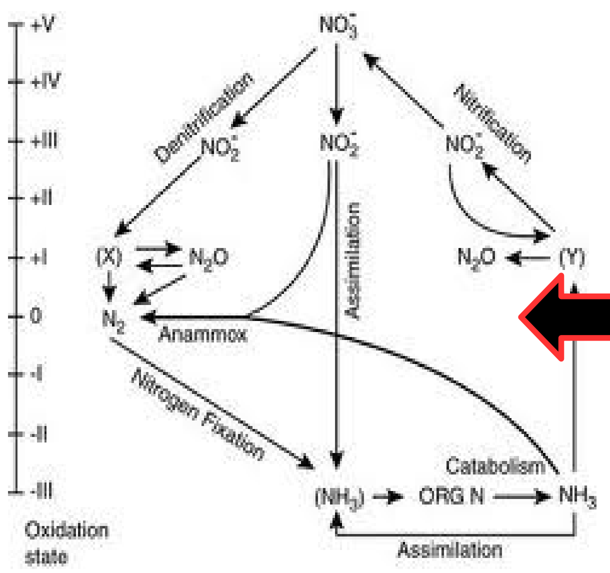
Optimized Water Sensitive Urban Design: Trade-offs in Pollutant Removal Efficiency



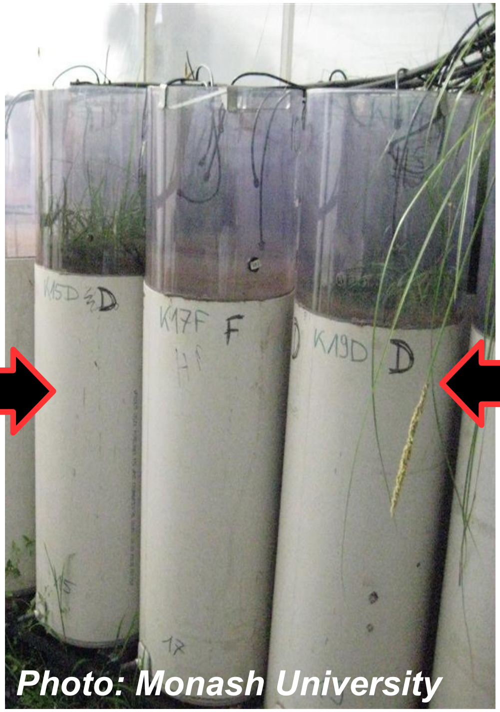


Photo: Monash University


Photo: Sustainable Melbourne

UCI Water - PIRE

Partnerships For International Research

Outline

Water Sensitive Urban Design Technologies; biofilters

- Common in SE Australian urban landscapes

Design Component: Saturation Zone (SZ)

- Nitrogen removal

Are there tradeoffs associated with the implementation of SZ that affect other pollutants of concern?

Implications of tradeoffs for urban watershed management

- Are there lessons that Southern California can learn from the Australian experience?

Engineered WSUD Systems: Biofilters

Designed to:

Strain, sediment, adsorb, precipitate, lyse, immobilize, or degrade <u>suites of pollutants</u> in stormwater or wastewater

Characterized by:

- Small Spatial footprint (2.5% CA)
- Vertical flow
- Layered media
- Vegetation
- Soil microbe and animal communities

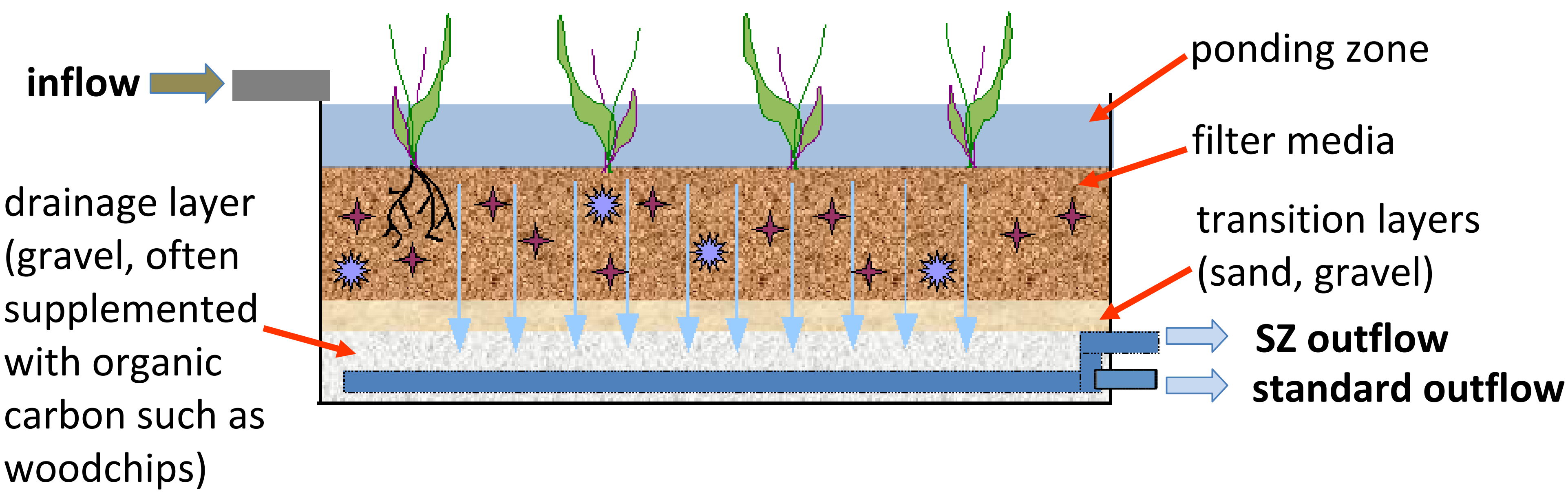


Figure modified from Grant *et al.*, 2013

Pollutants of Concern: Biofilters

Nutrients:

- Nitrate, Ammonia
- Phosphate

Heavy Metals:

- Lead
- Copper
- Zinc

Suspended Solids

Indicator Protozoa, Bacteria, and Viruses:

- *C. perfringens* spores
- *E. coli*
- F-RNA coliphages

Organic Micropollutants:

- Trihalomethanes: disinfection of drinking water
- PAHs: fossil fuel and coal combustion
- Phthalates: plasticizers
- Glycophosphate: herbicide
- Triazines: resin manufacture & herbicide base

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Removal efficiency is constantly high (> 70%)

Removal varies from 90% pollutant capture to net leaching

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Port Phillip Bay:

Concerns regarding nitrogen loading

- Reduce nitrogen inputs
  - * 100 Tonnes per year
  - * ½ by runoff reduction

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Can biofilters be optimized to remove nitrogen using SZ technology & still effectively remove other pollutants of concern like phosphate, *E. coli* and F-RNA coliphages?

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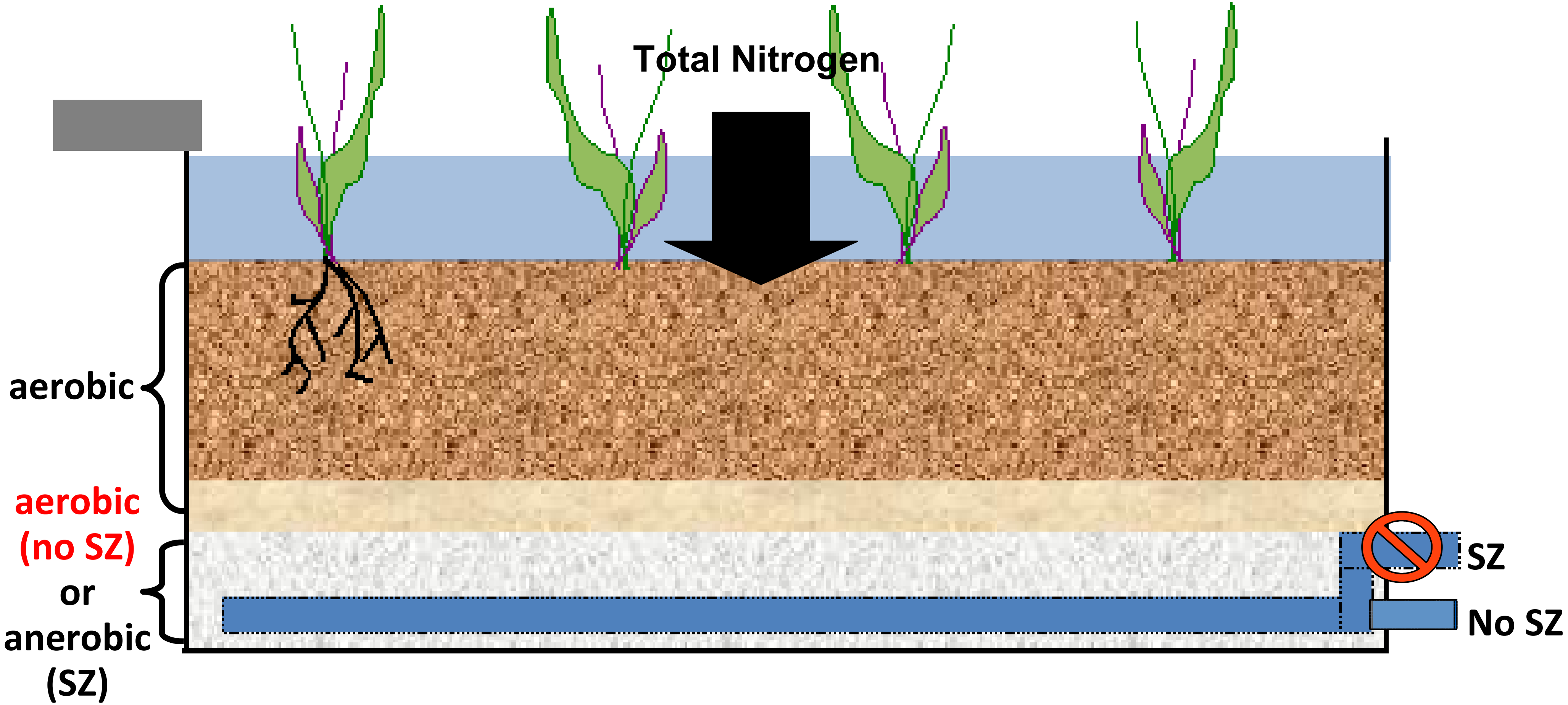
Removal varies from 90% pollutant capture to net leaching

How does a Biofilter Remove Nitrogen?



