Biochemical Reactors for Selenium Treatment




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CH2MHILL®

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Albuquerque, New Mexico
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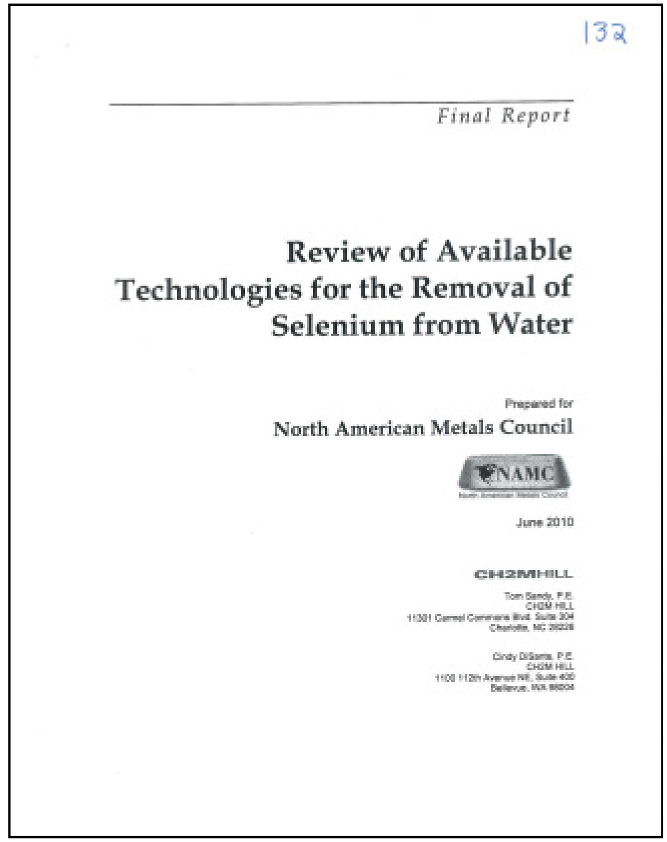
Overview of Presentation

Outline

- Selenium Transformations, Wetland Examples
- Selected Recent Pilot Systems
- New Full Scale System Detailed review
- O&M Overview
- Constraints Review
- Summary

NAMC Selenium Report 2010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Final Report

Review of Available Technologies for the Removal of Selenium from Water

Prepared for
North American Metals Council

June 2010

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http://www.namc.org/docs/00062756.PDF

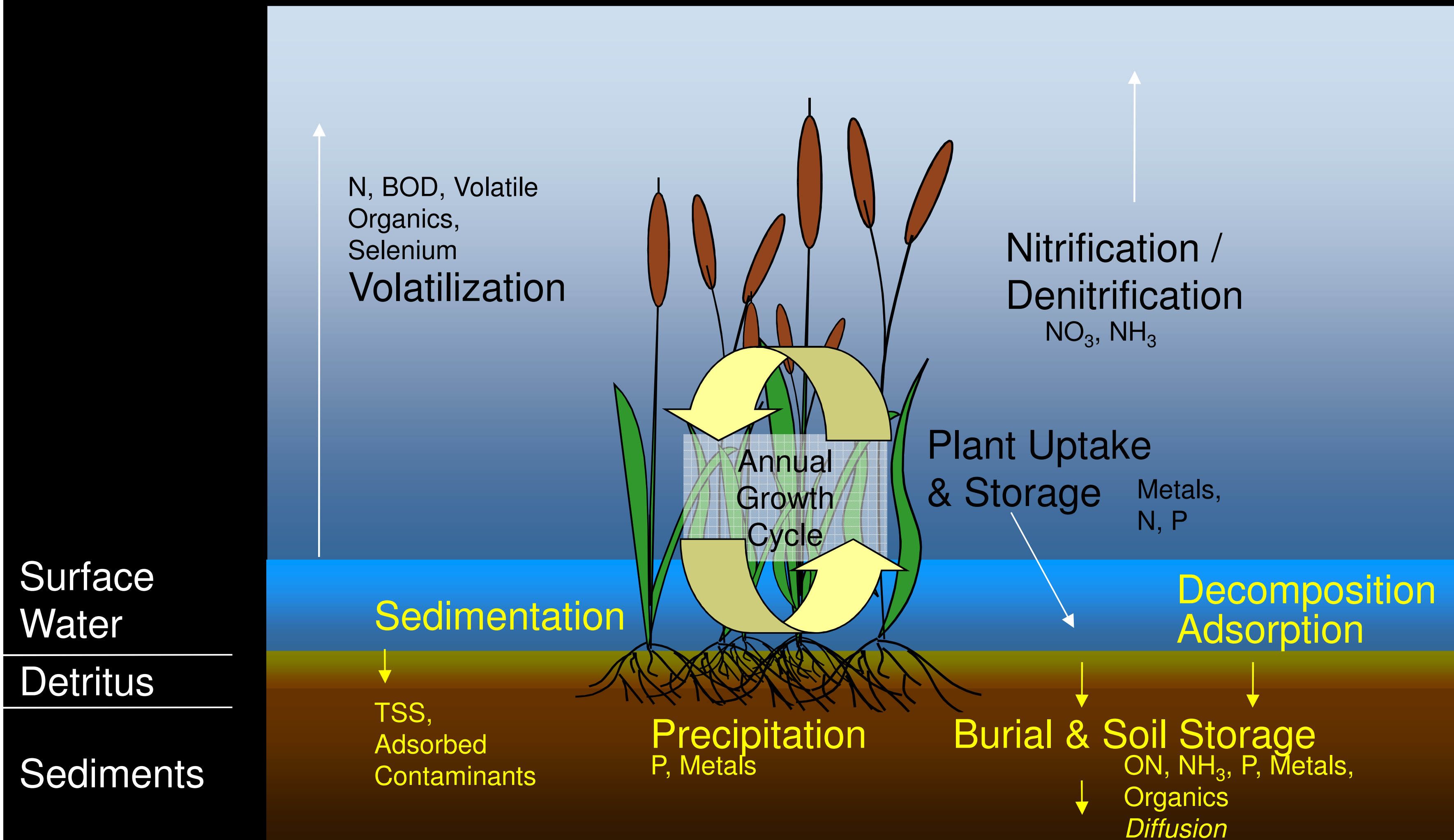
Selenium Passive Treatment Systems: Free Water Surface Wetlands Provide Starting Point

Chevron's Water Enhancement Wetland, Richmond CA

Hansen et al, 1998

- Area: 36 ha
- Flow: ~6,540 m^3/d
- Date: since 1991
- HRT: 7-10 days
- Se reduction: 89%
- Se in: 20-30 µg/L
- Se out: <5 µg/L
- Volatilization: 10-30%

Treatment Wetlands: Multiple Processes, Multiple Scales



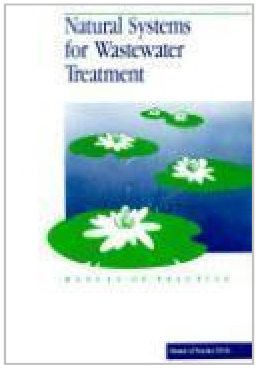
Natural Oxidation/Reduction Processes in Flooded Organic Soils

- Aerobic respiration
  - ½ $O_2 + 2e^- + 2H^+ \rightarrow H_2O$
- Denitrification
  - $2NO_3^- + 12\ H^+ + 10e^- \rightarrow N_2 + 6H_2O$
- Manganese reduction:
  - $MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$
- Iron reduction:
  - $Fe(OH)_3 + 3\ H^+ + 2e^- \rightarrow Fe^{2+} + 2H_2O$
- Sulfate reduction:
  - $SO_4^{2-} + 10H^+ + 8e^- \rightarrow H_2S + 4H_2O$
- Methane production:
  - $CO_2 + 8\ H^+ + 8e^- \rightarrow CH_4 + 2\ H_2O$

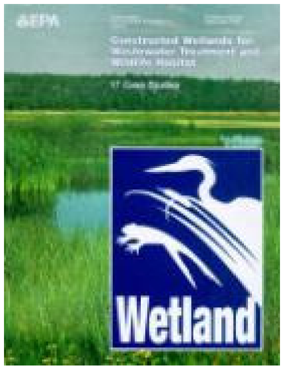
Process	Eh (mV)
Aerobic respiration	+330
Denitrification	+220
Manganese reduction	+200
Ferric to ferrous reduction	+120
Sulfate reduction	-150
Methanogenesis	-250

Organic carbon substrate provides electrons via microbial process

Progress in Design of Treatment Wetlands and Passive Systems



1989

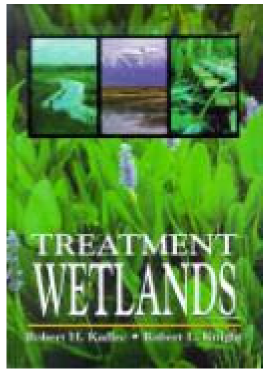


1993

Hedin, R.S., R.W. Nairn, and R. Kleinmann.

Passive treatment of coal mine drainage.

USBM 9389



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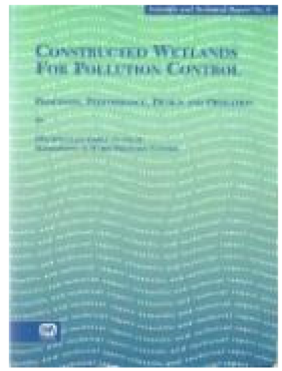

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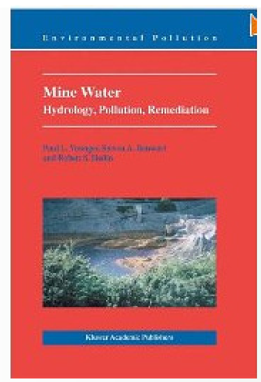
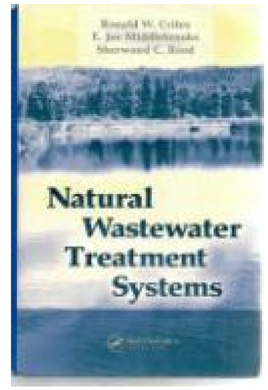
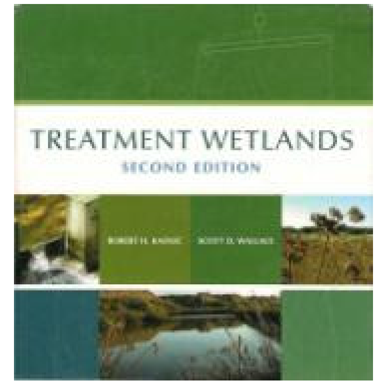




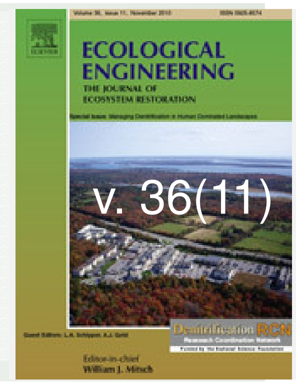
2006

ASMR

IMWA



2009



v. 36(11)

1990 2000 2010

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Biochemical Reactors - Definitions

ITRC 2013

- *…engineered treatment system that uses an organic substrate to drive microbial and chemical reactions to reduce concentration of metals, acidity, and sulfate in mine-impacted water.*

Pulles 2009

- *A water treatment system that utilizes naturally available energy sources such as topographical gradient, microbial metabolic energy, photosynthesis and chemical energy and requires regular but infrequent maintenance to operate successfully over its design life.*

Biochemical Reactors – Sustainable Treatment Through Naturally Renewable Components

- Wood
  - Chips, sawdust
- Grass
  - Hay
- Wetland Plants
  - Bulrush, cattail
- Manure and Soil
- Natural Power
  - Gravity
  - Solar

