WASTEWATER MANAGEMENT IN THE 21ST CENTURY: ISSUES FOR THE DESIGN OF TREATMENT WETLANDS

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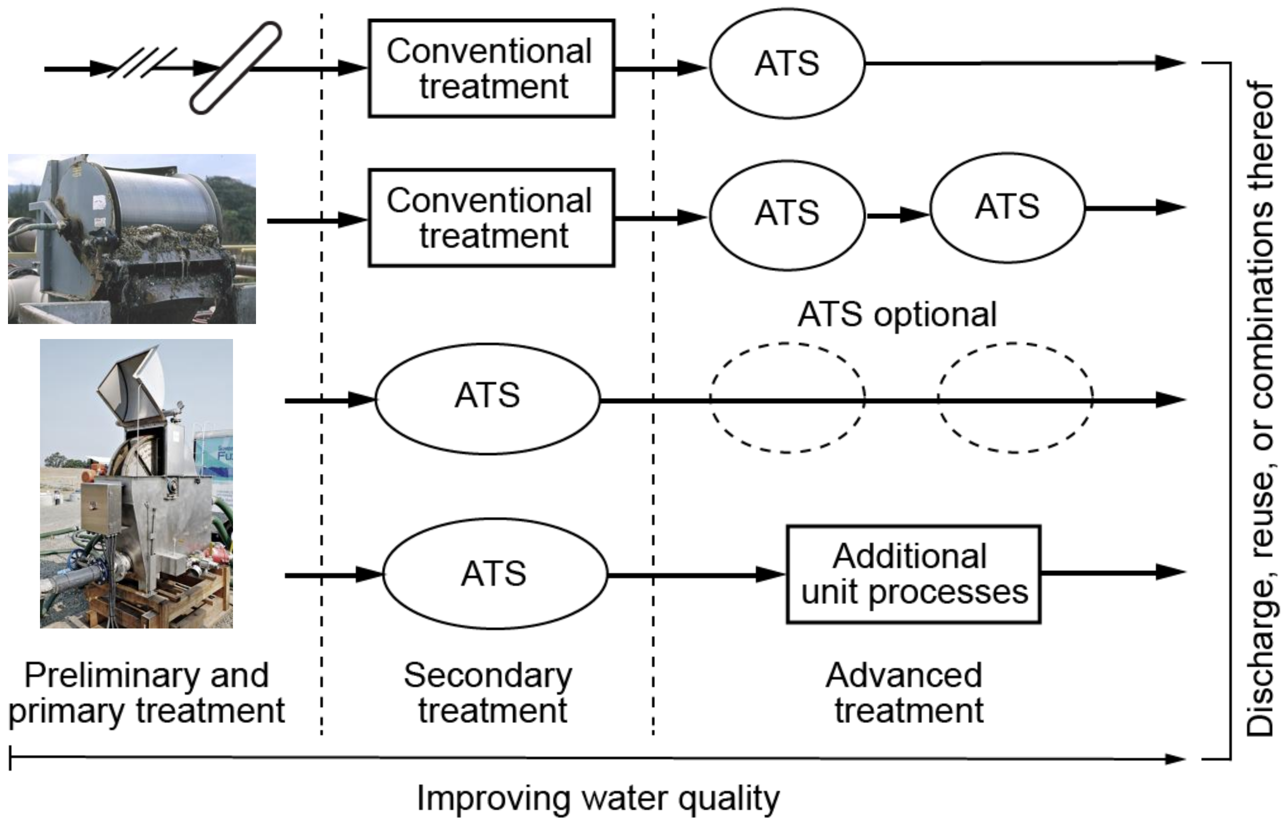
TOPICS

- Use of aquatic treatment systems (ATS)
- Types of non and intensified treatment wetlands
- Paradigm shift in view of wastewater
- A fundamental question
- Wastewater management challenges
- Wastewater treatment opportunities
- The status of wetlands
- Modeling wetlands
- Intensified treatment wetland
- Closing thoughts

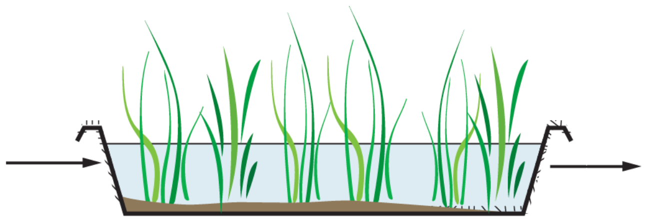
TYPICAL USES OF AQUATIC TREATMENT SYSTEMS (ATS) FOR WASTEWATER TREATMENT



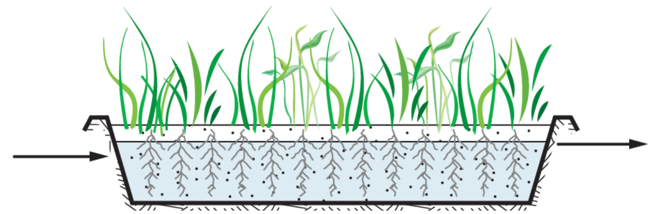
TYPES OF NON-INTENSIFIED CONSTRUCTED TREATMENT WETLANDS

- Surface flow wetland with:
  - Emergent aquatic vegetation and open water zones
  - Free floating aquatic vegetation
  - Emergent aquatic vegetation grown on floating structures
  - Submerged aquatic vegetation
- Horizontal sub-surface flow wetland without surface flooding
- Vertical down-flow flow wetland without surface flooding
- Vertical up-flow flow wetland with flooded surface
- Fill and draw (tidal-flow) wetland

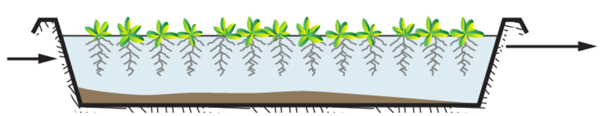
TYPES OF NON-INTENSIFIED CONSTRUCTED TREATMENT WETLANDS



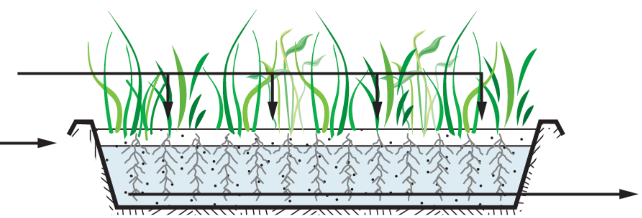
Surface flow with
emergent aquatic vegitation



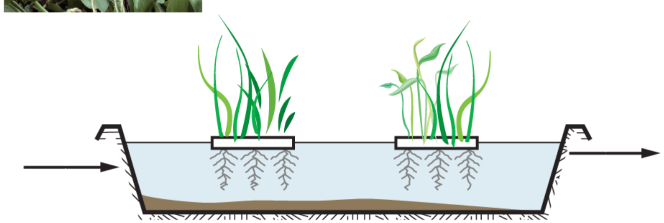
Horizontal sub-surface flow
without surface flooding



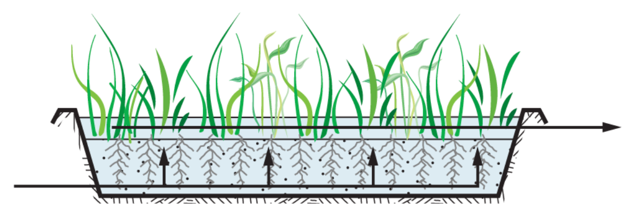
Surface flow with
floating aquatic vegitation



