Sources of Iron (Fe) and Factors Regulating the Development of Flocculate from Fe-Oxidizing Bacteria in Regenerative Streamwater Conveyance Structures (RSCs)

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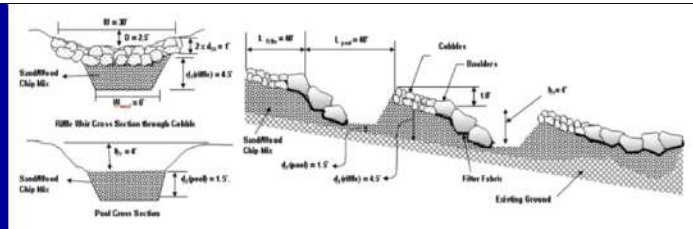
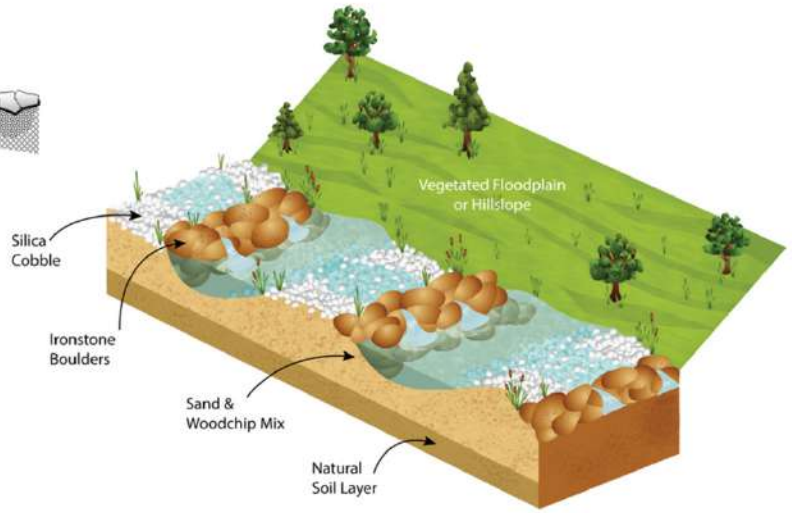
Impetus of Study

- Flocculate from Fe-oxidizing bacteria is ubiquitous in streams of the region (viz. the Coastal Plain)
- Flocculate mat densities in RSCs may be enhanced by allochthonous Fe and/or hydrological alterations
- Deleterious effects of flocculate include a reduction in macroinvertebrate habitat (smothering, avoidance) and and viable food sources (constipation)
- Other possible effects
  - Alteration of redox potential of benthic sediments
  - Reduced percolation
  - Heavy metal accumulation w/ high initial stormflow flux
  - Poor aesthetics

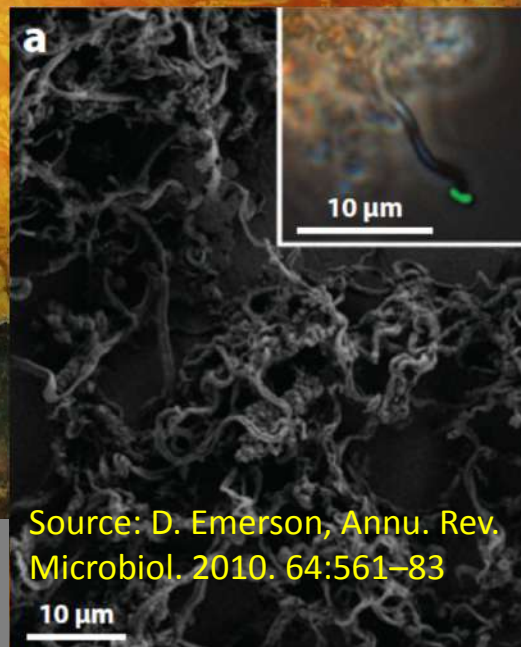
(RSC) Design





- Best management practice (BMP) intended to create habitat, reduce runoff, recharge groundwater, etc.
- Fill soil is used in badly incised channels to raise the grade
- Covered by mixture of 80% sand and 20% organic matter (soil, wood-chips, and leaves)
- Boulder weirs (Ironstone, also called Bog Iron) and silica-cobble are used to create a series of stepped pools separated by riffles

