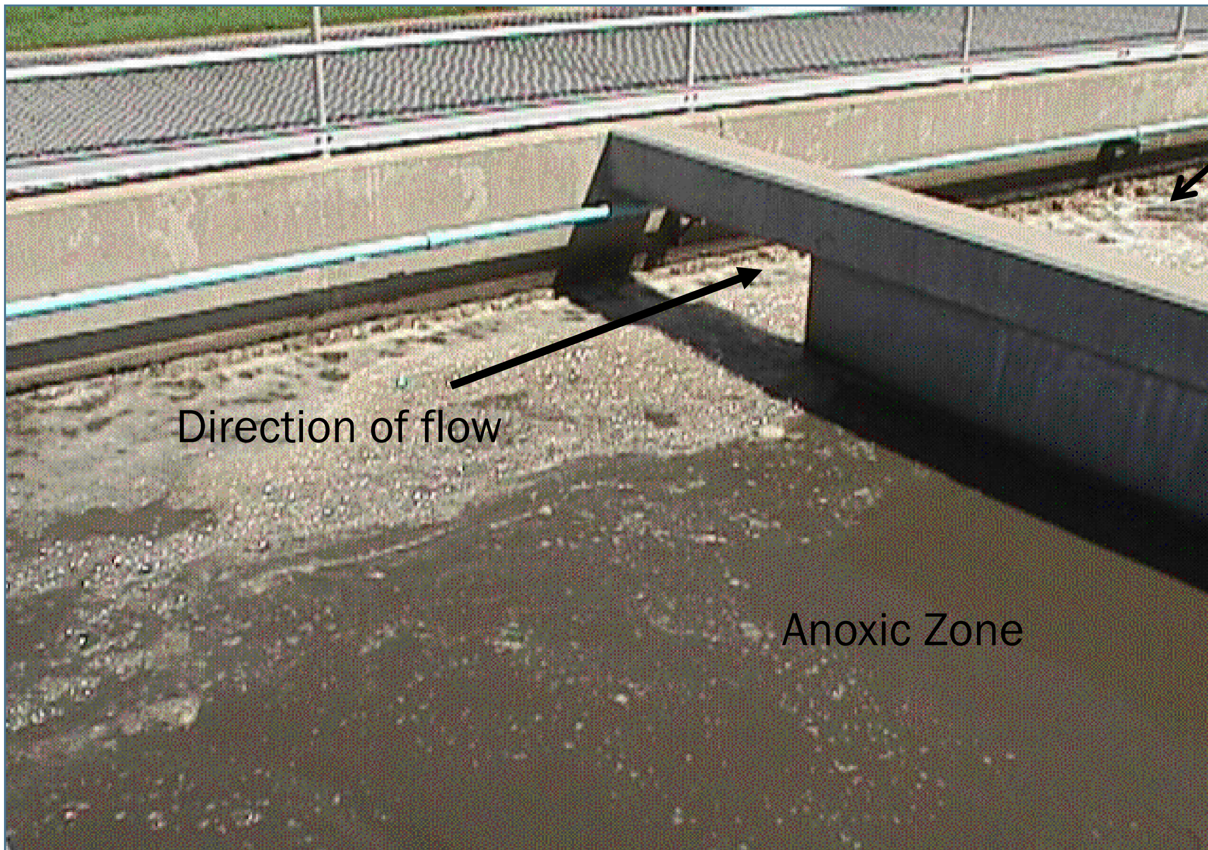


Mixer Vortex



Staff trimmed blades to prevent vortex.

Backmixing



Aerobic Zone

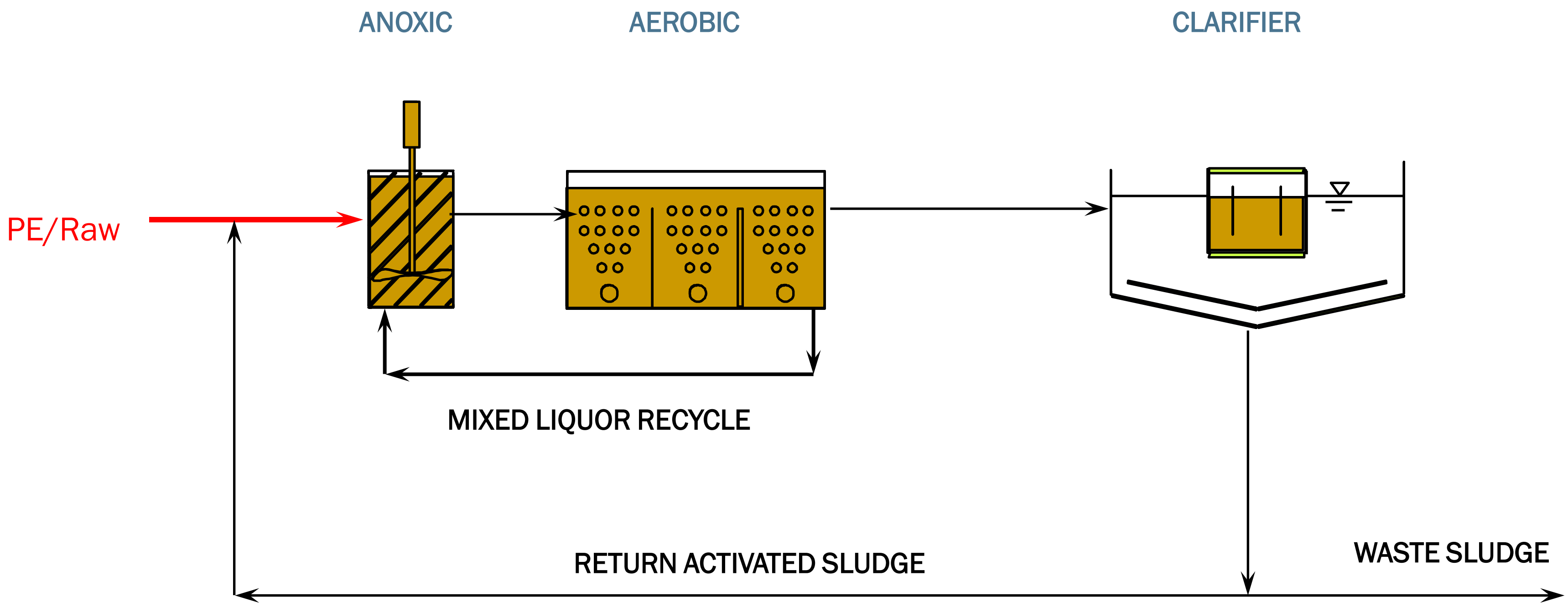
Surface Discharges

MBR Facility

Click Image for Video

Denitrification Filter

What is the source of carbon?



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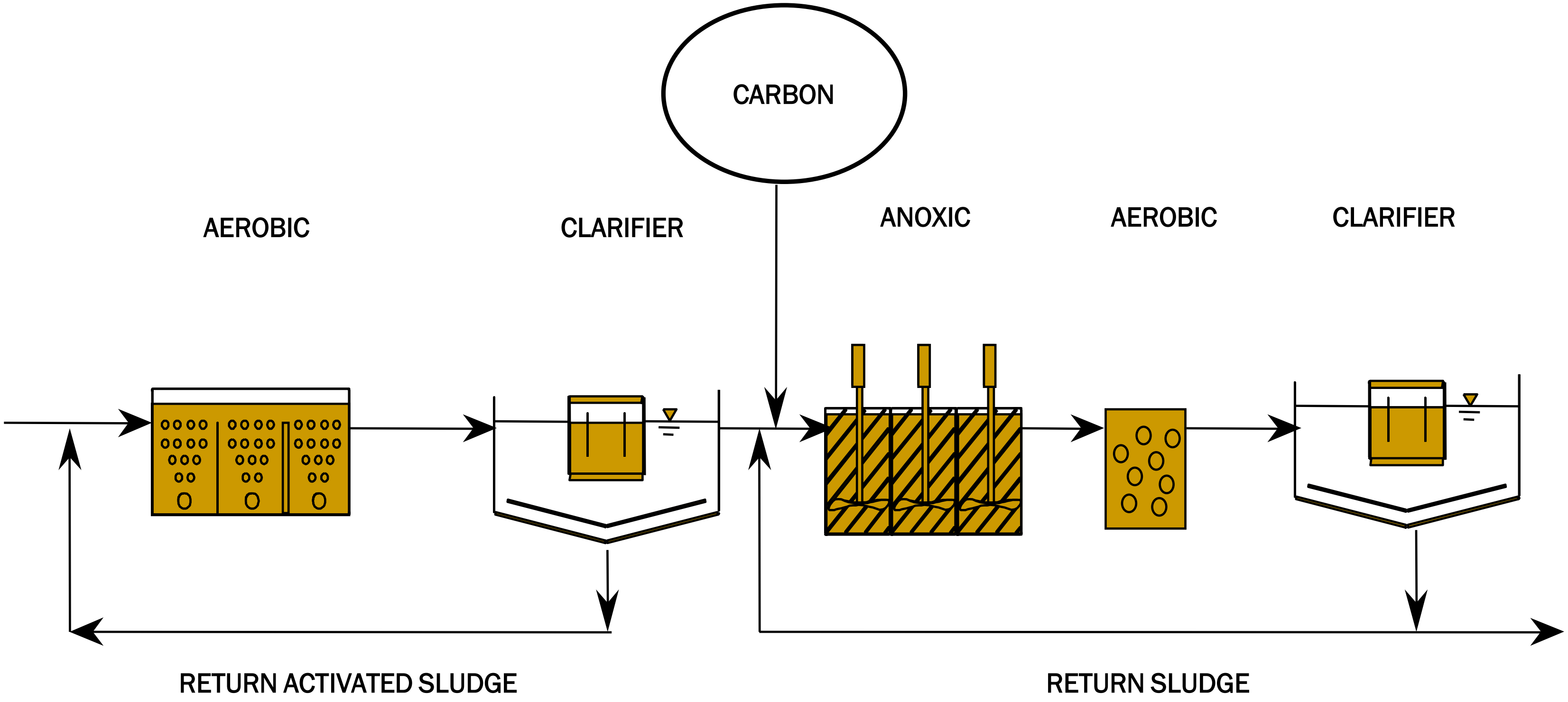

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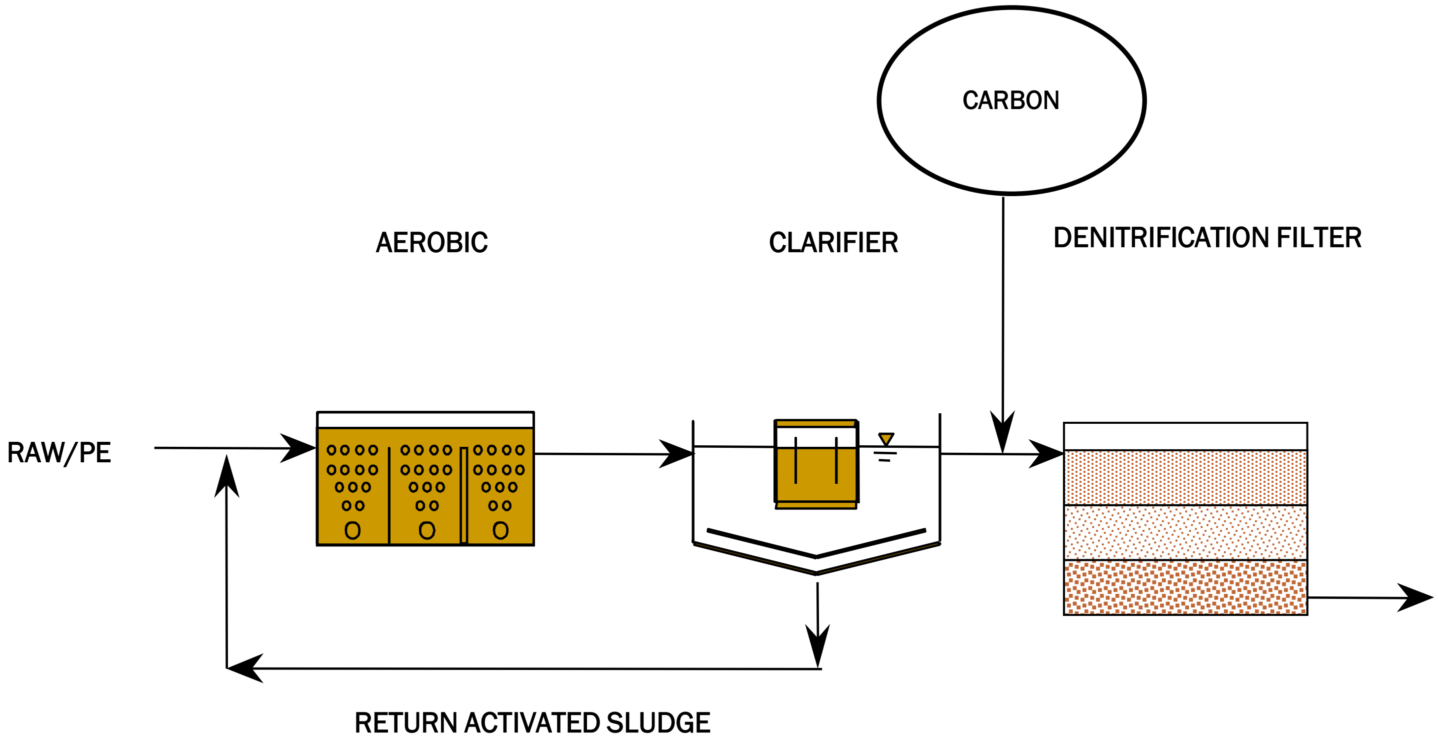
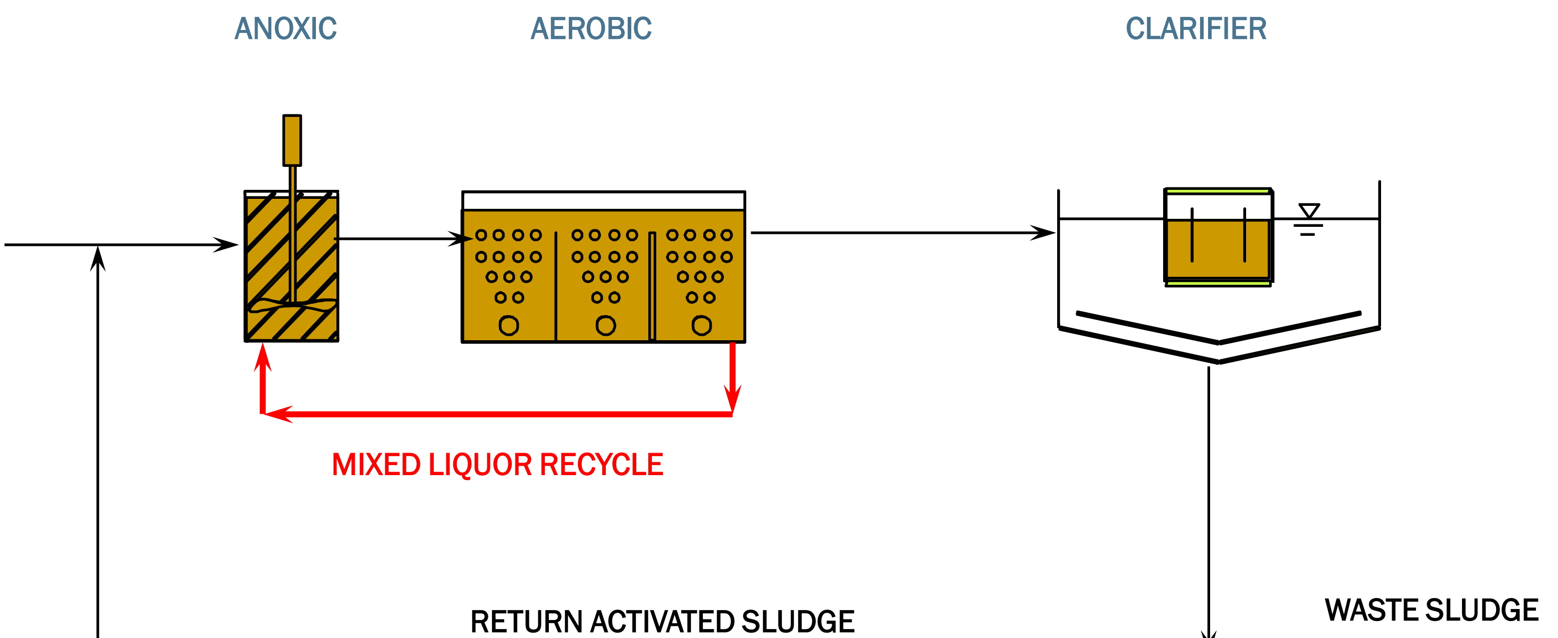