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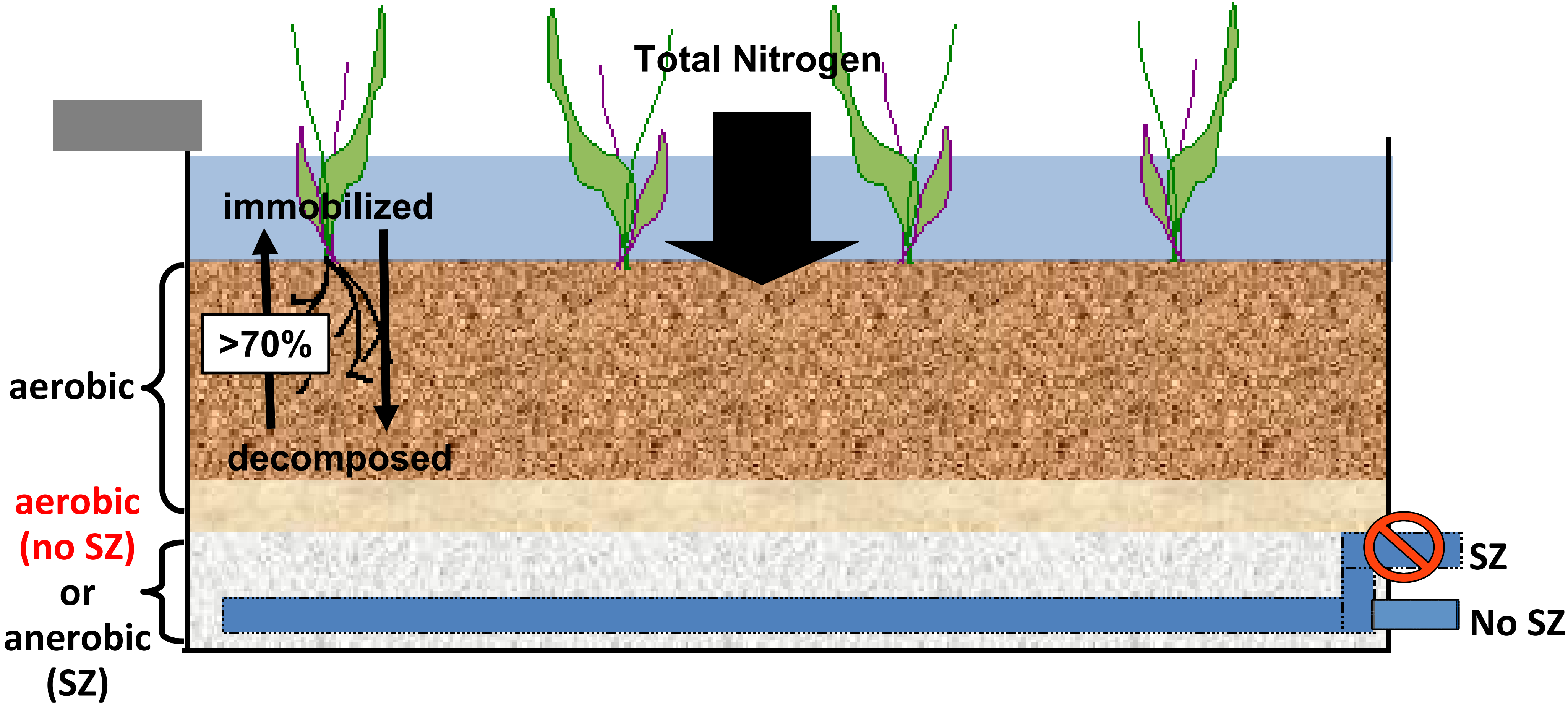

Immobilization: plant uptake (varies by plant species)

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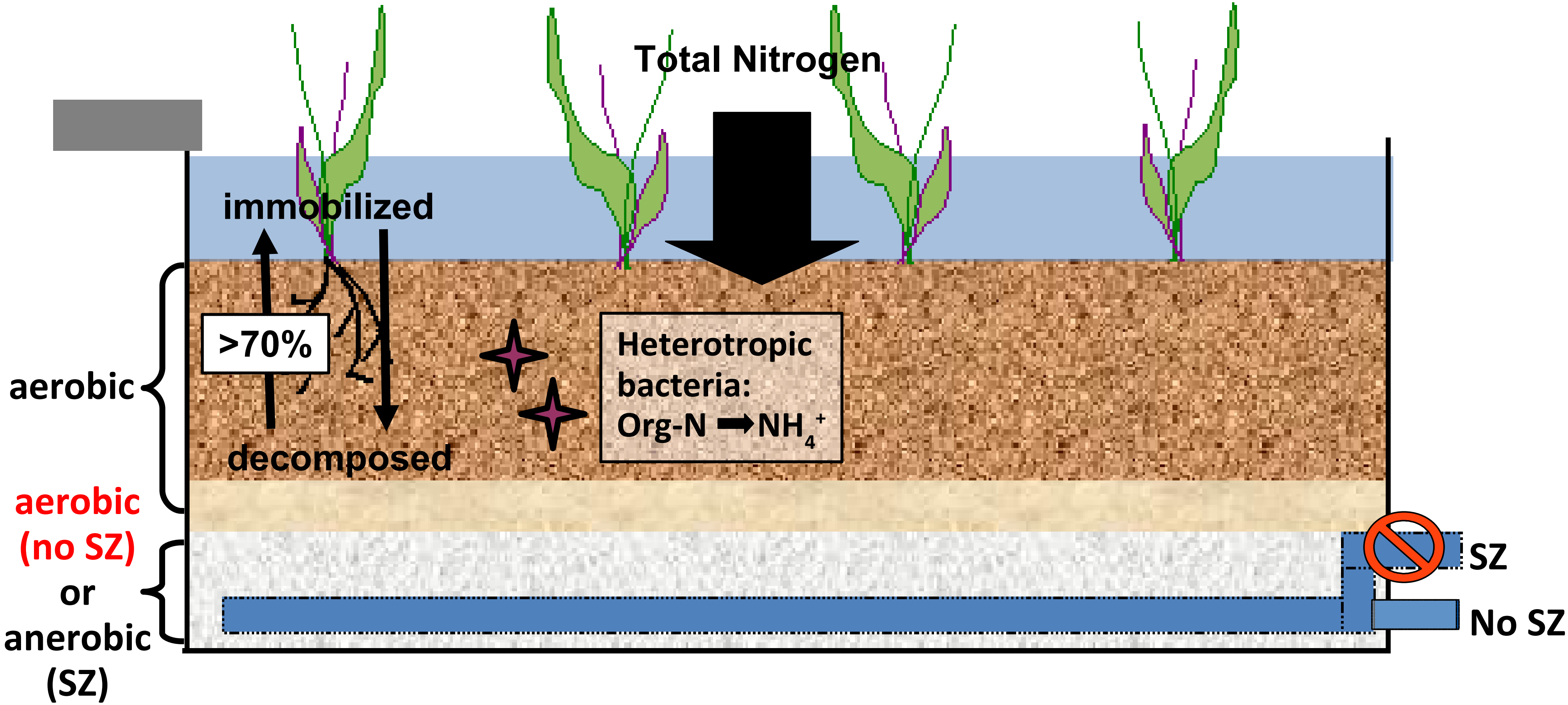

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Aerobic heterotrophic bacteria: metabolize organic nitrogen compounds

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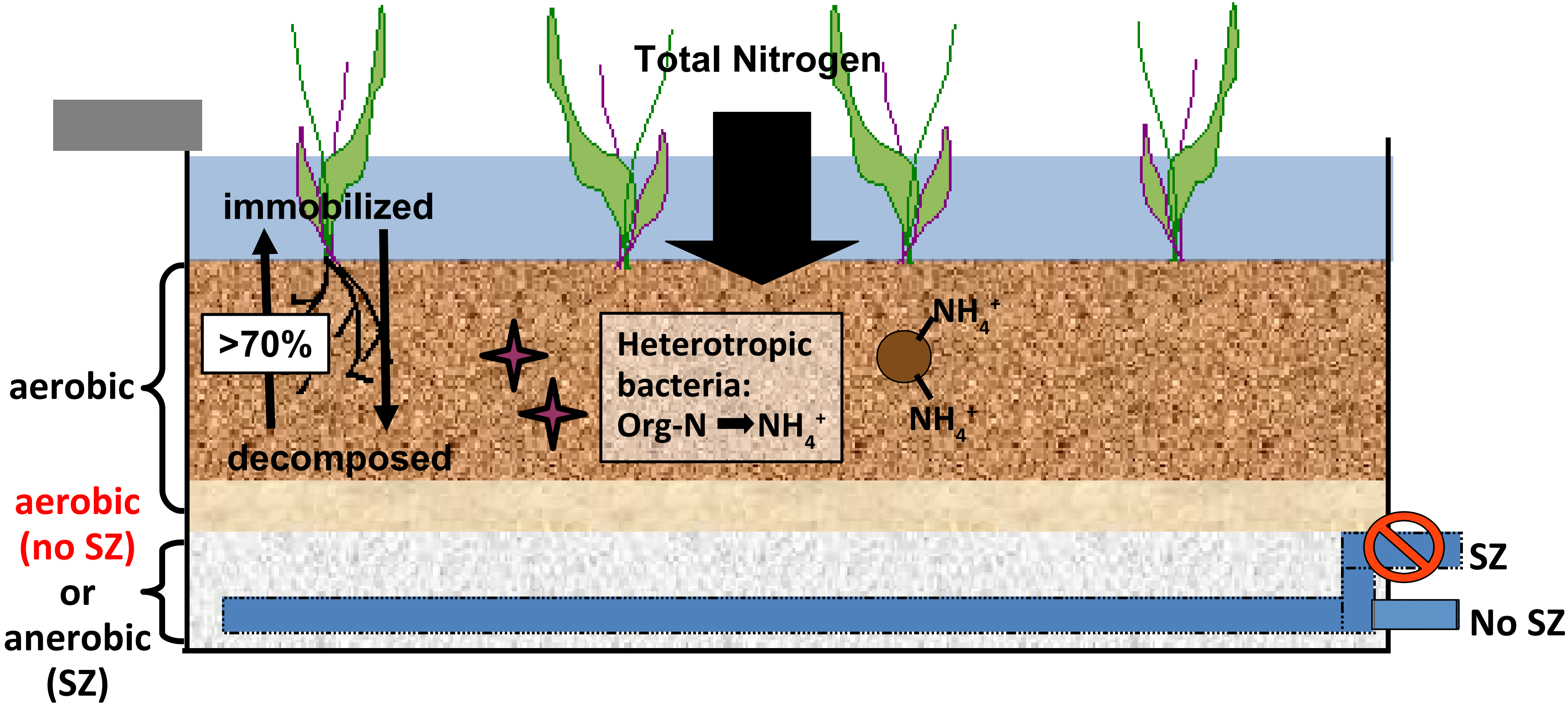

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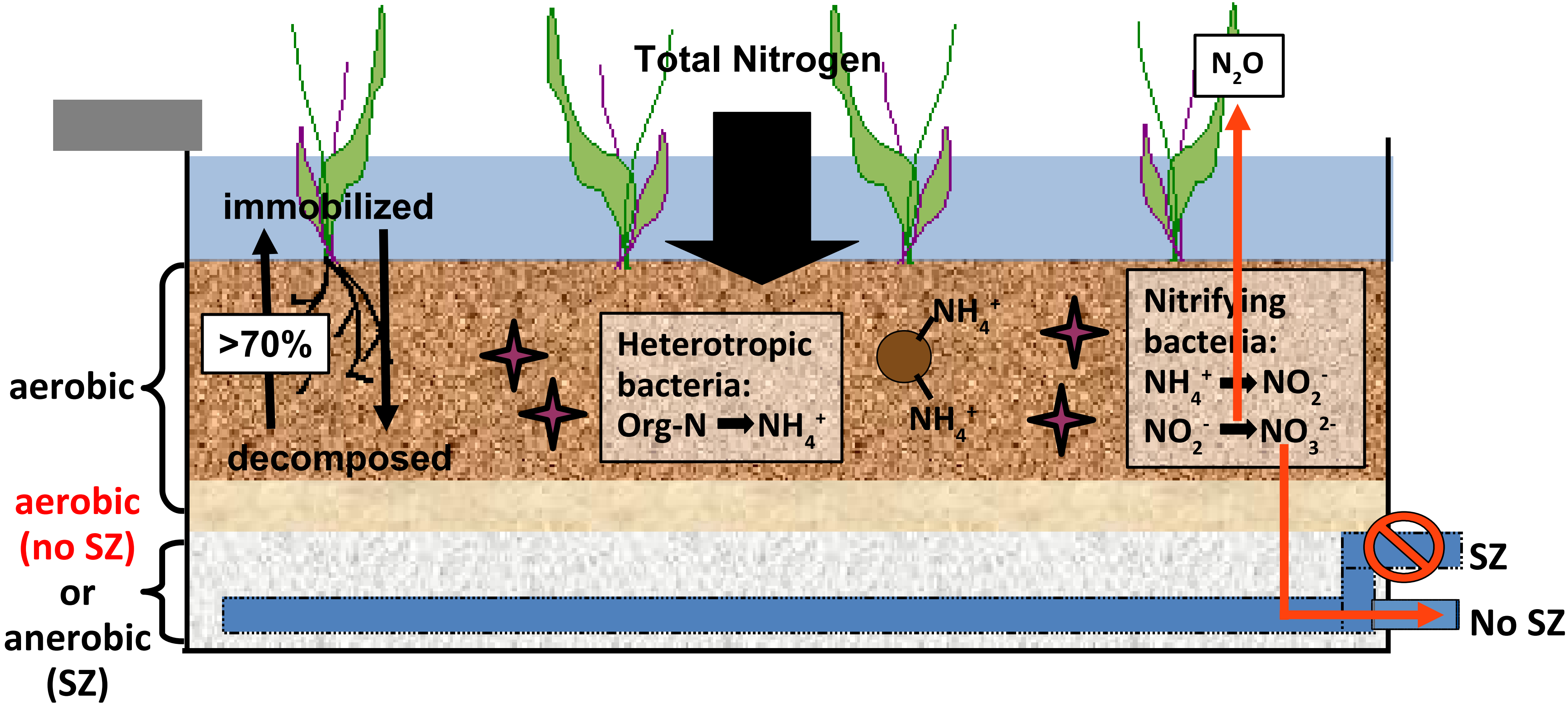

