Sewage associated microbes in the Hudson River Estuary: distribution, sources, and ecological connections

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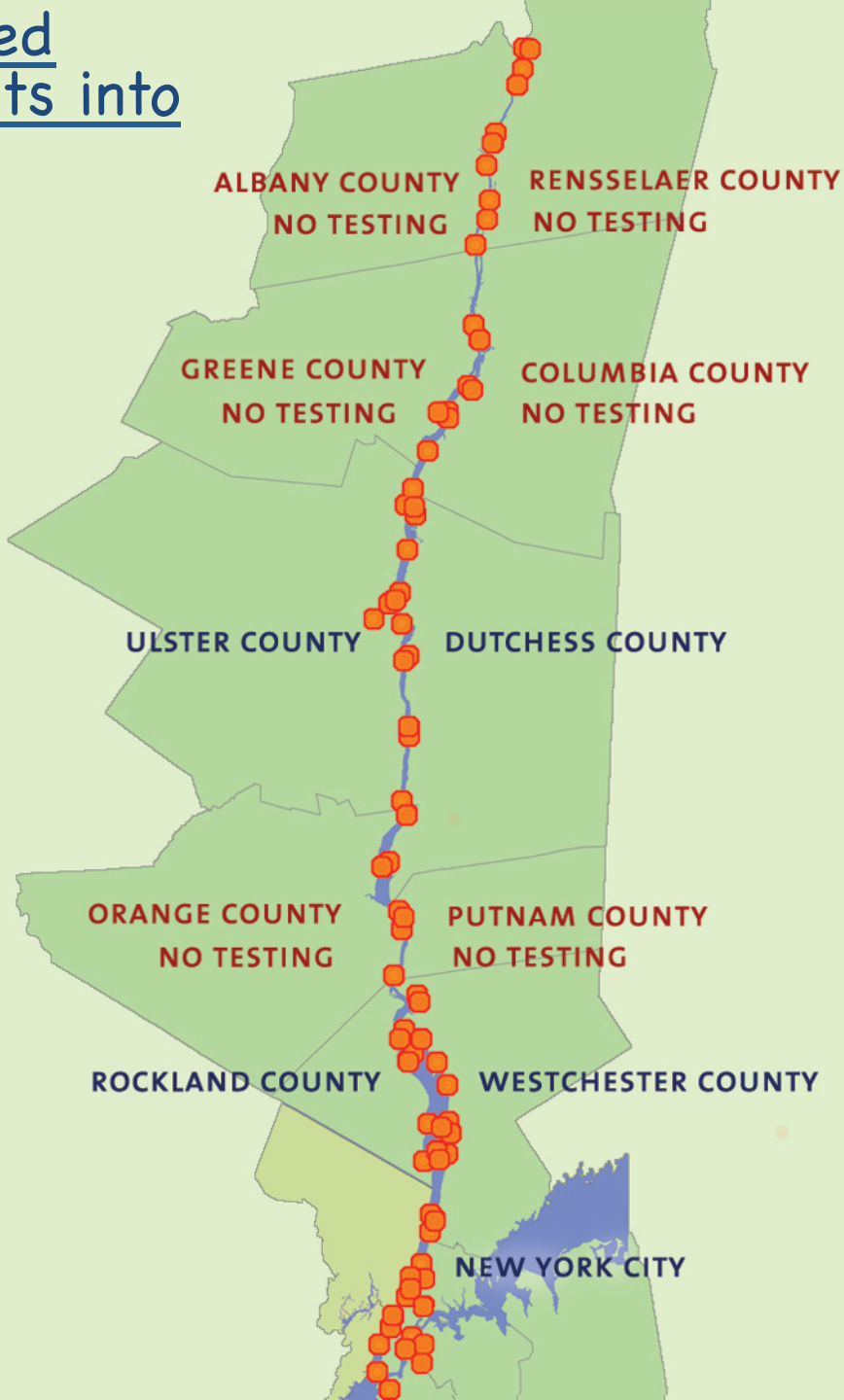
RIVERKEEPER. NY's clean water advocate
LAMONT-DOHERTY EARTH OBSERVATORY THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY
QUEENS COLLEGE

Over the last decade, expanded monitoring has provided insights into HRE bacterial water quality

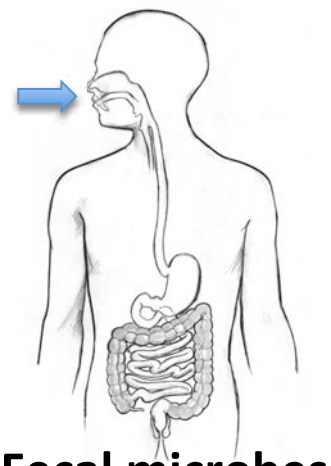
Riverkeeper's HRE sampling program:

- 75 testing sites
- 5000 samples processed
- *Enterococcus* ("Entero"): a fecal indicating bacteria (FIB)

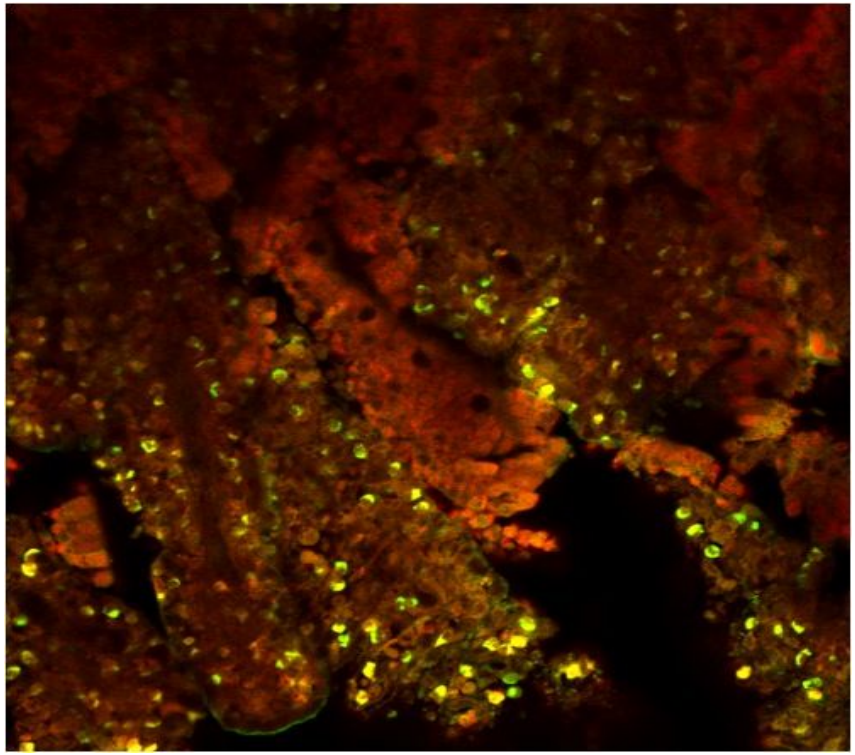
DATA & REPORTS AVAILABLE ONLINE:
www.riverkeeper.org/water-quality



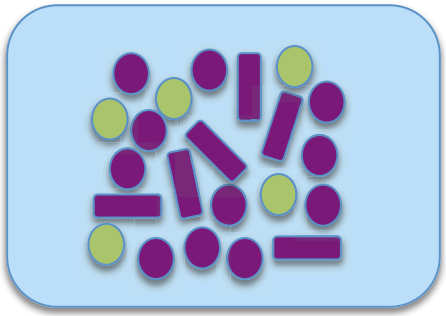
Enterococcus as an indicator



Enterococcus is one of many genera in fecal material

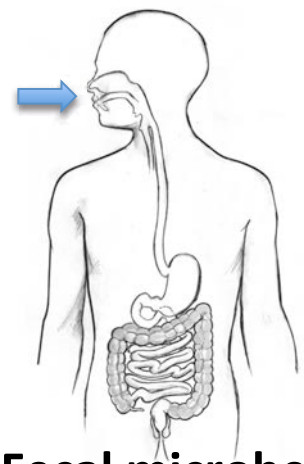


Immunofluorescence (green) of Enterococcus in mouse intestine; Dr. J Huebner



Ubiquitous, but not dominant (<1% gut consortia), in healthy human GI tract.

Enterococcus as an indicator



Fecal microbes

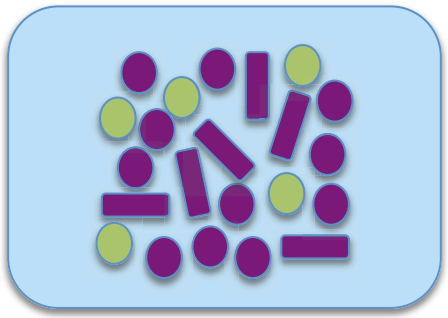
Sewage microbes

Low abundance in most water samples:

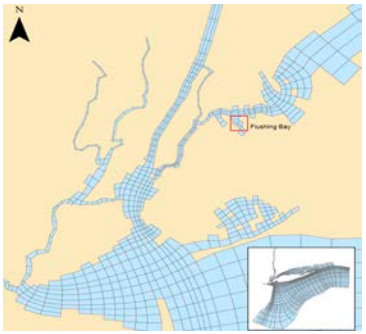
- At EPA Beach Action Value (60/100ml), there will be <1 Enterococcus cell per 10^6-10^7 microbes

As an indicator we rely on Entero:

- coupling to other sewage associated microbes and pathogens
- short persistence (indicates recent input)
- absence in pristine waterways



Natural System



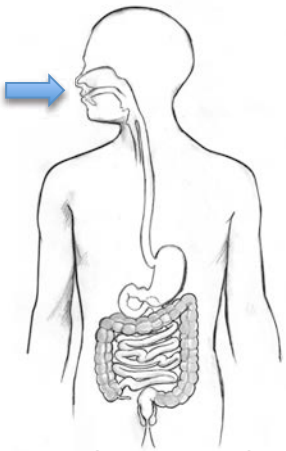
Polluted waterway

Vs

Pristine waterway

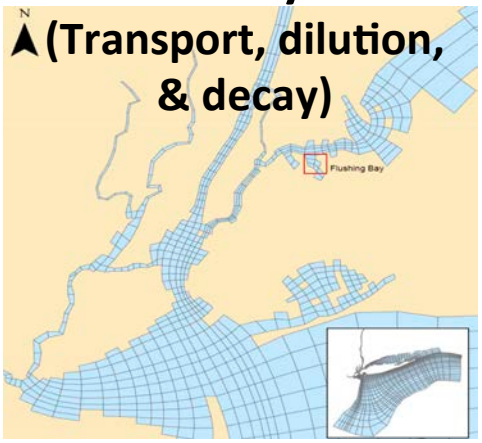
Microbial Pathway

Food



Exposure via water contact

Natural System



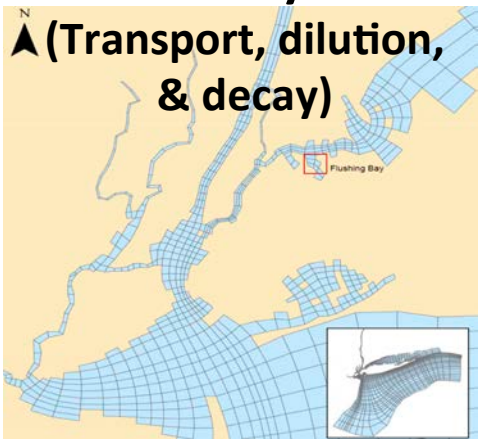
Fecal microbes (*Enterococcus*)

Sewage input (WWTP + CSO)

Management Pathway

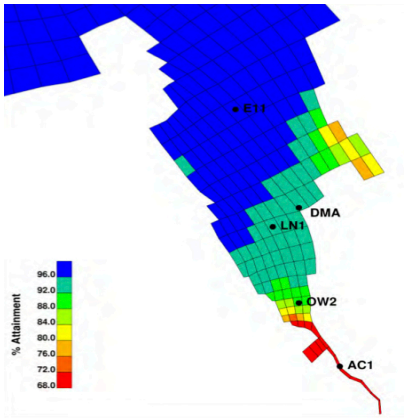
Waterway monitoring

Natural System



(Transport, dilution, & decay)

Notification, education, & forecasting

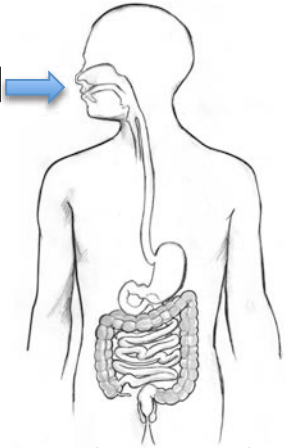


mitigation

Microbial Pathway

Management Pathway

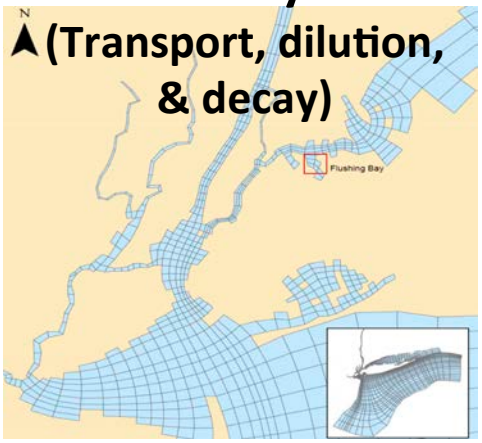
Food



Fecal microbes (*Enterococcus*)