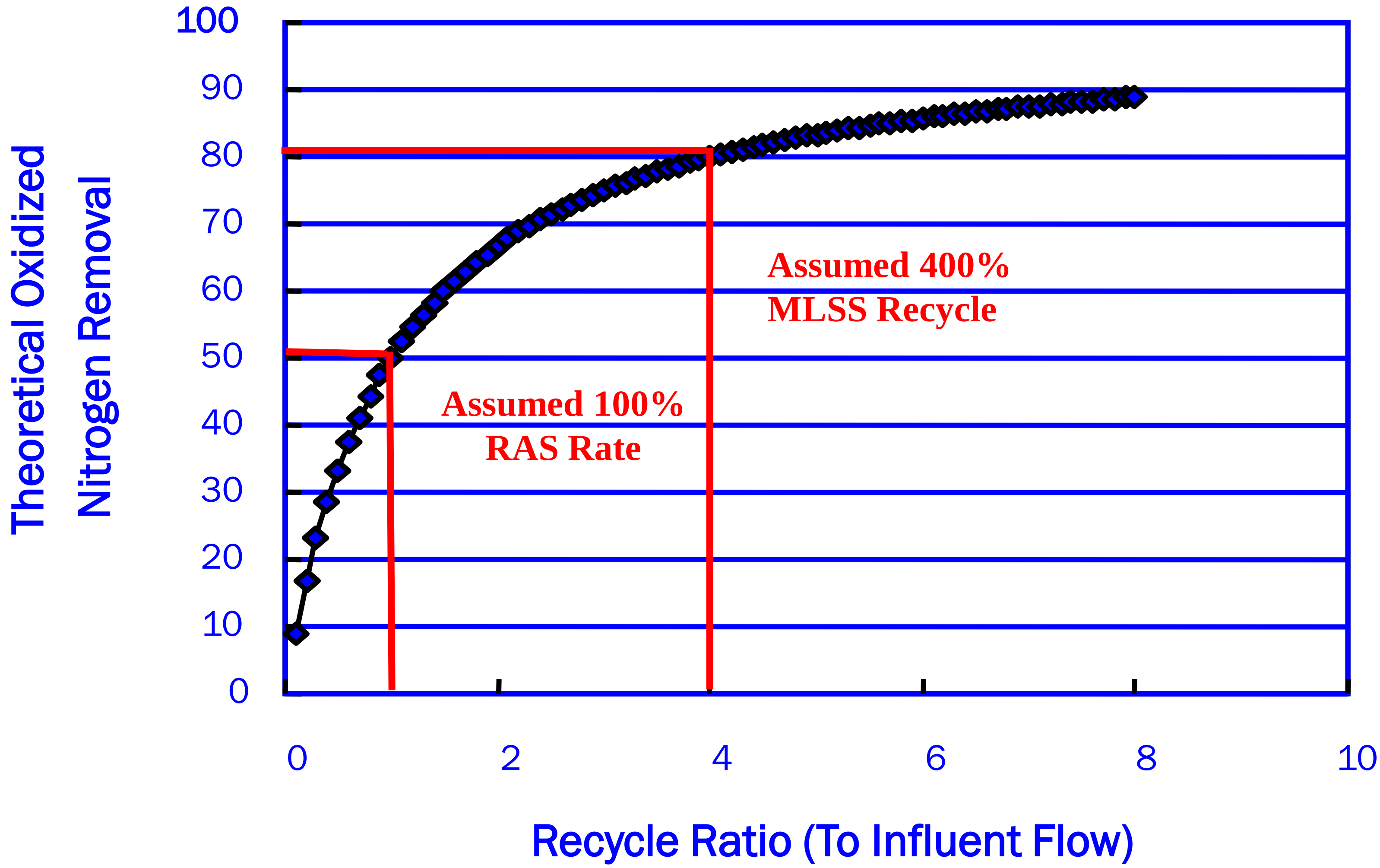
What is the source of nitrate?

- Nitrate is not common in raw wastewater
- Produced during nitrification
- Return activated sludge
- Mixed liquor recycle pumps

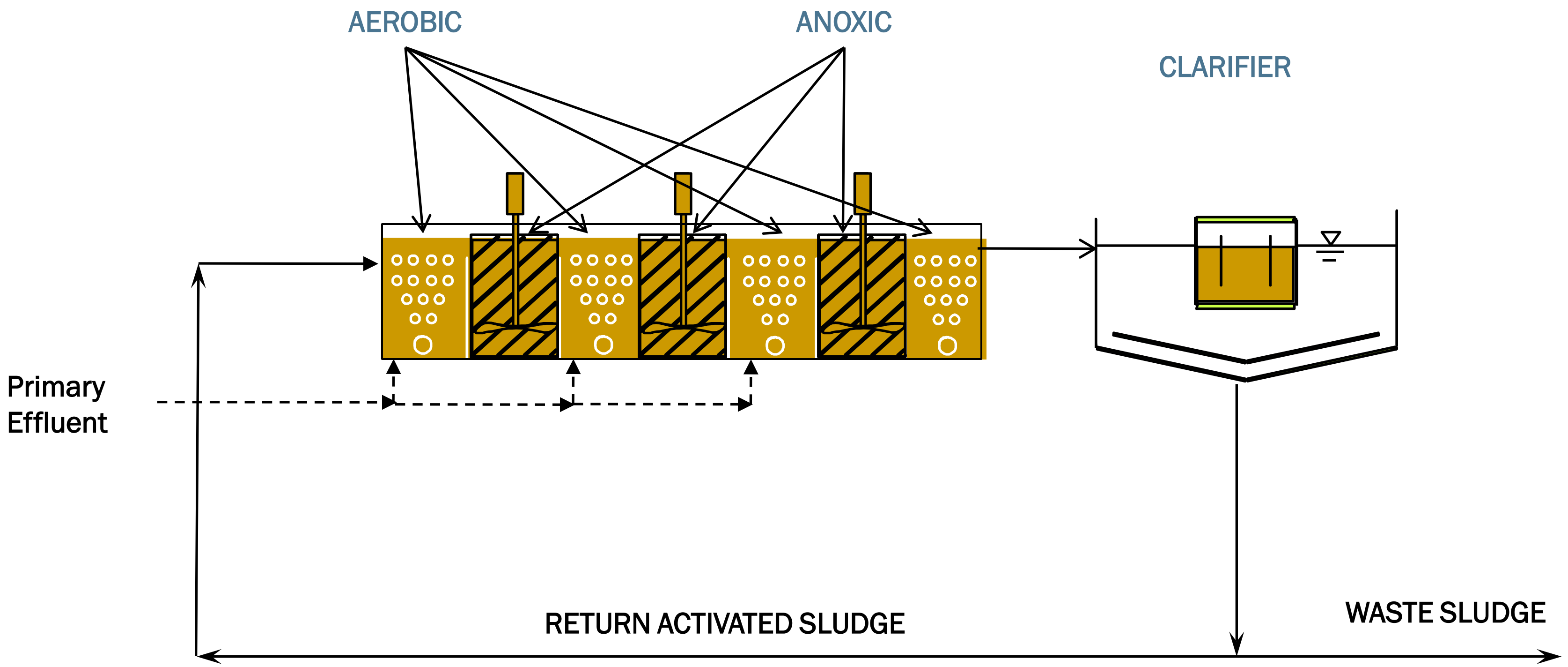
What is the source of nitrate?



N-Removal Depends on Nitrate Recycle



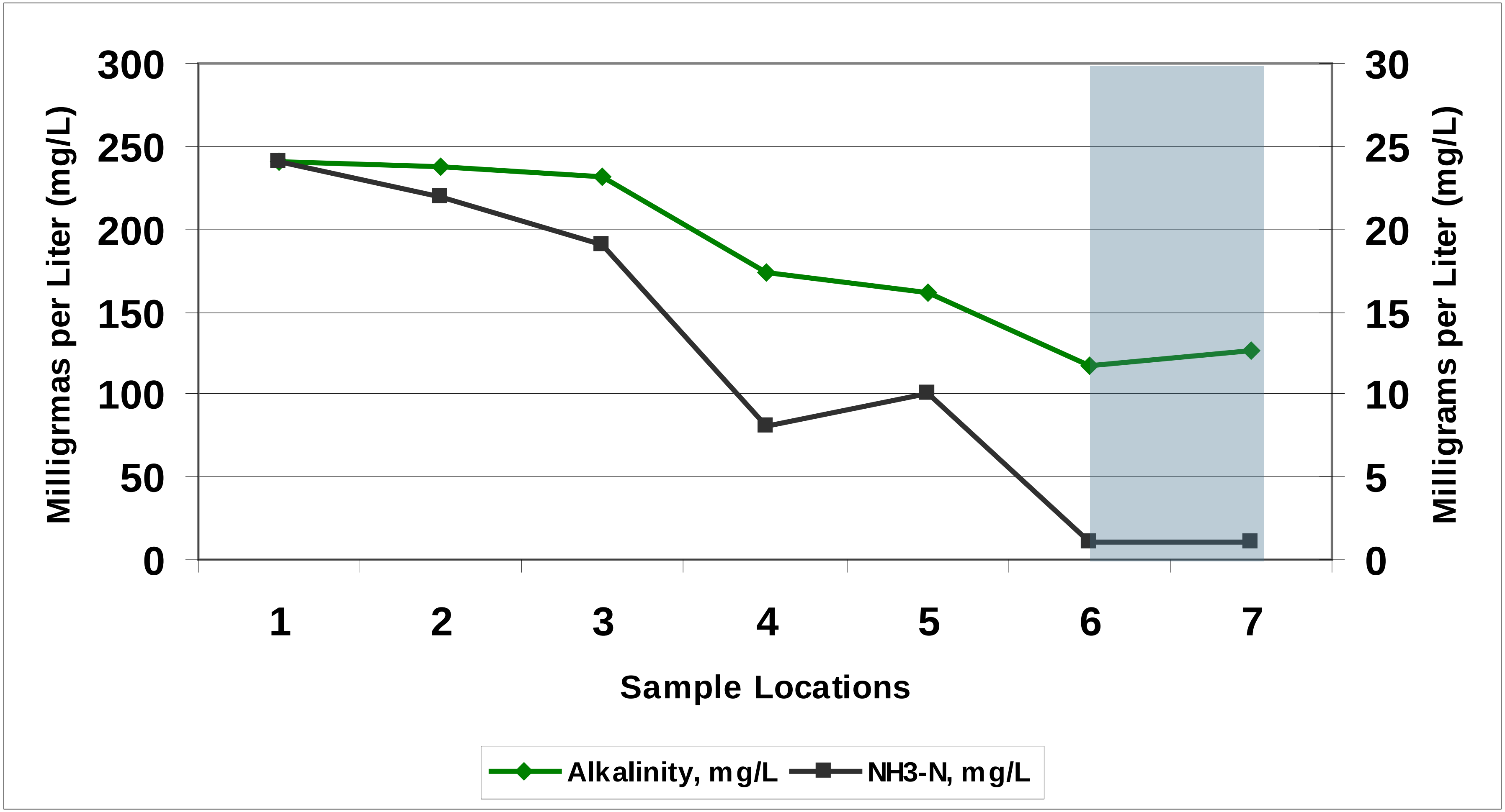
What is the source of nitrate?



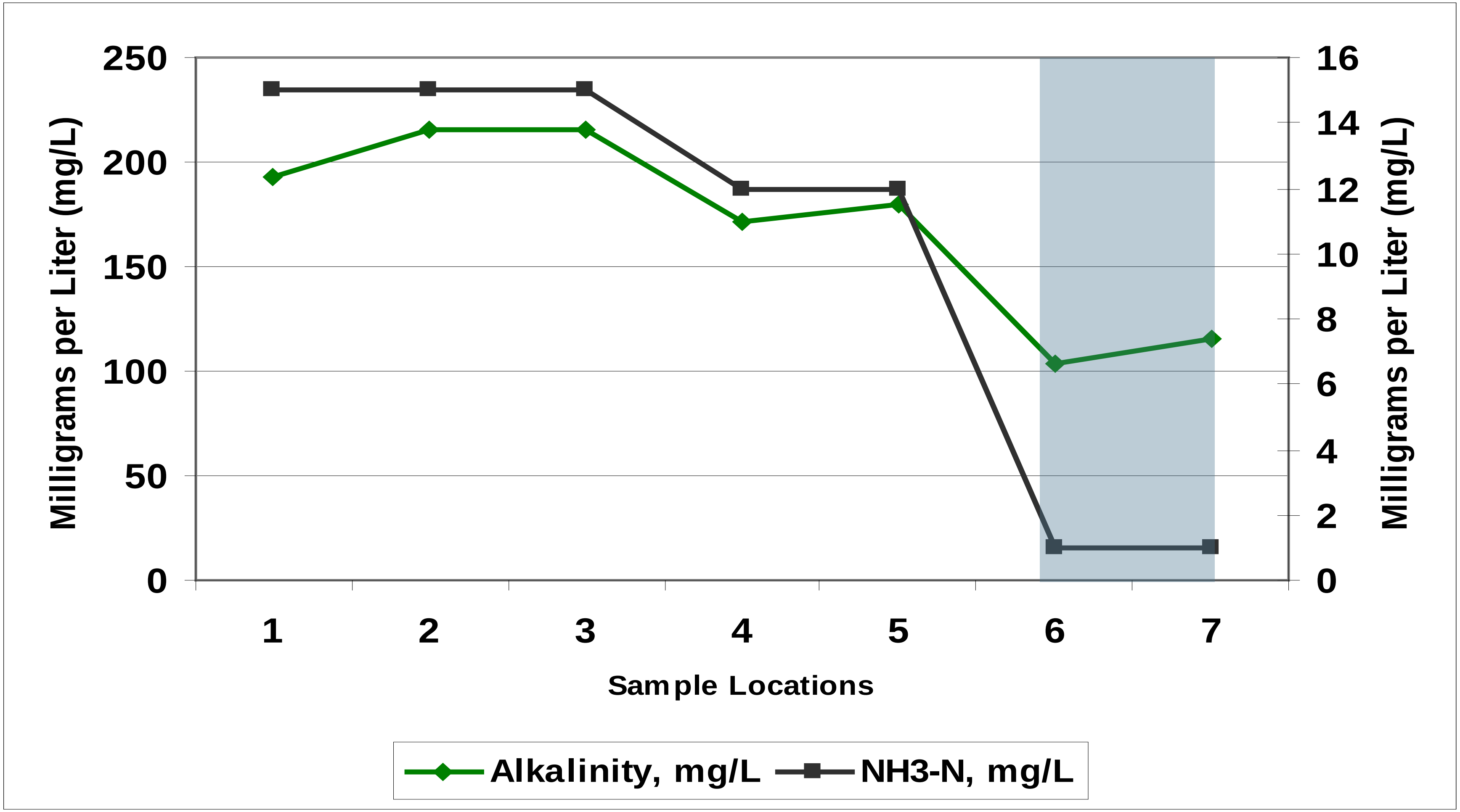
Simultaneous Nitrification-Denitrification (SND)

Water Reclamation Facility	Expected Nitrogen Removal, %	Actual Nitrogen Removal, %
Kihei	62	75
Lahaina	45	71
Wailuku-Kahului	40	63