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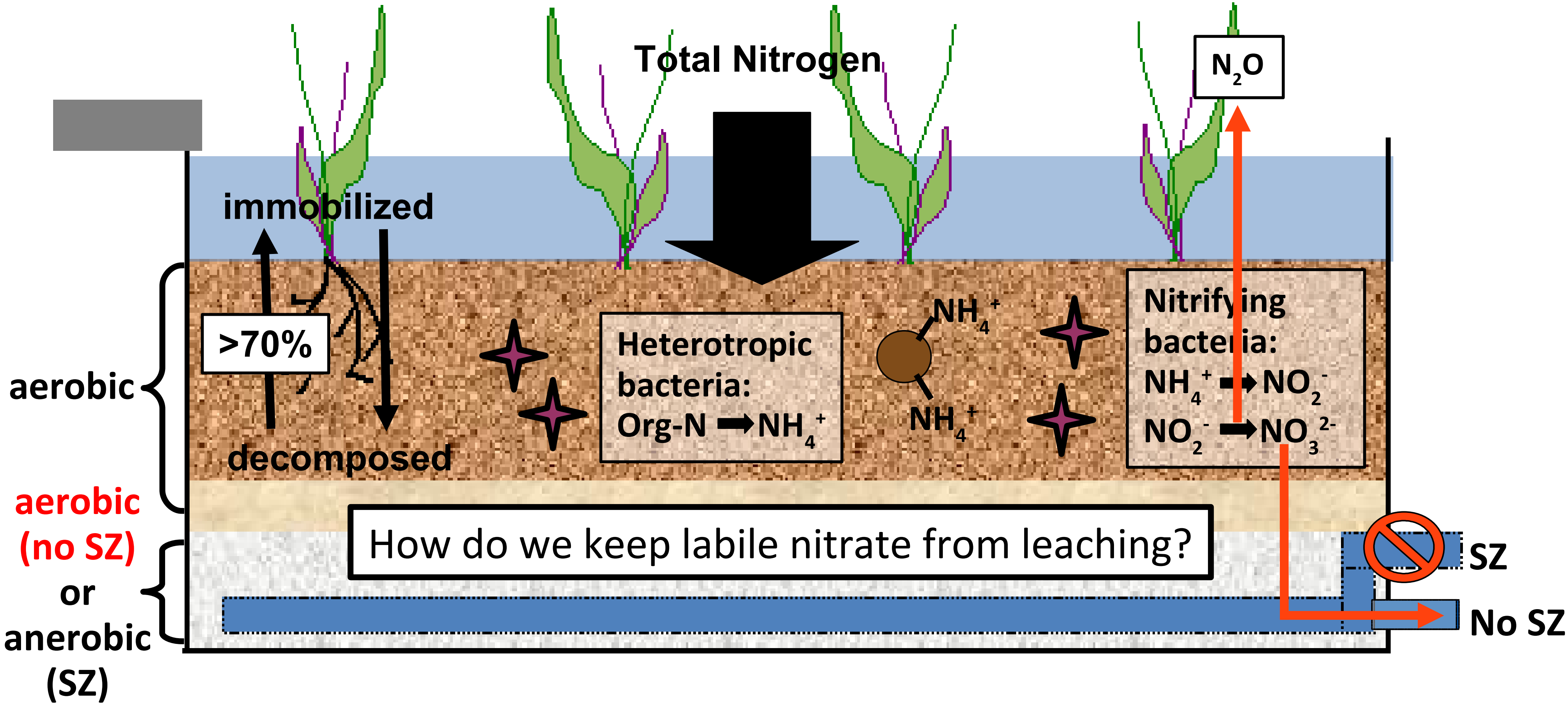

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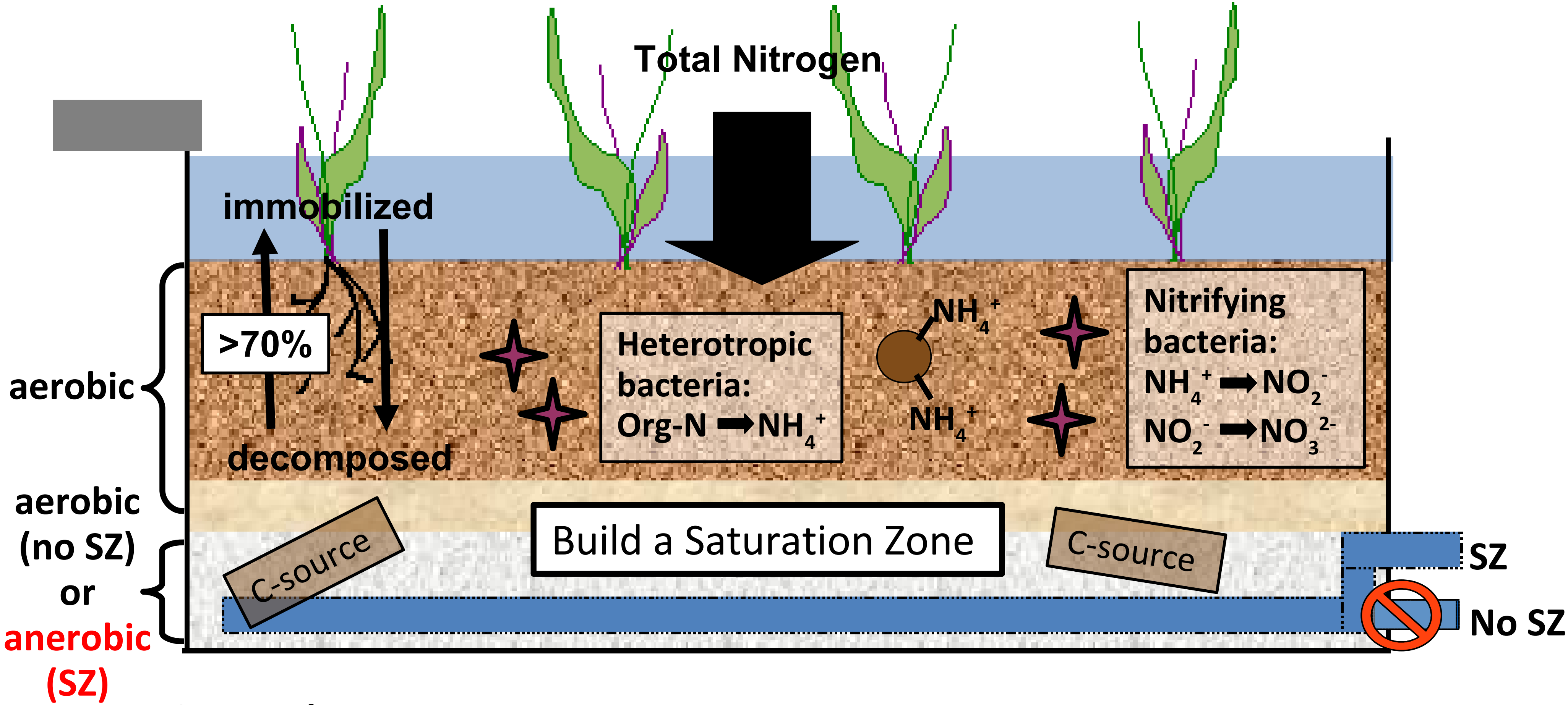
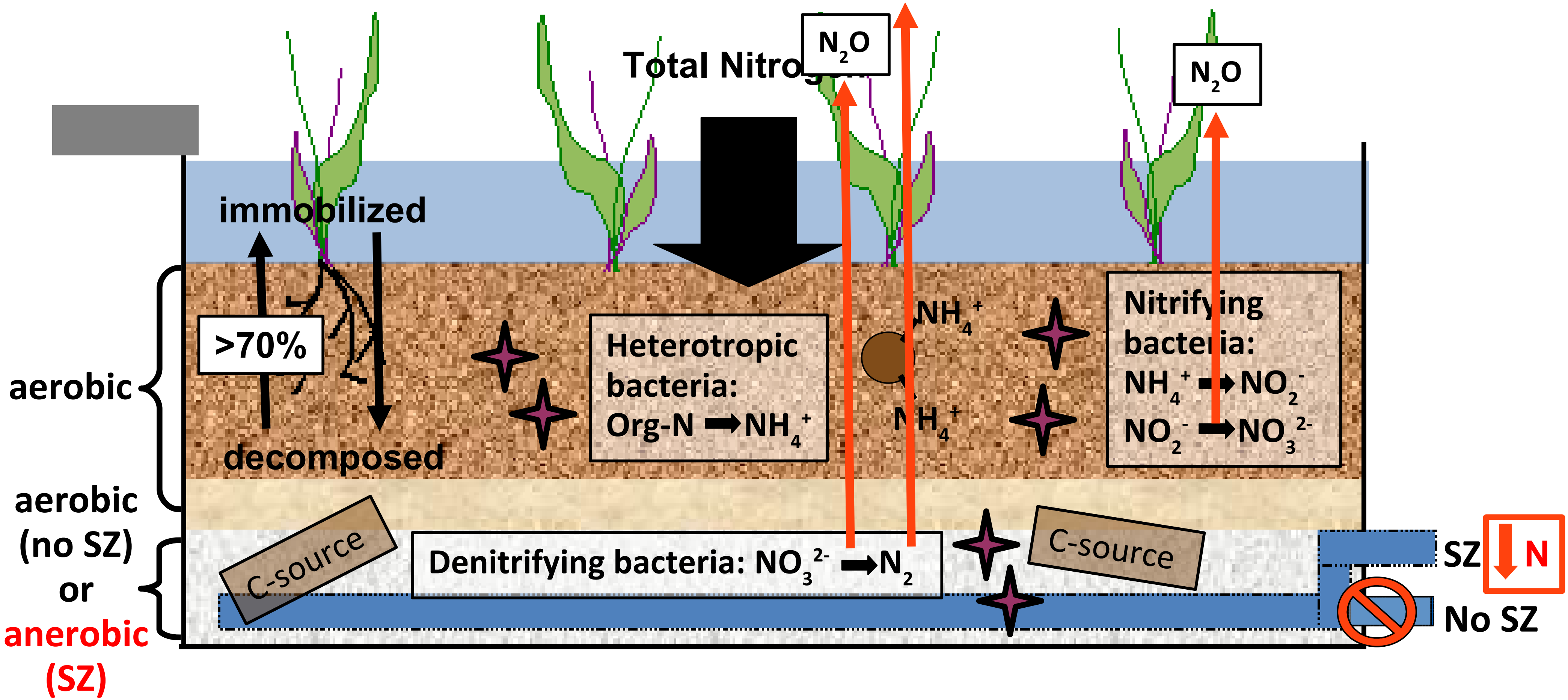


Saturation Zone:

- Elevate outflow to increase moisture / decrease aeration (promotes an O_2 gradient)
- Add a carbon source to the biofilter bed to serve as an electron donor

How does a Biofilter Remove Nitrogen?



