Constructed Wetland Systems: Design Approaches

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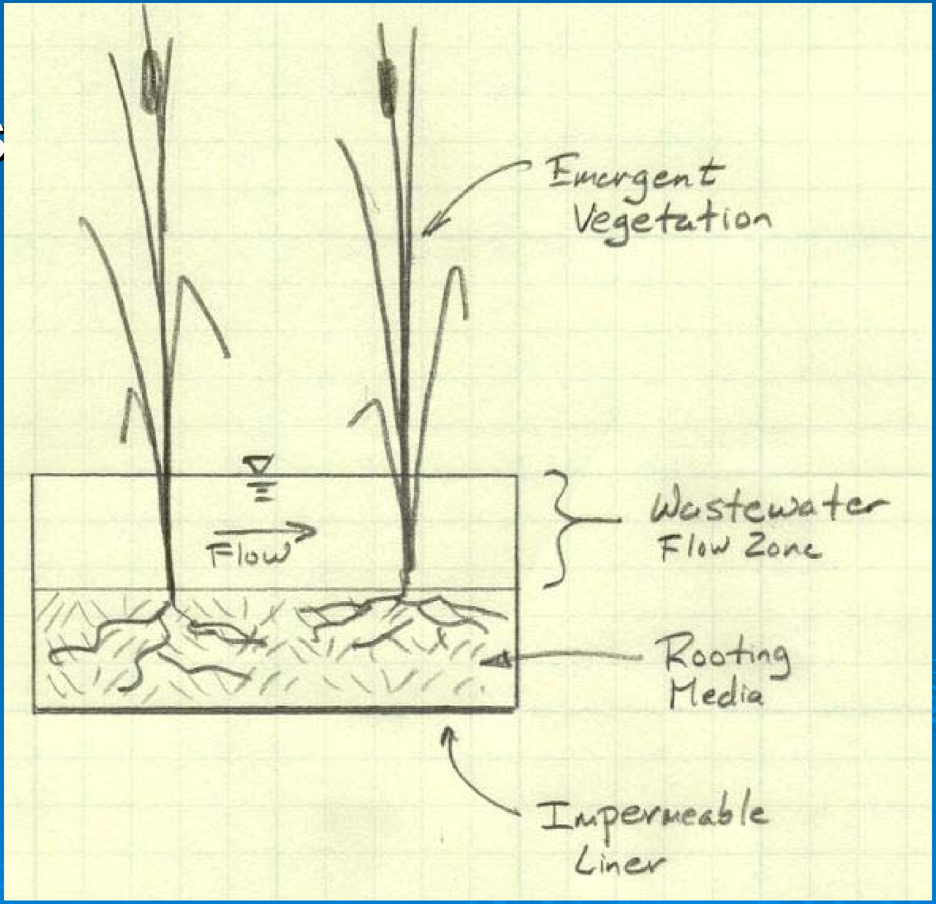
Types of Constructed Wetlands

- Free Water Surface (FWS)
- Vegetated Submerged Bed (VSB)
- Vertical Flow (VF)

Free Water Surface Wetland

- FWS wetlands have exposed water bodies similar to natural marshes.



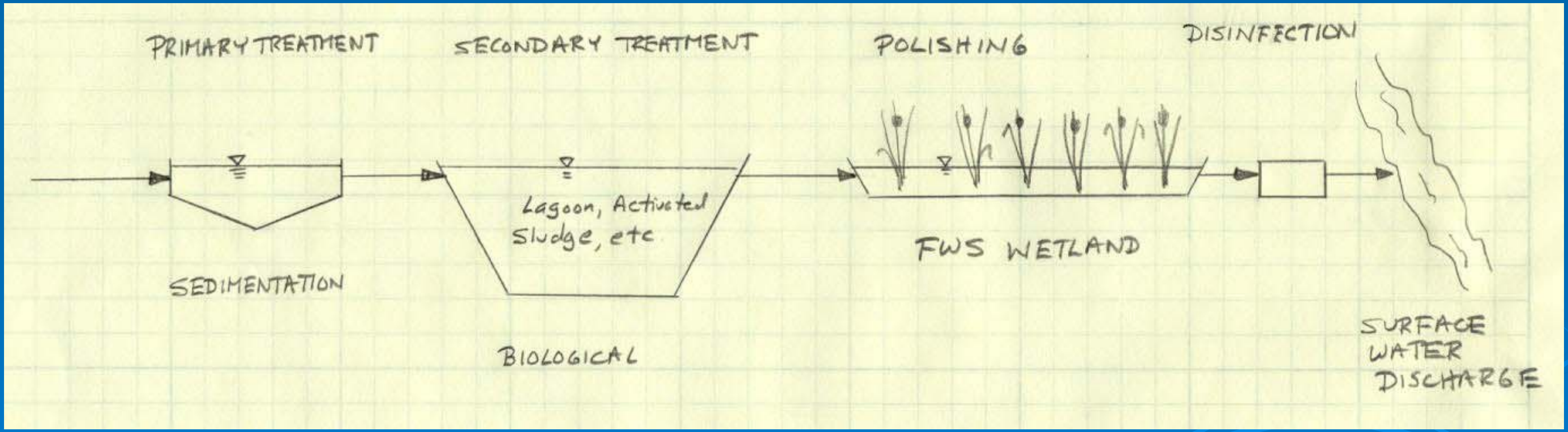
Free Water Surface Wetland

FWS Wetland operating near Pensacola, Florida

Photo courtesy S. Wallace

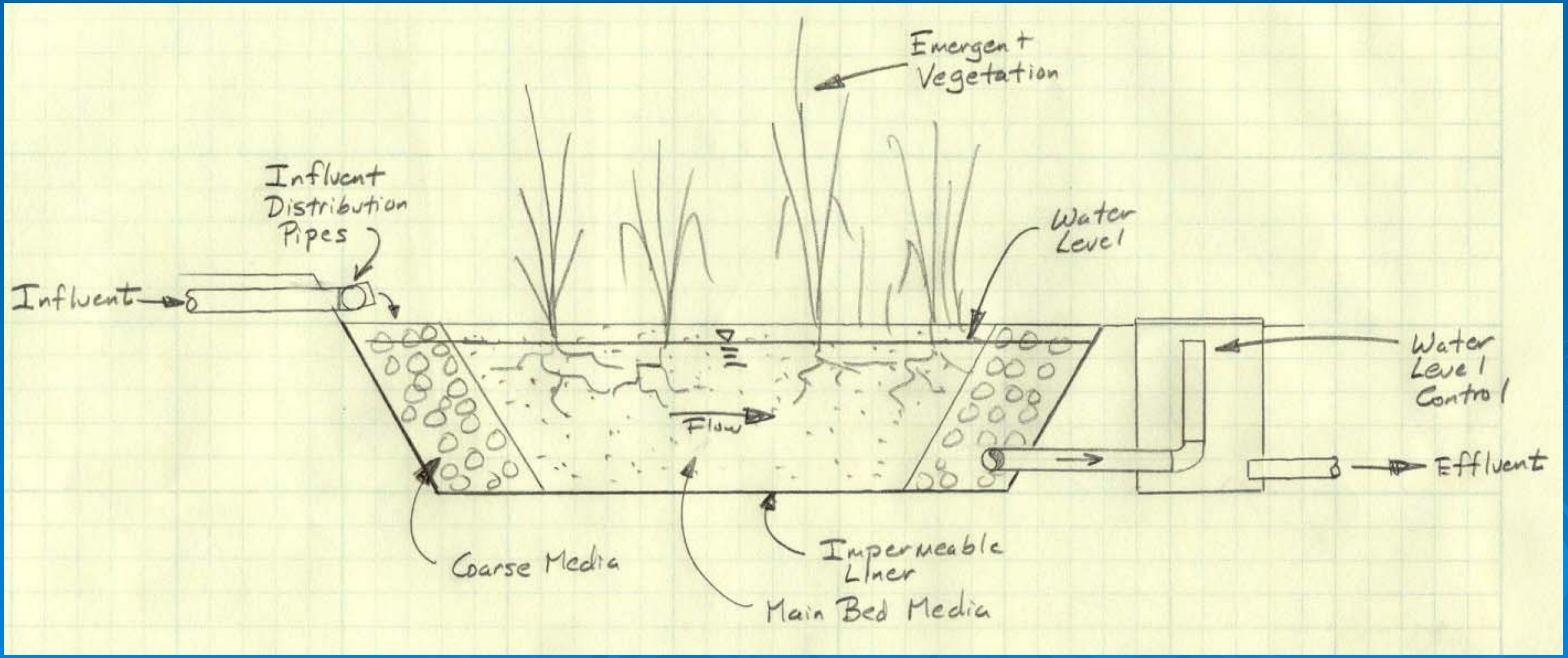
Free Water Surface Wetland

- Typical applications are for polishing effluent from a lagoon, activated sludge, or other secondary treatment process



Vegetated Submerged Bed

- VSB wetlands employ a gravel bed planted with wetland vegetation. The water is kept below the surface of the gravel.



