Wetland technology for wastewater treatment and water quality improvement
IV. Mechanisms

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Basic Principles for Treatment

- Wetlands provide habitat for both aerobic and anaerobic bacteria
- Rhizomes grow thereby opening up the bed to provide hydraulic pathways
- The rhizosphere of the rhizomes provide habitat for aerobic and anaerobic bacteria which will treat water
- Oxygen is transported to rhizosphere and leaks out into the growing substrate

Predominant Removal Mechanisms

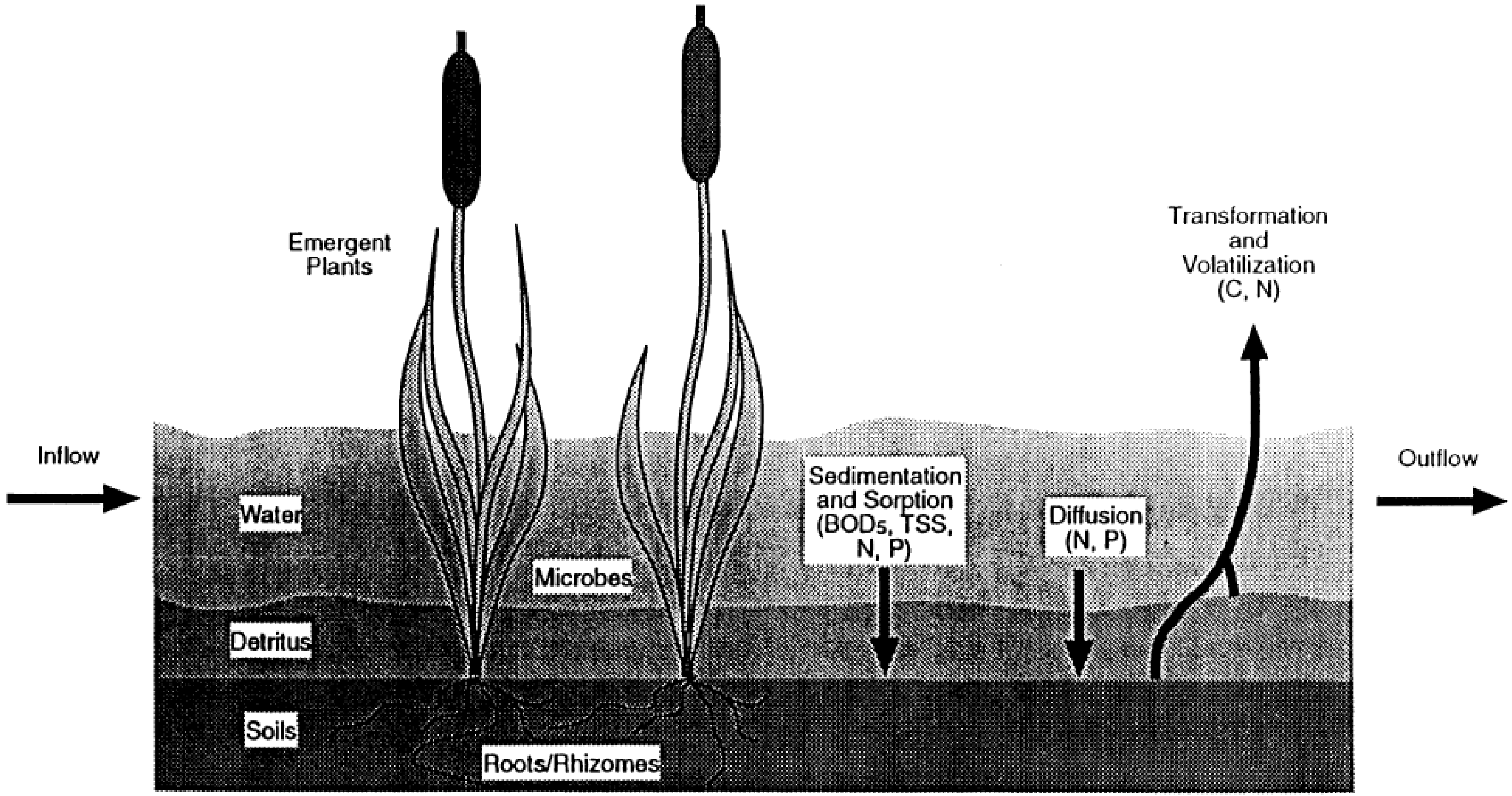
WASTEWATER CONSTITUENT	REMOVAL MECHANISM
Suspended solids	● Sedimentation ● Filtration
Soluable organics	● Aerobic microbial degradation ● Anaerobic microbial degradation
Nitrogen	● Ammonification followed by microbial nitrification ● Denitrification ● Plant uptake ●Matrix adsorption ●Ammonia volatilization
Phosphorus	● Matrix sorption ● Plant uptake
Metals	● Adsorption and cation exchange ● Complexation ● Precipitation ● Plant uptake ● Microbial oxidation/reduction
Pathogens	● Sedimentation ● Filtration ● Natural die-off ● Predation ● UV irradiation ● Excretion of antibiotics from roots of macrophytes

(Taken from: Cooper et al. 1996)

Typical Treatment Wetland Influents-Sewage

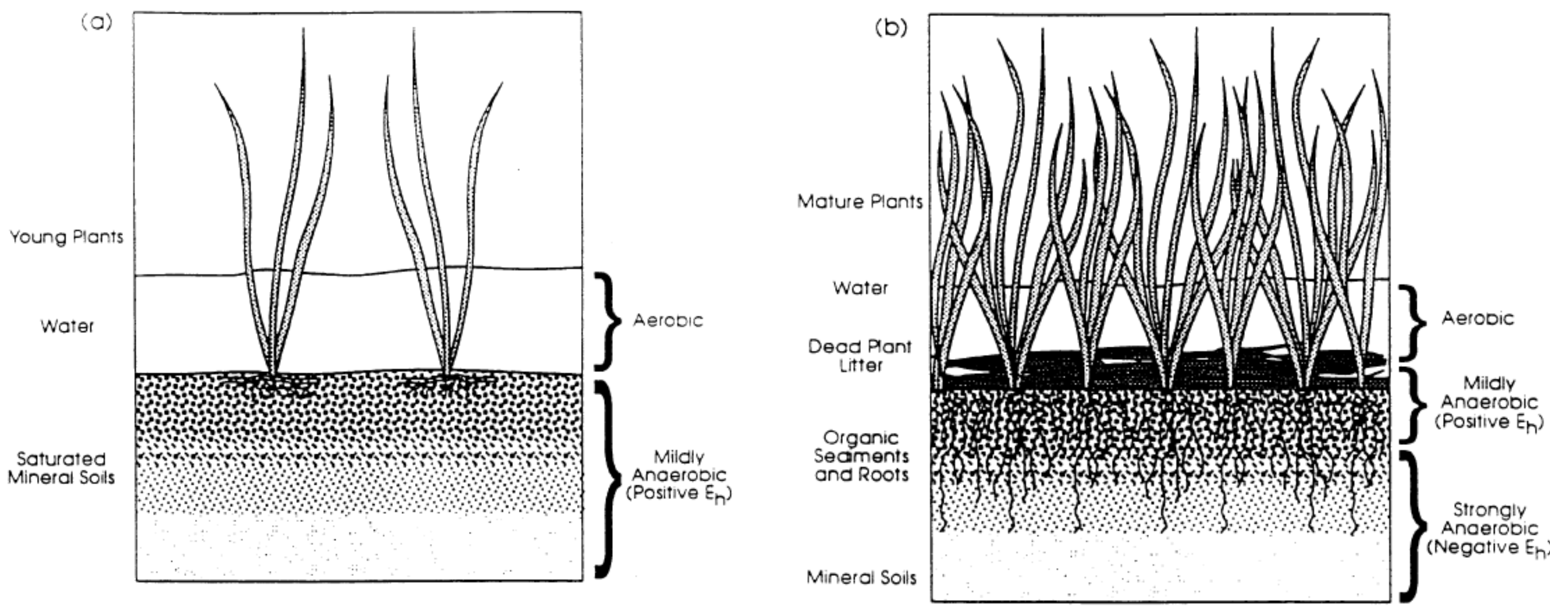
Constituent (mg/L)	Septic Tank Effluent[1]	Primary Effluent[2]	Pond Effluent[3]
BOD	129-147	40-200	11-35
Sol. BOD	100-118	35-160	7-17
COD	310-344	90-400	60-100
TSS	44-54	55-230	20-80
VSS	32-39	45-180	25-65
TN	41-49	20-85	8-22
NH_3	28-34	15-40	0.6-16
NO_3	0-0.9	0	0.1-0.8
TP	12-14	4-15	3-4
OrthoP	10-12	3-10	2-3
Fecal coli (log/100ml)	5.4-6.0	5.0-7.0	0.8-5.6

