Passive biological treatment approaches to reduce conductivity in waters affected by mine drainage:

key challenges and research needs

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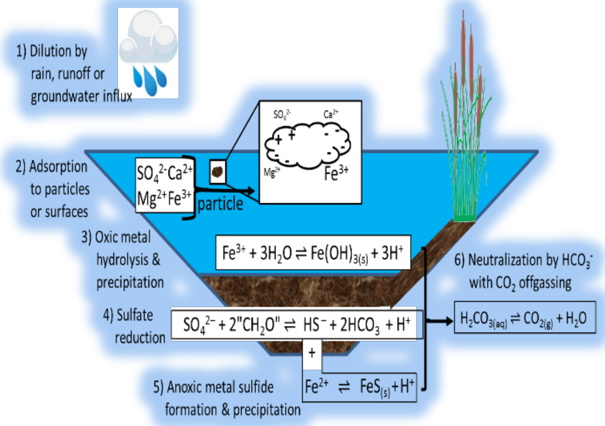
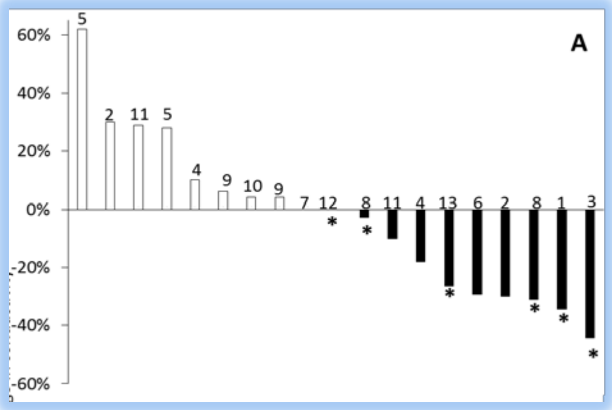
Overview

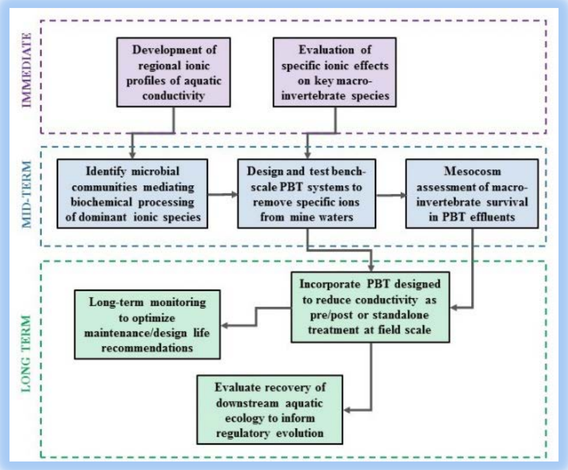
Background



Methods



Results



Future Work

Overview

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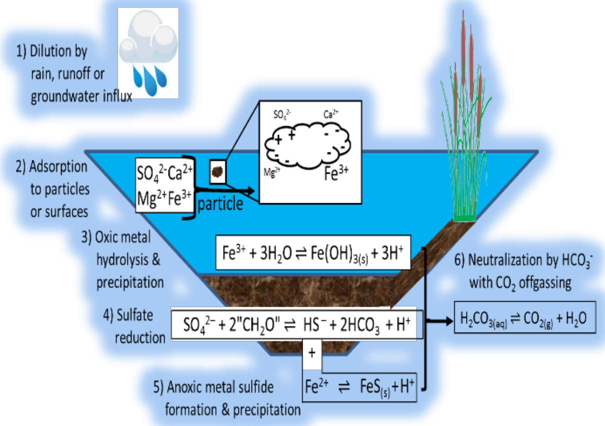

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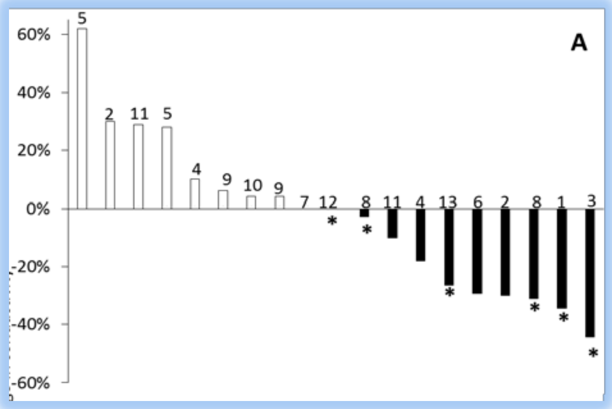

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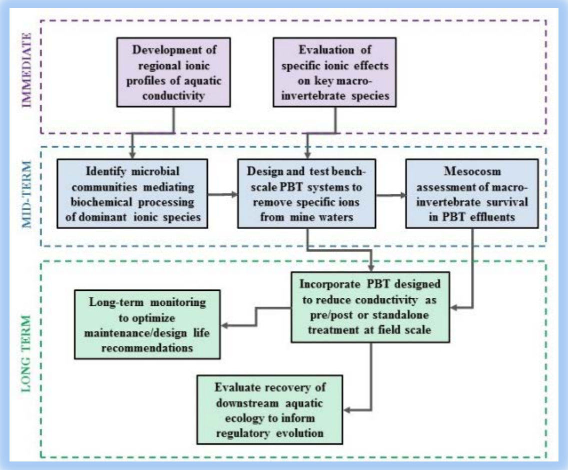


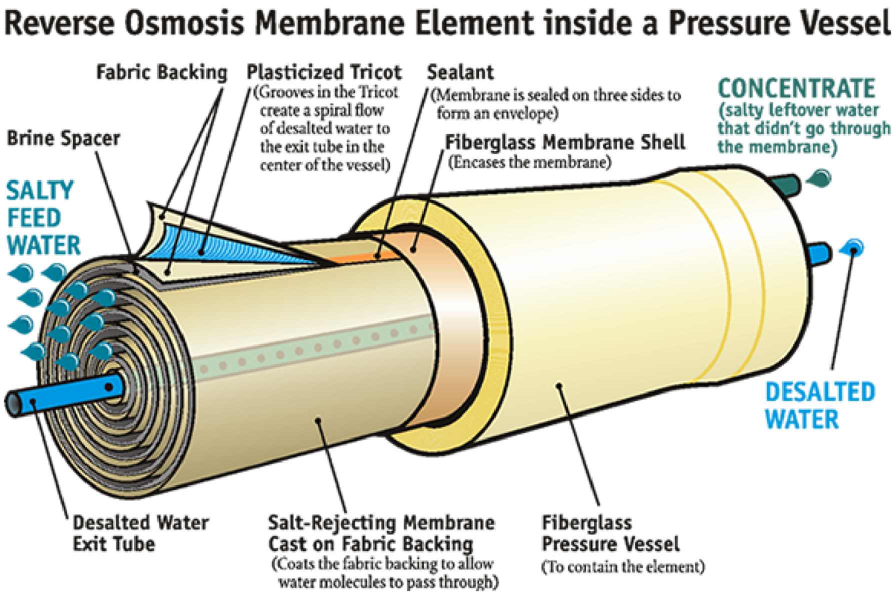
Future Work

Why Care About Conductivity?

- Aquatic habitat degradation linked to conductivity
  - Is it the ions or salinity?

- Moving towards conductivity regulation
  - EPA has proposed limits
    - **300 µS/cm** in Appalachia

Current Approaches…



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- Adsorbents
- Desalination
- Ion exchange
- Chemical precipitation
- Membrane filtration
  - Reverse osmosis

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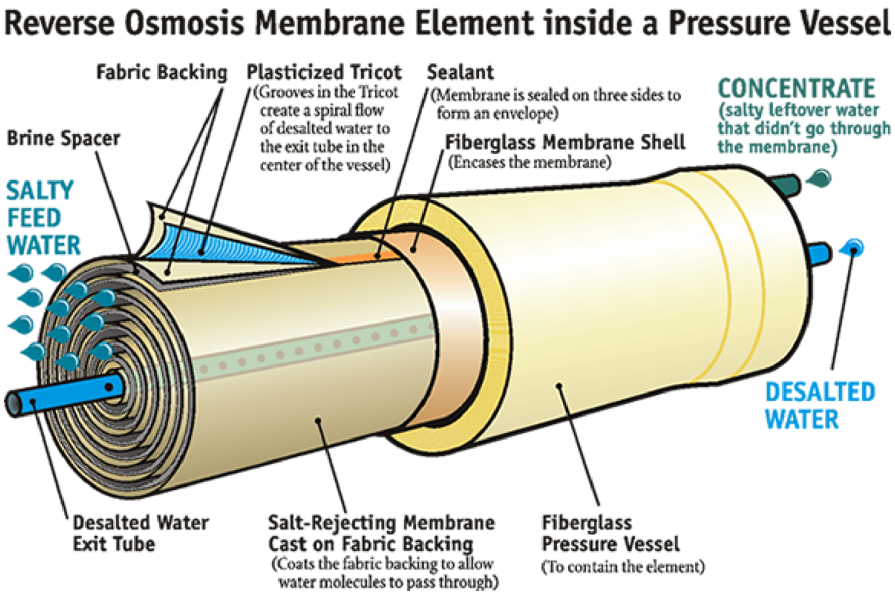