Denitrification: anaerobic microbial heterotrophy that reduces nitrate to N_2 gas

With SZ	TN
Outflow Conc.	↓

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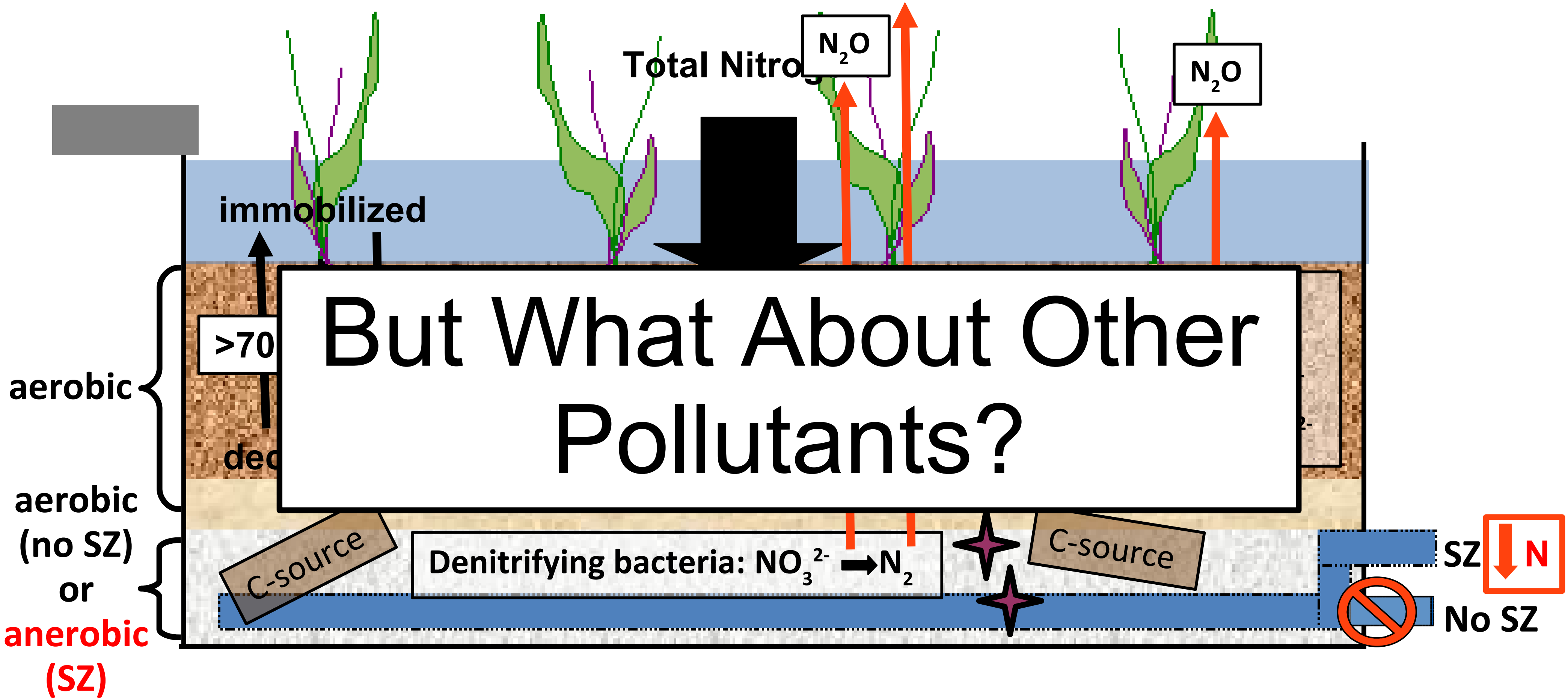
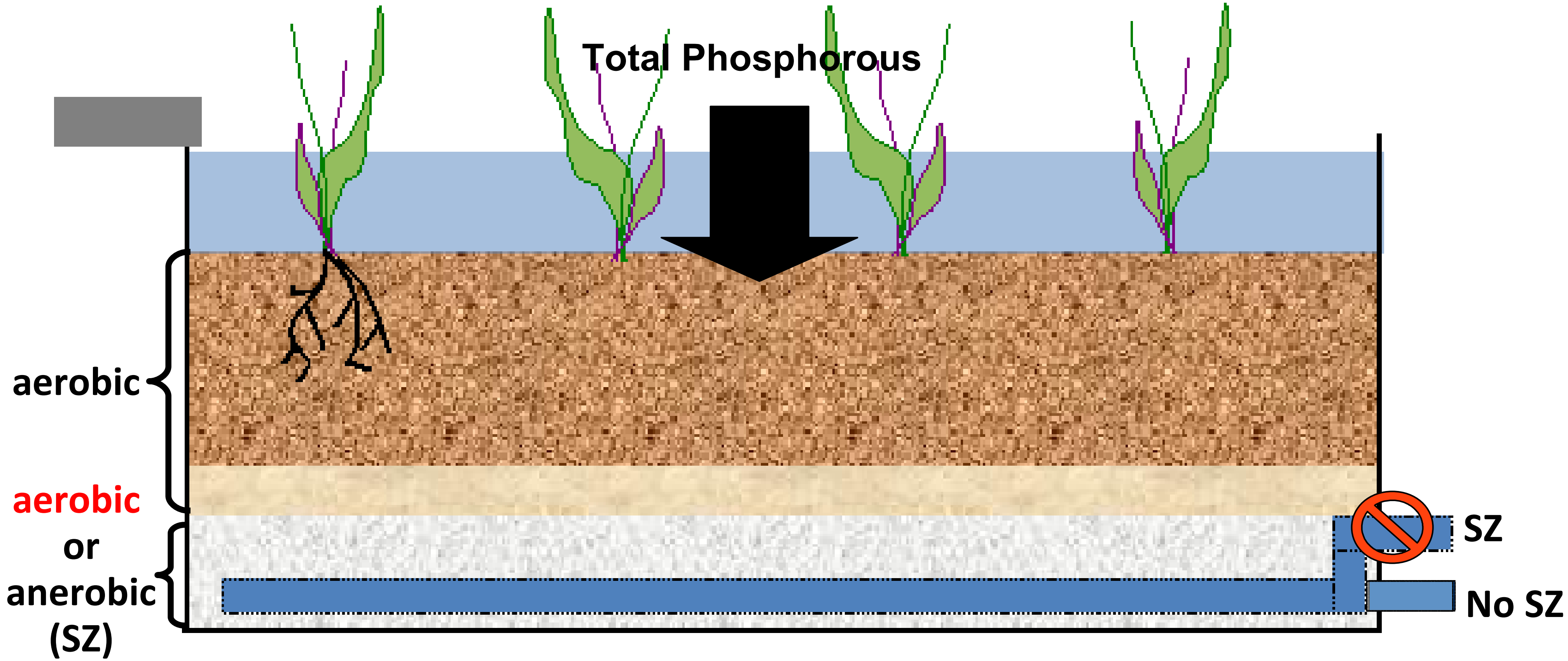


Denitrification: anaerobic microbial heterotrophy that reduces nitrate to N_2 gas

With SZ	TN	TP	*E. coli*	Coliphages
Outflow Conc.	↓			

How does a SZ affect removal of Total Phosphorous?



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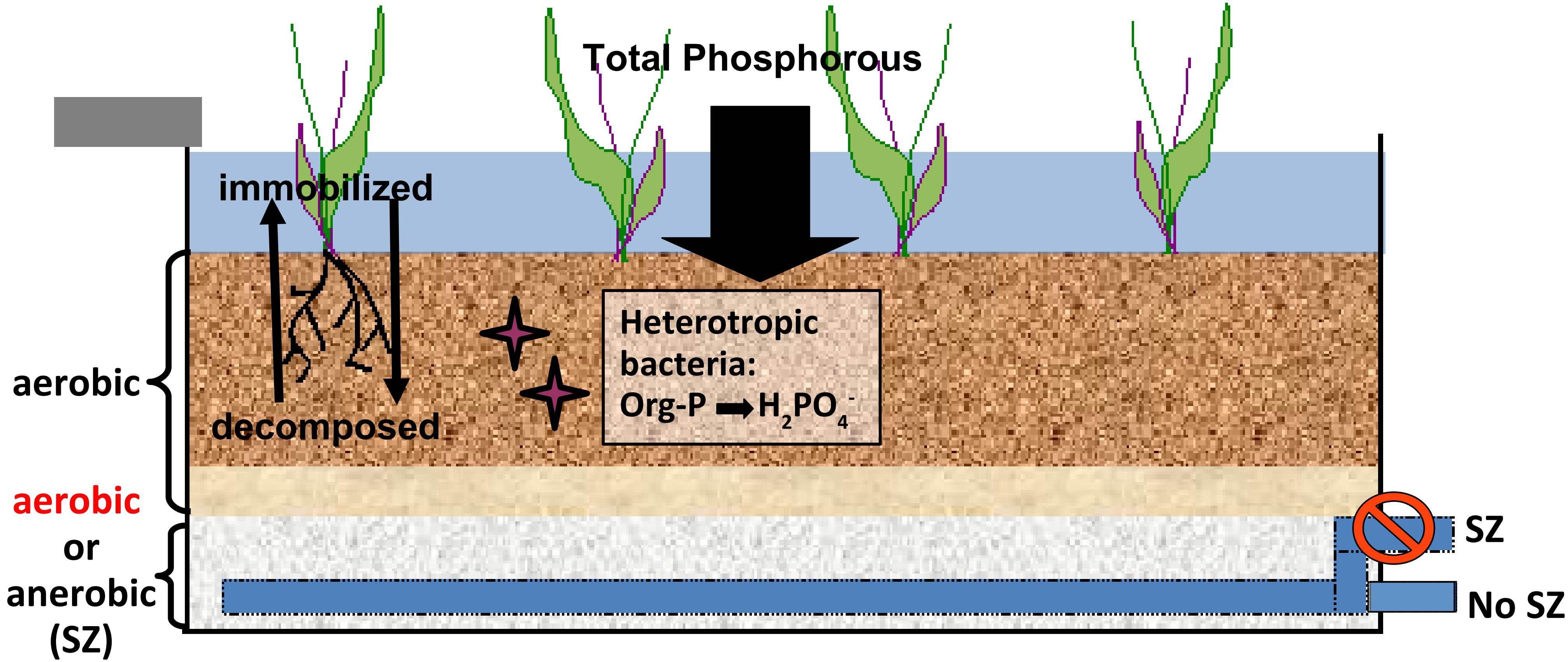

Immobilization **Aerobic heterotrophic bacteria**

With SZ	TN	TP	*E. coli*	Coliphages
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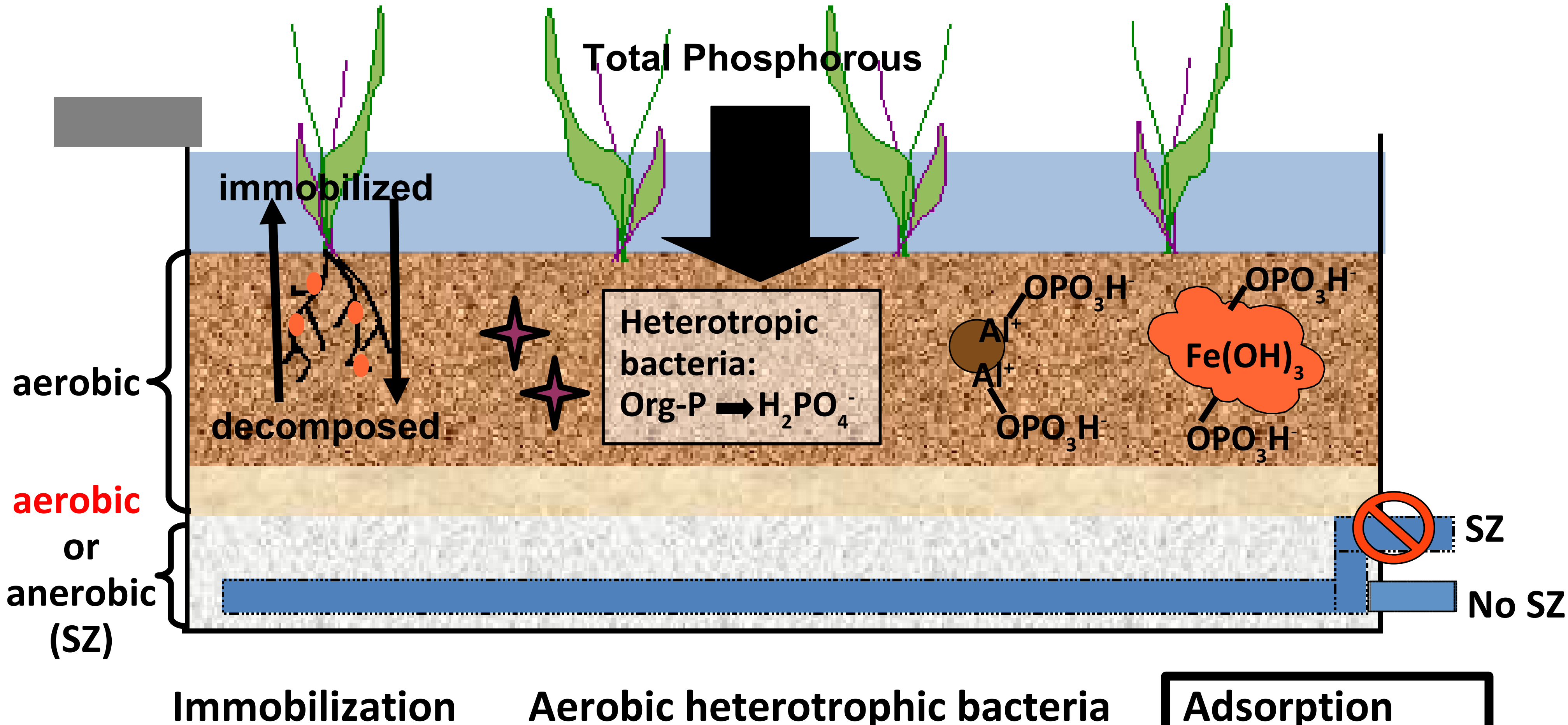

