Evaluating the Possibility of Passively Treating a Heap Leach Pad Drain Solution

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Outline

- Project Goals
- Bench Scale Selection & Construction
- Bench Scale Operation
- Destruction of Nitrate
- Destruction of Cyanide
- Conclusions

Project Goals

- Existing plans for heap leach pad closure:
  - Include Chemical and Physical Stabilization;
  - Require large quantities of water; and
  - Typically exclude metals removal.
- Evaluate the potential to treat weak acid dissociable (WAD) cyanide and nitrate (NO_3) passively.
- Long term anaerobic biochemical treatment for draindown of residual solutions is a cost effective way to close a heap leach pad.

Project Goals

- WAD cyanide removal to 0.2 mg/L
- Total Nitrogen removal to 10 mg/L as N
- Establish removal efficiency and detention time
- Determine design parameters

Project Goals

- Previous Efforts
  - Mudder et al., 1985: Laboratory study;
  - Wildeman et al., 1994: Gold tailings pond; and
  - Wildeman et al., 2006: Spent cyanide solution.
- Previous Problems
  - Lack of understanding how cyanide is destroyed, and
  - Lack of understanding of destruction products.

Project Background

- Heap Leach Gold Mining
- Heap Leach Pad inactive
- Heap Leach pad contains cyanide as a metal complex

$$2\ Au^{-} + 4\ CN^{-} + O_2 + 2\ H_20 \rightarrow 2\ Au(CN)_2 + H_2O_2 + 2\ OH^{-}$$

Influent Water Quality

Parameter	Unit	Average
Alkalinity	mg/l as CaCO3	132.89
Gold [Au]	µg/L	81.99
Cyanide - Total [CN]	mg/l	5.07
Cyanide - WAD [CN]	mg/l	0.930
Iron [Fe]	mg/l	2.16
Ammonia [NH3-N]	mg/l	0.15
Nitrite [NO2-N]	mg/l as N	0.46
Nitrate [NO3-N]	mg/l as N	257.82
Cyanate [OCN]	mg/l	0.09
Ph [s.u.]	s.u.	8.08
Thiosulfate [S2O3]	mg/l	0.01
Tetrathionate [S4O6]	mg/l	0.01
Thiocyanate [SCN]	mg/l	0.27
Sulfate [SO4]	mg/l	1771.06
Total Dissolved Solids [TDS]	mg/l	5148.95

Proof of Principle

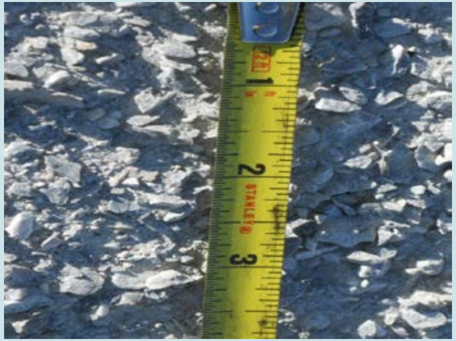
- Laboratory Bench Scale
- Passive bio-detoxification using anaerobic bacteria
- Three (3) alternatives evaluated using substrates local to the site
- Anaerobic vertical-flow passive reactors treat water though the substrate

Substrate Selection

- Organic Materials
  - Type
    - Coarse texture or grain size greater than 50 mm
    - Non Uniform Shape
  - Limestone
  - Potato Mash
  - Hay/Straw
  - Manure

Substrate Selection

Limestone



Hay / Straw

Potato Mash

Manure

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Substrate Selection

Substrate	BCR-1	BCR-2	BCR-3
Potato Mash & Skins	0.0%	0.0%	44.9%
Crushed Limestone	10.0%	10.0%	10.0%
Animal Manure	0.1%	0.1%	0.1%
Hay/Straw	89.9%	79.9%	45.0%
Plastic Spacers	0.0%	10.0%	0.0%
Total	100.0%	100.0%	100.0%
Logic	Baseline 1 Hay/Straw	Baseline 2 Hay/Straw + Spacers	Potato Mash & Skins

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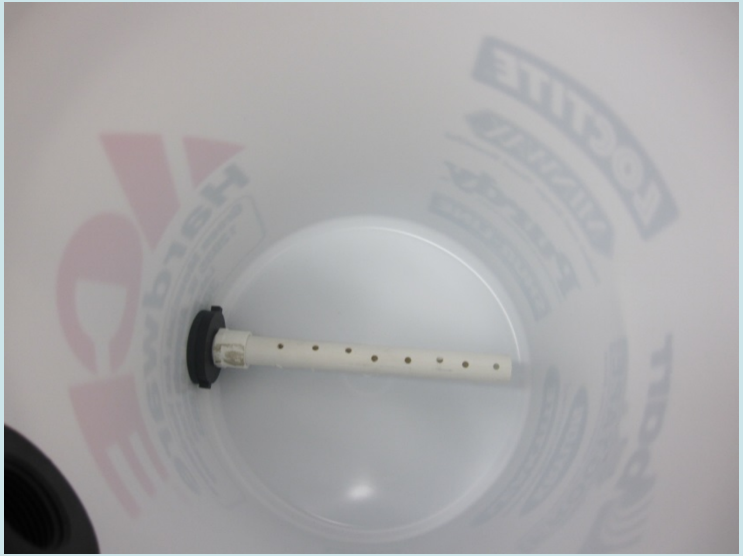
BCR Construction