Exposure via water contact

Natural System (Transport, dilution, & decay)

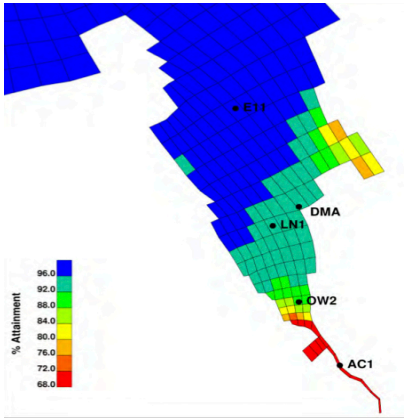


Waterway monitoring

Sewage input (WWTP + CSO)

mitigation

Notification, education, & forecasting



Patterns of FIB distribution observed in HRE monitoring data:

1) Despite recent improvements in HRE water quality, large % of collected samples were unacceptable relative to the EPA Beach Action Value (BAV) for Enterococcus:

- 23% of HRE samples
- 72% of citizen tributary samples
- 48% of NYC access point samples

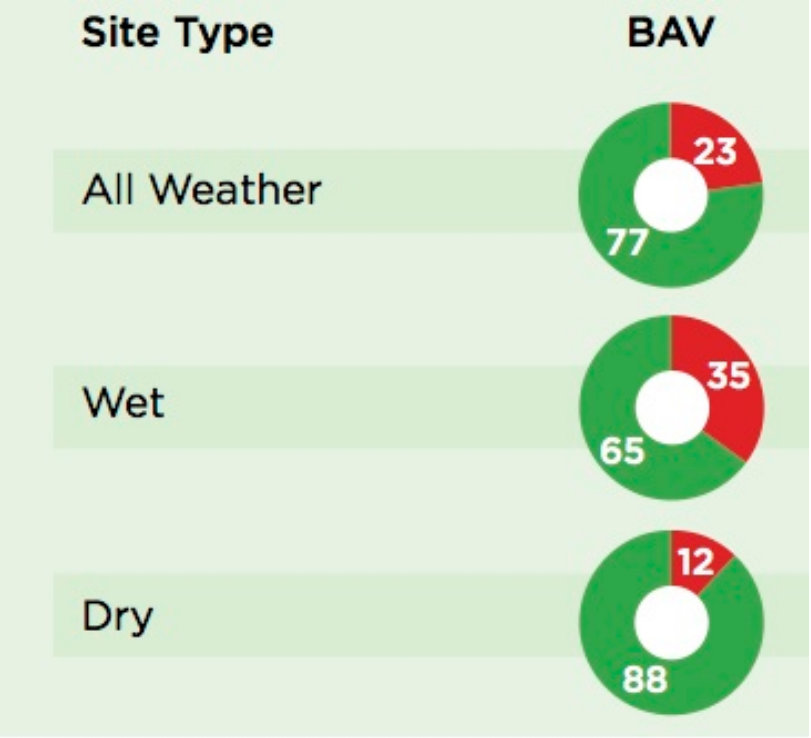
There is still a lot of work to be done to improve regional water quality and better understand patterns in monitoring data…

Patterns of FIB distribution observed in HRE monitoring data:

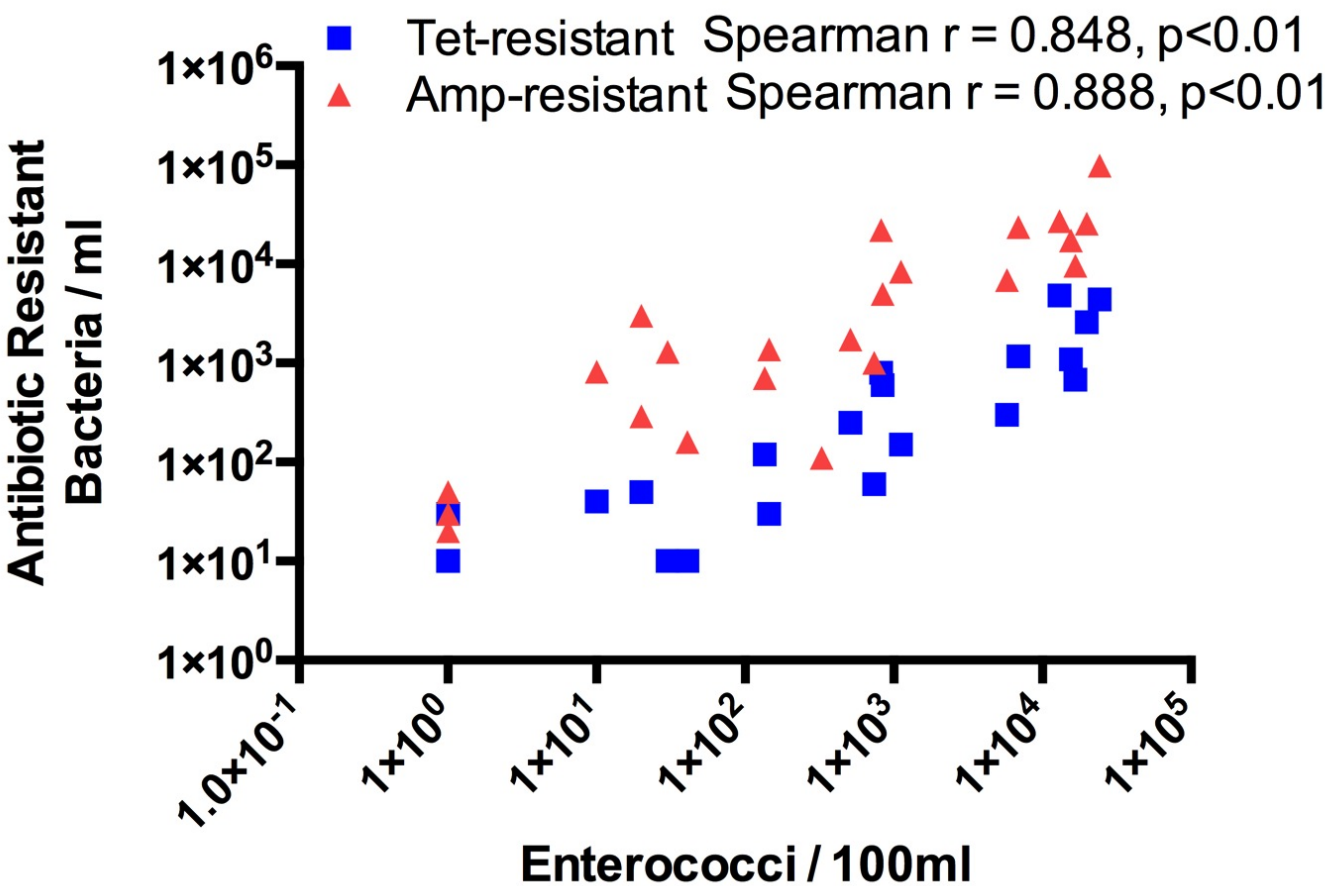
1) Despite recent improvements in HRE water quality, large % of collected samples were unacceptable relative to the EPA Beach Action Value (BAV) for Enterococcus:

2) Contamination patterns are found to vary temporally, with weather as a major controlling factor. Rainfall increases unacceptable conditions:

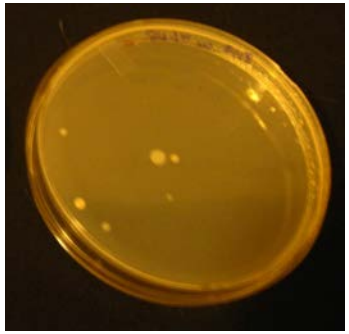
- Do fecal microbes or microbes of concern also increase?
- Are CSOs the only source of FIB during rain?



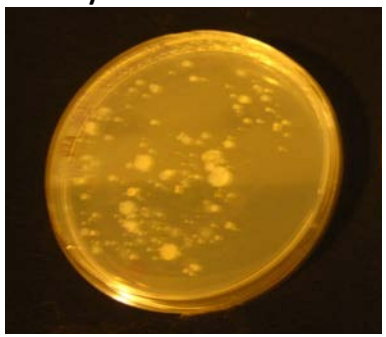
Antibiotic resistant bacteria (ARB) abundances were correlated with Entero in Flushing Bay…



w/ antibiotic

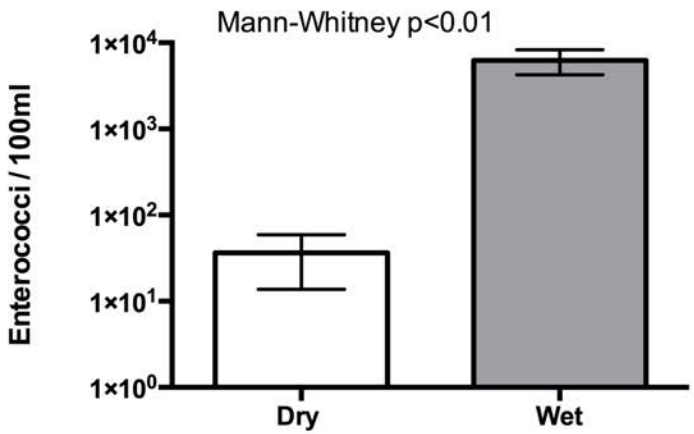


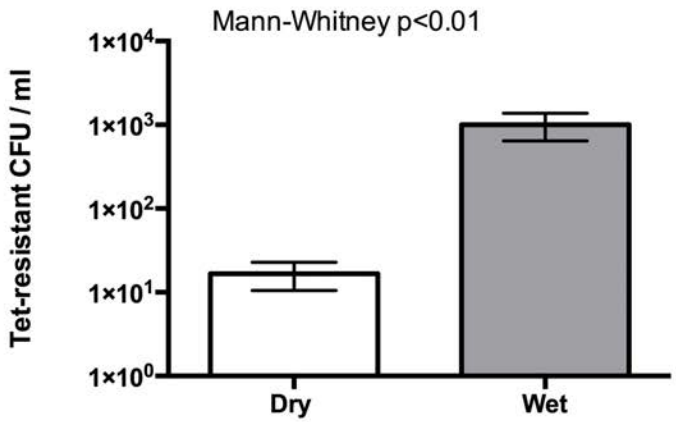
w/o antibiotic

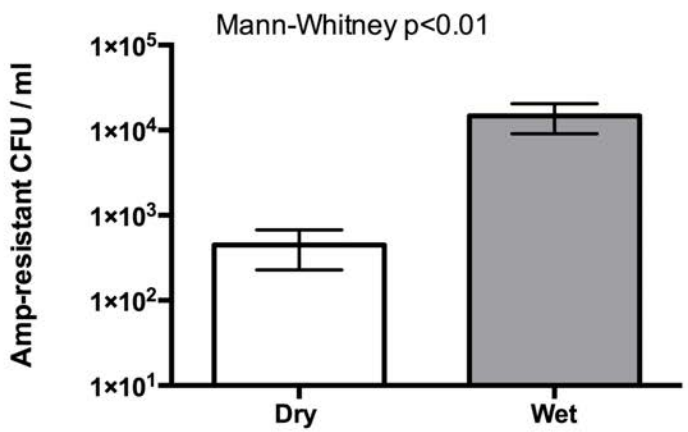


Young, Juhl, and O'Mullan. 2013. Journal of Water and Health 11(2):297-310.

Both ARB and FIB increased significantly after rain…



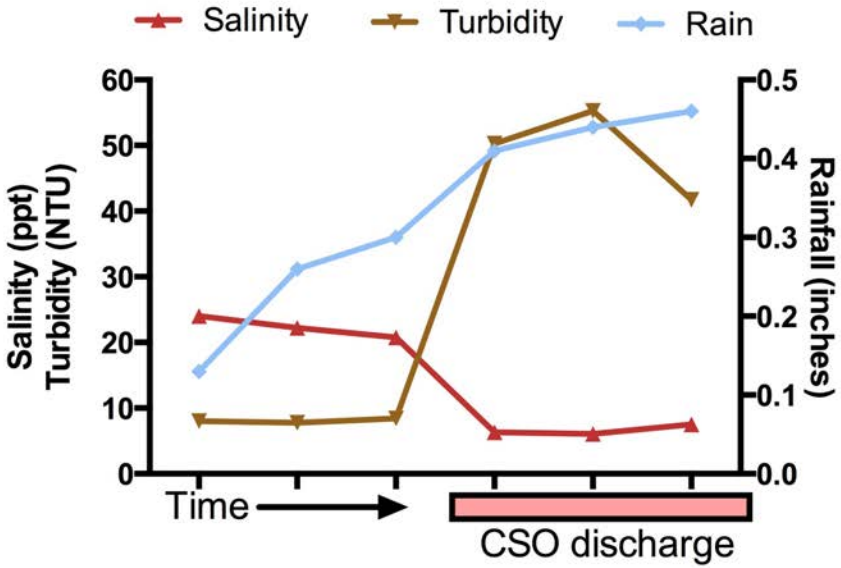




% of resistant isolates identified as Enterobacteriaceae (by 16S rRNA sequencing) was significantly higher following rain (21%) compared to “dry” conditions (5%).