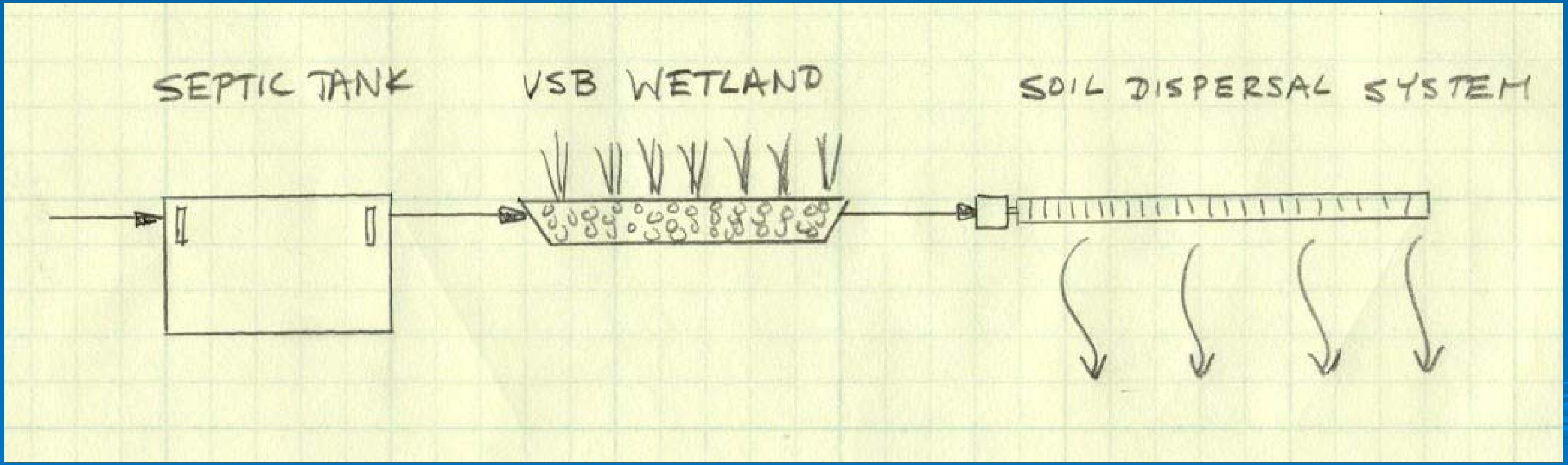
Vegetated Submerged Bed

VSB Wetland operating near Lindstrom, Minnesota

Photo courtesy North American Wetland Engineering

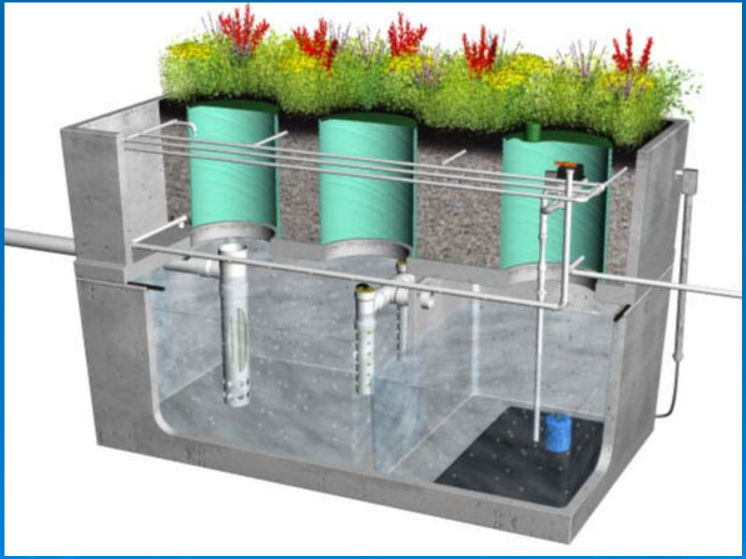
VSB Wetlands

- Most commonly used for onsite wastewater treatment for single-family homes



Vertical Flow Wetlands

- VF wetlands have much higher oxygen transfer rates, allowing for nitrification.
- 2 design types:
  - Recirculating (more common in US)
  - Single-pass (more common in Europe)



Recirculating VF wetland schematic courtesy Reactor Dynamics Inc.

FWS Wetland Processes

- Flow governed by Manning's Equation

$$v = \frac{1}{n}(d_w^{\frac{2}{3}})(s^{\frac{1}{2}})$$

v = liquid flow velocity, ft/s
n = Manning's coefficient s/ft$^{1/3}$
d_w = depth of water in wetland, ft
s = hydraulic gradient or slope of the water surface ft/ft

Crites & Tchobanoglous, 2002

FWS Wetland Processes

- Manning's coefficient a function of the density of the vegetation and flow depth

$$n = \frac{a}{d_w^{1/2}}$$

a = resistance factor, $s \cdot ft^{1/6}$

Resistance Factor, a	Water depth, d_w
0.487 for sparse vegetation	>1.3 ft
1.949 moderately dense vegetation	1.0 ft
7.795 very dense vegetation	<1.0 ft

Crites & Tchobanoglous, 2002

FWS Wetland Processes

- Evapotranspiration in FWS is generally estimated as 80% of pan evaporation

Kadlec & Knight, 1996

Role of Plants in FWS Wetlands

1. Increase sedimentation by reducing water column mixing and resuspension
2. Provide surface area in the water column to increase biofilm biomass and pollutant uptake.
3. Increase the removal of particles from the water column by increasing biofilm and plant surfaces available for particle interception.
4. Provide shade from the plant canopy over the water column to reduce algae growth.
5. Containing and preserving duckweed fronds which greatly limit reaeration and light penetration into the water column.
6. Structurally cause flocculation of smaller colloidal particles into larger, settleable particles.

Sinclair Knight Mertz, 2000; USEPA, 2000

Oxygen Transfer in FWS Wetlands

Oxygen is supplied to the FWS wetland through three passive mechanisms:

1. Atmospheric diffusion
2. Phytoplankton (algae) photosynthesis
3. Plant-mediated oxygen transfer

FWS wetlands can also be mechanically aerated to increase oxygen transfer.

Effect of Algae photosynthesis on dissolved oxygen levels

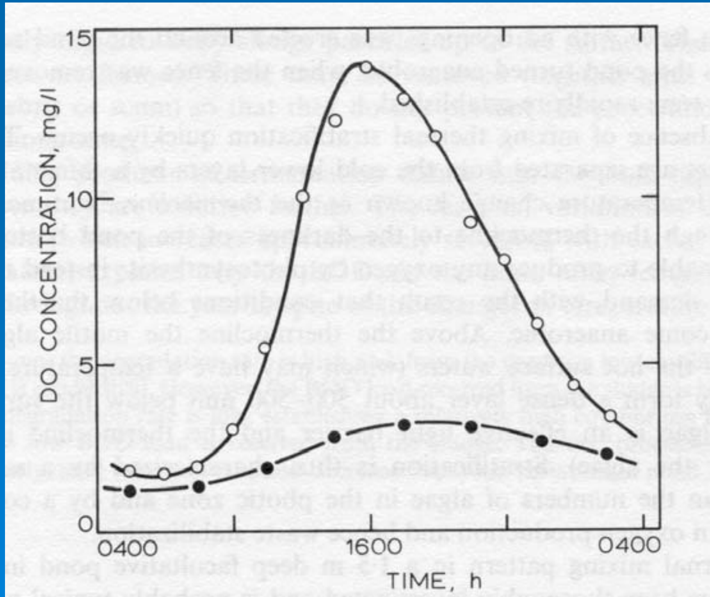


Figure 7.3 Diurnal variation in dissolved oxygen; ○, top 200 mm of pond; ●, 800 mm below surface

Mara, 1976

Suspended Solids Removal in FWS Wetlands

- Sedimentation (discrete particle settling)
- Aggregation (flocculation)
- Interception
- Predation

Removal mechanisms predominate in emergent vegetation zones. About 80% of the influent TSS can be removed within a 2-day retention time (USEPA, 2000)

Solids Generation in FWS wetlands

- Resuspension (carp, nutria, etc)
- Production (algae blooms)

Generation mechanisms predominate in open water zones. Retention time in open water zones should be kept to less than 2-3 days per zone to avoid algae blooms (USEPA, 2000)