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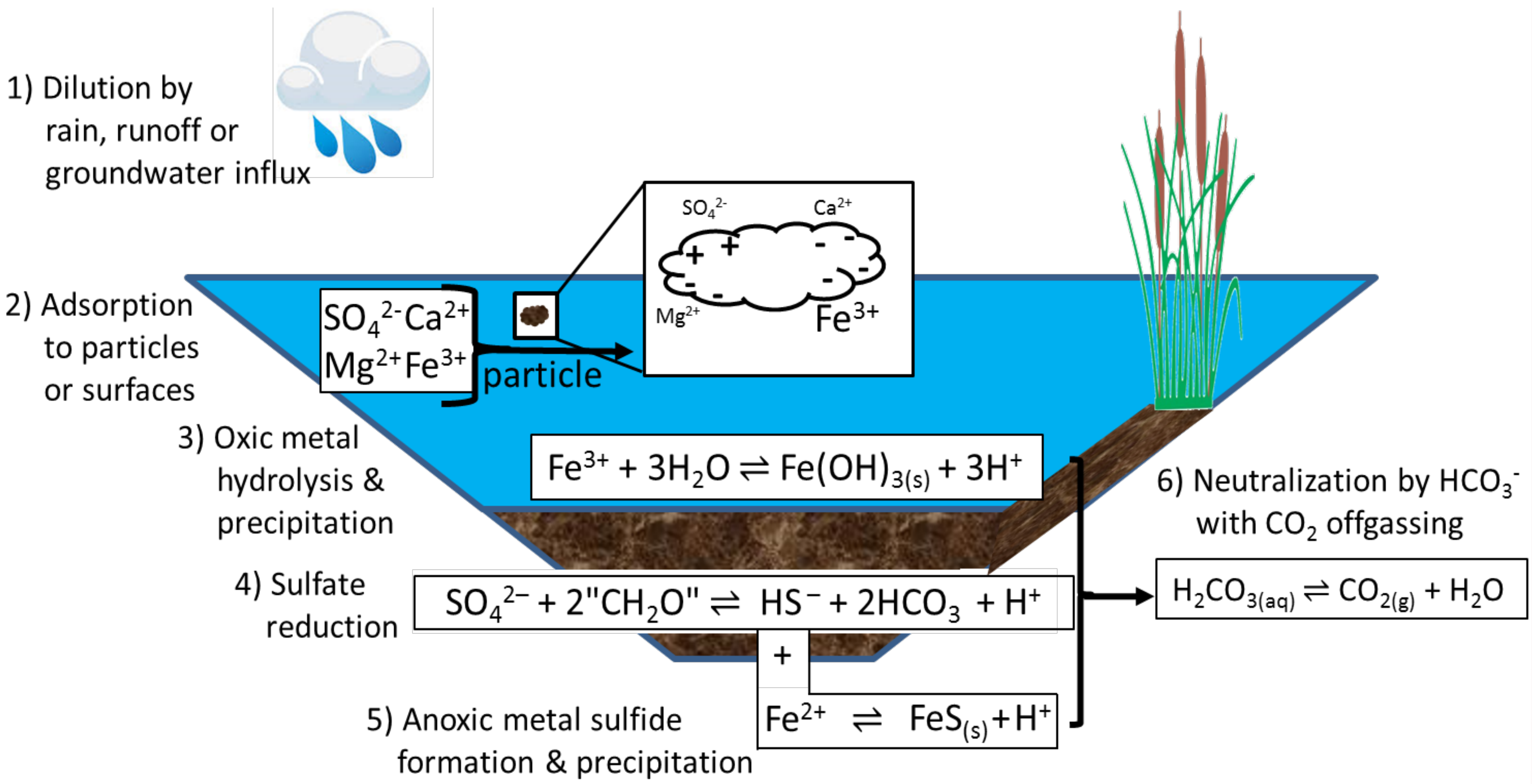
A Role for Passive Treatment?

- The scope of passive treatment has continually broadened since its inception
  - Treatment wetlands
    - OLCs
      - ALDs
        - SAPS
          - Bioreactors
            - Co-treatment
              - ???

Passive Possibilities



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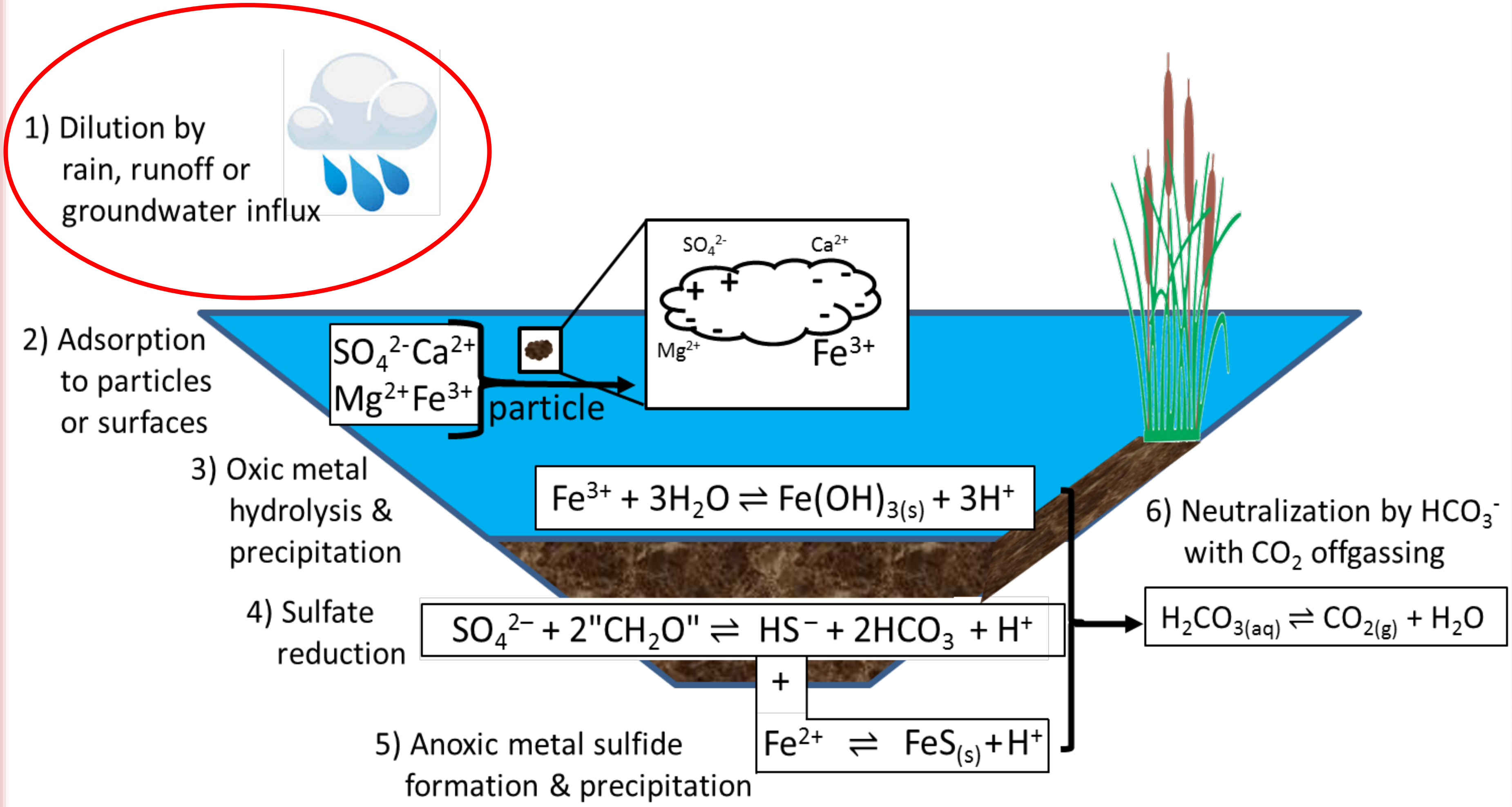