BCR Construction

Homogeneous Substrate Mixture

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BCR Construction

BCR-2

BCR-3

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BCR Construction

BCR Construction

- Incubation Period
  - Stagnant
  - Allows microbes to acclimate and multiply in each cell prior to continuous flow.
- Pore Volume

Substrate	BCR-1	BCR-2	BCR-3
Pore Volume	13 L	13 L	12.5 L
Estimated Porosity	66%	66%	63%

BCR Operations

- BCR Inoculation
  - Nitrate reducing bacteria obtained from local municipal source
  - Incubation Period
- Test Conditions
  - Low Flow
  - Intermittent Flow
  - WAD Cyanide Spike

BCR Results

Parameter	Unit	Influent	BCR-1	BCR-2	BCR-3
Alkalinity	mg/l as CaCO3	132.89	1240.76	1217.81	1244.75
Gold [Au]	µg/L	81.99	9.18	5.50	7.88
Cyanide - Total [CN]	mg/l	5.07	2.59	2.37	2.00
Cyanide - WAD [CN]	mg/l	0.930	0.007	0.008	0.008
Iron [Fe]	mg/l	2.16	1.95	1.91	1.81
Ammonia [NH3-N]	mg/l	0.15	9.77	14.68	13.08
Nitrite [NO2-N]	mg/l as N	0.46	0.87	1.69	2.84
NItrate [NO3-N]	mg/l as N	257.82	0.36	0.44	0.53
Cyanate [OCN]	mg/l	0.09	0.06	0.06	0.06
Ph [s.u.]	s.u.	8.08	8.21	8.20	8.08
Thiosulfate [S2O3]	mg/l	0.01	0.85	3.00	4.95
Tetrathionate [S4O6]	mg/l	0.01	0.01	0.01	0.01
Thiocyanate [SCN]	mg/l	0.27	0.48	0.50	0.45
Sulfate [SO4]	mg/l	1771.06	1731.61	1712.67	1733.70
Total Dissolved Solids [TDS]	mg/l	5148.95	5226.47	4710.63	4746.25

BCR Results

Parameter	Unit	BCR-1	BCR-2	BCR-3
Alkalinity	mg/l as CaCO3	89.3%	89.1%	89.3%
Gold [Au]	µg/L	88.8%	93.3%	90.4%
Cyanide - Total [CN]	mg/l	48.9%	53.2%	60.5%
Cyanide - WAD [CN]	mg/l	99.2%	99.1%	99.2%
Iron [Fe]	mg/l	9.7%	11.3%	16.0%
Ammonia [NH3-N]	mg/l	98.5%	99.0%	98.9%
Nitrite [NO2-N]	mg/l as N	46.7%	72.6%	83.7%
NItrate [NO3-N]	mg/l as N	99.9%	99.8%	99.8%
Cyanate [OCN]	mg/l	33.3%	33.3%	33.3%
Ph [s.u.]	s.u.			
Thiosulfate [S2O3]	mg/l	98.8%	99.7%	99.8%
Tetrathionate [S4O6]	mg/l	influent = effluent = MDL		
Thiocyanate [SCN]	mg/l	43.9%	46.1%	40.1%
Sulfate [SO4]	mg/l	2.2%	3.3%	2.1%
Total Dissolved Solids [TDS]	mg/l	1.5%	8.5%	7.8%

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Summary

- No clear substrate winner based on analytical;
- Based on carbon consumption, the estimated lifetime of a BCR would be 10 – 25 years with BCR-1 lasting the longest; and
- Based on experience and cost;
  - BCR-1 is the best selection.

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Discussion of Results

Analysis of what happened to nitrate and cyanide

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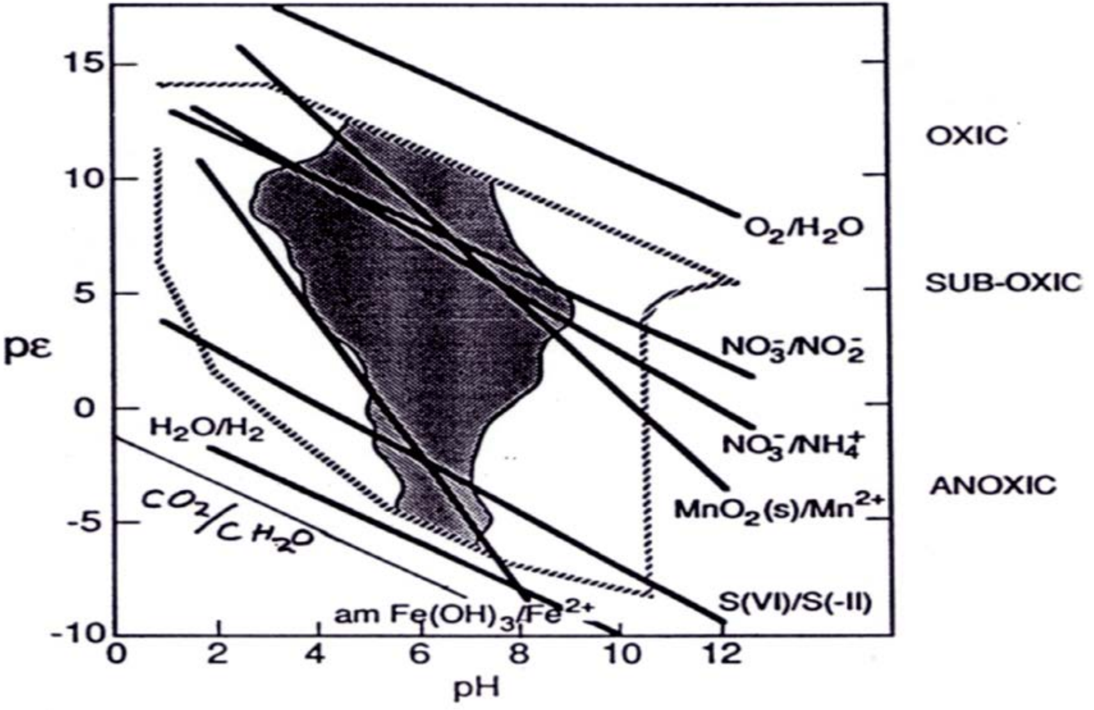
Removal of Nitrogen Species