Organic Matter Degradation

- In FWS wetlands, there is large amount of internal carbon cycling

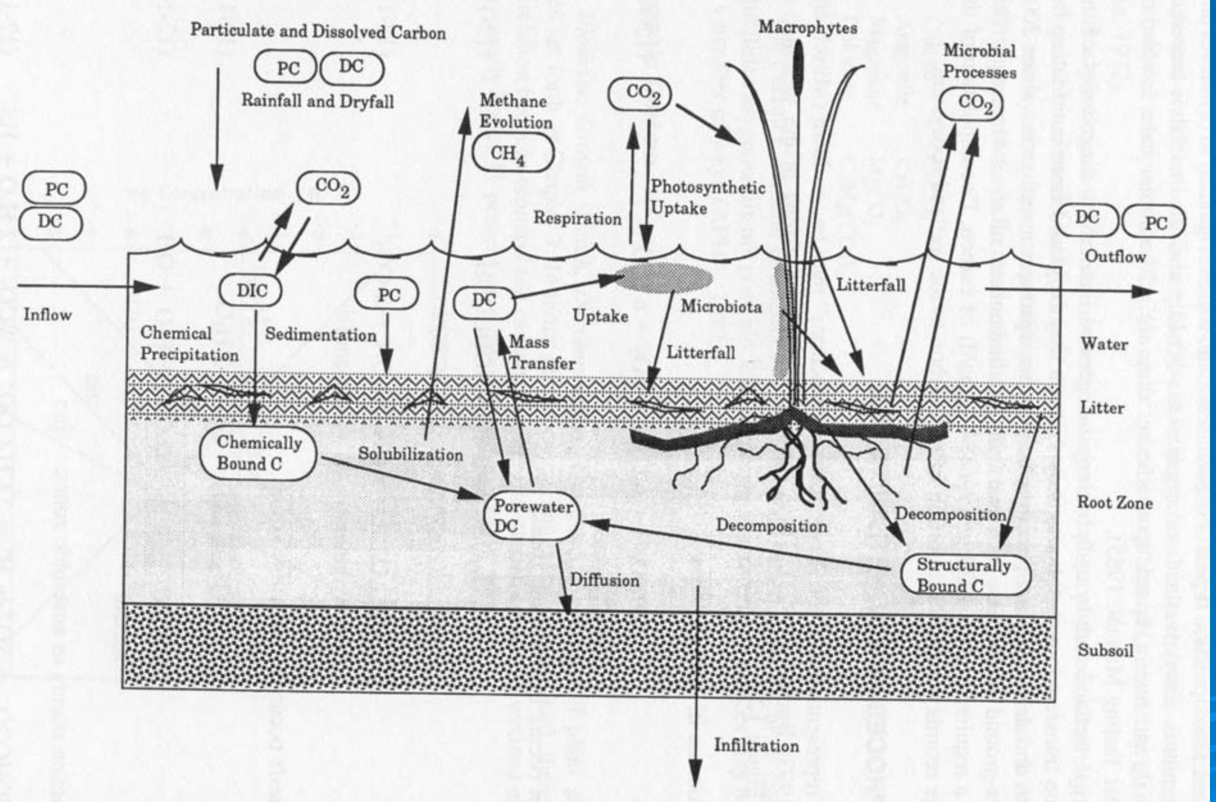


Figure 12-2 Carbon storages and transfers in the wetland environment. DC = dissolved carbon, PC = particulate carbon, DIC = dissolved inorganic carbon, DOC = dissolved organic carbon, CH_4 = methane, and CO_2 = carbon dioxide. Biomass carbon consists of living and dead biomass and organic decomposition products.

Kadlec & Knight, 1996

Organic Matter Degradation

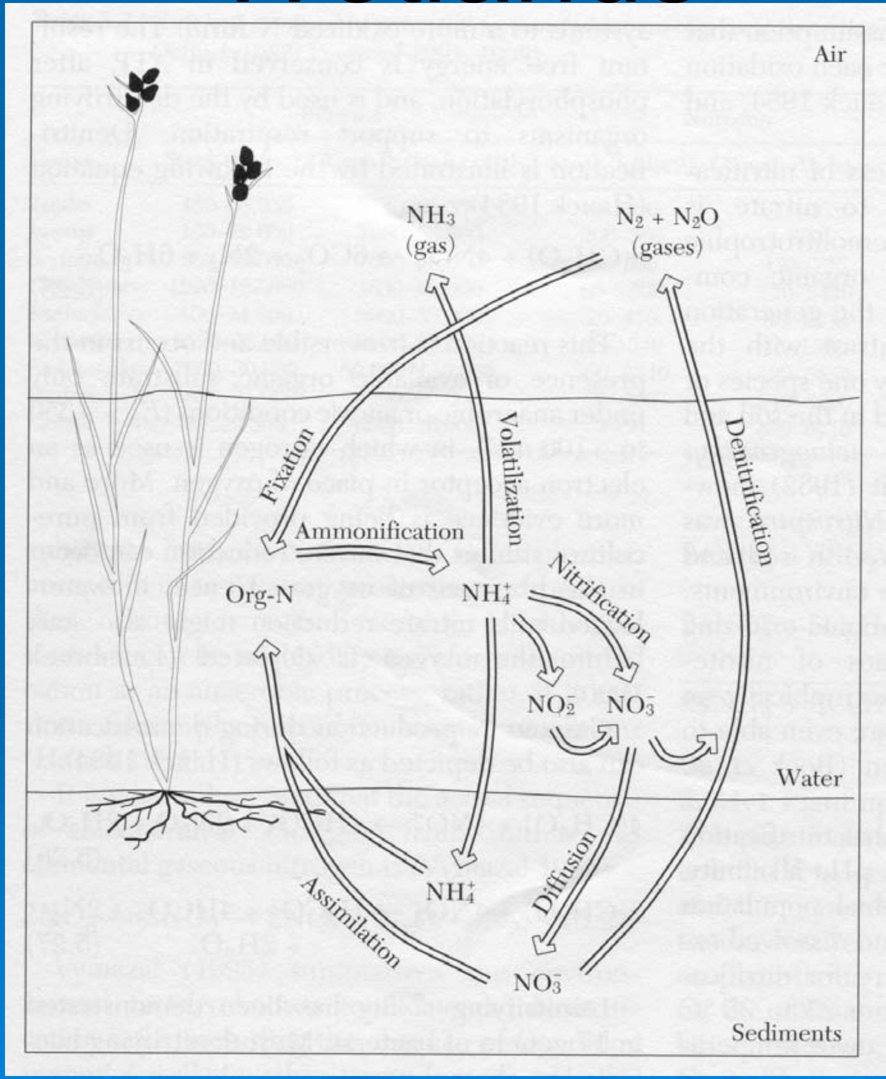
- Type of decomposition depends on organic loading and oxygen transfer rate
- Loadings that exceed oxygen transfer result in anaerobic conditions in the wetland.
  - Odors
  - More favorable mosquito habitat

Organic Loading Rates for FWS Wetlands

FWS Type	Typical Loading kg/ha d	Range kg/ha d
Semi-plug flow	60	50-200
Semi-plug flow with 2:1 recycle and step feed	150	100-200
Semi-plug flow with step feed, 2:1 recycle and supplemental aeration	200	150-300

Tchobanoglous, 1987

Nitrogen Cycling in FWS Wetlands



Kadlec & Knight, 1996

Nitrogen Processes

- Mineralization
  - Convert organic nitrogen to ammonia (NH_4^+)

- Nitrification

$$NH_4^+ + 1.5O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2H^+ + H_2O$$

$$NO_2^- + 0.5O_2 \xrightarrow{\text{Nitrobacter}} NO_3^-$$

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O$$

- Denitrification

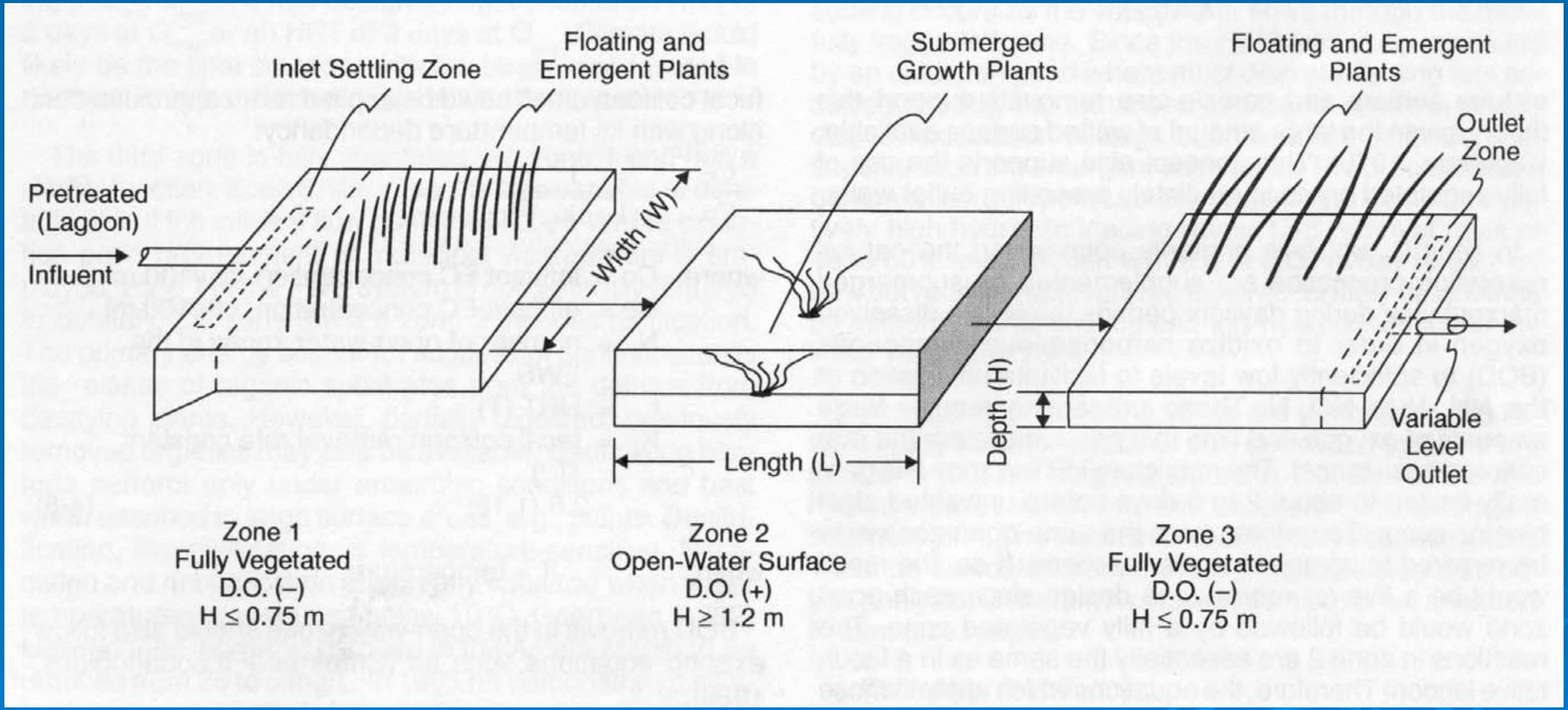
$$6(CH_2O) + 4NO_3^- \longrightarrow 6CO_2 + 2N_2 + 6H_2O$$