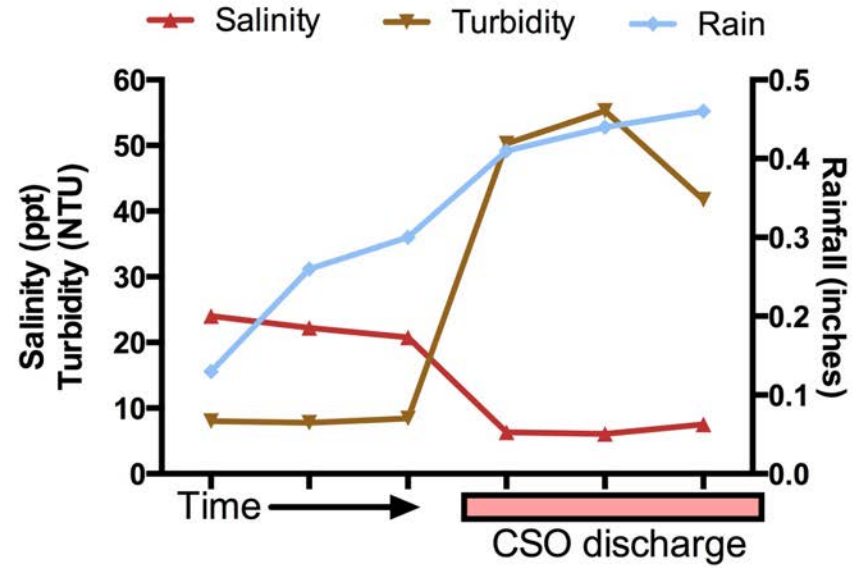
Young, Juhl, and O’Mullan. 2013. Journal of Water and Health 11(2):297-310.

CSO event sampling in Flushing Bay



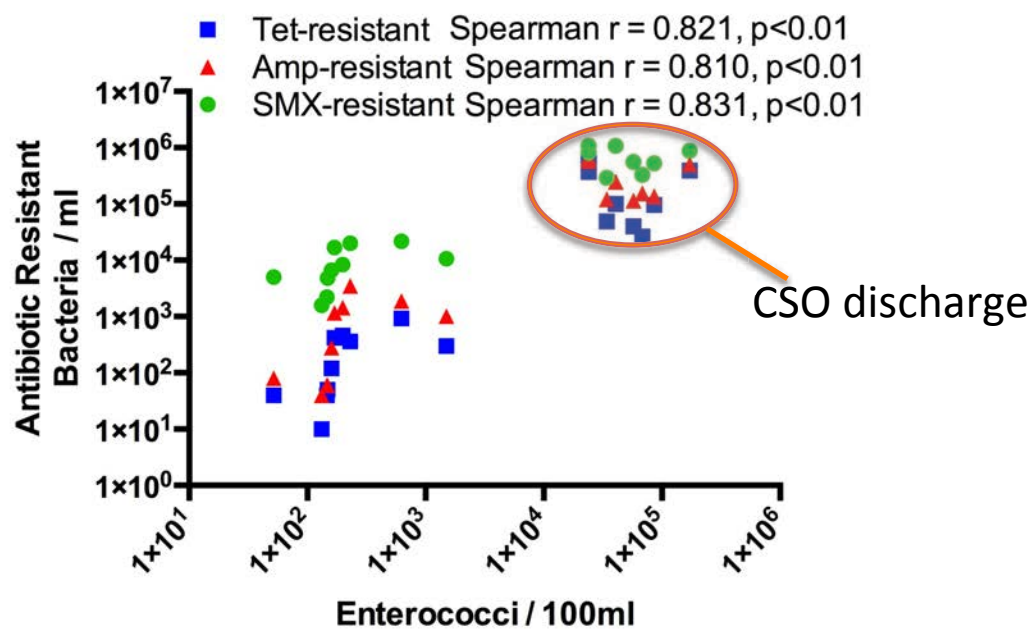
November 2014 storm event

CSO event sampling in Flushing Bay

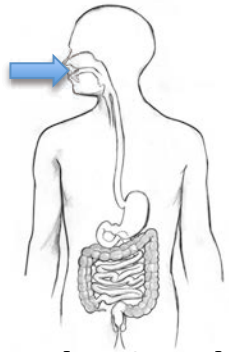


- Greater than two order of magnitude increase in *Entero* and ARB detected during CSO flow.

- The 4 most abundant ARB isolates (Shigella, Acinetobacter, Aeromonas, Pseudomonas) from CSO discharge were also the most abundant ARB genera detected in Flushing Bay water.



Fecal microbes are not deposited directly in waterway during rain…

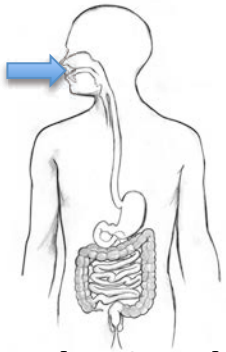


Fecal microbes

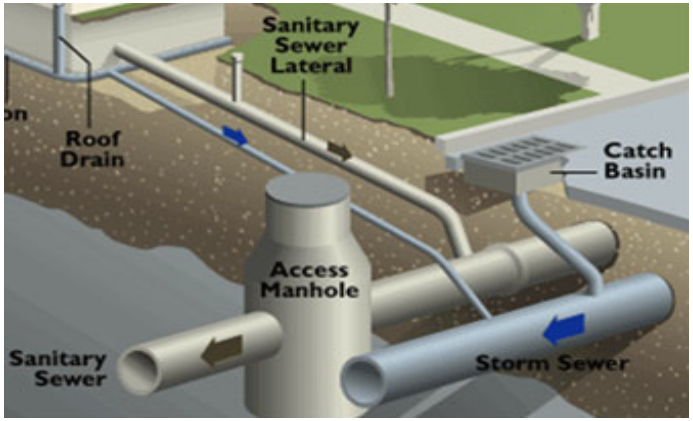
X

Sewage input (WWTP + CSO)

Fecal microbes are not deposited directly in waterway during rain…



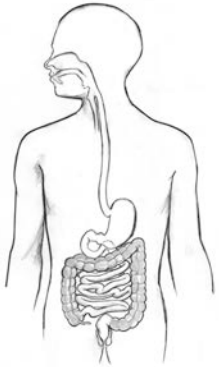
Fecal microbes

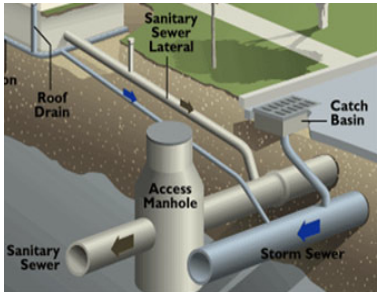


X

Sewage input (WWTP + CSO)

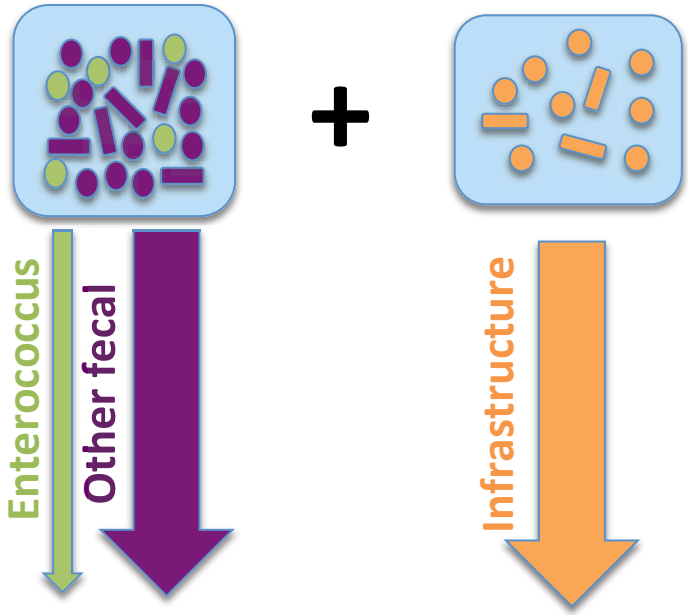
Source mixing and succession occur in sewage delivery system





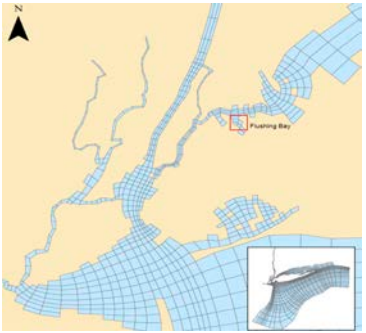
Fecal microbes

Infrastructure microbes

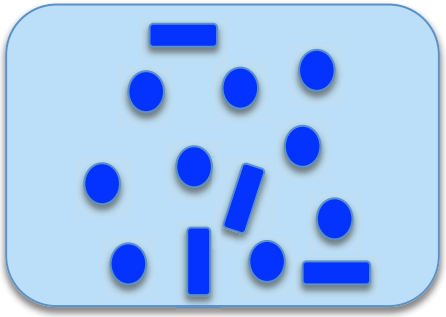


Sewage associated microbes

Natural System

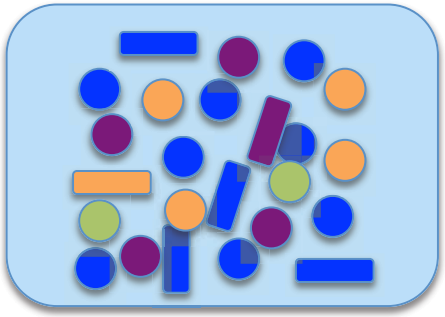


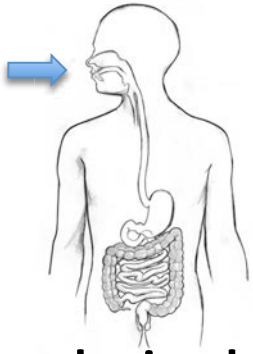
Pristine waterway



Vs

Polluted waterway



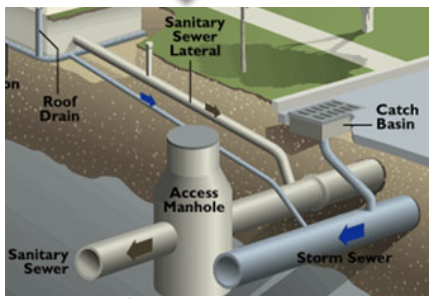


Comparison of the Microbial Community Structures of Untreated Wastewaters from Different Geographic Locales

Orin C. Shanks,[a] Ryan J. Newton,[b] Catherine A. Kelty,[a] Susan M. Huse,[c,d] Mitchell L. Sogin,[c] Sandra L. McLellan[b]

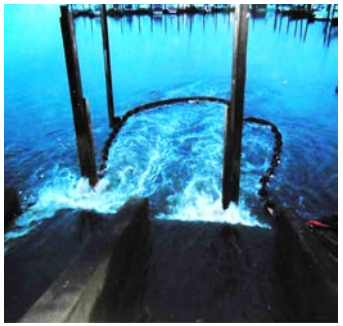
2013 Applied & Environmental Microbiology 79(9):2906-2913

Fecal microbes



+ Infrastructure microbes

Sewage input

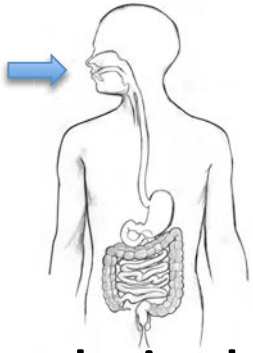


Used next generation DNA sequencing of wastewater and fecal material (human and animal) to identify taxonomic groups of bacteria that represent the "fecal core" and "sewage infrastructure core" microbiomes.

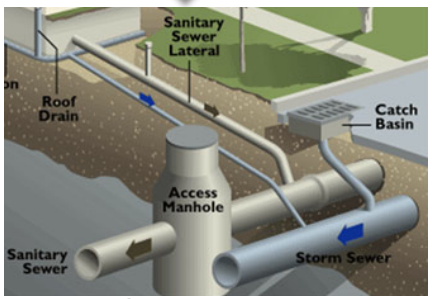
<u>Microbial signature</u> approach has been used to examine influence of infrastructure & fecal microbes on waterways:

4 sewage infrastructure "core" genera:
Acinetobacter, *Aeromonas*, *Arcobacter*, Trichococcus.