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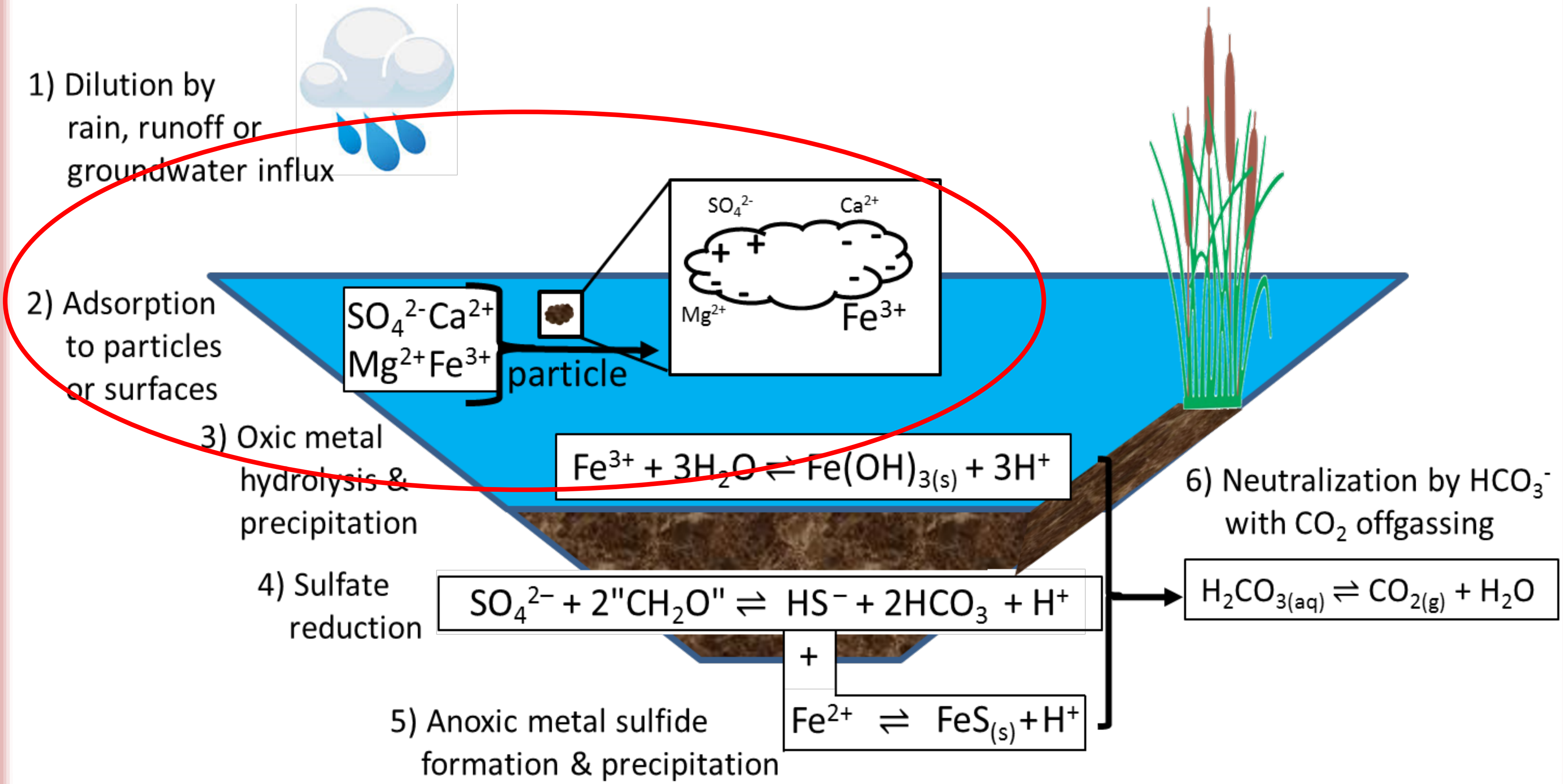

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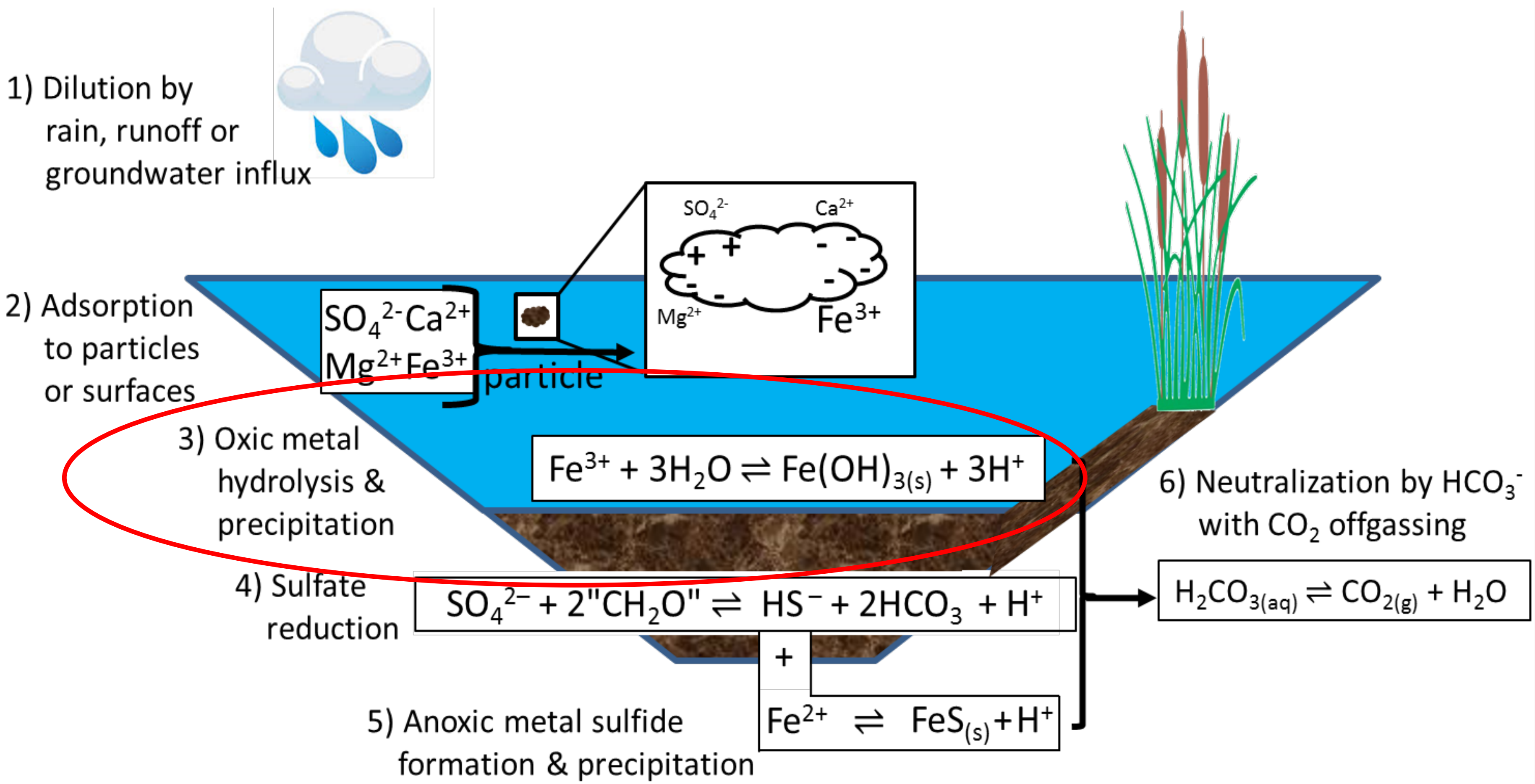