(Where CH_2O represents biodegradable organic matter.)

Nitrogen Removal in FWS Wetlands

- Nitrification has to occur followed by denitrification
- Only areas in FWS with adequate oxygen transfer for nitrification are open water zones
- Emergent vegetation zones will create a reducing environment suitable for denitrification, assuming adequate organic carbon is available
- Highly temperature-dependent process

FWS Configuration with Open Water Zones



USEPA, 2000

Phosphorus Cycling in FWS Wetlands

- Initially, phosphorus will be removed by adsorption onto sediments
  - Finite amount of adsorption sites
  - Only a temporary removal mechanism
- Phosphorus will be cycled through plant biomass
  - Since wetland can only support a finite standing stock of biomass, removal limited unless wetland is very large

Consequently, phosphorus removal is minimal under normal loading scenarios

Pathogen Reduction in FWS Wetlands

- Pathogens are removed through sedimentation, adsorption, interception and predation.
- However, pathogens are often re-introduced back in the wetland by waterfowl and other wildlife
- Disinfection of FWS effluent often required to meet surface water discharge standards

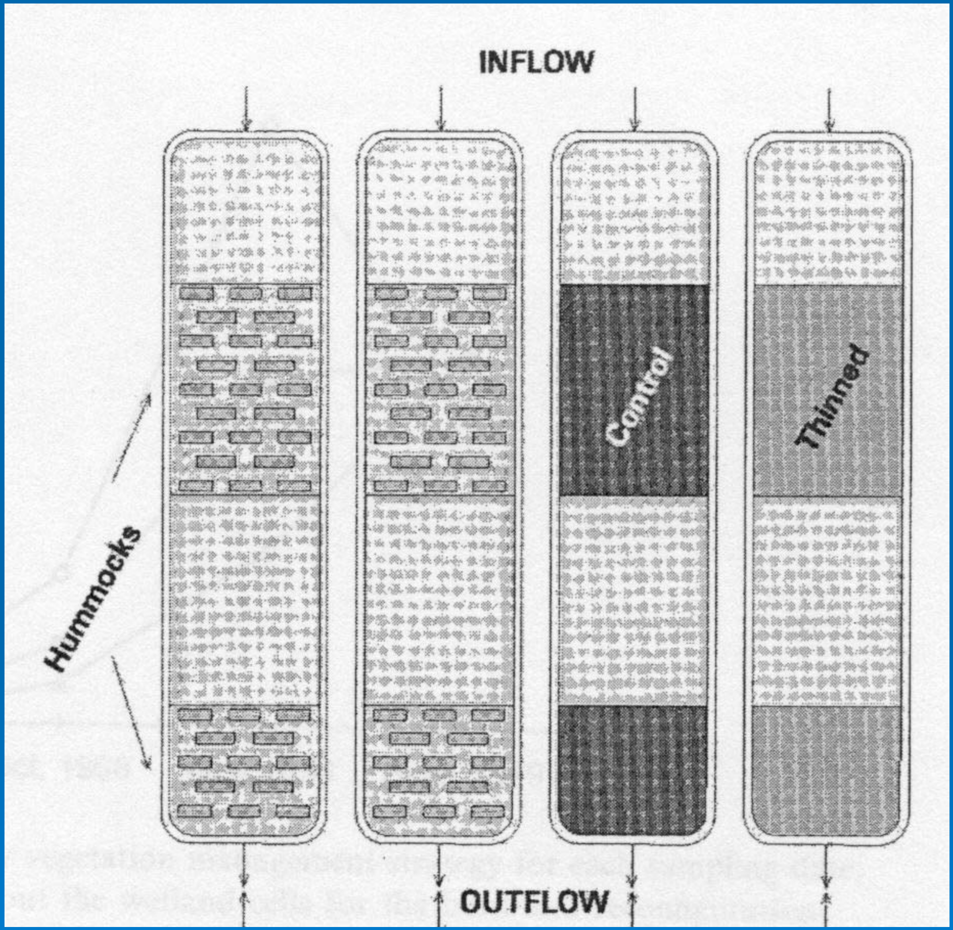
Mosquito Management in FWS Wetlands

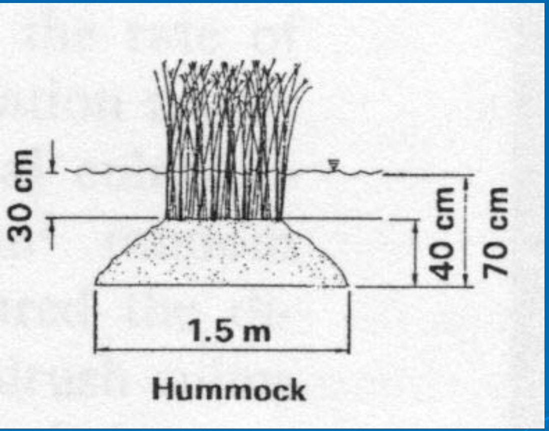
- FWS wetlands provide suitable habitat for mosquitoes
- Design goal is to create an environment where larvae do not survive to become adult mosquitoes
- Access of predator organisms (fish, water insects) to larvae is critical to effective management

Mosquito Management in FWS Wetlands

- Predator access limited by:
  - Low dissolved oxygen levels
  - Large hummocks of plant detritus (plant bridging)
  - Physical isolation of larvae
- Improved predator access results from:
  - Increasing open water areas
  - Avoiding large monotypic stands of emergent vegetation
  - Good design of inlet and outlet structures

Mosquito Management in FWS Wetlands





Example of wetland modified for improved predator access. Thullen et al. 2002

Mosquito Management in FWS Wetlands

- FWS wetlands cannot be made "mosquito free"
- Realistic goal is to minimize mosquito production to the level found in adjacent natural wetlands
- The potential for mosquito production and impacts to neighbors should be carefully considered when choosing a site

Water Temperature in FWS Wetlands

- Water temperature affects biological treatment processes
- Lagoon equations can be used to estimate water temperature

$$T_w = \frac{(0.5A)(T_a) + (Q)(T_i)}{0.5A + Q}$$

Where:

T_w = water temperature, $^{\circ}C$

T_a = ambient air temperature, $^{\circ}C$

A= surface area of wetland, m^2

Q= wastewater flow rate, m^3/d

USEPA, 1983

VSB Wetland Processes

- Flow governed by Darcy's Law:

$$Q = k_s A_c S$$

Where:

Q=average flow through wetland, m^3/d

k_s =hydraulic conductivity, m/d

A_c =cross-sectional area of bed, m^2

S=slope of hydraulic gradeline, m/m

VSB Wetland Processes

- Wastewater loading and biomat growth dramatically reduces the hydraulic conductivity
- Recommended design values:
  - Initial 30% of VSB: design K value = 1% of clean bed K
  - Final 70% of VSB: design K value = 10% of clean bed K