Fe-Oxidizing Bacteria



Source: D. Emerson, Annu. Rev. Microbiol. 2010. 64:561–83

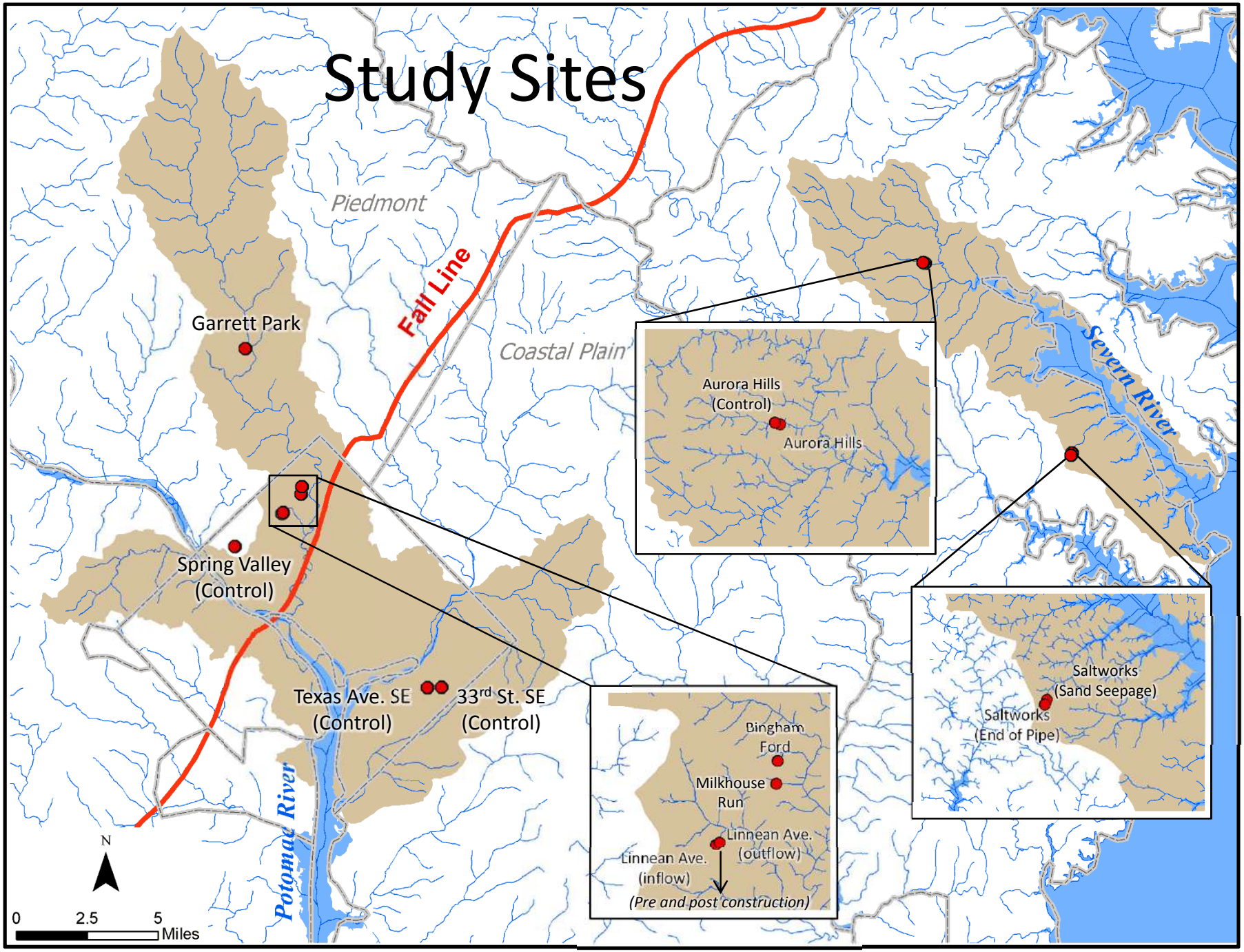
Gallionellales (e.g., *Gallionella ferruginea*) - Helical stalk-forming
Leptothrix ochracea - Tubular sheath-forming