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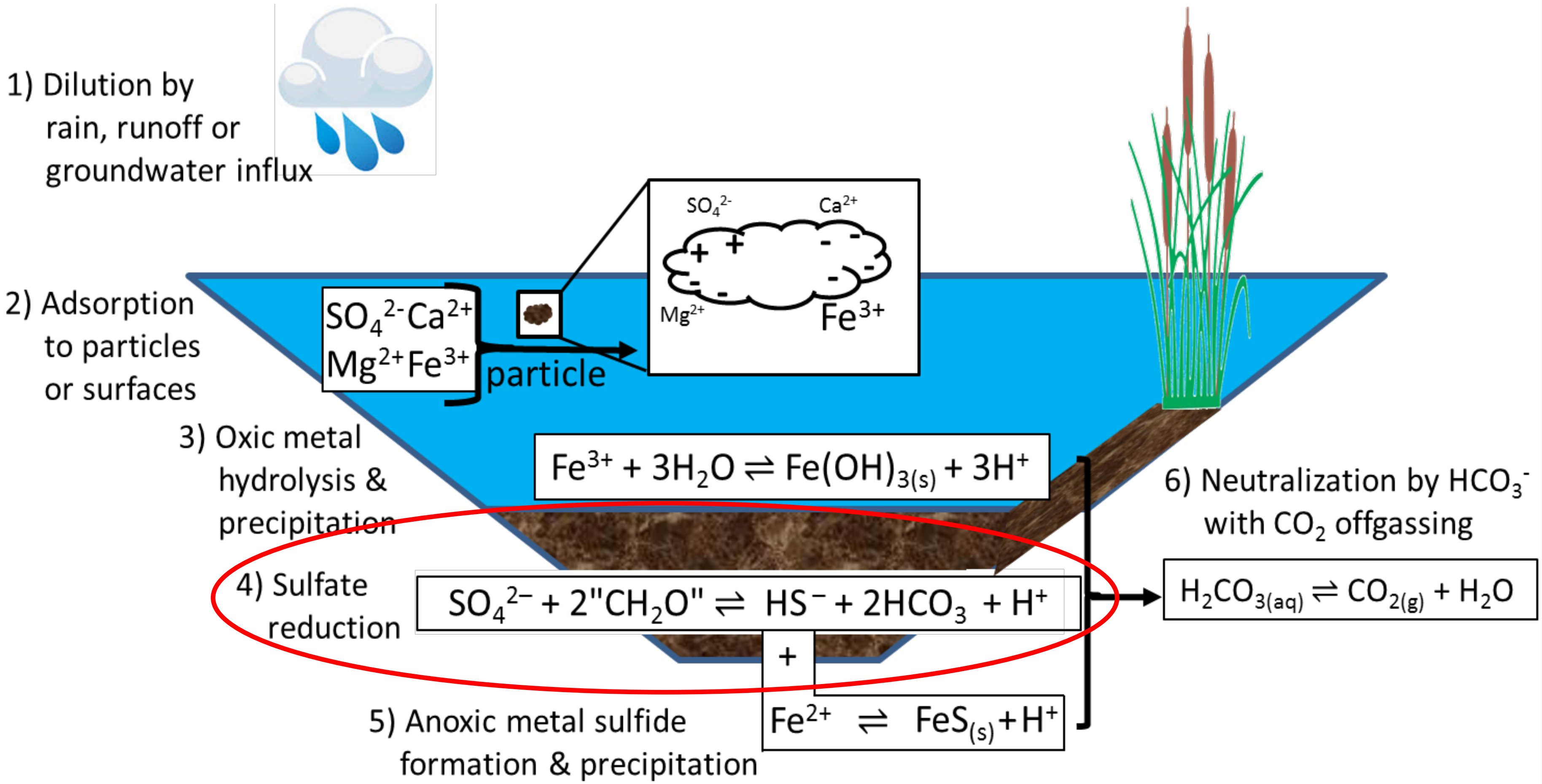

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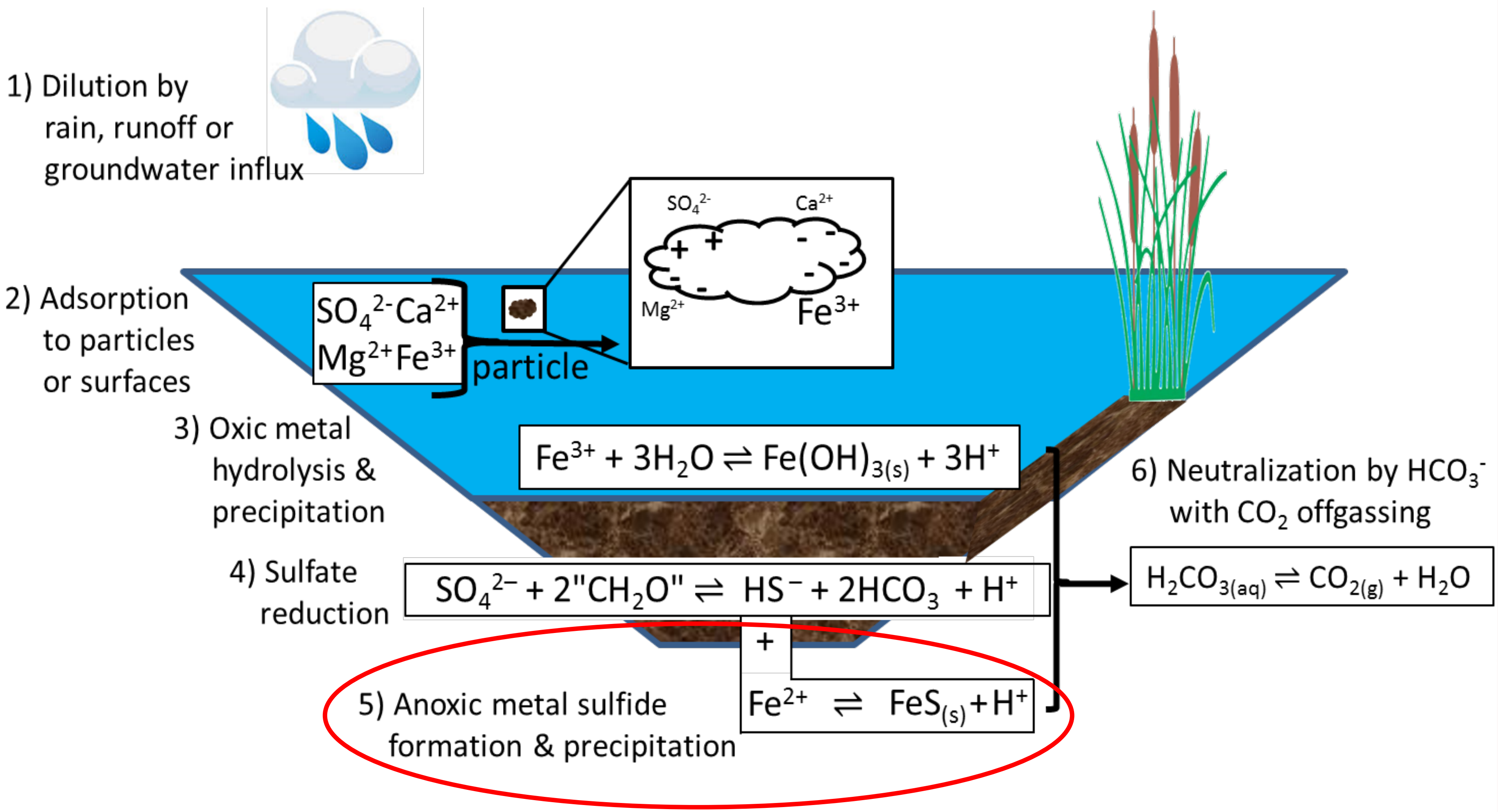