Taken from: EPA (2000)



(Taken from Reddy & DeLaune 2008)

Biology of New and Established Treatment Wetland

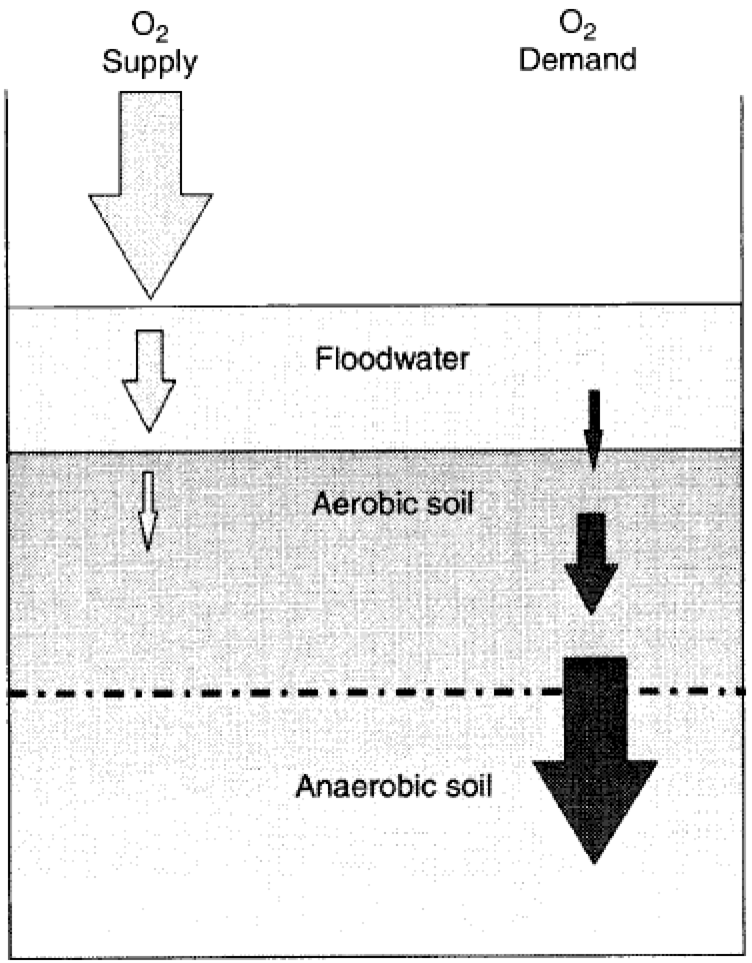


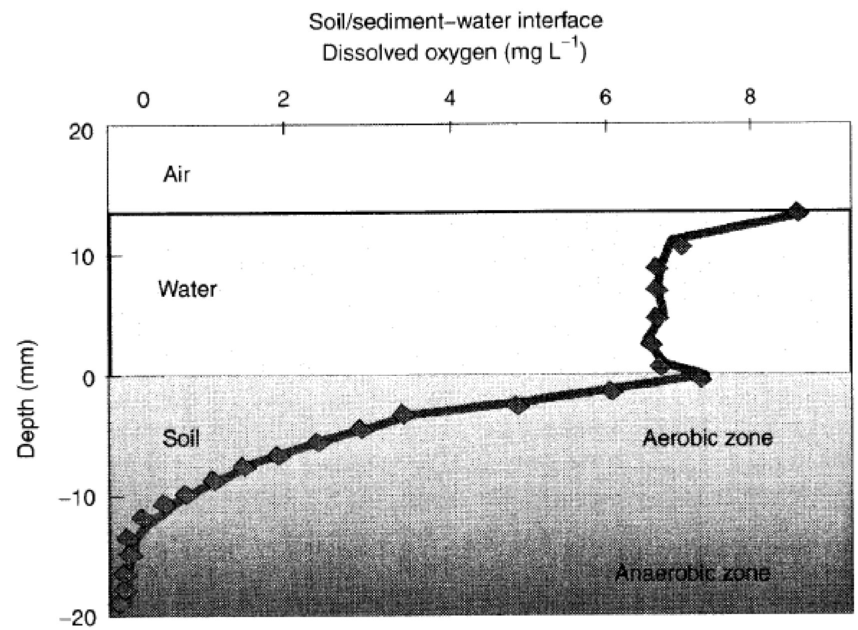
-low organic C
-mildly anaerobic and low rate microbial respiration

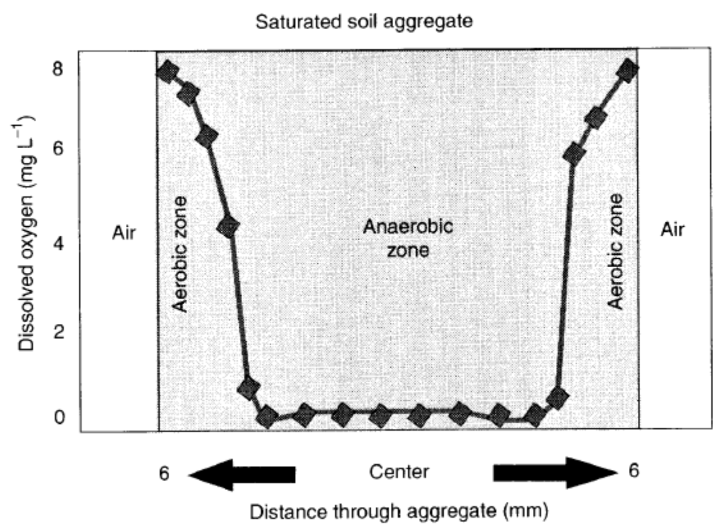
-more organic C build-up
-lower redox due to higher rate microbial respiration

(From Kadlec 1988)

Oxygen







Aerobic-anaerobic interfaces

(From Reddy & DeLaune 2008)

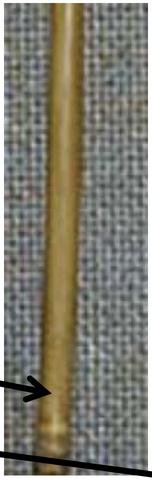
Plant Selection – Native species

- Emergent – big roots
  - Cattail (*Typha*)
  - Reed (*Phragmites*)
  - Bulrush (*Scirpus*)
- Floating
  - Rooted
  - Free floating
- Submerged

(From:www.great-lakes.net; courtesy Janice Gilbert)

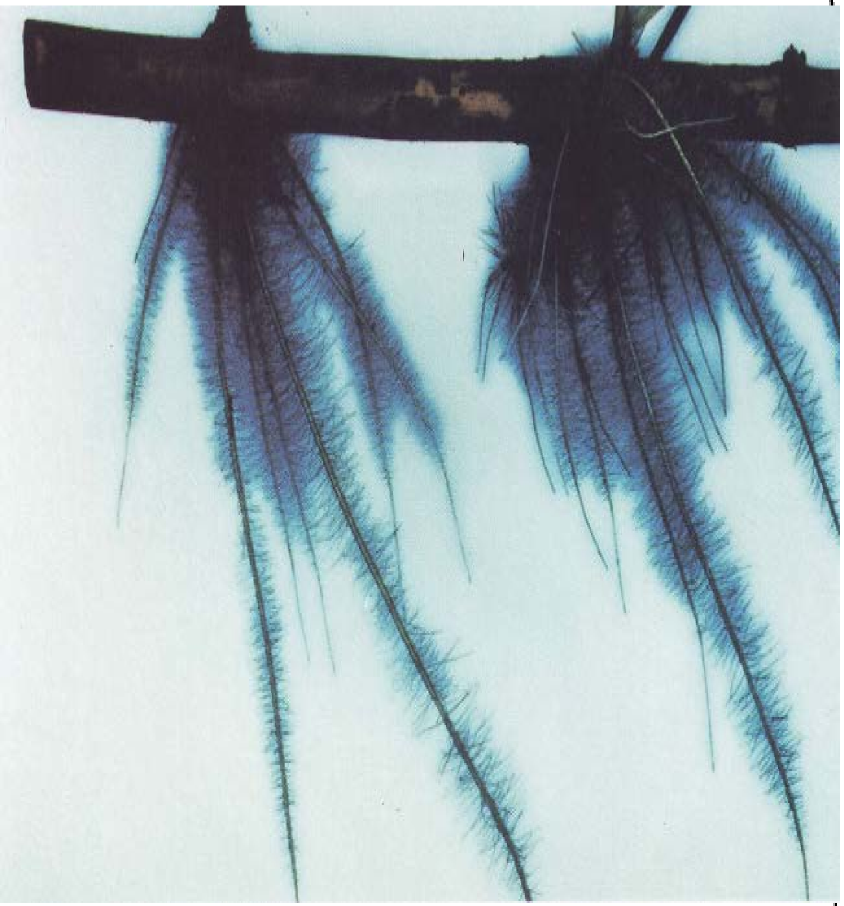
Phragmites: Native vs alien race

Feature	Native	Alien
leaf sheaths	fall off	stay on
stem base colour-winter	greenish	tan
stem base colour-summer	reddish	tan
stem density	low and fragile	dense & tough
stem texture	smooth & shiny	rough & dull
Inflorescence	small	thick/full