SND

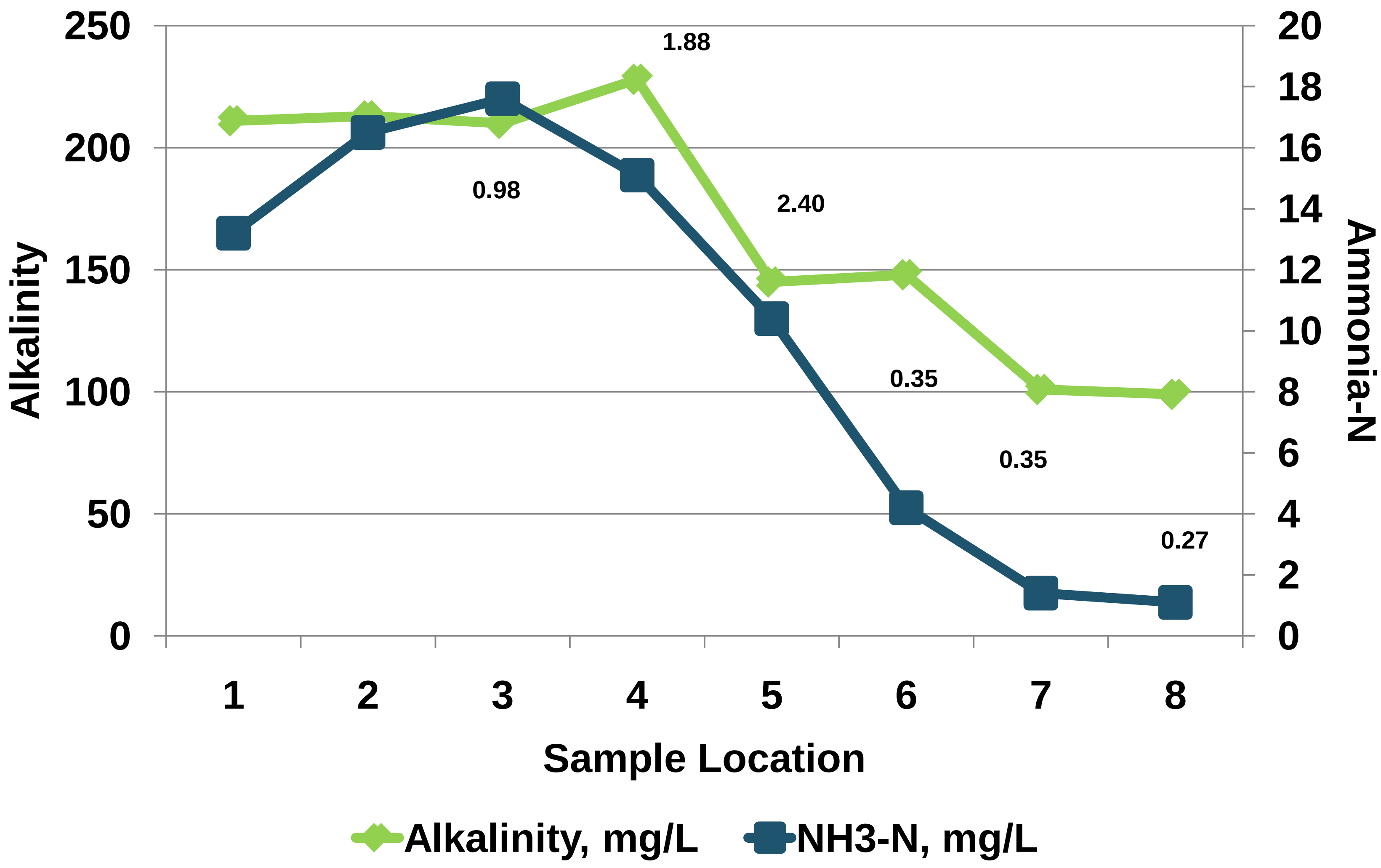

Milligrmas per Liter (mg/L)
300
250
200
150
100
50
0
Milligrams per Liter (mg/L)
30
25
20
15
10
5
0
1
2
3
4
5
6
7
Sample Locations
Alkalinity, mg/L
NH3-N, mg/L

SND



250
200
150
100
50
0
16
14
12
10
8
6
4
2
0
Milligrams per Liter (mg/L)
Milligrams per Liter (mg/L)
1
2
3
4
5
6
7
Sample Locations
Alkalinity, mg/L
NH3-N, mg/L

SND

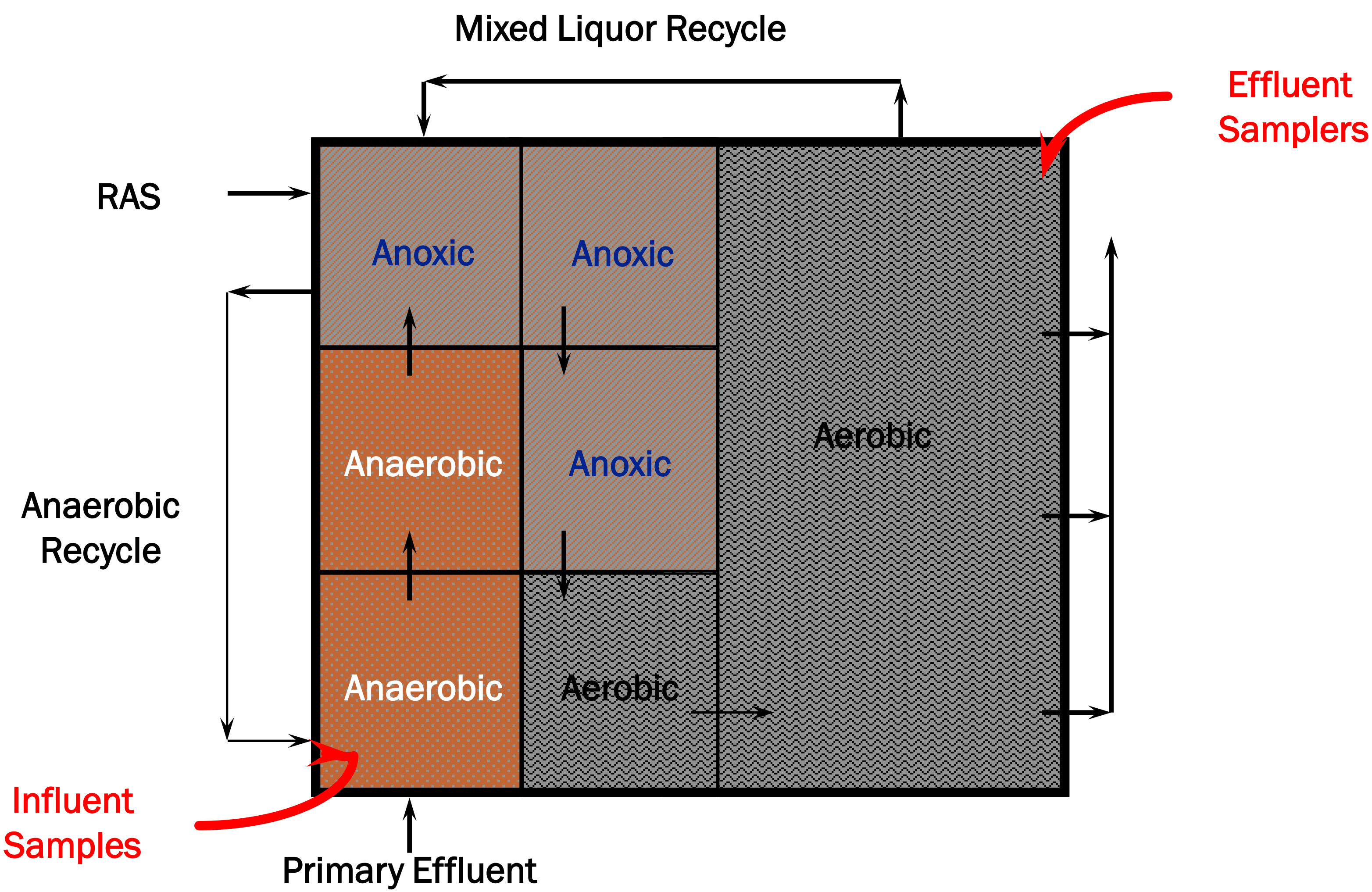


250
200
150
100
50
0
20
18
16
14
12
10
8
6
4
2
0
Alkalinity
Ammonia-N
1.88
0.98
2.40
0.35
0.35
0.27
1
2
3
4
5
6
7
8
Sample Location
Alkalinity, mg/L
NH3-N, mg/L

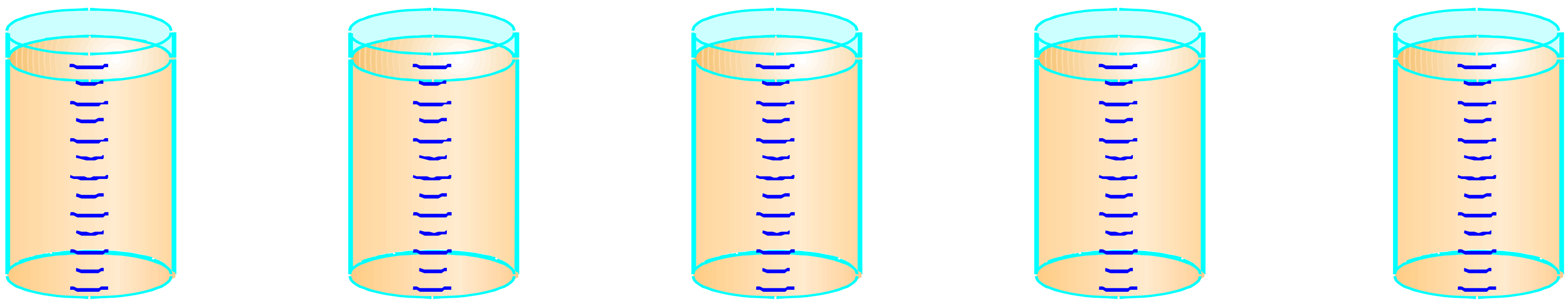
Environmental Conditions for Denitrification

- Denitrifying organisms present
- Zero or low dissolved oxygen
- Nitrate or nitrite present
- Organic carbon present

Durham Process Mode



Settleometer Set-up



Aerator Influent

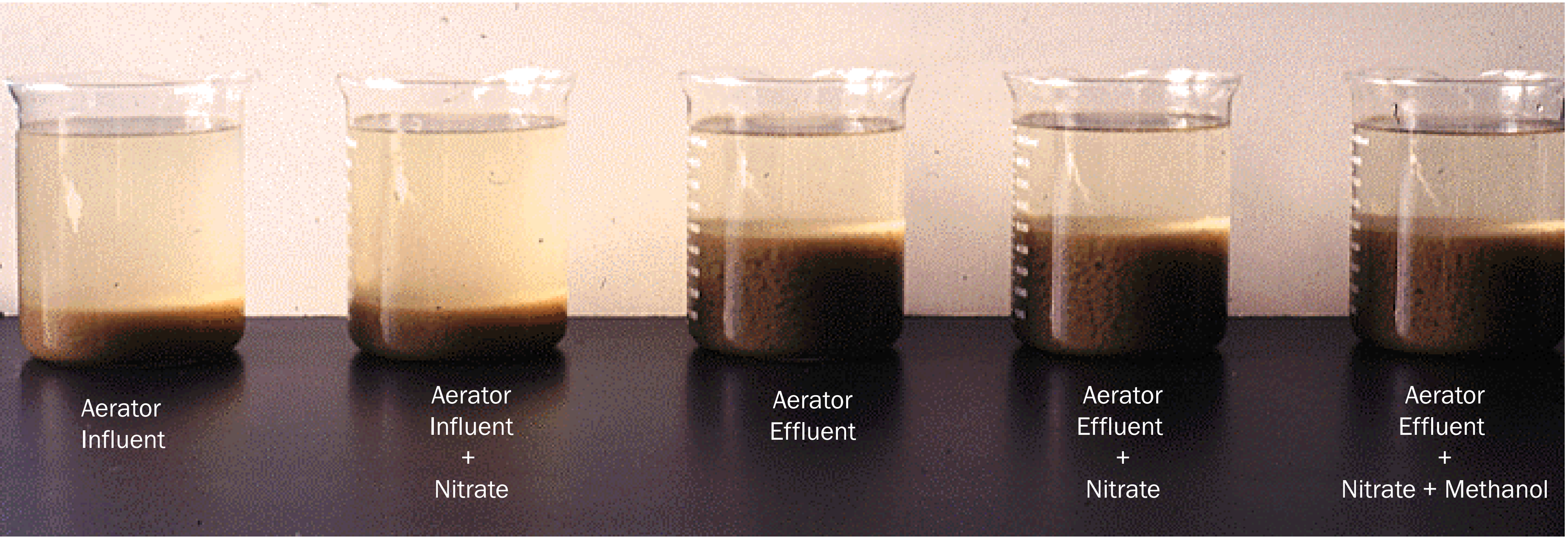
Aerator Influent (Nitrate added)

Aerator Effluent

Aerator Effluent (Nitrate added)

Aerator Effluent (Nitrate & Methanol added)

Predict the order that the sludge will float…



Denitrification Summary

Benefits	Environmental Conditions
• Removes nitrogen • Removes organic carbon • Produces alkalinity • Serves as a selector	• Presence of denitrifying organisms • Presence of nitrates • Presence of readily biodegradable organic carbon • Absence of dissolved oxygen

Combining Energy and Respiration

Treatment	Description	Respiration	Energy Source
cBOD Removal	Oxidation of organic carbon to carbon dioxide and water	Aerobic	Heterotrophic
Nitrification	Two-step oxidation of ammonia (NH_4^+-N) to nitrite (NO_2^--N), and nitrite to nitrate (NO_3^--N).	Aerobic	Autotrophic
Denitrification	Oxidation of organic carbon to nitrogen gas, carbon dioxide, and water	Anoxic	Heterotrophic

Aeration Basin Profiles

Brown AND Caldwell

Acknowledgement

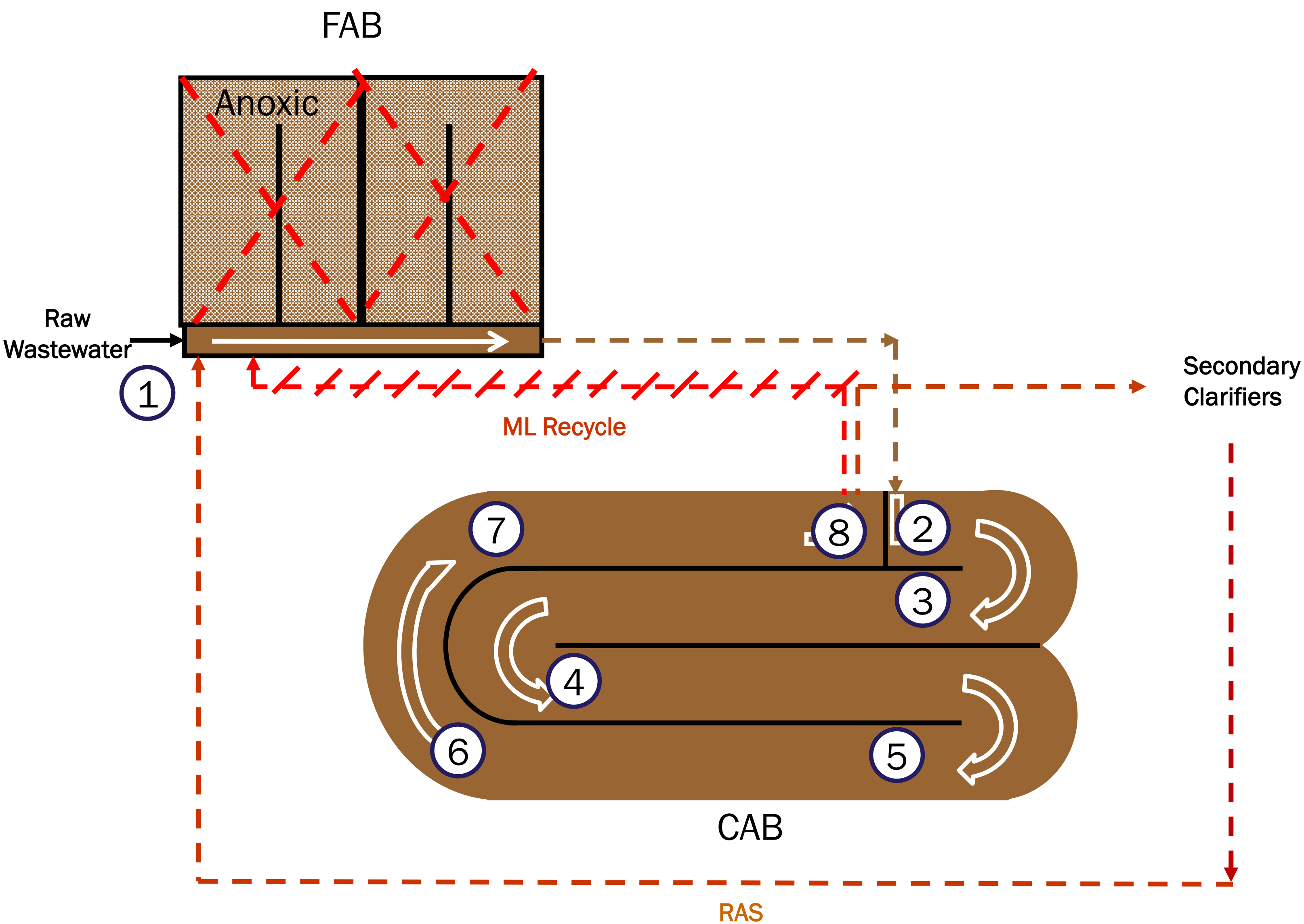
- County of Maui Wastewater Reclamation Division
  - Theo Leong
- Wailuku-Kahului Wastewater Reclamation Facility
  - Mike Kaya
  - Bradley Pierce
  - Rusty Silva
- Kihei Wastewater Reclamation Facility
  - Billy Mohlman
- Lahaina Wastewater Reclamation Facili
  - Calvin Flores
  - Joe Jares
  - Kathleen Lawson
- Central Laboratory
  - Anita Fernandez
  - Robert Rychlinski