USEPA, 2000

Role of Plants in VSB Wetlands

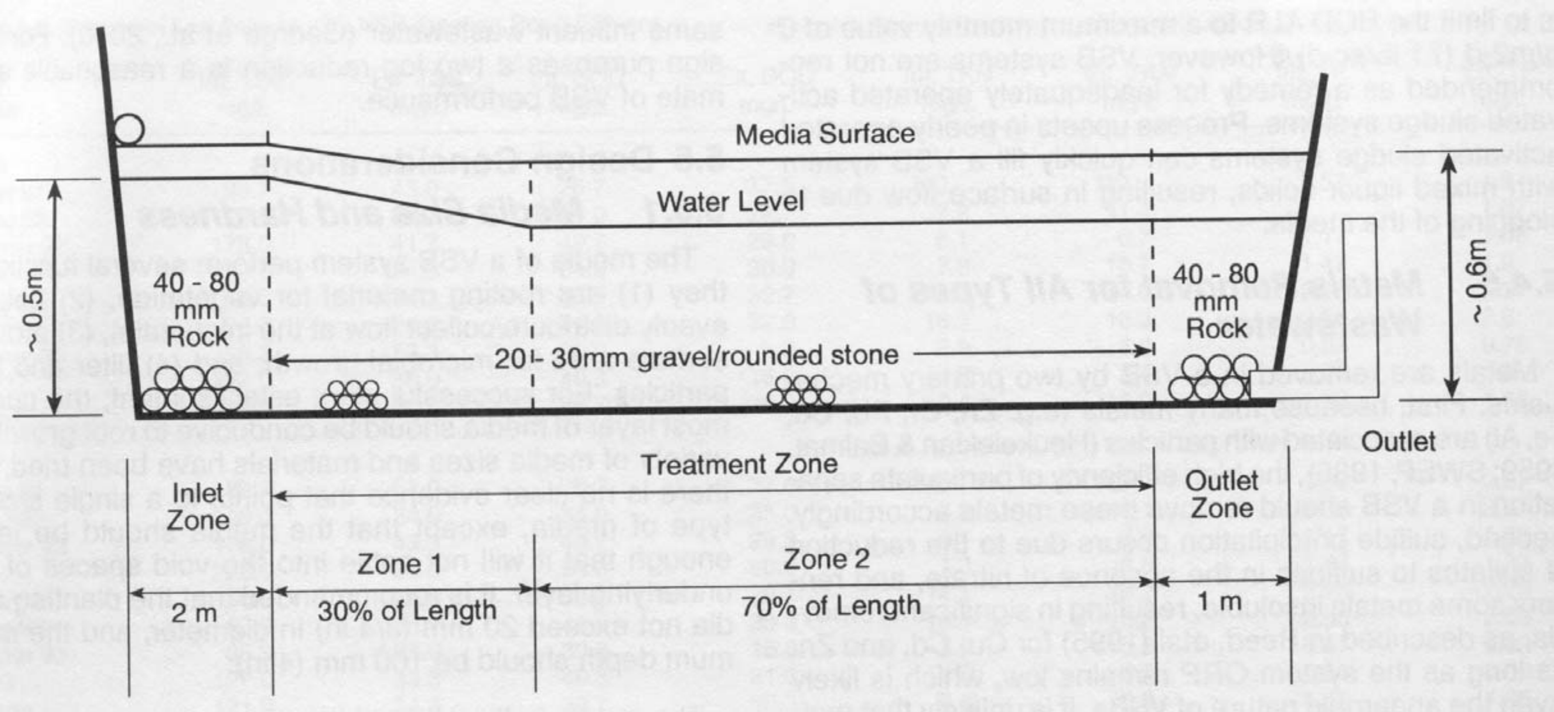
- Oxygen transfer from plants is minimal (about 0.02 g/m^2d)
- Plant roots generally do not penetrate to bottom of gravel bed
- Plant roots support symbiotic bacteria and fungi, resulting in a more diverse microbial environment
- Net effect of plants on treatment is minimal

Oxygen Transfer in VSB Wetlands

- Oxygen transfer through atmospheric diffusion and plant-mediated transport is minimal.
- BOD removal is mainly through physical-chemical processes
- Insufficient oxygen transfer for nitrification
- Alternative VSB designs (aeration, tidal flow) address some of these limitations

Suspended Solids Removal

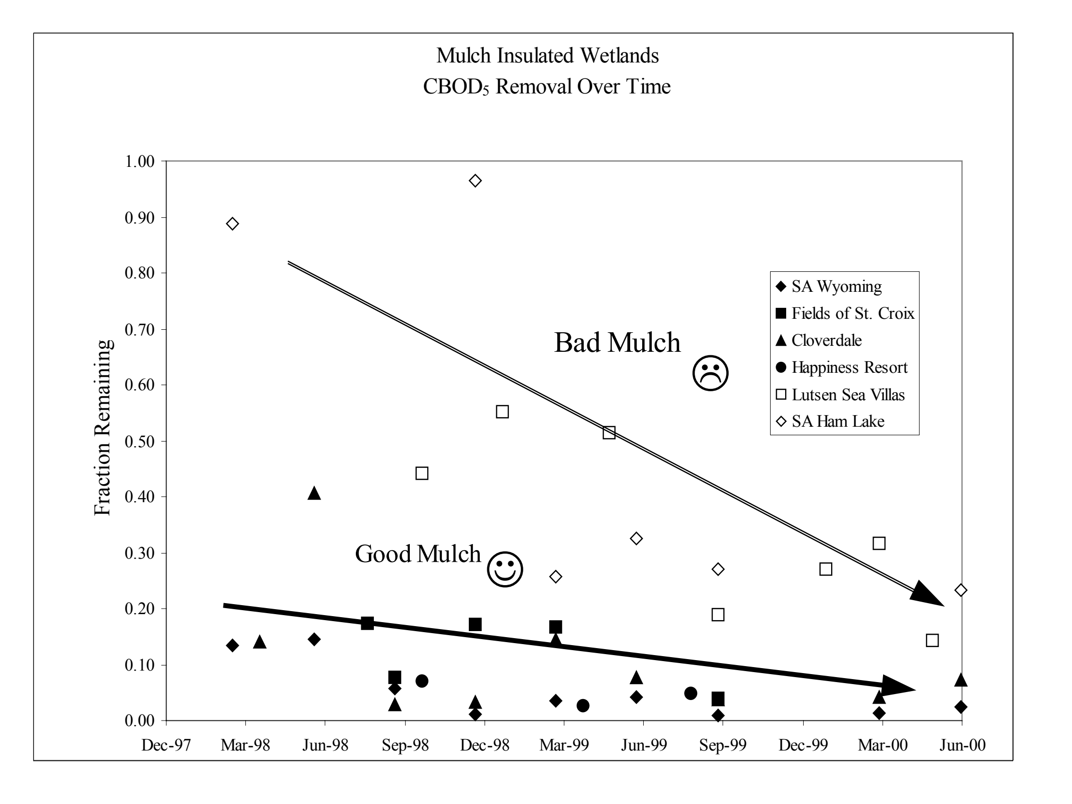
- VSB's are extremely effective in trapping and removing TSS
- Accumulation of sediments affects hydraulic conductivity of bed media:



USEPA, 2000

Organic Matter Degradation

- BOD removal is mainly by physical-chemical processes
- Mulch materials can provide a secondary organic loading, affecting treatment



Wallace et al, 2001

Nitrogen Cycling in VSB Wetlands

- Insufficient oxygen transfer for nitrification
- Reducing conditions suitable for denitrification
- Significant nitrogen reduction only occurs when the influent nitrogen has already been converted to nitrate
- Plant Harvesting
  - Removes less than 10% of applied nitrogen
  - Not a cost-effective nutrient management option

Vymazal et al, 1998; Platzer, 1996; Kuusemets et al 2002

Phosphorus Removal in VSB Wetlands

- Adsorption onto media is only a short-term removal mechanism with standard medias
- Expanded shale and clay aggregates with very high phosphorus sorption capacities have been used to increase phosphorus retention in VSBs
  - Sacrificial bed media
- Plant Harvesting
  - Removes less than 5% of applied phosphorus
  - Not cost-effective

Jenssen, 1996; Zhu et al, 1997; Kuusemets et al 2002

Sulfur Cycling in VSB's

- VSB's will reduce sulfate to sulfide
  - Sulfide can be an odor source (H_2S)
  - Influent sulfides represent an additional oxygen demand
- Some VSB's designed to remove heavy metals through sulfide precipitation