Vertical down-flow
without surface flooding



Surface flow with
aquatic vegitation grown
on floating platforms



Vertical up-flow
with flooded surface

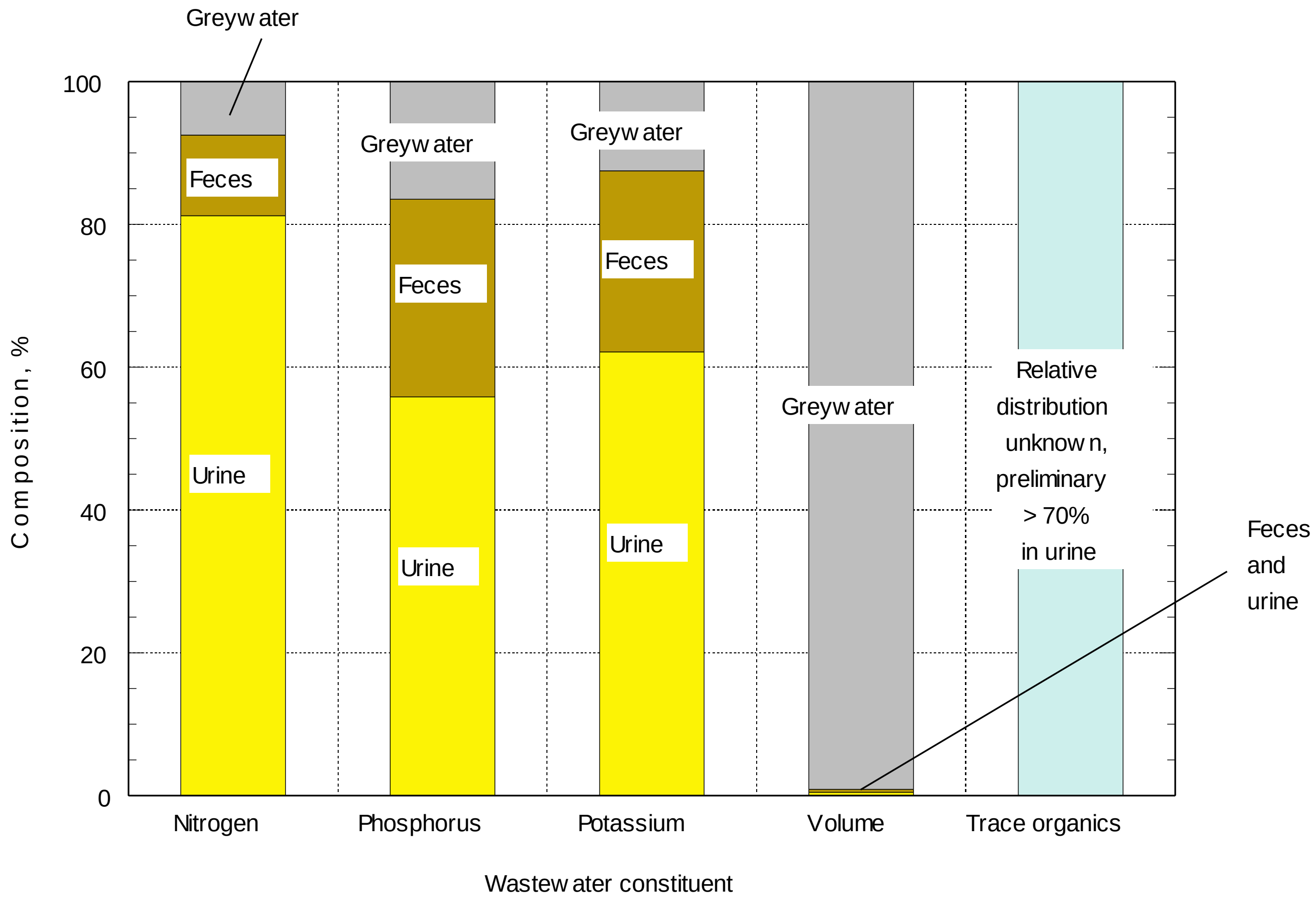
TYPES OF INTENSIFIED CONSTRUCTED TREATMENT WETLANDS

- Surface flow wetland with:
  - Alternative flow configurations with aeration and recycle
  - Side stream oxygenation for nitrification
  - Side stream anammox reactor
  - P-binding enhanced (sub-charge neutralization dosing of alum or $FeCl_3$ dose)
- Horizontal sub-surface flow wetland without surface flooding with aeration
- Horizontal sub-surface flow anoxic wetland
- Vertical down- or up-flow flow wetlands with aeration
- Fill and draw (tidal-flow) wetland with:
  - Single pass (high NH_4^+ exchange capacity medium)
  - Recirculating (low NH_4^+ exchange capacity medium)

PARADIGM SHIFT IN VIEW OF WASTEWATER FOR THE 21ST CENTURY

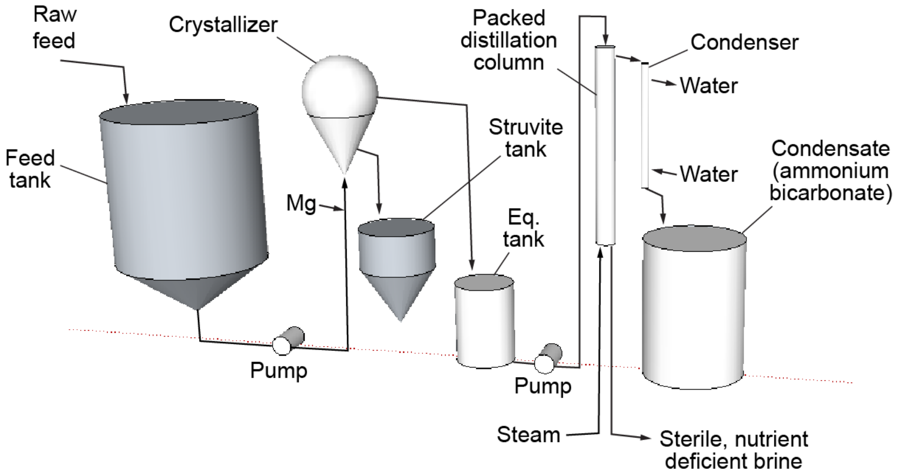
WASTEWATER is a RENEWABLE RECOVERABLE SOURCE of POTABLE WATER, RESOURCES, and ENERGY

REMOVAL OF NUTRIENTS AND TRACE ORGANICS IN DOMESTIC WASTEWATER UPSTREAM REDUCES DOWNSTREAM TREATMENT REQUIREMENTS



Source: Jönsson et al.(2000) Recycling Source Separated Human Urine.

NUTRIENT RECOVERY FROM SOURCE SEPARATED URINE



Phosphate is recovered from urine as magnesium ammonium phosphate and/or magnesium potassium phosphate; nitrogen is recovered as ammonium bicarbonate

ENERGY CONTENT OF WASTEWATER CONSTITUENTS

Item	Unit	Range
Wastewater, heat basis	$MJ/10°C \cdot 10^3\ m^3$	41,816
Wastewater, COD basis	MJ/kg COD	12 - 16
Primary sludge, dry	MJ/kg TSS	15 - 15.9
Biosolids, dry	MJ/kg TSS	12.4 - 13.5

REQUIRED AND AVAILABLE ENERGY FOR WASTEWATER TREATMENT, EXCLUSIVE OF HEAT ENERGY

- Energy required for secondary wastewater treatment

  1,200 to 2,400 MJ/1000 m^3

Energy available in wastewater for treatment (assume COD = 500 g/m^3)

Q = [500 kg COD/1000 m^3) (1000 m^3) (13 MJ/ kg COD)

= 6,000 MJ/1000 m^3

- Energy available in wastewater is 2 to 4 times the amount required for treatment

A FUNDAMENTAL QUESTION

WHAT IS THE OPTIMAL USE OF THE CARBON IN WASTEWATER?