- **Heap Leach Drain Down Solution (DDS)**
  - Nitrate as N (NO_3): 260 mg/L
  - Total Cyanide (Tot CN): 5.0 mg/L
  - WAD Cyanide (WAD CN): 0.93 mg/L

- **Treatment Goals**
  - WAD CN: 0.2 mg/L
  - Total Nitrogen Species: 10 mg/L as N

Anaerobic Microbial Activity



FROM: HERING & STUMM (1990), SPOSITO (1989), AND BAAS-BECKING, ET AL (1960)

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Denitrification Conditions

- Presence of microbial denitrifiers
- Anaerobic conditions
- Nitrate reducing electron donor

$$4\ NO_3^- + 5\ \text{“}CH_2O\text{”} + 4\ H^+ \rightarrow 2\ N_2\ g + 5\ CO_2\ g + 7\ H_2O$$

Ammonia Complications

- **Microbes like NO_3^- for general cell growth**

$$4\,NO_3^- + 5\,\text{“}CH_2O\text{”} \xrightarrow{\text{metabolism}} NH_3 + \text{“Cells”}$$

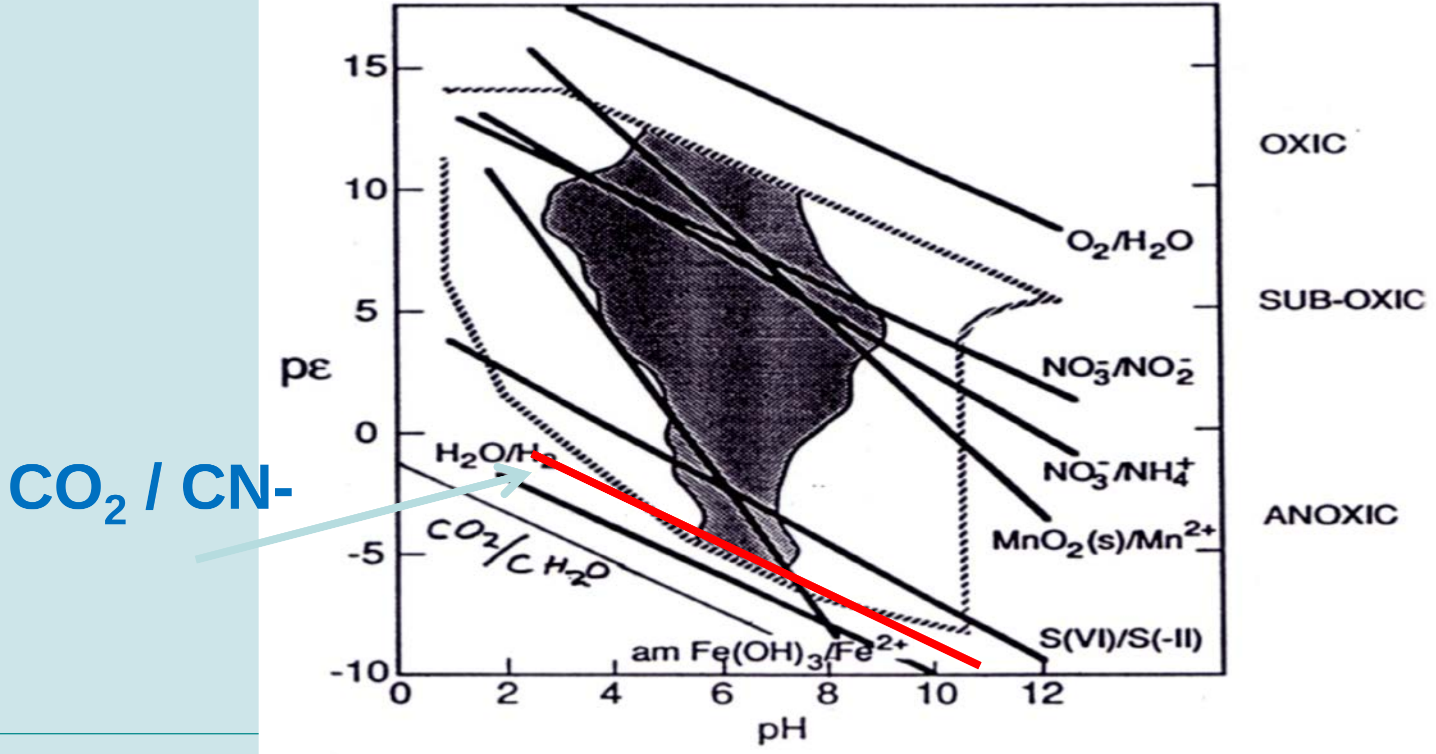
- **Consequences:**
  - Could have build-up of gelatinous material.
  - Production of NH_3 makes another constituent of concern
  - Will use more organic matter than denitrification reaction suggests