Eger, 1992; Frostman, 1993; Eger & Lapakko, 1989

Pathogen Reduction in VSBs

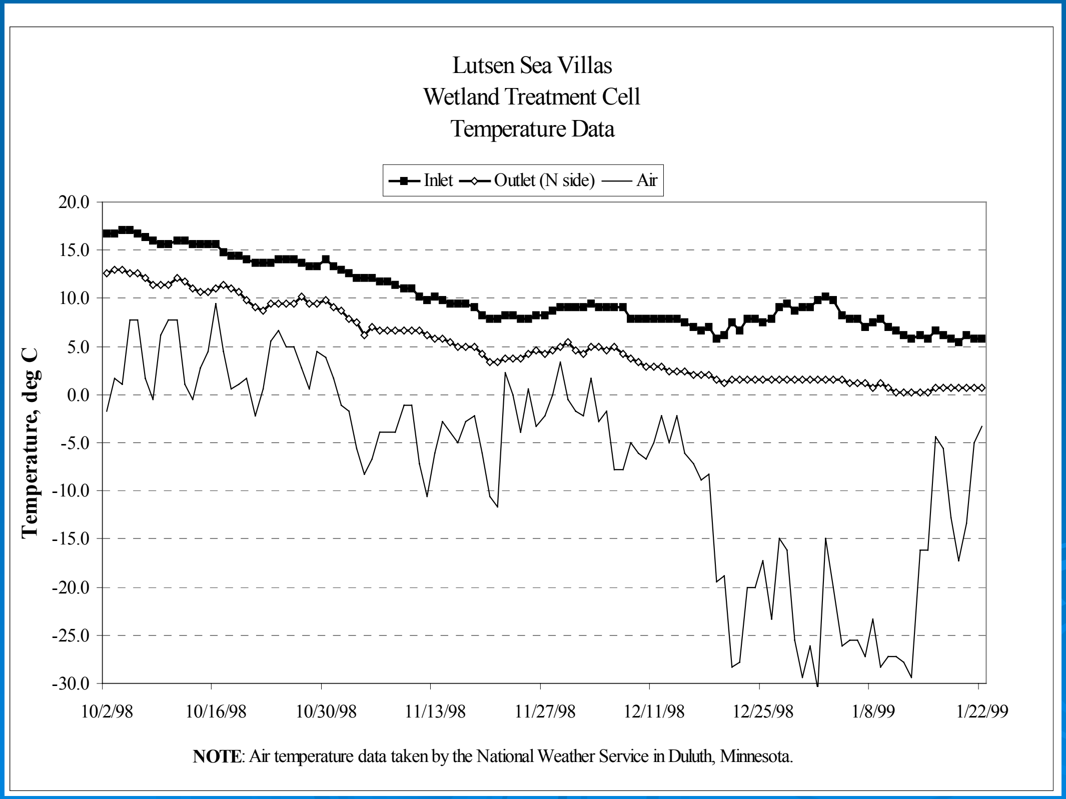
- Typical removal rates:
  - 98-99% fecal coliform bacteria
  - 93-99% helminth ova
  - 95-99% viruses

- Disinfection may be required to meet surface water discharge standards

Gerba et al, 1999; Gersberg et al, 1989; Mandi et al, 1998; Stott et al 2002

Cold-Climate VSB's

- VSB systems can be insulated with a mulch layer to provide freeze resistance in cold climates
- The insulation requirement can be calculated using energy balance methods



Wallace et al, 2001

Commonly Used Wetland Design Methods

- Small and Decentralized Wastewater Management Systems, Crites & Tchobanoglous, 1998
- Constructed Wetlands Treatment of Municipal Wastewaters, USEPA, 2000
- Treatment Wetlands, Kadlec & Knight, 1996
- Natural Systems for Waste Management and Treatment, 2nd ed., Reed et al 1995
- TVA Wetland Design Manual, Steiner & Watsom, 1993

Crites & Tchobanoglous, 1998

- FWS Wetland Design – BOD Removal

Determine residence time for BOD Removal

$$t = \frac{V}{Q} = \left[\frac{1}{(C_n/C_0)^{1/n}} - 1 \right] \times \frac{n}{k_0}$$

Where:

t = detention time for BOD removal, d

V = total volume of wetland, ft^3

Q = flow rate, ft^3/d

C_n = effluent BOD concentration from the nth reactor in series, mg/L

Co = influent BOD concentration, mg/L

n = number of complete mix reactors in series (4 is recommended)

k_0 = overall BOD removal rate constant, corrected for temperature, d^{-1} (1.01 d^{-1} is recommended at 20 ^{o}C)

Crites & Tchobanoglous, 1998

- FWS Design – BOD removal

Temperature Correct Removal Rates

$$\frac{k_2}{k_1} = \theta^{(T_2 - T_1)}$$

Where:

k_2 = BOD rate constant at T_2, °C

k_1 = BOD rate constant at T_1, °C

θ= temperature correction factor (1.02-1.06 recommended)

Crites & Tchobanoglous, 1998

- FWS Wetland Design – BOD Removal

Organic Loading Rate Should be less than 100 lb BOD/ac·d

$$L_{org} = \frac{C_0 \times d_w \times \eta \times F_1}{t \times F_2}$$

Where:

L_{org}=organic loading rate, lb BOD/ac×d

C_o=BOD concentration in influent wastewater, mg/L

d_w = water depth, typically 1.25 ft

η=plant based void ratio, typically 0.65 to 0.75

F_1=conversion factor, $8.34\text{lb}/[\text{Mgal}\times(\text{mg/L})]$

t=detention time, days

F_2=conversion factor, 3.07ac×ft/Mgal

Crites & Tchobanoglous, 1998

- FWS Design – BOD Removal

Calculate Required Area

$$A = \frac{Q_{ave} \times t \times 3.07}{d_w \times \eta}$$

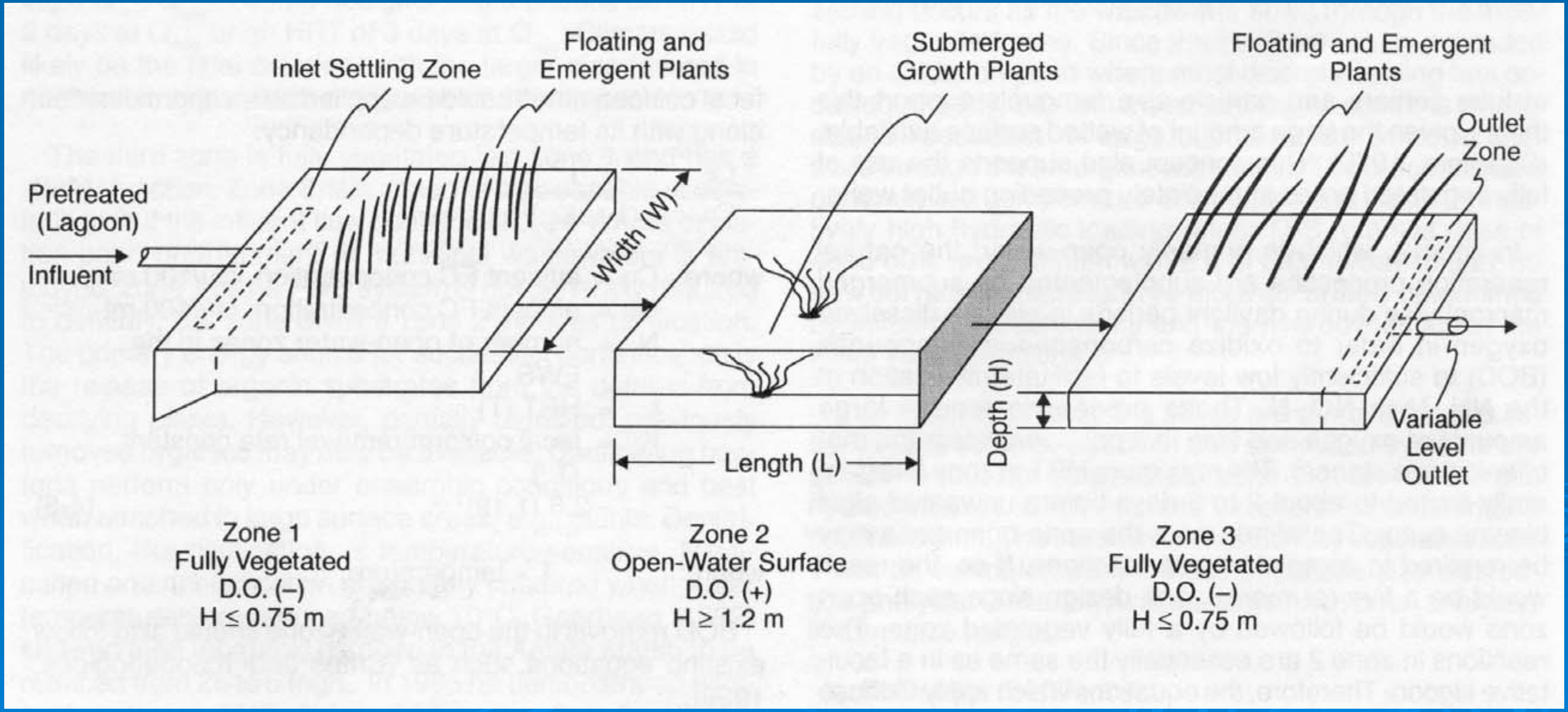
Where:

Q_{ave} = average daily flow through FWS wetland, Mgal/d

A= area, ac

USEPA, 2000

- FWS Wetland Design



USEPA, 2000

- FWS Wetland Design

Mass Loading Rates

Parameter	Area Loading	Effluent Concentration
BOD	45 kg/ha·d	<20 mg/L
	60 kg/ha·d	30 mg/L
TSS	30 kg/ha·d	<20 mg/L
	50 kg/ha·d	30 mg/L

USEPA, 2000

- Zone 1 (vegetated) 2-3 day residence time
- Zone 2 (open water) 2-3 day residence time (break into multiple open water zones if necessary)
- Zone 3 (vegetated) 2-3 day residence time

Kadlec & Knight, 1996

- FWS Wetland Design

$$\ln\left(\frac{C_e - C^*}{C_i - C^*}\right) = -\frac{k_{A,T}}{q}$$

k-C* Model

Where:

C_e = outlet target concentration, mg/L

C_i = inlet concentration, mg/L

C^* = background concentration, mg/L

$k_{A,T}$ = temperature dependent first-order areal rate constant, m/yr

q= hydraulic loading rate, m/yr

Kadlec & Knight, 1996

- FWS Wetland Design

k-C* Model rearranged to determine area

$$A = \left(\frac{0.0365 \times Q}{k_A} \right) \times \ln \left(\frac{C_i - C^*}{C_e - C^*} \right)$$

Where:

A = required wetland area, ha

Q = water flow rate, m^3/d

Kadlec & Knight, 1996

- FWS Wetland Design

  Temperature correct removal rates

$$k_{A,T} = k_{A,20}\theta^{(T-20)}$$

Where:

$k_{A,T}$ = first-order areal rate constant at temperature t, $^{\circ}C$

$k_{a,20}$ = first-order areal rate constant at 20 $^{\circ}C$

θ = temperature correction factor

T = wetland water temperature, $^{\circ}C$

Kadlec & Knight, 1996

- FWS Wetland Design

k-C* Model Parameters

Parameter	$k_{A,20}$ (m/yr)	θ	C*, mg/L
BOD	34	1.00	3.5 + 0.053Ci
TSS	1000	1.00	5.1+0.16Ci
Organic-N (sequential)	17	1.05	1.5
NH_4-N (sequential)	18	1.04	0.00
NO_x-N (sequential)	35	1.09	0.0
Total-N (overall)	22	1.05	1.50
Total P	12	1	0.02
Fecal Coliform	75	1.00	300 cfu/100 mL

Reed et al, 1995

- FWS Wetland Design – BOD Removal

$$\frac{C_e}{C_o} = e^{-K_T \times t}$$

Loading should be less than 100 kg/ha-d

Where:

C_e = effluent BOD, mg/L resulting from influent BOD

C_o = influent BOD, mg/L

K_T = temperature dependent, first order rate constant, d^{-1}

t = detention time, days

Reed et al, 1995

- FWS Wetland Design – BOD Removal

Rearranging to solve for area

$$A_s = \frac{Q_{ave}\left(\ln C_o - \ln C_e\right)}{K_T \times d_w \times \eta}$$

Where:

A_s = wetland surface area, m^2

Q_{ave} = average flow rate, m^3/d

d_w = water depth, typically 0.1-0.46 m

η = wetland porosity, typically 0.65-0.75

Reed et al, 1995

- FWS Wetland Design – BOD Removal

Temperature correct removal rates

$$K_T = K_{20}\left(1.06\right)^{(T-20)}$$

$$K_{20} = 0.678\ d^{-1}$$

Reed et al, 1995

- FWS Wetland Design – TSS removal

$$C_e = C_o\left[0.1139 + 0.00213\left(HLR\right)\right]$$

Where:

C_e = effluent TSS, mg/L

C_o = influent TSS, mg/L

HLR = hydraulic loading rate, cm/d

Reed et al, 1995

- FWS Wetland Design - Nitrification

$$\frac{C_e}{C_o} = e^{-K_T \times t}$$

$$A_s = \frac{Q_{ave} \ln\left(C_o / C_e\right)}{K_T \times d_w \times \eta}$$

Where:

A_s = surface area of wetland, m^2

C_e = effluent ammonia concentration, mg/L

C_o = influent TKN concentration, mg/L

K_T = temperature dependent rate constant, d^{-1}

$$K_T = \begin{cases} 0\ d^{-1} \text{ at } 0^\circ C \\ 0.2187(1.048)^{(T-20)} \text{ at } 1+^\circ C \end{cases}$$

η = wetland porosity; typically 0.65-0.75

t = hydraulic residence time, d

d_w =waterdepthinwetland,m

Q_{ave} =averageflowthroughwetland,m^3/d= $\frac{Q_{in} - Q_{out}}{2}$

Reed et al, 1995

- FWS Wetland Design - Denitrification

$$\frac{C_e}{C_o} = e^{-K_T \times t}$$

$$A_s = \frac{Q_{ave}\ln\left(C_o/C_e\right)}{K_T \times d_w \times \eta}$$

Where:

A_s = surface area of wetland, m^2

C_e = effluent nitrate concentration, mg/L

C_o = influent nitrate concentration, mg/L (influent + ammonia oxidized in wetland)

K_T = temperature dependent rate constant, d^{-1}

$$K_T = \begin{cases} 0\ d^{-1} \text{ at } 0\,^{o}C \\ 1.000(1.15)^{(T-20)} \text{ at } 1+\,^{o}C \end{cases}$$

η = wetland porosity; typically 0.65-0.75

t = hydraulic residence time, d

d_w =waterdepthinwetland,m

Q_{ave} =averageflowthroughwetland,m^3/d=$\frac{Q_{in} - Q_{out}}{2}$

Crites & Tchobanoglous, 1998

- VSB Wetland Design – BOD Removal

Determine residence time

$$t = -\frac{\ln C/C_o}{k_{apparent}}$$

Where:

t = detention time for BOD removal, d

C_o = influent BOD concentration, mg/L

C = effluent BOD remaining from influent (BOD_{RIW}), mg/L

$k_{apparent}$ =overall BOD removal rate constant,corrected for temperature,d^{-1} (1.1d^{-1} recommended)

Crites & Tchobanoglous, 1998

- VSB Wetland Design – BOD Removal

Calculate required area

$$A_s = \frac{Q_{ave} \times t \times 3.07}{\eta \times d_w}$$

Where,

A_s = surface area of VSB, ac

Q_{ave} = average flow through wetland, Mgal/d

t = detention time, d

η = porosity of gravel bed media

d_w = water depth, ft

Crites & Tchobanoglous, 1998

- VSB Wetland Design - Nitrification

$$A = \frac{Q_{ave}\left(\ln N_o - \ln N_e\right)}{k \times d_w \times \eta \times F}$$

Where:

A = surface area of VSB for ammonia removal, ac

Q_{ave} = average flow through wetland, ft^3/d

N_o = influent ammonia concentration, mg/L

N_e = effluent ammonia concentration, mg/L

k = ammonia removal rate constant, $0.107\mathrm{d}^{-1}$ at $20^\circ\mathrm{C}$

d_w = depth of water in bed, ft

η = effective porosity of bed media

F = conversion factor, 43,560 $\mathrm{ft}^2/\mathrm{ac}$

USEPA, 2000

- VSB Wetland Design

Mass Loading Rates

Parameter	Area Loading Rate	Effluent Concentration
BOD	6 $g/m^2 \cdot d$	30 mg/L
TSS	20 $g/m^2 \cdot d$	30 mg/L

USEPA, 2000

- VSB Wetland Design

Calculate Width Using Darcy's Law

Initial 30% of VSB   Ki = 1% of clean K
Final 70% of VSB   Kf = 10% of clean K

Kadlec & Knight, 1996

- VSB Wetland Design

$$\ln\left(\frac{C_e - C^*}{C_i - C^*}\right) = -\frac{k_{A,T}}{q}$$

k-C* Model

Where:

C_e = outlet target concentration, mg/L

C_i = inlet concentration, mg/L

C^* = background concentration, mg/L

$k_{A,T}$ = temperature dependent first-order areal rate constant, m/yr

q= hydraulic loading rate, m/yr

Kadlec & Knight, 1996

- VSB Wetland Design

k-C* Model rearranged to determine area

$$A = \left(\frac{0.0365 \times Q}{k_A} \right) \times \ln \left(\frac{C_i - C^*}{C_e - C^*} \right)$$

Where:

A = required wetland area, ha

Q = water flow rate, m^3/d

Kadlec & Knight, 1996

- VSB Wetland Design

  Temperature correct removal rates

$$k_{A,T} = k_{A,20}\theta^{(T-20)}$$

Where:

$k_{A,T}$ = first-order areal rate constant at temperature t, ^{o}C

$k_{a,20}$ = first-order areal rate constant at 20^{o}C

θ = temperature correction factor

T = wetland water temperature, ^{o}C

Kadlec & Knight, 1996

- VSB Wetland Design

k-C* Model Parameters

Parameter	$k_{A,20}$ (m/yr)	θ	C*, mg/L
BOD	117	1.057	3.0
TSS	43.4	1.00	6.0
Organic-N (sequential)1	35	1.05	1.5
NH_4-N (sequential)1	34	1.05	0.00
NO_x-N (sequential)1	50	1.05	0
Total-N (overall)2	10	1.05	1.5
Total P	9.1	1.097	0.0
Fecal Coliform	100	1.003	200 cfu/100mL

Reed et al, 1995

- VSB Wetland Design – BOD Removal

$$\frac{C_e}{C_o} = e^{-K_T \times t}$$

Calculate required retention time

Where:

C_e = effluent BOD, mg/L resulting from influent BOD

C_o = influent BOD, mg/L

K_T = temperature dependent, first order rate constant, d^{-1}

t = detention time, days

Reed et al, 1995

- VSB Wetland Design – BOD Removal

$$A_s = \frac{Q_{ave}\left(\ln C_o - \ln C_e\right)}{K_T \times d_w \times \eta}$$