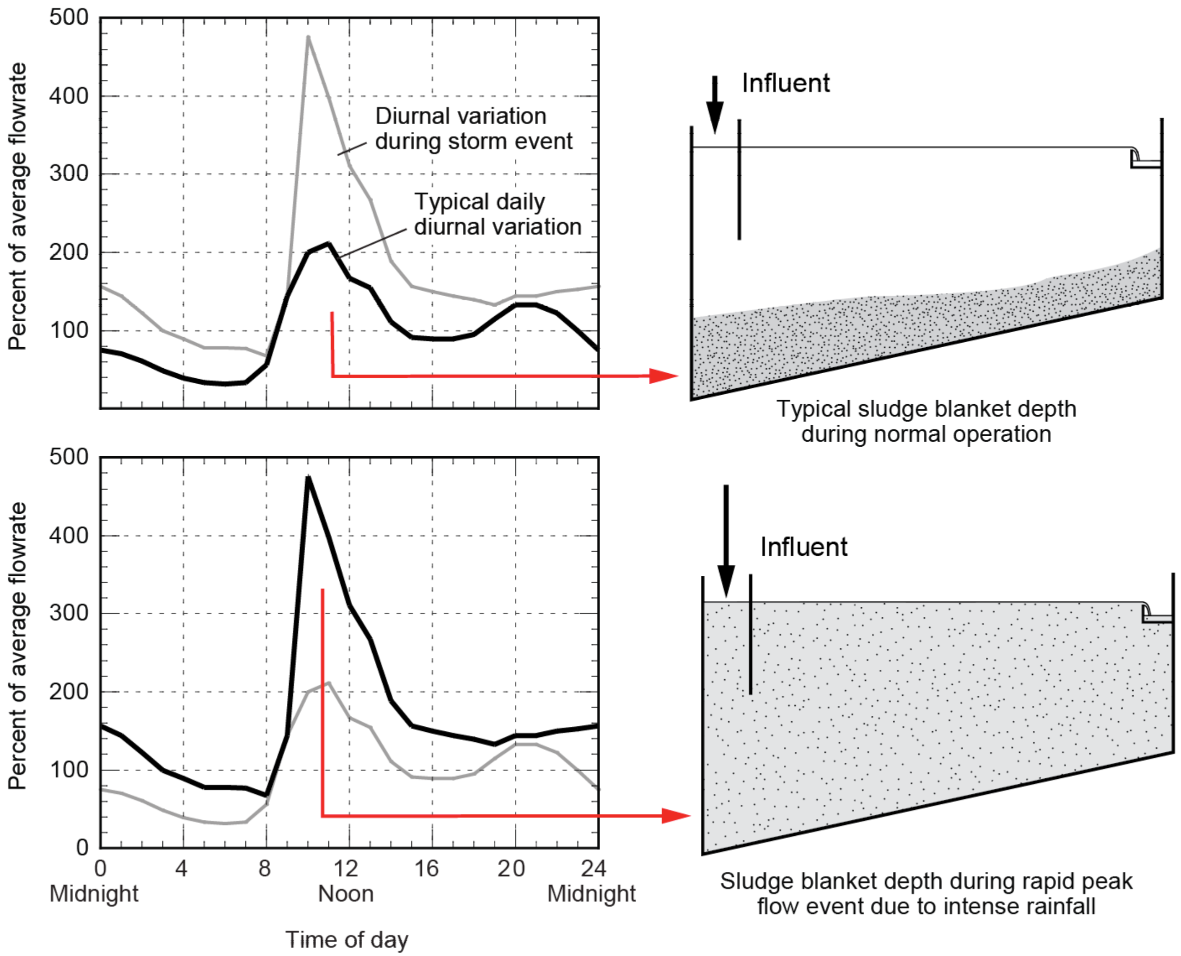
OPTIMAL USE OF CARBON IN WASTEWATER

*Is the optimal use of the carbon in wastewater for **nitrogen removal, resource recovery** (e.g. fiber, organic polymers, etc.) or **energy production** or some combination?*