Fecal "core" includes genera from 7 families:
Bacteroidaceae, Porphyromonadaceae, Clostridiaceae, Lachnospiraceae, Ruminococcaceae, Rikenellaceae, Prevotellaceae

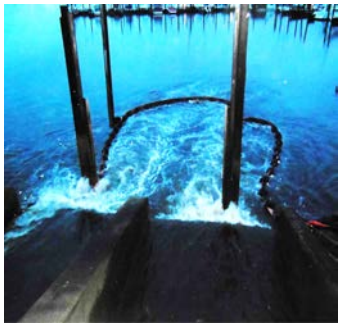


Fecal microbes



+ Infrastructure microbes

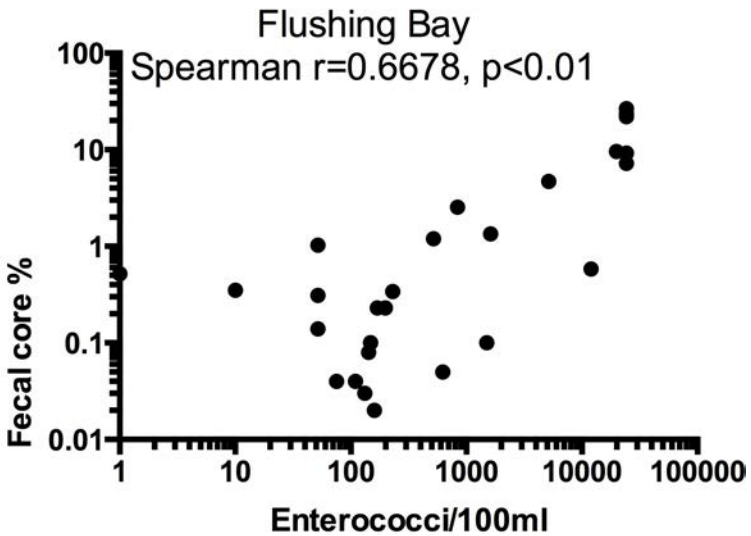
Sewage input

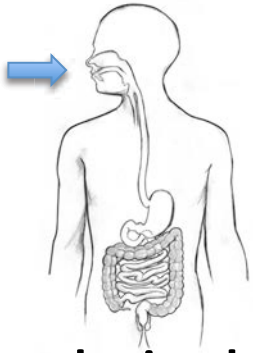


The fecal (27%) and infrastructure (33%) "core" can together represent the majority of DNA sequences from CSO discharge into Flushing Bay (22,000 sequences in total).

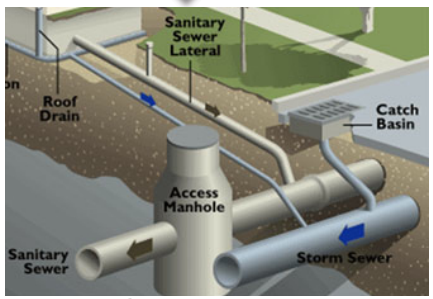
In contrast the FIB *Enterococcus* represented less than 0.04% of these CSO sequences.

The [Entero] and % fecal core representation are correlated in Flushing Bay monitoring samples.



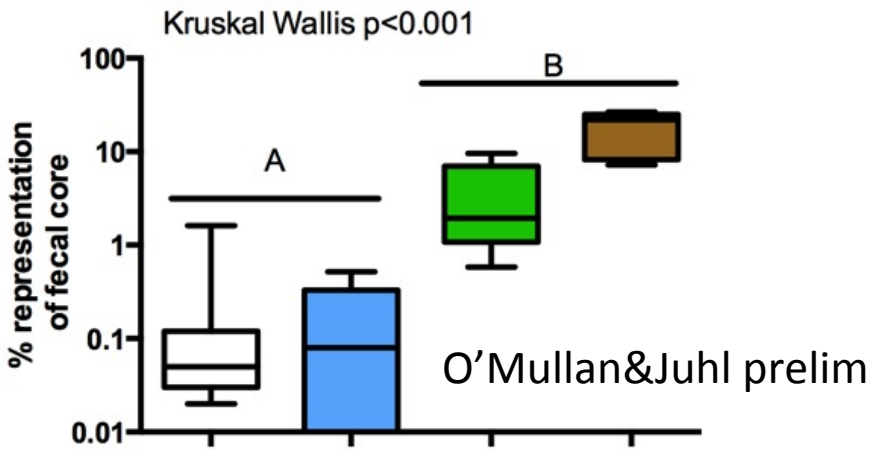


Fecal microbes

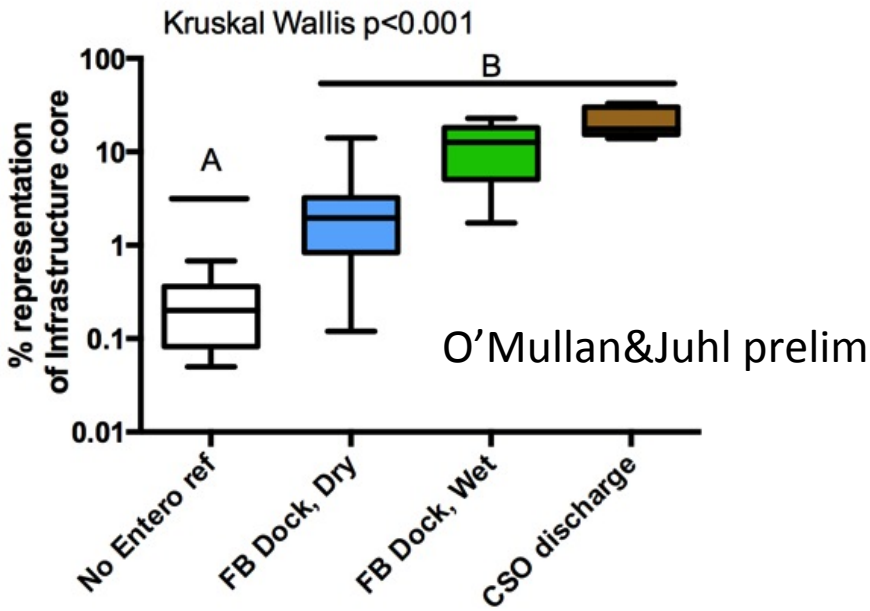


+ Infrastructure microbes

Sewage input

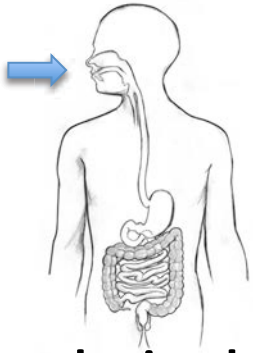


fecal core max:
CSO 27%
Wet 10%
Dry 0.5%

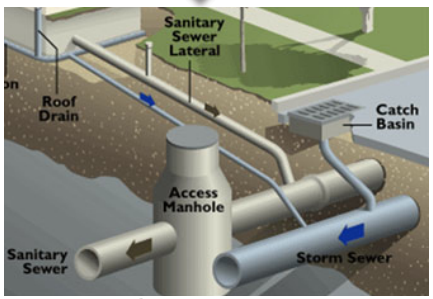


Infrastructure core max:
CSO 33%
Wet 23%
Dry 14%

However, not all locations have CSOs and sewage may not be the only source of FIB during rain…



Fecal microbes



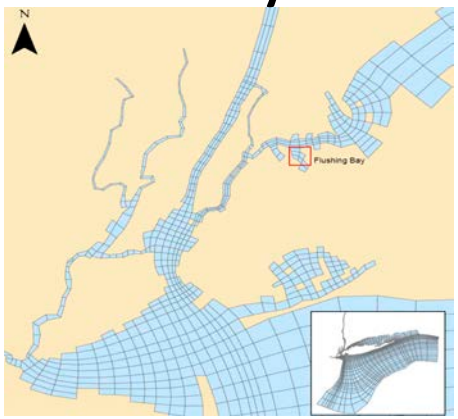
+ Infrastructure microbes

Sewage input

X

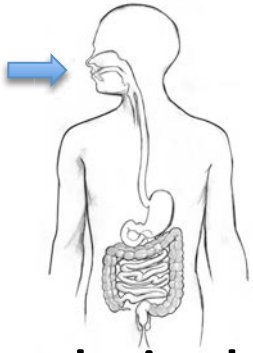
Not only source..

Natural System

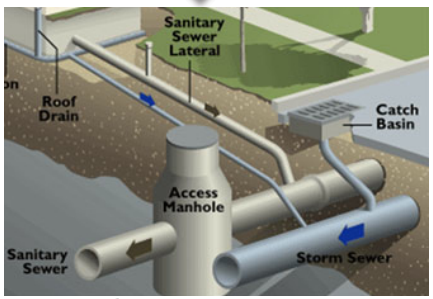


Stormwater and wildlife may other major sources of FIB..

Is Entero elevated in non-CSO inputs?
And if so, is Entero coupled to other microbes of concern?