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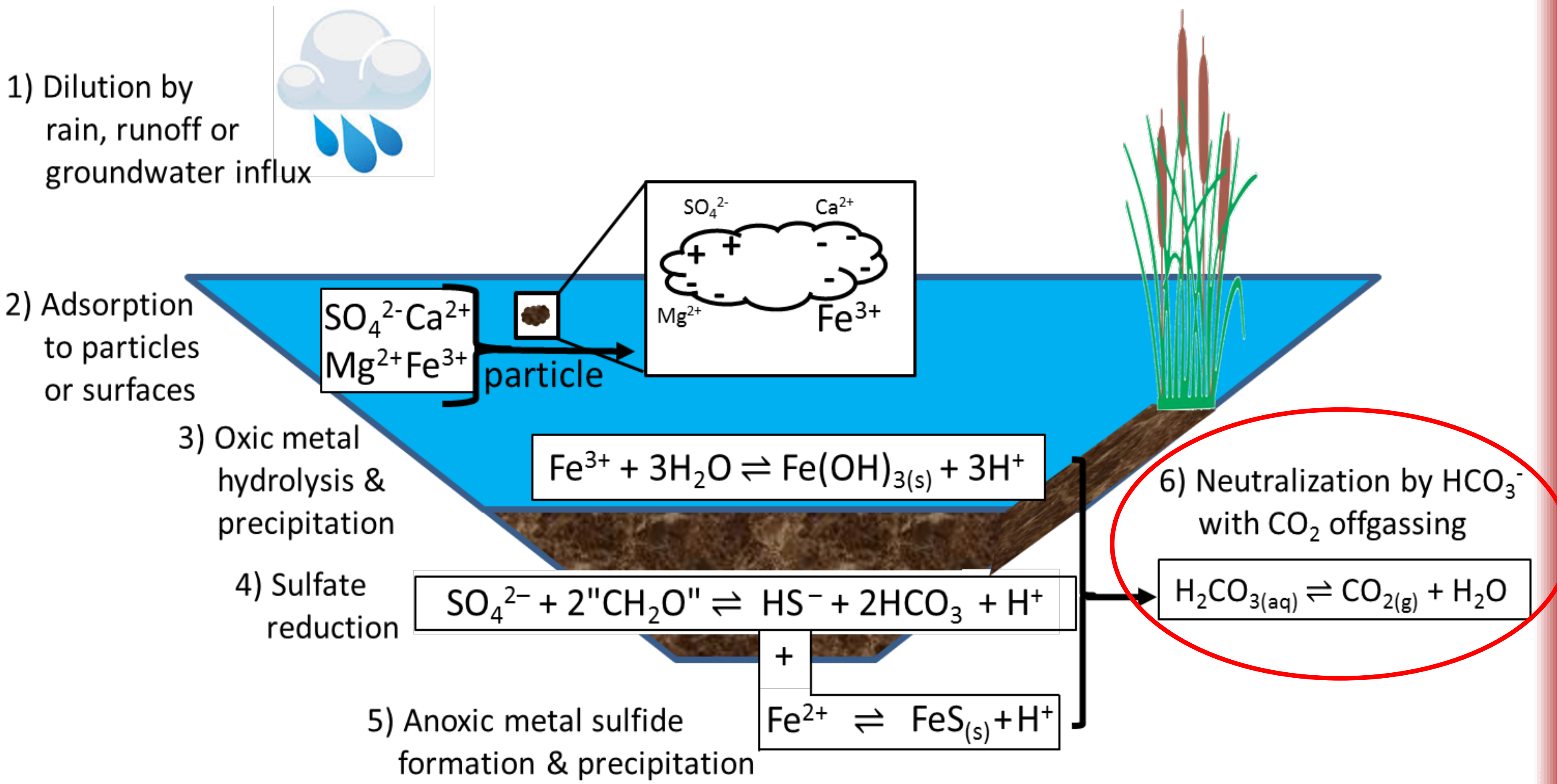

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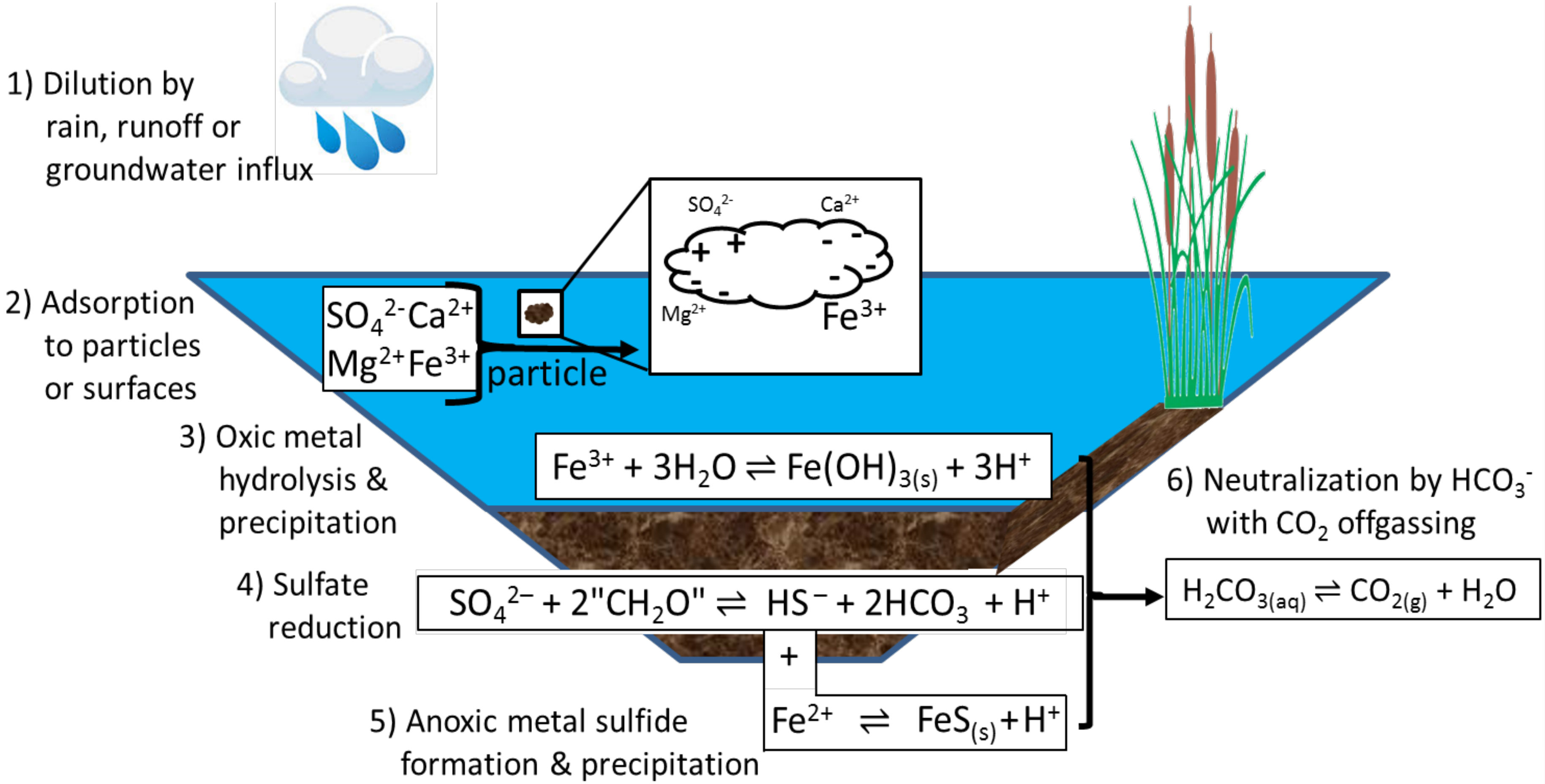

However, no analysis exists in the literature

Overview

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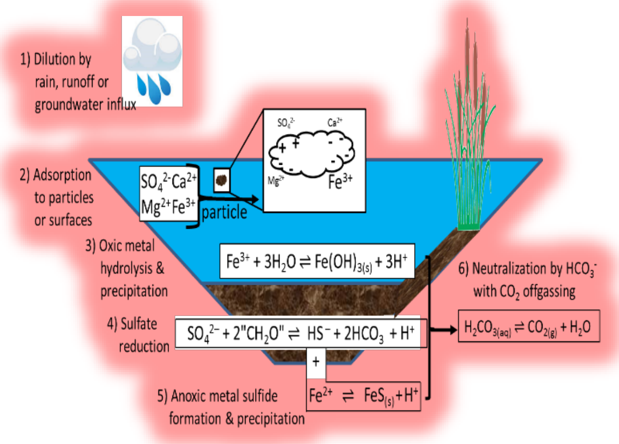

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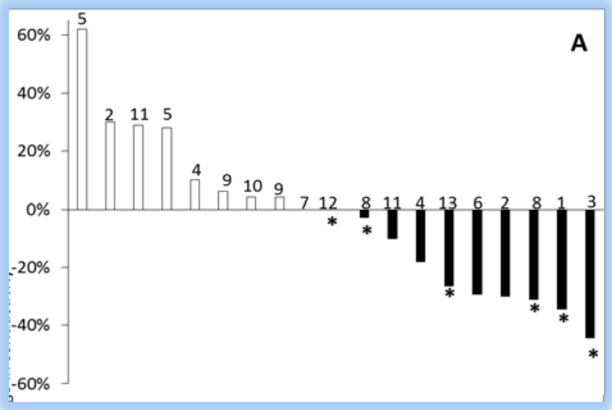