Progress in Biorechemical Reactor Design

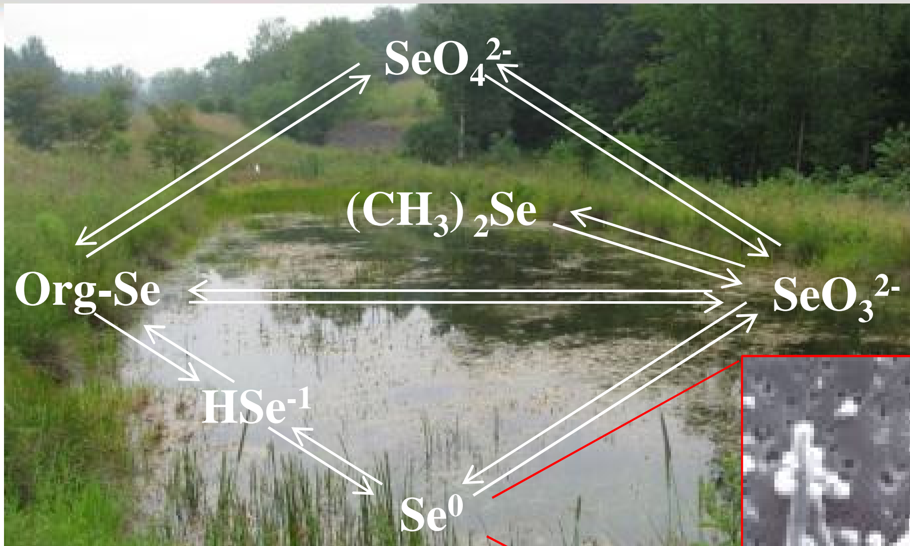
www.sdcornblog.com

Denitrifying Bioreactors for Agricultural Wastewater Treatment

Bob Nairn

www.nps.gov

Wetland Processing and Storage of Selenium



Dissimilatory Reduction

$SeO_4^{2-} \rightarrow SeO_3^{2-} \rightarrow Se^0 \rightarrow Se^{2-}$

- Distribution in wetland sediments:
  - 0:13:41:46
- 89-92% reduction from selenate to elemental Se in 10 - 16 days

Precipitation

- Abiotic precipitation with S^-

Volatilization

- Organic + $SeO_3^{2-} \rightarrow (CH_3)_2Se$
- Volatilized from plant tissues
- 5-30% cumulative loss from sediments and plants

Sorption

- Selenite sorbs to sediments and soil constituents: Fe^-, Mn^- or Al^- oxyhydroxides and organic matter

Plant Uptake

- Rapid uptake
- Tissue concentrations increase but not detrimental
- No long term storage in plants; Se transferred to sediments

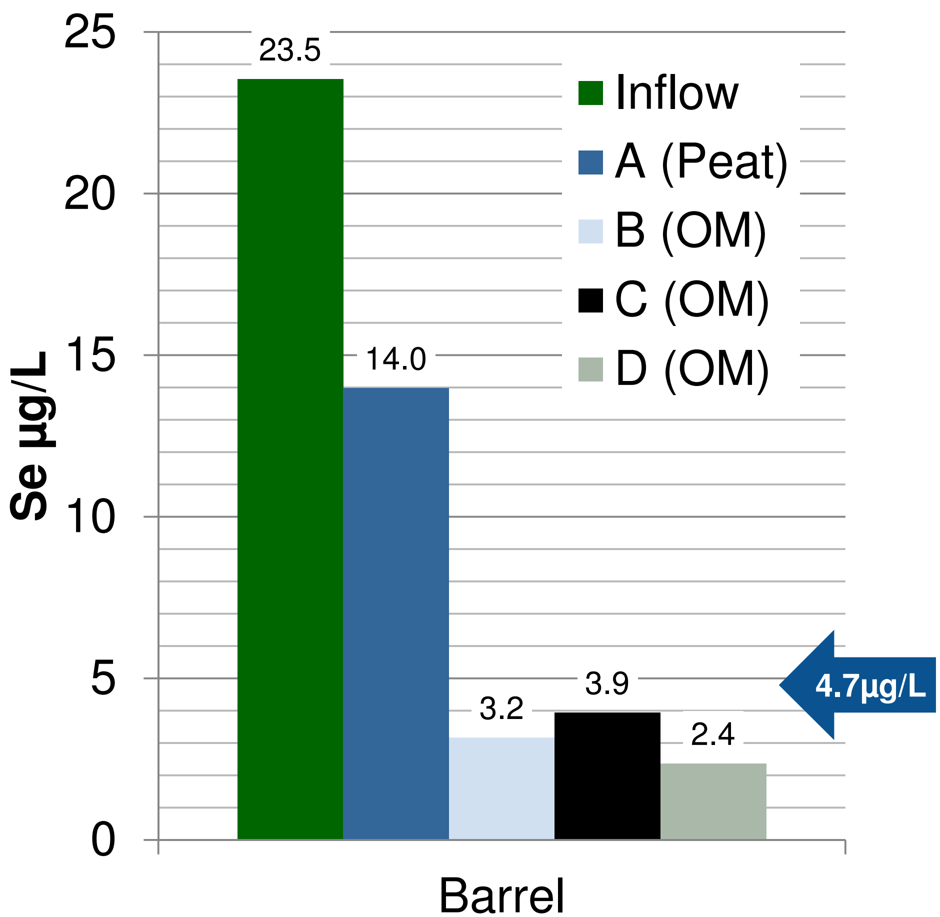
BCR Example: Anaerobic "Bioreactor" Wetland Demonstration Showed High Efficiency in Minimal Area

■ Source:	gravel pit seep
■ Volume:	4,380 ft^3
■ Flow:	2-24 gpm
■ Date:	9/08-10/09
■ HRT:	2.4 d
■ Se in flow	1-34 µg/L
■ Se reduction:	98% (90% winter)
■ Se removal rate:	16 $mg/d/m^3$
■ Se out:	0.5 µg/L
■ TCLP	<1 µg/L Se

Walker and Golder. 2010. US Bureau of Reclamation

Recent SeBCR Case Histories: Pilot and Full-Scale Passive Treatment in West Virginia

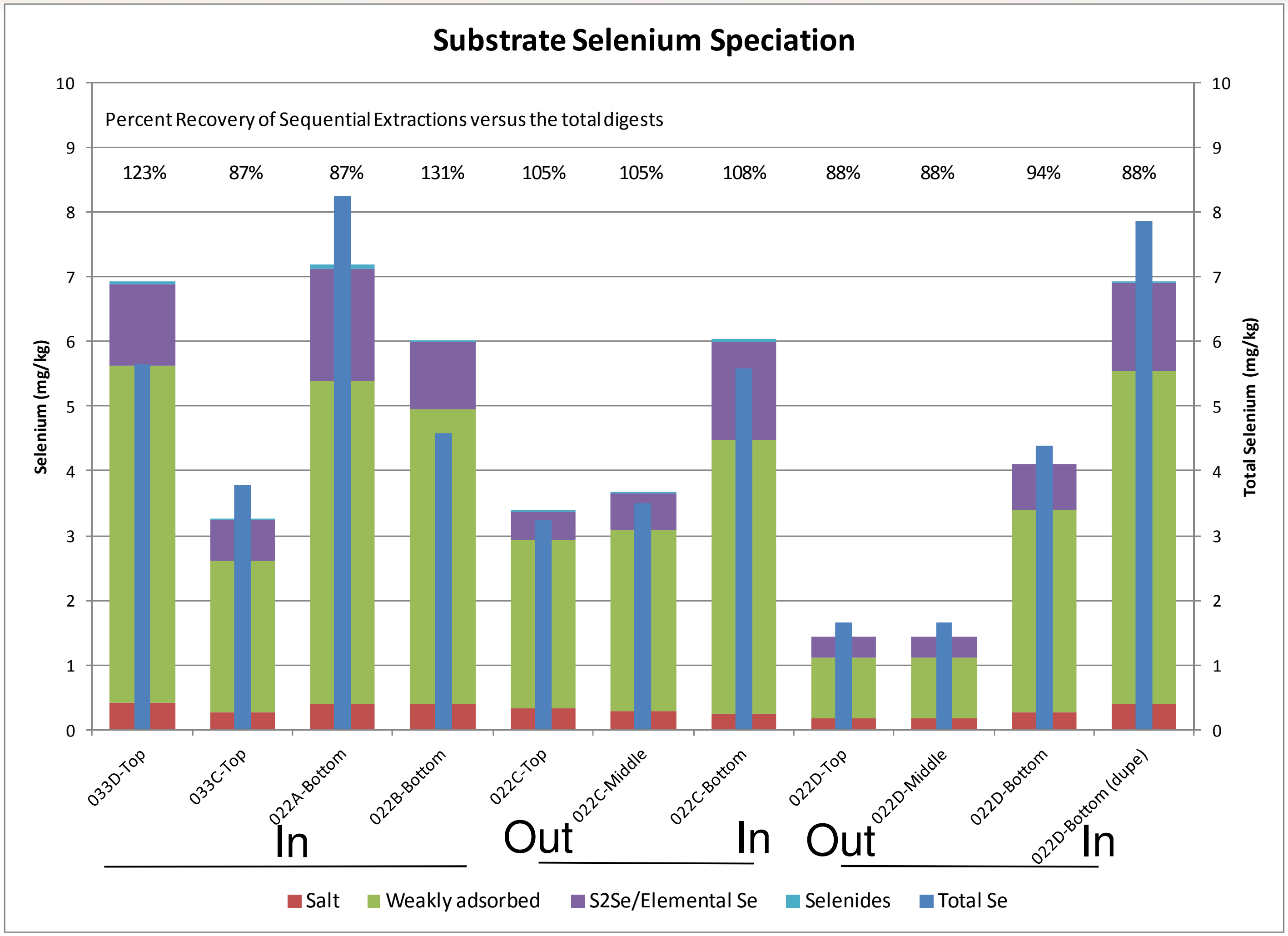
Pilot Study Demonstrated Target Compliance By Media Bioreactors



Upflow Media Bioreactors (200 L)

Material	Pilot Barrel			
	A	B	C	D
Woodchips	--	20%	16%	20%
Sawdust	--	20%	47%	30%
Hay	--	15%	16%	20%
Organic Peat	--	20%	--	--
Sphagnum Moss	100%	20%	--	--
Composted Manure	--	--	15%	23%
Limestone Chips	--	5%	6%	7%
Total (by volume)	100%	100%	100%	100%

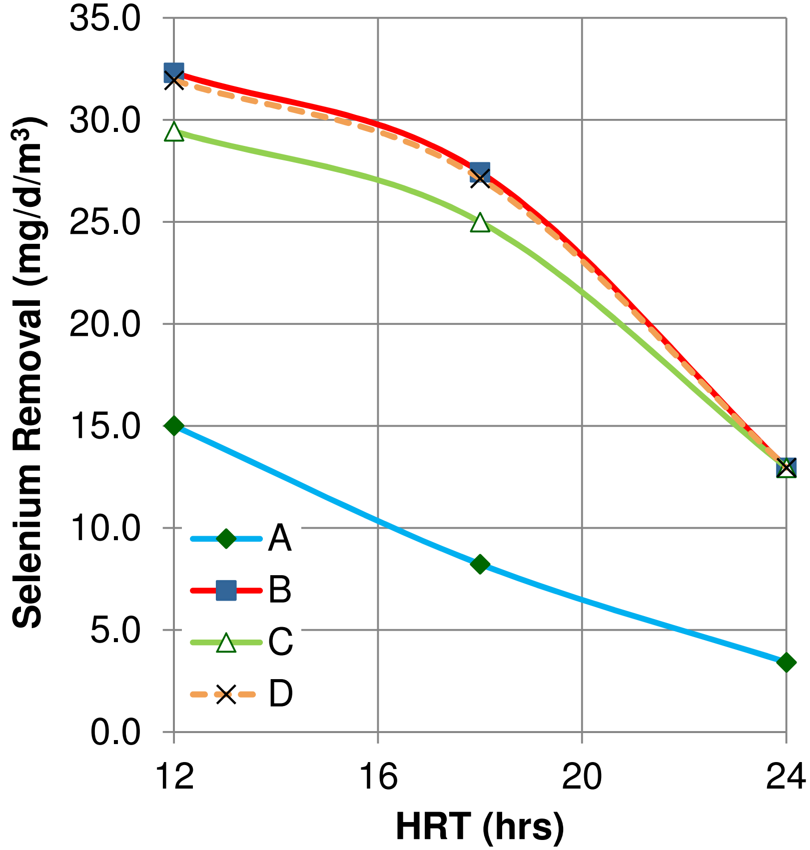
Vertical Distribution and Speciation of Selenium: Reduction, Sorption, Volatilization