Research Questions

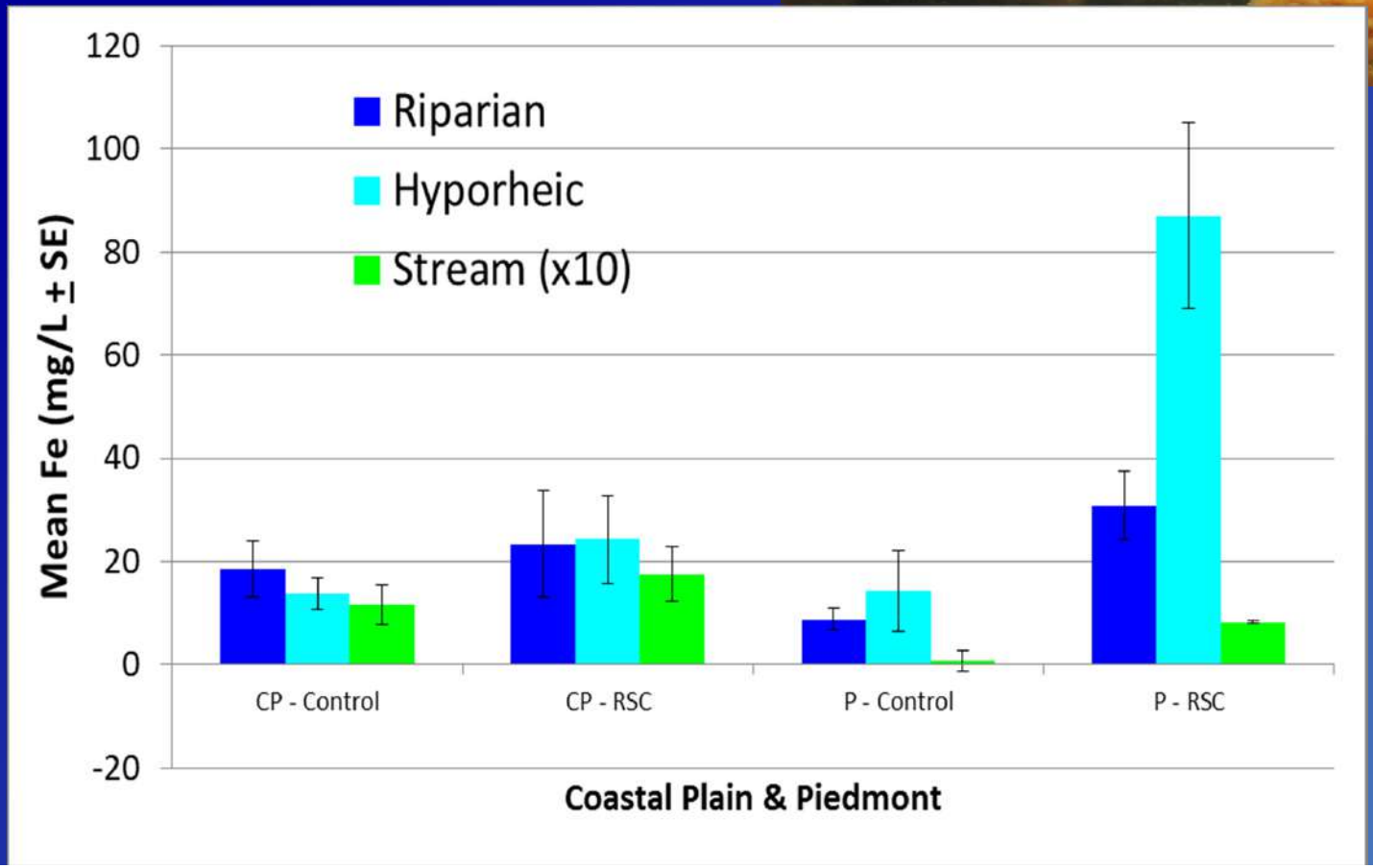
- What are sources of Fe and carbon in RSCs?
- Are Fe and dissolved organic carbon (DOC) concentrations higher in ground and stream water in RSCs than in controls?
- Is Fe flocculate more prevalent in RSCs than in control streams?
- What conditions are needed to form flocculate?
- How does flocculate affect RSC habitat and performance?