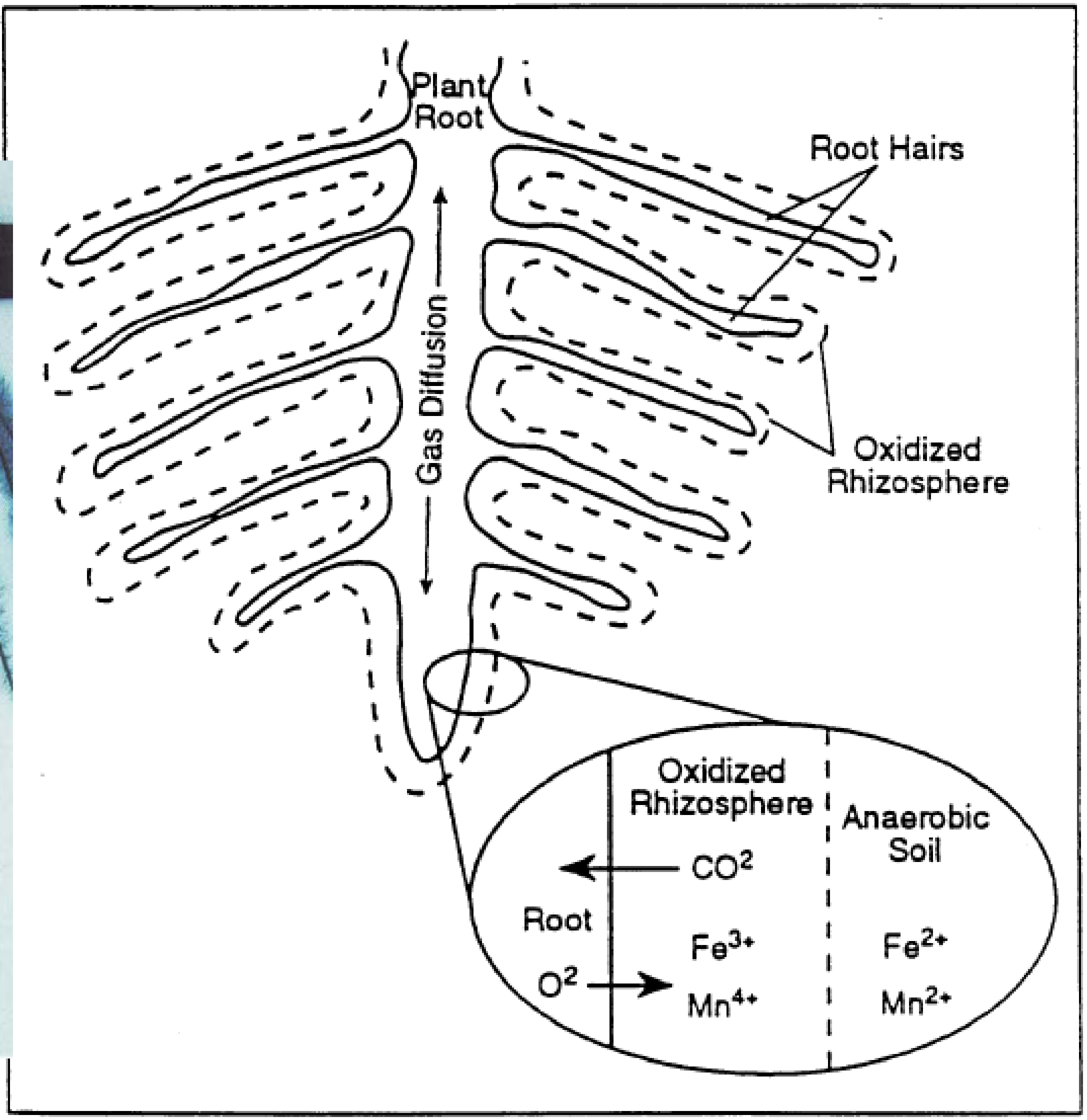


(From: http://www.invasiveplants.net/phragmites/morphology.htm)