What are Denitrification Kinetics

- **Kadlec & Knight (1995) suggest denitrification in wetlands has a half life of 1 – 3 days**
  - 250 mg/L to 10 mg/L takes 5 half lives.
  - So, consider a retention time of 5- 15 days

One review said there are good references to denitrification kinetics in agricultural journals .

Anaerobic Microbial Activity



FROM: HERING & STUMM (1990), SPOSITO (1989), AND BAAS-BECKING, ET AL (1960)

Cyanide Destruction

- **Cyanide Destruction**
  - Has been successfully treated in sulfate-reducing bioreactors

- **Previous Problems**
  - Lack of understanding how cyanide is destroyed, and
  - Lack of understanding of destruction products.

Cyanide Species Methods & DLs

Constituent	Analytical Method	DL (mg/L)
Free CN	Flow Injection Amperometric	0.005
WAD CN	Flow Injection Amperometric	0.002
Total CN	Flow Injection Amperometric	0.002
OCN^-	Ion Chromatography	1.0
SCN^-	Ion Chromatography	0.02
S_2O_3	Ion Chromatography	1.0
NO_3^- as N	Ion Chromatography	0.02
NO_2^- as N	Ion Chromatography	0.002
NH_3 as N	Colorimetric	0.01

Nitrate Results

Species	Units	Initial	BCR-1	BCR-2	BCR-3
NItrate [NO_3-N]	mg/l as N	259.	0.31	0.46	0.30
Nitrite [NO_2-N]	mg/l as N	0.12	1.41	2.51	4.0
Ammonia [NH_3-N]	mg/l as N	0.11	10.6	14.7	11.2
Ammonia [NH_3-N] [a]	mg/l as N	0.14	6.31	6.38	10.91

a. NH_3 omitting week 12

Nitrate Conclusions

- NO_3^- / $N0_2^-$ destroyed
- Not as much NH_3 buildup in the anaerobic cells as in treatment wetlands or in active water treatment.
- Skins appear to generate the most NH_3