Objectives and Methods

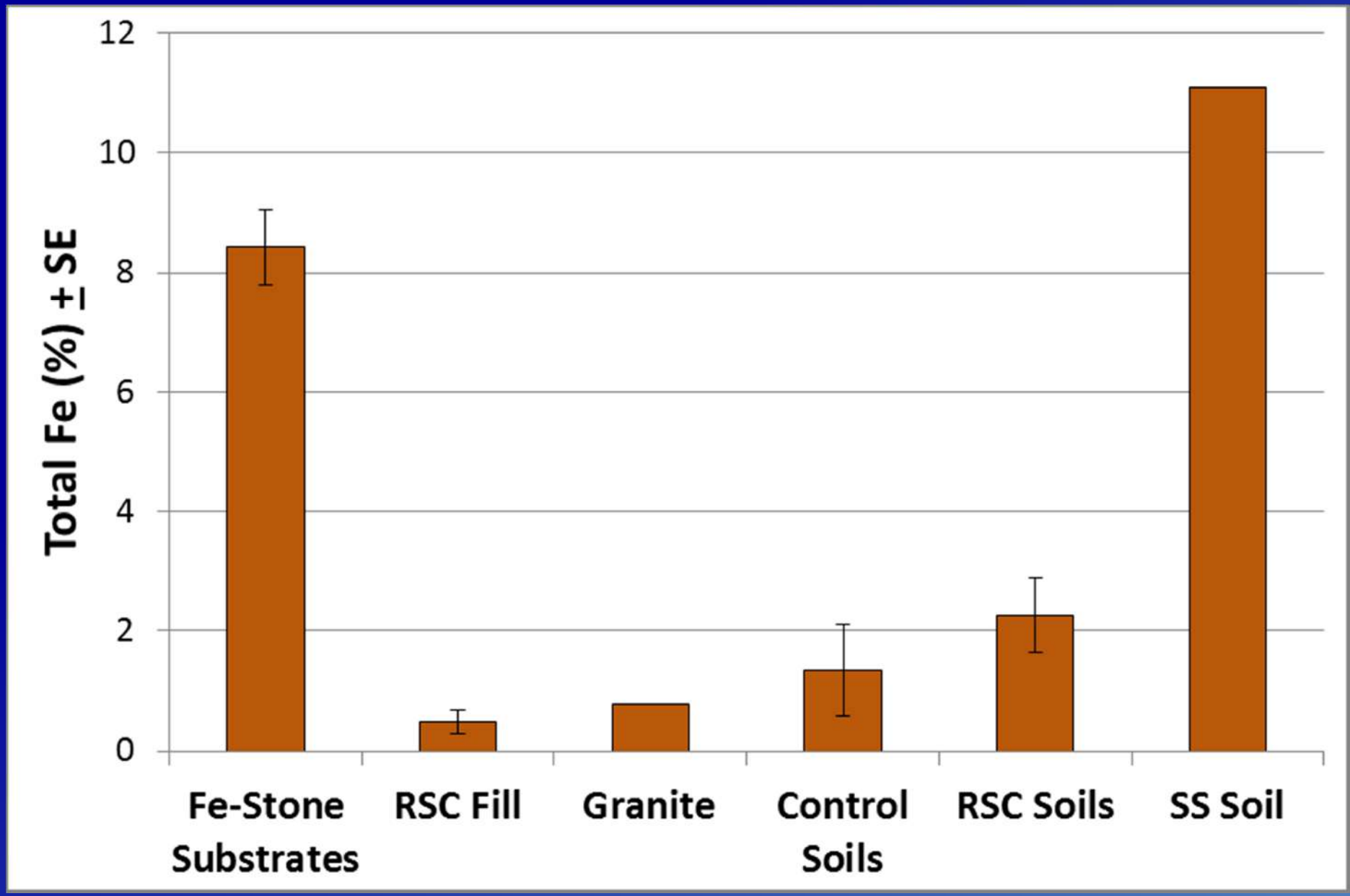
- Objectives
  - Compare control and RSC sites in the Coastal Plain and Piedmont physiographic provinces to determine:
    - prevalence of Fe-oxidizing bacteria
    - Fe content of construction materials and soils
    - whether RSC construction materials and/or changes in hydrology increase [Fe] thereby enhancing flocculate formation
- Methods
  - Comparison of [Fe] in riparian and hyporheic wells, and surface water
  - Leaching experiment - construction materials and riparian soils with and w/o DOC addition
  - Comparison of pre- and post-construction water table levels in well transects and [Fe] in wells and stream water at intensively monitored Piedmont RSC site


Study Sites
Piedmont
Fall Line
Coastal Plain
Garrett Park
Spring Valley
(Control)
Texas Ave. SE
(Control)
33rd St. SE
(Control)
Potomac River
Severn River
Aurora Hills
(Control)
Aurora Hills
Saltworks
(Sand Seepage)
Saltworks
(End of Pipe)
Bingham
Ford
Milkhouse
Run
Linnean Ave.
(outflow)
Linnean Ave.
(inflow)
(Pre and post construction)
N
0
2.5
5
Miles

