Addressing Salinity Accumulation in Agricultural Regions

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Bureau of Reclamation

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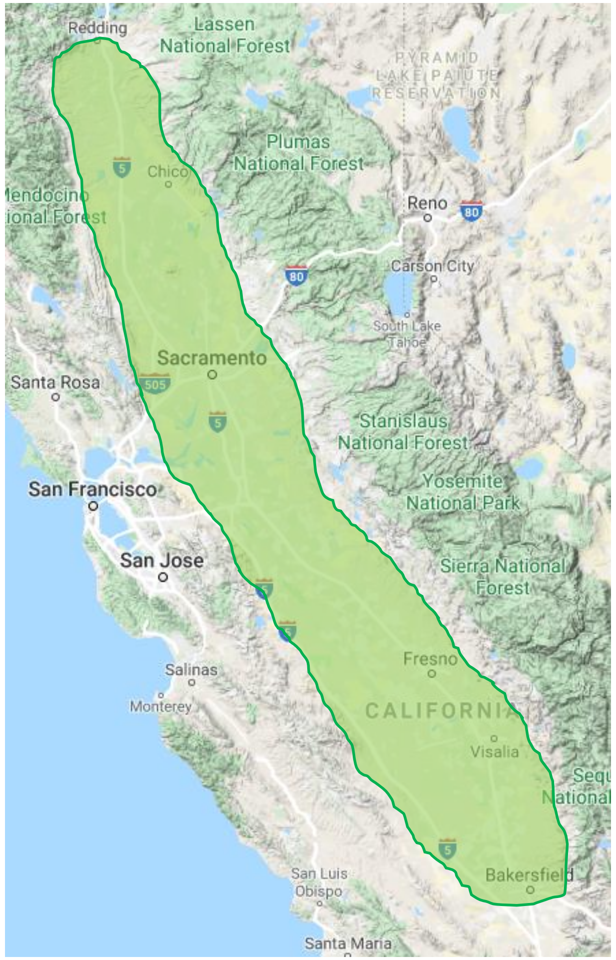
BUREAU OF RECLAMATION

California Central Valley

- World's largest patch of Class 1 agricultural soil – very little agriculture limits
- ~ 450 miles long x ~ 60 miles wide
- Between Sierra Nevada and Coast Ranges; Redding and Bakersfield
- Ideal (~13°C) daily temperature swing, 300 sunny days / year – no snow
- 1920s – Groundwater irrigation
  - Drawing water unseen source - dependence for farmers
  - 1922 - 33,000 acres irrigated by groundwater
  - End of the 1930s (despite the Depression), ~90,000 acres irrigated by groundwater
  - 10' drop per year water table



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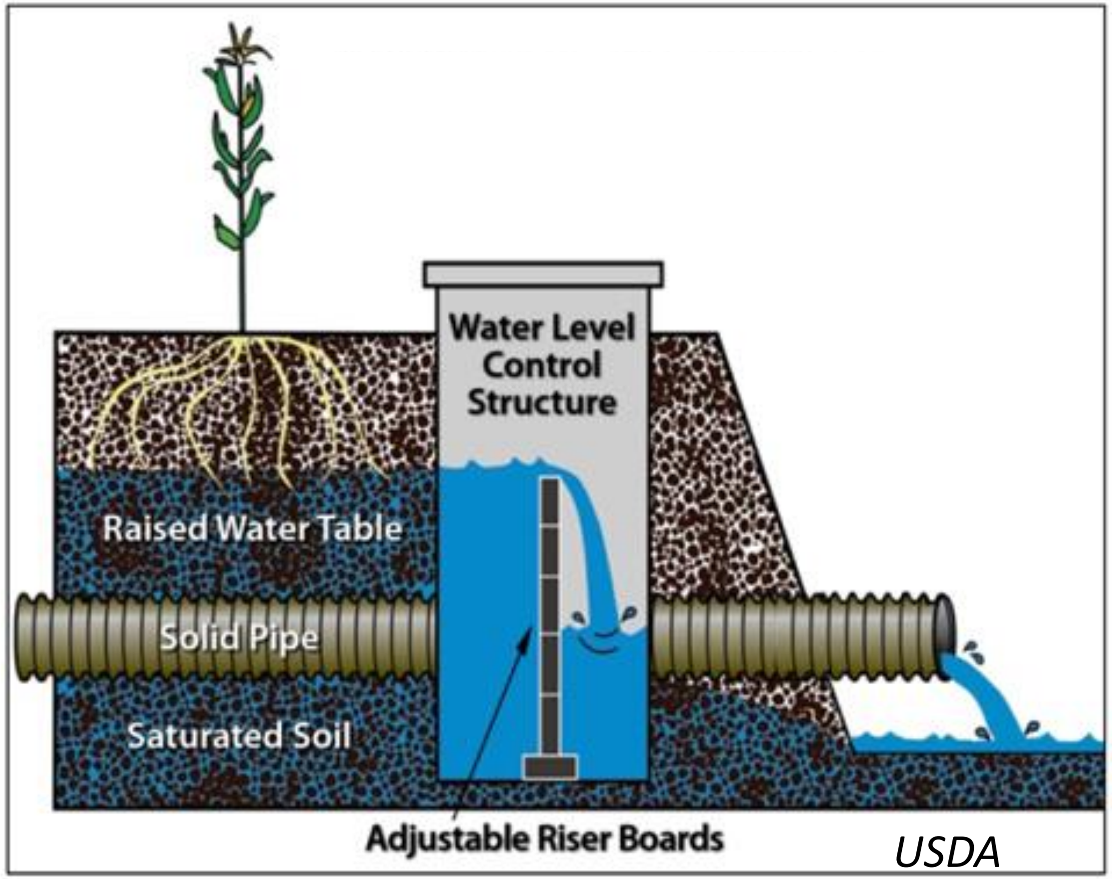
Changes in Agriculture – Water Driven

- 1950s overdraft of groundwater - up to 500,000 acre-feet per year
- Central Valley Project - Imported fresh water river sources:
  - Sacramento
  - Trinity
  - American
  - San Joaquin
- New river sources irrigating too much clay - water pooling impacts productivity
  - Tile drains installed



USDA

Central Valley Agricultural Yield

- Irrigation practices drastically changed agriculture
  - Grazing and grain production decreased
  - Fruit, nut, and vegatable production increased
- Central Valley yields **a third** of all produce grown in the United States[1]
  - >230 crops grown - indigenous to Asia and Mexico, some have no English names[1]
  - Largest production of canned tomatoes in the world – two billion pounds per week during harvest[2]
  - ~85% of carrots eaten by Americans - Bolthouse processes six million pounds of carrots a day[1]