Lahaina Profile

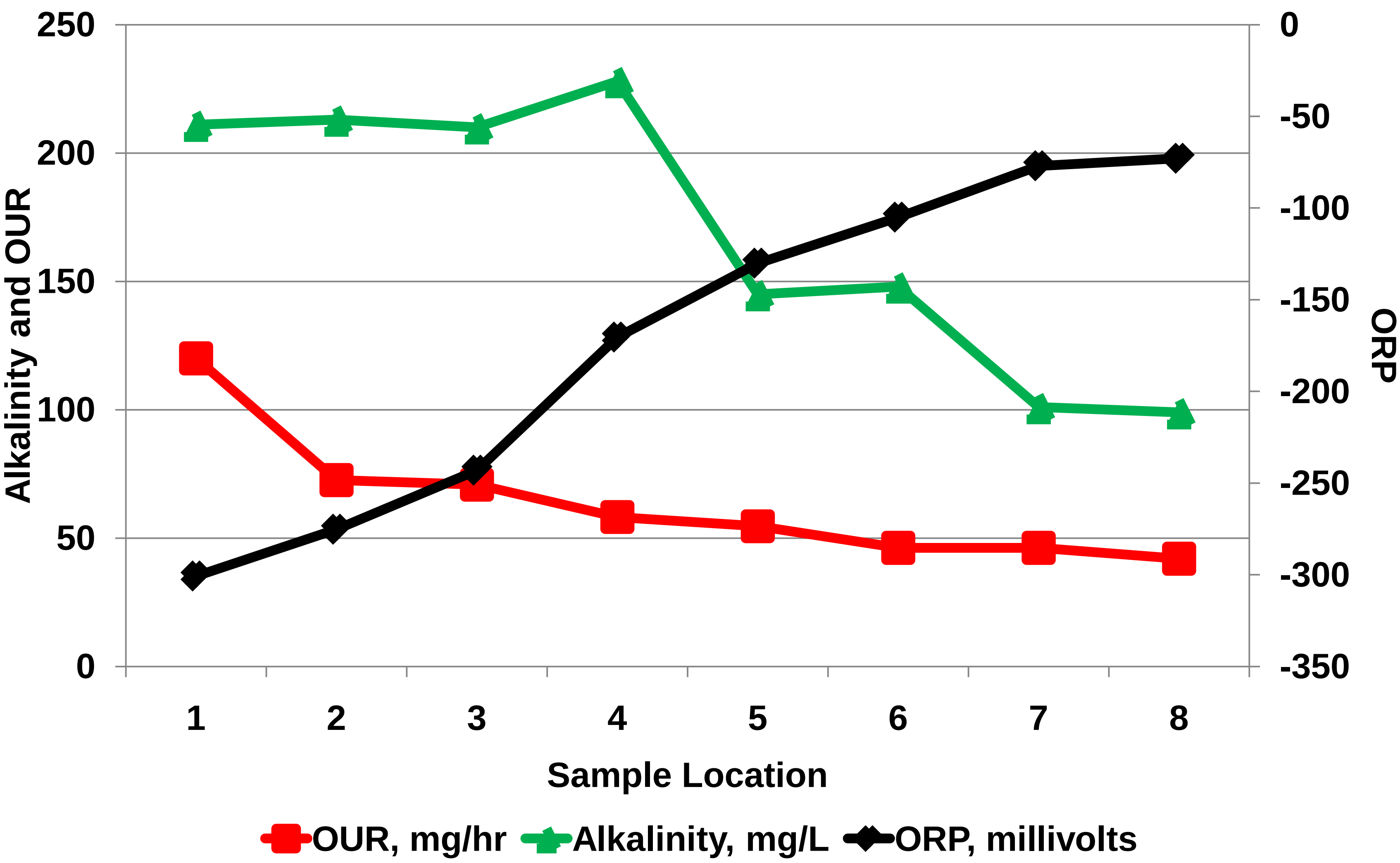
May 30, 2010

Brown AND Caldwell

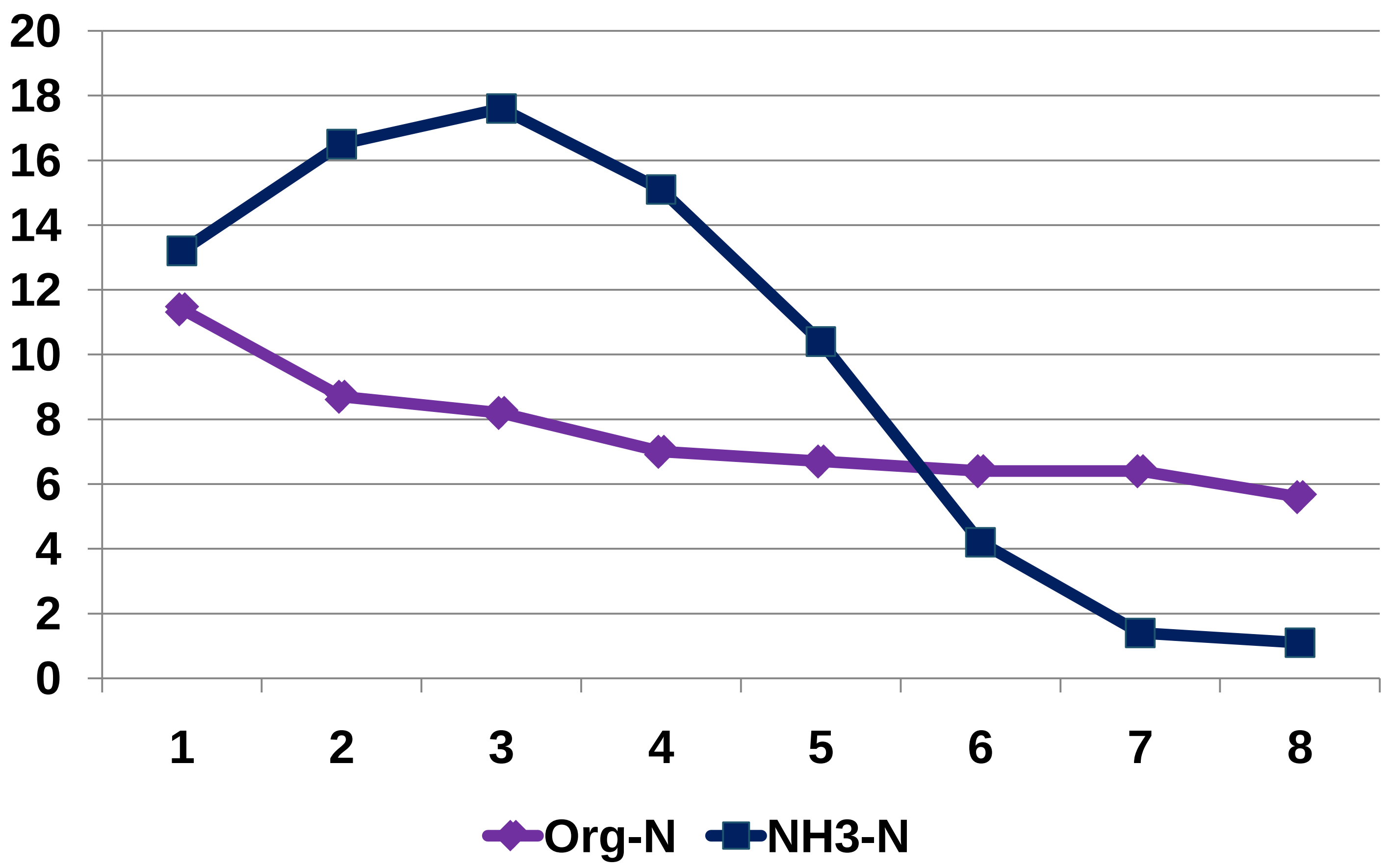
Lahaina Sample Locations



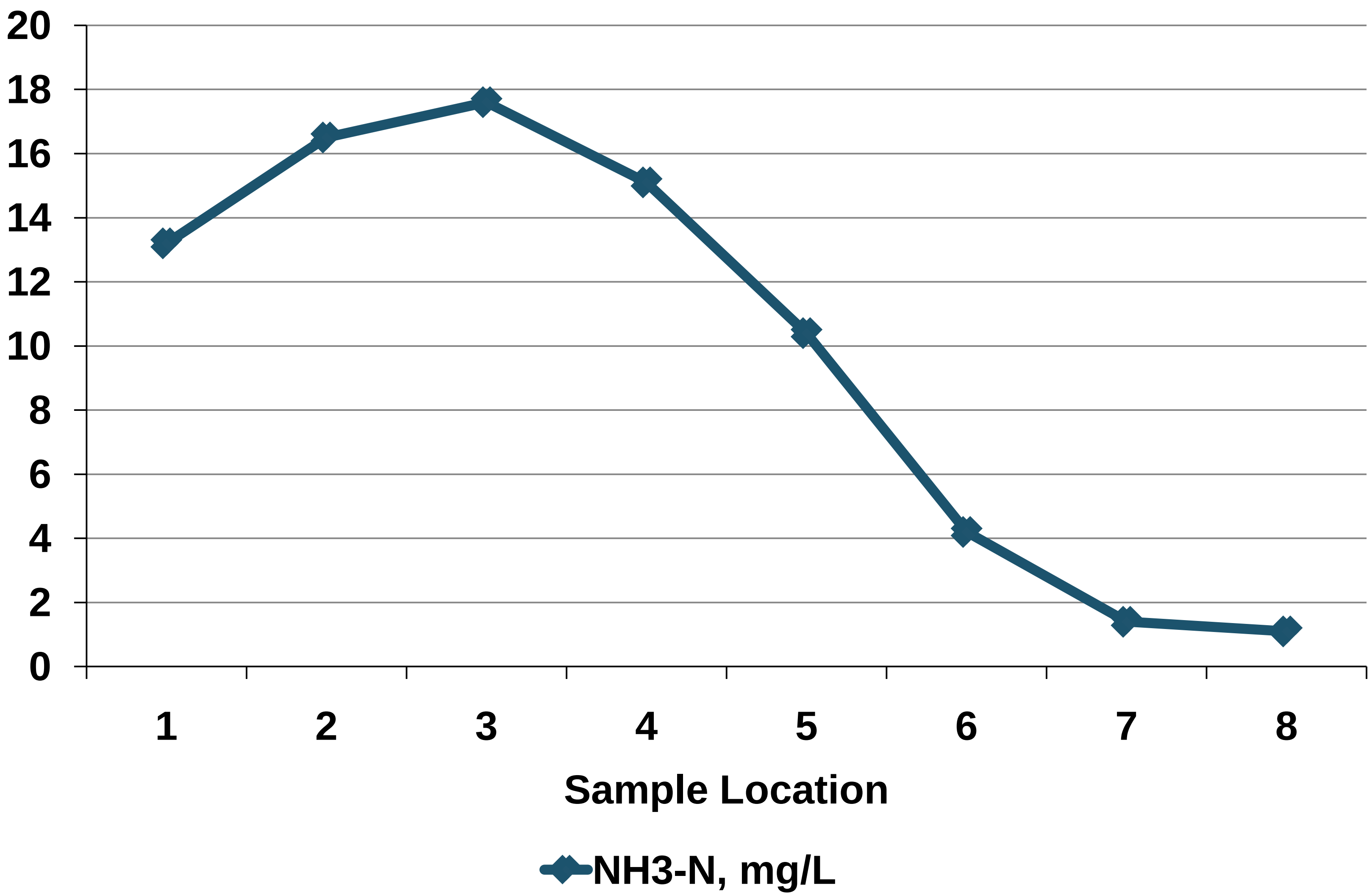
Comparison of Field Parameters



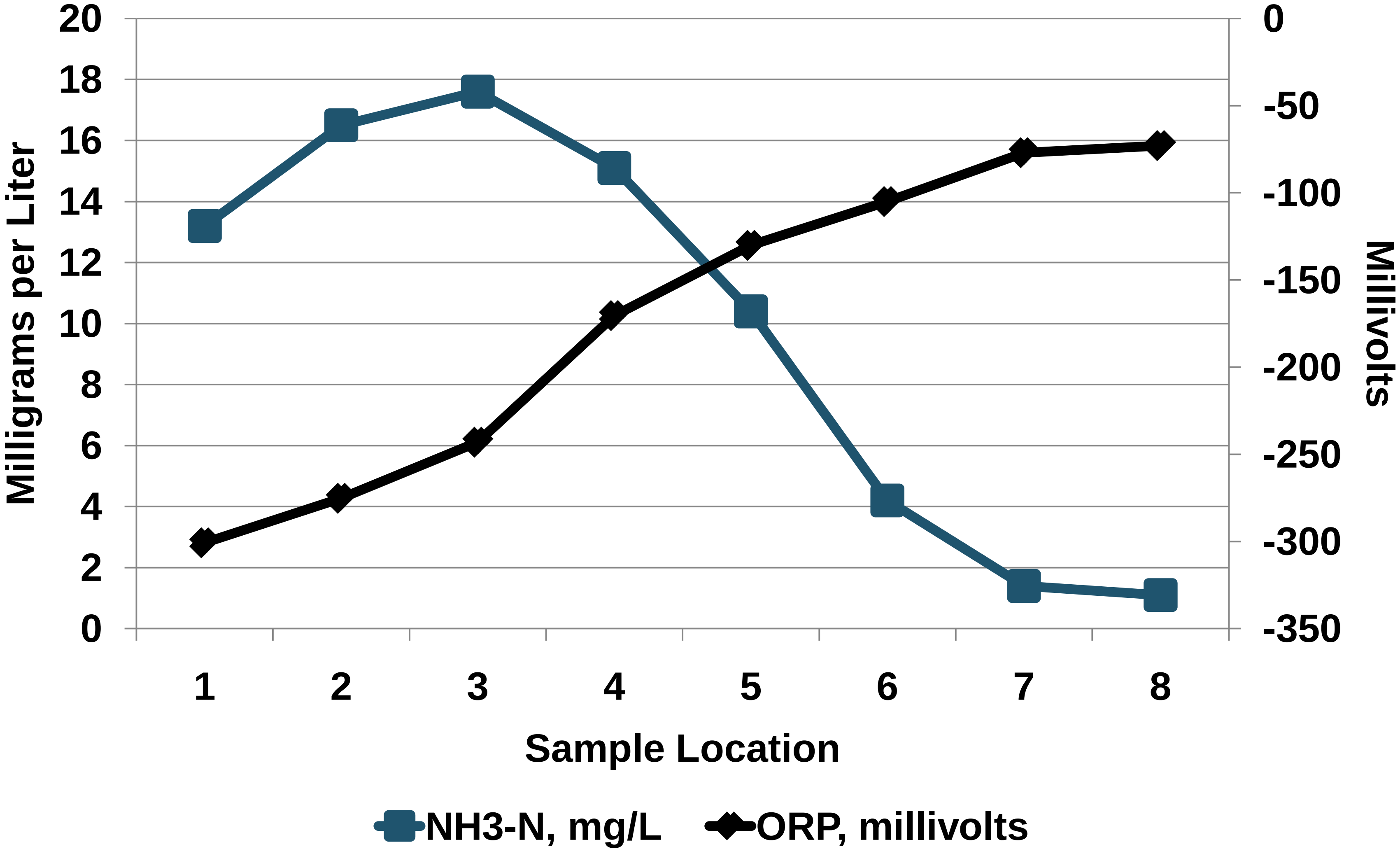
Comparison of Ammonia-N and Organic-N



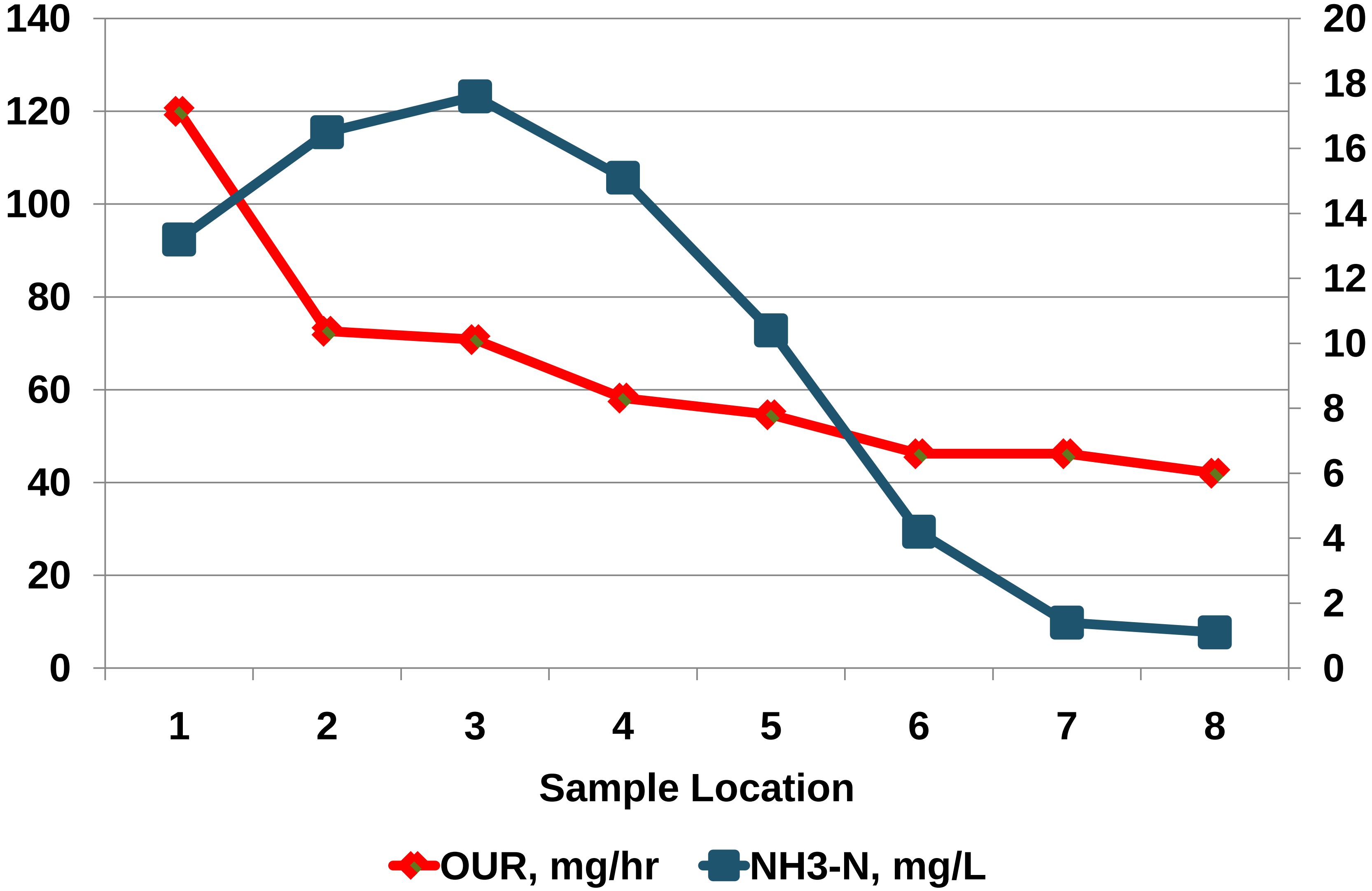
Ammonia



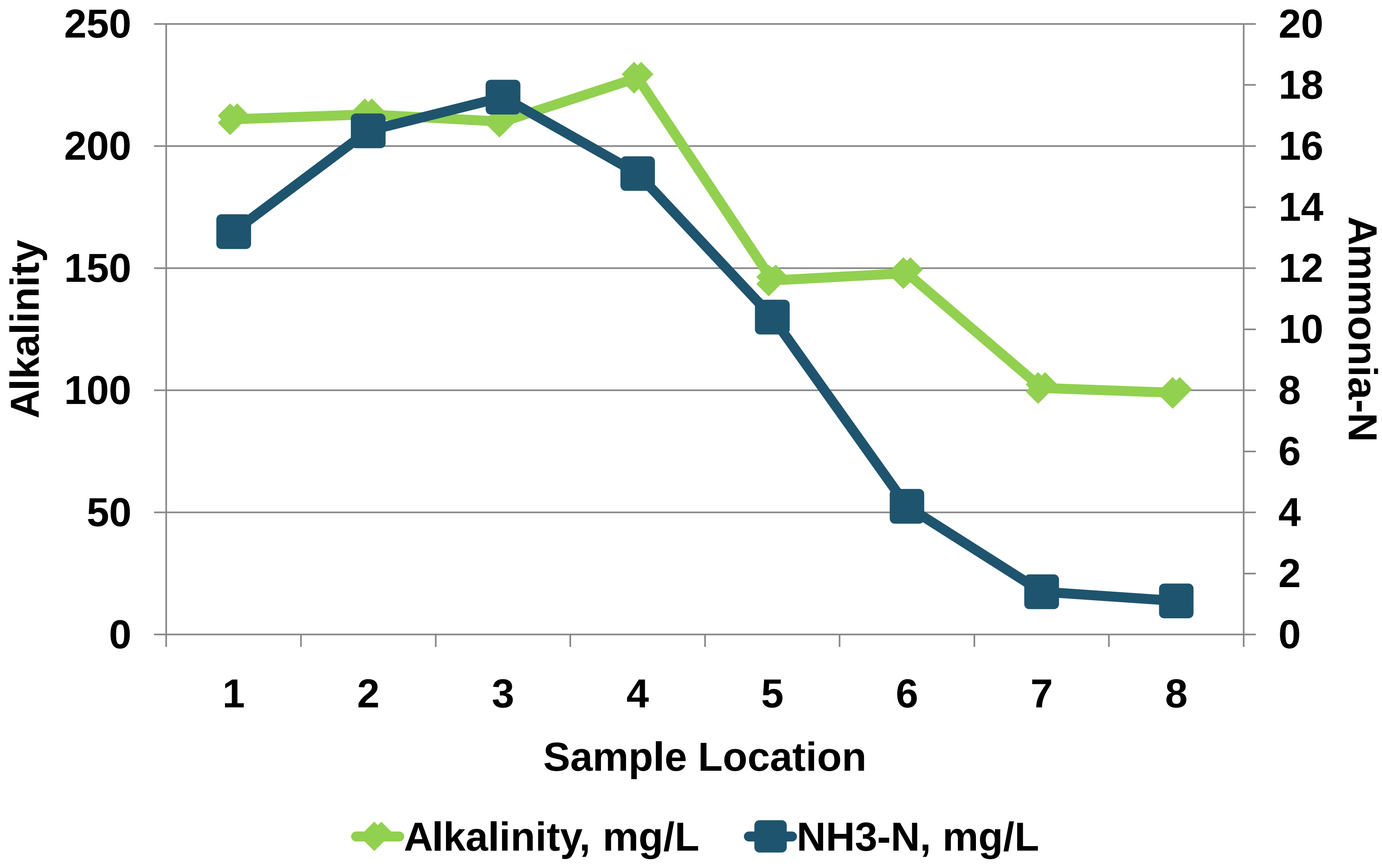
Comparison of Ammonia and ORP



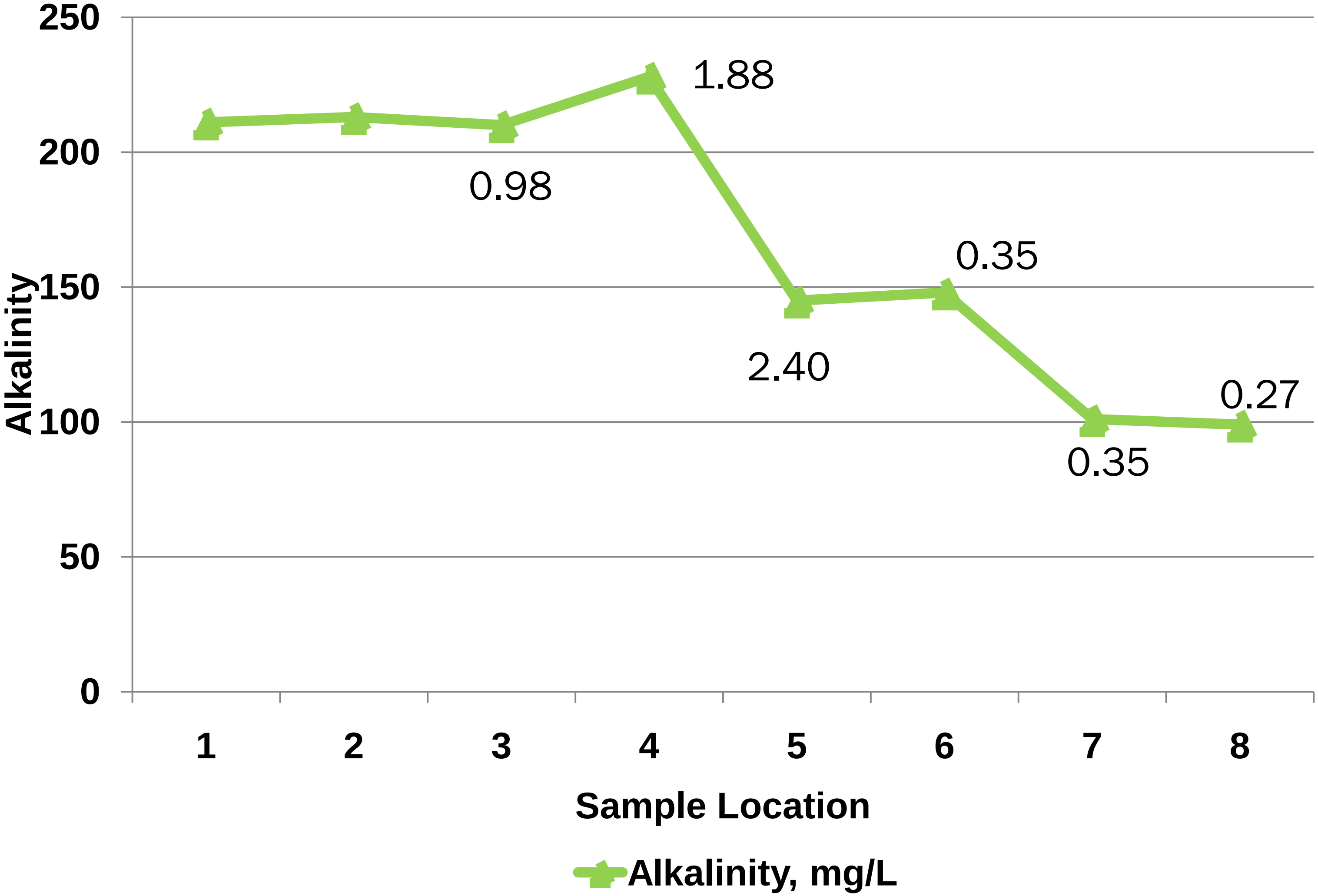
Comparison of Ammonia and OUR