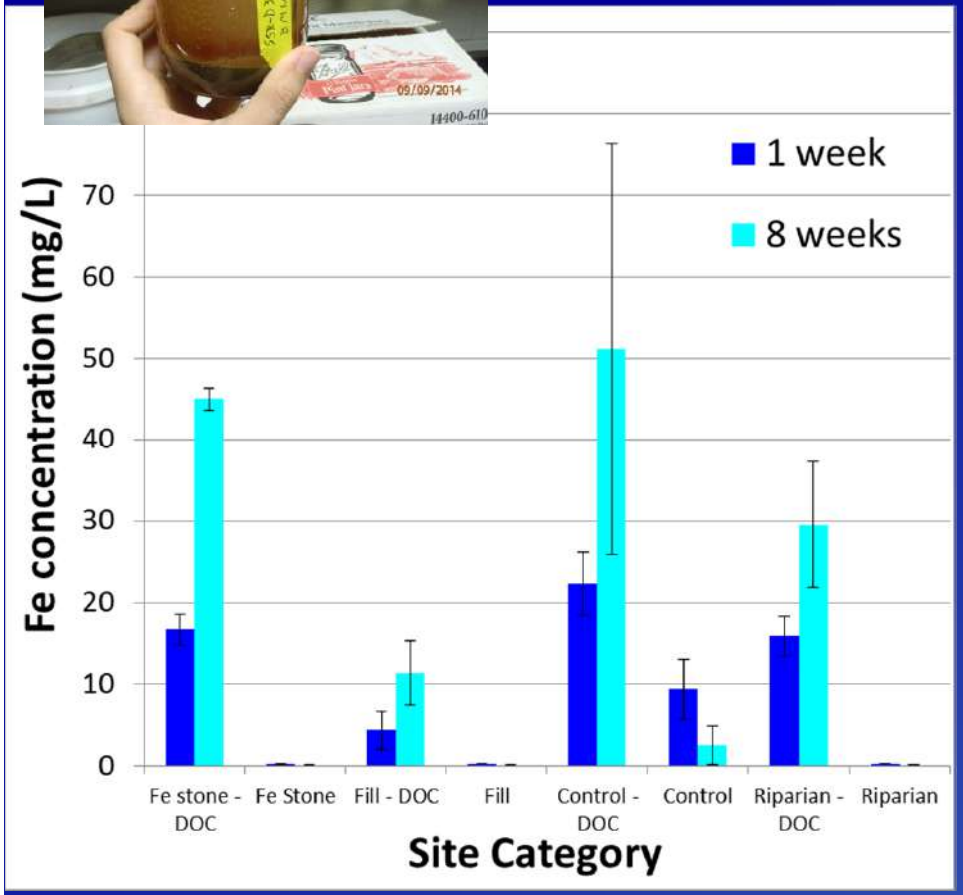
[Fe] Higher in RSCs than in Controls

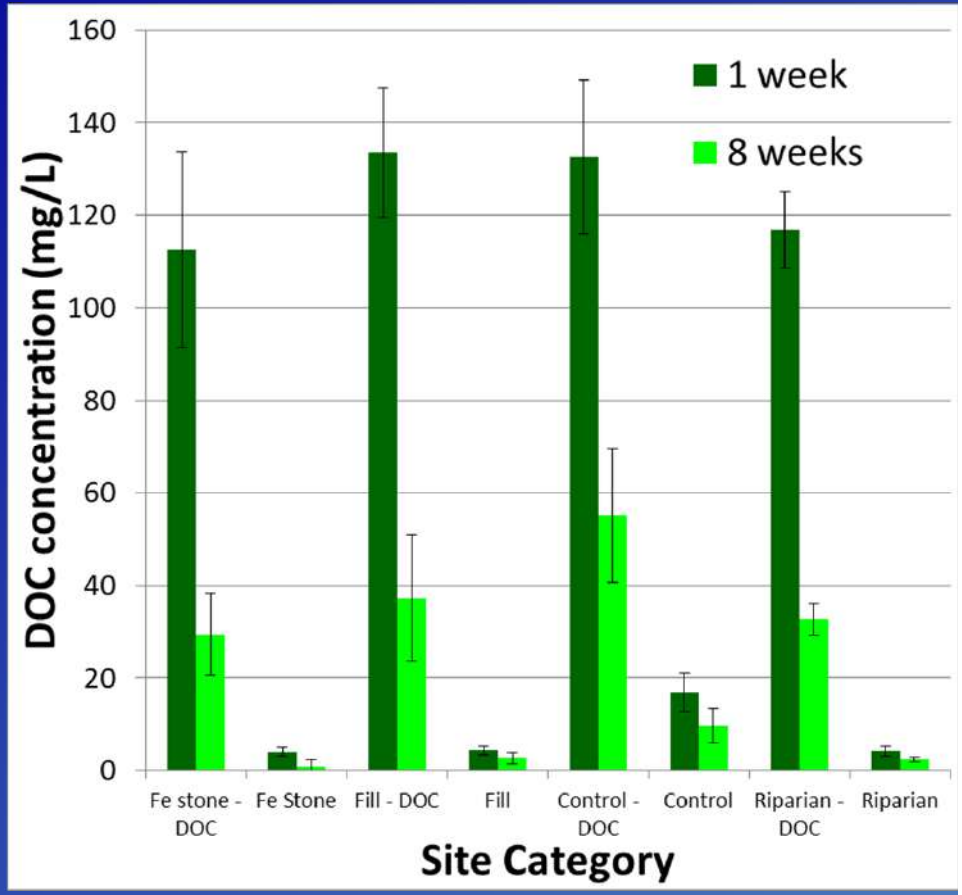


Total Iron Content - High in Ironstone



Leaching Experiment: [Fe] increased [DOC] decreased

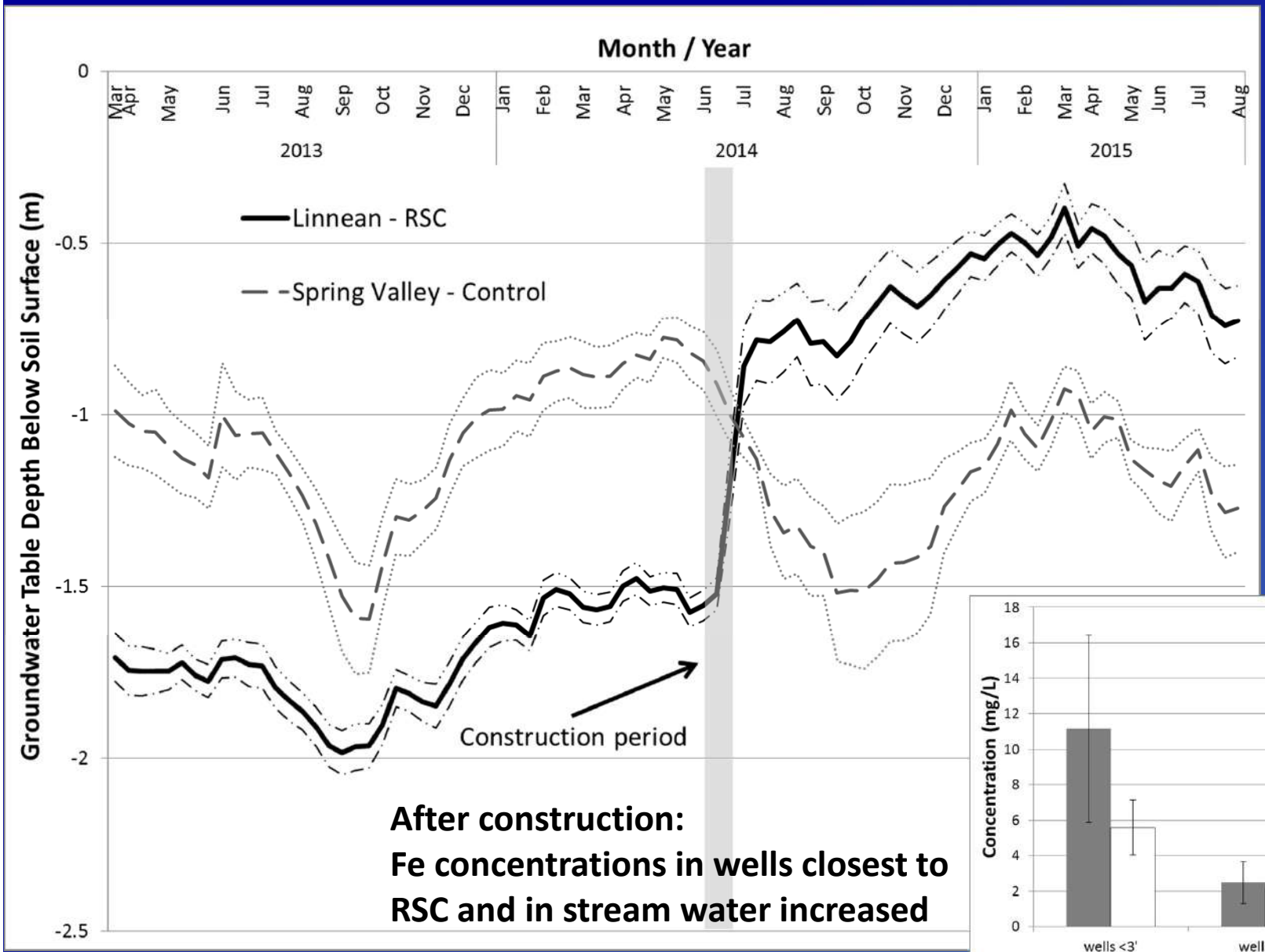




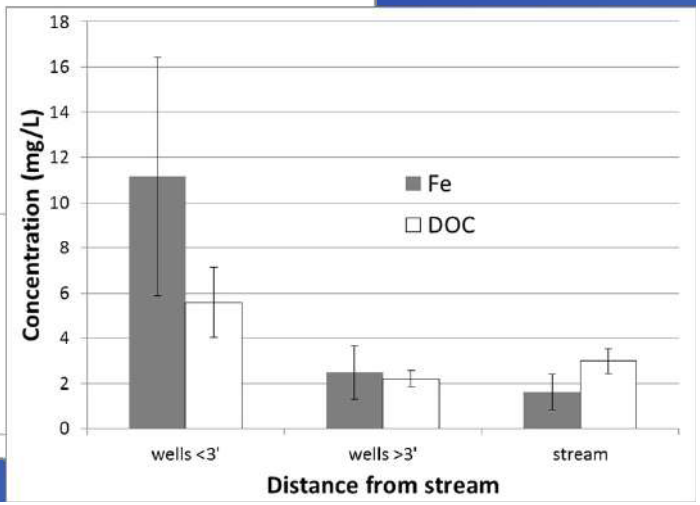
Interplay of Iron, Carbon and Microbes

- Groundwater containing dissolved organic matter (DOM) is commonly de-oxygenated by microbes feeding on DOM/DOC
- In such anoxic environments, Fe-reducing microbes convert insoluble ferric oxide from Fe-bearing minerals to soluble ferrous hydroxide
- When anoxic groundwater enters oxygenated stream water, Fe bacteria use O_2 to convert the soluble ferrous iron back into insoluble ferric oxide (flocculate)
- Although Fe oxidation can occur as an abiotic process at neutral pH, much of the Fe oxidation is microbially mediated