Interlude on aging of cyanide containing tailings slurries 8 month anoxic study

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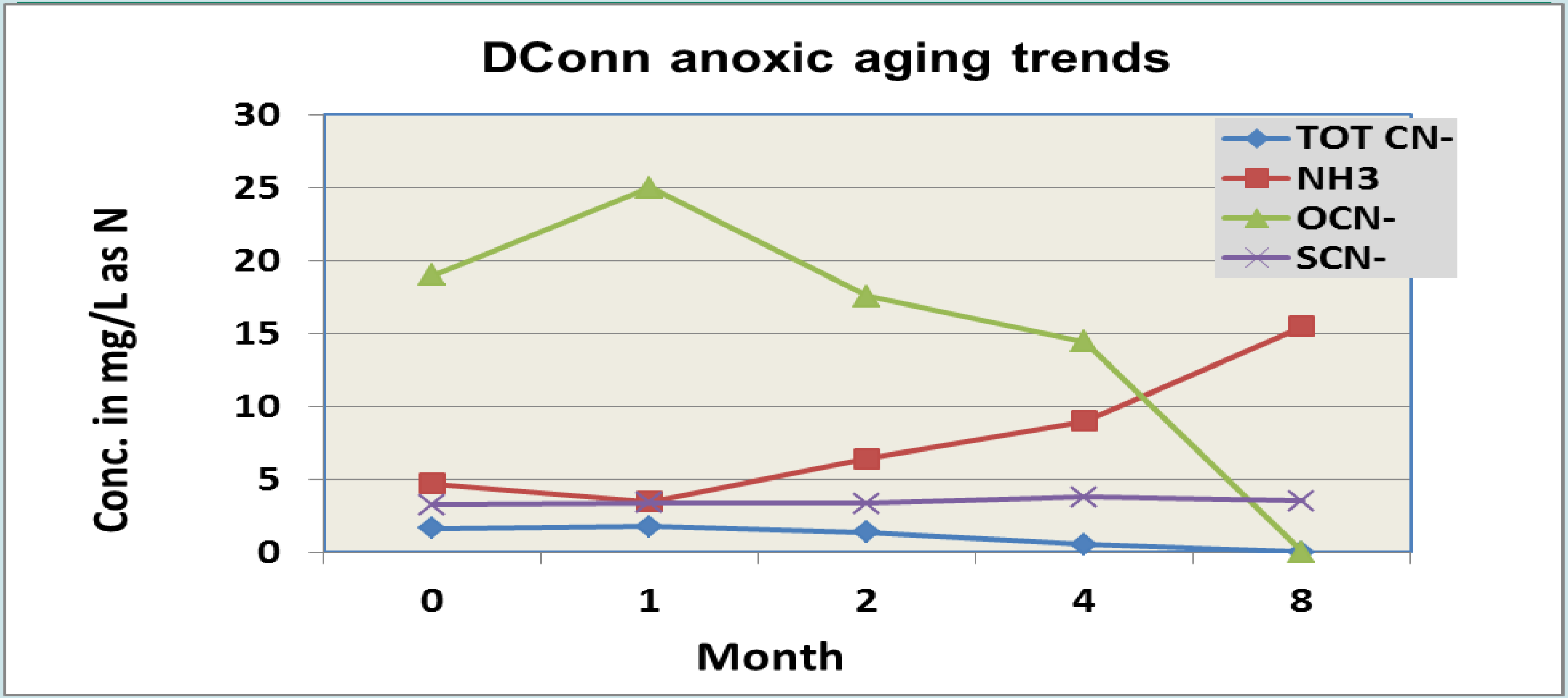
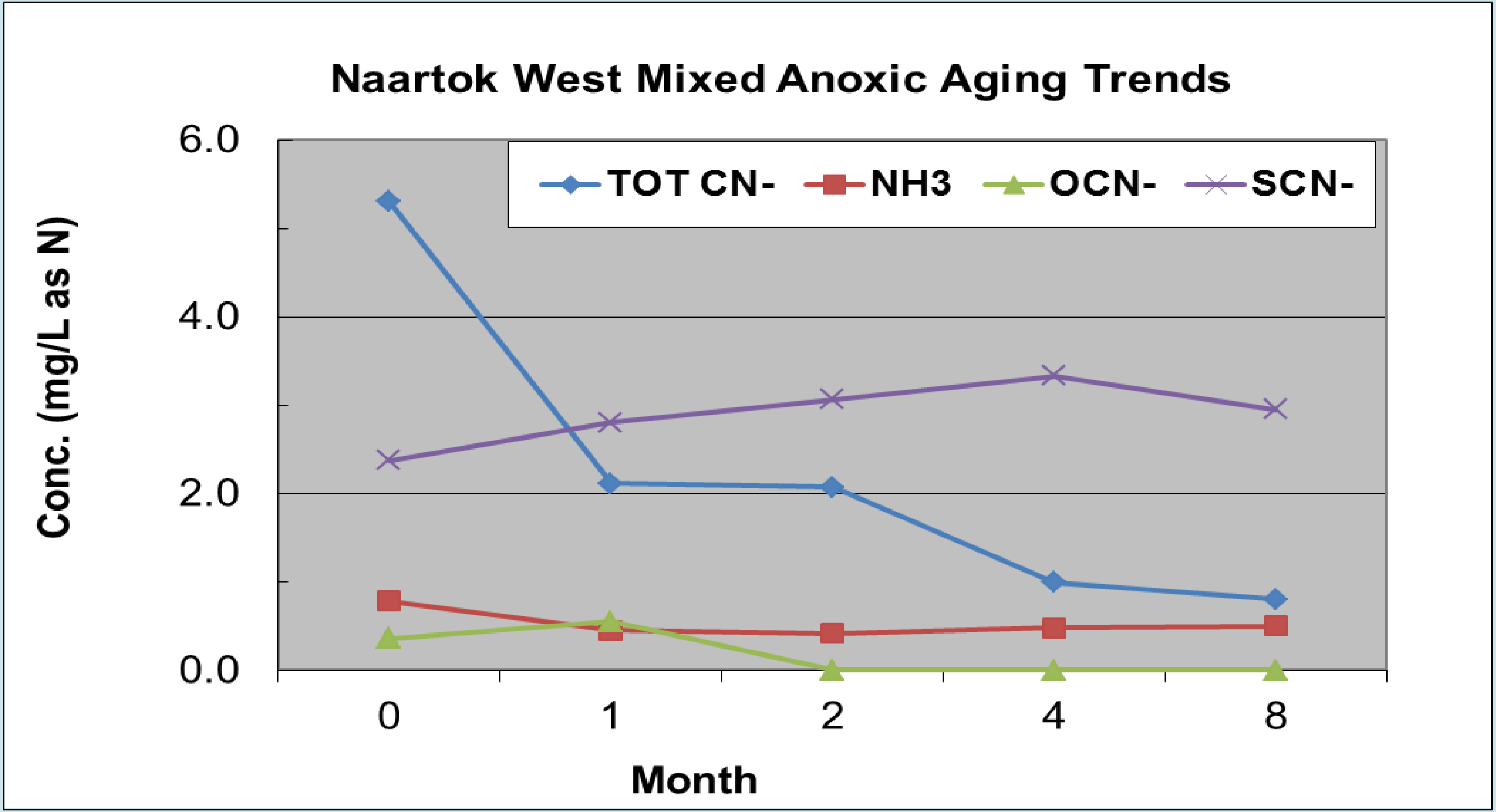
Anoxic Aging Protocol