Comparison of Ammonia and Alkalinity



D.O. Setpoints and Alkalinity



Conclusions

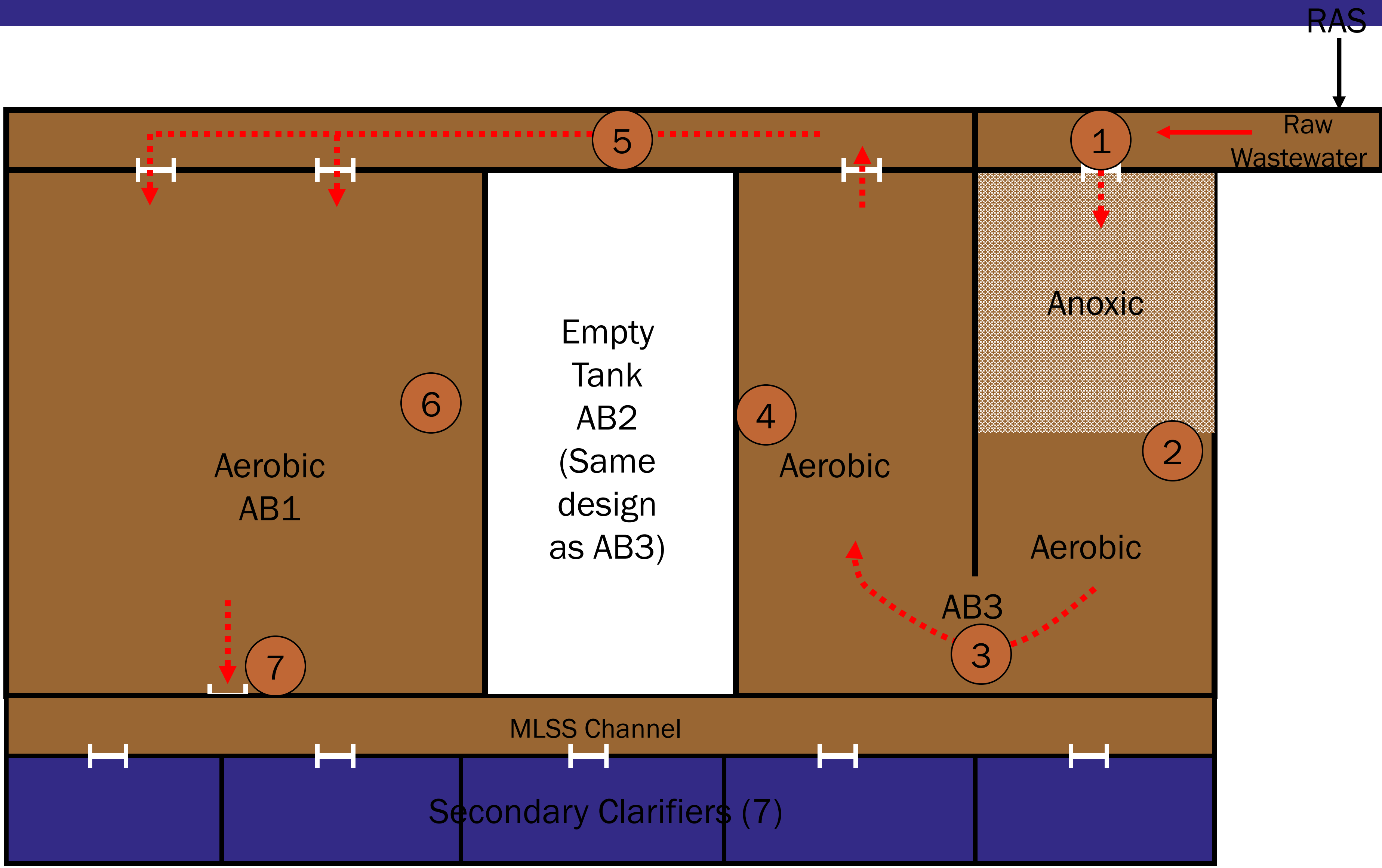
- Some anomalous data in early sample locations.
- OUR was a good predictor of complete nitrification
- Alkalinity was a good predictor of complete nitrification
- ORP was a good predictor of complete nitrification.
- Profile showed complete nitrification occurred somewhere between sample location 6 and 7.
- Alkalinity profile indicates post-anoxic zone is effective.