Rearranged to determine area

Where:

A_s = wetland surface area

Q_{ave} = average flow rate, m^3/d

d_w = water depth, typically 0.6 m

η = wetland porosity, dependent on media selected, 0.28-0.45

Reed et al, 1995

- VSB Wetland Design – BOD Removal

Temperature correct removal rates

$$K_T = K_{20}\left(1.06\right)^{(T-20)}$$

$$K_{20} = 1.104\ d^{-1}$$

Reed et al, 1995

- VSB Wetland Design – TSS Removal

$$C_e = C_o\left[0.1058 + 0.0011\left(HLR\right)\right]$$

Where:

C_e = effluent TSS, mg/L

C_o = influent TSS, mg/L

HLR = hydraulic loading rate, cm/d

Reed et al, 1995

- VSB Wetland Design - Nitrification

Nitrification rate constant

$$K_{NH} = 0.01854 + 0.3922(rz)^{2.6077}$$

Where:

K_{NH} = nitrification rate constant at 20 ^{o}c, d^{-1}

rz= fraction of VSB bed depth occupied by root zone, (0 to 1)

Reed et al, 1995

- VSB Wetland Design - Nitrification

$$\frac{C_e}{C_o} = e^{-K_T \times t}$$

$$A_s = \frac{Q_{ave} \ln\left(C_o / C_e\right)}{K_T \times d_w \times \eta}$$

Where:

A_s = surface area of wetland, m^2

C_e = effluent nitrate concentration, mg/L

C_o = influent nitrate concentration, mg/L (influent nitrate + ammonia oxidized in wetland)

K_T = temperature dependent rate constant, d^{-1}

$$K_T = \begin{cases} 0\ d^{-1} \text{ at } 0\,^{o}C \\ K_{NH}(0.4103) \text{ at } 1\,^{o}C \\ K_{NH}(1.048)^{(T-20)} \text{ at } 1+\,^{o}C \end{cases}$$

η = wetland porosity; dependent on bed media

t = hydraulic residence time, d

d_w =water depth in wetland, m

Q_{ave} =average flow through wetland, $m^3/d = \frac{Q_{in} - Q_{out}}{2}$

Steiner & Watson, 1993

- VSB Wetland Design

Hydraulic Loading Rate

1.3 ft^2/gpd (unrestricted area or cold climates)

0.87 ft^2/gpd (restricted small area)

Steiner & Watson, 1993

- VSB Wetland Design

Width determined by organic loading rate

Organic Loading Criteria = $1.0 ft^2 / 0.05$ lb BOD

Wetland Vegetation

- The plant species must be matched to the hydrology of the wetland.
- The plant material (seed, tuber, rhizome, pot, etc.) must be viable at the time of planting.
- Water level management during the startup phase must be compatible with the needs of the newly-establishing plants.

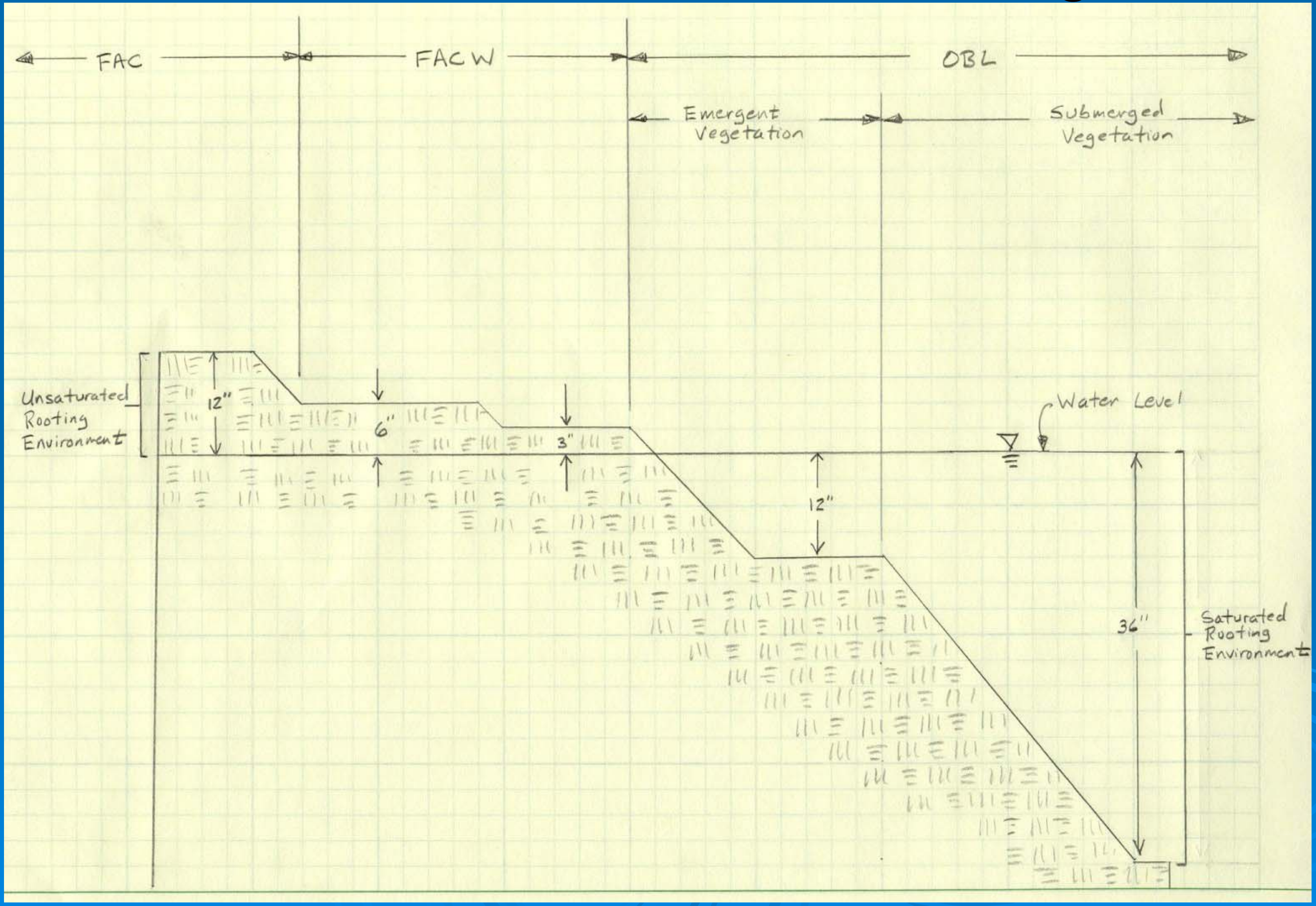
Wetland Vegetation

- Plant species are grouped by hydrology:

Indicator Category	Symbol	Description
Obligate Wetland	OBL	Plants that occur almost always (>99%) in wetlands under natural conditions
Facultative Wetland	FACW	Plants that occur usually (67-99%) in wetlands but can also occur (1-33%) in upland areas
Facultative	FAC	Plants with a similar likelihood (33-67%) of occurring either in wetlands and nonwetlands (uplands)
Facultative Upland	FACU	Plants that occur sometimes (1-33%) in wetlands but occur more often (67-99%) in uplands
Obligate Upland	UPL	Plants that occur almost always (>99%) in uplands

Wetland Vegetation

- The hydrologic tolerances of the plant species must be matched to the wetland design:



Wetland Vegetation

- Plants need access to sunlight and air to survive. The water level must be gradually raised during the plant establishment phase

Commonly Used Wetland Plant Species

Scientific Name	Common Name	Status	Region
Carex nebrascensis	Nebraska sedge	OBL	Southwest
Carex stricta	Uptight sedge	OBL	Southwest
Iris missouriensis	Rock Mountain Iris	FACW, OBL	West
Iris pseduocorus	Yellow Iris	OBL	Midwest, Northeast
Iris versicolor	Blueflag Iris	OBL	Midwest, Northeast
Juncus balticus	Baltic Rush	FACW, OBL	Southwest

Commonly Used Wetland Plant Species (continued)

Scientific Name	Common Name	Status	Region
Scirpus acutus	Hardstem Bulrush	OBL	across US
Scirpus atrovirens	Green Bulrush	OBL	Midwest, East
Scirpus californicus	Bulrush (Restorer)	OBL	West
Scirpus fluviatilis	River Bulrush	OBL	Midwest, East
Scirpus validus	Softstem Bulrush	OBL	across US
Typha latifolia	Cattail, Broadleaf	OBL	across US
Typha angustfolia	Cattail, Narrowleaf	OBL	northern US

VSB System with Ornamental Plants

Wetland Design – Current Level of Understanding

- Technology still evolving
- Wetlands can be designed to meet overall treatment objectives, but mechanisms within the “black box” are not yet quantified
- Current state of the art is “semi-empirical”
  - Area requirements are determined based on commonly used design equations
  - Internal configuration of the wetland often based on the intuitive judgement of the designer