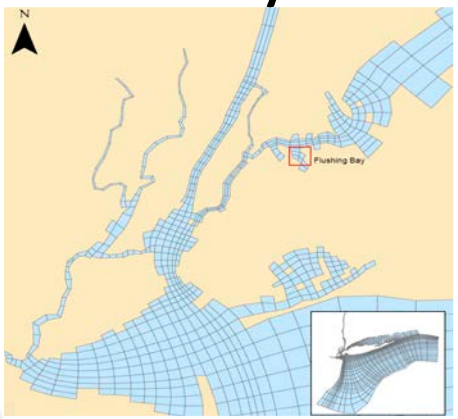
Fecal microbes



Infrastructure microbes

Sewage input

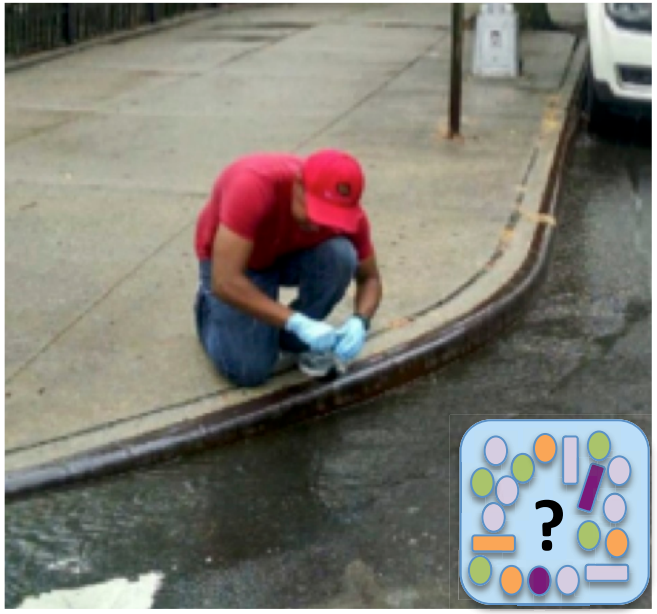
Natural System

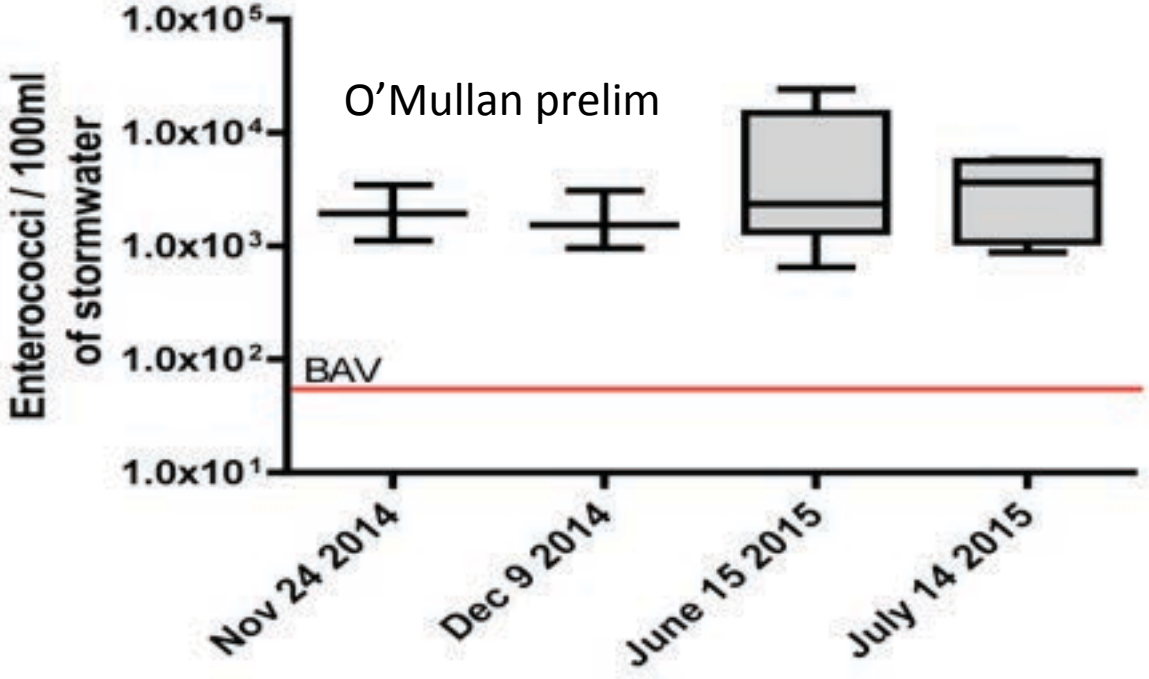


Stormwater input

Wildlife input

Stormwater can be a major source of FIB…

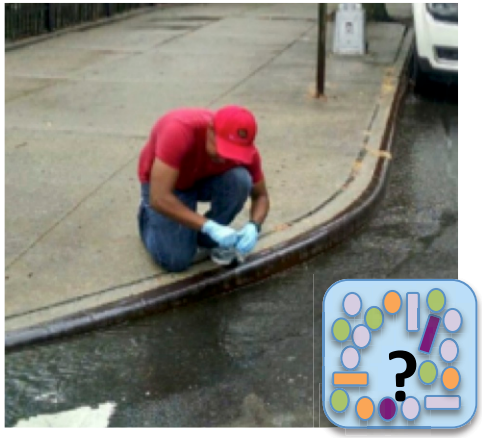


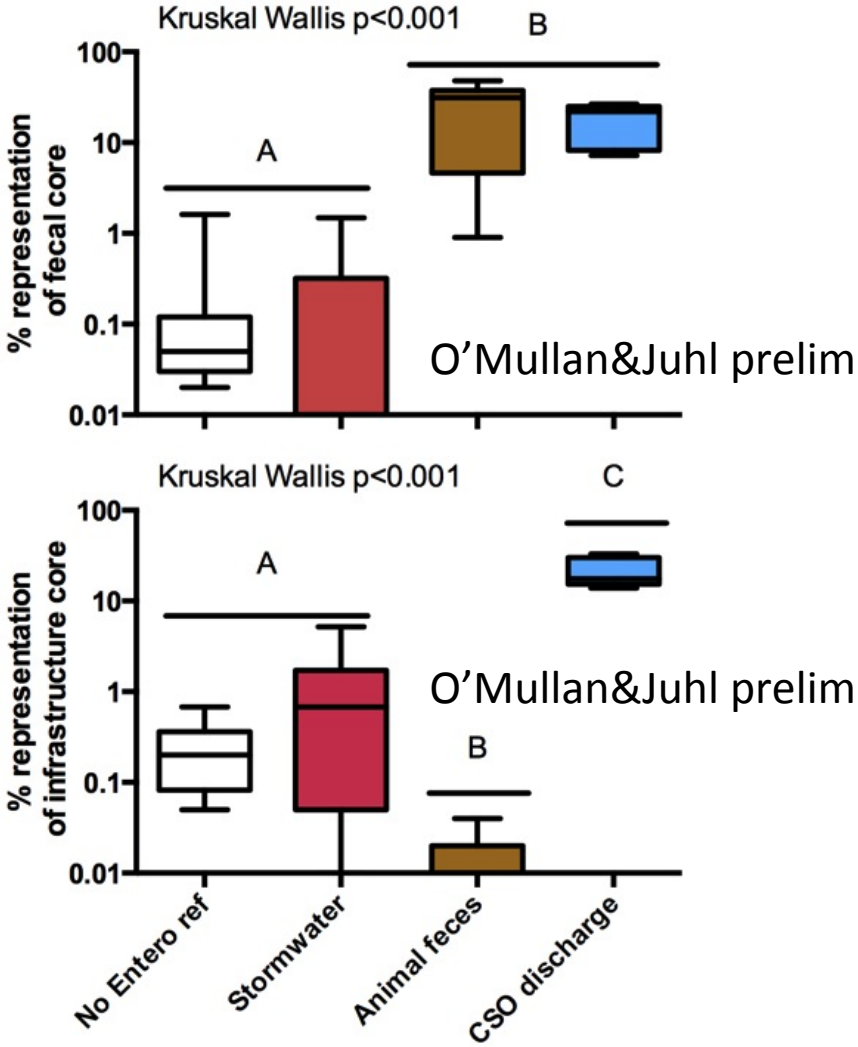


Median Entero levels in urban street stormwater from 8 sites in Queens were more than an order of magnitude greater than the EPA beach action value; and were significantly higher than levels in Flushing Bay even during wet weather.

Stormwater contains high levels of Entero…but preliminary data indicate very low levels of fecal microbes…

[Entero] and % representation of the fecal core are **not** correlated in stormwater….





Management Relevance-
[Entero] in waterways may remain elevated even if CSOs are removed…

Far more people interact with the stormwater in streets…public health consequences and management?

Initial conclusions

- Enterococcus and other groups of sewage associated bacteria are correlated in the urban waterways and increase following rain.
- CSOs are a large source of Entero and other sewage associated bacteria following rainfall, but stormwater (and wildlife) can be as well…
- DNA sequencing for community signatures can be used to assess sewage/fecal impact and perhaps to untangle sources…
- Preliminary data suggests that while stormwater carries a large Entero concentration it does not carry many fecal bacteria.

Patterns of FIB distribution observed in HRE monitoring data:

3) Water quality varies at small spatial scales- adjacent sites can have very different conditions

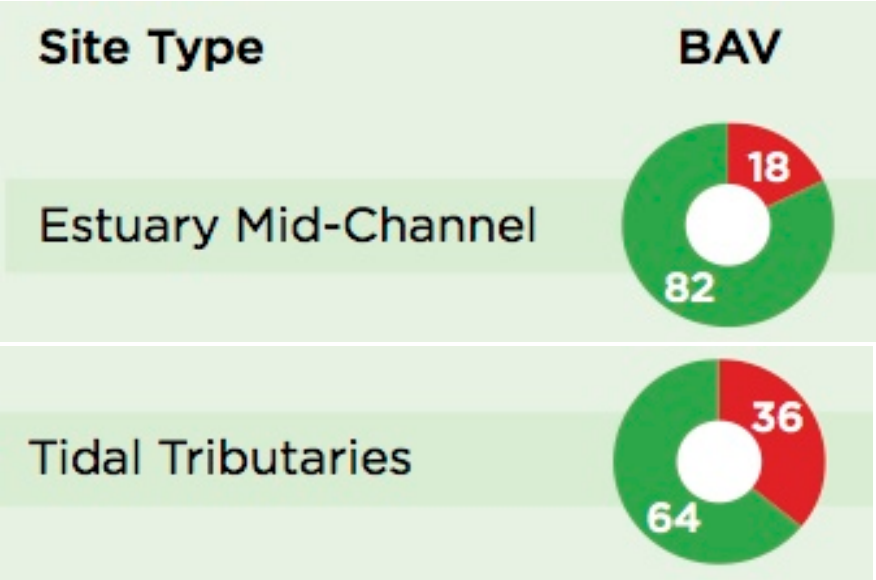
% of samples unacceptable (red) relative to EPA-BAV:

Patterns of FIB distribution observed in HRE monitoring data:

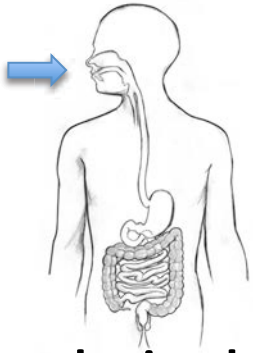
3) Water quality varies at small spatial scales- adjacent sites can have very different conditions

4) Contamination is greater near-shore, especially where tributaries mix, and in tributaries compared to the Hudson mid-channel

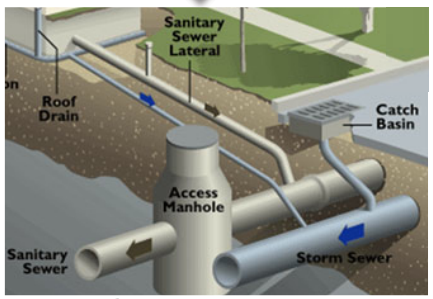
Why are mid-channel locations less impacted?



Understanding the variable spatial distribution requires inputs and dynamics within waterways to be explored..