[1] *Bittman (2012) NYT Magazine*

[2] *California Tomato Growers Association (2015)*

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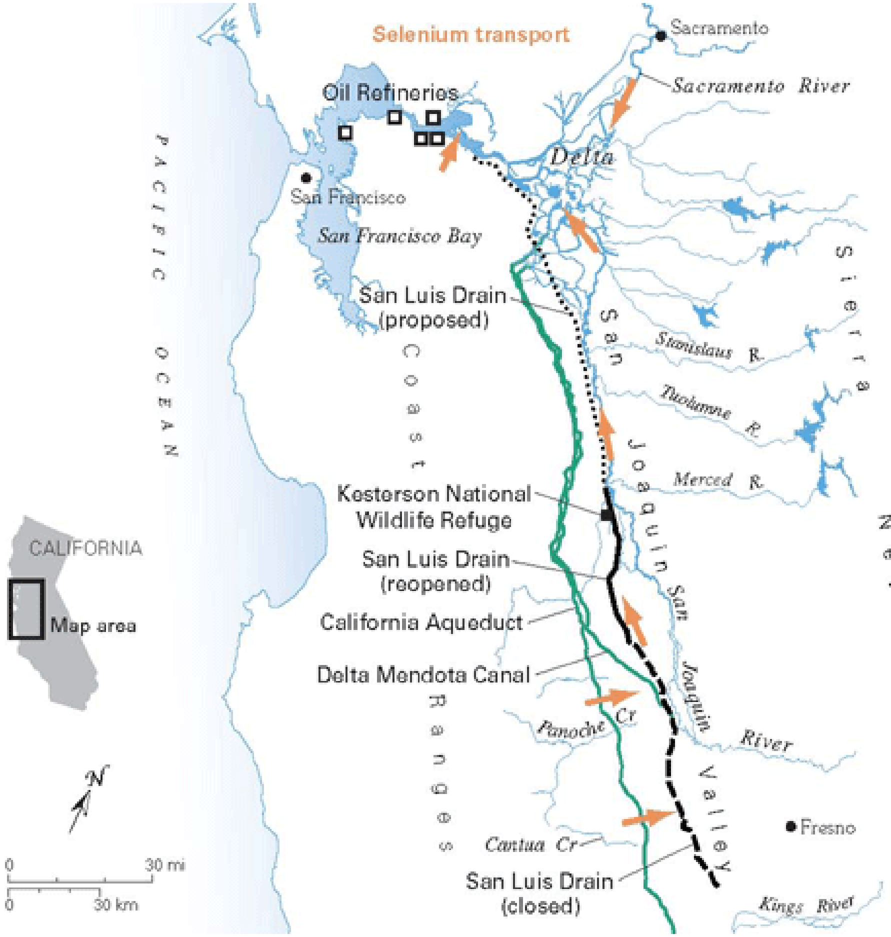
Outlet for Agricultural Drainage?

- **1960** San Luis Drain authorized by Congress to be constructed by Reclamation
  - No natural outlet for collected subsurface drainage
  - Limit salt accumulation / water saturation in root zone
  - Preferred Drain terminus San Francisco Bay Delta Estuary
- **1968-1975** 87 of planned 188 miles constructed – stopped at Kesterson
  - Mounting costs / water quality concerns in the Delta
  - Ponding / evaporating in Kesterson National Wildlife Refuge



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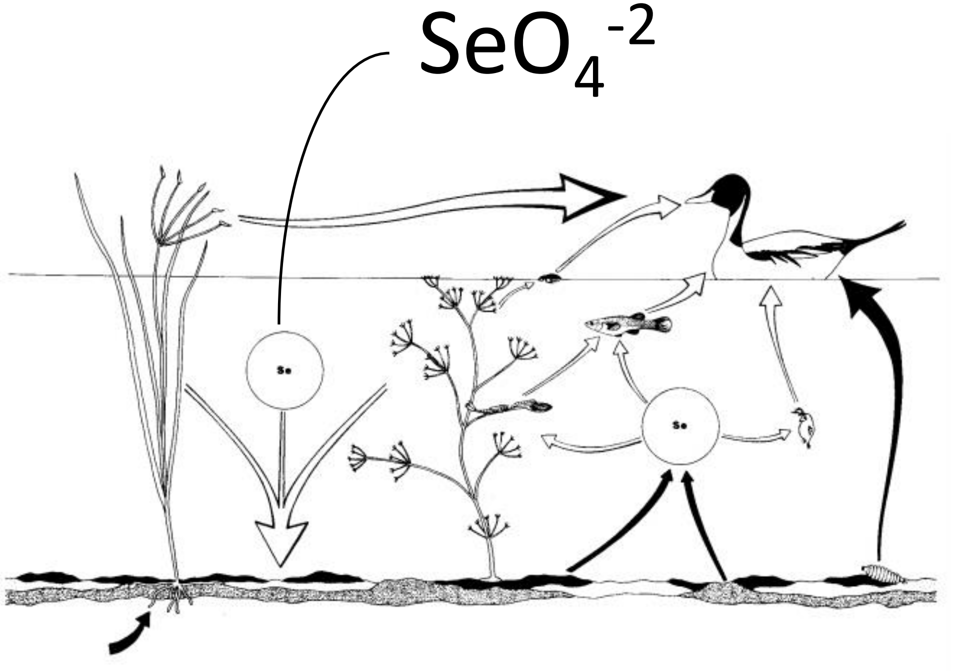
1985. Flow Stops.

- 1979: Early warning signs – fish populations
- 1985: Agricultural (Ag) drainage flow to Kesterson stopped
  - San Luis Drain: selenium (selenate) 140-1400 μg/L
- Selenium bio-accumulating fish and birds
  - Mosquitofish 100x selenium control areas
    - All other fish had died
  - 1983: 1681 bird eggs were studied
    - 14.6% had dead embryos 6.3% deformed
- 1989: More million cubic yards clean dirt used to bury the selenium laden sediments
- Flow Stops – In Valley Solution



Lemly and Smith FWS, 1987

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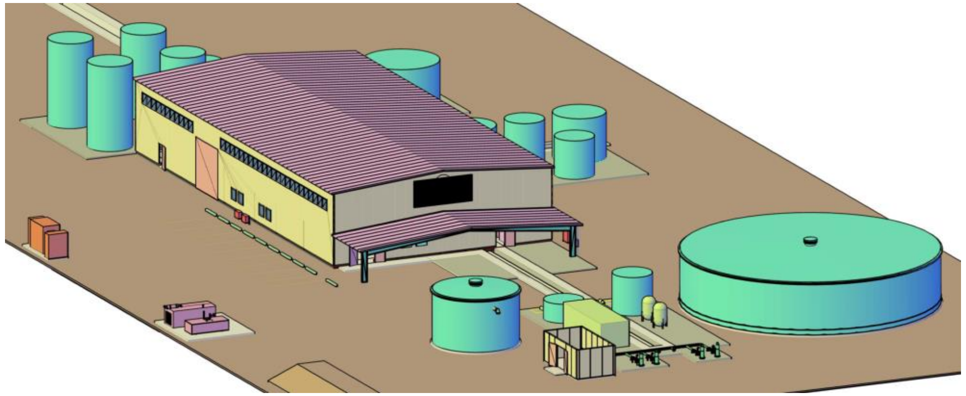
In Valley Solution: Demonstration Treatment Plant