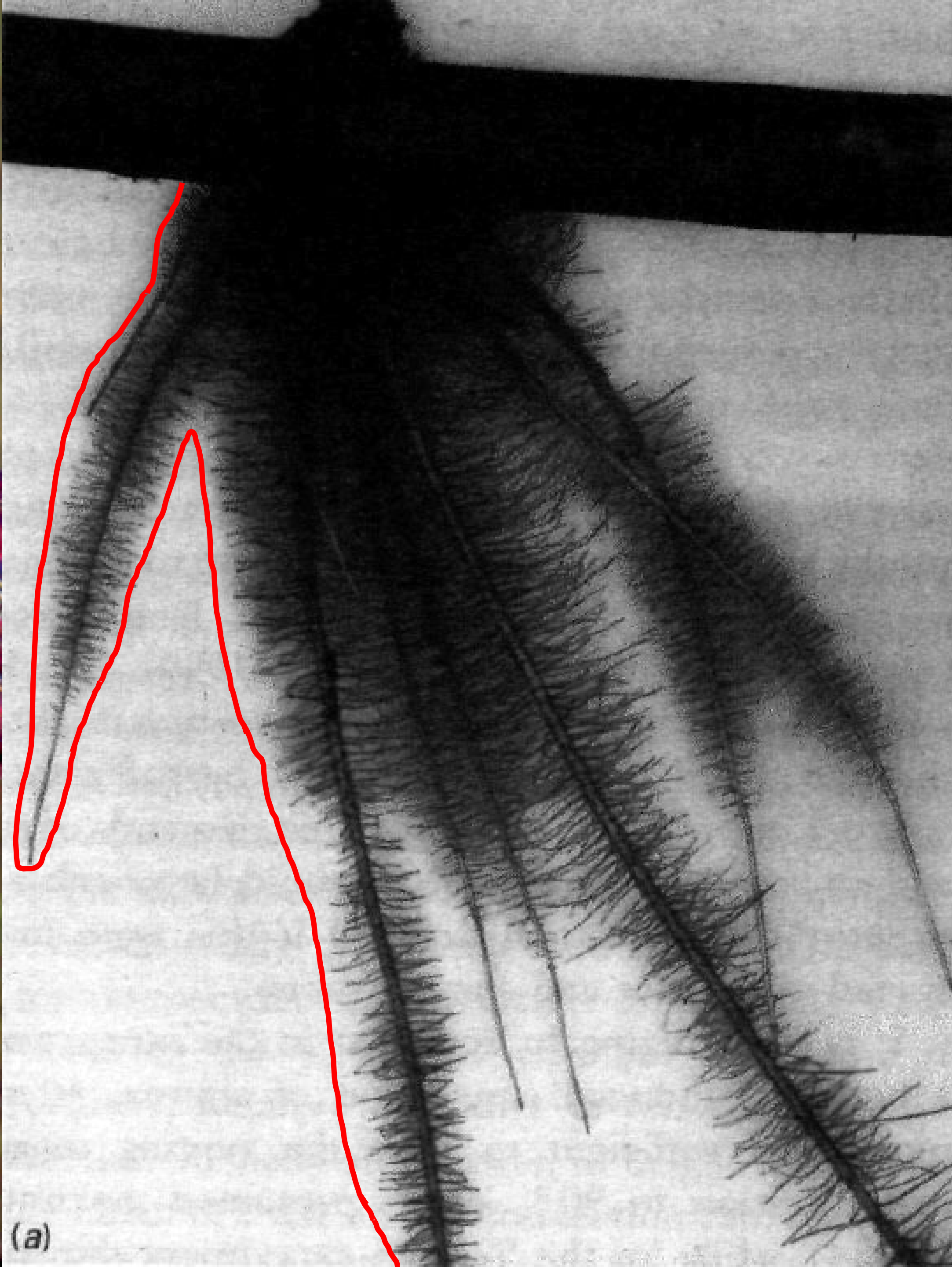
Radial oxygen loss



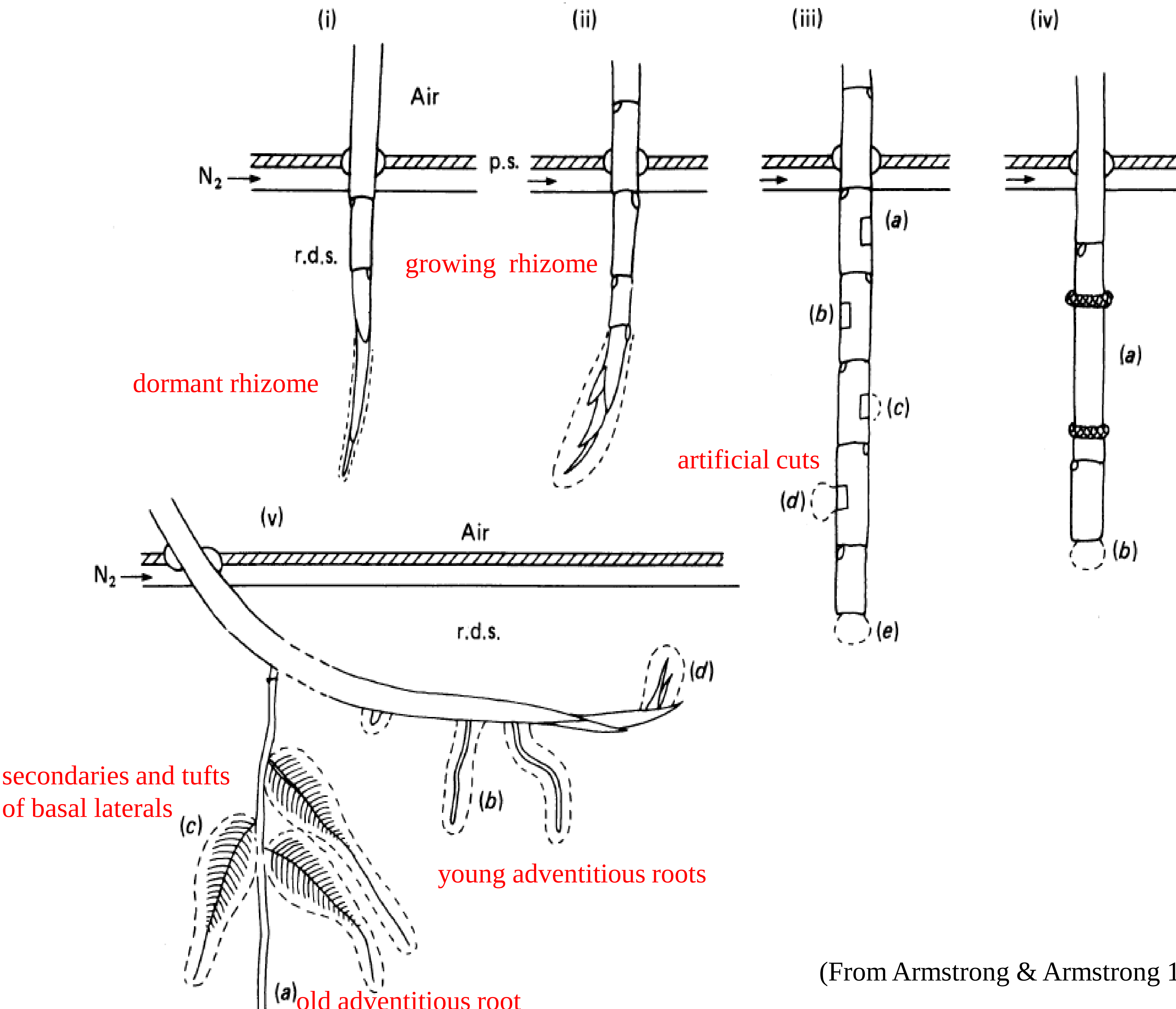
(from Cooper et al. 1996)



(from Kadlec 1988)



(a)



(From Armstrong & Armstrong 1988)

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V. Performance, Operation, Monitoring, & Troubleshooting

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BIOL 462

Typical concentrations for selected contaminants

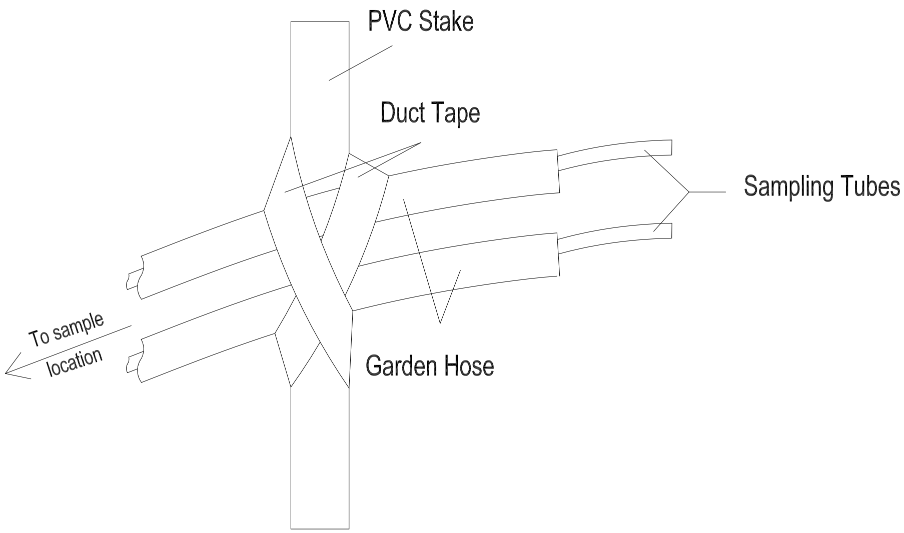
Background Concentrations of Contaminants of Concern in FWS Wetland Treatment System Effluents

Constituent	Range (mg/L)	Typical (mg/L)	Factors Governing Value
TSS (open water)	2-5	3	Plant types, coverage, Climate, wildlife
BOD_5 [1] (open water)	2-8	5	Plant types, coverage, Climate, plant density
BOD_5 [2]	5-12	10	Plant types, coverage, Climate, plant density
TN	1-3	2	Plant types, coverage, Climate, oxic/anoxic
NH_4- N	0.2-1.5	1.0	Plant types, coverage, Climate, oxic/anoxic
TP	0.1-0.5	0.3	Plant types, coverage, Climate, soil type
Fecal Coli CFU/100 ml	50-5,000	200	Plant types, coverage, Climate, wildlife

Taken from: EPA (2000)

Minimum Monitoring for Operational Control

Parameters	Sample Locations	Sample Frequency
Water quality –pH, DO, temp., cond., BOD_5, COD, TSS, SSC, TKN, nitrate, nitrite, ammonium, TP, turbidity, (chlorides)	Inflow and outflow, and a few stations inside wetland	Monthly in growing season, with some sampling other times
Metals	As above	Seasonally
?Microbial: *E. coli*, total bacteria, total fungi	As water quality stations	As above
Flow	Inflow and outflow	Daily or as possible
Rainfall & snowfall	Near wetland	Daily or as possible
Evaporation	Near wetland	Daily or as possible
Water level	In wetland	Daily or as frequently as possible
Plant cover	Representative station	Height of growing season