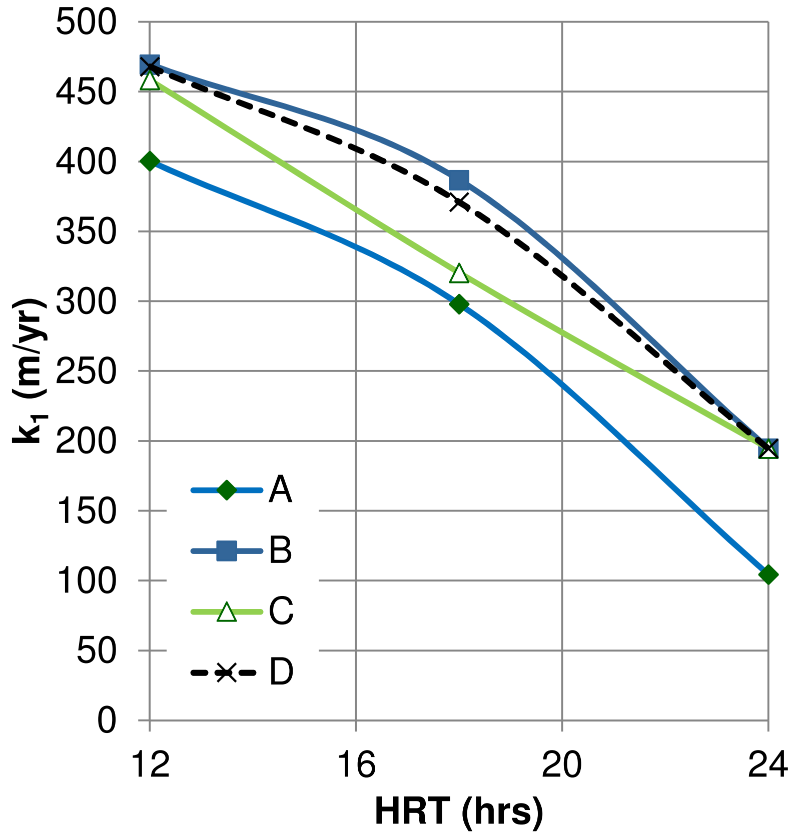
Source:
CH2MHILL (2012)

Removal Rates Estimated Based on HRT

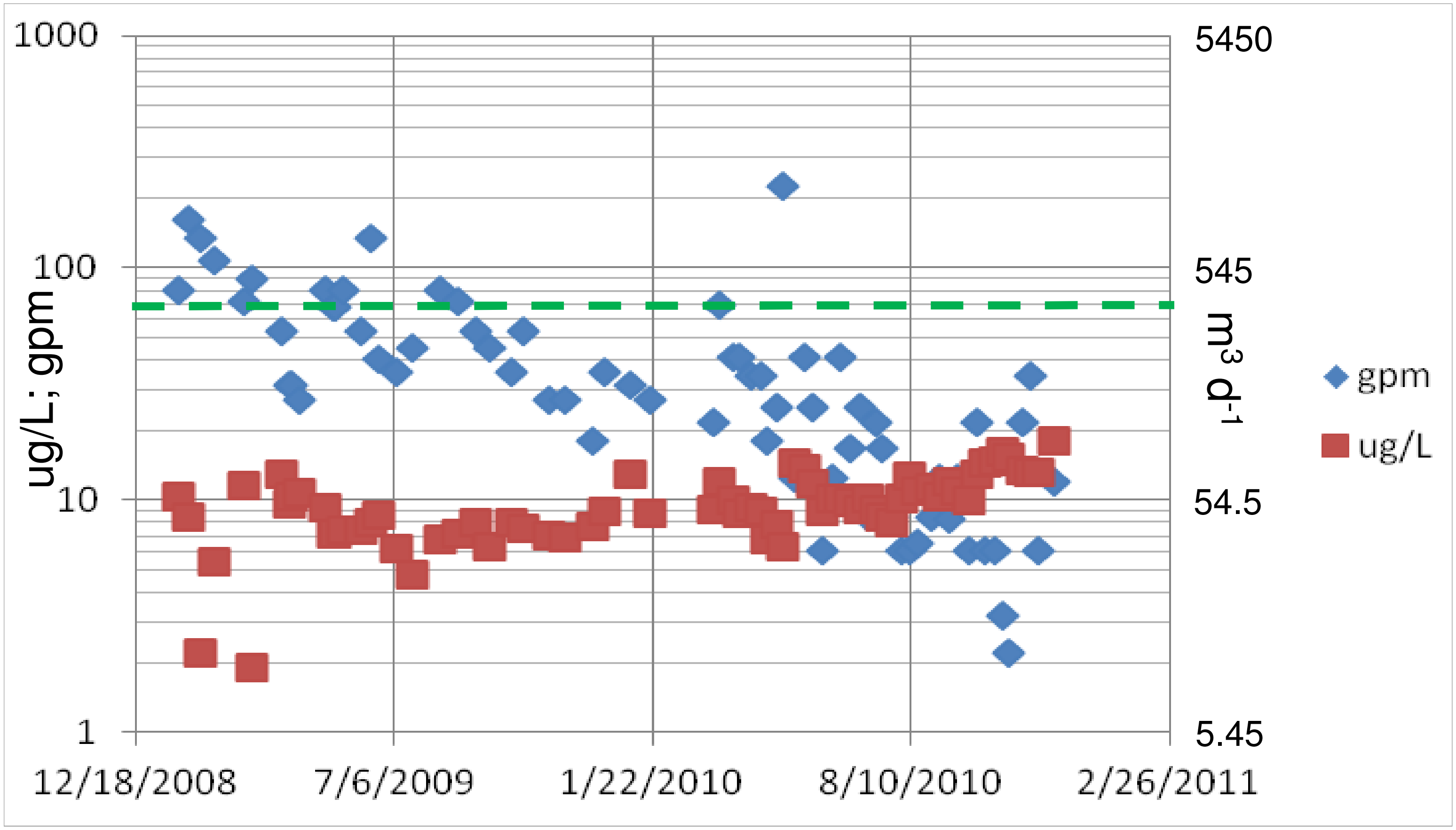
Zero-order volumetric



First-order area-based

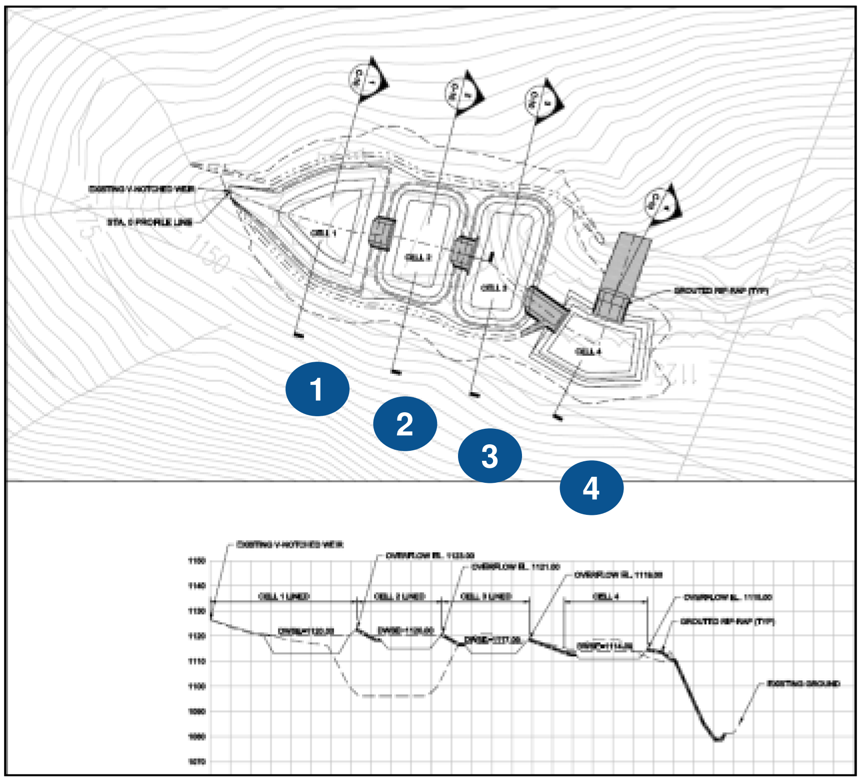


PTS 2: Design Flow Set to Capture Load and Account for Inter-annual Variation



Full-scale System Designed Based on Pilot Results: Gravity Flow and Sequential Process

PTS 2 Plan and Profile



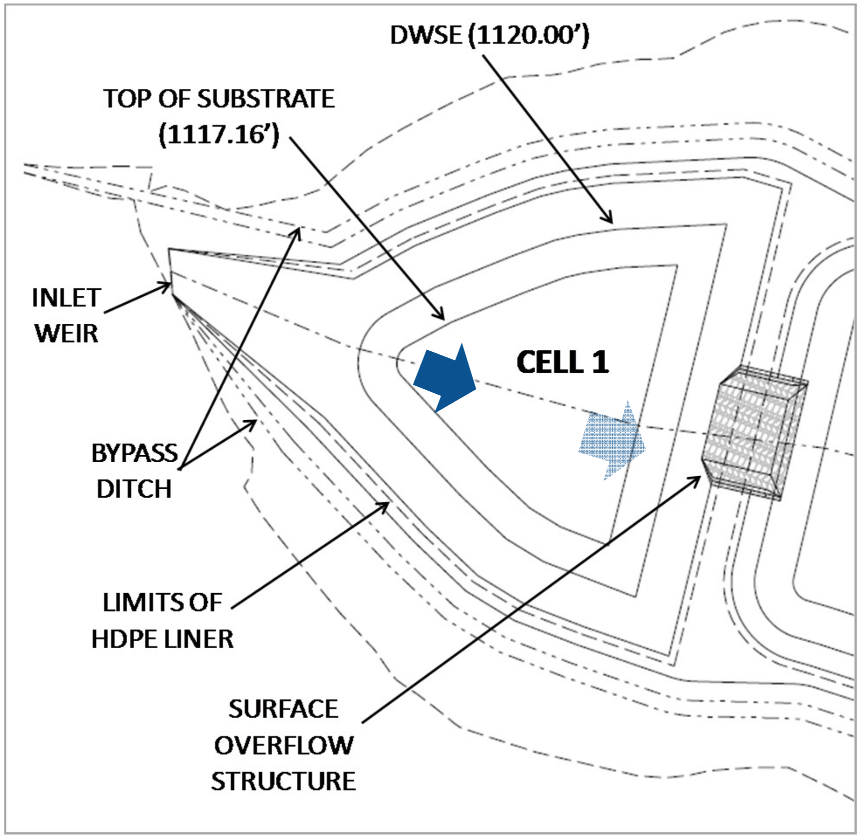
Design Concepts

- Replace existing sediment pond
  - ➢ 30 gpm base flow
- Four cells-in-series:
  1. Downflow biochemical reactor
  2. Anaerobic upflow wetland
  3. Fill-and-drain wetland
  4. Aerobic surface flow marsh

Source:
CH2MHILL (2912)

Cell 1: Downflow Biochemical Reactor (BCR)

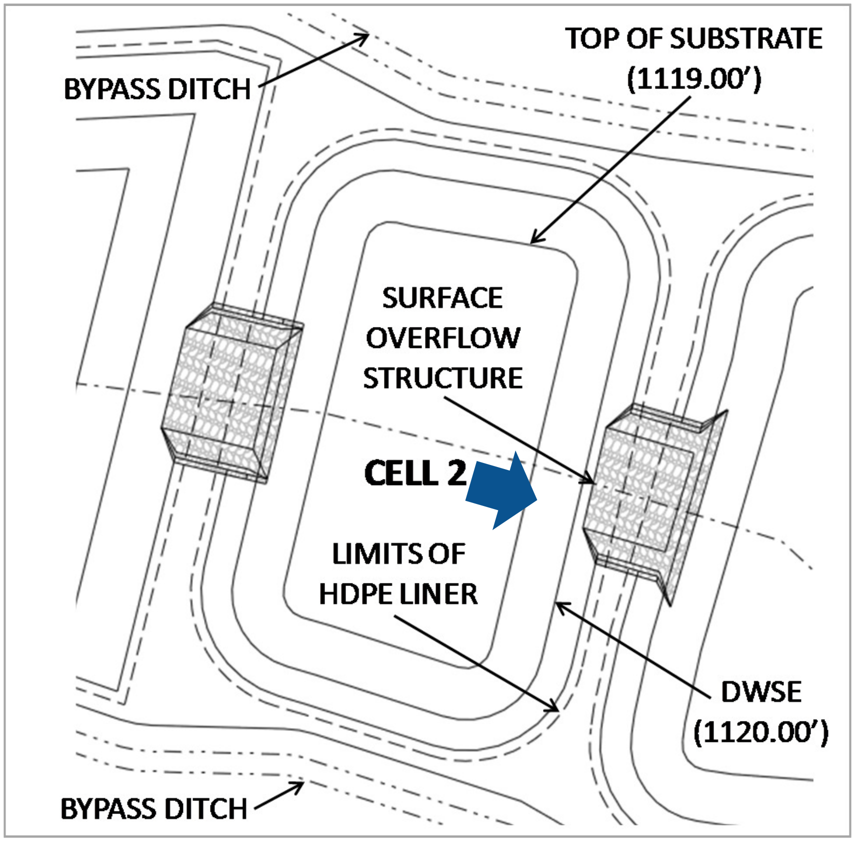
Plan



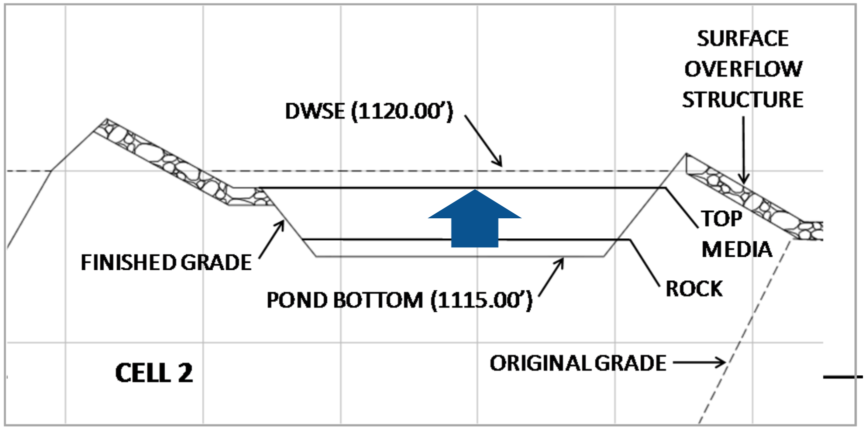
m²	Type	Media	Plants	Function
526	Downflow biochemical reactor	Mixed organic	None	Selenium reduction