200 gpm plant operate / demonstrate reverse osmosis and Selenium biotreatment

- Basis final design of full-scale Ag drainage service treatment
- $2.7 billion 2008 $$$

Selenium not exceed 10 micrograms per liter (µg/L) biotreatment / reverse osmosis concentrate

- Sent to evaporation ponds



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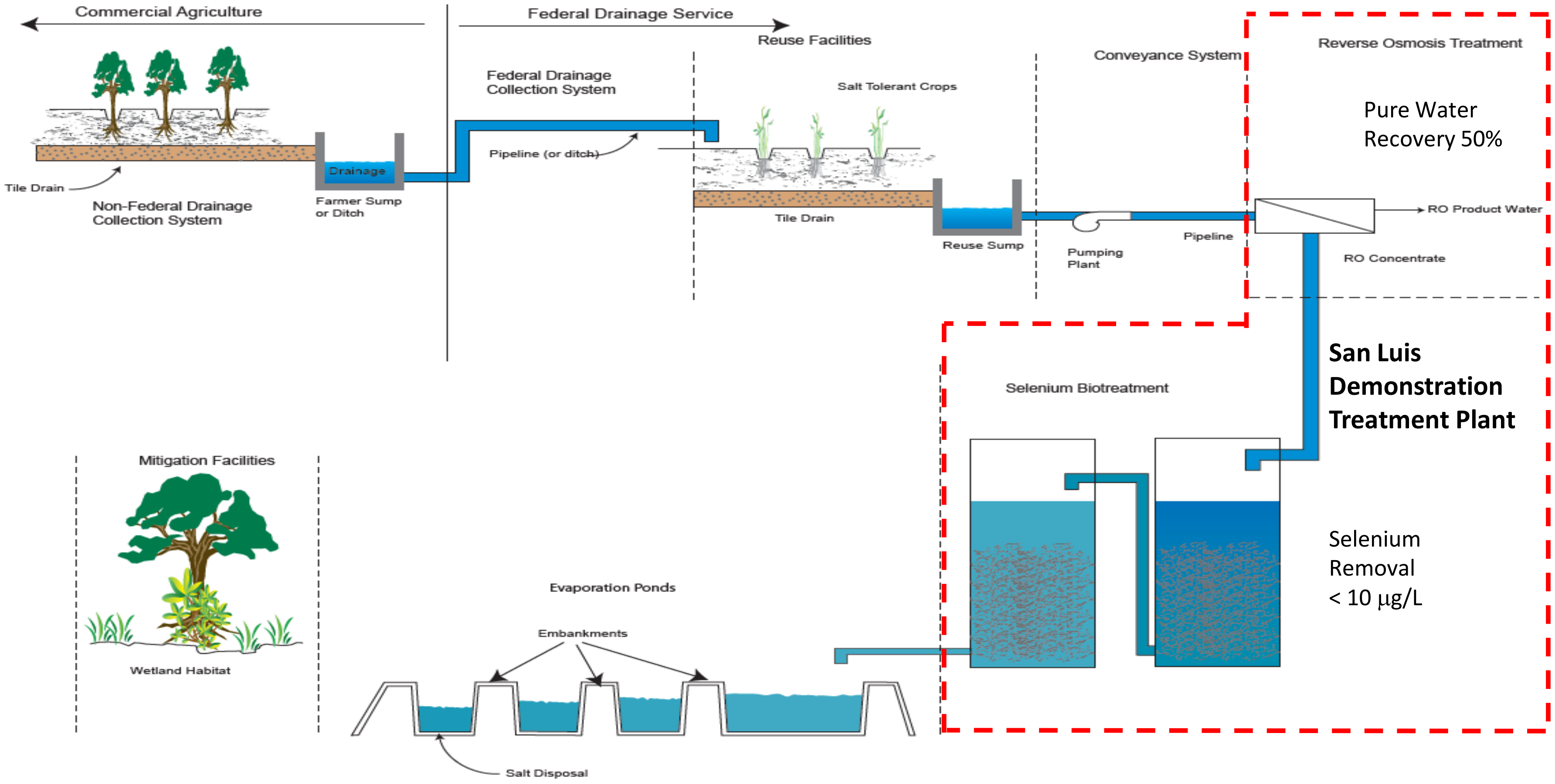
In Valley Solution: Demonstration Treatment Plant



Catastrophic Scaling Event (startup 2014)

Agricultural Drainage Water Quality

pH (SU)	7.0
Sulfate (mg/L)	7,415
TDS (mg/L)	17,044
TOC (mg/L)	12.9
TSS (mg/L)	5.5
Turbidity (NTU)	1.0
Arsenic (µg/L)	38.7
Boron (µg/L)	54.1
Cadmium (µg/L)	0.50
Calcium (mg/L)	502
Chromium (µg/L)	22.1
Copper (µg/L)	39.5
Iron (mg/L)	1.60
Magnesium (µg/L)	304
Manganese (mg/L)	0.10
Mercury (µg/L)	0.40
Nickel (µg/L)	12.3
Selenium (µg/L)	619
Silica (mg/L)	51.8
Sodium (mg/L)	5,209
Strontium (µg/L)	7,314