wetlands with free water/open water surfaces


FRAGILE

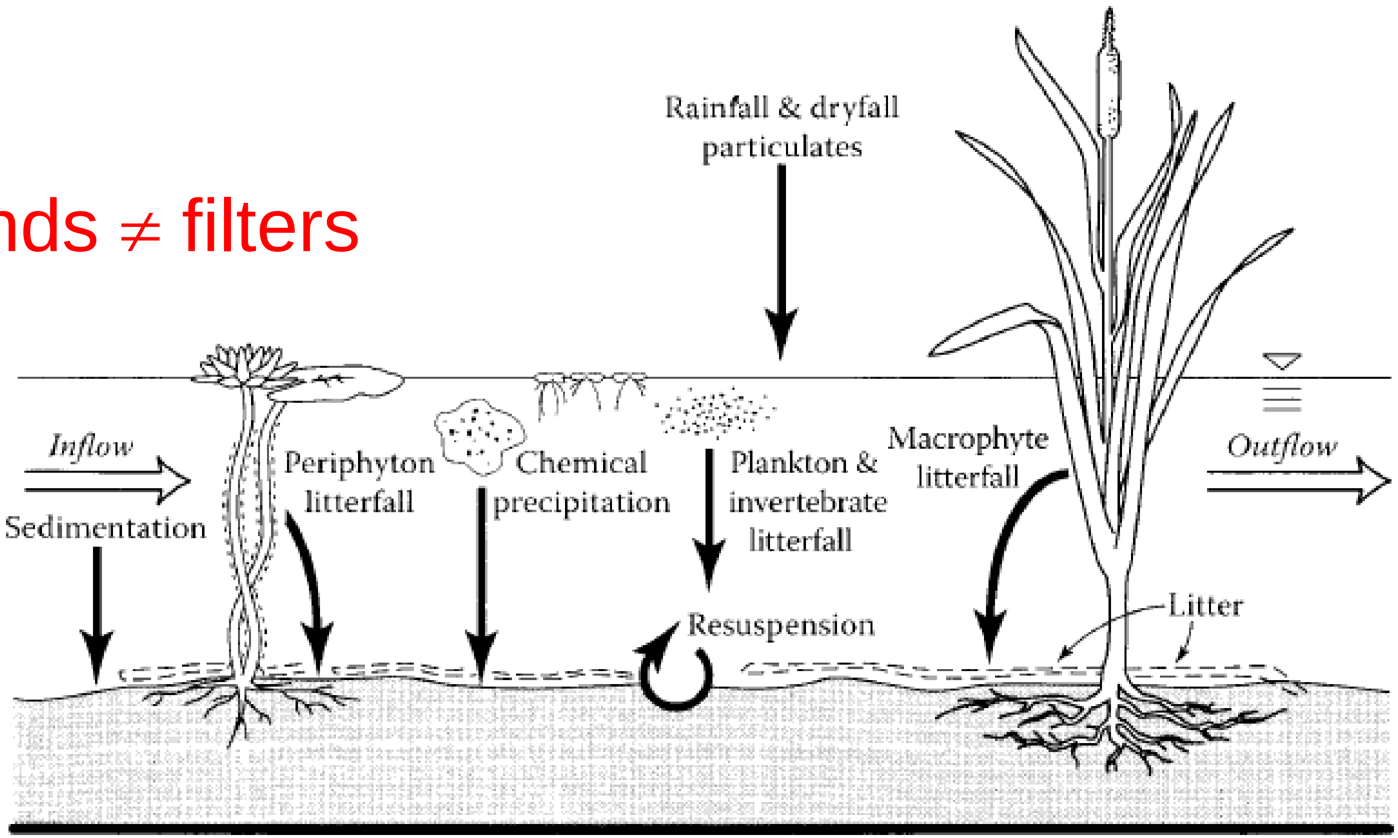
groundwater beeper tape

peristaltic pump

(from www.solinst.com)

Suspended solids

wetlands ≠ filters



Particulate matter removal and formation

(Taken from Kadlec & Wallace 2008)

Biological Oxygen Demand (BOD_5): *only organic compounds*

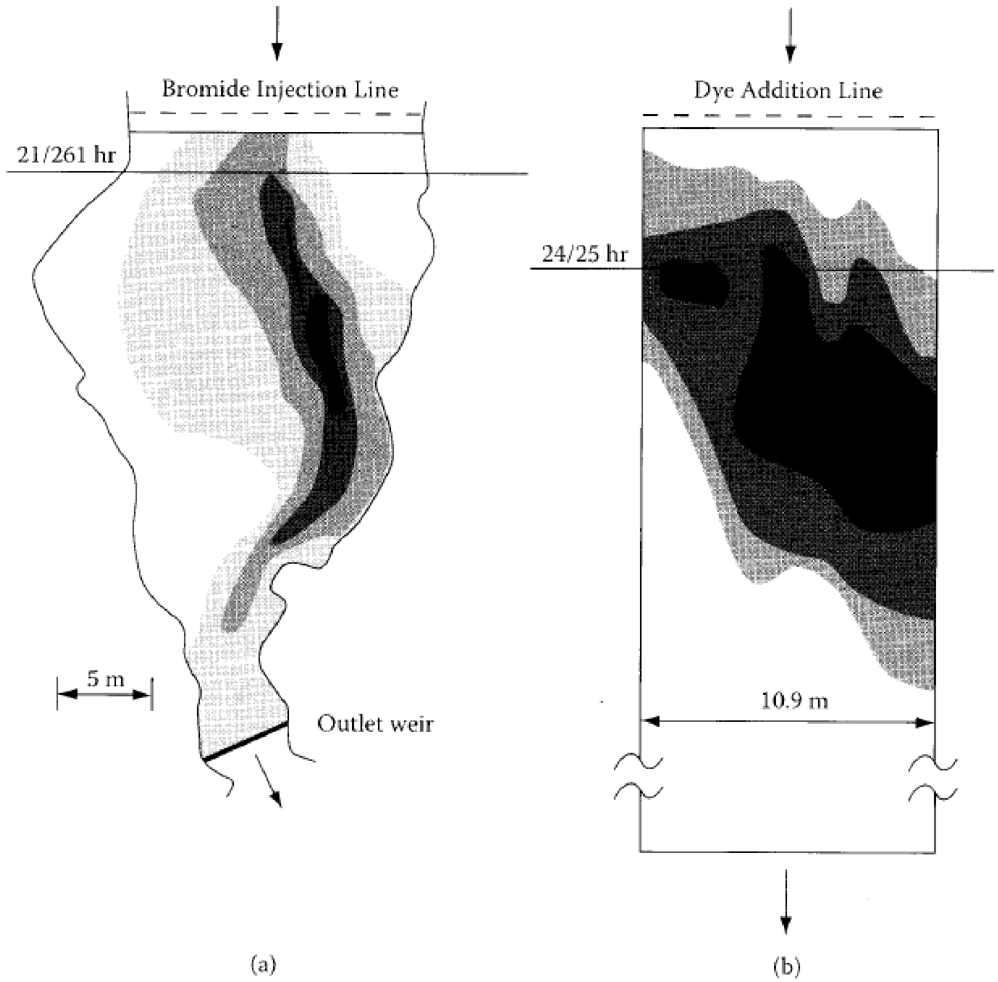
- Measure of the amount of oxygen consumed by bacteria during the decomposition of organic materials; OM & N from the wastewater act as a food source for the bacteria
- Measure of oxygen consumption by microbes to oxidize organic matter & N
- Conducted in air-tight bottles over 5 days
- Some oxygen may be used in nitrification if necessary organisms present

(From: Fisher Scientific)

Chemical Oxygen Demand (COD): *organic & inorganic compounds*

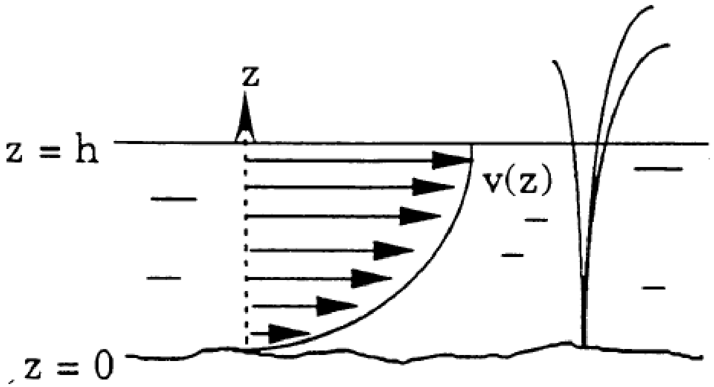
- Measure of the total amount of oxygen required to oxidize all organic and inorganic compounds into carbon dioxide and water
- Usually higher than BOD_5 because strong oxidant on greater range of compounds (i.e. even reduced iron and manganese)
- Wetlands lead to very high COD relative to BOD_5
- eg. BOD = 5 mg/L, COD = 100 mg/L for natural wetland