Fecal microbes



Infrastructure microbes

Sewage input

Exposure via water contact

Natural System

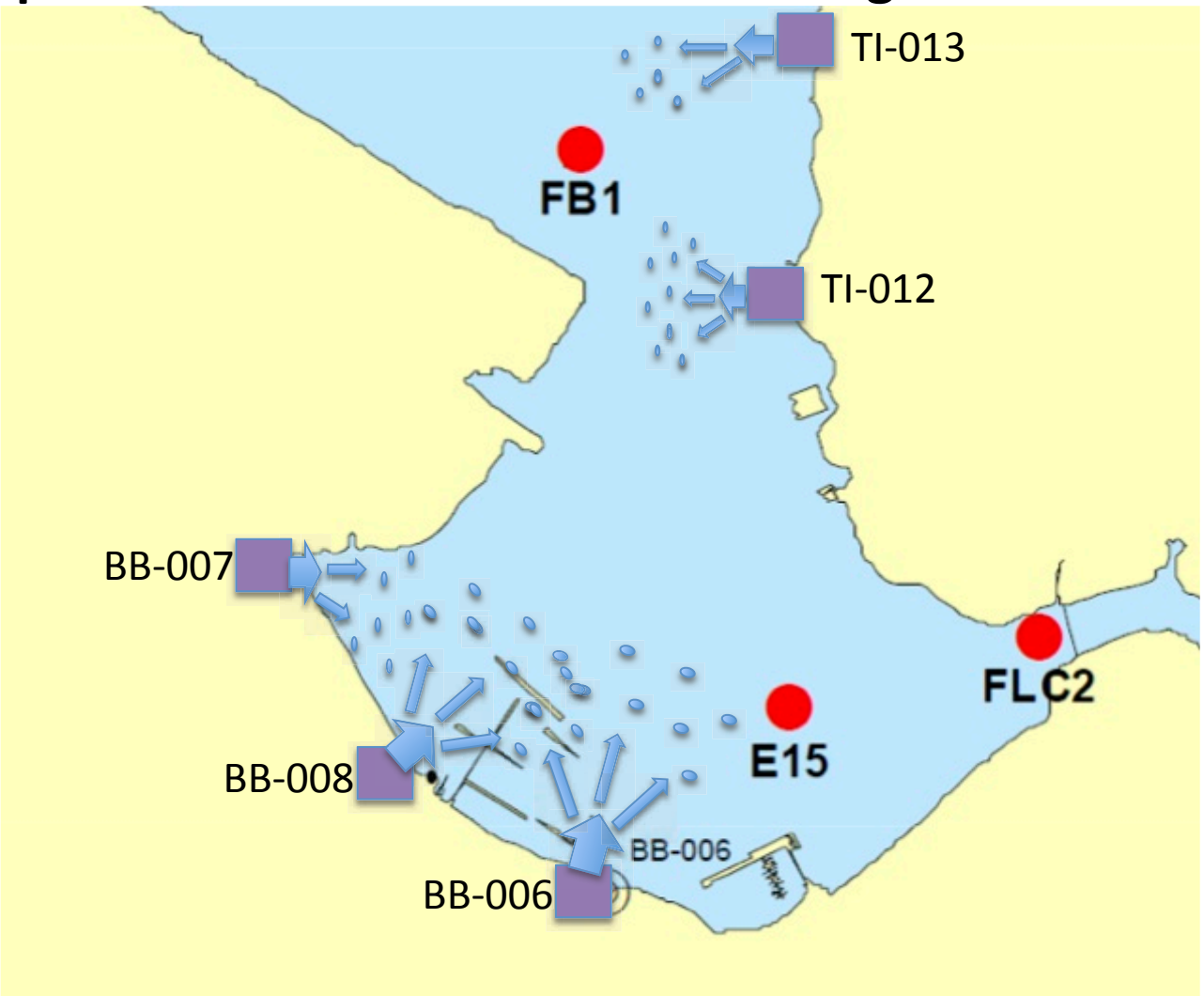
Transport, dilution, & decay

Stormwater input

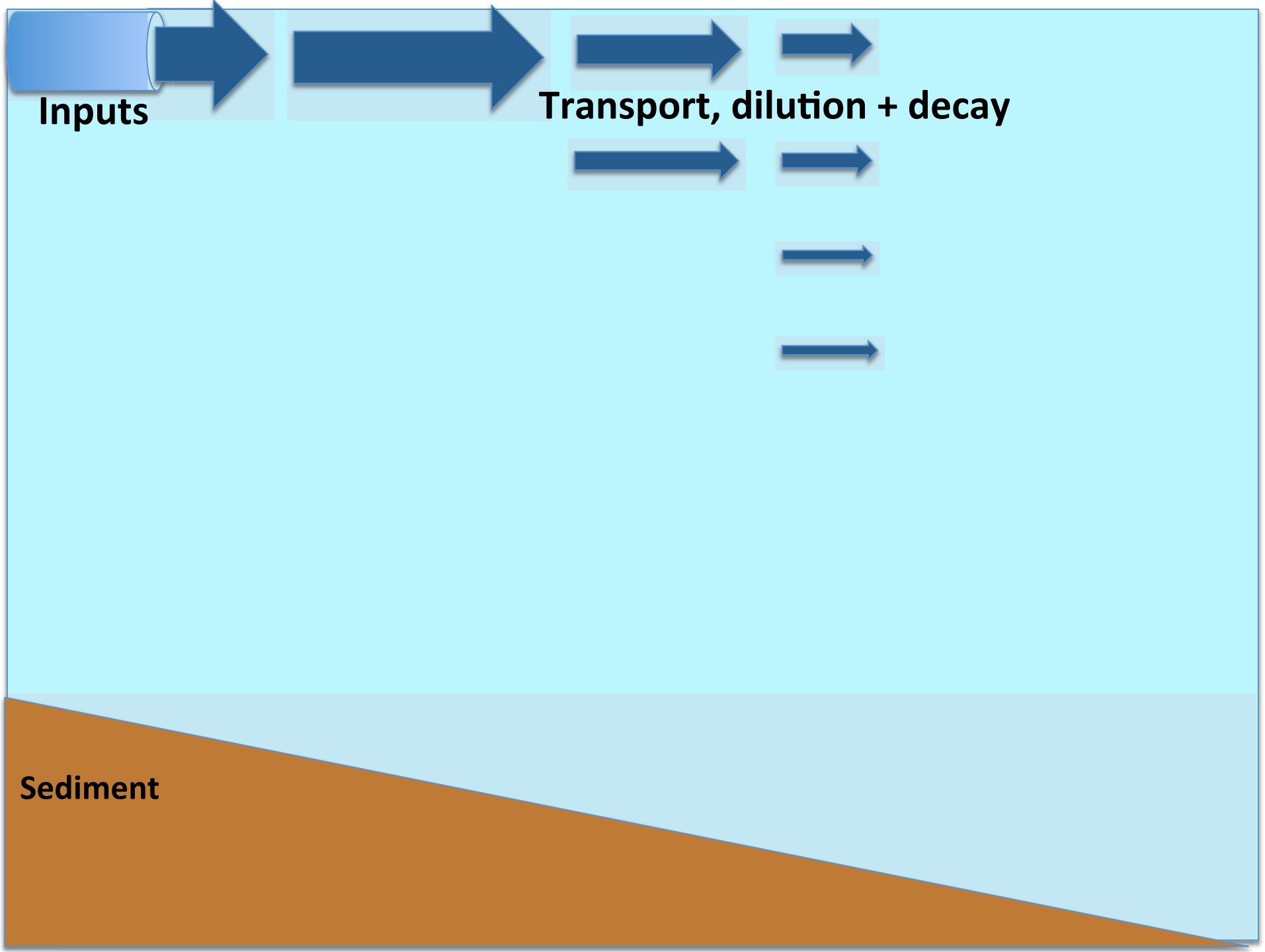
Wildlife input

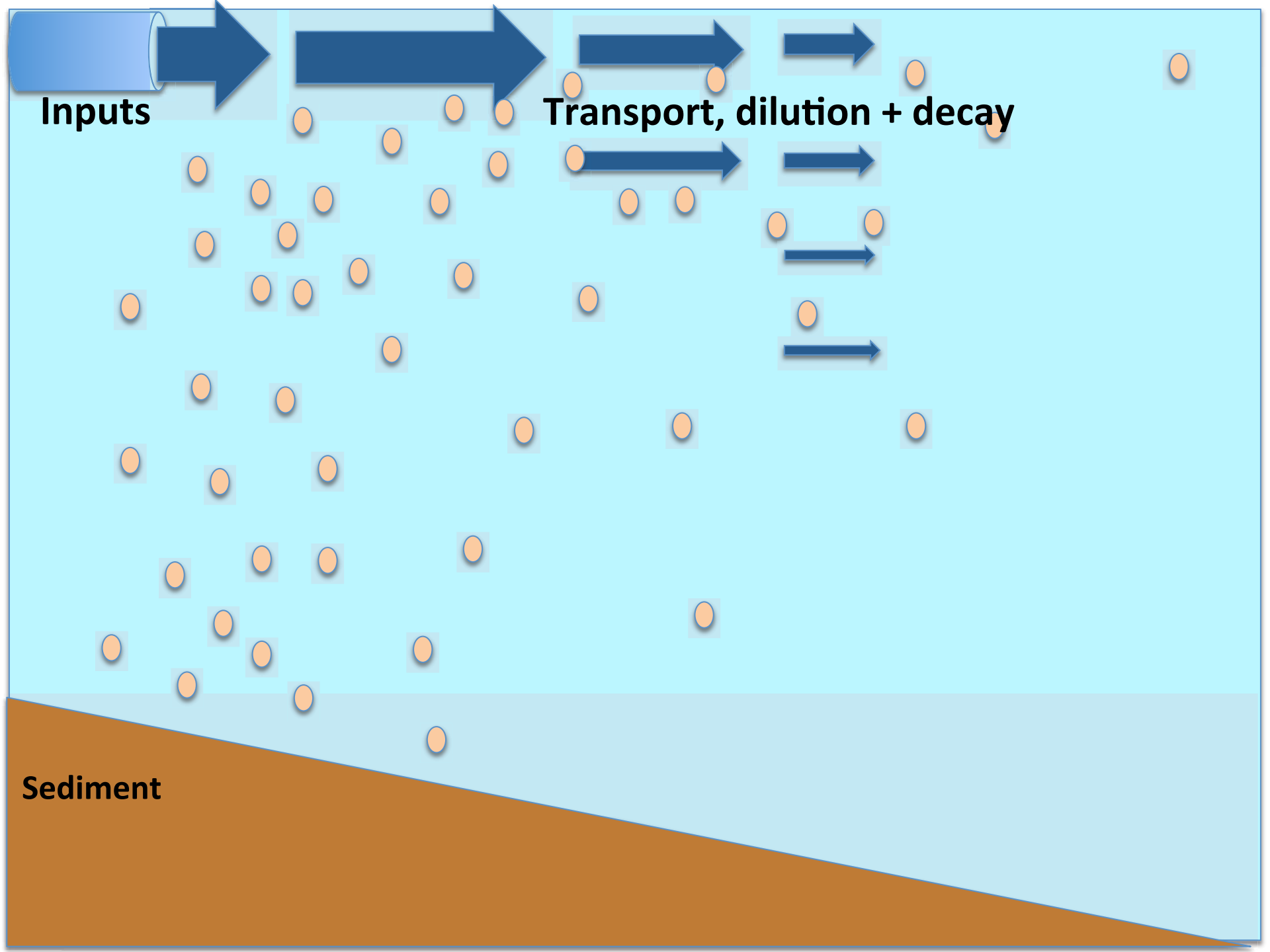
We assume that (1) input location, combined with (2) transport, dilution & decay functions will explain waterway distribution

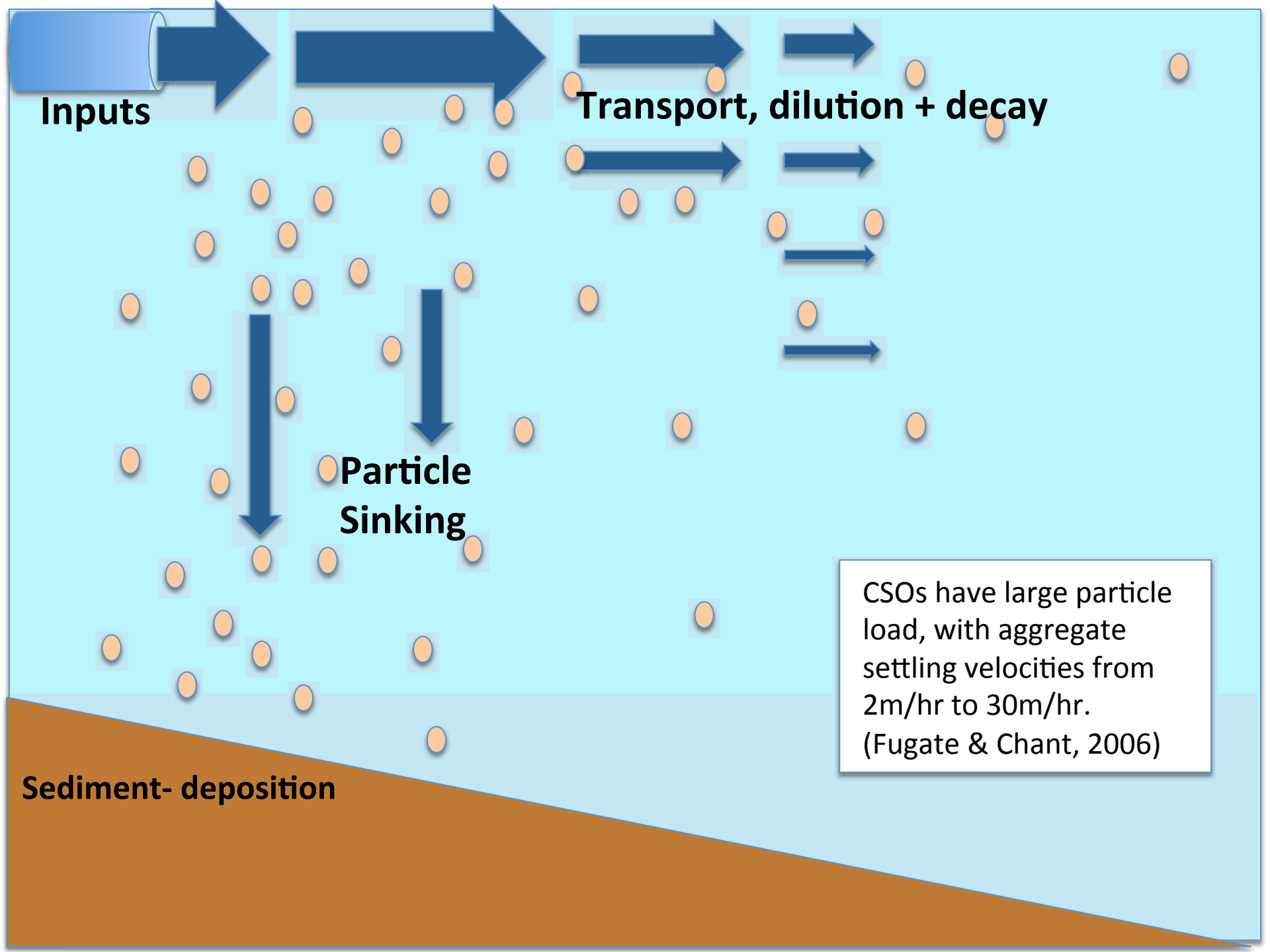
Inputs tend to be concentrated along the shoreline



Sewage inputs (■) Transport, dilution + decay


Inputs
Transport, dilution + decay
Sediment

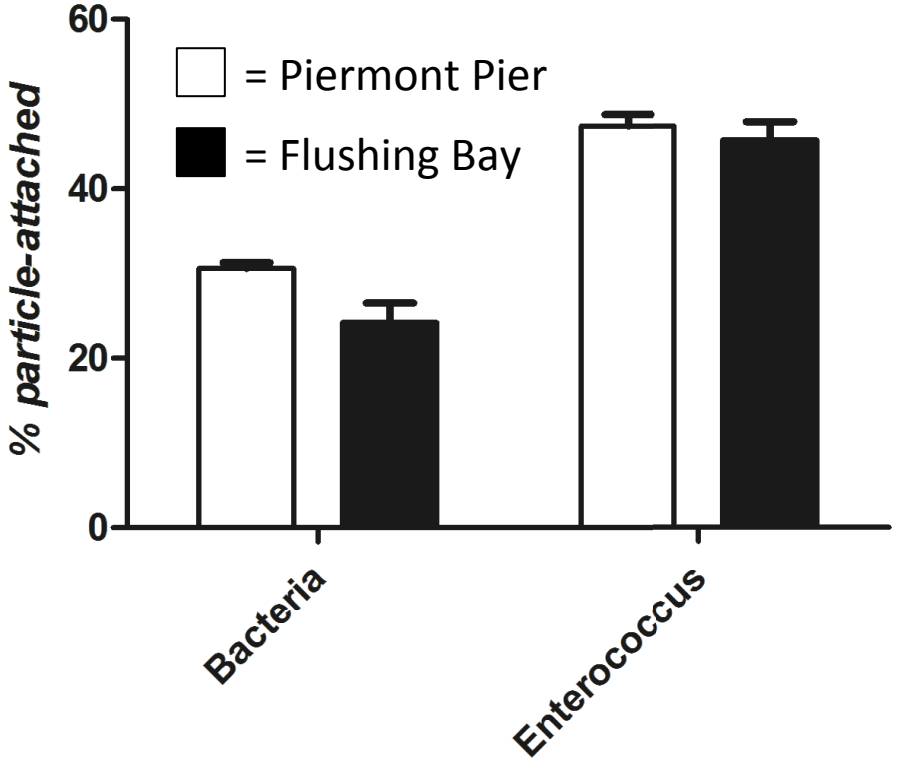

Inputs
Transport, dilution + decay
Sediment



CSOs have large particle load, with aggregate settling velocities from 2m/hr to 30m/hr. (Fugate & Chant, 2006)

Particle association of sewage indicators:

Importance: particle association can alter transport



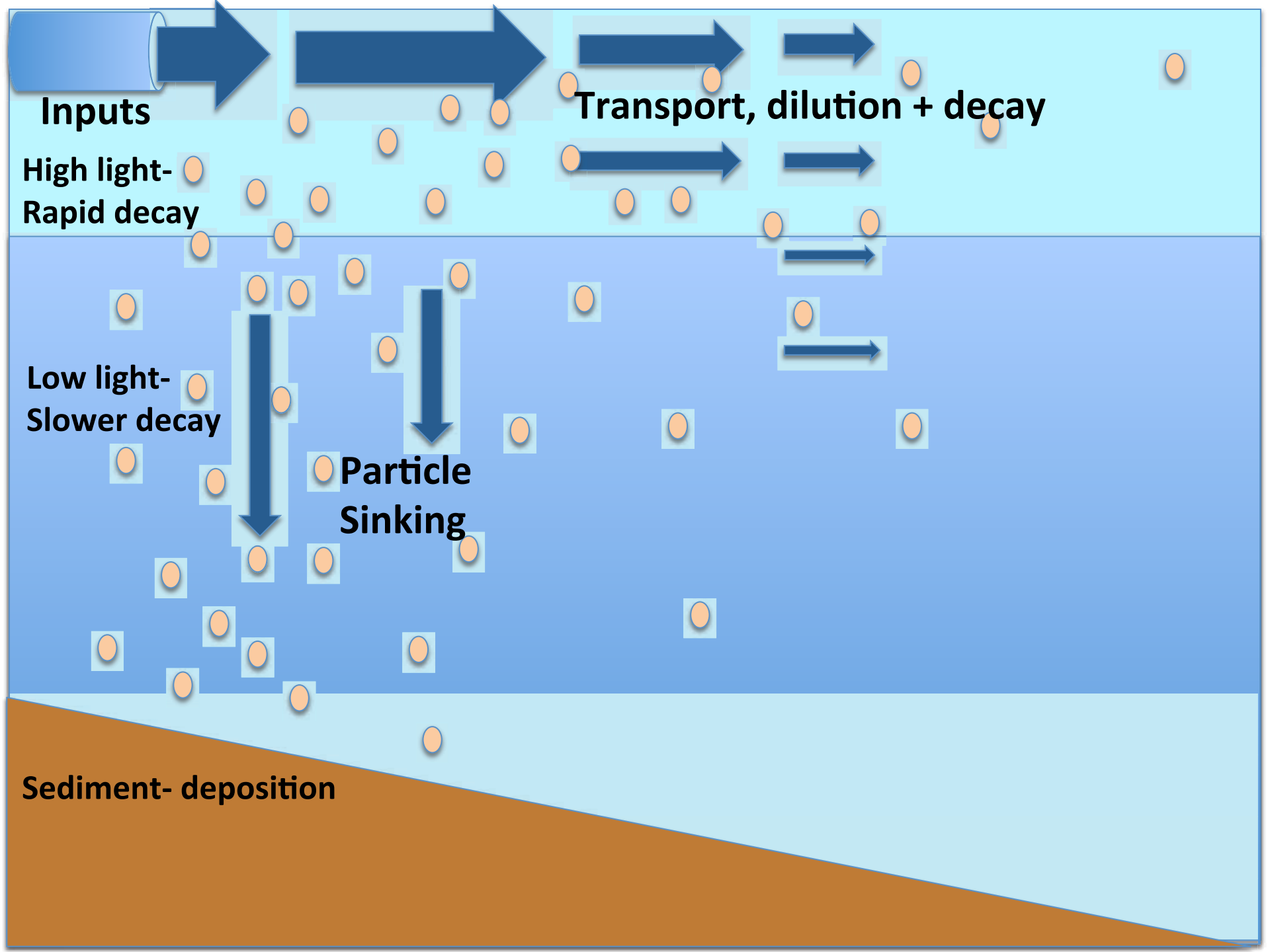
- Larger % of *Enterococci* attached to particles (>3µm) as compared to the total bacterial community.

- Particle attached cells have a greater sinking rate than free living cells.

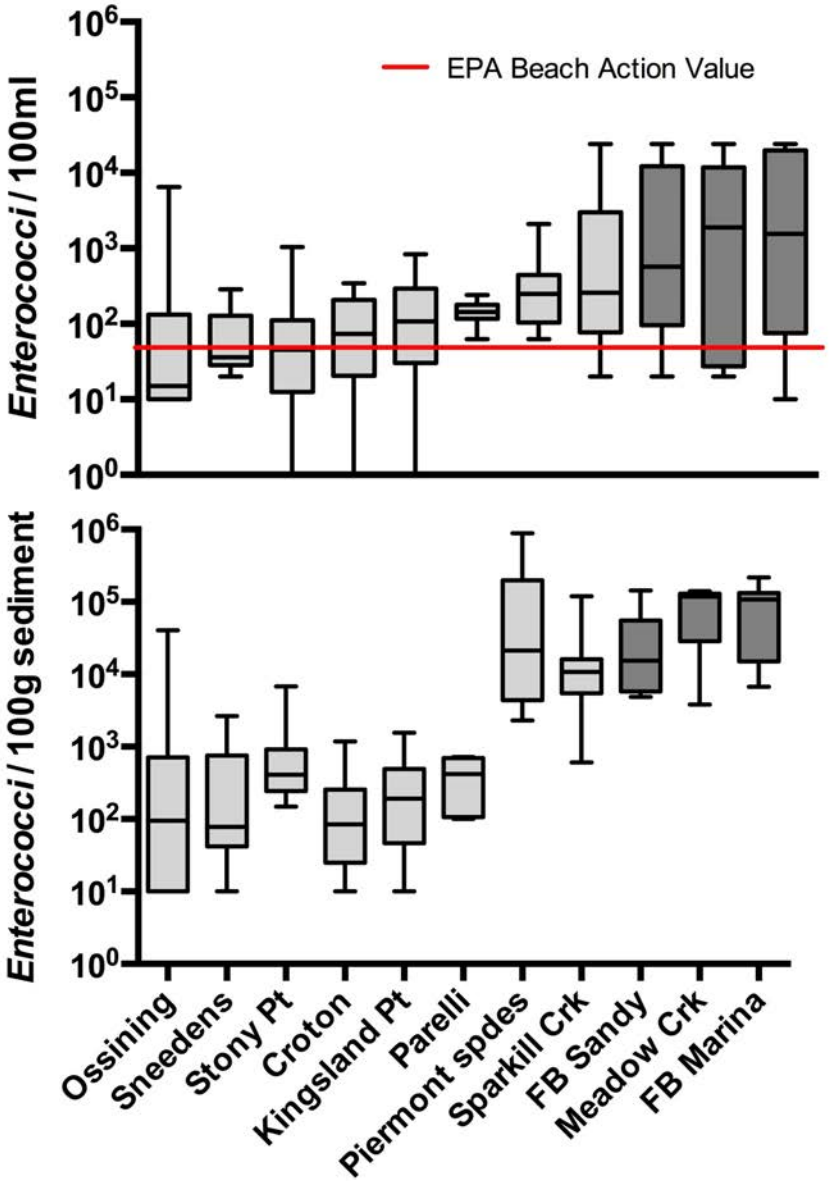
<u>(Suter et al. 2011) across six HRE sites:</u>

- **23.8%** ± 15.0% of bacteria were particle attached
- **52.9%** ± 20.9% of sewage indicators were particle attached

Suter, E., Juhl, A., O'Mullan, G. (2011). *Journal of Water Resource and Protection 3: 715:725*

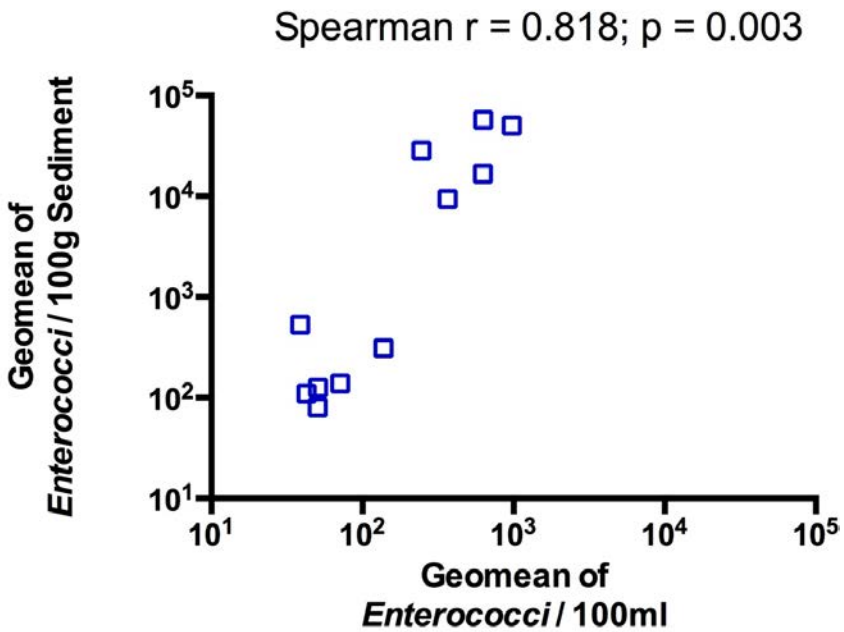

Inputs
Transport, dilution + decay
High light-
Rapid decay
Low light-
Slower decay
Particle
Sinking
Sediment- deposition

Spatial surveys detected high Entero concentrations in HRE sediment

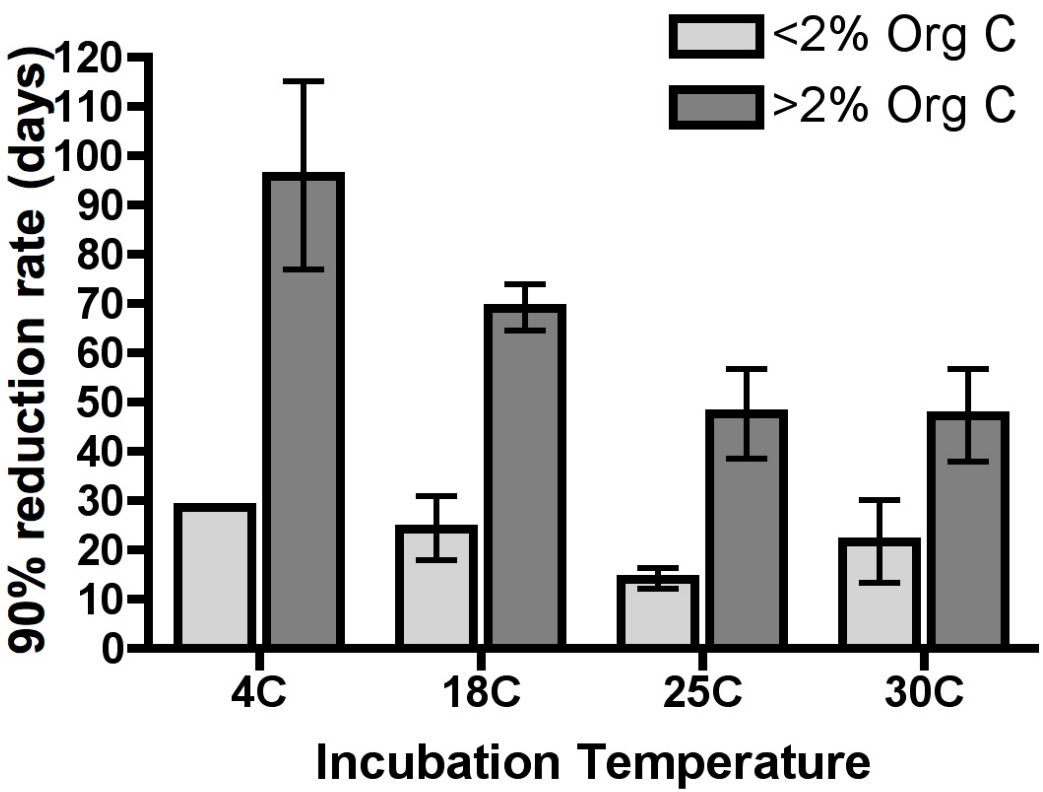


-Sites with high water column [Entero] also have elevated sediment [Entero]

-Sediment [Entero] often an order of magnitude greater than in water (by mass)



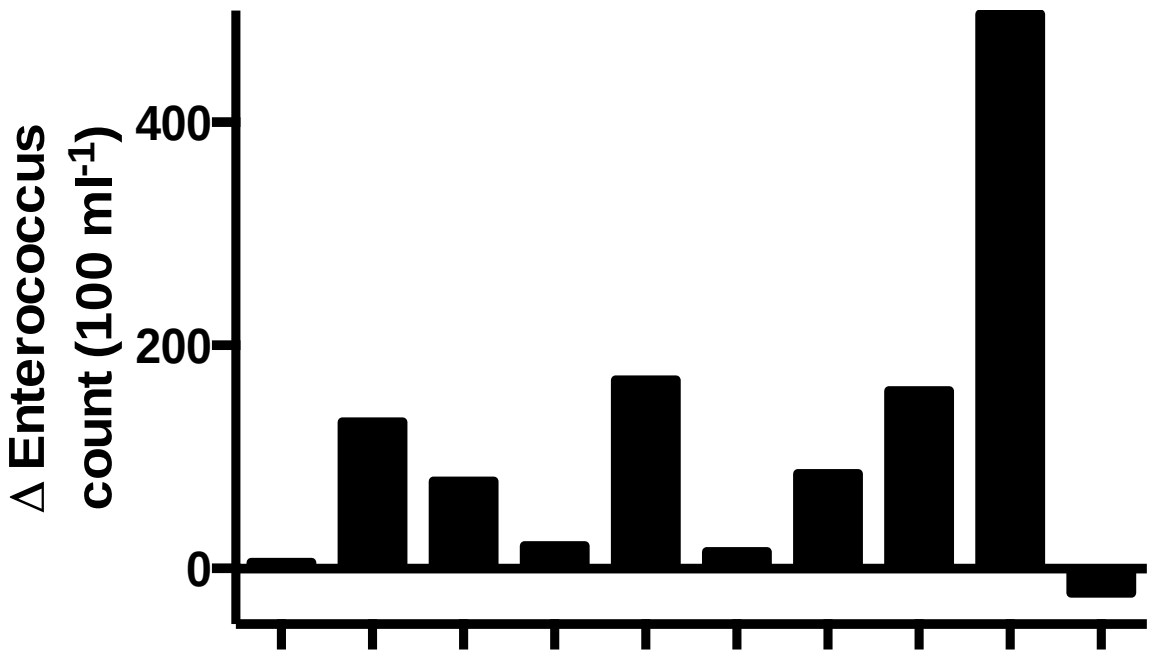
Sediment acts as an environmental reservoir