Wailuku-Kahului Profile

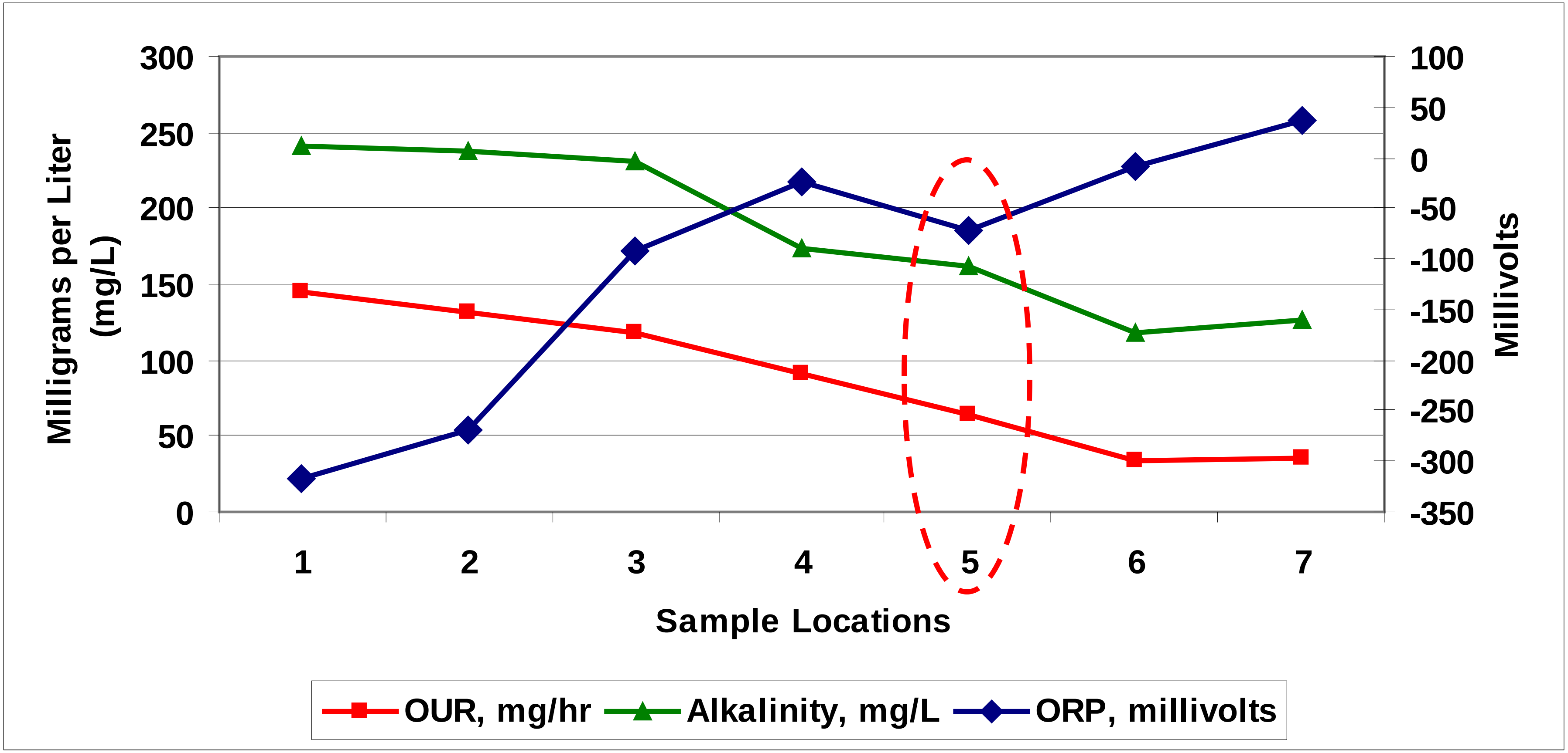
May 29, 2010

Brown AND Caldwell

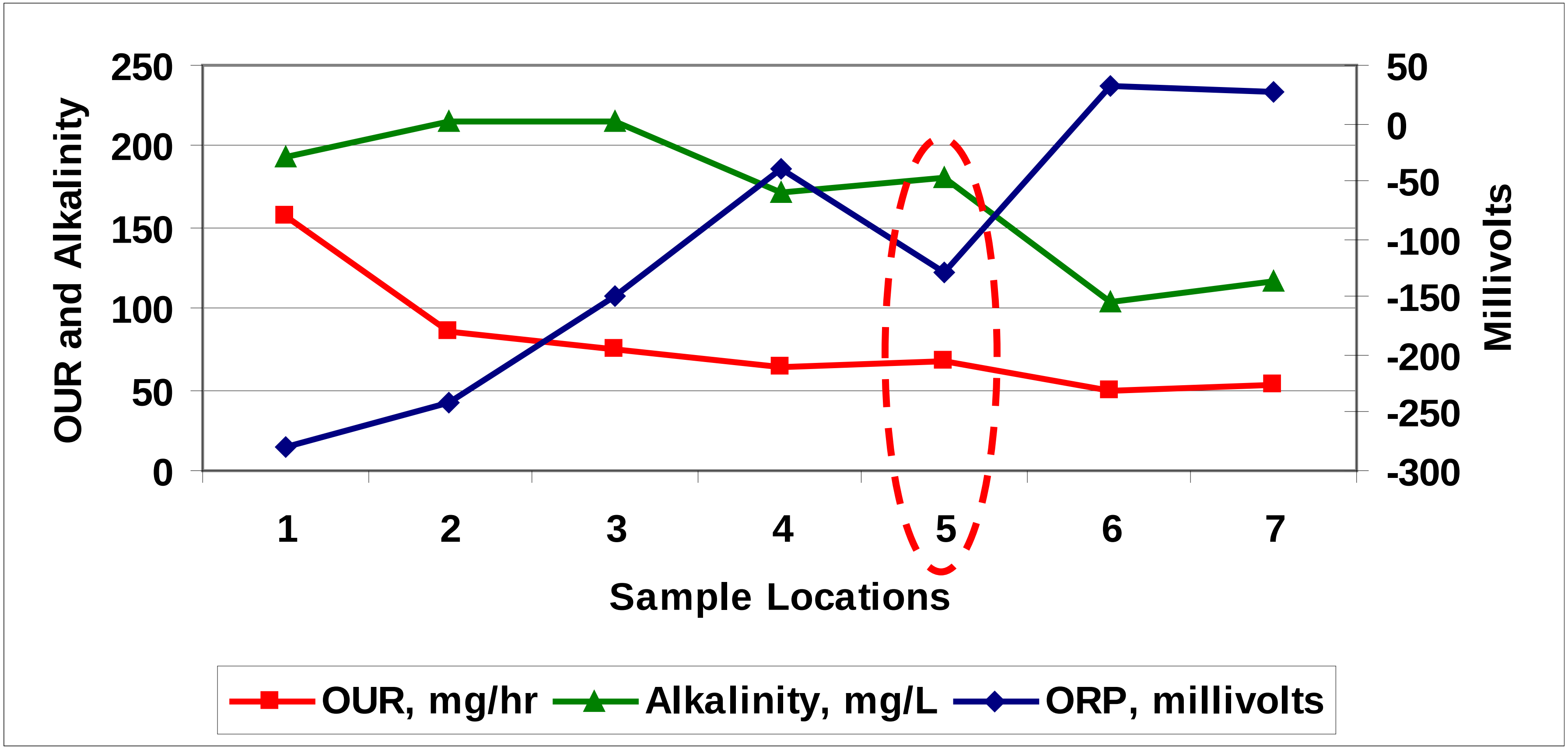
Kahului Sample Locations



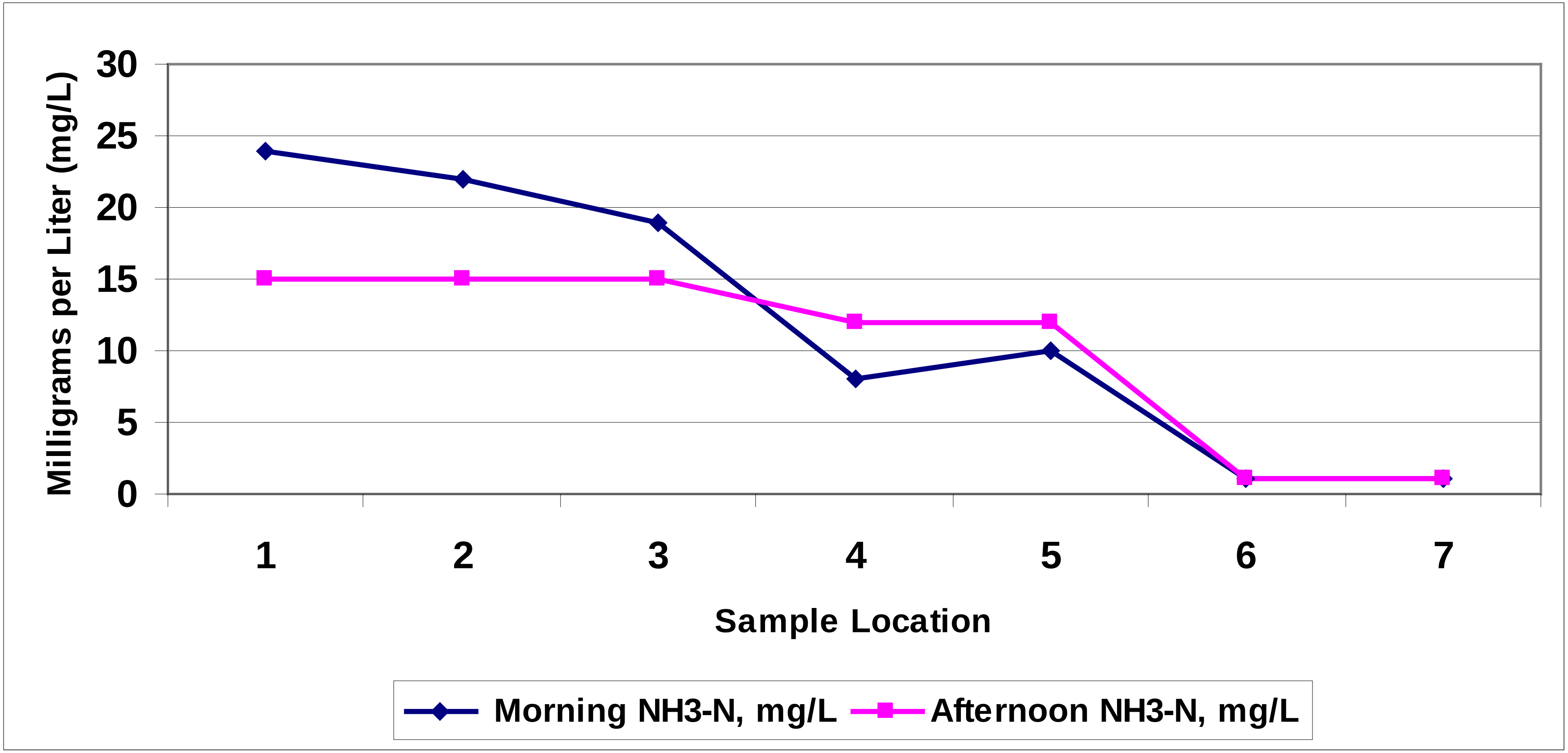
Morning Profile



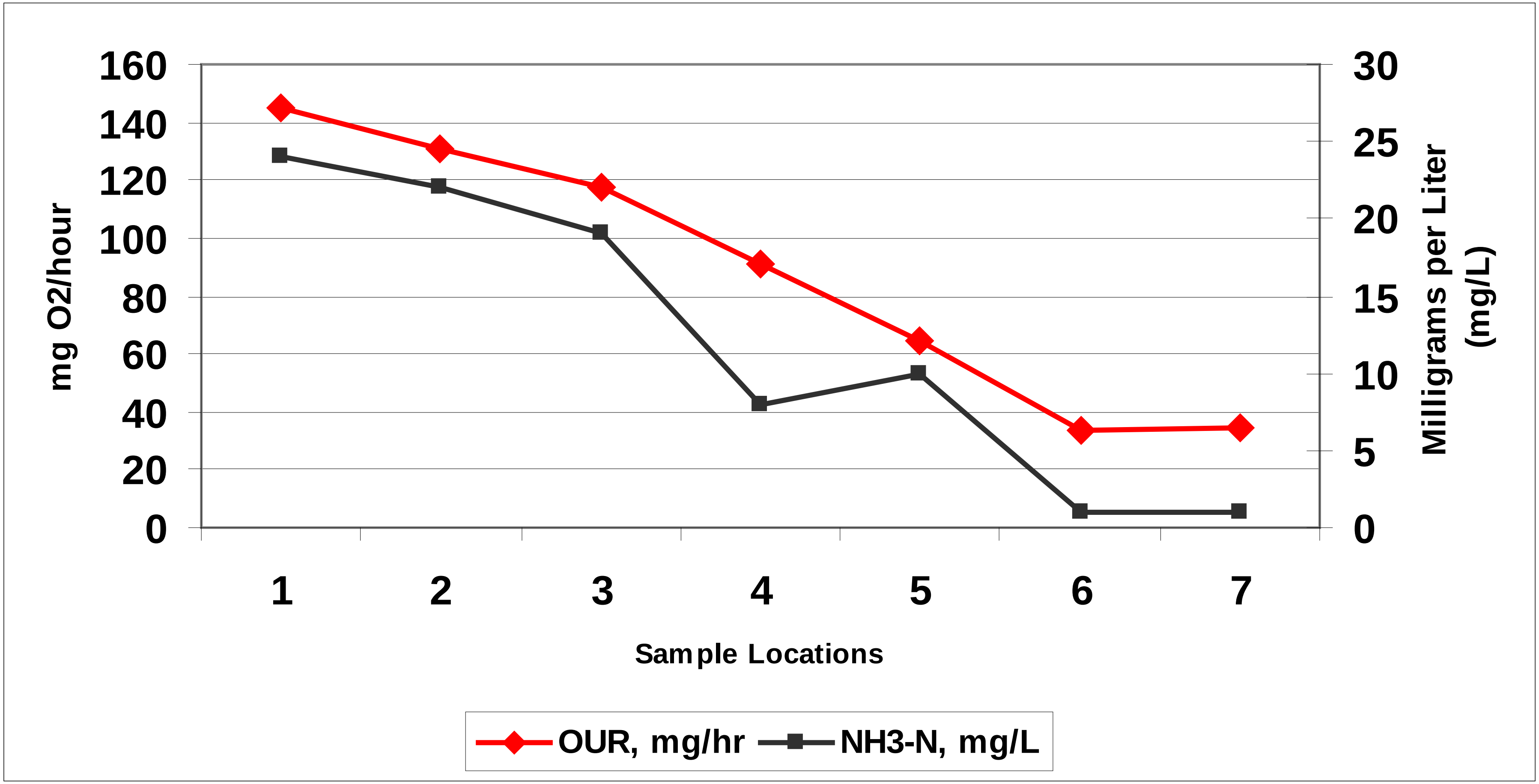
Afternoon Profile



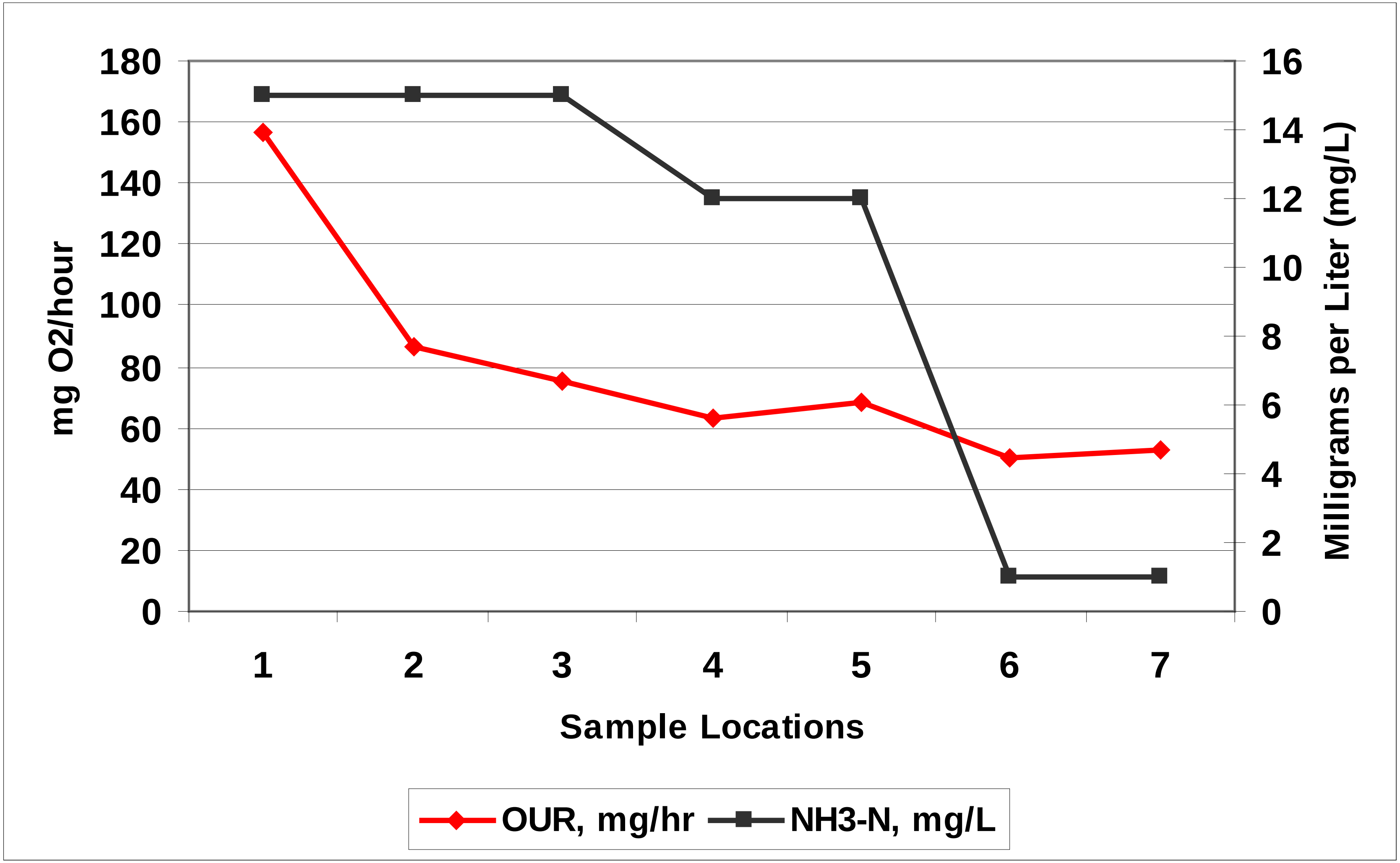
Ammonia-N Profiles