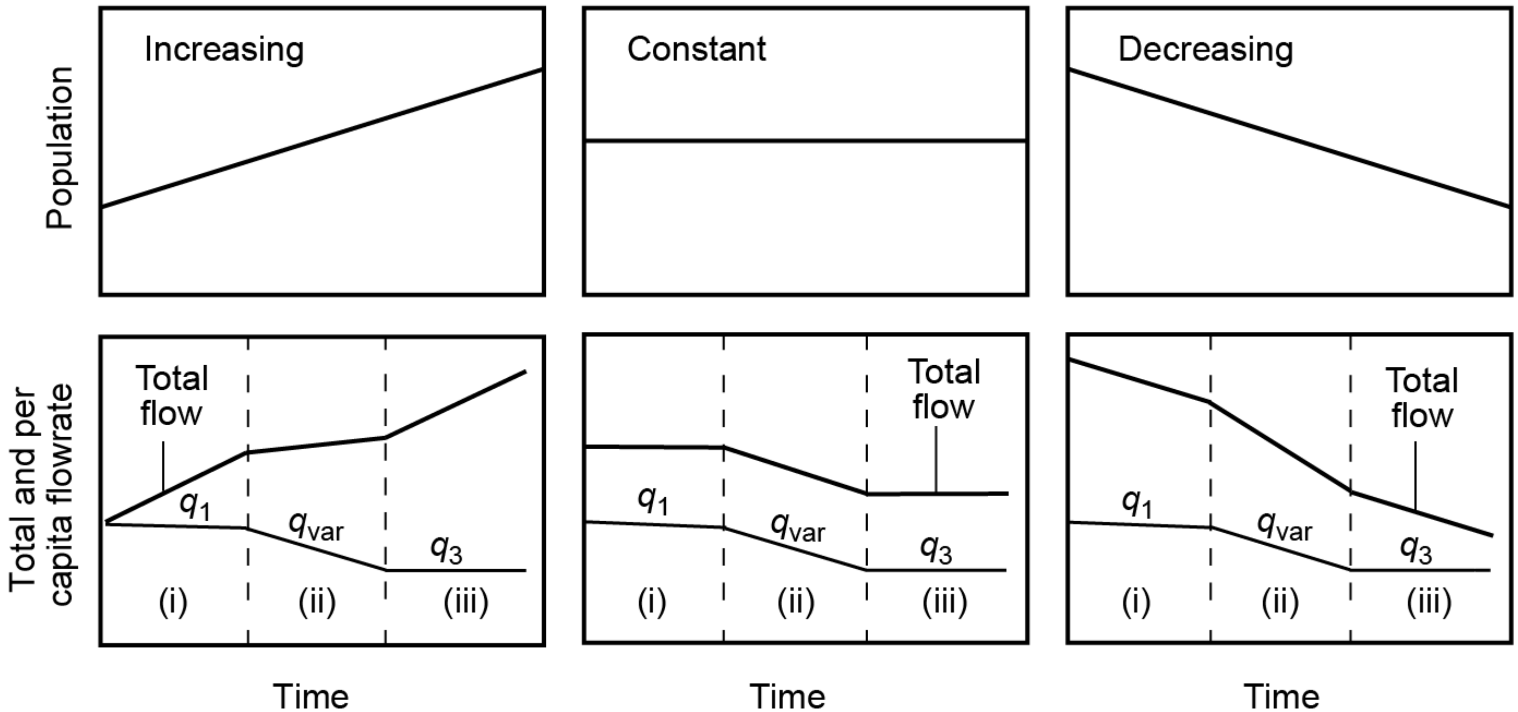
CHALLENGES AND ISSUES FOR WASTEWATER MANAGEMENT

- ***IMPACT OF CLIMATE CHANGE***
- ***DECREASING PER CAPITA FLOWRATES***

IMPACT OF CLIMATE CHANGE ON RAINFALL INTENSITY AND OPERATION OF WWTPS



IMPACT OF DECREASING FLOWRATES ON OPERATION OF COLLECTION SYSTEMS AND WWTPs



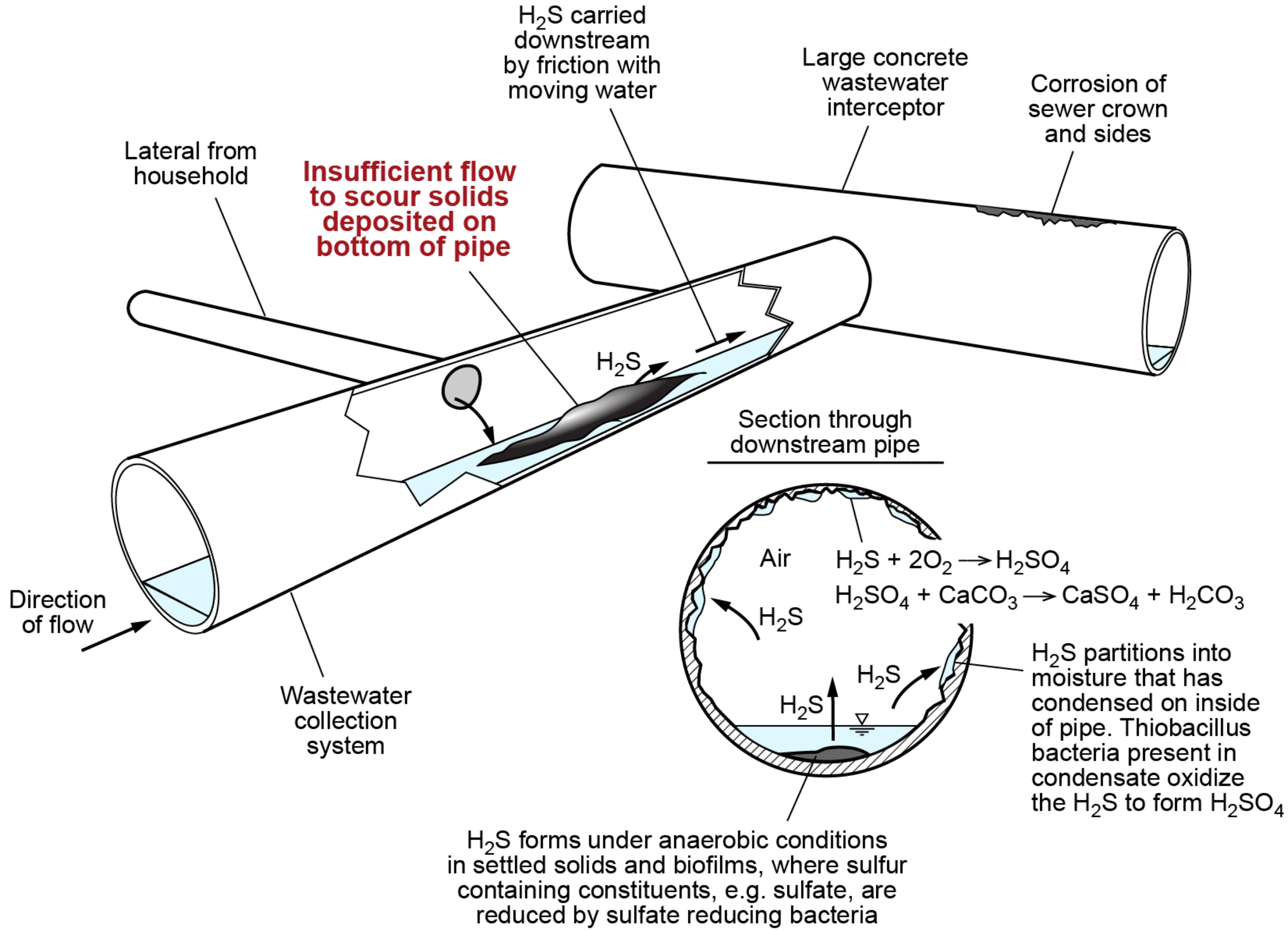
q = per capita wastewater flowrate

(i) Pre-1992

(ii) Improved water conservation, period end point unknown

(iii) Maximum water conservation

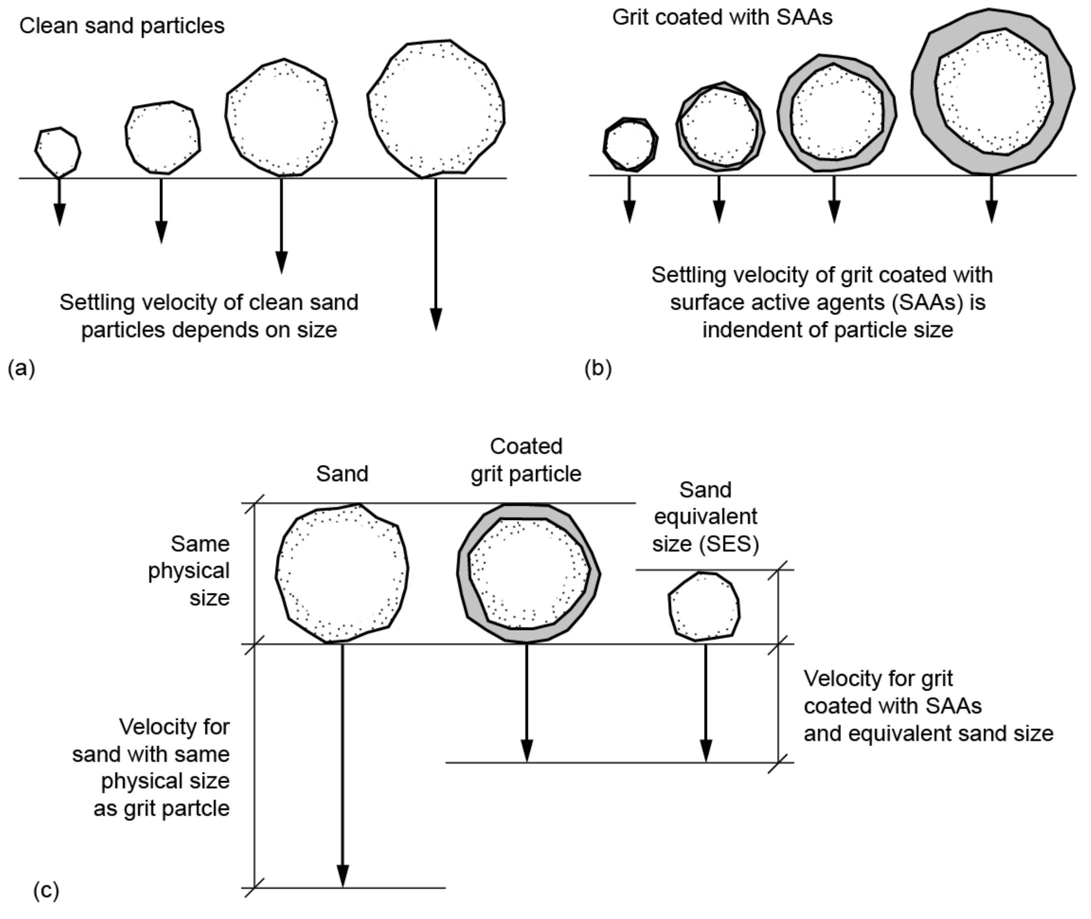
IMPACT OF WATER CONSERVATION AND DROUGHT: SOLIDS DEPOSITION, H_2S FORMATION, AND DOWNSTREAM CORROSION DUE TO REDUCED FLOWS



WASTEWATER TREATMENT: OPPORTUNITIES THAT WILL IMPACT THE DESIGN OF TREATMENT WETLANDS

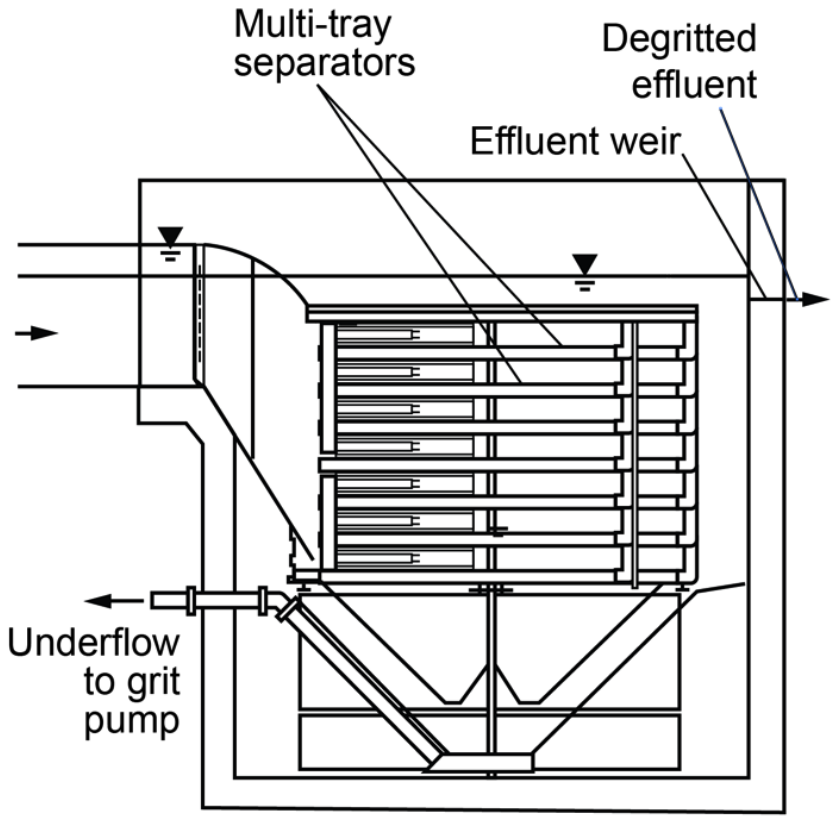
- Enhanced preliminary treatment
- Alternative primary processes
- Altering the characteristics of wastewater
- Replace primary clarification facilities
- Design for alternative endpoint(s)

ENHANCED PRELIMINARY TREATMENT THROUGH BETTER CHARACTERIZATION OF GRIT



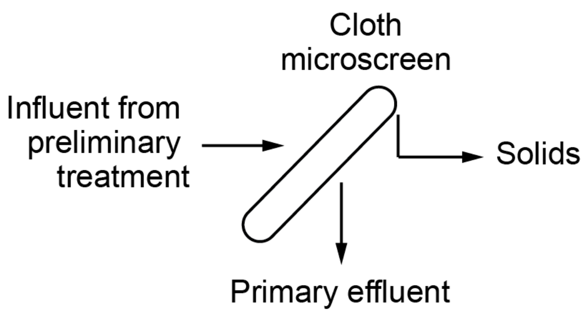
Source: *Wastewater Engineering,* 5th ed, McGraw-Hill, 2014