Tracer Tests

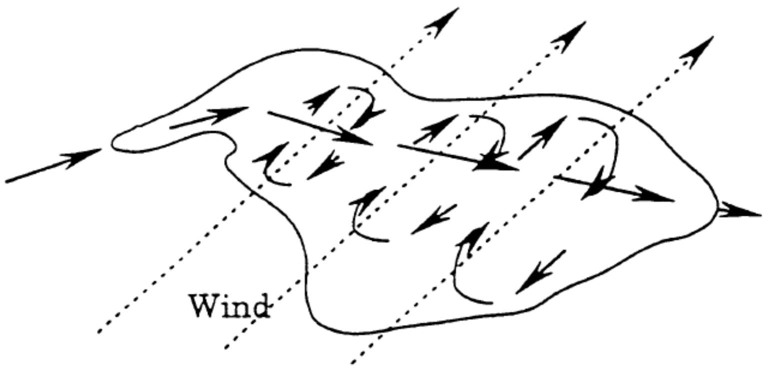


Natural *Typha* wetland Free water surface treatment wetland

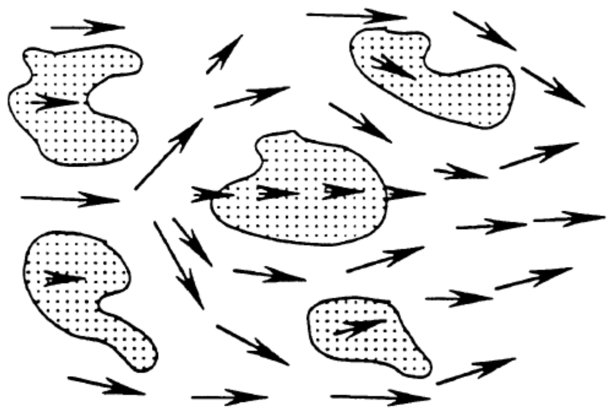
Internal Flow Patterns



A. Vertical velocity profile; mixing at exit

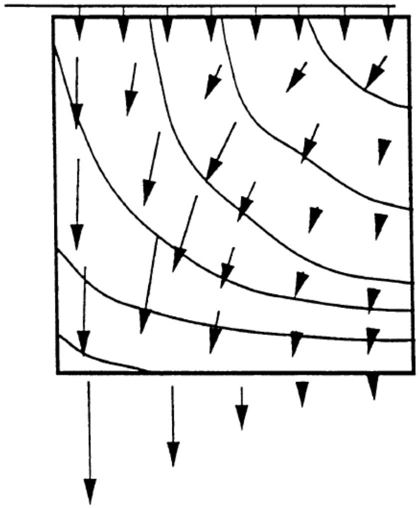


C. Wind causes cross currents and mixing



B. Water flow paths; different lengths & speeds

(from Kadlec 1988)



D. Gross topography and short circuiting

Potential Problems with Vegetation Maintenance

Problem	Corrective Measures
water stress (too low)	-raise outlet weirs; increase flows
flood stress (too high)	-lower outlet weirs; reduce flows
nutrient stress (NPK)	-fertilize; drawdown for season
micronutrient stress	-add Fe, Mg, etc; drawdown for season
DO stress: organic loading, ammonia loading, sludge/solid buildup	-reduce input of O demanding substances; lower water levels; oxygenate; physically remove
Pathogens/herbivory	-do not add chemicals; burn in winter to reduce resting places; trapping
Frost, heat, wind	-maintain flooded conditions to maintain favourable root temperatures

(after Kadlec and Wallace 2008)

Potential Problems with Animals

- Must be controlled
- ? waterfowl and wetland birds
- ?muskrats
- ?beaver
- Humans

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VI. Steps to Design

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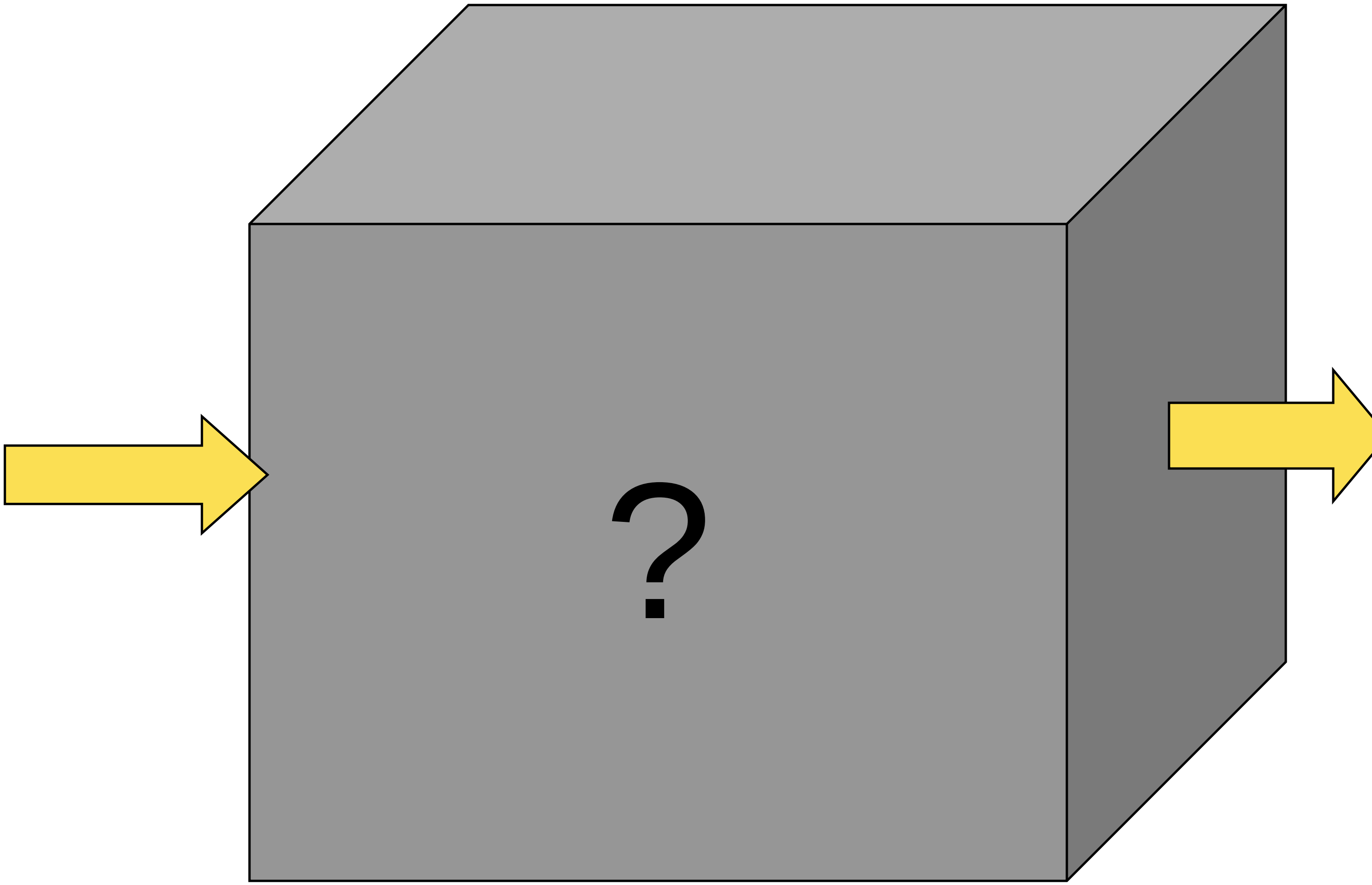
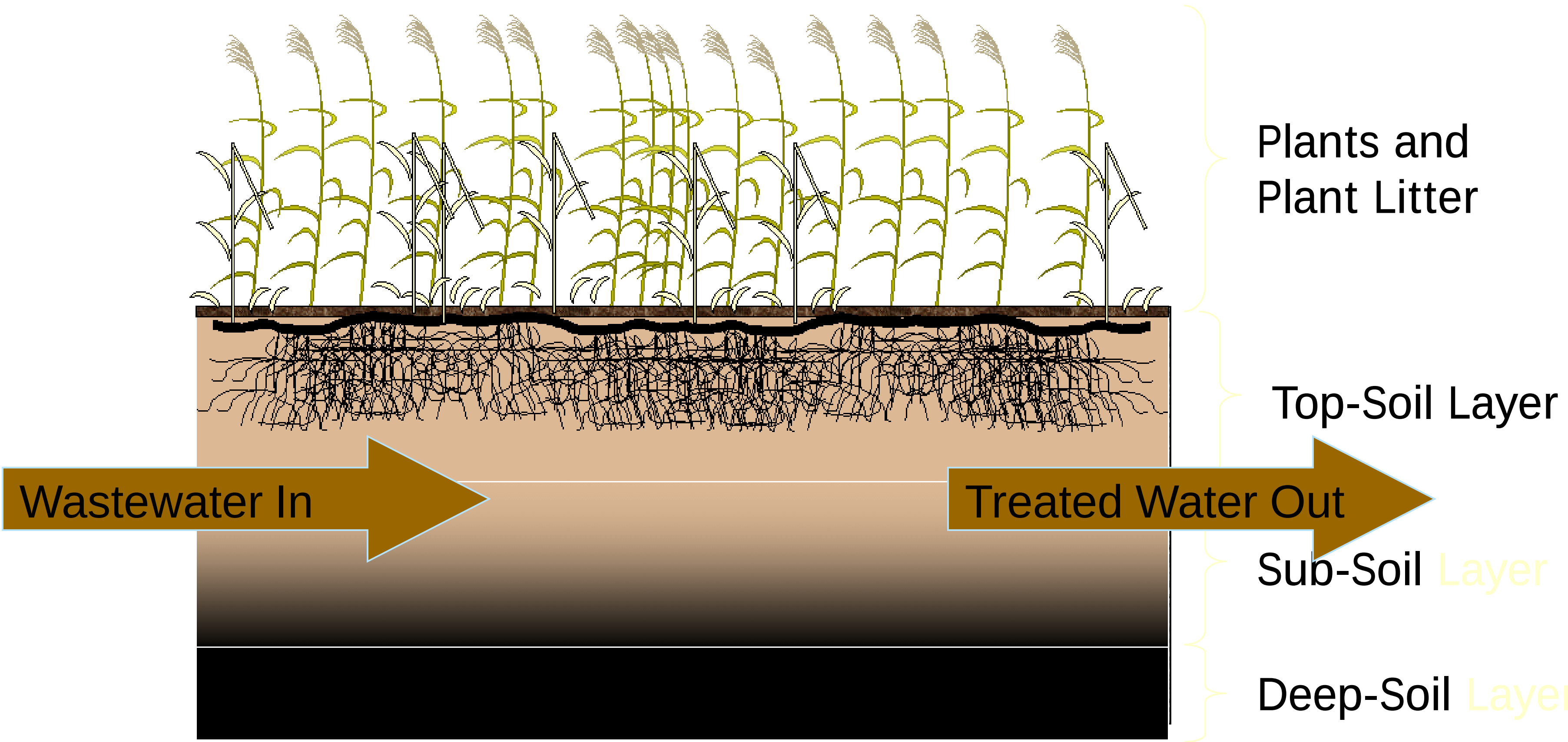
Performance and Success