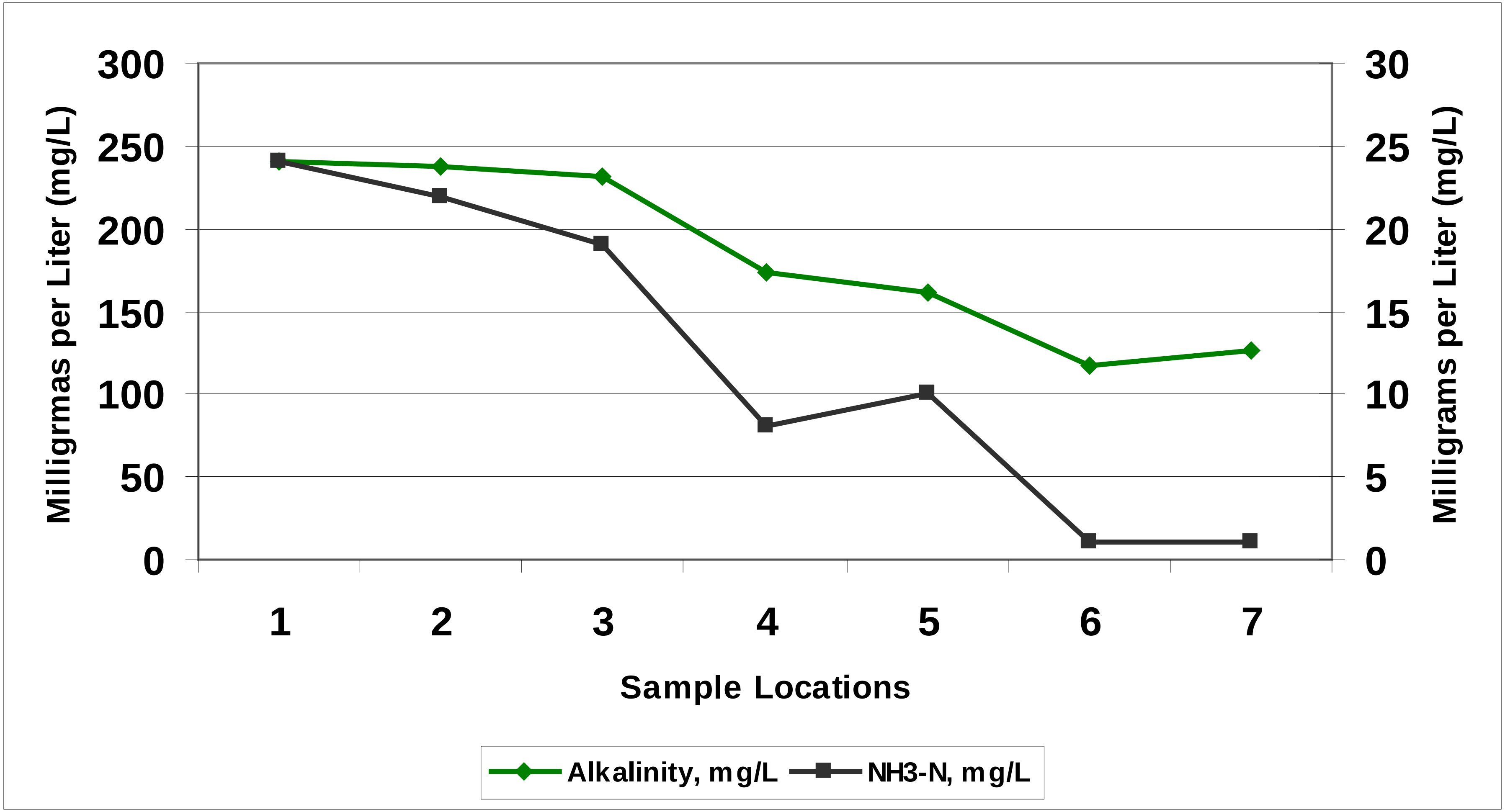
AM – Profile
OUR and NH_3-N



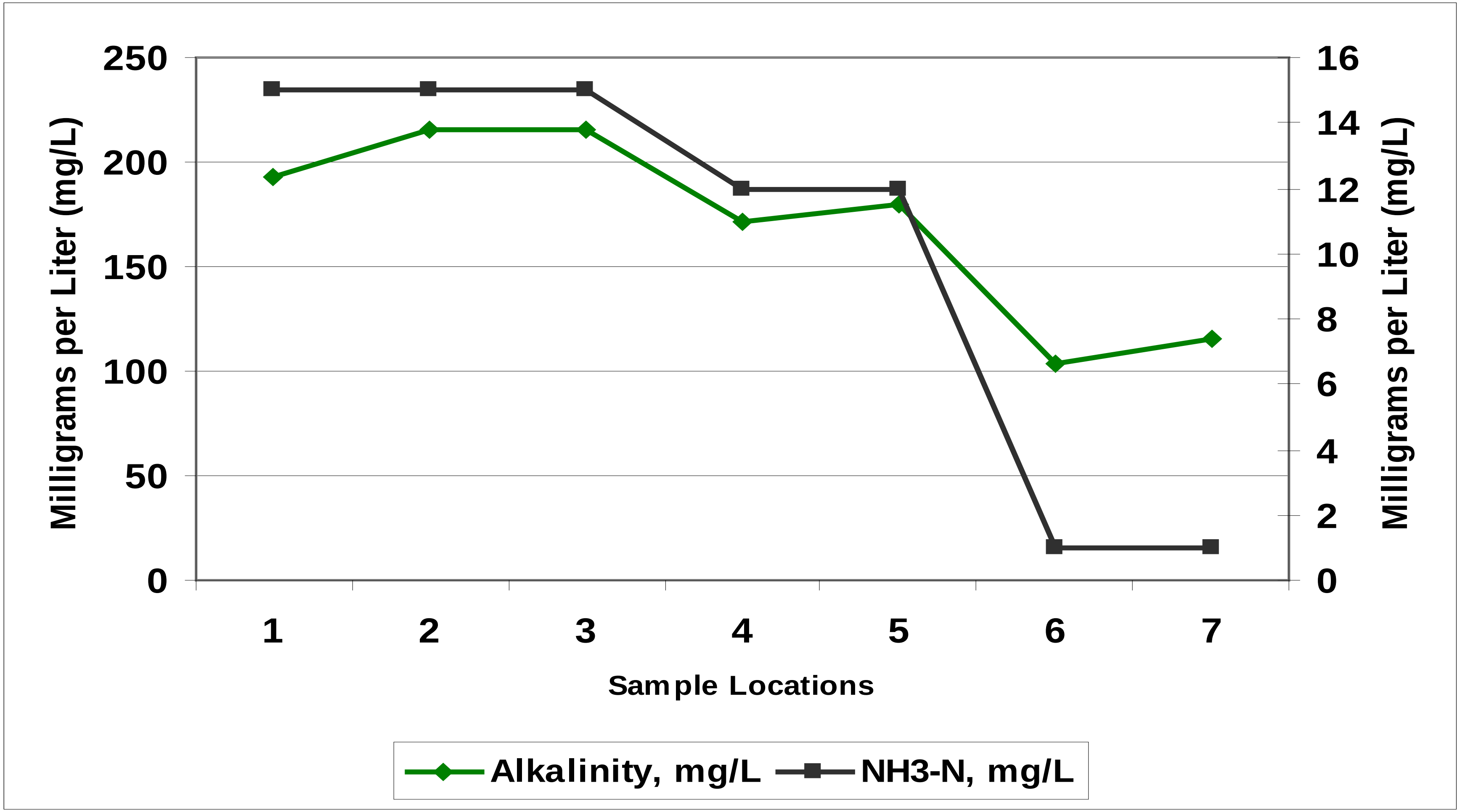
PM Profile
OUR and NH_3-N



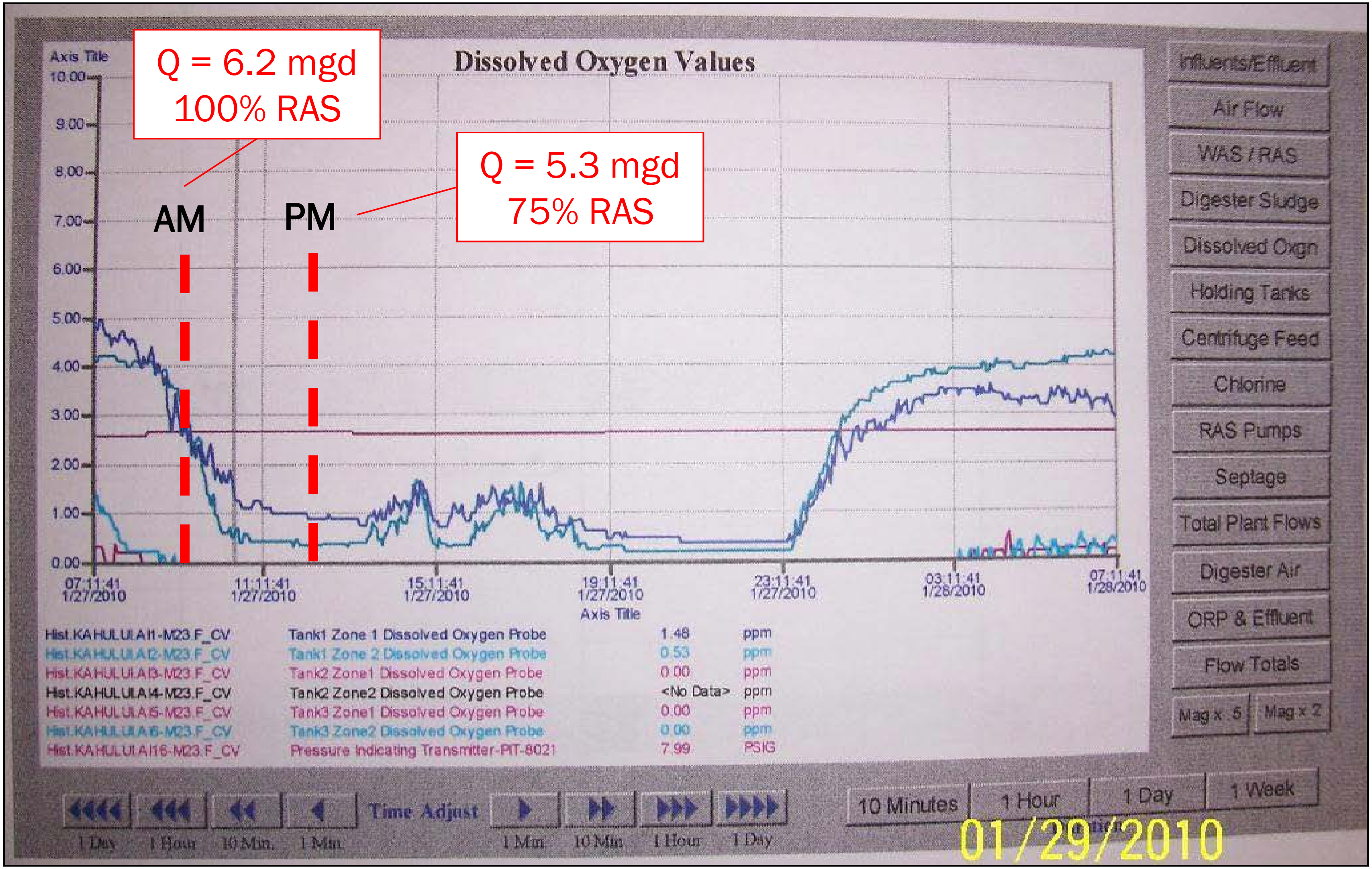
AM Profile
Alkalinity and NH_3-N



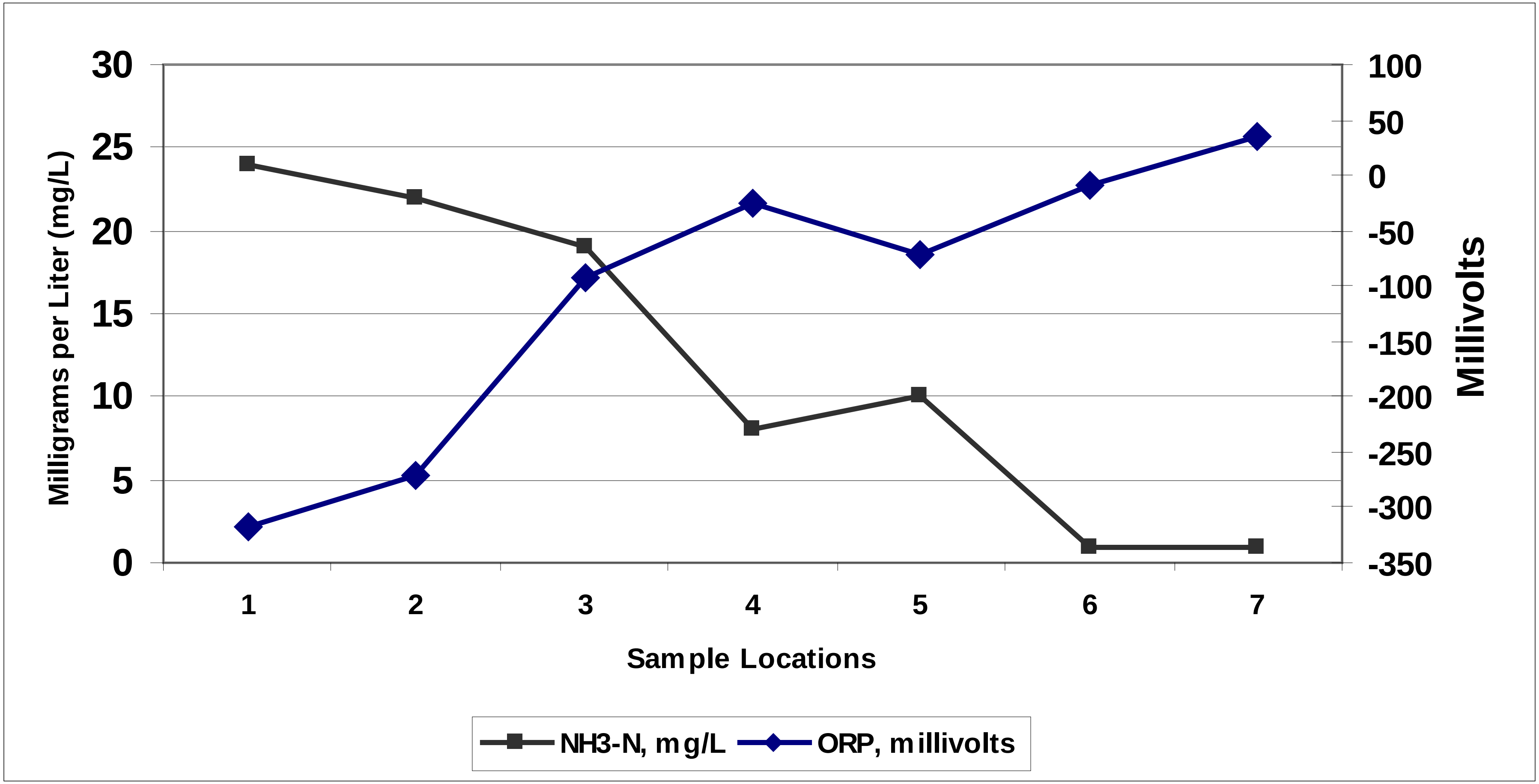
PM Profile
Alkalinity and NH_3-N



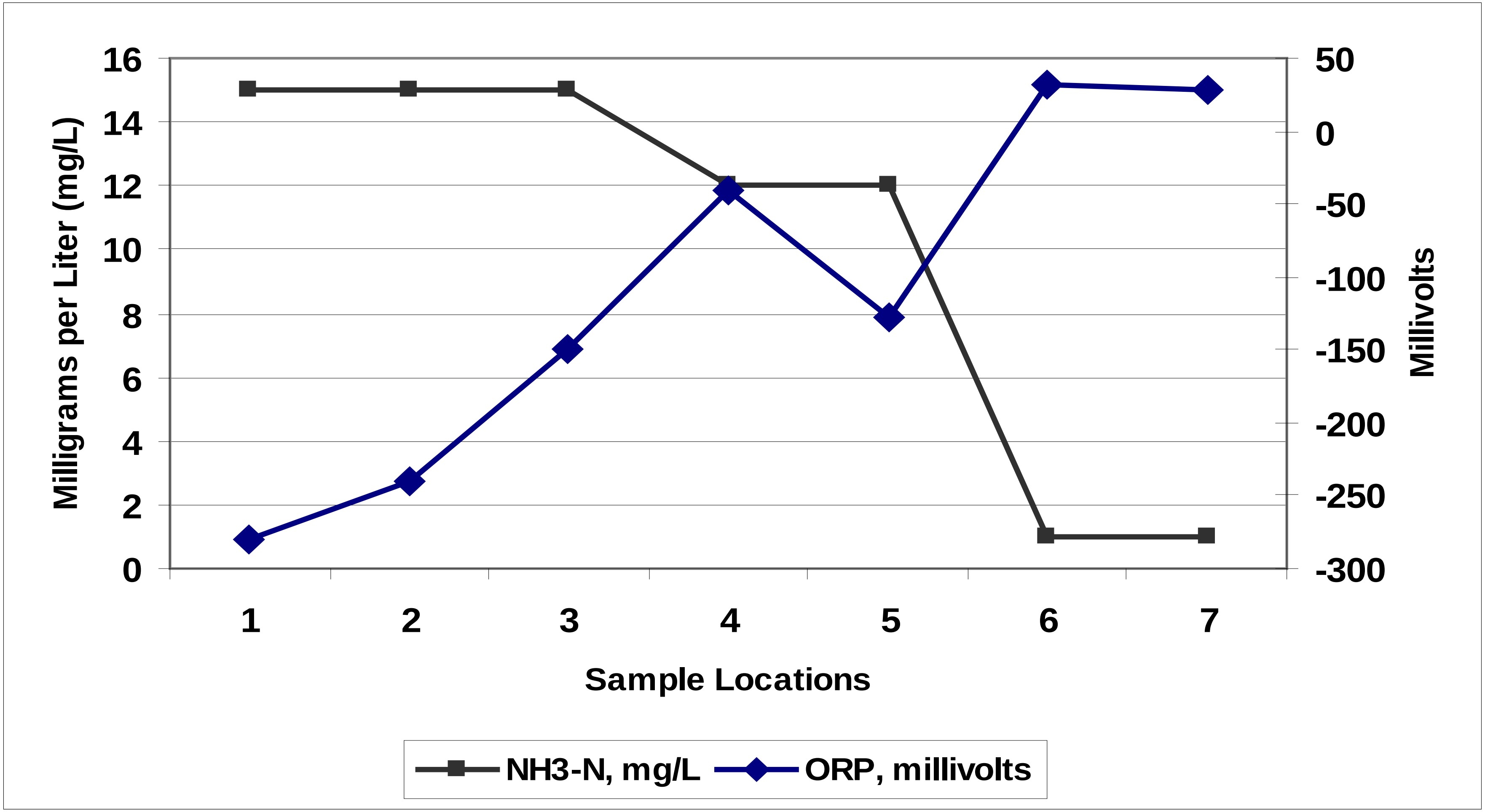
Aeration Basin 1 D.O.