Adsorption
- **Clays**
- **Ferric Oxides**

With SZ	TN	TP	*E. coli*	Coliphages
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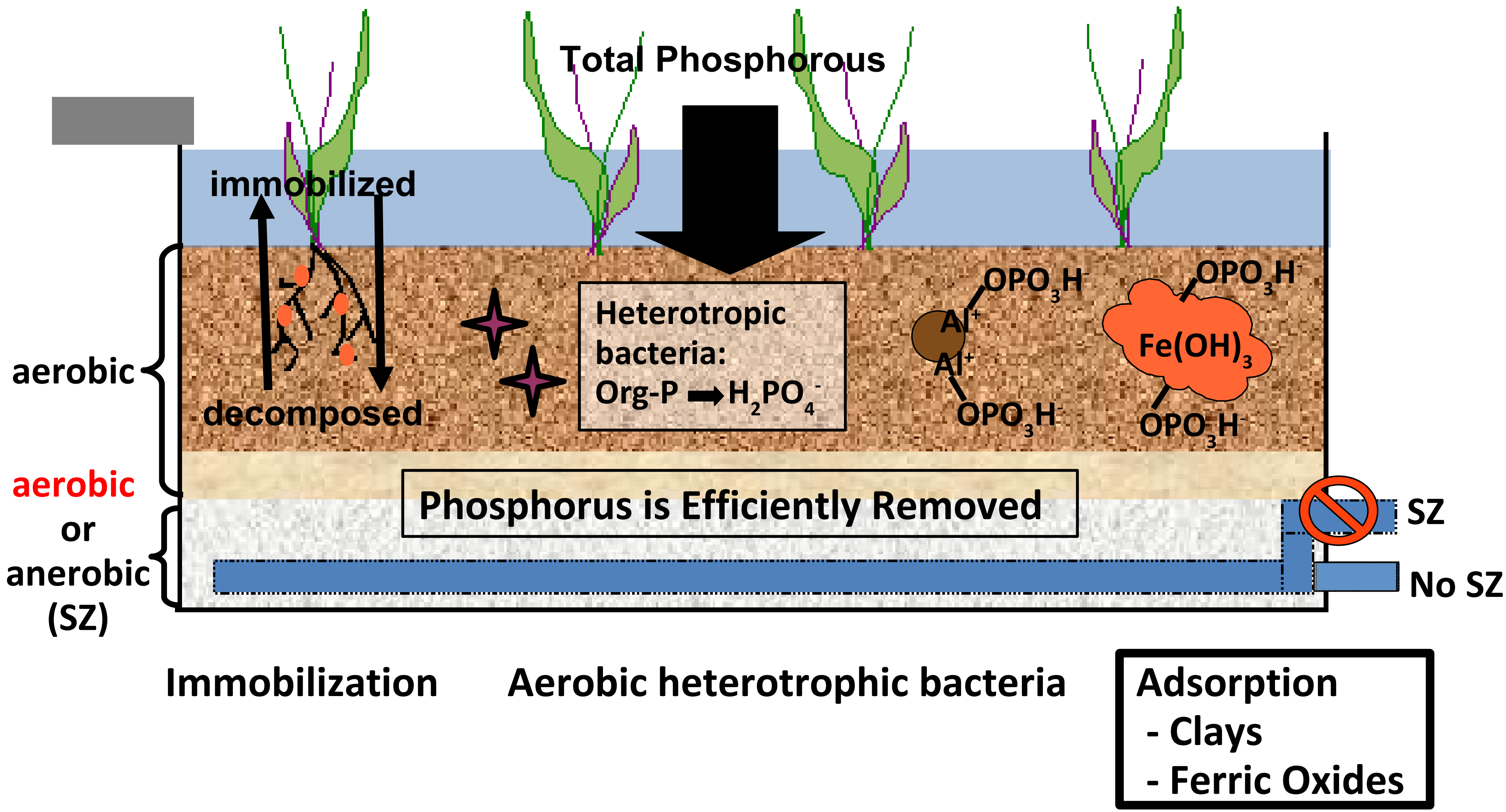

With SZ	TN	TP	*E. coli*	Coliphages
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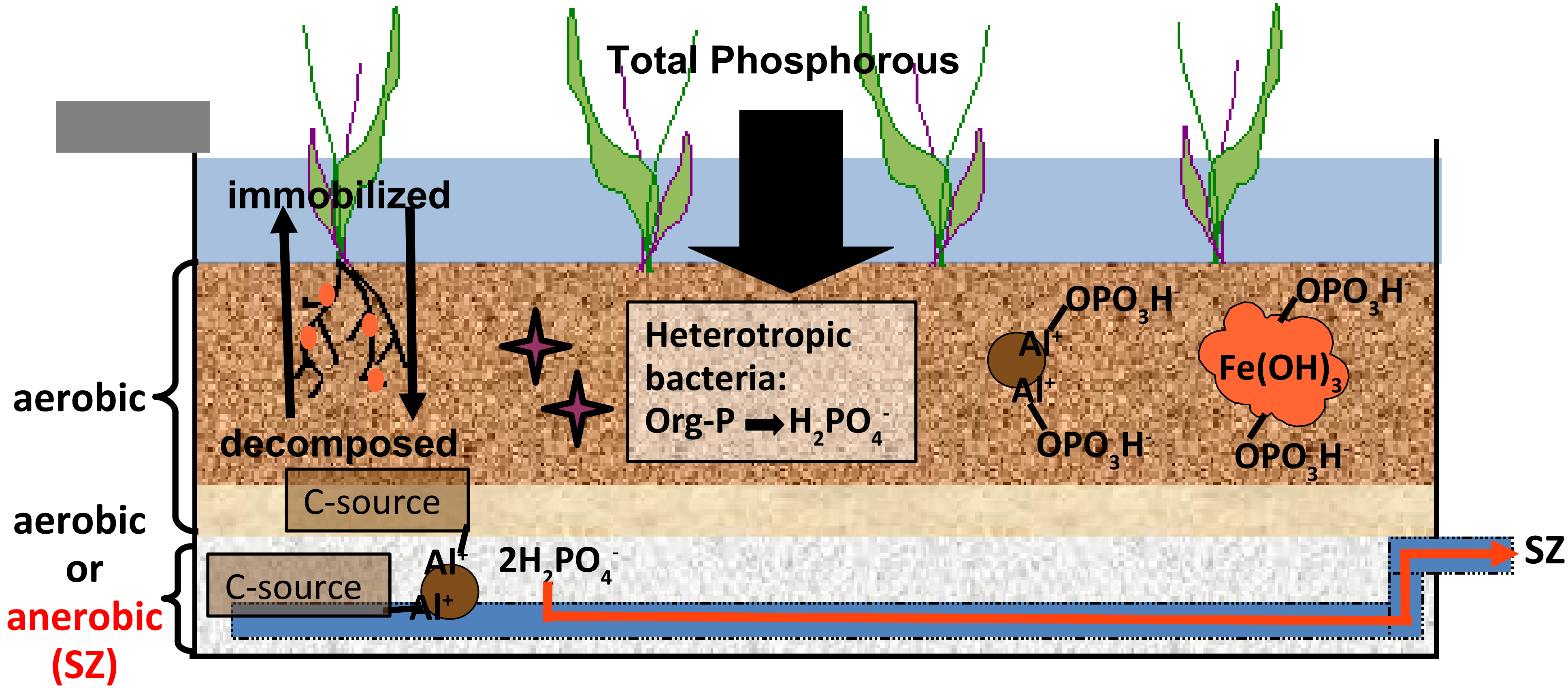
Anaerobic, high carbon SZ does not favor TP adsorption



Desorption: C-source competes with phosphorous for binding site

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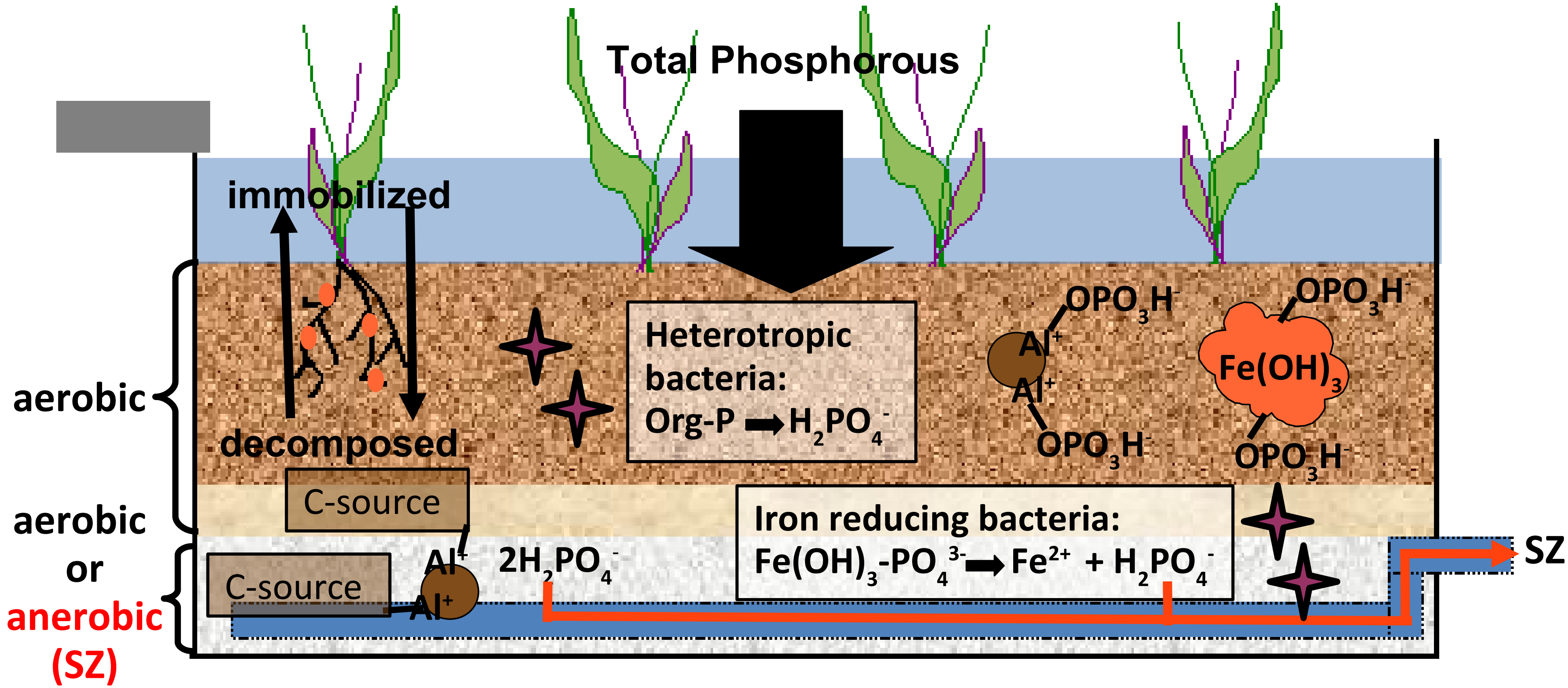