- must be able to **predict** and achieve **sustained** levels of performance
- need to characterize and quantify inherent **variability** $\Rightarrow$ standardize designs
- parameterize **reliability**: probability of adequate process performance
- tools to measure and evaluate processes (i.e. isotopic techniques, experiments, models)



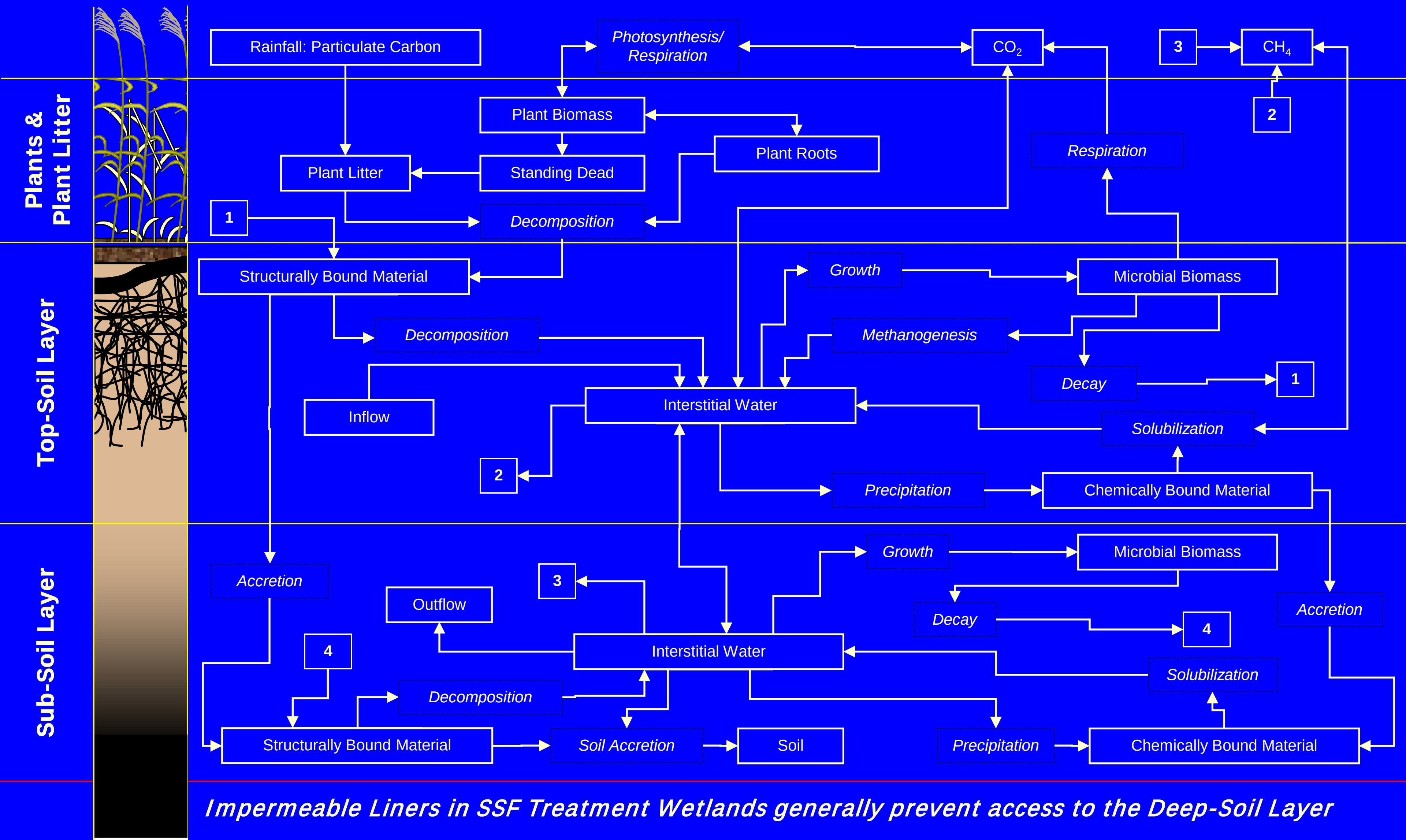
Opening the Black Box…

Most treatment wetland models consider these systems as “black box” technologies



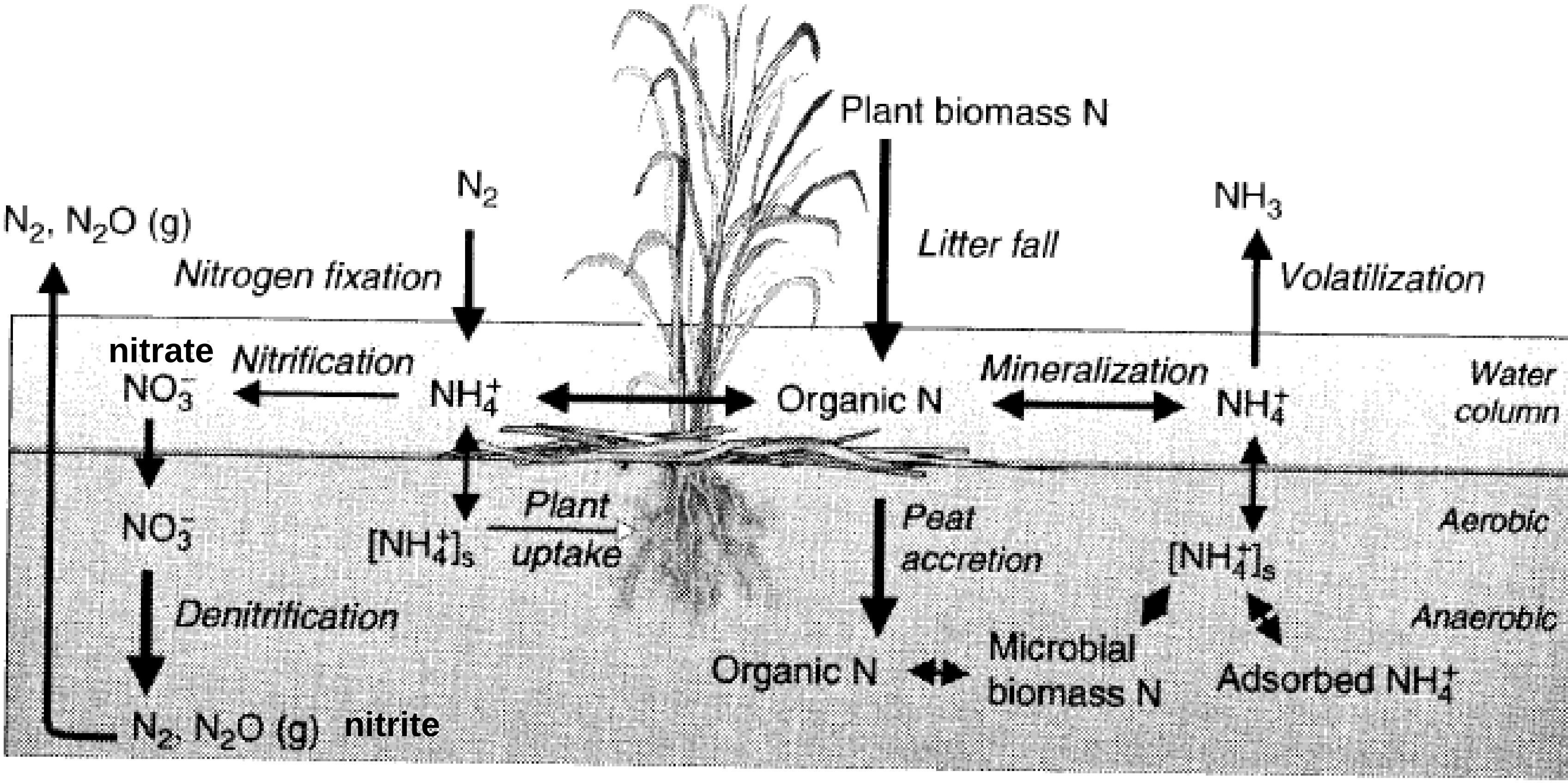
Opening the Black Box: Carbon Cycle

(courtesy J. Steffler)



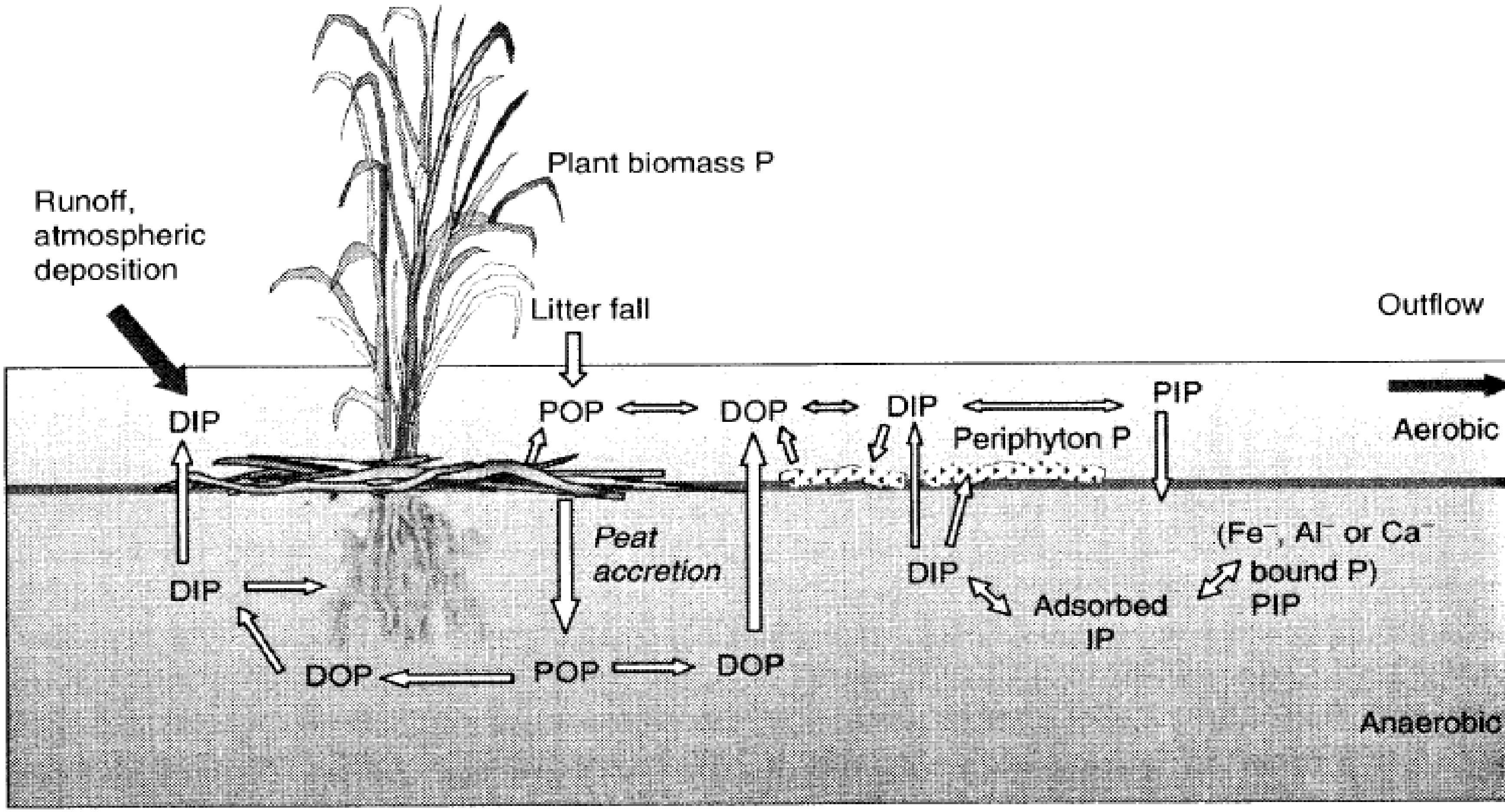
Impermeable Liners in SSF Treatment Wetlands generally prevent access to the Deep-Soil Layer

Nitrogen



(Taken from Reddy & DeLaune 2008)

Phosphorus



(Taken from Reddy & DeLaune 2008)

Open water areas

Deep zones

- Ponds act as settling basins - $\downarrow$ TSS but can $\uparrow$ TSS by algae and resuspension
- Have deep zones within wetland to $\uparrow$ TSS removal if there is aquatic vegetation but not if there is no vegetation

Ponds preceding wetlands

- Can be good if acts as fast settling basin
- Removes undesirables that may interfere with wetland processes
- Reduces resuspenson
- Possibly more O_2 in water column to transform particulates

Conclusions

- Designs should account for hydraulic, treatment and seasonal inefficiencies
- Multiple inlet and outlet locations at various depths and widths in the wetland to correct for hydraulic problems may be better options
- Wetland systems do work in Canadian winters

Performance Summary Average Concentration mg/l

Parameter	Inflow	Outflow
BOD_5	30	8
TSS	46	13
NH_4-N	5.0	2.4
TN	9.7	4.5
TP	3.8	1.7

(At average HLR = 3.6 cm/d; Taken from North American Wetland Treatment System Database)

(after Kadlec 1998)

Operation & Maintenance

- This technology requires careful maintenance at least for first few years of operation