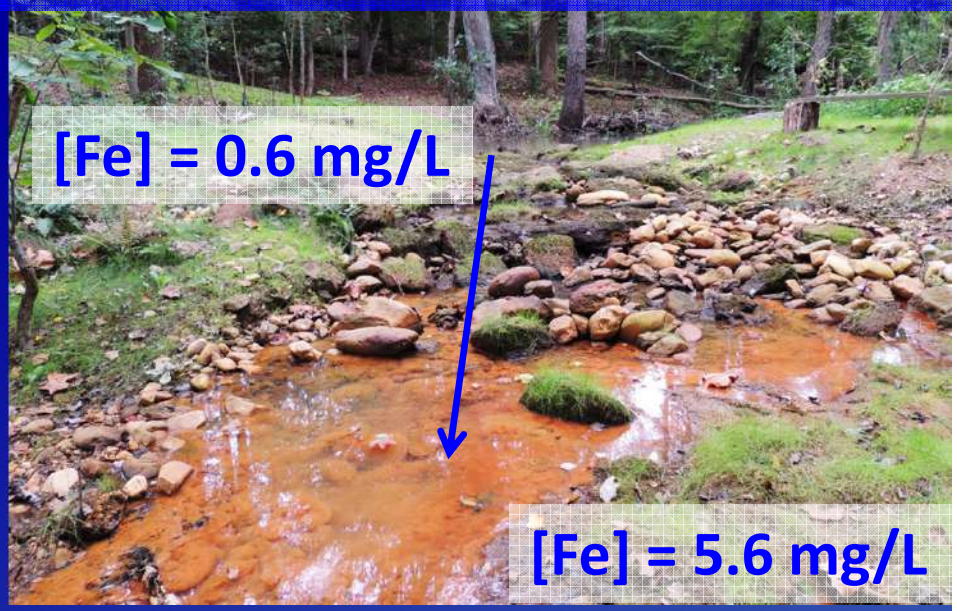
Groundwater Table Increased



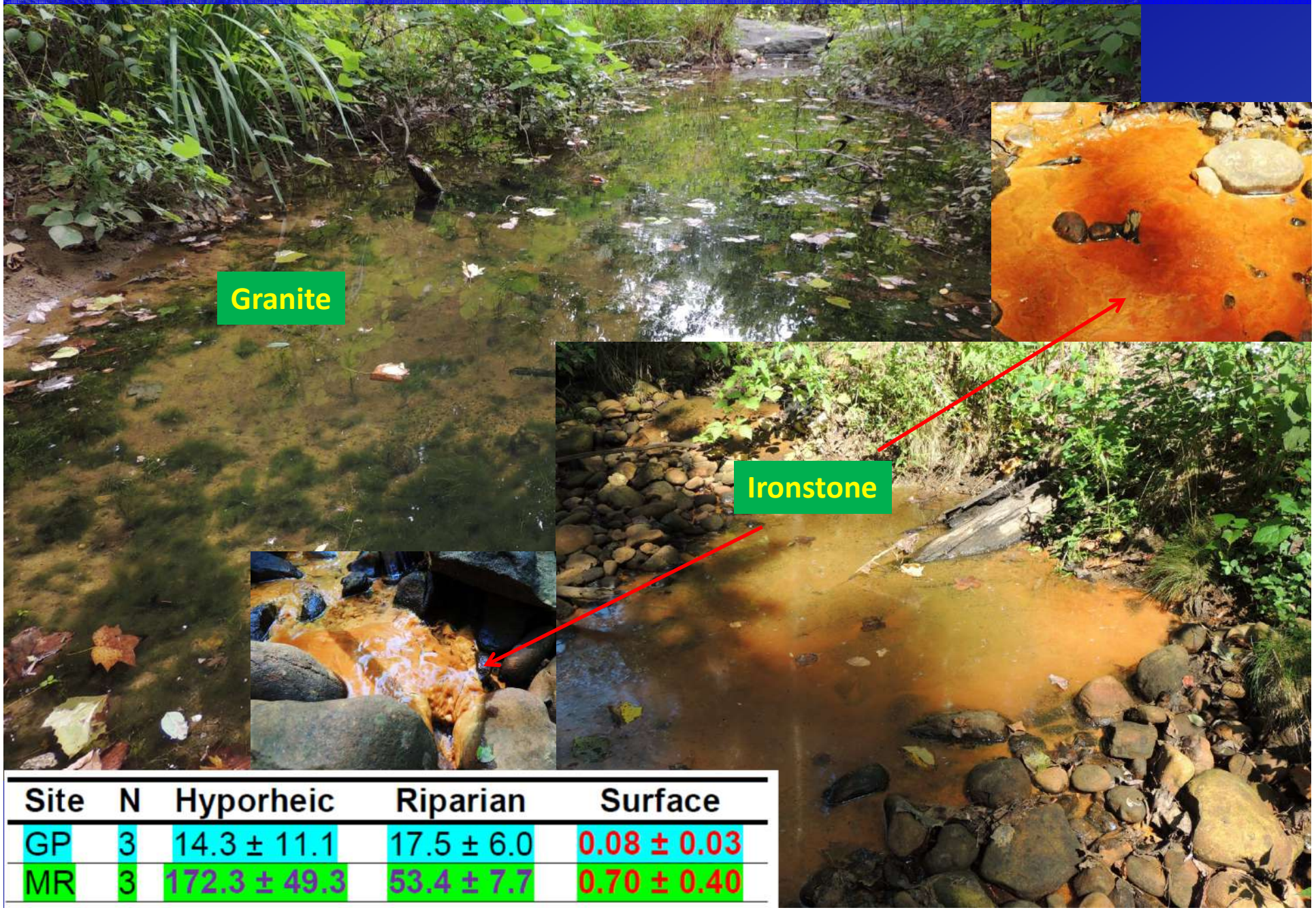
After construction:
Fe concentrations in wells closest to RSC and in stream water increased