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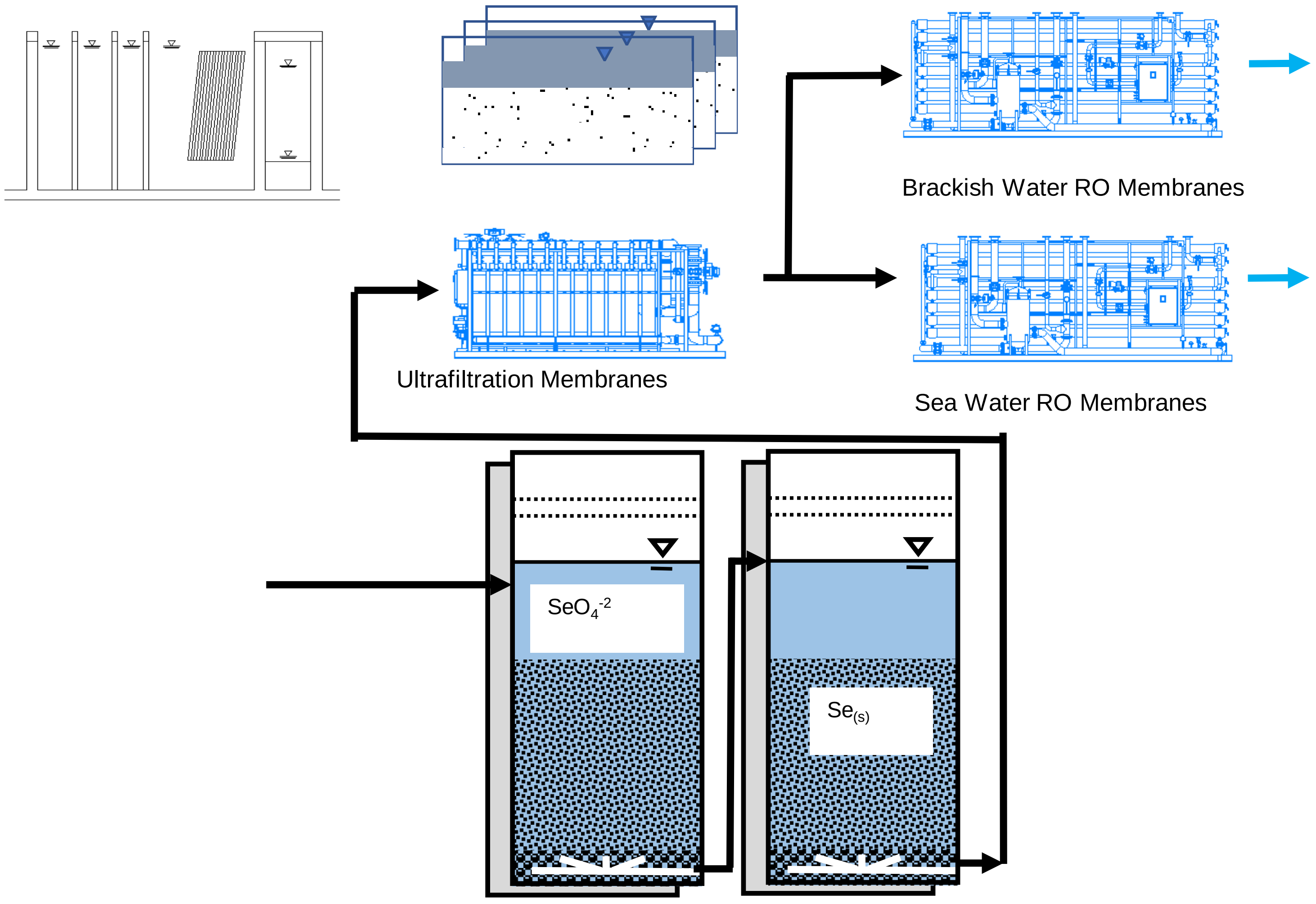
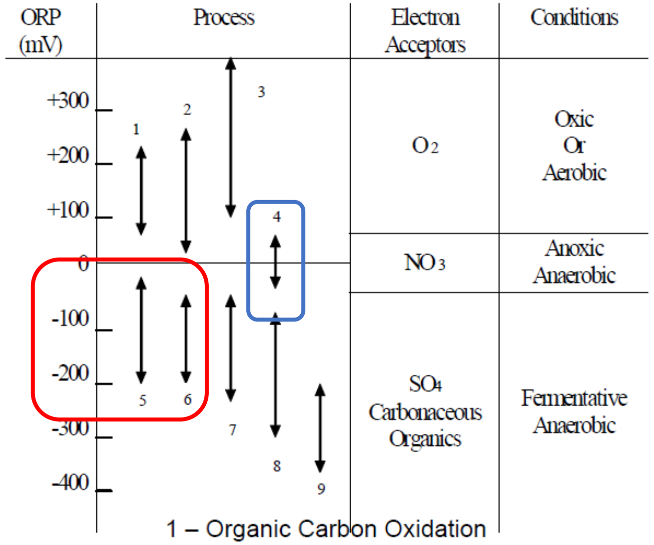
Demonstration Plant Re-Configuration



Biofiltration Anoxic Process



1 – Organic Carbon Oxidation
2 – Polyphosphate Development
3 – Nitrification
4 – Denitrification
5 – Polyphosphate Breakdown
6 – Selenium Reduction
7 – Sulfide Formation
8 – Acid Formation
9 – Methane Formation

(Sonstegard et al. 2008)

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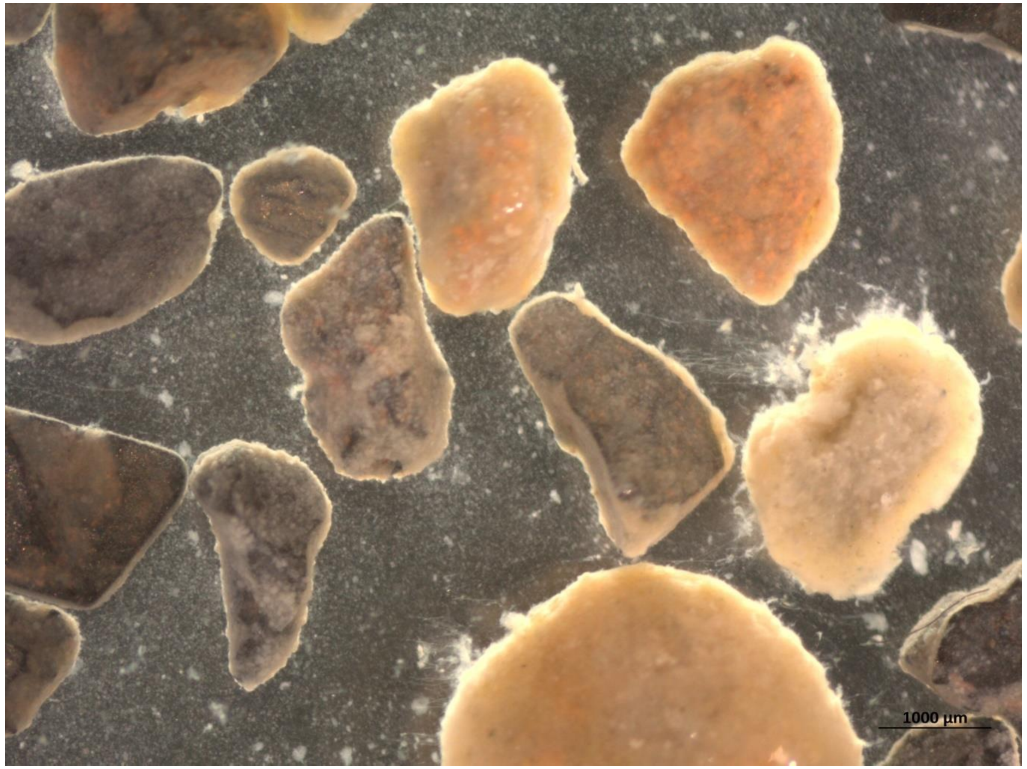
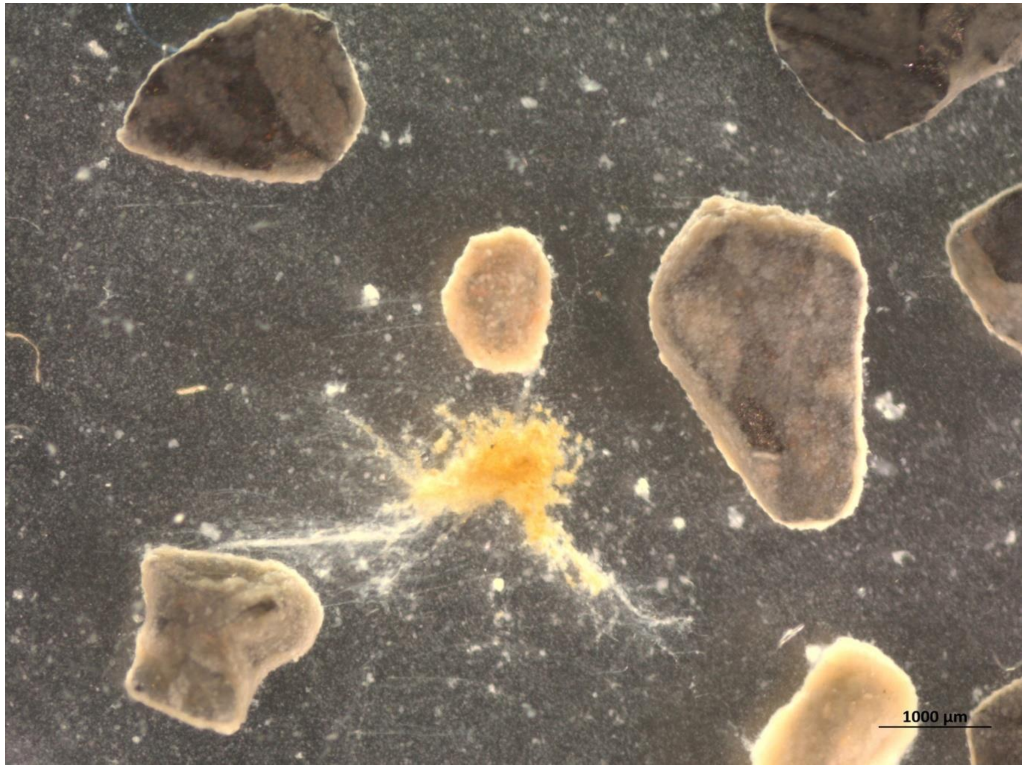
Bioreactor Operational Problems