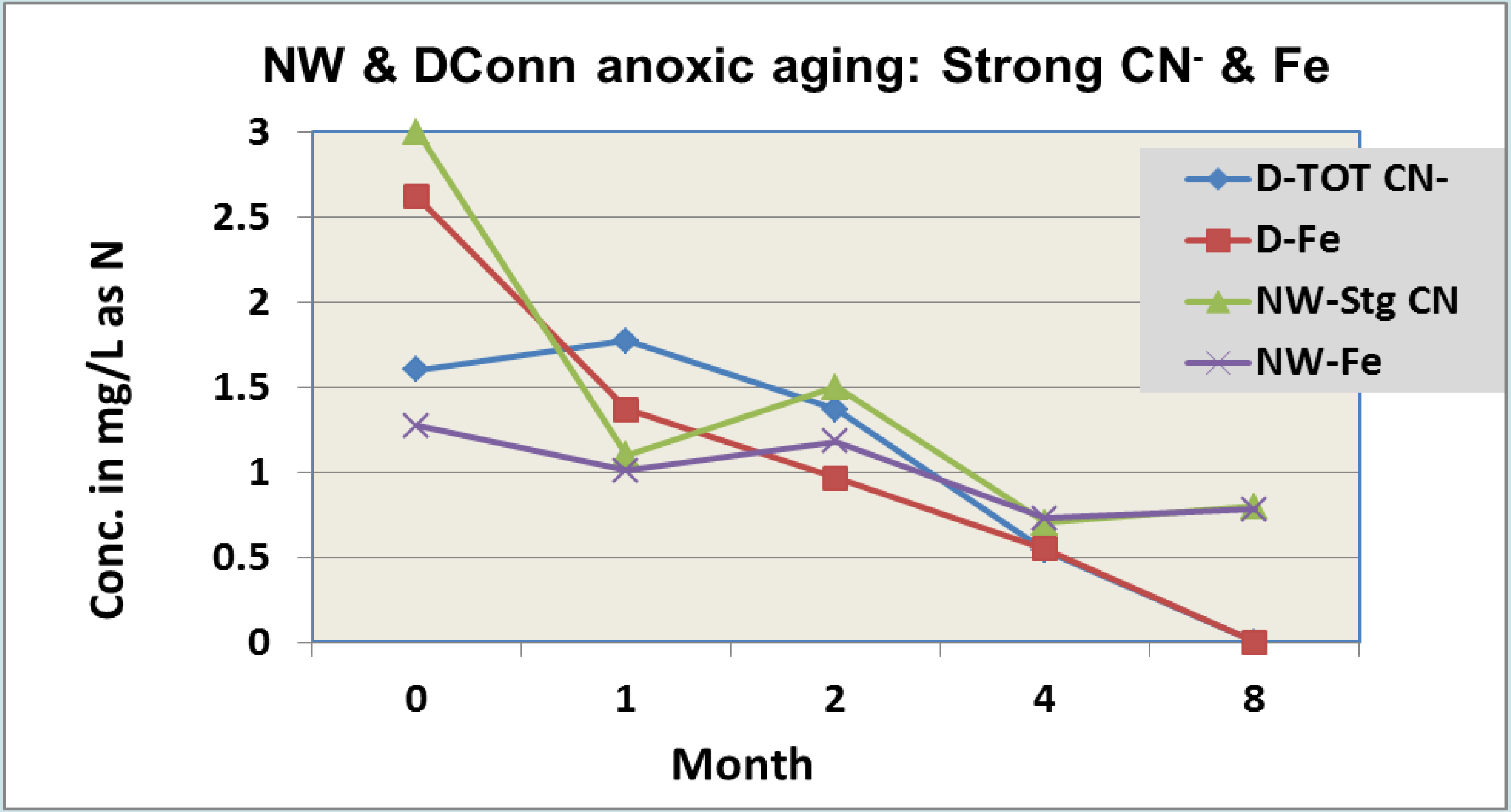
- **Anoxic samples were sparged with N_2 after splitting**
- **Samples then prepared in N_2 purged glove bags for storage.**
  - Samples placed in vapor barrier bags with oxygen absorbers & oxygen indicators.
  - Samples stored in continuously N_2 purged glove bags in a refrigerator
- **Samples processed for analysis in N_2 purged glove bag through analytical preservation step.**

Anoxic Preparation in Vapor Barrier Bag



$$OCN^- + 3\,H^+ + HCO_3^- \rightarrow NH_4^+ + 2\,CO_2$$


Naartok West Mixed Anoxic Aging Trends
TOT CN-
NH3
OCN-
SCN-
6.0
4.0
2.0
0.0
Conc. (mg/L as N)
0
1
2
4
8
Month


NW & DConn anoxic aging: Strong CN- & Fe
3
2.5
2
1.5
1
0.5
0
Conc. in mg/L as N
0
1
2
4
8
Month
D-TOT CN-
D-Fe
NW-Stg CN
NW-Fe