Cell 2: Upflow Anaerobic Wetland

Plan



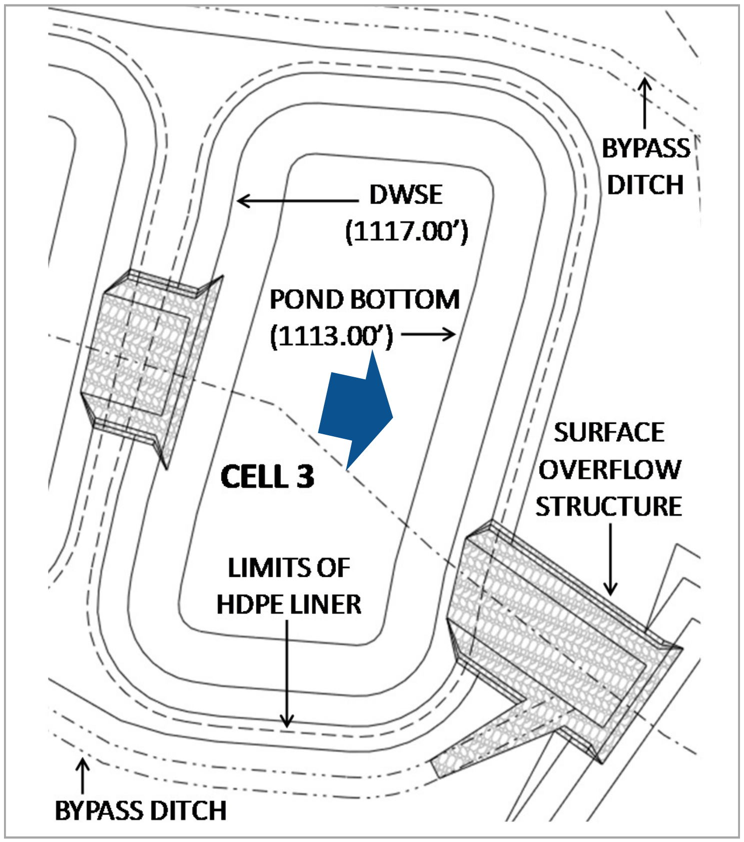
Profile



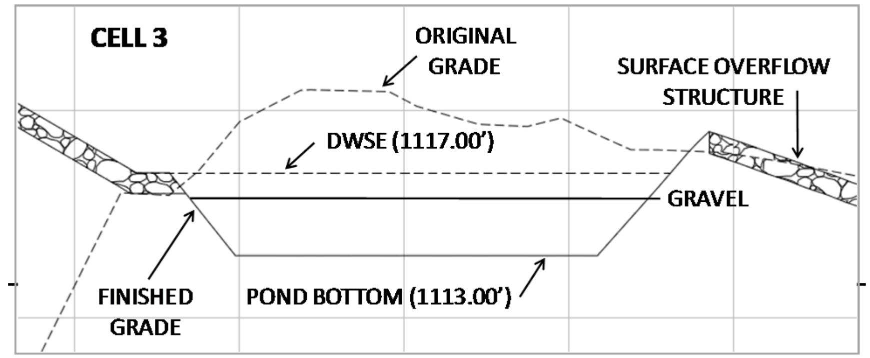
m^2	Type	Media	Plants	Function
567	Upflow anaerobic	Peat	Sedges, rush	Selenium reduction, Byproduct polishing

Cell 3: Subsurface Flow Gravel Bed

Plan



Profile



m^2	Type	Media	Plants	Function
648	Subsurface fill and drain	Limestone gravel	Cattails	Byproduct polishing

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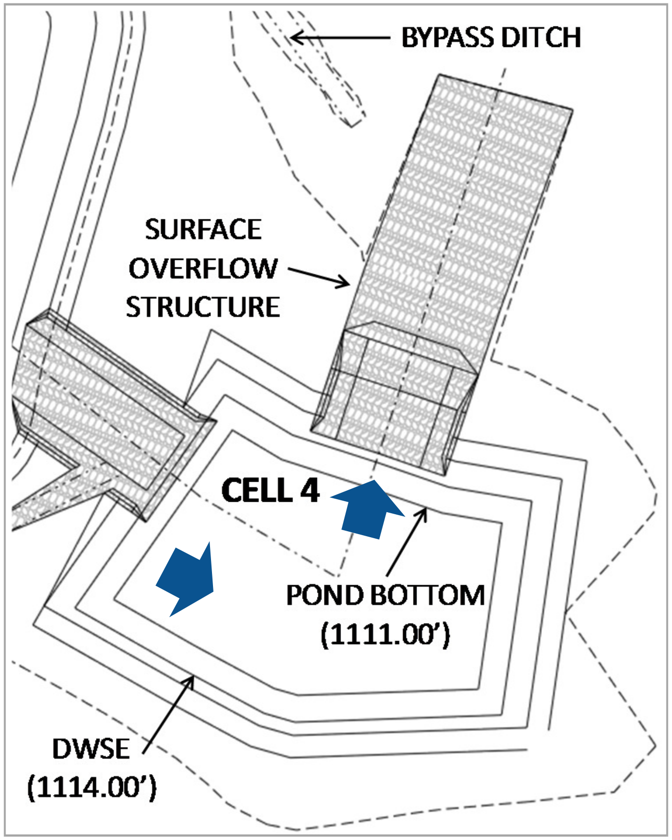
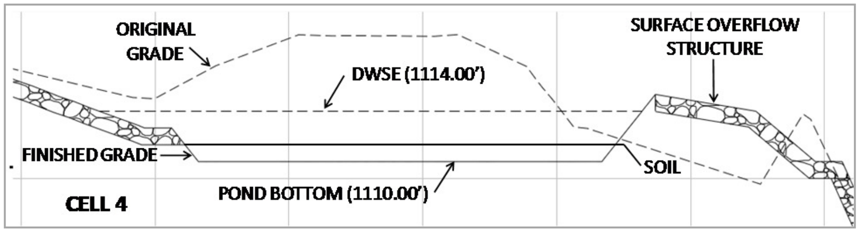
Cell 4: Free Water Surface Wetland