Granules on the top of first stage



Granules on the top of second stage



Flocs seemed to have filamentous morphology.
Saved for DNA extraction - Fungus

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External Carbon (FOOD) Dosing Rate

- Electron donor requirement (not counting yield)
- Nitrate: $0.25O_2 + e^- + H^+ \rightarrow 0.5H_2O$

$$0.20NO_3^- + e^- + 1.2H^+ \rightarrow 0.1N_2 + 0.6H_2O$$

$$\text{Electron Donor Required} = 2.86\ \text{g}\ \text{O}_2/\text{g}\ \text{NO}_3\text{–N}$$

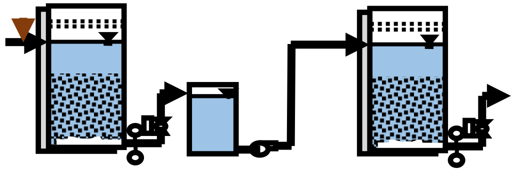
- Selenate: $0.25O_2 + e^- + H^+ \rightarrow 0.5H_2O$

$$0.5SeO_4^{2-} + e^- + H^+ \rightarrow 0.5SeSO_3^{2-} + 0.5H_2O$$

$$0.25SeO_3^{2-} + e^- + 1.5H^+ \rightarrow 0.25Se + 0.75H_2O$$

$$\text{Electron Donor Required} = 0.61\ \text{g}\ \text{O}_2/\text{g}\ \text{Se}$$

- Typical COD:N ratio in denitrification filter with glycerin ~5-6



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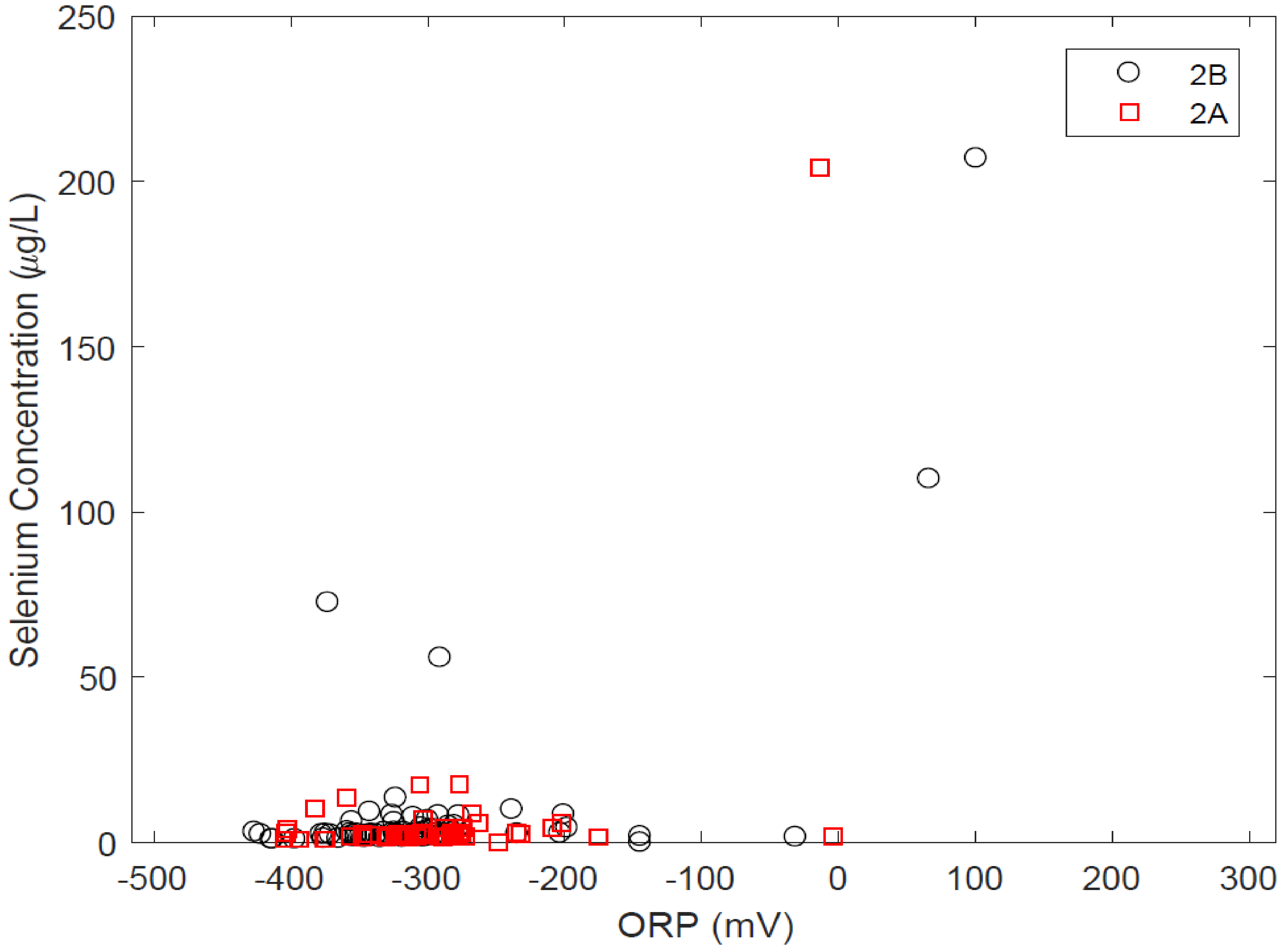
Selenium Removal