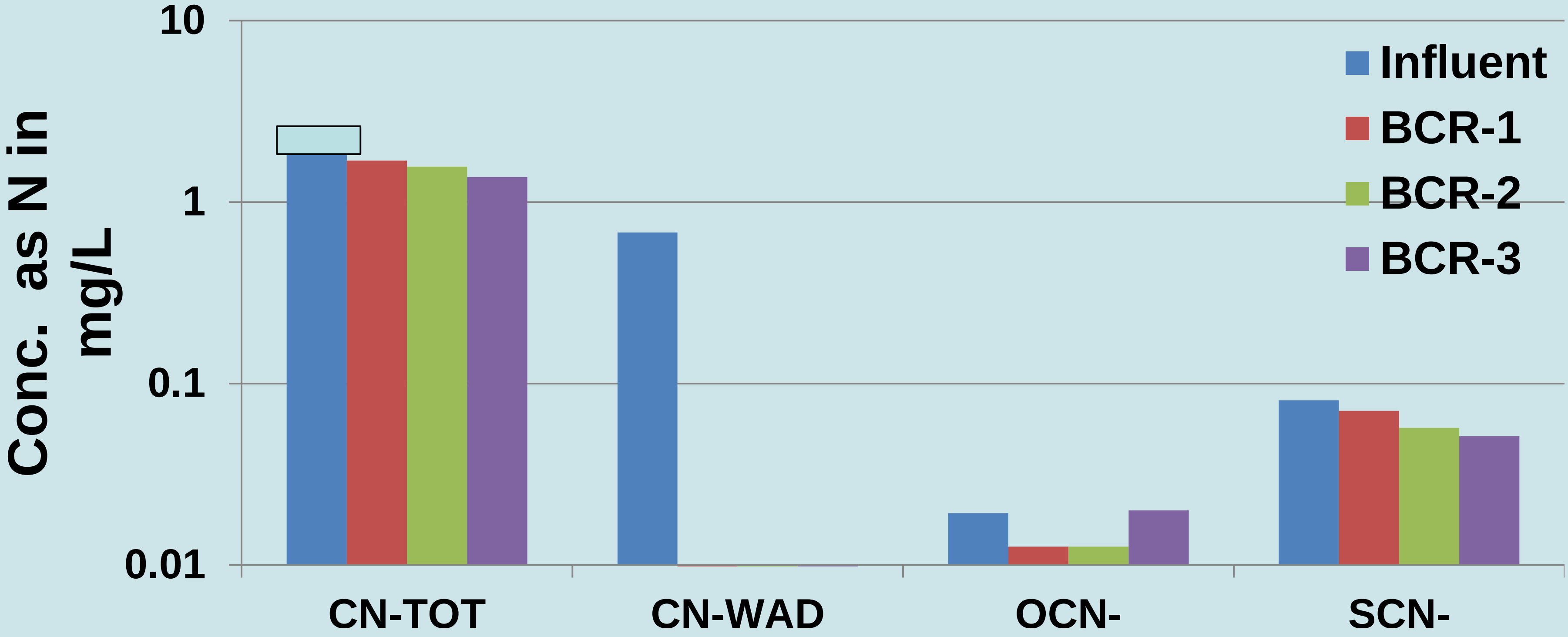
What will happen…

in 20 day anaerobic reactor

in comparison with

an 8 month anoxic aging study?

Cyanide Species: 12 week average



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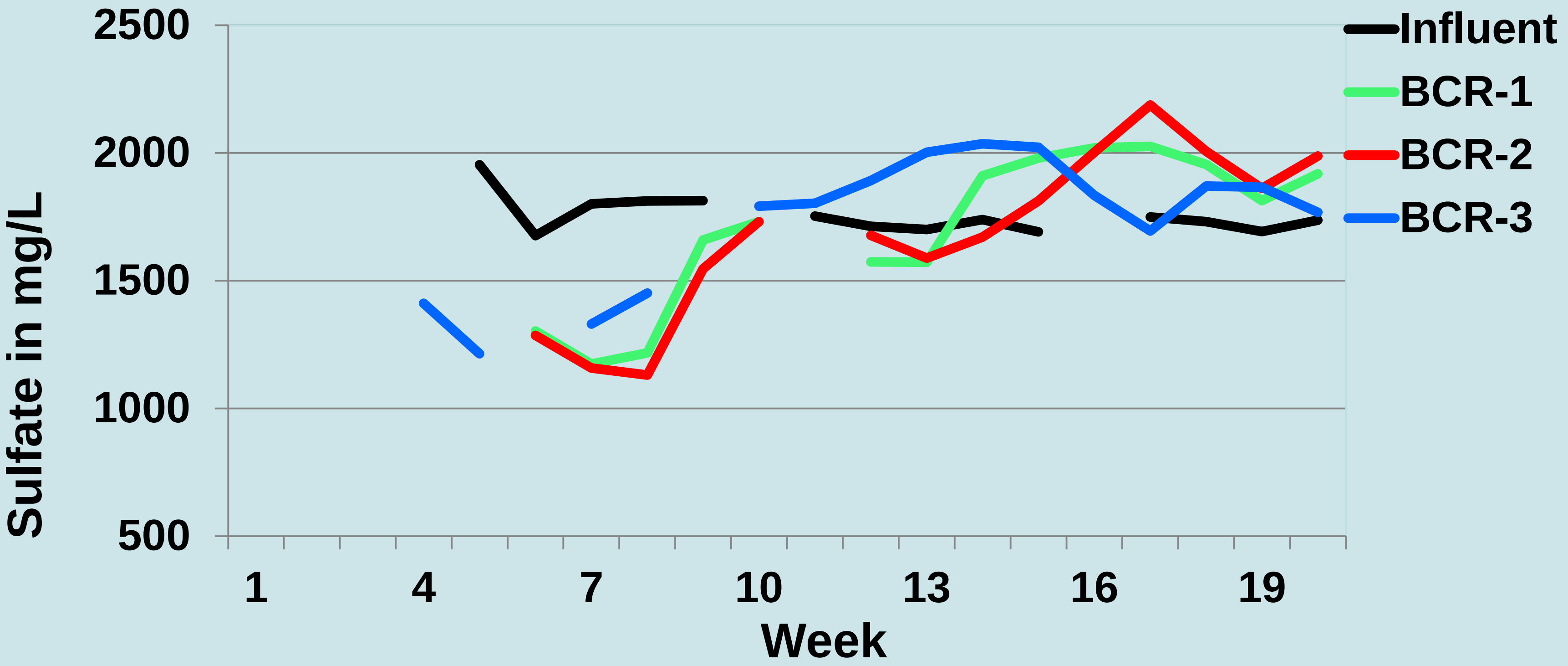
Sulfate Reduction