Plan

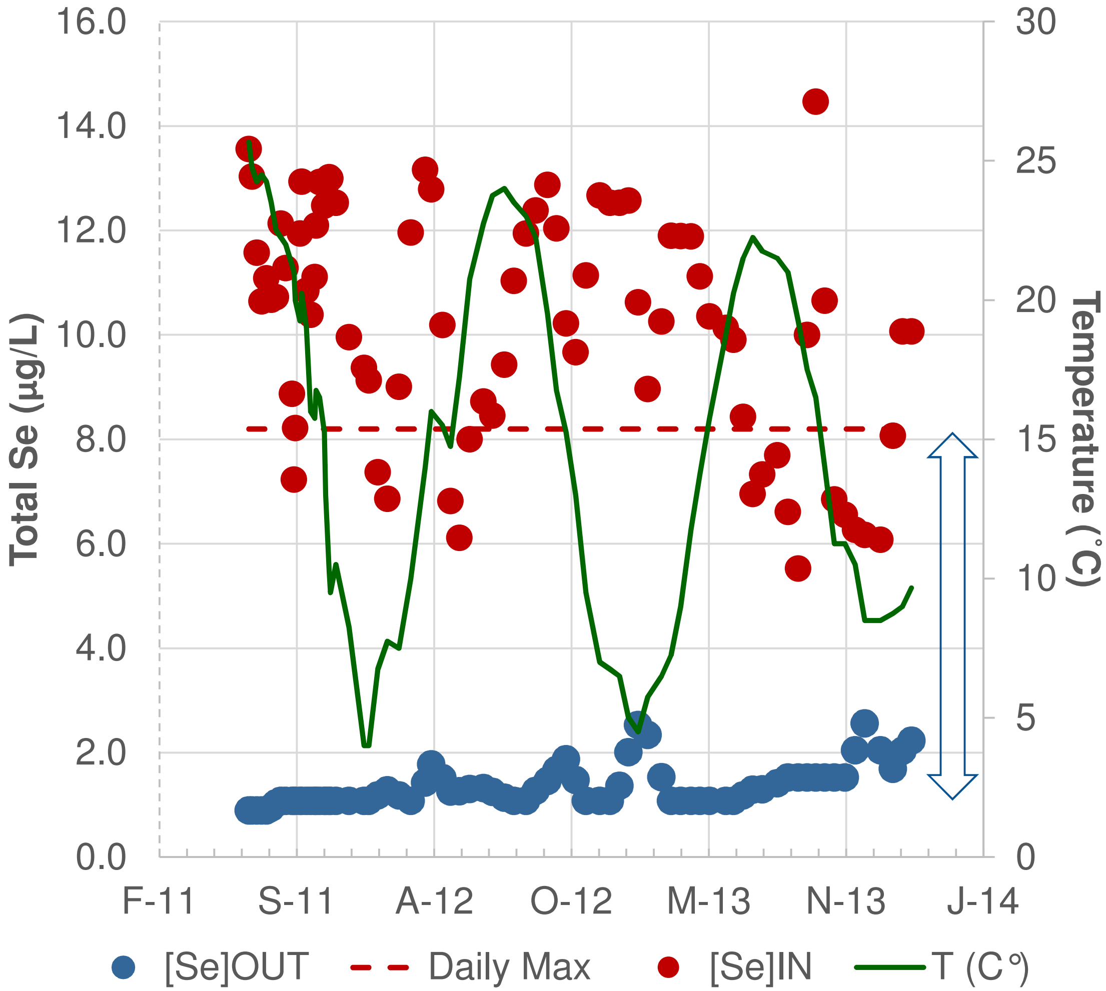


Profile



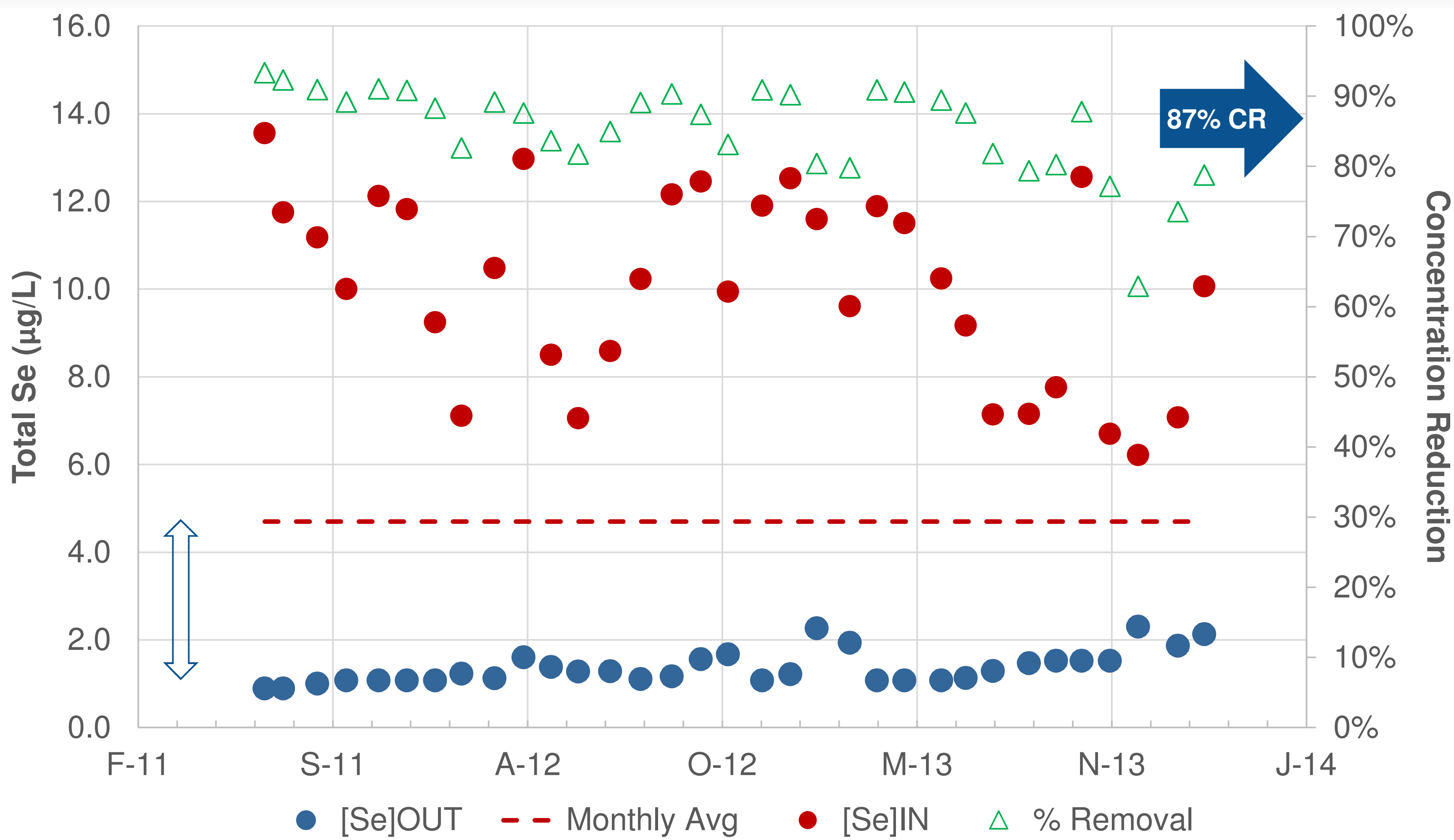
m^2	Type	Media	Plants	Function
445	Free water surface	Topsoil and ponded water	Cattails	Byproduct polishing

PTS 2 Selenium Meeting Daily Criterion Year-Round

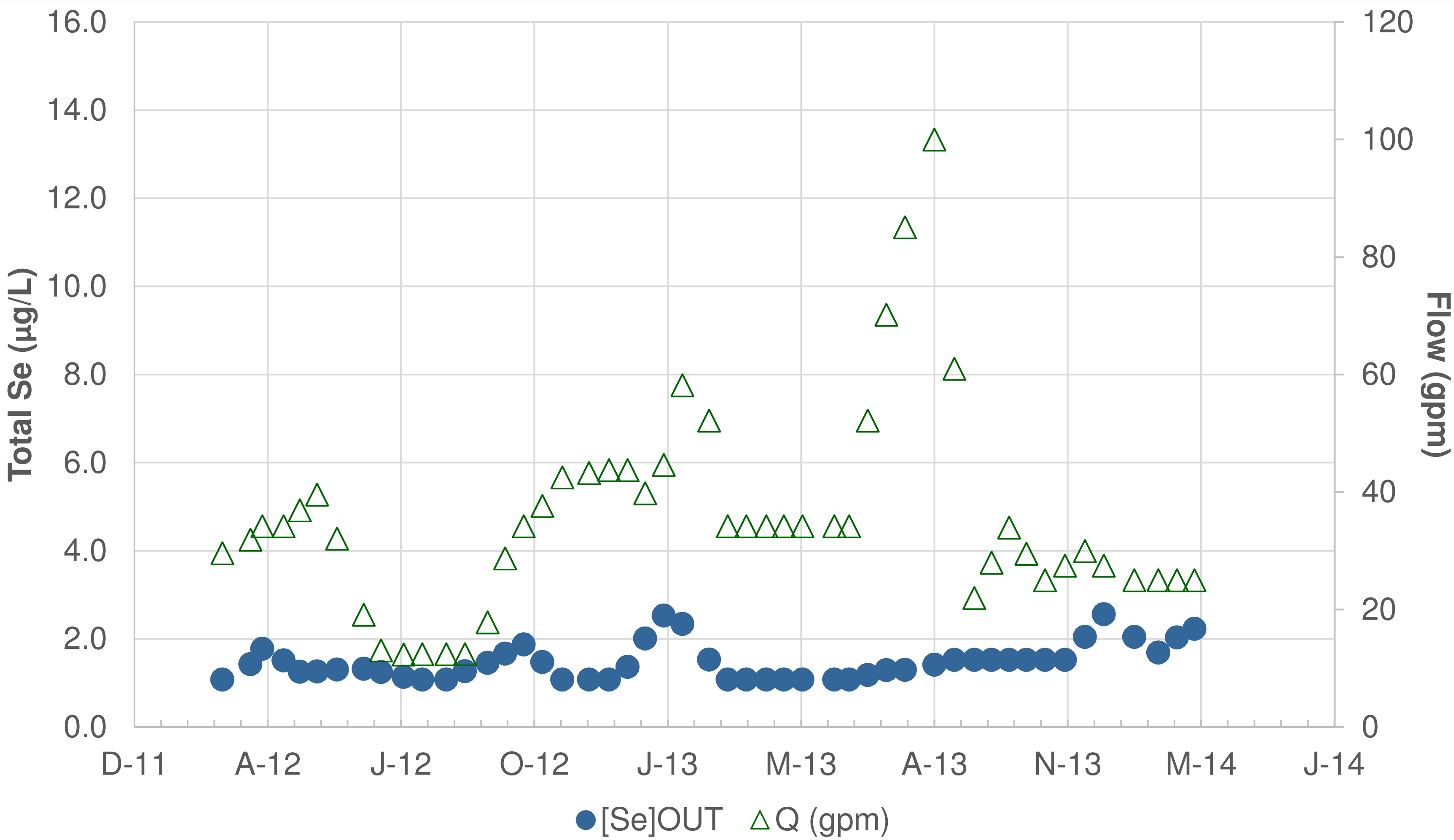


µg/L	In	Out
Average	10.24	1.32
Max	14.47	2.57
Min	5.53	0.90
Range	8.9	1.7

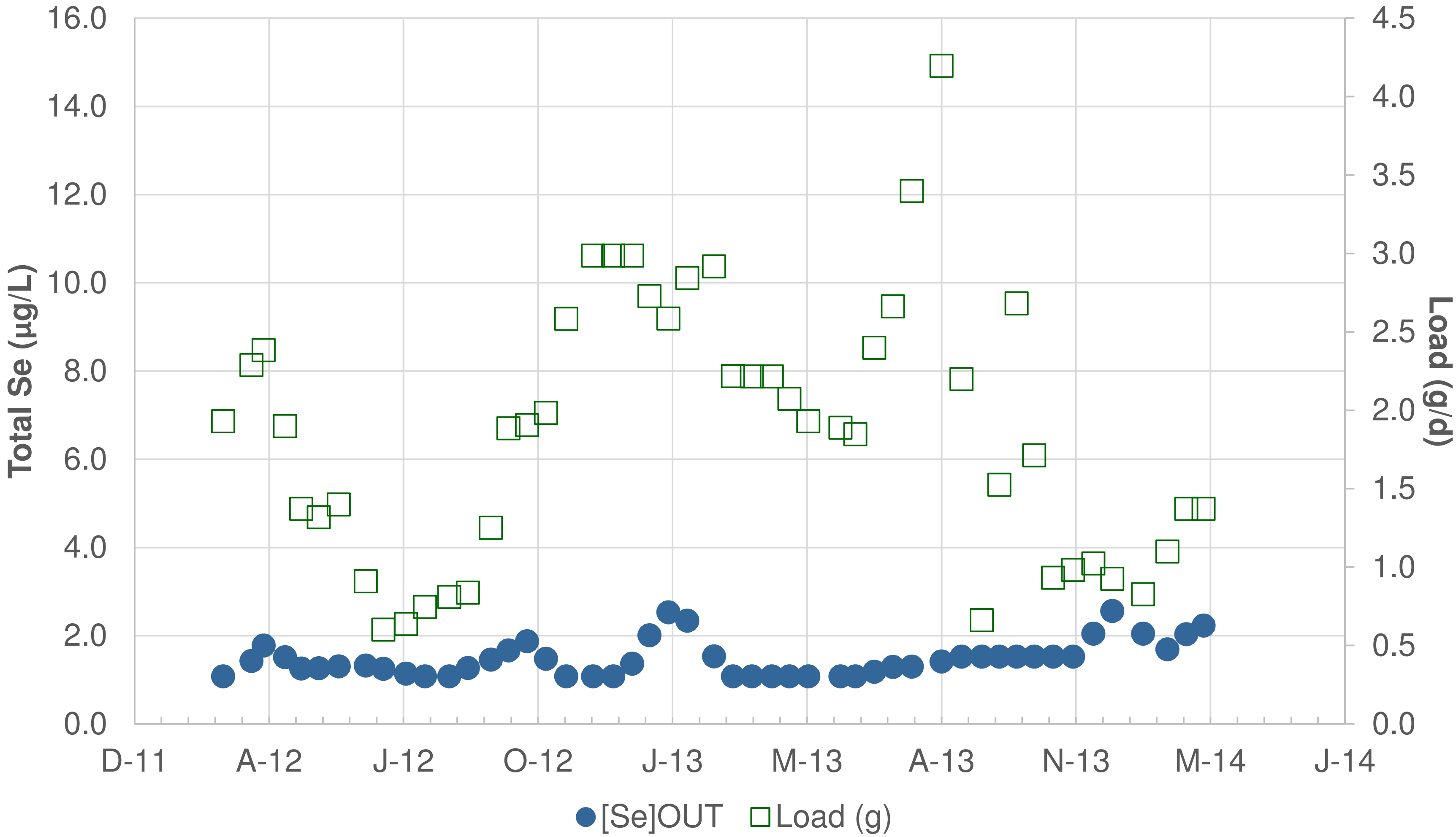
PTS 2 Selenium Meeting Monthly Criterion