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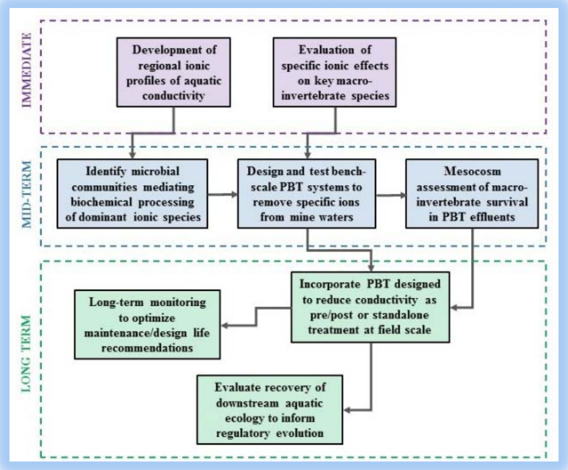


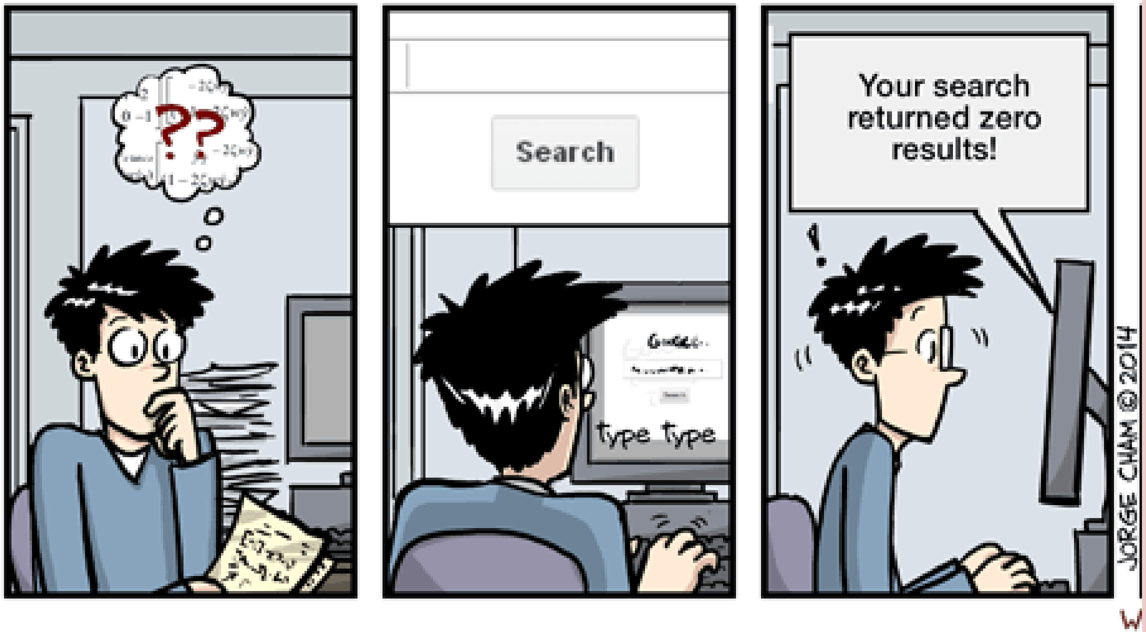
Interpretation

Methodology

- Defined "passive biological treatment" as systems with a significant biotic component
- Literature search for:
  - Wetlands
  - Oxidation ponds
  - Vertical flow bioreactors (i.e., RAPS, SAPS, etc.)

Methodology

- Peer-reviewed journals
  - Google Scholar & WorldCat
- Proceedings
  - IMWA
  - WVMDTF
  - ASSMR & ASMR



Hoping for "extraneous" data!

Overview

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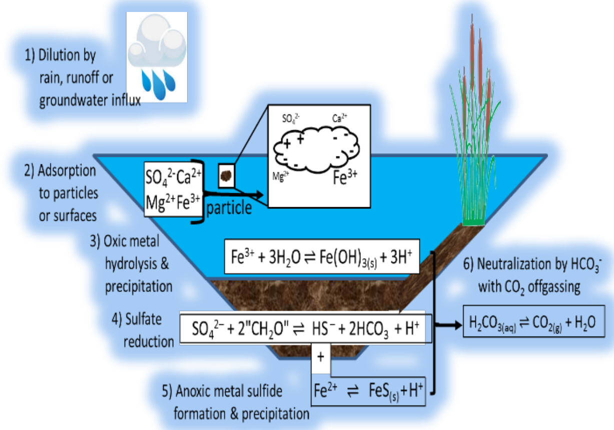

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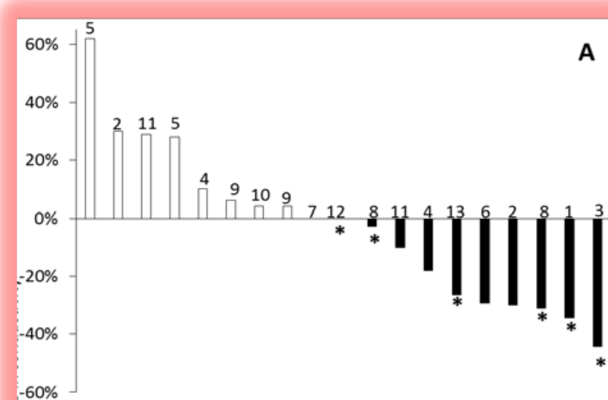

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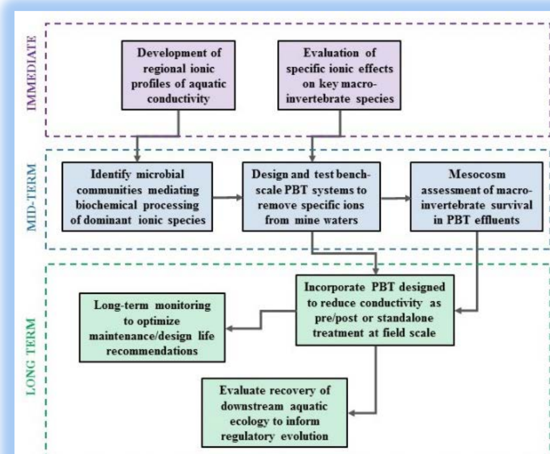