- O & M principles for conventional treatment technologies probably do not apply
- Requires special training

Operation & Maintenance

- not design, build, leave-alone systems
- require start-up times; 3-5 years
- inlet and outlet structures
- water level control
- flow routing
- vegetation maintenance
- berm maintenance (if applicable)
- solids removal
- monitoring
- avoiding nuisances

Regulatory Considerations

- Traditional regulatory wastewater and water quality guidelines probably do not apply
- Current guidelines do not consider range of variability in operation of these “living” systems
- General guiding principles of O & M required
- Should consider hydraulic testing, i.e. tracer tests in first few years of operation
- Should consider different monitoring, i.e. total fungi, heterotrophic bacteria, more suited to biological systems
- Ecological technology is the future

Information Needs and Technology Development

- science- based technology development –what goes on inside the black box
- lack of information on ecologically mature systems and maturation processes
- limited number of well-designed and healthy systems available as models
- requires non-traditional monitoring parameters and innovative procedures
- Need qualified specialists with multidisciplinary background to design, build, operate, and maintain these system

Information Needs and Technology Development

- requires partnerships and investment between researchers, industry/private sector, government
- must ensure confidence in and reliability of the technology by realizing limitations and opportunities
- Canada has potential to be world-leader; currently large Canadian wetlands industry

Future

- Evaluate performance and success
  - lack of clear definition of success
  - need quantitative performance criteria and data
  - need regulatory guidelines
- Longer term operation, maintenance and monitoring
  - young technology and young systems
  - teach maintenance
  - develop cost-effective monitoring tools