PTS 2 Selenium Not Significantly Affected by Flow



Outlet 002 Selenium Accepting Significant Load Variation



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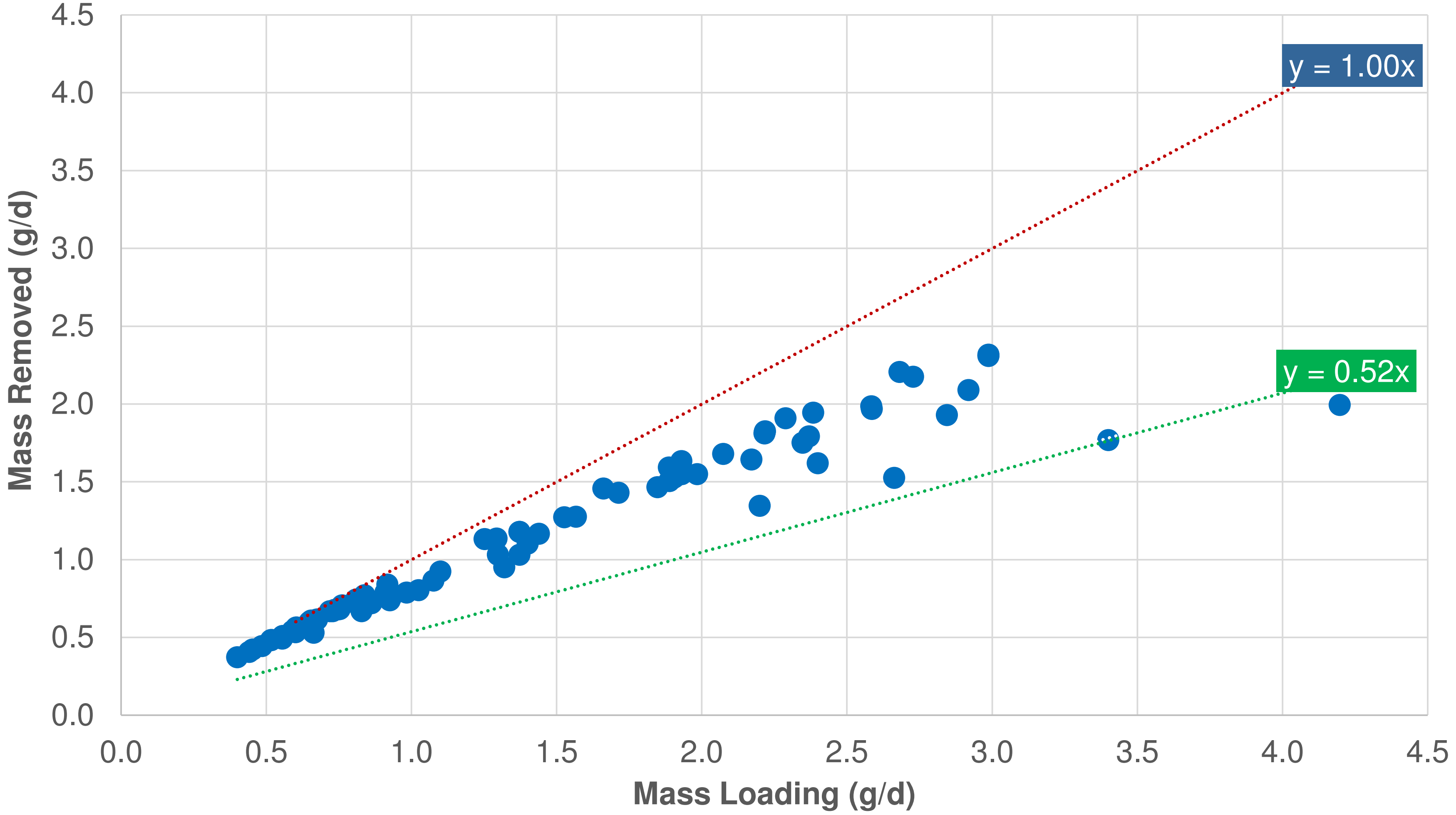
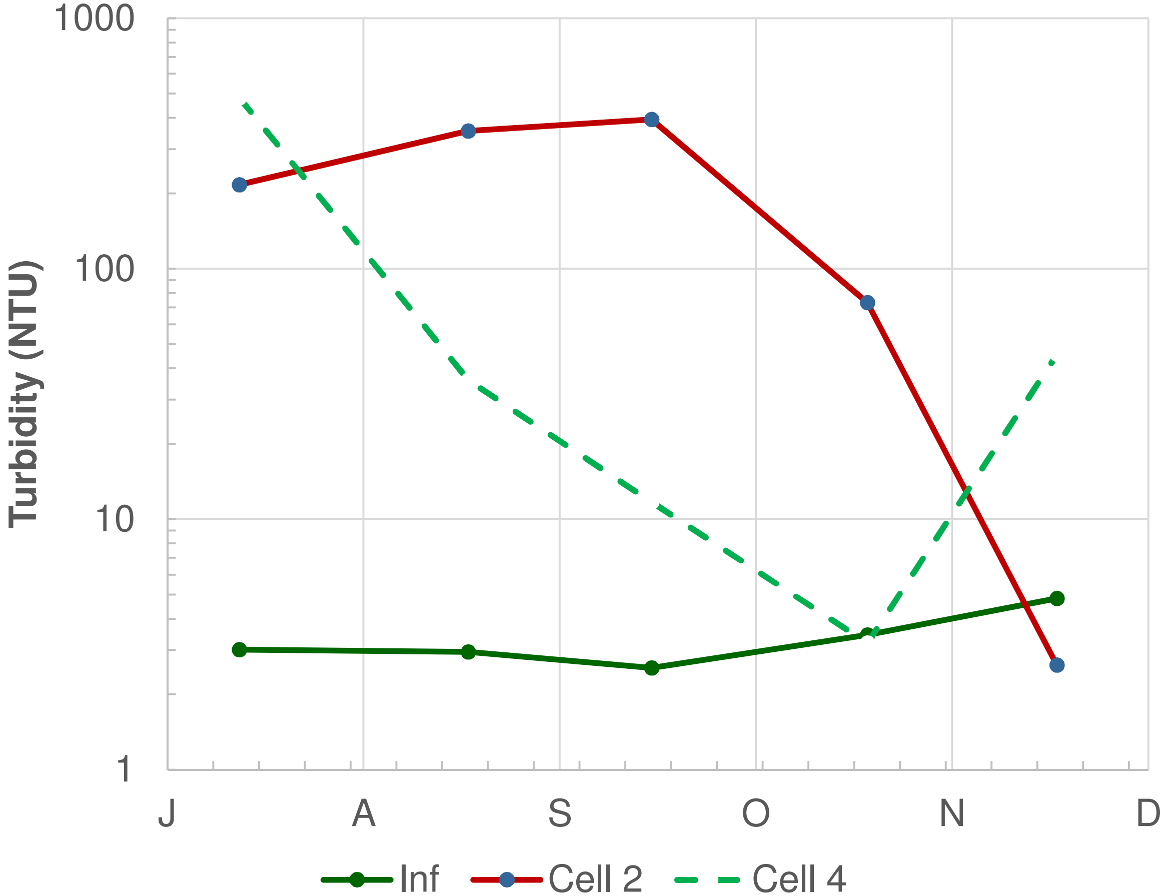
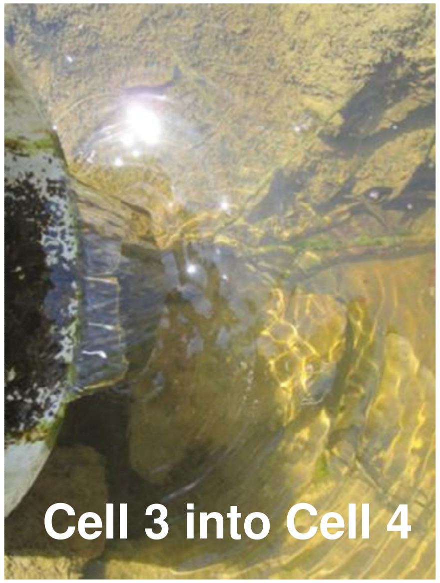
PTS 2 Removal Rate Sustaining Target Range



Polishing Wetlands Reduced Turbidity by 83%





On Balance, Natural Systems Favored (Coal Mine Drainage Example)

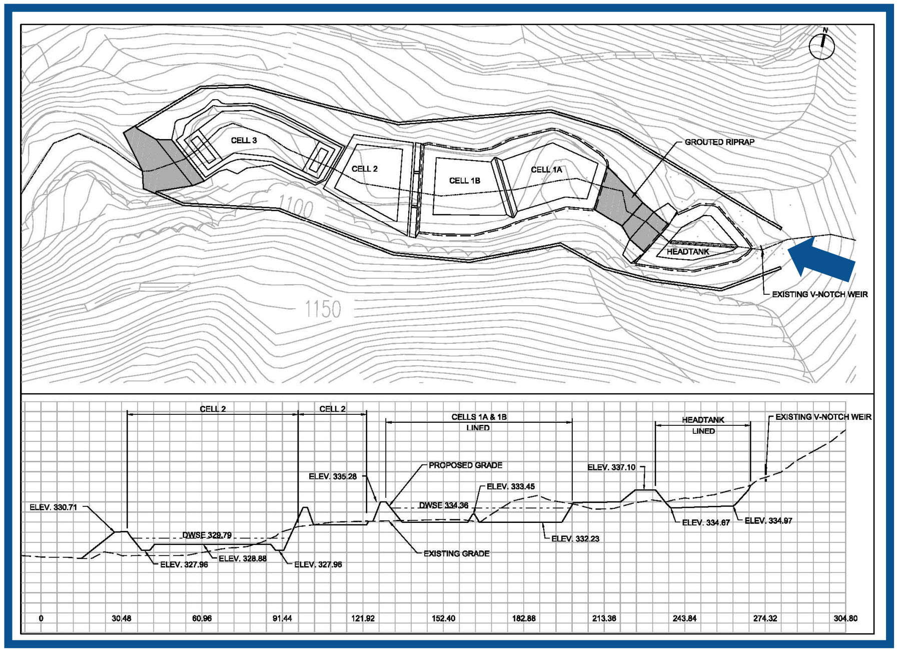
Natural Systems

- BCR+wetland footprint fits (just)
- Construction $762K
- Natural processes
- O&M $15K/yr

Conventional Systems

- Can be made to fit
- Construction $18MM
- Engineered processes
- O&M $500K

PTS 14: Higher Flow, Higher Concentration, Still Compliant with Criteria



- ➢230 gpm base flow
- ➢24 µg/L mean Se to <4.7

Source:
CH2MHILL (2011)

- Five cells-in-series:
  1. 0.12 ac Head tank
  2. 0.48 ac Upflow BCR
  3. 0.30 ac Upflow BCR
  4. 0.23 ac Surface flow marsh
  5. 0.38 ac Sedimentation pond

Passive Treatment Operations & Maintenance: Basic Expectations

- Safety
  - Access, walkway, railings
- Hydraulic Control
  - Control structures, pipes, valves
- Process Performance Monitoring
  - Intermediate sampling
- Site Maintenance
  - Berms, liner & drainage
- Media
  - Long-term replacement
    - Can assume 20 yrs
    - Cap in place an option
  - Can supplement media/carbon
  - TCLP – not hazardous

Image Source
Bays, J. (2012)

Need to Identify Constraints Limiting Performance

- Physical
  - Winter flow
  - Summer flow
- Chemical
  - Oxidized Nitrogen
  - Solids
  - Salinity
  - Composition
  - pH, ORP, DO
- Biological
  - Establishment

Pilot Studies Recommended

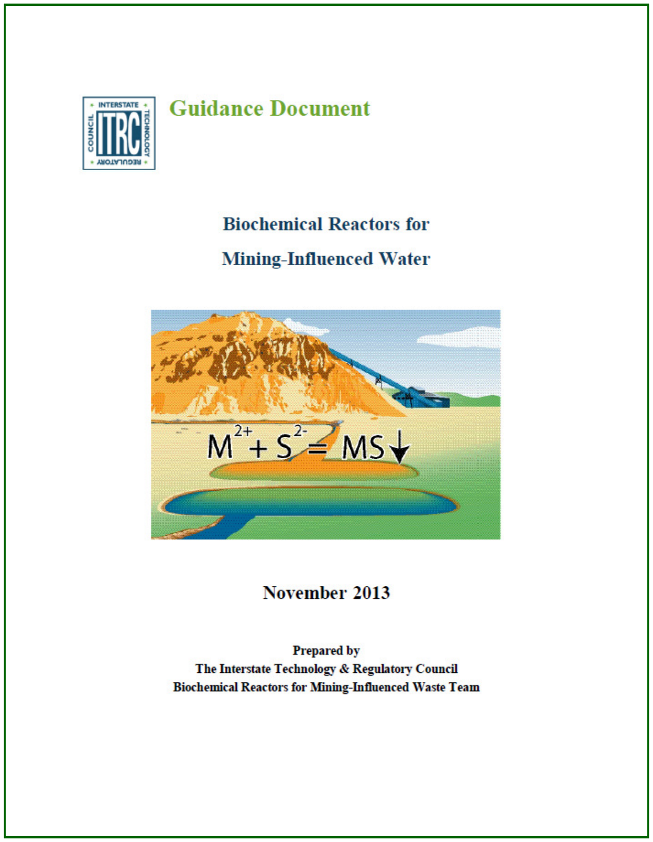
Image source:
[1] Bays, J. (2012)

Prospects Reasonable for Passive Treatment of Seleniferous Wastewaters

- Minewater quality
  - Amenable to passive treatment with appropriate design
  - Pilot studies recommended
- Reliable, natural anaerobic biological process
  - Selenium will be reduced, sequestered year-round
- Learn from real-world examples
  - Agriculture, mine-water, water treatment, power
- Cost-effective
  - Small footprint, lower cost, less maintenance effort

Sources of Additional Information

ITRC Bioreactor Guidance 2013



Guidance Document

Biochemical Reactors for
Mining-Influenced Water

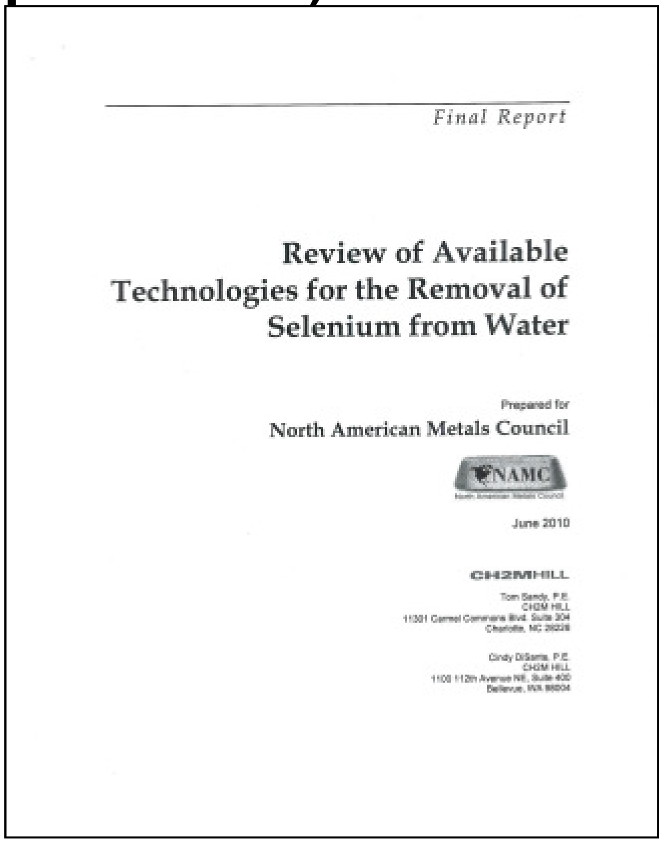
$M^{2+} + S^{2-} = MS\downarrow$

November 2013

Prepared by
The Interstate Technology & Regulatory Council
Biochemical Reactors for Mining-Influenced Waste Team

http://www.itrcweb.org/miningwaste-guidance/to_bioreactors.htm

NAMC Selenium Technology 2010 (update 2012)



Final Report

Review of Available
Technologies for the Removal of
Selenium from Water

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June 2010

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Tom Sandy, P.E.

http://www.namc.org/docs/00062756.PDF

Acknowledgements

Thanks to all of our collaborating private & public partners in the mining and power generation industries.