Future Work

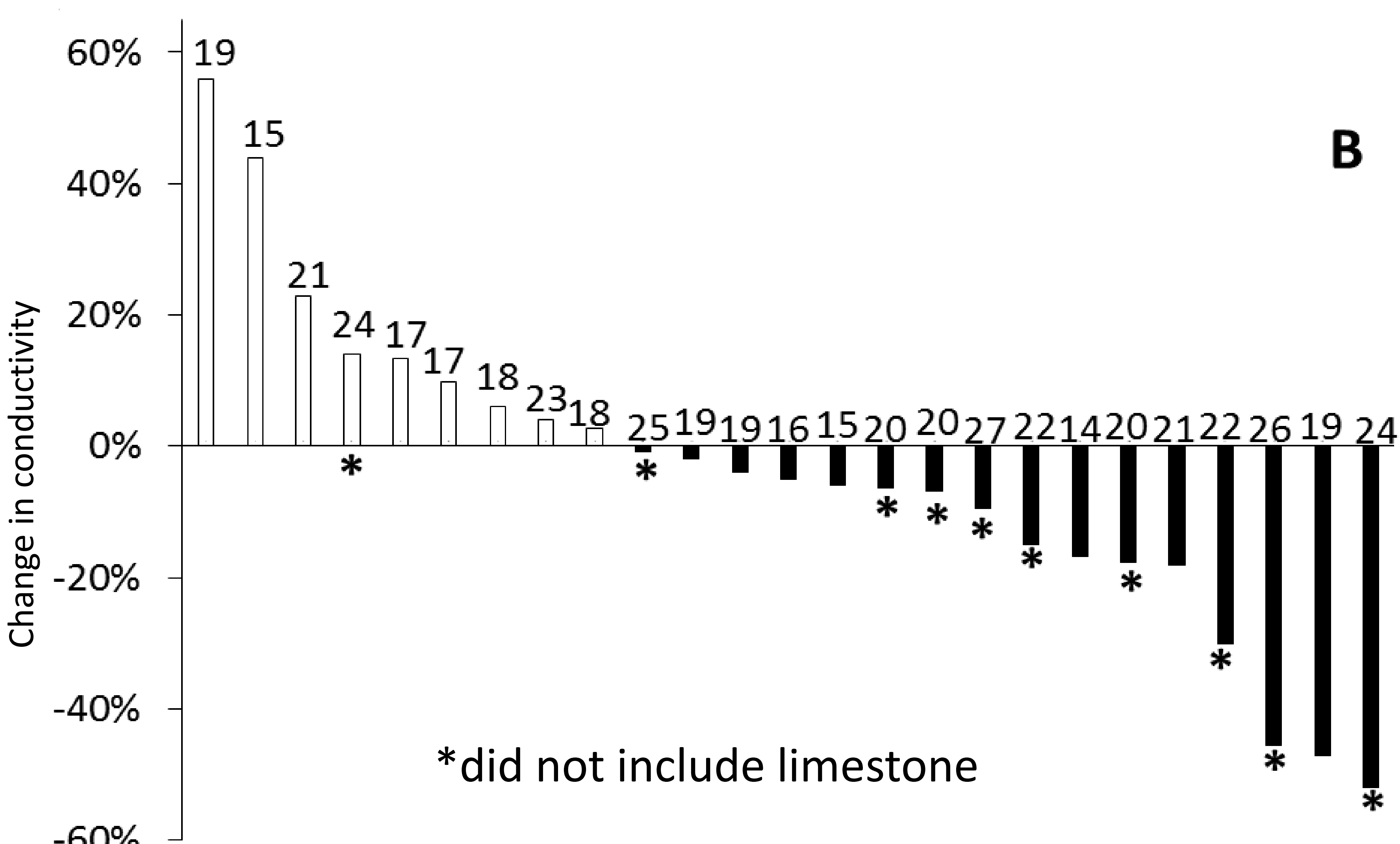
Results

- 9 publications in peer-reviewed journals

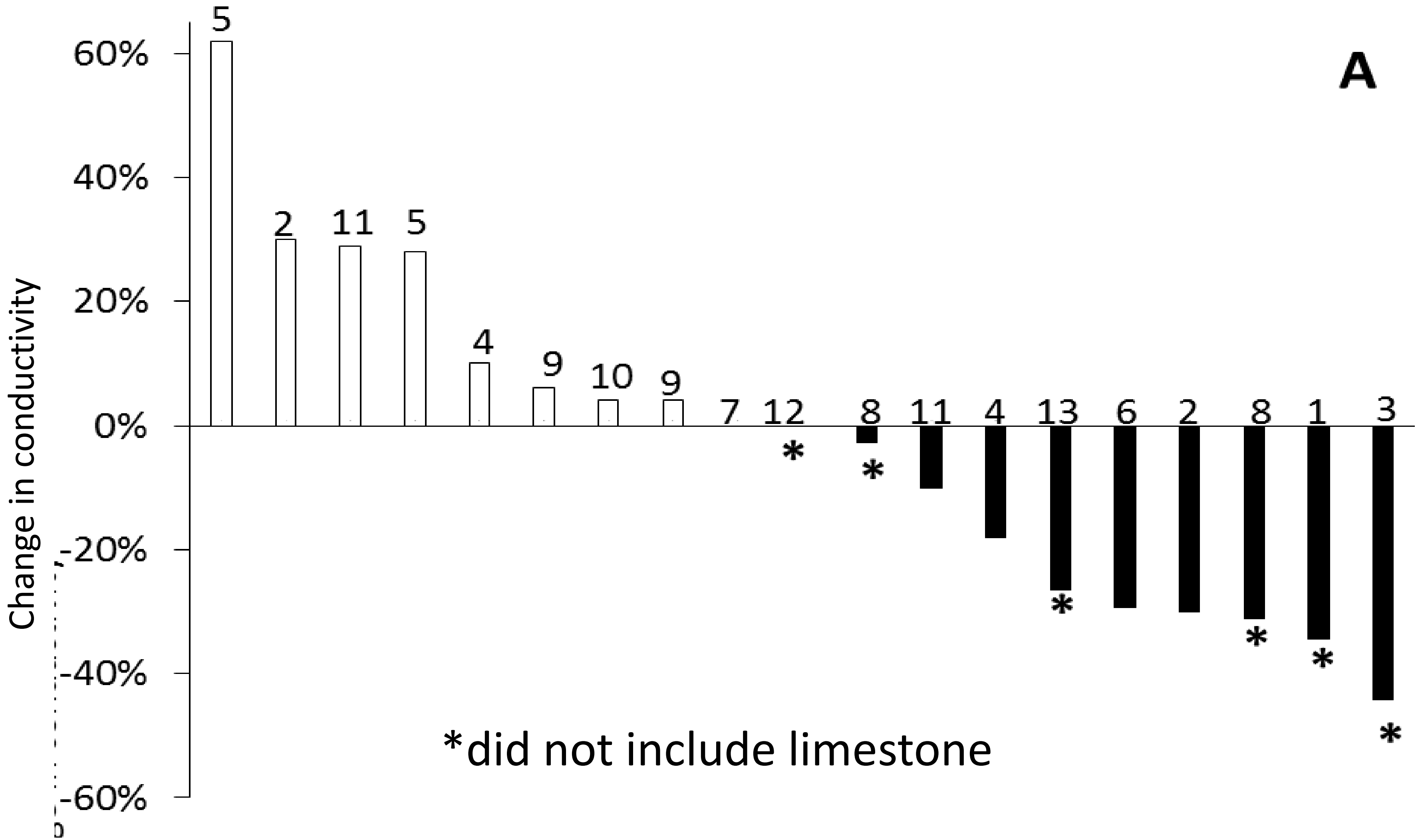
- 18 studies in conference proceedings
  - Some with multiple systems

Reference	Region	Treatment Type	Conductivity ($\mu s\ cm^{-1}$) Influent	Effluent	% Change
[1]Fyson et al. 1998	Germany	Lab scale VFB	1600	1200	-25%
[2]Keppler et al 1999	West Virginia & Pennsylvania	Field scale VFB	1000-3400	930-2560	-30 to +30%
[3]Fyson et al. 2006	Germany	Lab scale VFB	1033	576	-44%
[4]Pahler et al 2007	Colorado	Field scale VFB	3430 - 5760	3360 - 5560	-18 to +10%
[5]Blumenstein et al 2008	California	Lab scale VFB	2900	3700-4700	28 to 62%
[6]Gusek et al 2008	California	Field scale VFB	1453	1027	-29%
[7]Blumenstein et al 2009	California	Field scale VFB	3000	3000	0
[8]Kumar et al 2011	Australia	Lab scale VFB	11000	10700	-3%
[8]Kumar et al 2011	Australia	Lab scale VFB	10300	7100	-31%
[9]Gandy & Jarvis 2012	England	Lab scale VFB	580	615	6%
[9]Gandy & Jarvis 2012	England	Field scale VFB	580	604	4%
[10]Song et al. 2012	South Korea	Field scale VFB	2400	2500	4%
[11]Santamaria 2014	Oklahoma	Lab scale VFB	1200 - 1320	1150 - 1550	-10 to +29%
[12]Yim et al. 2015	South Korea	Field scale VFB	2000	2000	0%
[13]Marcillo et al. in review	Pennsylvania	Lab scale VFB	863	635	-26%
[14]Tarutis & Unz 1990	Pennsylvania	Constructed wetlands	711	592	-17%
[15]Wildeman et al 1993	Colorado	Constructed wetlands	8000 - 10830	9240 - 12200	-6 to 44%
[16]Stark et al 1994	Ohio	Constructed wetlands	1790	1702	-5%
[17]Sikora et al 1996	Alabama	Constructed wetlands	1120	1230 - 1270	9.8 to 13%
[18]Heil and Kerins 1998	Montana	Constructed wetlands	3349	3440	3%
[18]Heil and Kerins 1998	Montana	Constructed wetlands	2414	2559	6%
[19]Skousen et al 1999	West Virginia	Constructed wetland & anoxic limestone drain	900	880 - 1400	-2 to +56%
[19]Skousen et al 1999	West Virginia	Constructed wetland & anoxic limestone drain	4700	1200 - 4500	-47 to - 4%
[20]Hilton et al 2003	Pennsylvania	VFB & constructed wetland	1880	1760	-6%
[20]Hilton et al 2003	Pennsylvania	VFB & constructed wetland	1432	1335	-7%
[20]Hilton et al 2003	Pennsylvania	VFB & constructed wetland	1140	939	-18%
[21]Rose et al 2004	Pennsylvania	VFB & constructed wetland	1100 - 3210	900 - 3210	-18 to +23%
[22]Sheoran 2005	India	Natural wetland	7240 - 8153	7082 - 5474	-15 to -30%
[23]Behum et al 2006	Oklahoma	Constructed wetland	480	500	4%
[24]Sheoran 2006	India	Lab scale constructed wetland system	1520 - 1590	737 - 1810	-52 to +14%
[25]Cravotta 2007	Pennsylvania	Oxidation pond & constructed wetlands	517	513	-1%
[26]Eger et al 2007	Minnesota	Natural wetland	1100	600	-45%
[27]Hedin 2013	Pennsylvania	Oxidation pond & constructed wetlands	2688	2434	-9%