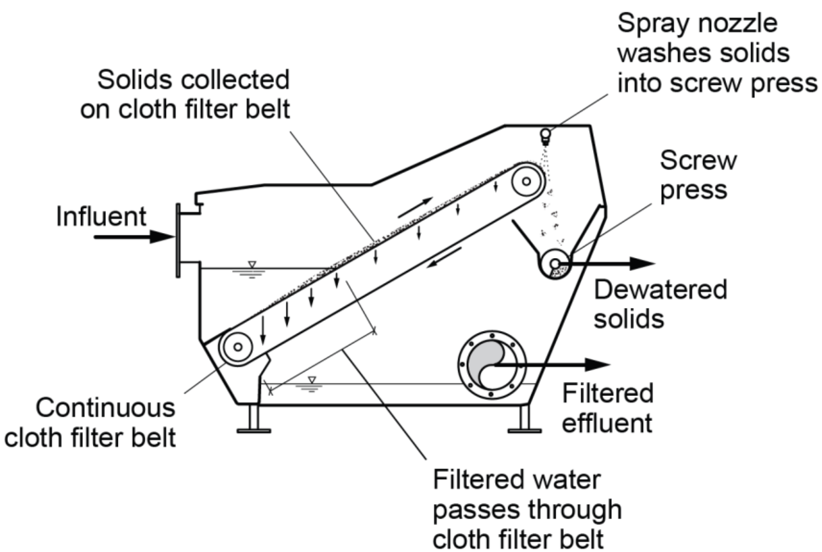
MULTI-TRAY GRIT SEPARATOR
FOR ENHANCED GRIT REMOVAL

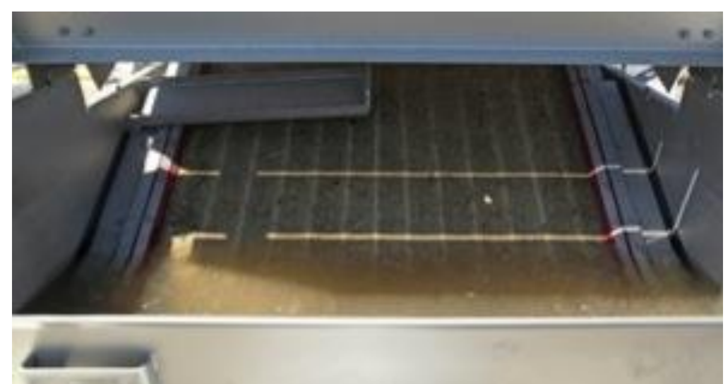


Source: *Wastewater Engineering,* 5th ed, McGraw-Hill, 2014

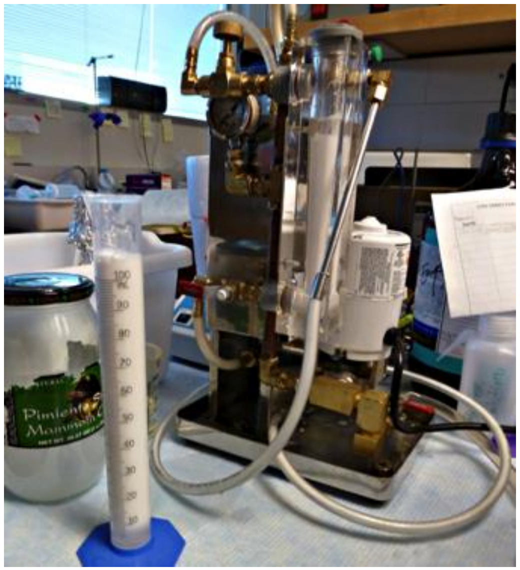
ALTERNATIVE TECHNOLOGIES FOR ENHANCED PRIMARY TREATMENT: CLOTH SCREEN (250-300 MM)

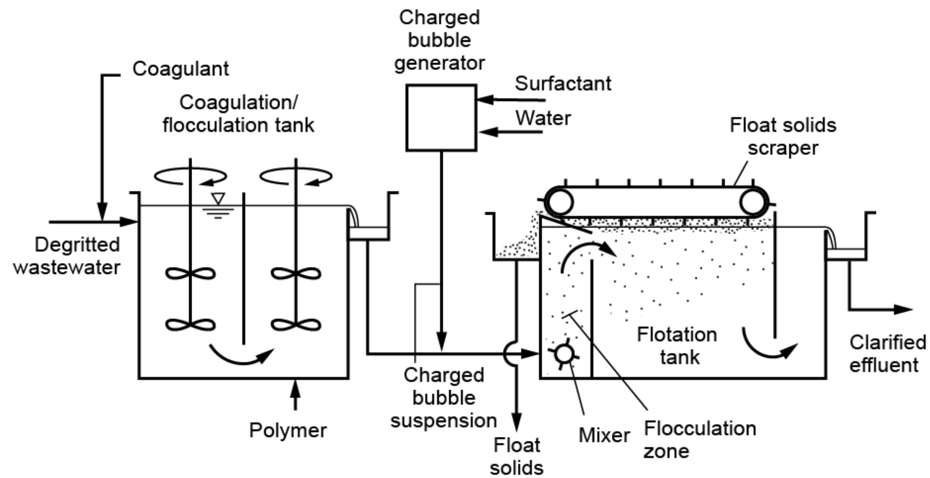






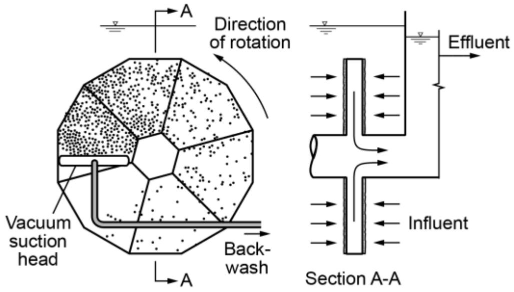
ALTERNATIVE TECHNOLOGIES FOR ENHANCED PRIMARY TREATMENT: CHARGED-BUBBLE FLOTATION

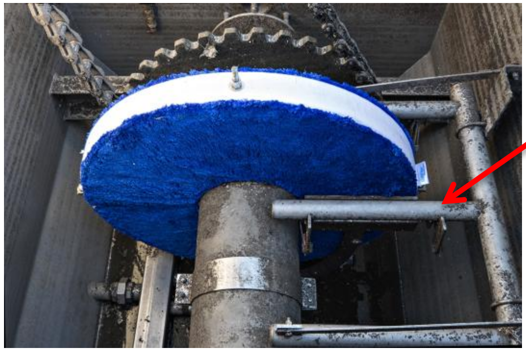




- 1/5th the size of conventional clarifiers
- Nanoparticles can be added to charged-bubble for removal of specific constituents

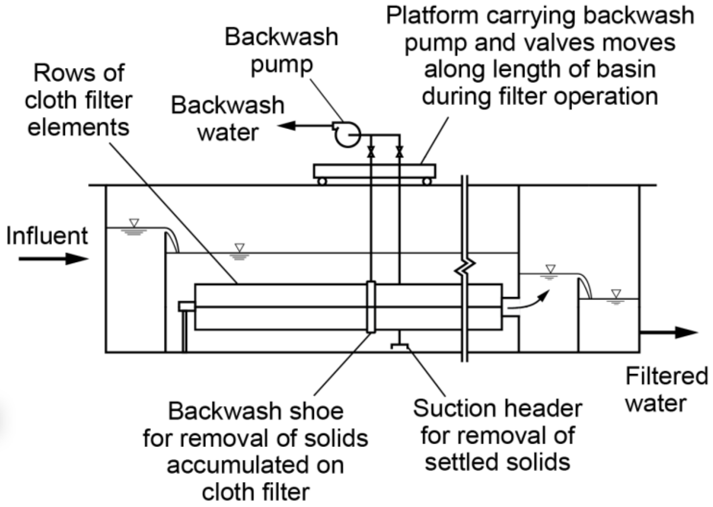
ALTERNATIVE TECHNOLOGIES FOR ENHANCED PRIMARY TREATMENT: CLOTH DISK FILTER (5-10 μm)





Vacuum suction head

Fiber thickness = 0.007 mm
Depth filter L/D = 400 to 800
Cloth filter L/D = 425 to 725



Parameter	Unit	Average influent	Average effluent	Average removal, %
BOD	mg/L	169	59	64.2
COD	mg/L	417	147	62.8
TSS	mg/L	221	26	87.5
VSS	mg/L	116	36	69.0
Turbidity	NTU	143	37	73.5
TKN	mg/L	39	36	7.7
FOG	mg/L	14	10	28.6
UVT	%	28	44	+59.9

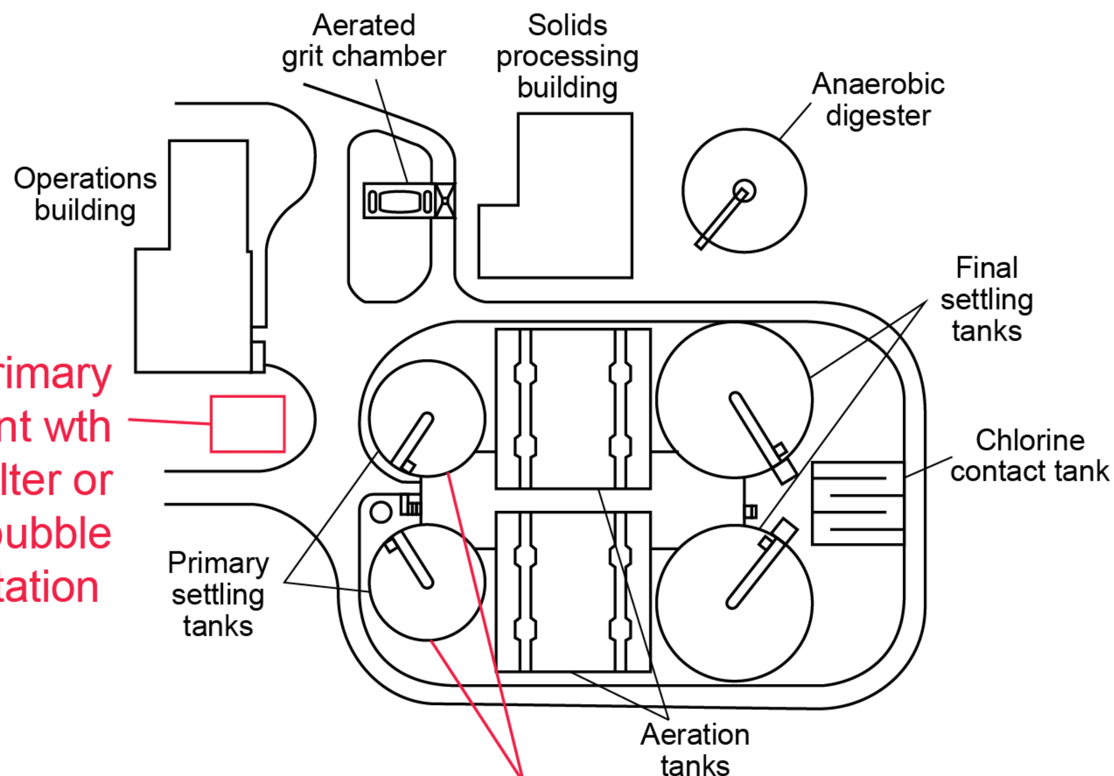
ALTERING THE CHARACTERISTICS OF RAW WASTEWATER FOR ENHANCED DOWNSTREAM TREATMENT