- Removal of:
  - Nitrate
  - Chromium
  - Uranium
  - Some Arsenic

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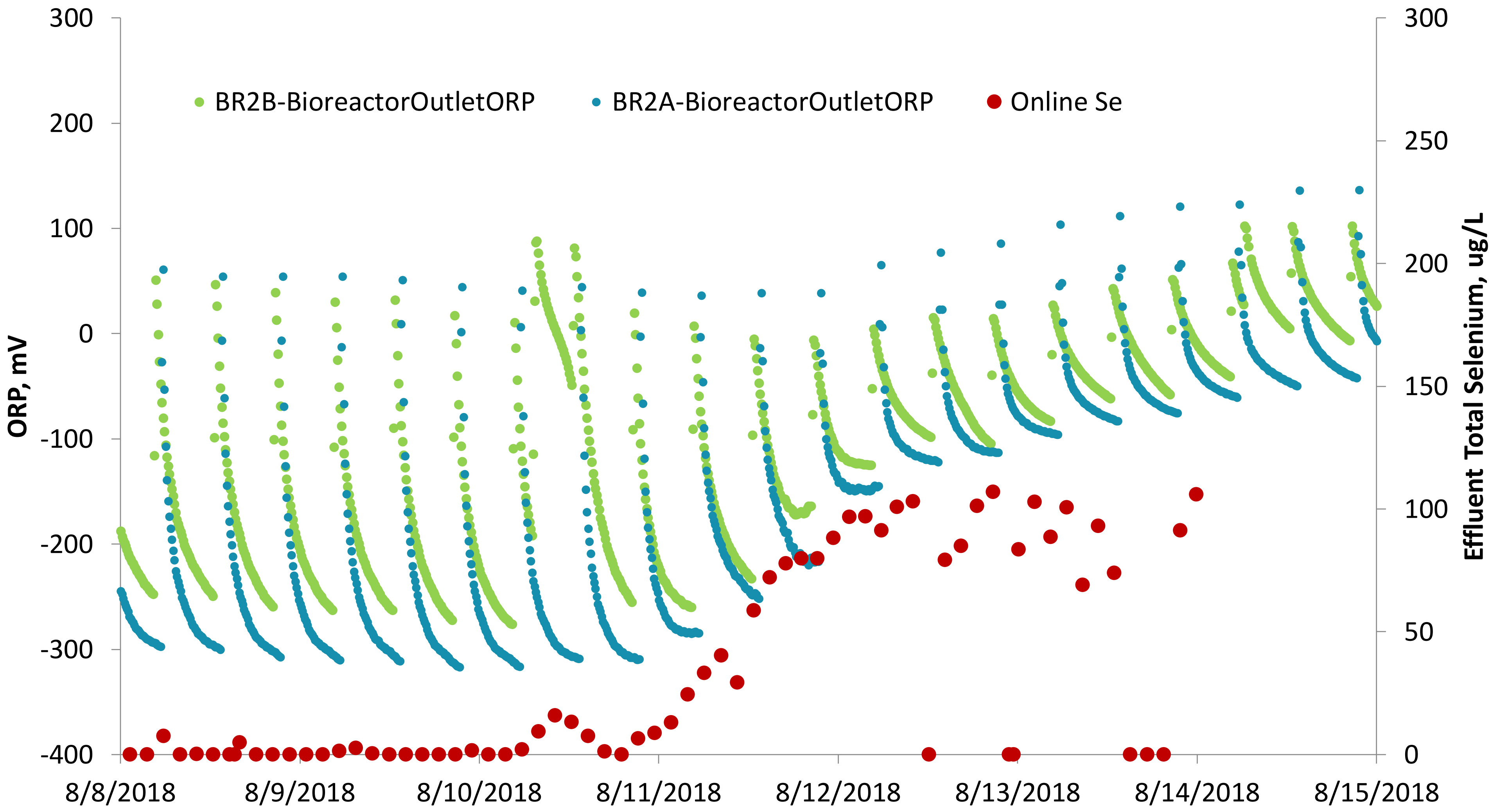
Monitoring Performance: Effluent Selenium