“Wetlands / Ponds”



“Vertical Flow Bioreactors”



Sulfate Reduction

- Theory matching results
  - 27-37% decrease in conductivity possible with typical AMD
    - Replacing all sulfate with bicarbonate
    - Further reduction possible with metals to form metals sulfides
  - Up to 44% decrease noted

Limestone

- Limestone-free reduced conductivity better
  - Only 1 of 16 systems without limestone caused increase in conductivity
  - 4 of 5 top conductivity reducers were limestone free

Overview

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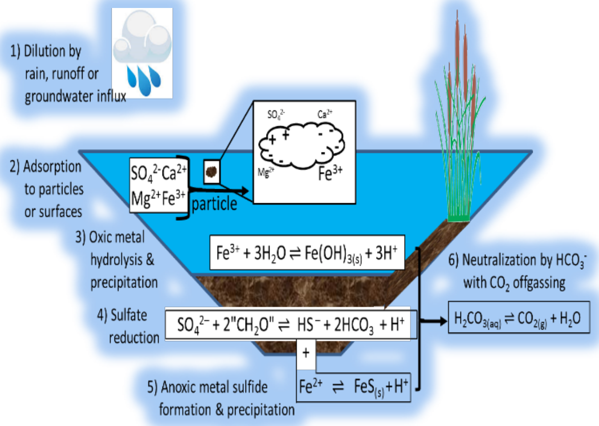

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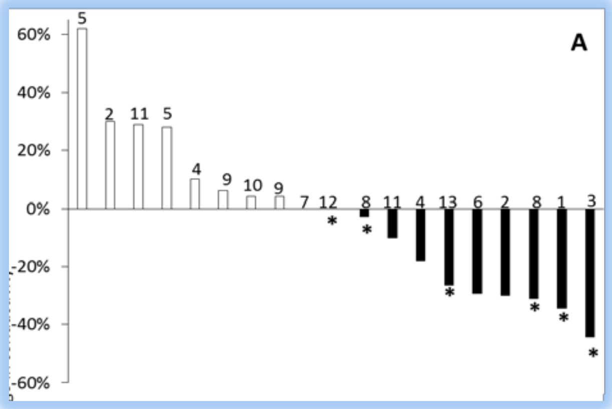

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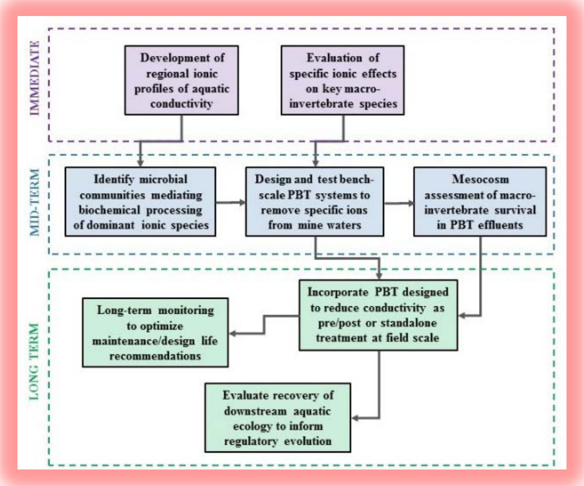


Future Work

Design Challenges

- Sulfate reduction is primary possibility
  - However 30-40% decrease in conductivity is max predicted by stoichiometry
    - And max noted in our review
- How to maximize for conductivity removal without losing critical metal treatment?

Issues and Challenges

- Low pH drainage may be better fit
  - Bicarbonate reaction with H+
- Net alkaline drainage may be more difficult
- Seasonality
- Discharge sources

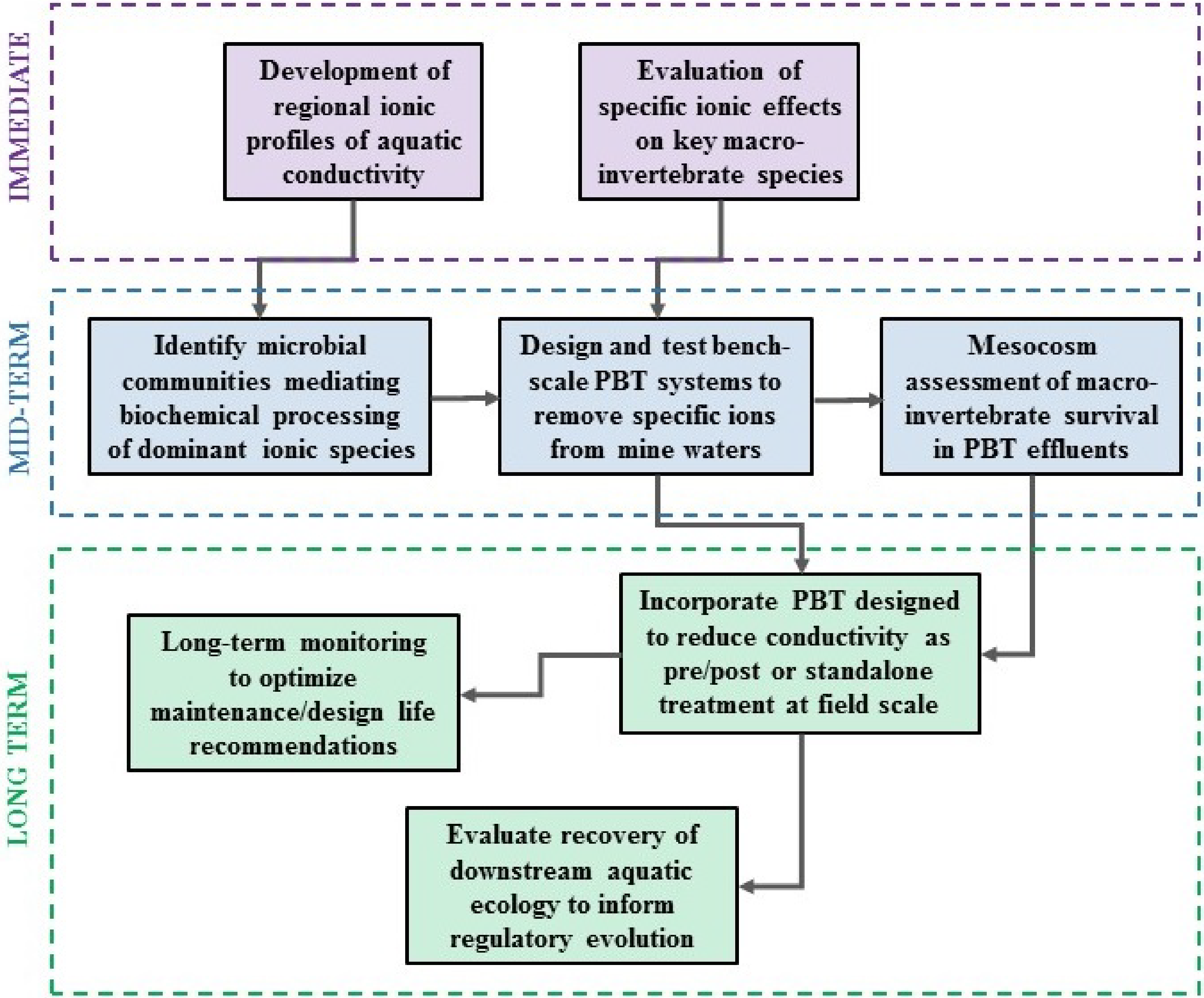
Is it Really Conductivity?

- SC/ sulfate correlation has been noted…but...
  - Elevated conductivity persists but metals are in sediments
  - “islands” of reaches with good water quality, high conductivity, but low richness/diversity
  - Impacts of unsteady treatment
    - Years to rebound

Issues with Regulating Conductivity

- The toxicity of ions is not equal
- Regional baseline conductivity profiles are quite variable
- Competitive inhibition (e.g. Ca^{2+} vs. Zn^{2+})

Future Work


IMMEDIATE
Development of regional ionic profiles of aquatic conductivity
Evaluation of specific ionic effects on key macro-invertebrate species
MID-TERM
Identify microbial communities mediating biochemical processing of dominant ionic species
Design and test bench-scale PBT systems to remove specific ions from mine waters
Mesocosm assessment of macro-invertebrate survival in PBT effluents
LONG TERM
Incorporate PBT designed to reduce conductivity as pre/post or standalone treatment at field scale
Long-term monitoring to optimize maintenance/design life recommendations
Evaluate recovery of downstream aquatic ecology to inform regulatory evolution

Thanks & Support

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