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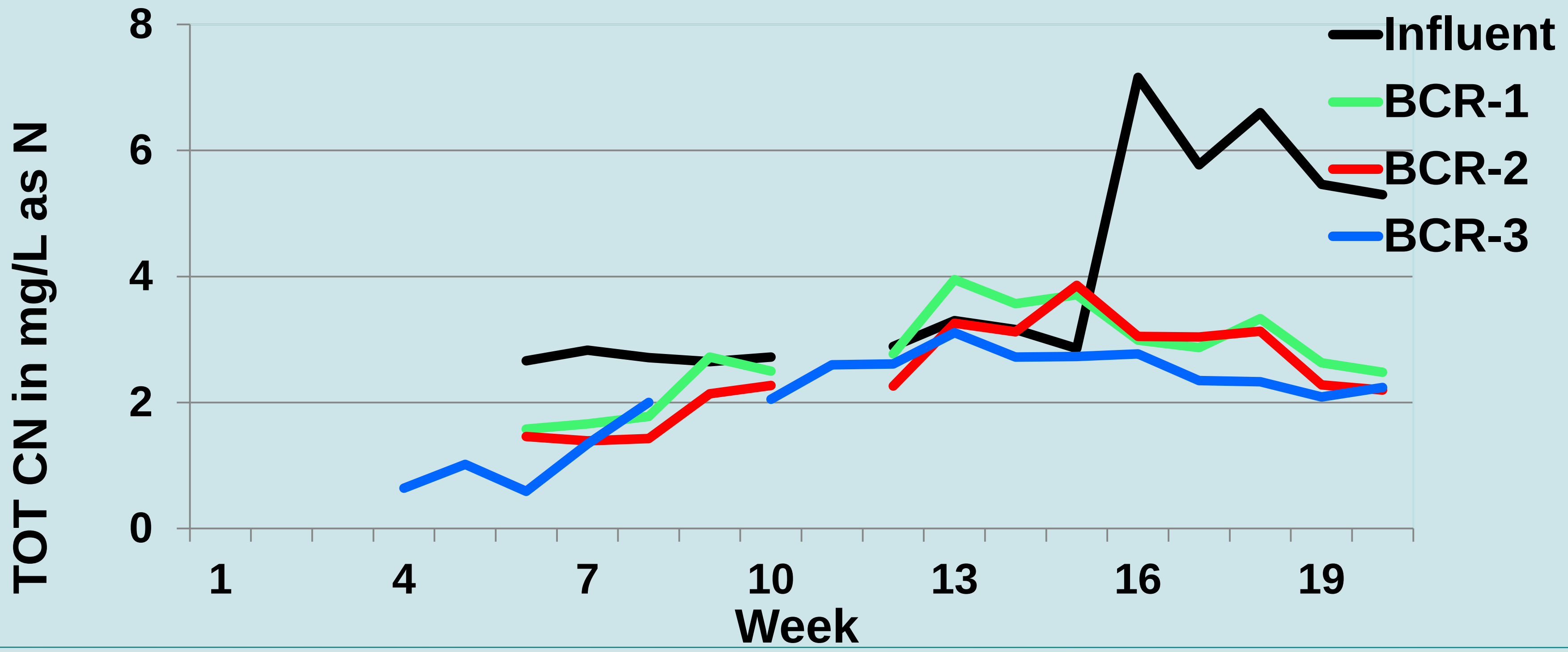
Total CN



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Cyanide Conclusions

- WAD CN is destroyed;
- Total CN is not completely destroyed;
- OCN^- is destroyed probably to NH_3;
- SCN- is mostly unchanged;
- Strongly complexed CN appears to be best destroyed when sulfate reduction is vigorous; and
- Products of CN destruction are unknown.

Overall Conclusions

- Denitrification is possible;
- Ammonia buildup is within limits;
- WAD CN is destroyed;
- Strongly complexed CN is only partially destroyed. Vigorous sulfate reduction helps;
- Products of CN destruction are unknown.

Thanks to Newmont for this Study

- Newmont Metallurgical Services, Englewood CO