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813-281-7705

Email: Jim.Bays@ch2m.com

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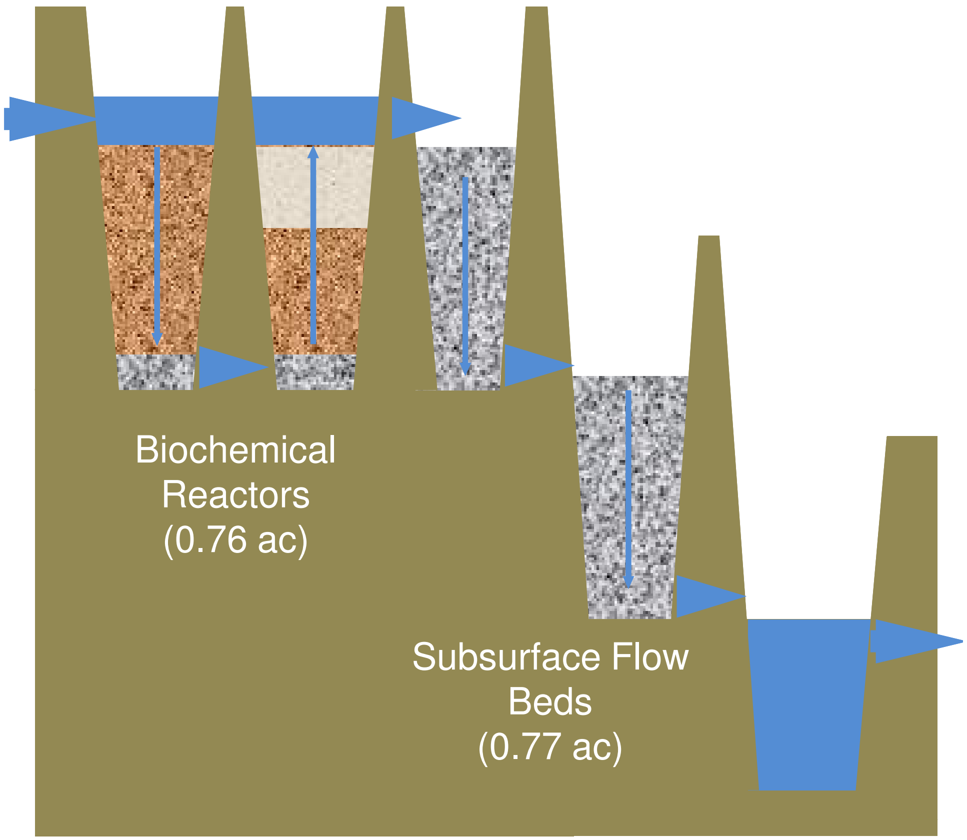
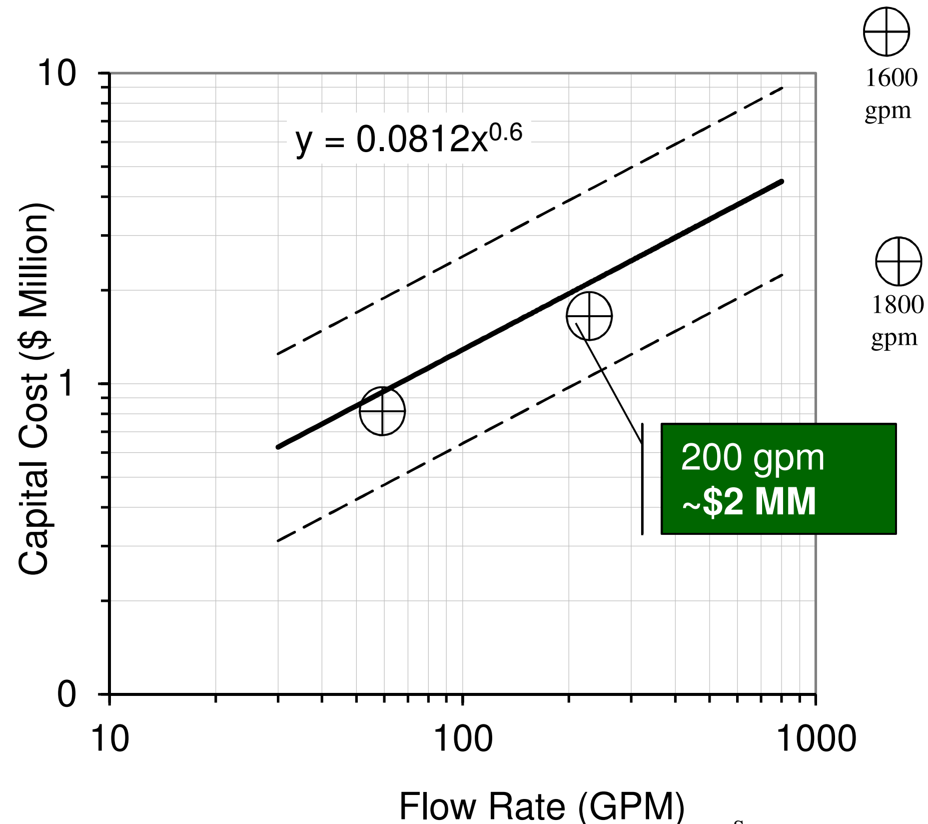
Cost Considerations (Class 5 AACEI) Scenario: 200 gpm, 50 ug/L Se_{in}, 5 ug/L Se_{out}

Sequential Systems



Total Installed Cost[1]

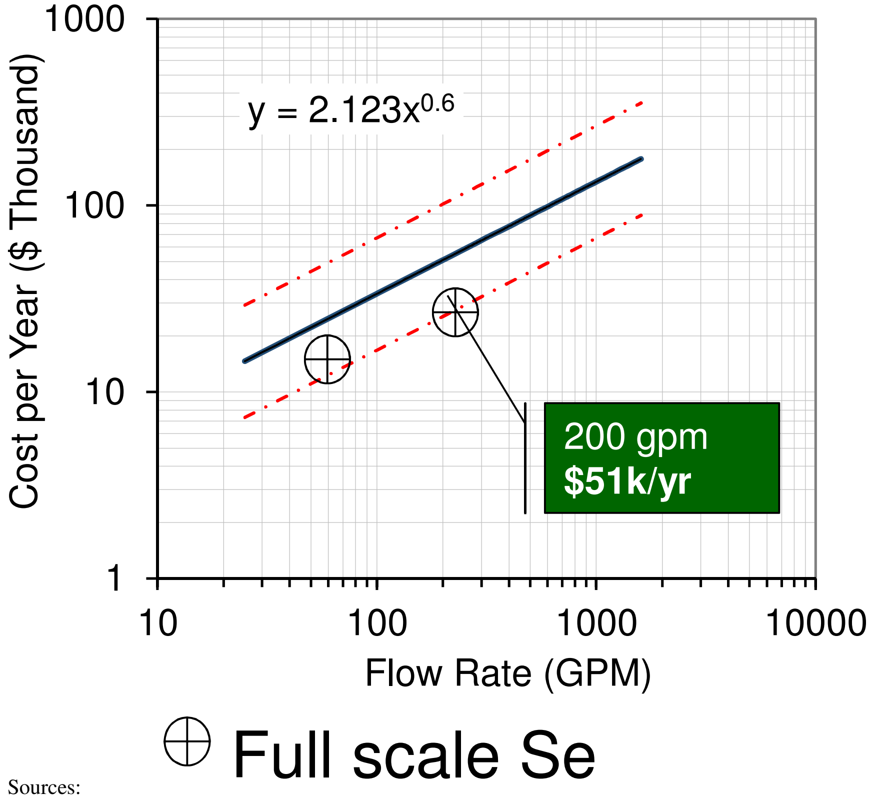


⊕ Full scale Se

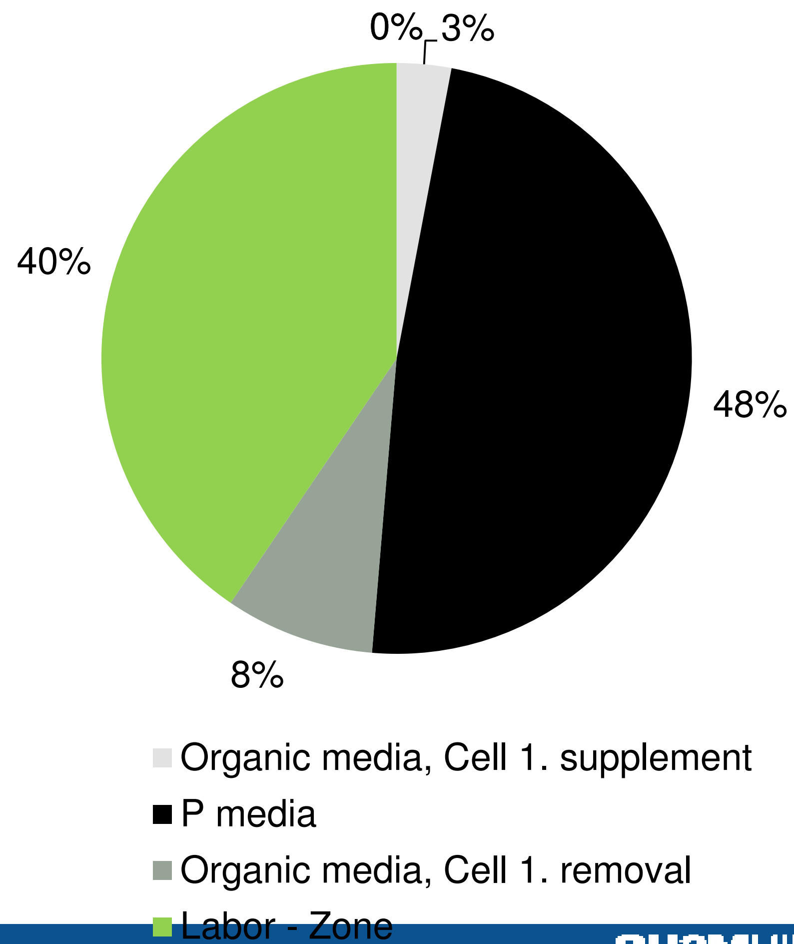
Sources:
[1] CH2MHILL (2013) NAMC Update

Conceptual O&M Costs (Class 5 AACEI) 200 gpm, 50 ug/L Se

Cost Curve[1]