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Dissimilatory iron reduction: anaerobic microbial heterotrophy that reduces ferric to ferrous iron

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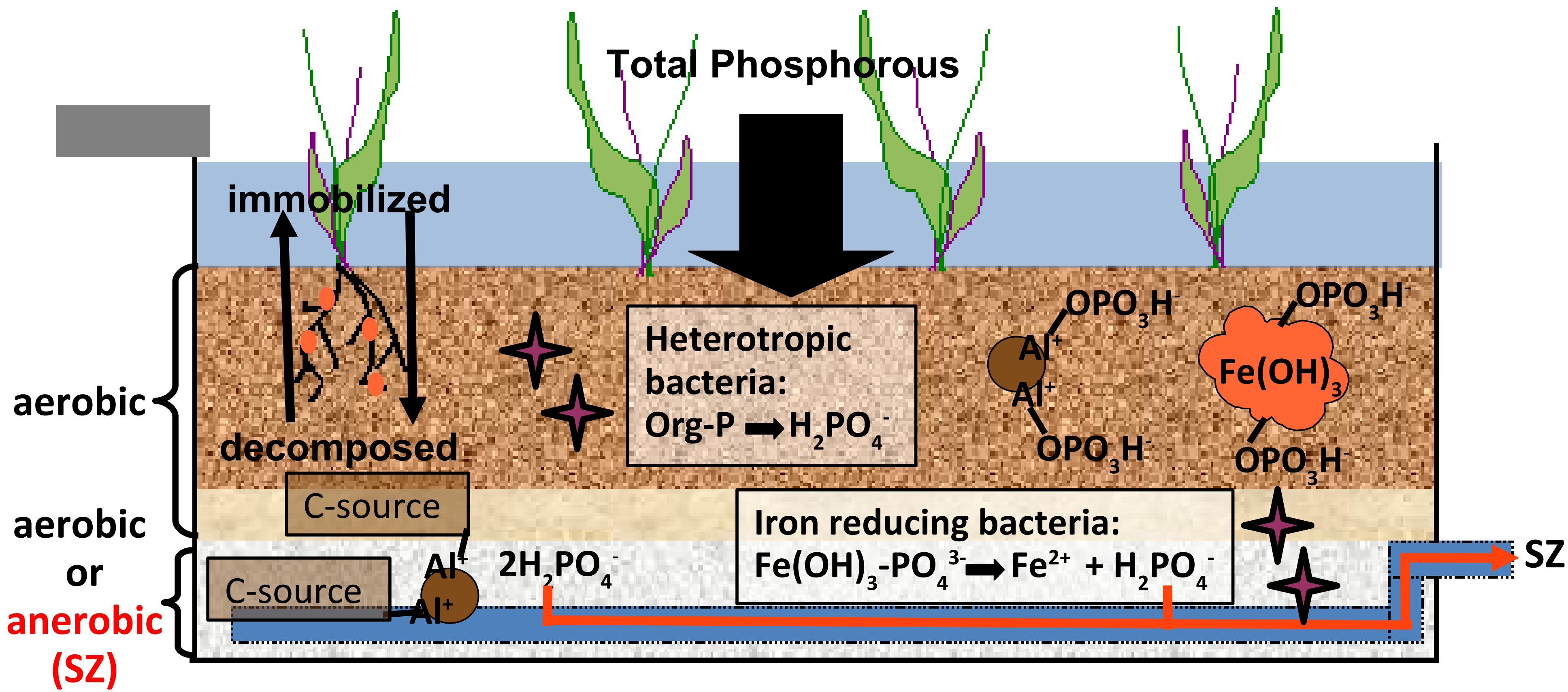

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TRADE-OFF: Phosphorus conc. in the outflow are enhanced when nitrogen removal is favored

Management Implications:
Eutrophication & Nutrient Limitation

Different nutrients are limiting in marine vs fresh receiving waters

Freshwater systems: P limited

Darling Barwin River, AU

Algal Blooms
Hypoxia
Native Ecosystem Collapse

Coastal marine systems: N limited

Port Phillip Bay, AU

Biofilters with a Saturation Zone may improve water quality in systems with coastal receiving waters

Biofilters with Saturation Zones may be inappropriate for systems with high phosphorus loading and/or fresh receiving waters

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Eutrophication & Nutrient Limitation

Different nutrients are limiting in marine vs fresh receiving waters

Freshwater systems: P limited

Darling Barwin River, AU

Coastal marine systems: N limited

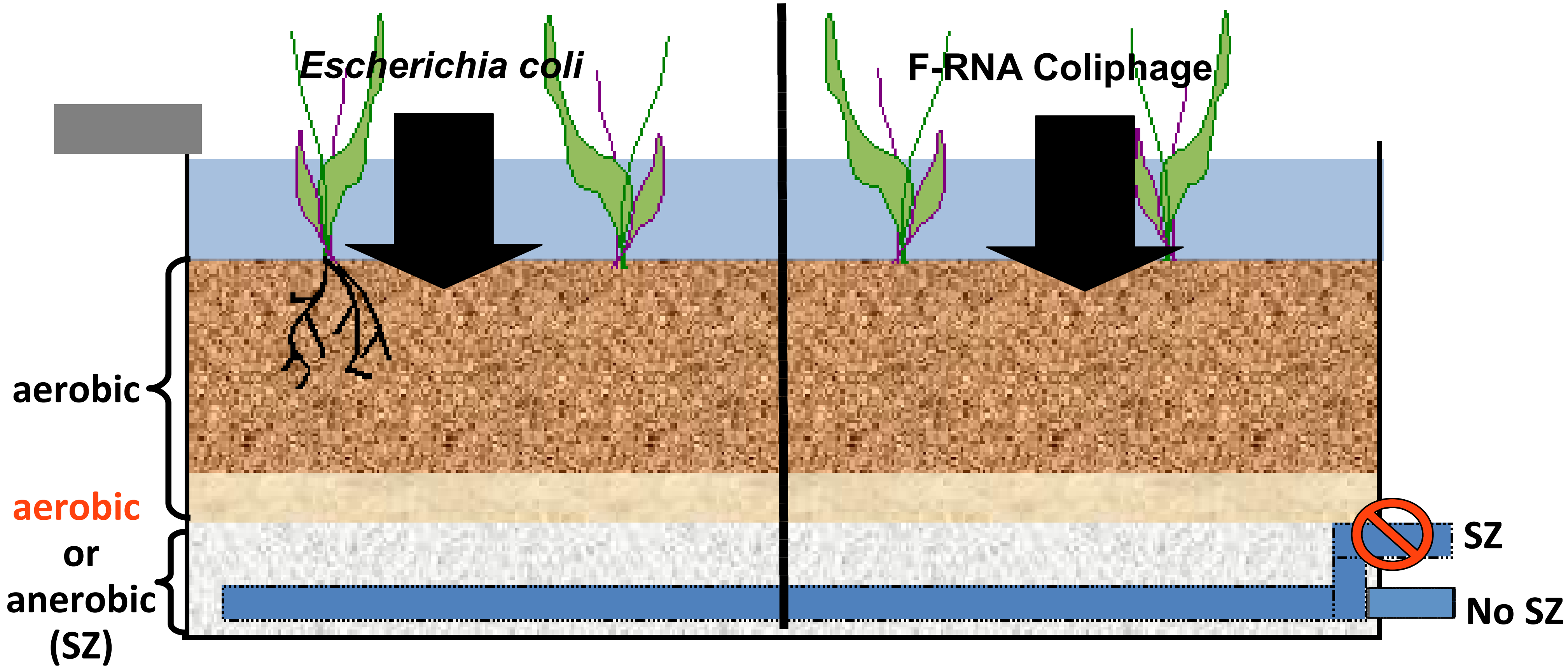
Port Phillip Bay, AU

Tailor biofilter design to receiving water type

Biofilters with a Saturation Zone may improve water quality in systems with coastal receiving waters

Biofilters without Saturation Zones may improve water quality in systems with fresh receiving waters

How does a SZ affect removal of Fecal Bacteria & Viruses?



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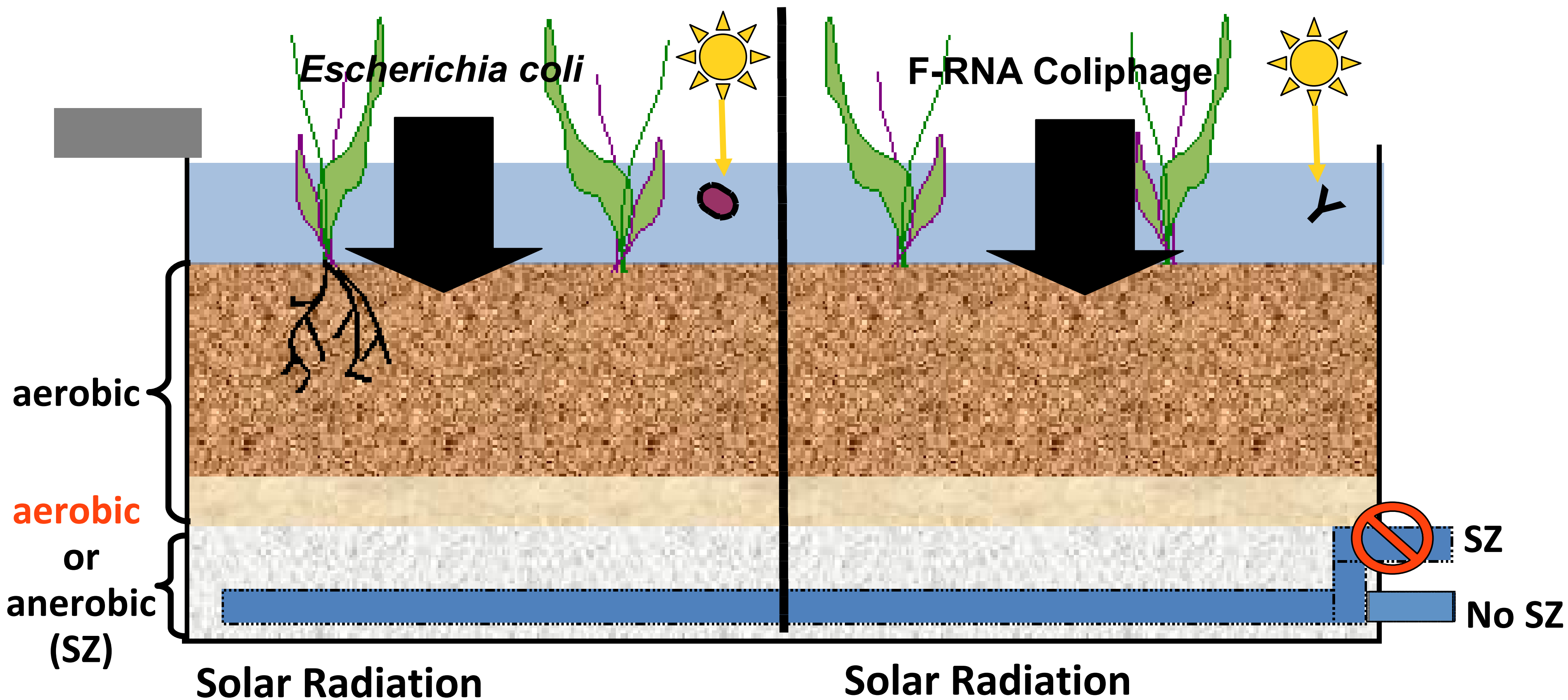