KINETIC COEFFICIENTS BASED ON PARTICLE SIZE

Fraction	Size range, μ	k (base 10), d^{-1}
Settleable	> 100	0.08
Supracolloidal	1-100	0.09
Colloidal	0.1-1.0	0.22
Soluble	< 0.1	0.39

REPLACE AND REPURPOSE EXISTING PRIMARY CLARIFIERS

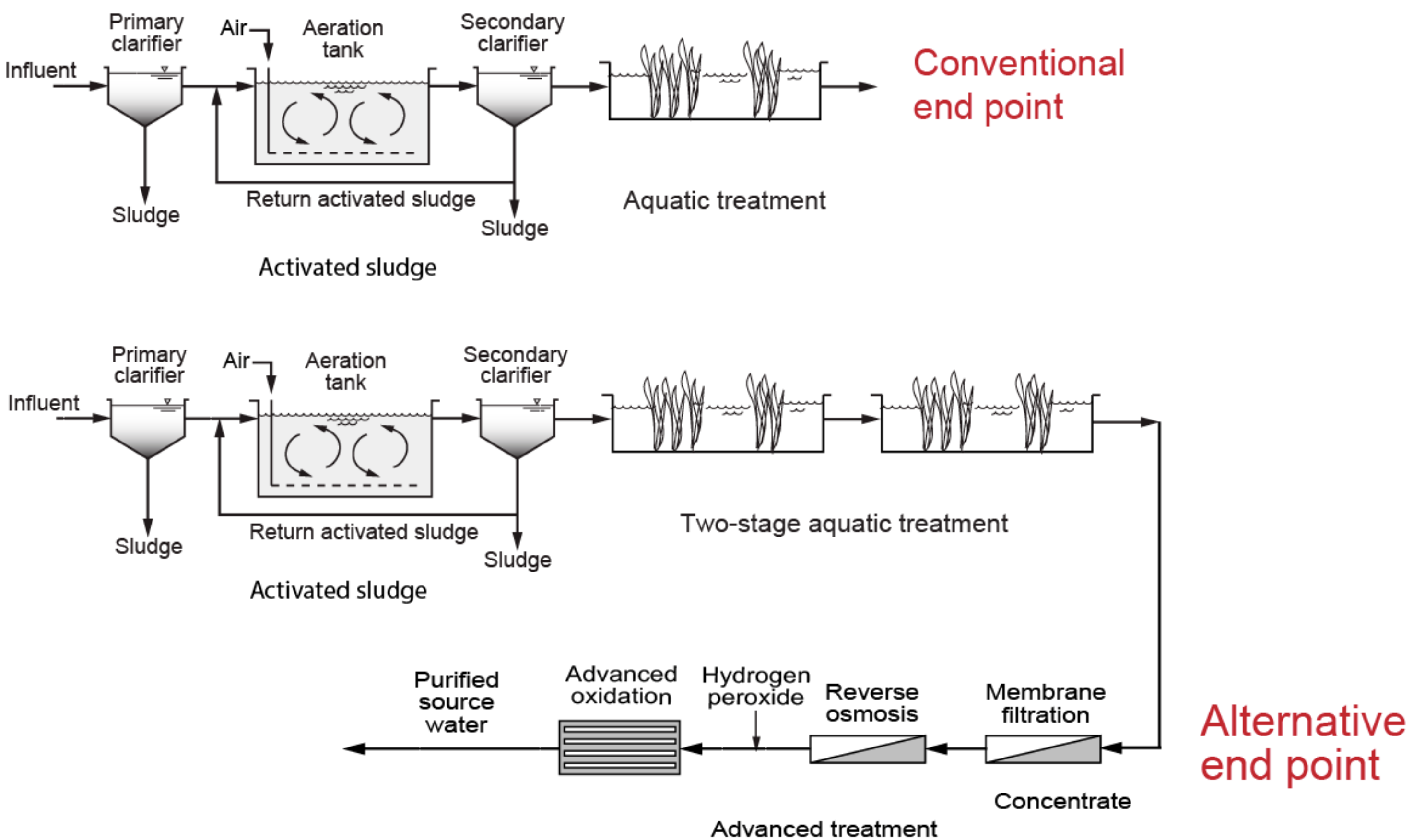
Primary treatment wth cloth disk filter or charged bubble flotation



Primary clarifiers can now be used for influent and/or return flow equalization

IN RESPONSE TO THE PARADIGM SHIFT, WASTEWATER TREATMENT PLANTS ARE BEING DESIGNED FOR ALTERNATIVE END USES

TREATMENT PROCESS DESIGN
FOR ALTERNATIVE END POINT OR POINTS



THE STATUS OF WETLANDS IN WASTEWATER MANAGEMENT

- Both conventional and intensified wetlands have been used for the treatment of a variety of different wastes.
- New design variants are being developed, tested, and implemented continually.
- Although easy to construct, understanding the role of microorganisms and their consortia in wetlands is still in its infancy.
- As experience is gained, wetlands are also being considered as a unit processes.
- In many locations, stringent effluent discharge standards limit the use of conventional wetlands.

Adapted from David Austin, CH2M

THE STATUS OF WETLANDS IN WASTEWATER MANAGEMENT

- **Modeling** of wetland systems is not well developed.
- To enhance their utility, the focus of wetland development is on process **intensification**, with special emphasis on improved wetland nitrification and TN removal.
- Phosphorus intensification is feasible and practical with micro-alum dosing.
- With passive intensification, zero to positive energy wastewater treatment may be possible.

Adapted from David Austin, CH2M

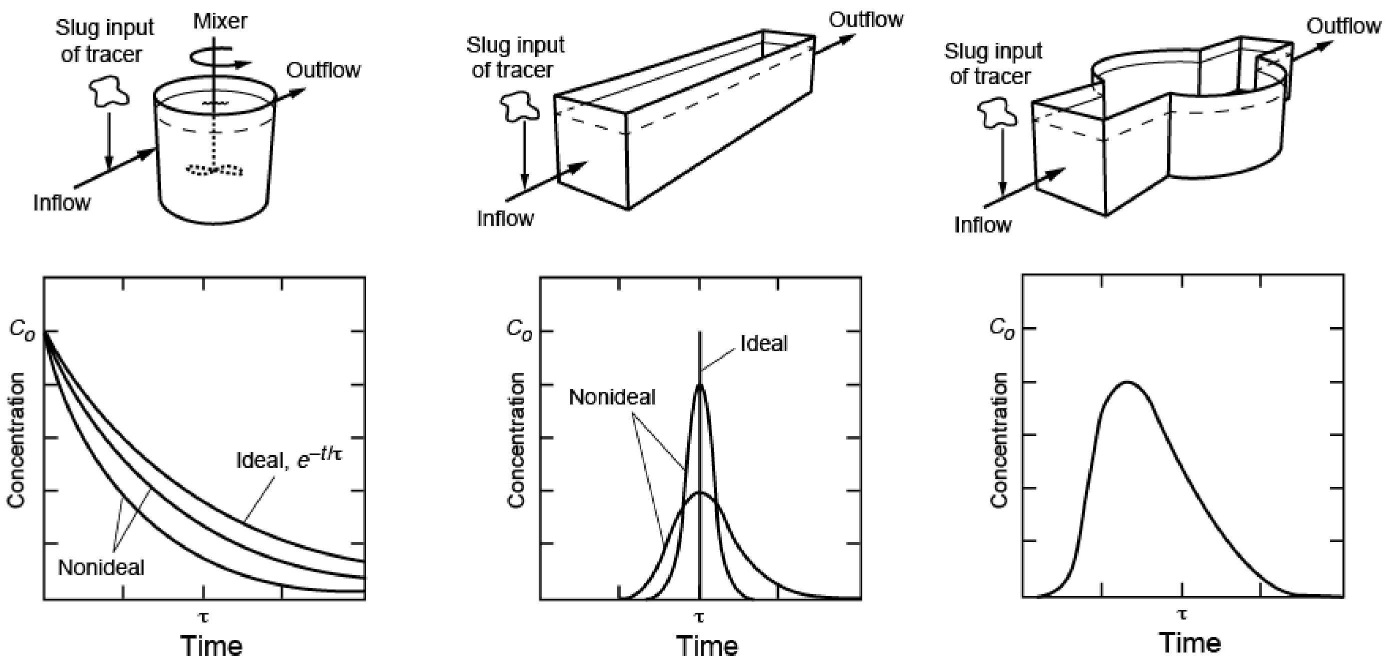
MODELING TREATMENT WETLAND SYSTEMS

- Must consider multiple removal and transformation mechanisms
- Wetland flow patterns
- Effect of particle size distribution
- Effect of sampling location
- Impact of short circuiting