AM – Profile
ORP and NH_3-N



PM Profile
ORP and NH_3-N



Kahului Profile Investigation

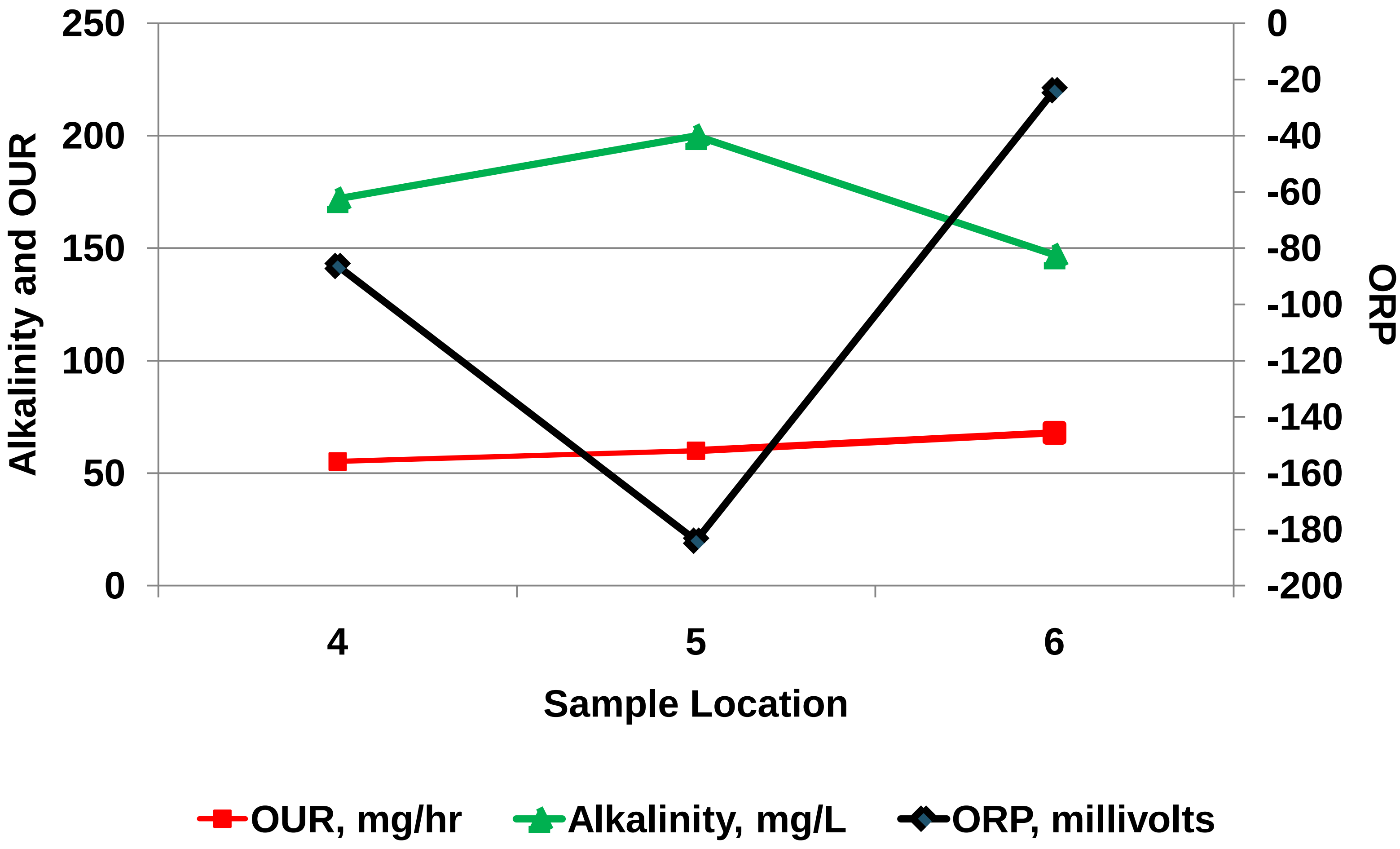
May 29, 2010

Brown AND Caldwell

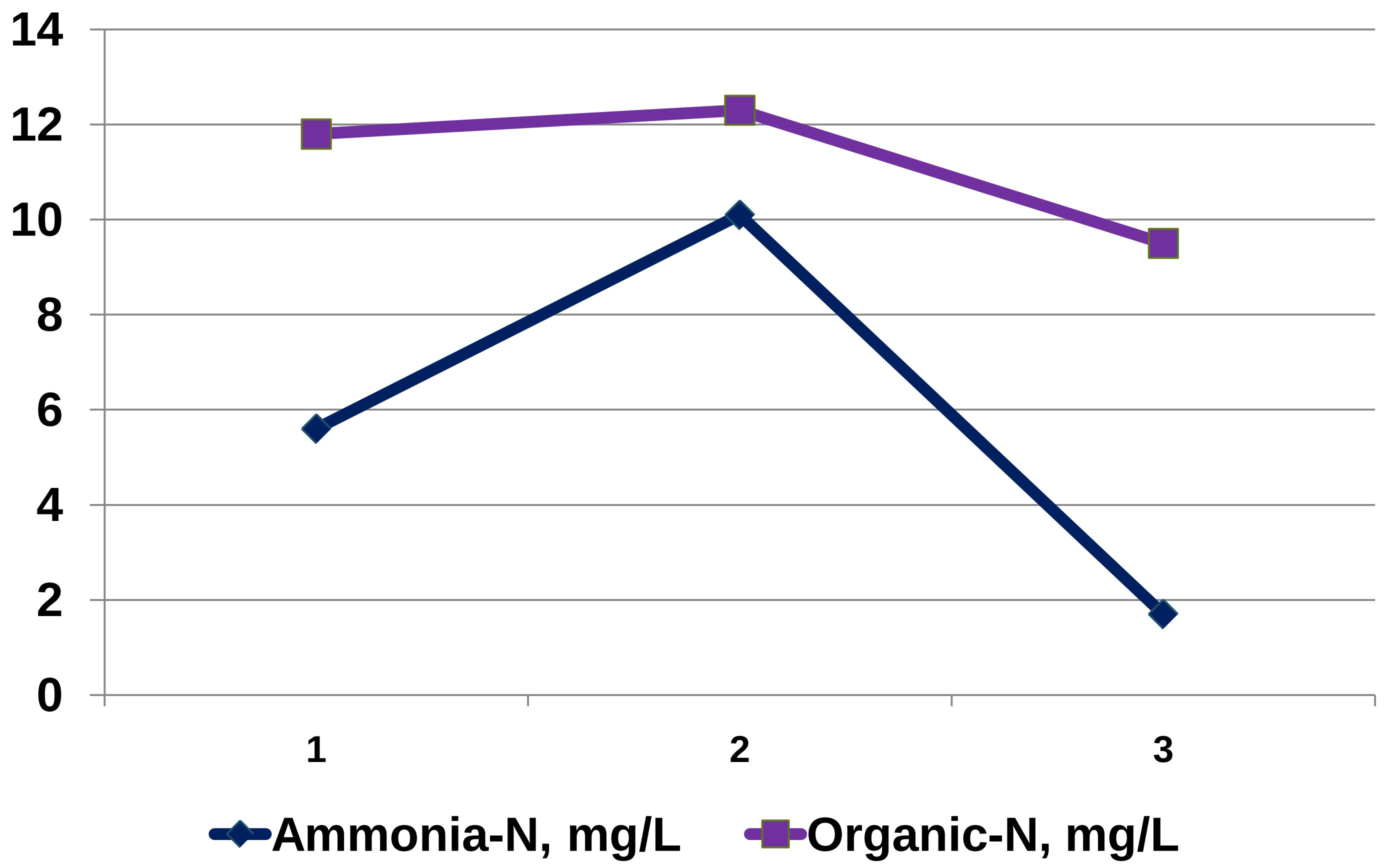
Sample 5a, 5, and 5b Locations

Sludge Accumulation in Channel

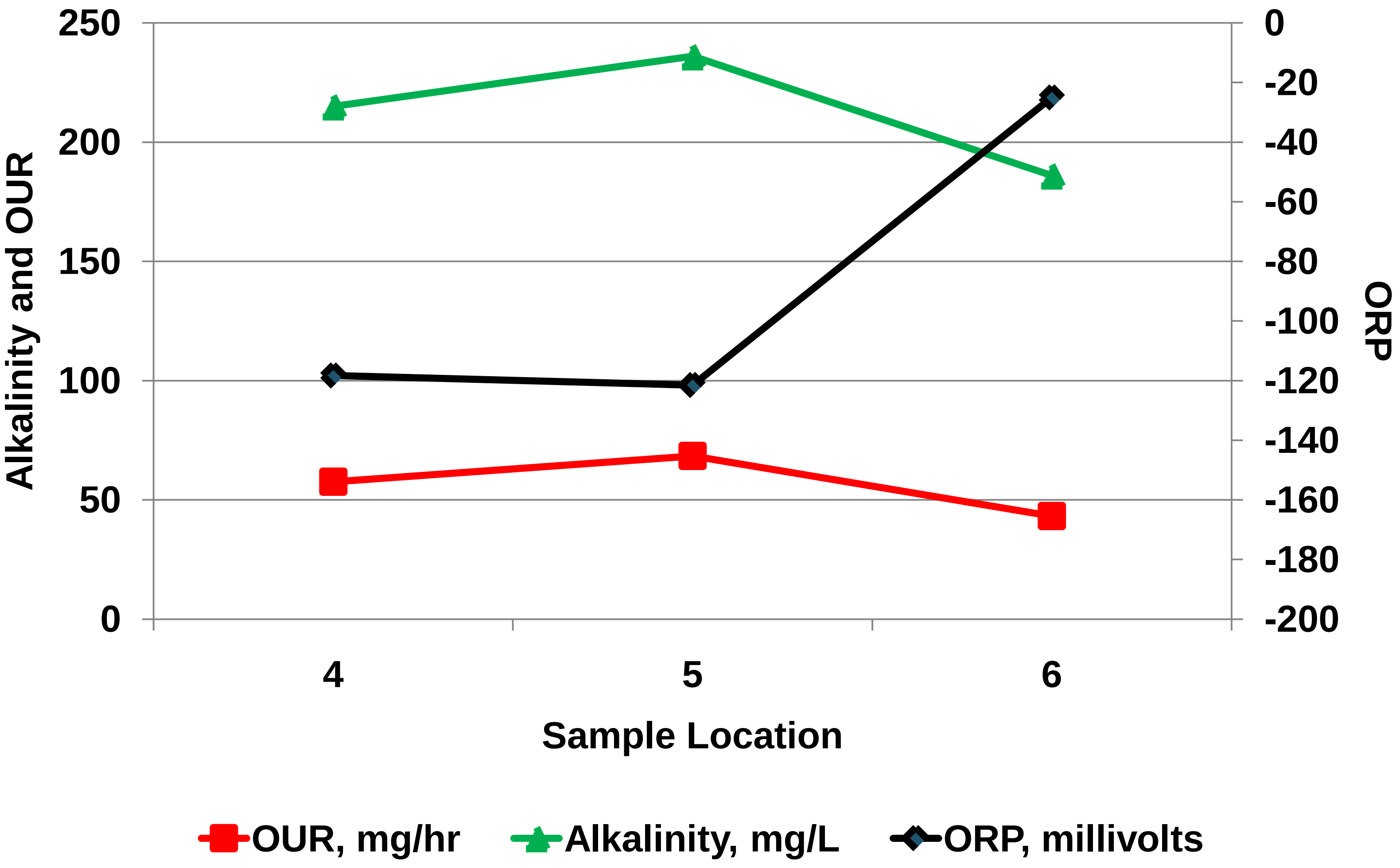
Channel Pre-Cleaning Results



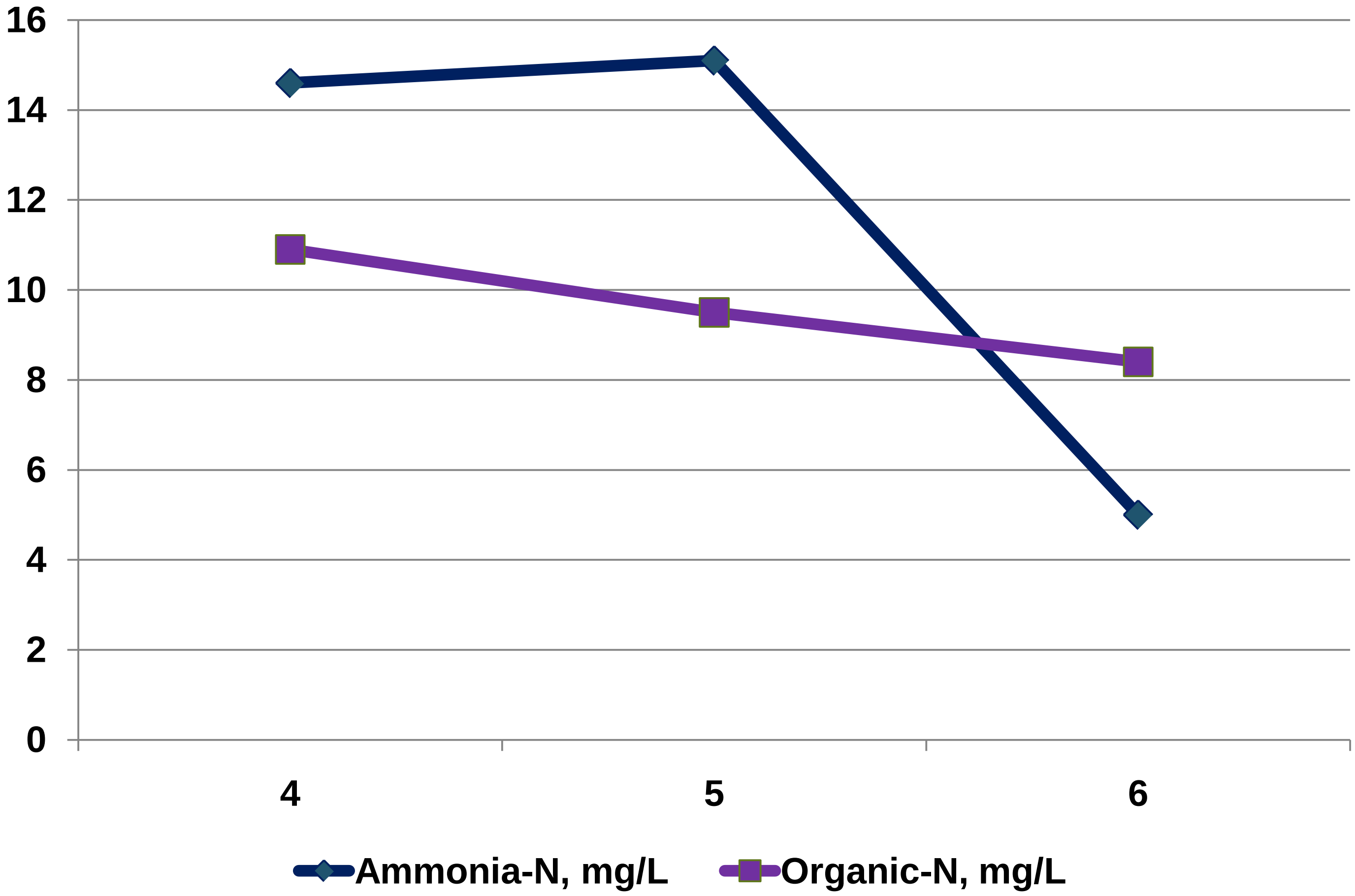
Channel Pre-Cleaning Results



Channel Post-Cleaning Results



Channel Post-Cleaning Results



Divider Wall Gap

Conclusions

- OUR was a good predictor of complete nitrification
- Alkalinity was a good predictor of complete nitrification
- ORP showed reasonable trend but is not as refined at predicting the endpoint of complete nitrification.
- ORP was the best indicator of the channel anomaly
- Both profiles showed complete nitrification occurred somewhere between sample location 5 and 6.
- Profiles like this could be used to refine the dissolved oxygen setpoint to achieve full nitrification closer to the end of the basin.
- The impact of the gap in the divider wall would not have been determined without conducting the profiles.