Example: Ironstone weir in organic-rich floodplain.



Example: Low- and high-Fe content construction materials



Site	N	Hyporheic	Riparian	Surface
GP	3	14.3 ± 11.1	17.5 ± 6.0	0.08 ± 0.03
MR	3	172.3 ± 49.3	53.4 ± 7.7	0.70 ± 0.40

Example: No ironstone - influential lateral seep

Upper reach - Breewood

Lateral seep

Stream at seep location

Example: Outflow of moderately-sloped ironstone weir

Lower Linnean post -construction

Example: Colloidal flocculate in ponding basins

Leaves provide labile source of carbon

*No flocculate in pre-construction period

Example: Seasonal Temperature Effect

Early April 2014

Mid-August 2014

Summary of Results & Observations

- Under anoxic conditions, DOC mobilizes reduced Fe from riparian soils and RSC construction materials
- These sources increase [Fe] in surface runoff and can enhance flocculate formation
- The extent & density of flocculate is controlled by:
  - Availability of labile Fe (reduced) and DOC
  - Time between stormflow events
  - Flow rate and availability of low-flow environments (riffles and shallow rivulets)
  - Unique geomorphology and hydrological flow paths
    - slopes >10% flush more groundwater from weirs; slopes > 30% generally have intermittent flow
  - Temperatures – low temperatures restrict growth

Pros and Cons of Using Ironstone

Pros

- Strong and easy to use in building rock weirs
- Porous and allows some plants and mosses to grow on surface
- May slightly decrease pH of stream water thereby possibly restricting invasive plant species

Cons

- Source of Fe that contributes to Fe-flocculate in certain conditions
- More expensive than other potential construction materials (e.g., granite)
- Foreign substrate in Piedmont physiographic province where control streams commonly have low [Fe] and flocculate is rarely observed

Comments & Recommendations

- Construction materials and natural soils leach Fe that can contribute to the development of Fe flocculate in RSCs
- Flocculate generally does not have an overwhelming influence, but can create localized impairments in RSC reaches
- Use of ironstone substrates and organic matter should be used wisely and more strategically:
  - Quantity and location of ironstone substrates should be based on soil conditions, slope, proximity to groundwater seeps, and involve an evaluation of trade offs
  - Optimizing the type and/or reducing the amount of OM in construction and preventing hydrological connections to localized OM and reduced Fe sources (i.e., groundwater seeps) should decrease the extent and density of flocculate in RSC reaches
  - Encourage limited use of ironstone in the Piedmont where Fe concentrations in stream water are commonly low (<0.1 mg/L)

END

Construction Materials


10/25/2014

Williams
Translation Slides

What does this mean for me?

- Iron in streams:
  - comes from both natural soils and may come from construction materials (ironstone and sand)
  - is higher when there is organic matter and anoxic conditions
- Iron flocculate:
  - can occur in some, but not all, RSCs

What does this mean for me?

- What do I take from this if I am a practitioner:

No action yet

- What do I take from this if I am a regulator:

No action yet