PRINCIPAL REMOVAL AND/OR TRANSFORMATION MECHANISMS OCCURRING IN TREATMENT WETLANDS FOR THE CONSTITUENTS OF CONCERN IN WASTEWATER

Constituent	Removal and/or transformation mechanism
Biodegradable organics	Bioconversion by aerobic, facultative, and anaerobic bacteria on plant and debris surfaces of soluble BOD. Adsorption, filtration, and sedimentation of particulate BOD with subsequent bioconversion
Suspended solids	Sedimentation, filtration, adsorption, bioconversion
Nitrogen	Nitrification/denitrification (various pathways), deammonification, plant uptake, adsorption/volatilization
Phosphorus	Sedimentation, plant uptake, charge neutralization, chemical precipitation (induced with binding agents or naturally in hard water, high pH environment)
Heavy metals	Adsorption of plant and debris surfaces, sedimentation, chemical precipitation in sulfidic minerals
Trace organics	Volatilization, adsorption, UV irradiation, biodegradation (various biological pathways)
Pathogens	Natural decay, predation, UV irradiation, sedimentation, excretion of antibiotics from roots of plants

WETLAND FLOW PATTERNS



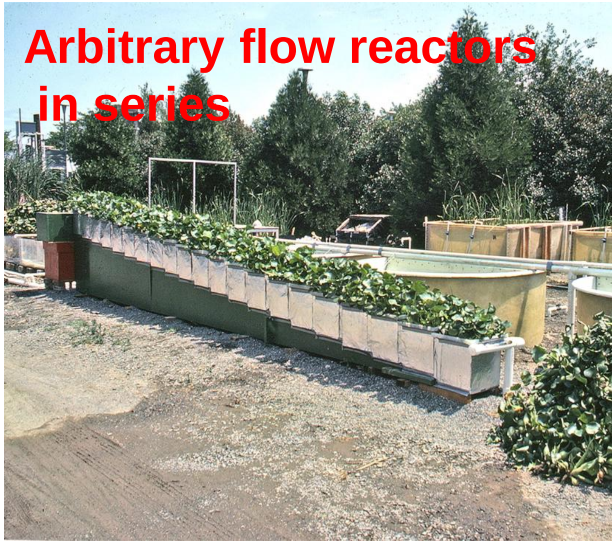
Complete mix

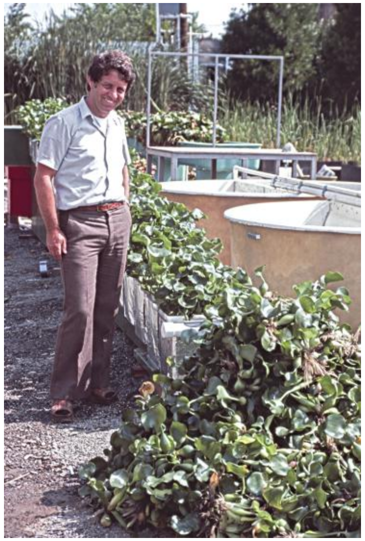
Plug flow

Arbitrary flow

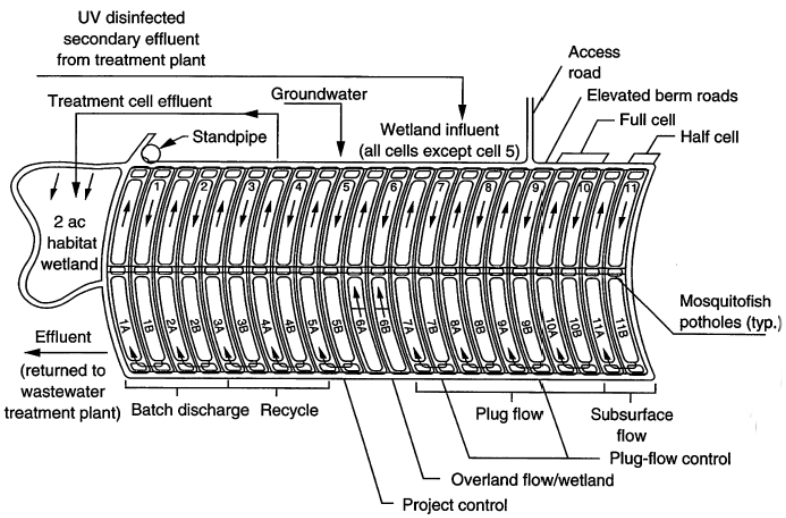
FLOW PATTERNS IN TREATMENT WETLANDS

FLOW PATTERNS IN TREATMENT WETLANDS





FLOW PATTERNS IN TREATMENT WETLANDS

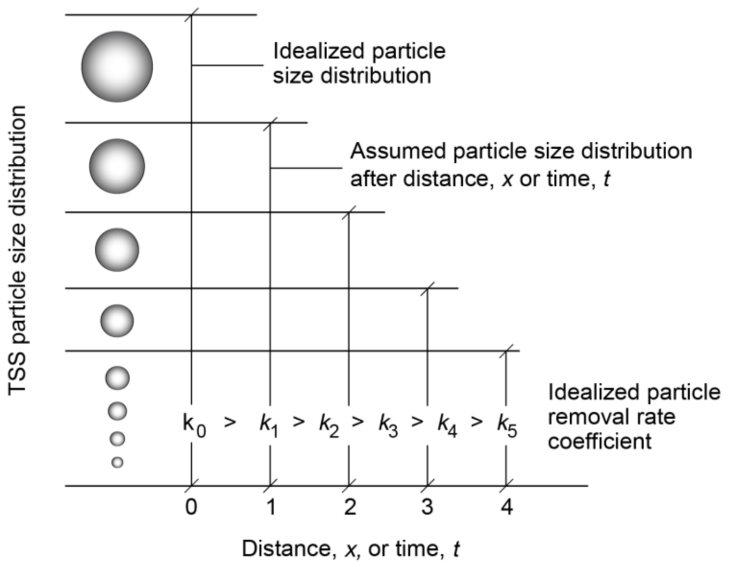


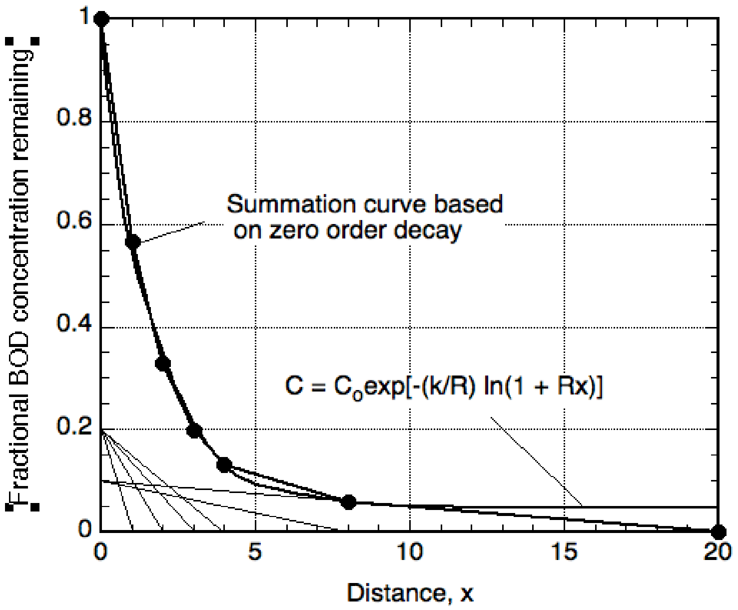

Preparing for planting

Arbitrary flow


After six months

REMOVAL OF PARTICLATE MATTER AND BOD IN WASTEWATER IN WETLAND





REMOVAL RATE COEFFICIENT CANNOT BE CONSTANT!