Selenium probe courtesy of Aqua Metrology Systems

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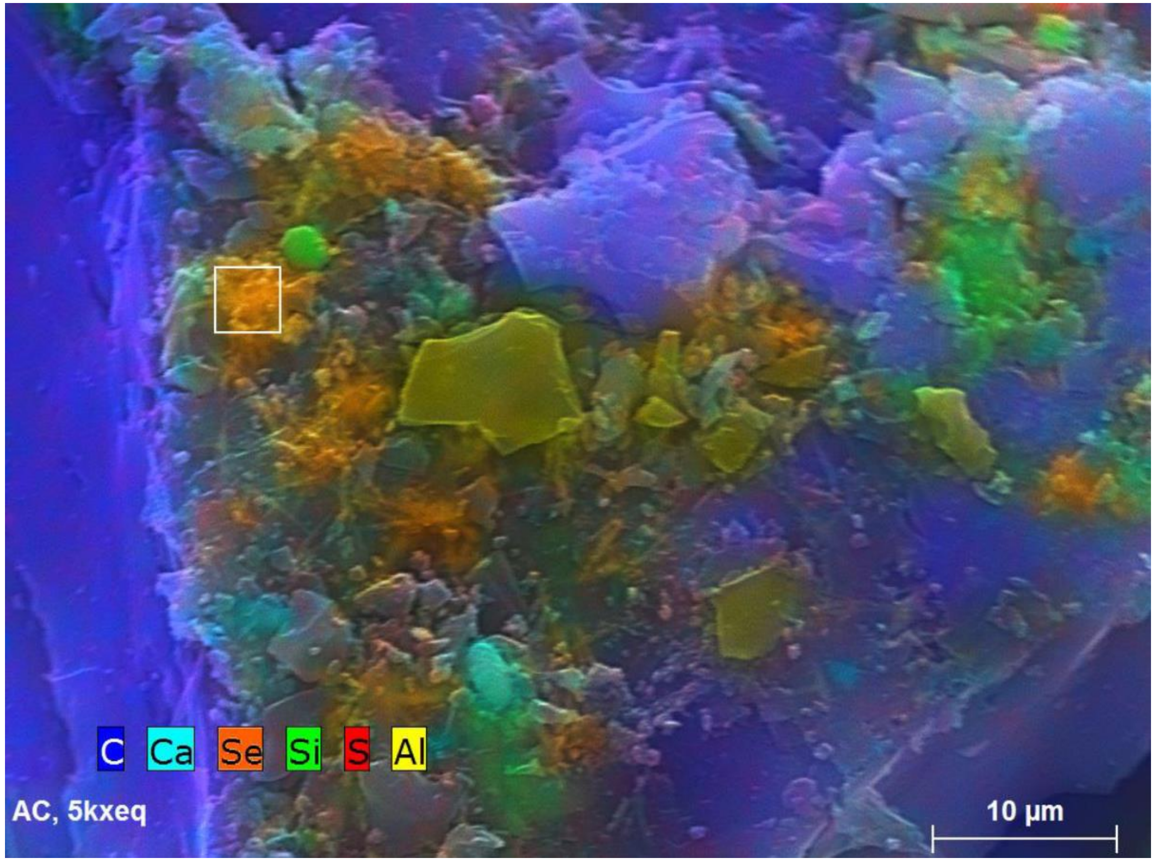
Selenium Accumulation Bioreactor Carbon Media



Elements	Wt%
Carbon	87.38
Oxygen	8.28
Selenium	**2.30**
Silicon	0.61
Aluminum	0.55
Sulfur	0.47
Calcium	0.41

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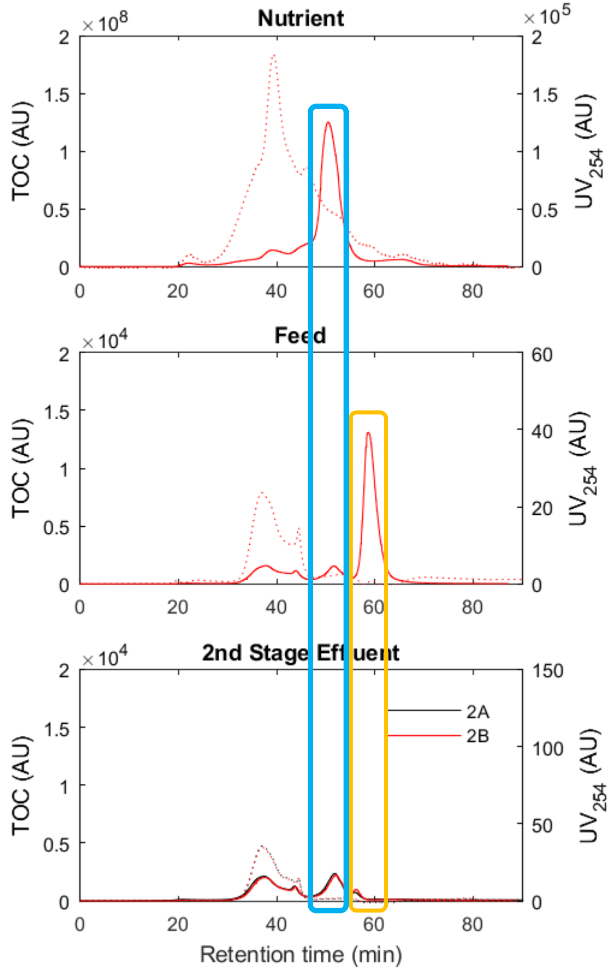
Bioreactor as Reverse Osmosis Pretreatment?

- Organic matter in feed and nutrient added is removed
- Organically bound iron?

Iron non-issue bioreactor pretreated



Size exclusion chromatography (SEC) with UV absorbance (254 nm) and TOC detectors

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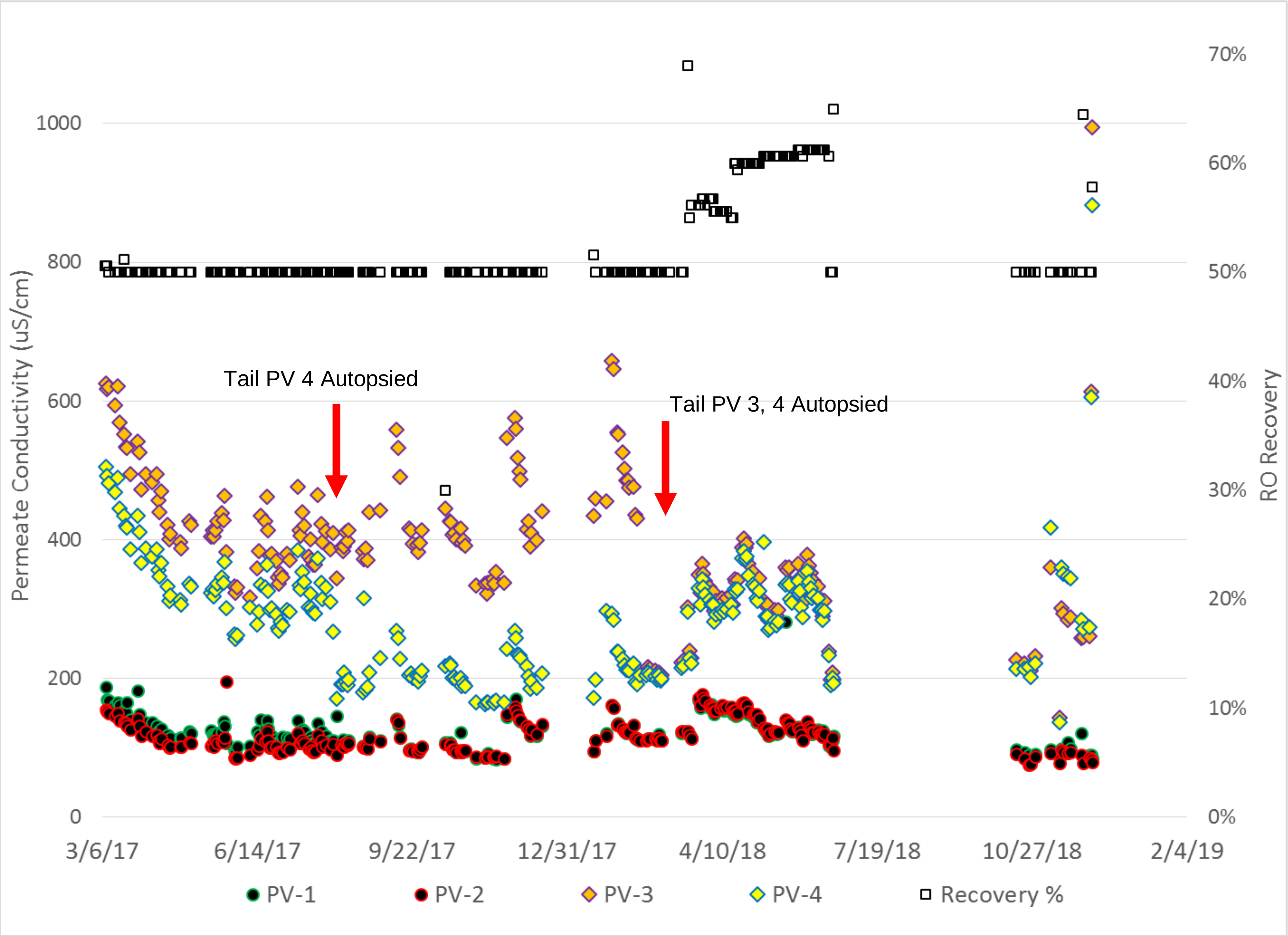
Reverse Osmosis Performance