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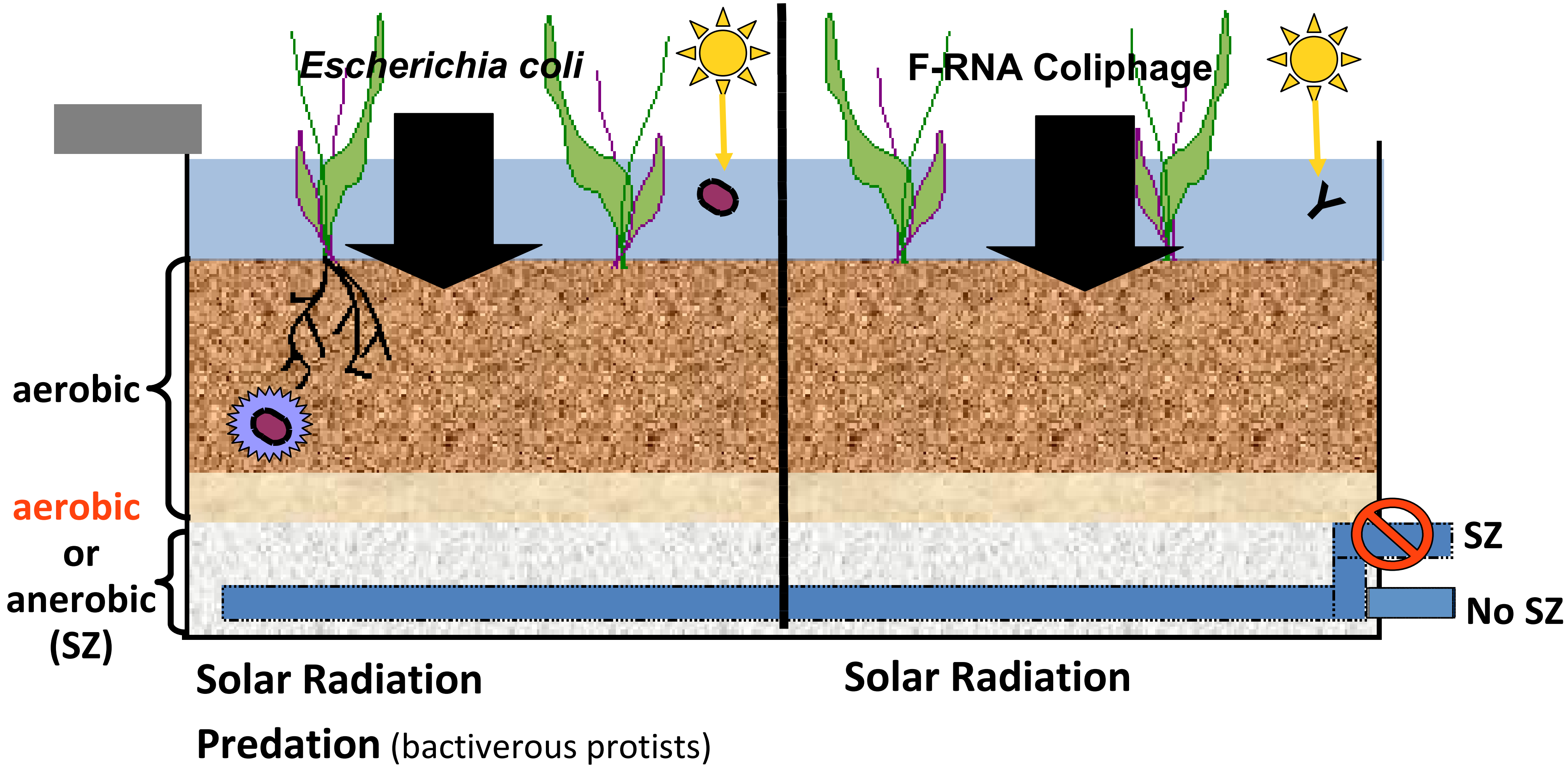

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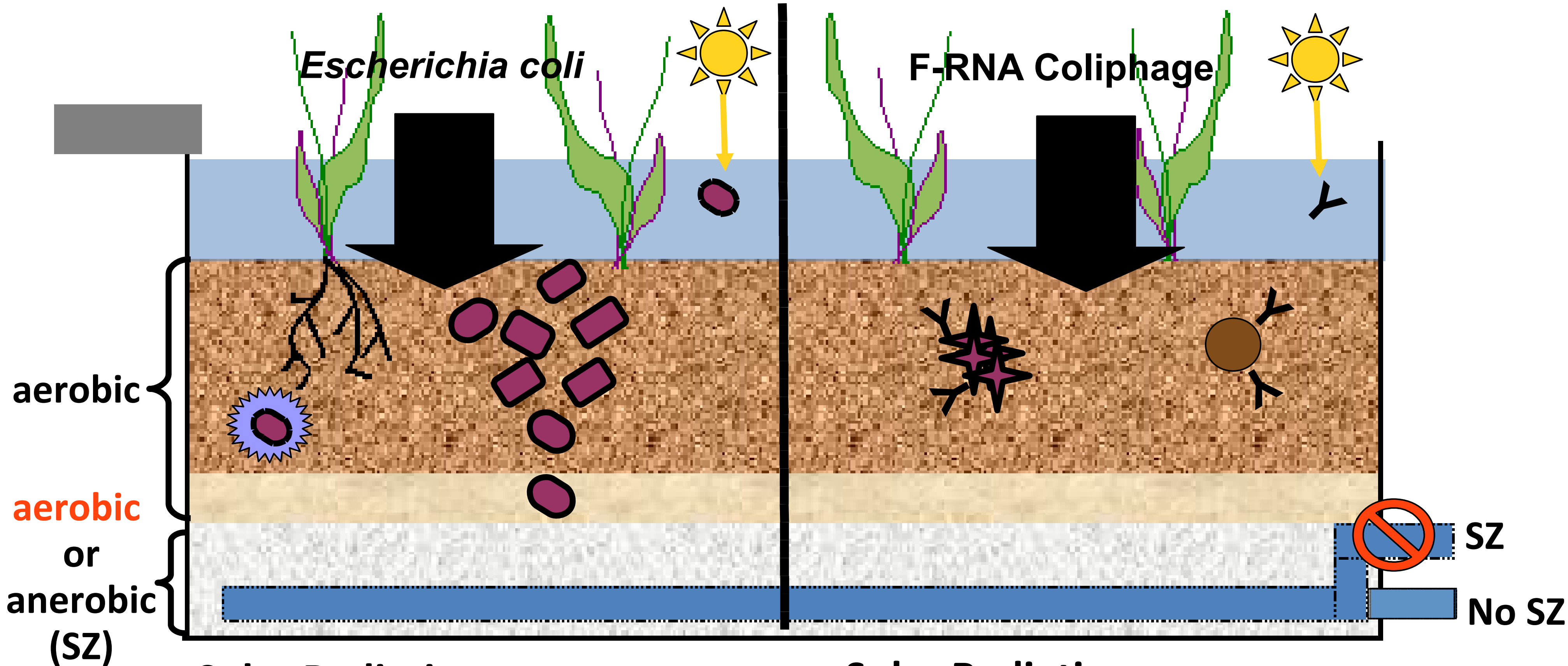

Solar Radiation

Predation (bactiverous protists)

Straining (bacterial attenuation)

Solar Radiation

Adsorption:
- microbial aggregations
- kaolinite clays and clay-loams

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Outflow Conc.	↓	↑		

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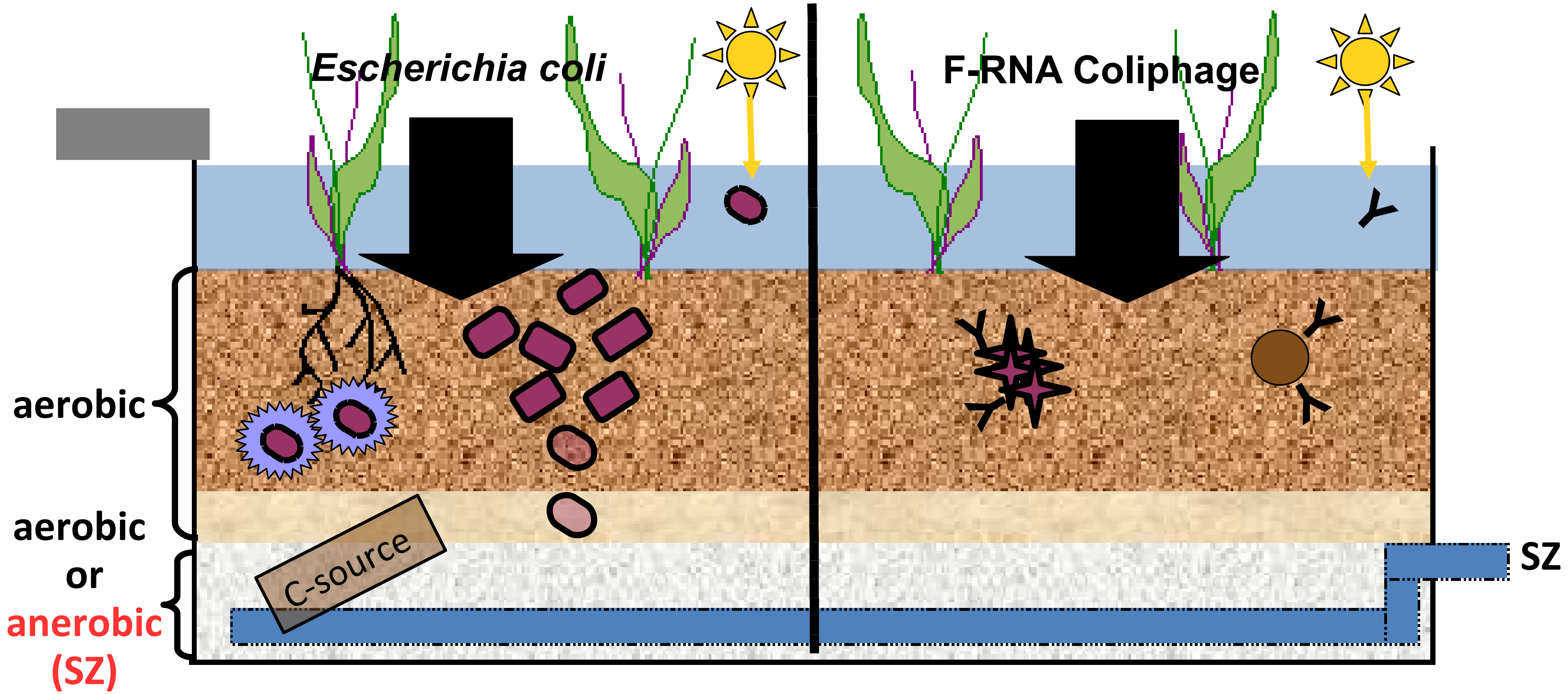