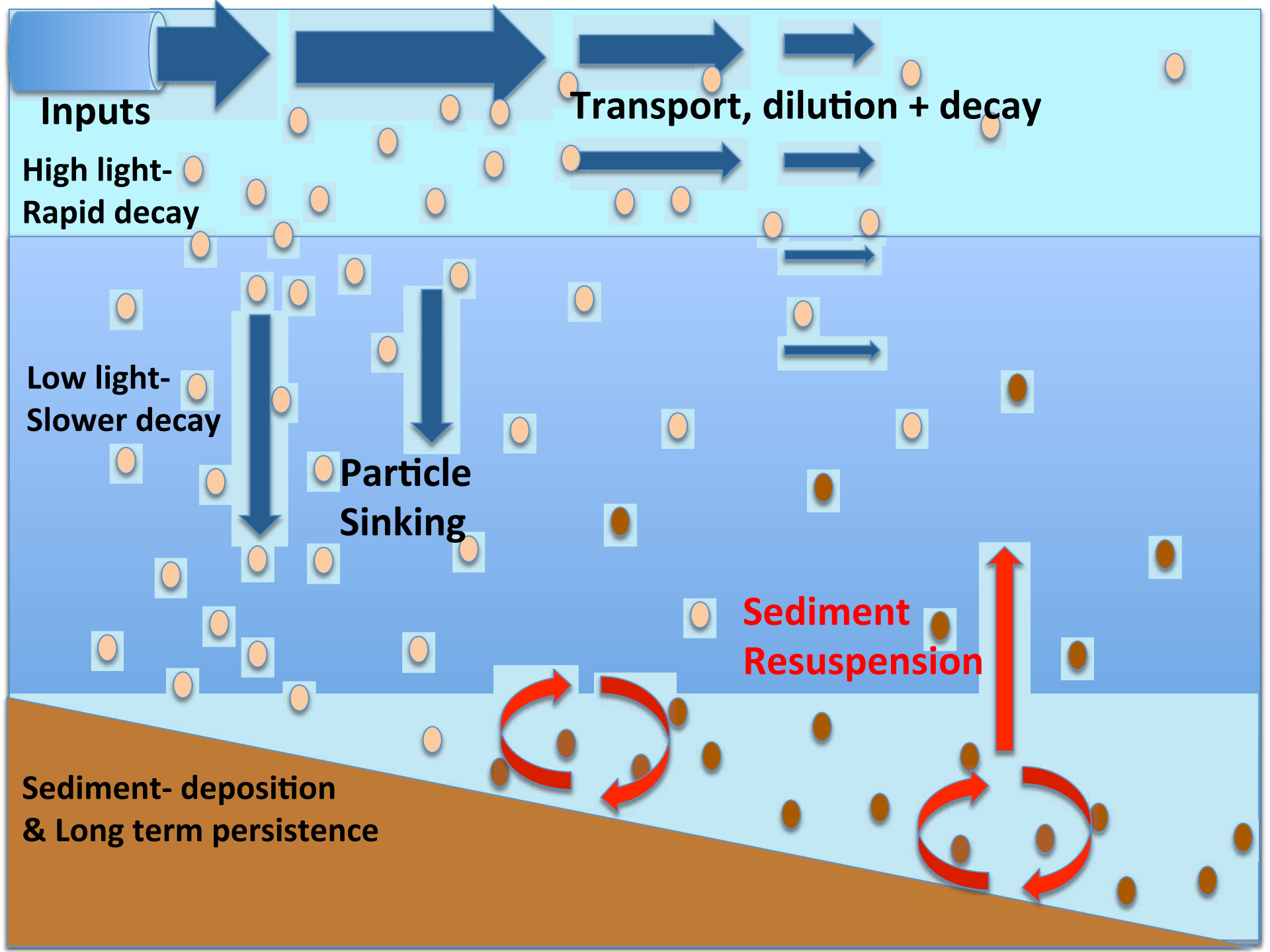
- 90% reduction rates in sediment incubations ranged from weeks to months.

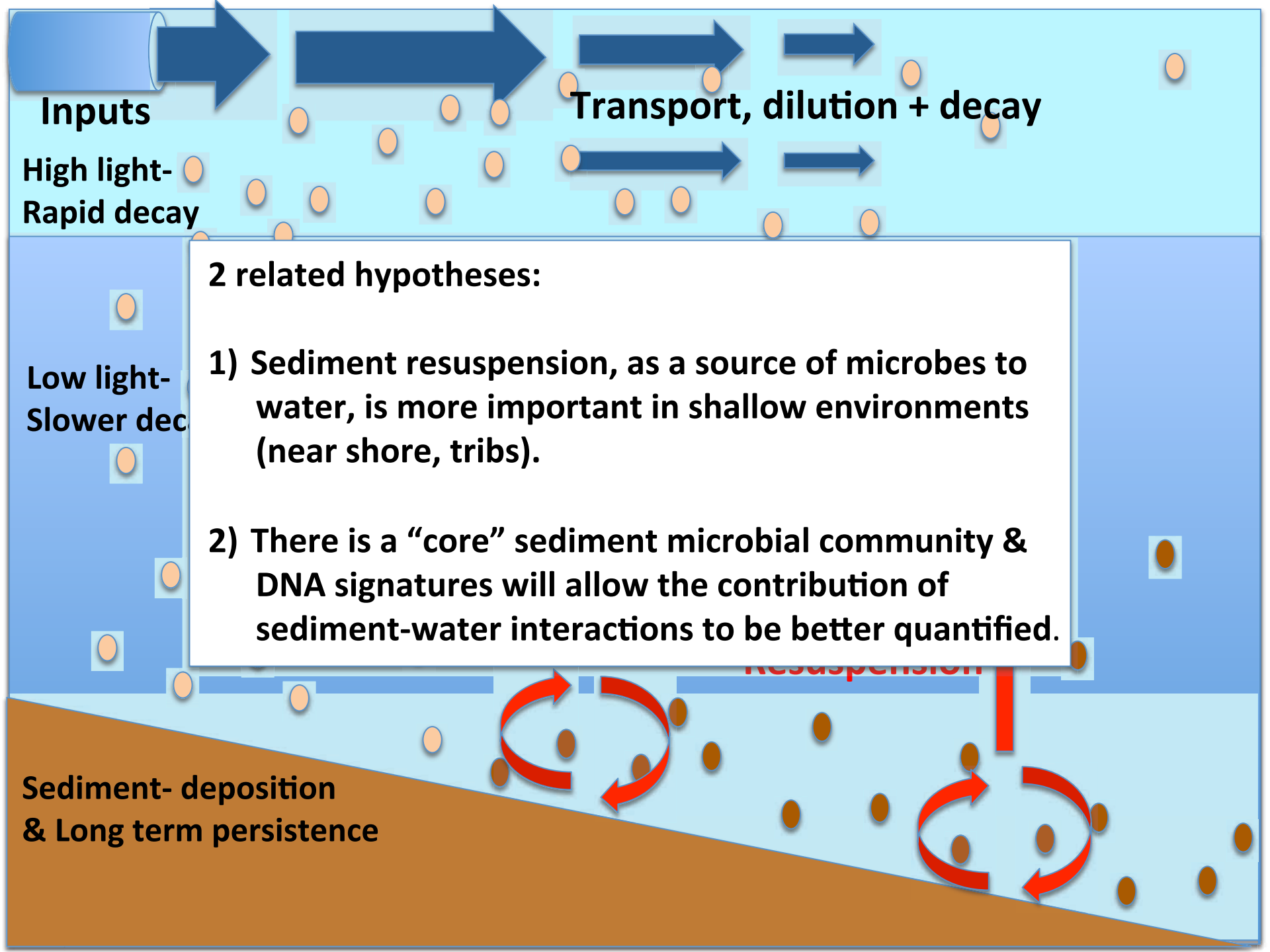
- Longest persistence observed with high organic content and low temperature.

Sediment resuspension can cause an increase in water column Entero concentration



10 wading trials were conducted near the Piermont Pier, with water column sampling before and after wading; 9 of 10 trials resulted in elevated Enterococci concentrations.

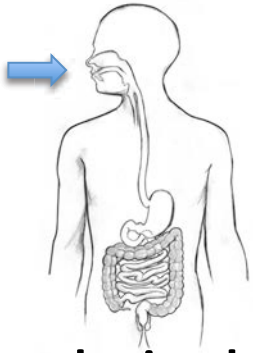

Inputs
Transport, dilution + decay
High light-
Rapid decay
Low light-
Slower decay
Particle
Sinking
Sediment
Resuspension
Sediment- deposition
& Long term persistence



2 related hypotheses:

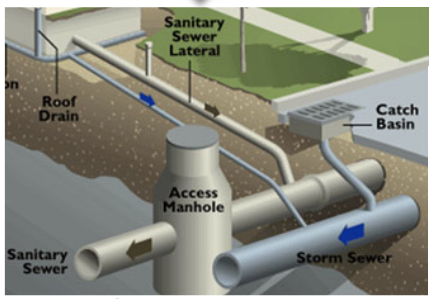
1) Sediment resuspension, as a source of microbes to water, is more important in shallow environments (near shore, tribs).

2) There is a "core" sediment microbial community & DNA signatures will allow the contribution of sediment-water interactions to be better quantified.



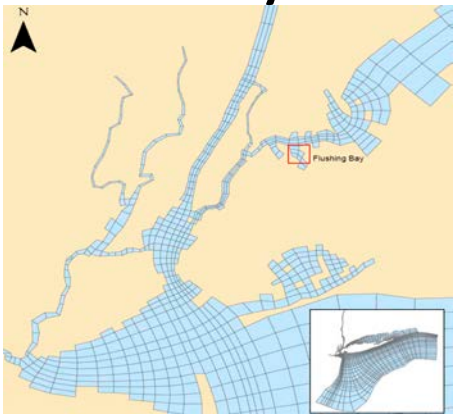
Exposure via water, sediment & aerosols

Fecal microbes



Infrastructure microbes

Natural System

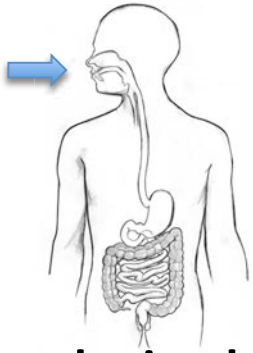


Ecological connections are far more complicated than water column transport, dilution, & decay….

Sewage input

Stormwater input

Wildlife input



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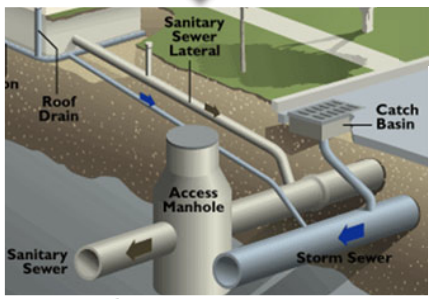
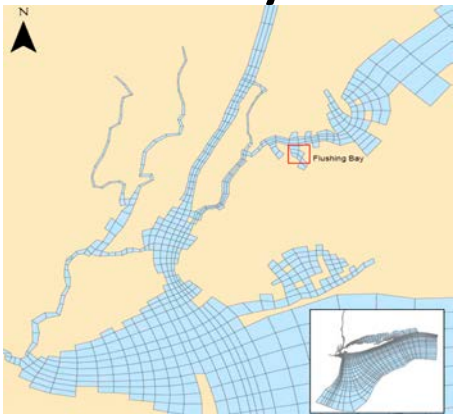


Infrastructure microbes

Natural System



Sewage input

Stormwater input

Wildlife input

As our understanding of microbial pathways become more complete, our approach to the management pathways should also evolve.

Conclusions:

- As indicator organisms travel through a system they become coupled, or de-coupled, with microbes associated with various components of that system (e.g. sewage, sediment, etc).

- Understanding microbial community composition in various components of the constructed and natural system can help to untangle the indicator interactions.

- Better understanding these complex microbial interactions can allow for optimization of the management process.

Management Implications:

- Entero is very useful in providing a framework to understand bacterial water quality; the addition of other tools (e.g. DNA signatures and source tracking) can help us to better understand water quality dynamics and better mitigate contamination sources.

- WTTP and CSOs are not the only inputs of FIB or bacterial contaminants; Exploration of other sources (e.g. stormwater and wildlife) and connections (sediment-water interactions) should be increased.

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