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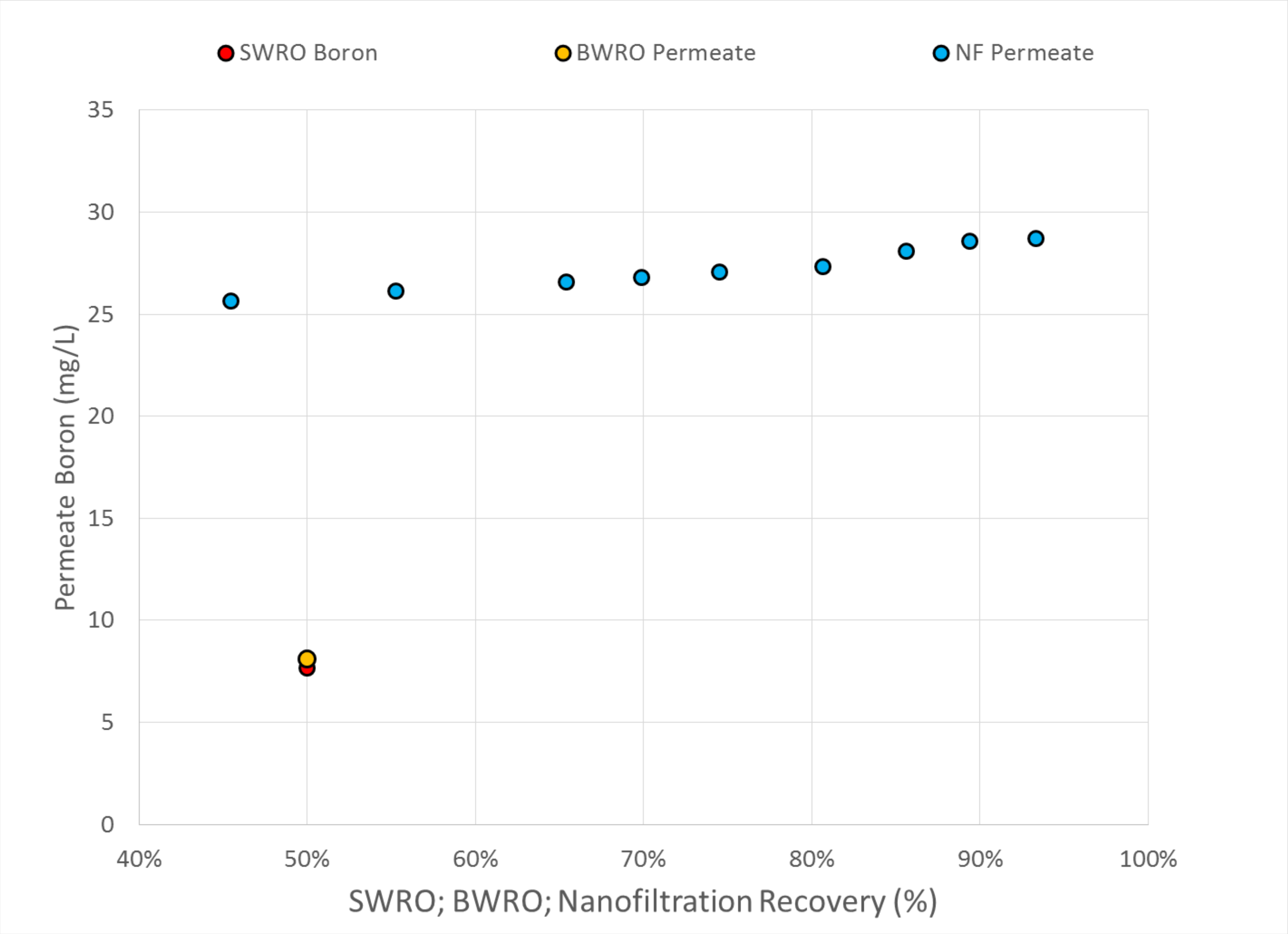
Reverse Osmosis Not for Everything



Final Thoughts

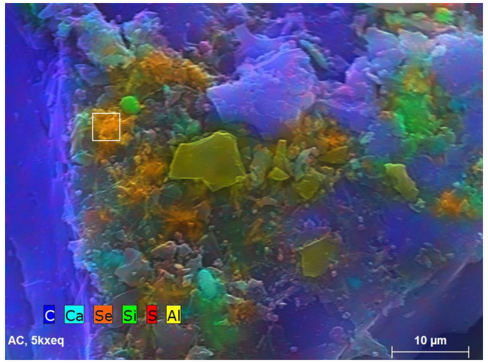
Soil Improvements

- Gypsum (calcium sulfate, $CaSO_4$)
  - Widely used
  - Soil flocculant for increased water permeability
  - Displaces sodium – sulfur source
  - Makes drainage water **VERY** difficult to treat

- Biochar (C, O, N, and ash)
  - Pyrolyzed biomass from any number of (preferably waste) sources (pine, manure, husks, bones, etc.)
  - Generally increases water holding capacity of soil
  - Supports microorganism attachment but degradation times very long (>1,000 years)

Solid Waste

Bioreactor media hazardous



Zero Liquid Discharge

Solids generation

$$0.017 \frac{\text{kg}}{\text{L}} \text{TDS} \bullet 2.2 \frac{\#}{\text{kg}} \bullet 3.78 \frac{\text{L}}{\text{gal}} \bullet 1 \frac{\text{MG}}{\text{day}} =$$

142,000 pounds per day per MG

Questions?

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