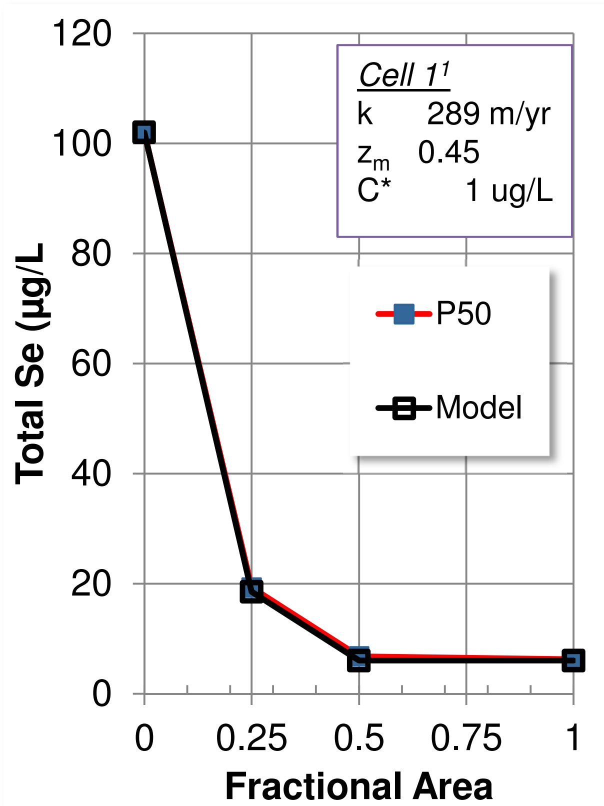


Cost Component



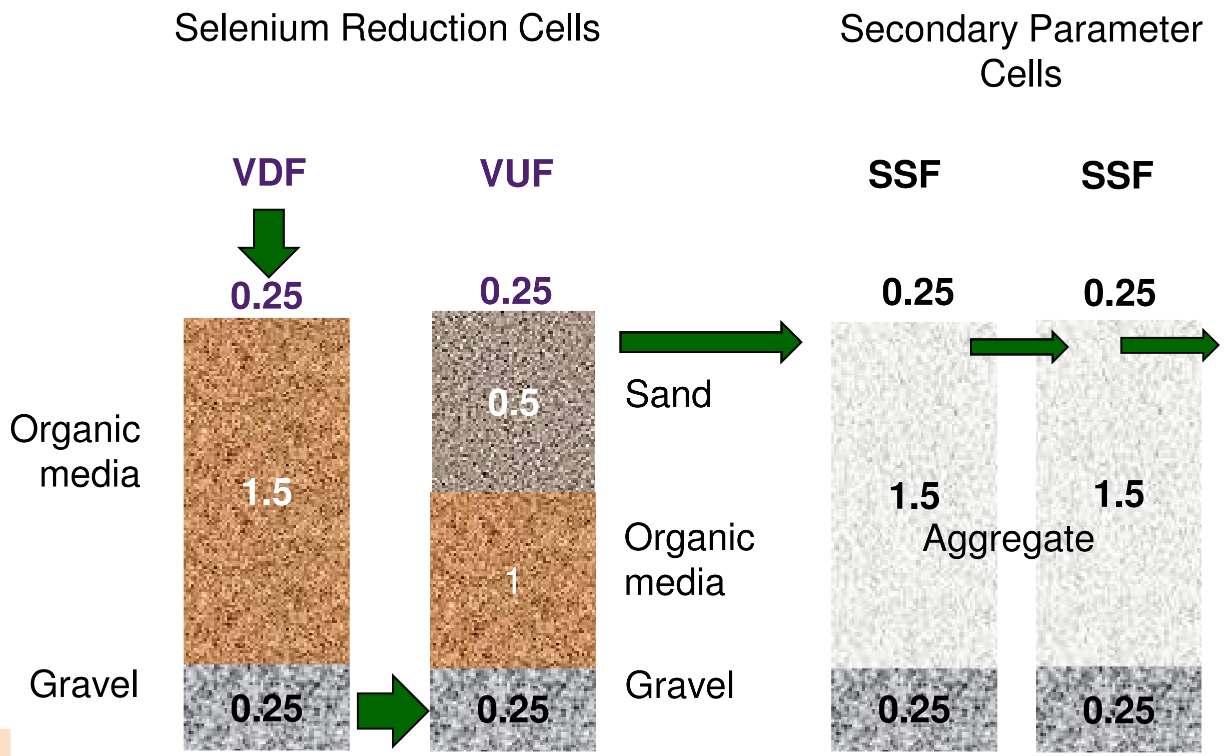
Sources:
[1] CH2MHILL (2013) NAMC Update

FGD Bioreactor Pilot Study
Midwest Power Utility



TDS	2-10 g/L
Se in	129 – 290 ug/L

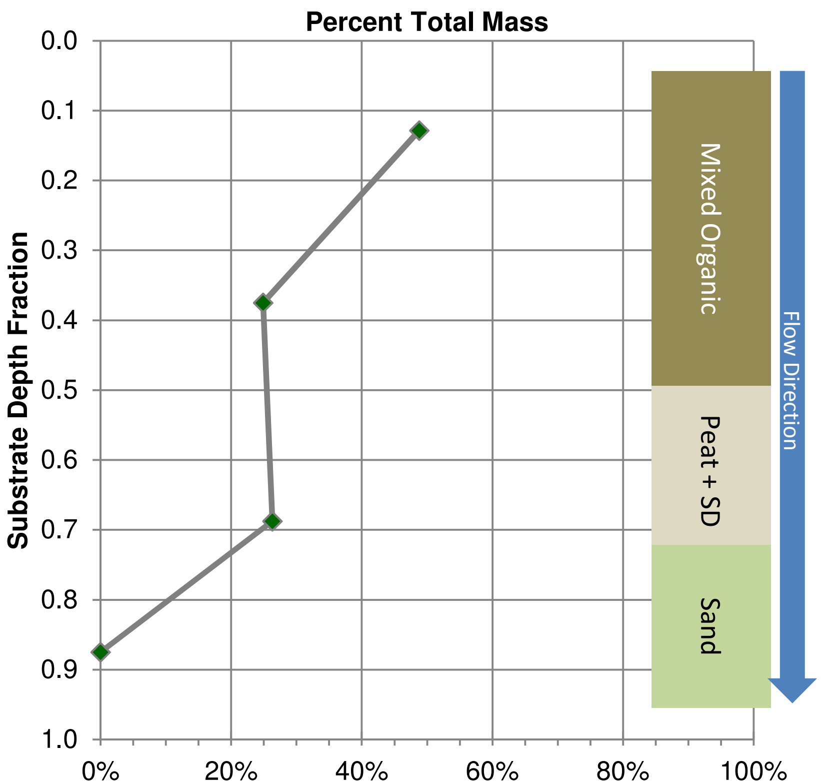
Passive Treatment Concept[1]



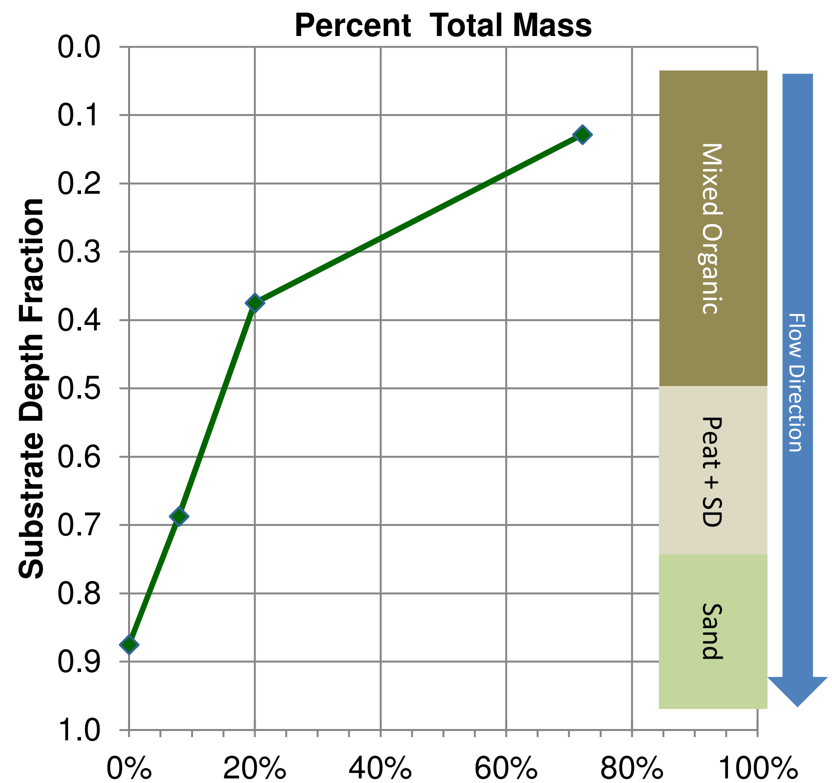
Sources:
[1] CH2MHILL (2013)

Vertical Distribution of Retained Mass

FGD

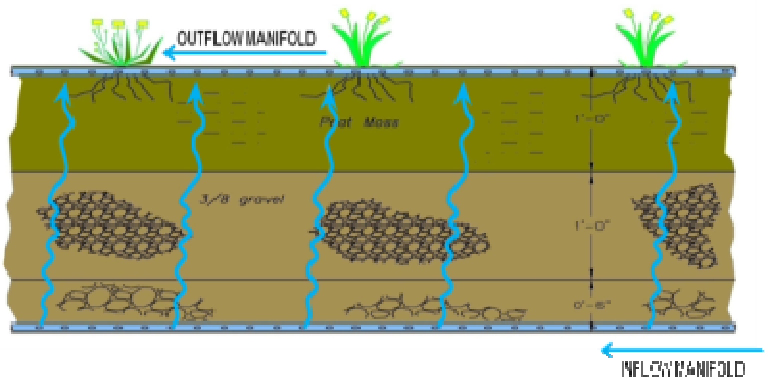


Ash Pond

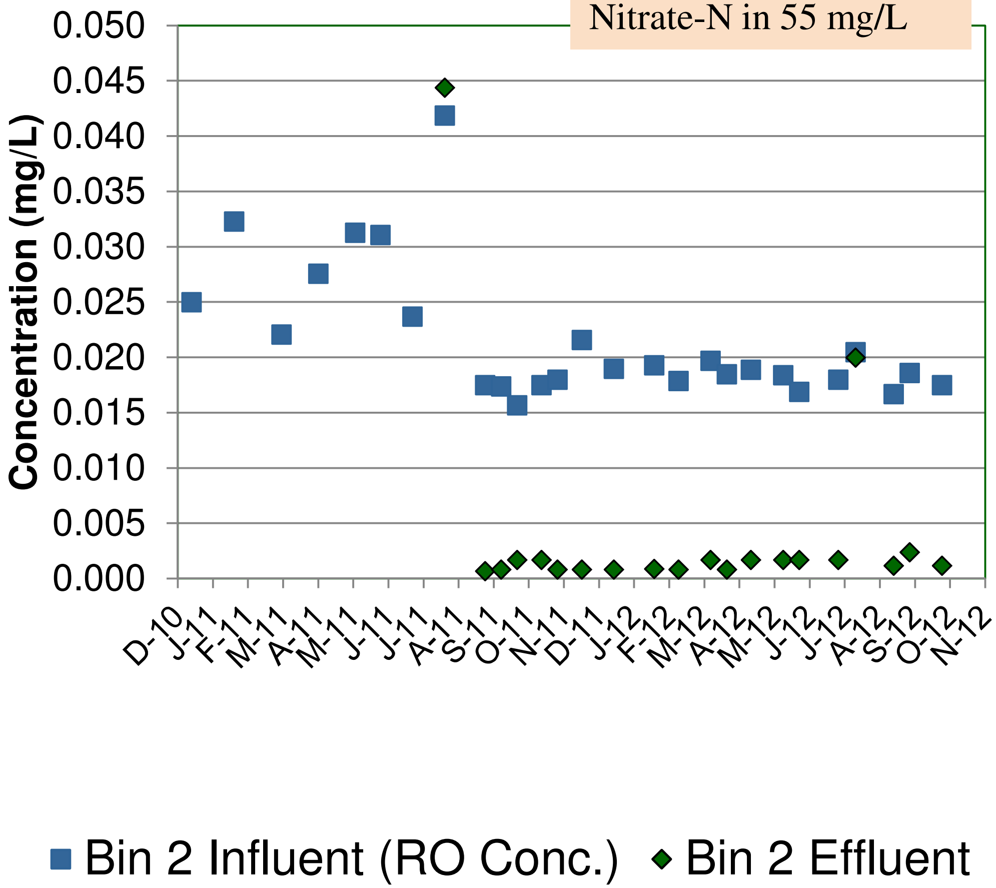


Sources:
[1] CH2MHILL (2013)

Saline Example: Continuous Se Removal BDL in Mixed Organic Media for RO Membrane Concentrate



TDS	~8 g/L
Se in	20 µg/L
Nitrate-N in	55 mg/L



Sources:
CH2MHILL (2012)
Image Source:
Bays, J. (2012)