Predation: increased protist survival

Straining: reduced macropore formation in dry periods

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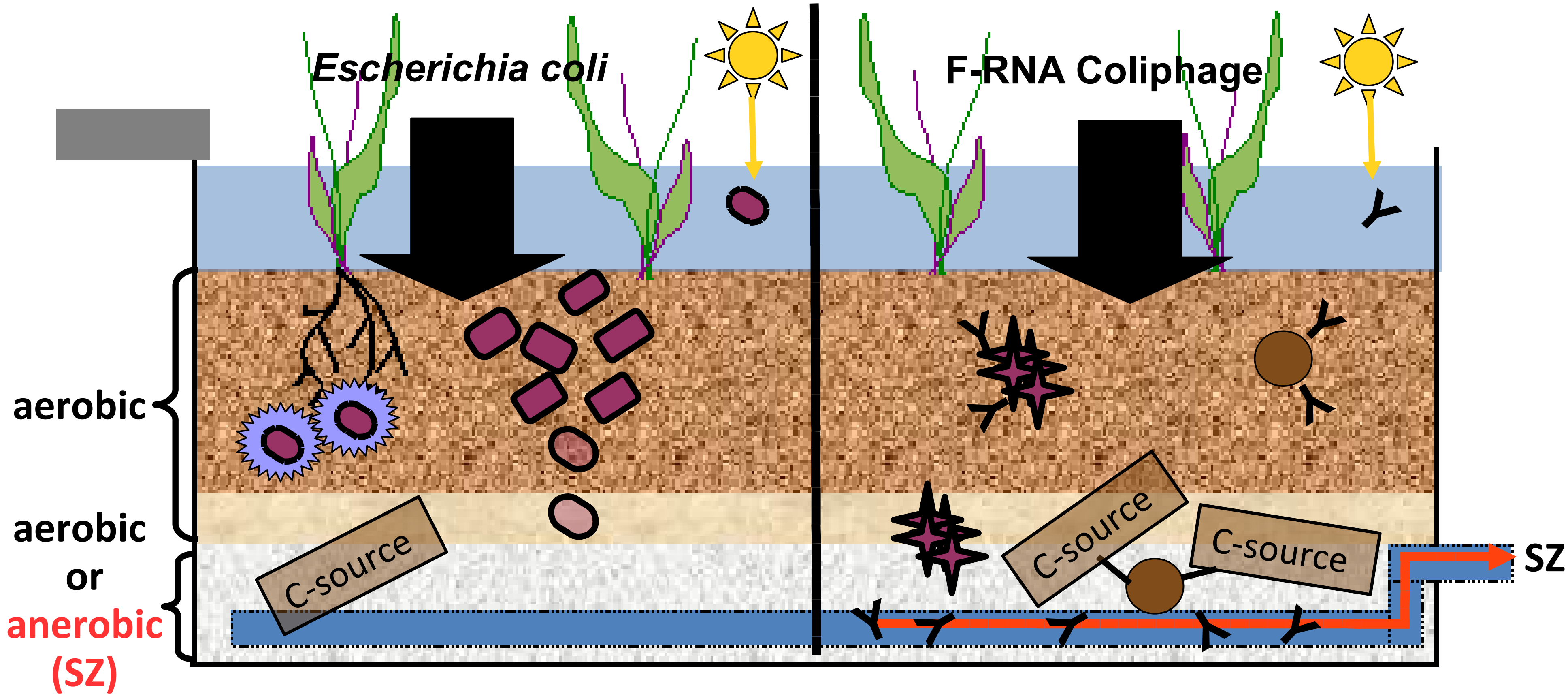

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Desorption:

- virus particles desorb from microbial aggregates
- C-source competes with virus for attachment sites

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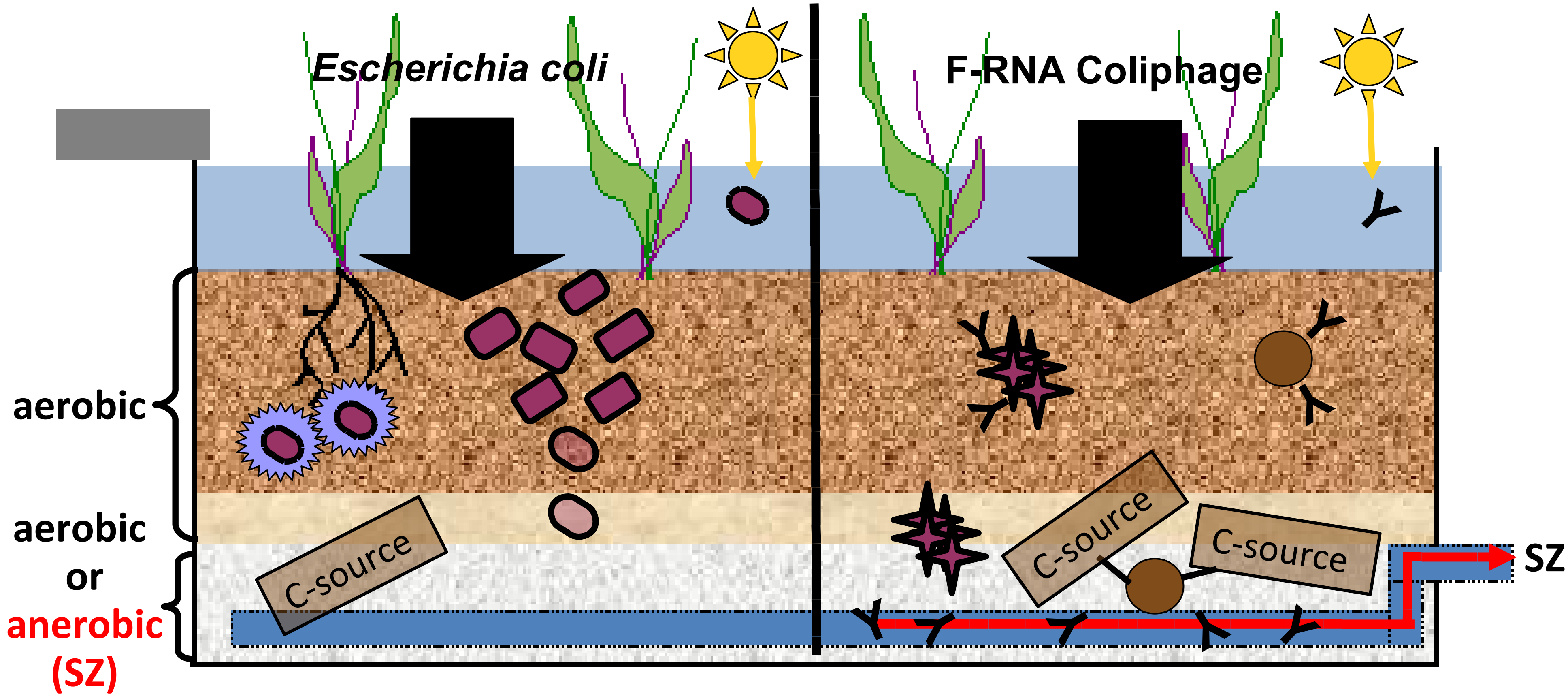


TRADE-OFF: Outflow virus loads (like phosphorus) are enhanced when FIB (and nitrogen) removal is favored

With SZ	TN	TP	*E. coli*	Coliphages
Outflow Conc.	↓	↑	↓	↑

Contaminants with adsorption as a dominant removal mechanism are removed less efficiently in biofilters with a SZ design

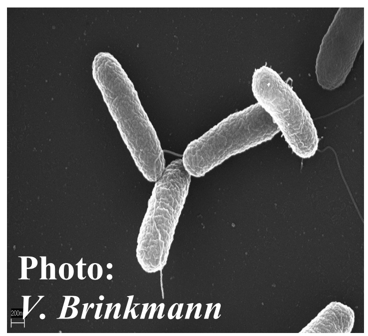
Management Implications?

How do we weigh the importance of bacterial vs viral removal in biofilters?

Relative Abundance in Stormwater Runoff or Specific Health Risk?

Bacteria:

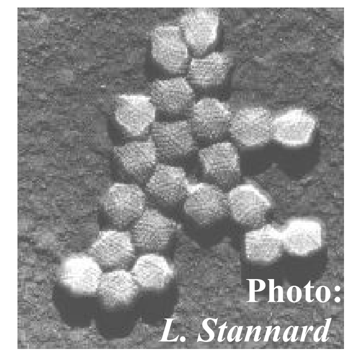
- *Campylobacter* (100% of samples)
- *Salmonella* (66% of samples)



Salmonella

Viruses:

- Adenovirus (84% of samples)
- Polyomavirus (50% of samples)



Adenovirus

Err on the Side of Caution

If a catchment has probable sewer inputs (from septic systems), a biofilter with a Saturation Zone is not recommended

Otherwise, biofilter design should reflect receiving water type
- SZ for coastal systems
- No SZ for freshwater systems

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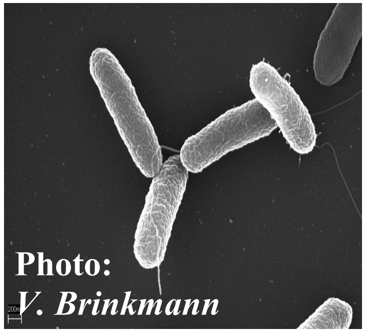

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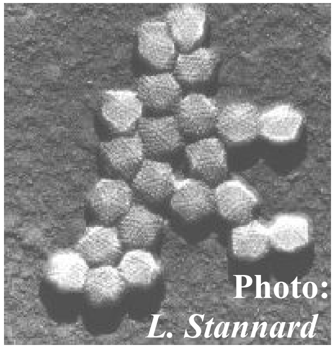

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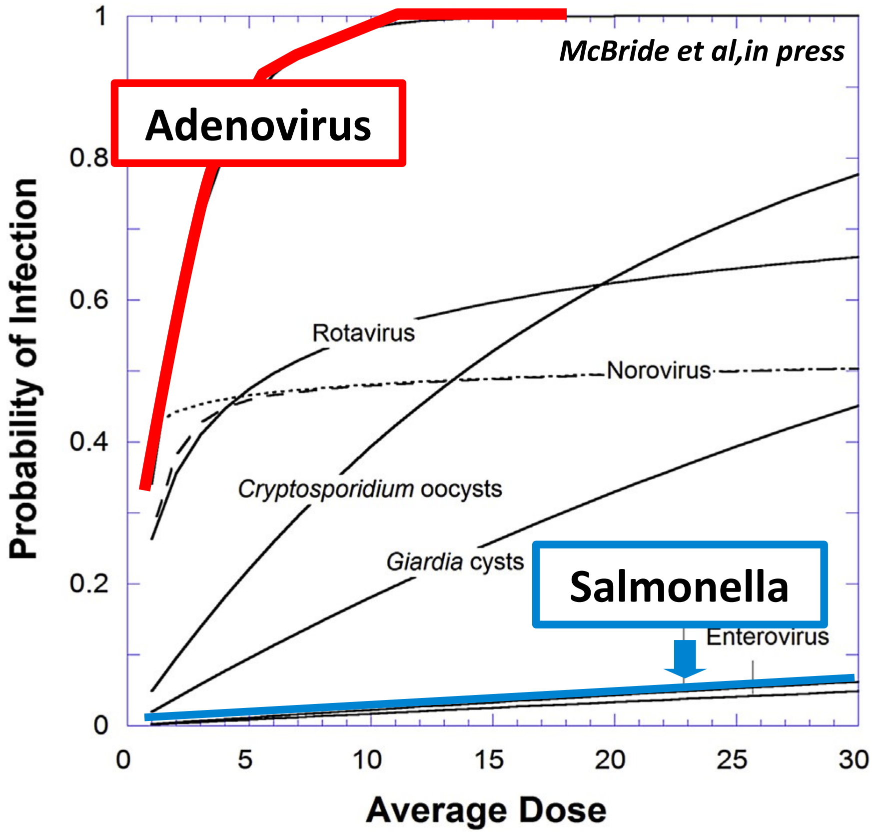

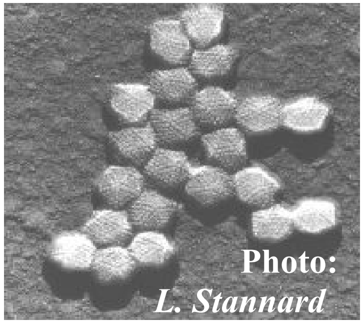

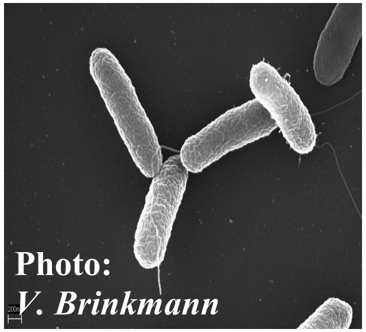

Viruses can have higher infectivity at lower doses

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Summary and Conclusions

Low energy technologies like biofilters can be designed to remove specific pollutants of concern like nitrogen

Trade-offs in removal efficiency exist and are linked to specific design features

- SZ favors N & FIB removal but increases outflow loads of P & viruses
- This tradeoff may be due to the dominant removal mechanism (biological or physical straining vs adsorption)
- Adsorptive processes are not favored in the SZ redox environment

These trade-offs can guide US biofilter implementation

- No SZ where septic inputs are suspect
- Receiving water type can guide design: marine – SZ; fresh – No SZ

Questions?