MODELING TSS AND BOD REMOVAL

- Removal rate coefficient cannot be constant
- A retarded rate coefficient must be used. For example**:**

$$k_{apparent} = \frac{k_{o\,(apparent)}}{(1 + R_x x)^n} = \frac{k_{o\,(apparent)}}{(1 + R_t t)^n}$$

$$C = C_o \exp\left[-\frac{k}{R}\ln(1+Rt)\right] \quad (\text{for } n = 1)$$

$$C = C_o \exp\left[-\frac{k}{R(n-1)}\left(1 - \frac{1}{(1+Rt)^{n-1}}\right)\right] \quad (\text{for } n \neq 1)$$

VOLUME VERSUS AREA BASED COEFFIEICENTS

$r_{BOD} = - k_v(BOD)^n$

k_v = volume based rate coefficient, 1/T

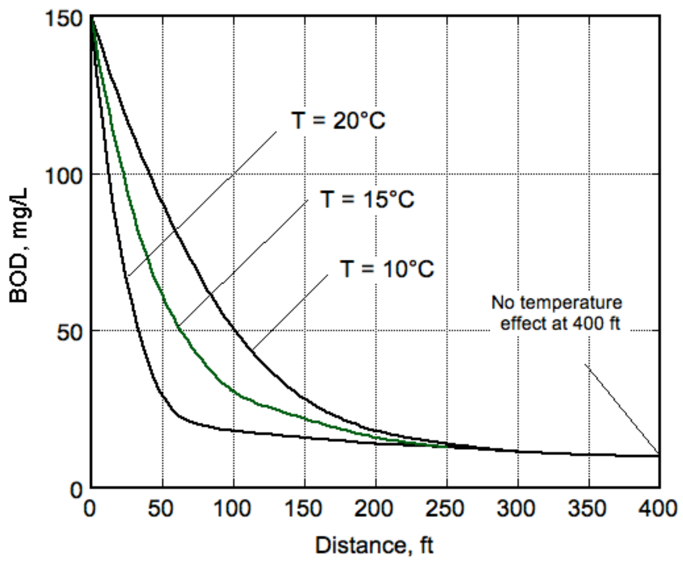
$r_{BOD} = - k_A(A/V)(BOD)^n = - (k_A/H)(BOD)^n$

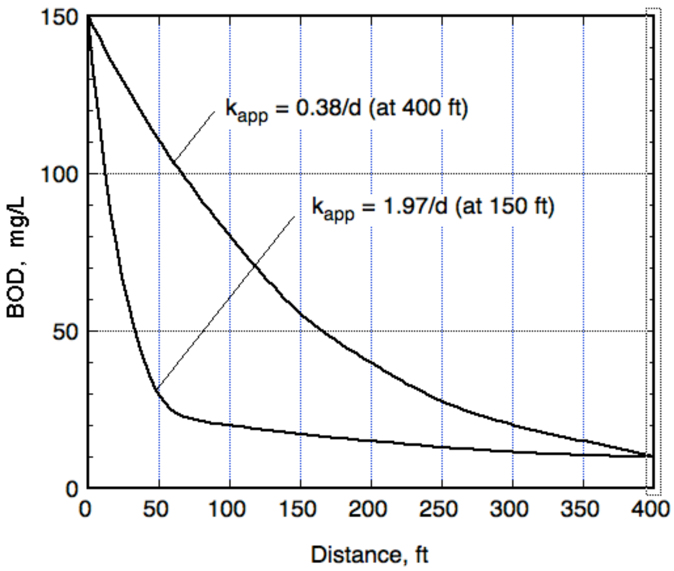
k_A = area based rate coefficient, L/T

A = surface area, L^2

V = volume, L^3

EFFECT OF SAMPLING LOCATION





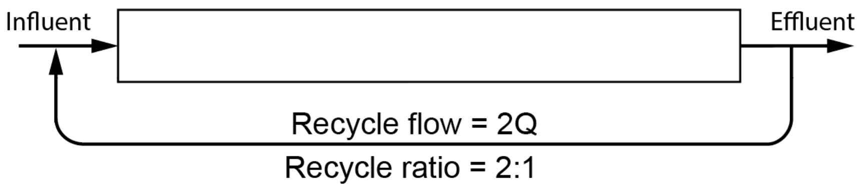
IMPACT OF SHORT CIRCUTING

- Measured removal rate coefficients are *apparent* removal rate coefficients
- Most plug-flow wetlands can be modeled as a series of complete-mix reactors

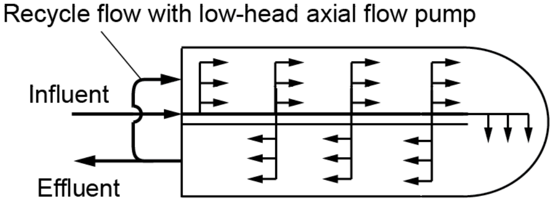
INTENSIFICATION OF WETLAND TREATMENT

- Surface flow wetland with step-feed and recycle flow in linear or wrap around design
- Surface flow wetland with step-feed, aeration, and recycle flow
- Surface flow wetland with side-stream pure oxygen aeration
- Horizontal sub-surface flow aerated wetland
- Horizontal sub-surface flow anoxic wetland
- Tidal flow (fill and draw) reciprocating flow wetland
- Single pass high ammonia exchange capacity
- Surface flow with side-stream zeolite anammox treatment

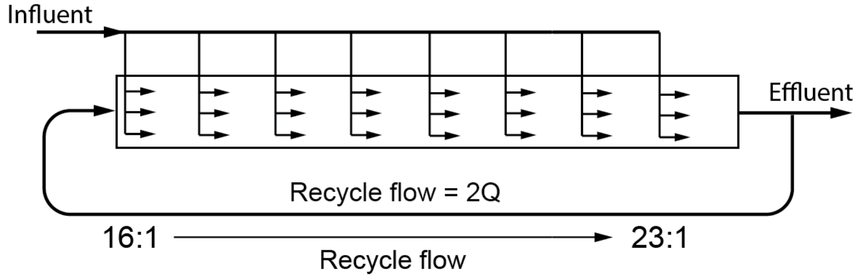
INTENSIFICATION WITH STEP-FEED AND LOW-HEAD RECYCLE



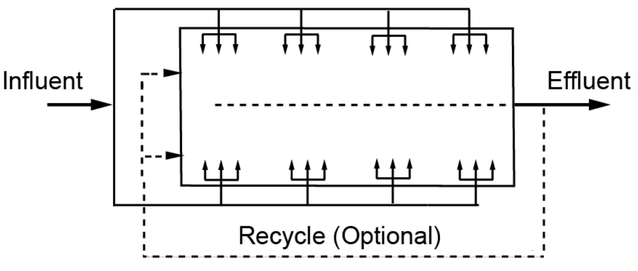
Plug-flow reactor with recycle



Wrap around step-feed plug-flow reactor with low-head recycle

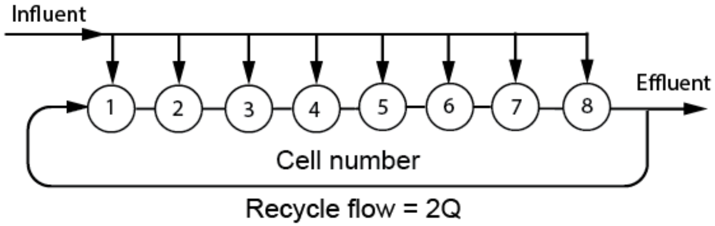


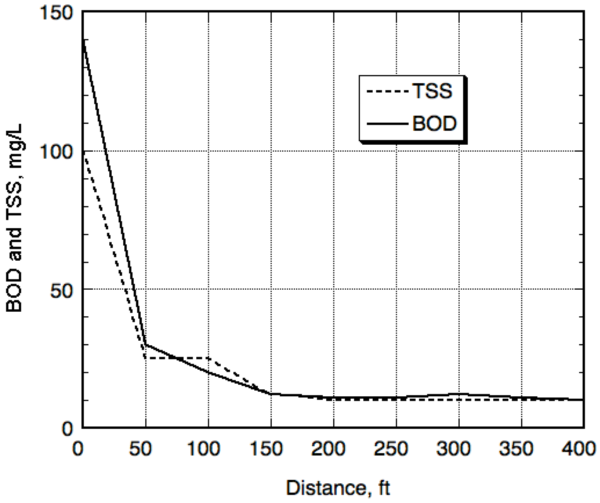
Step-feed plug-flow reactor with recycle



Periferal feed with center drawoff with optional recycling

SURFACE FLOW WETLAND WITH STEP-FEED, AERATION, AND RECYCLE FLOW

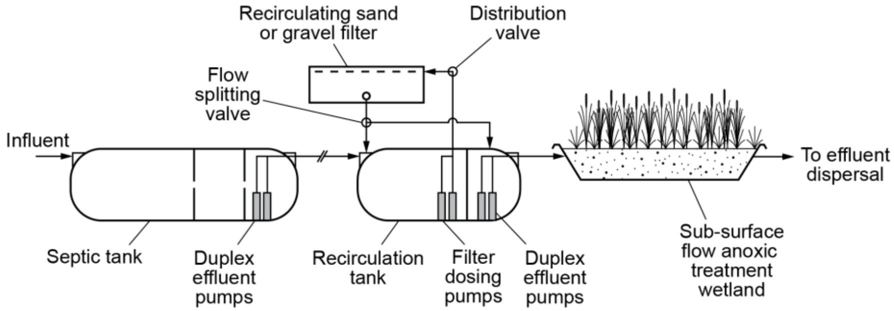




TYPICAL HORIZONTAL SUB-SURFACE FLOW AERATED WETLAND

Courtesy David Austin, CH2M

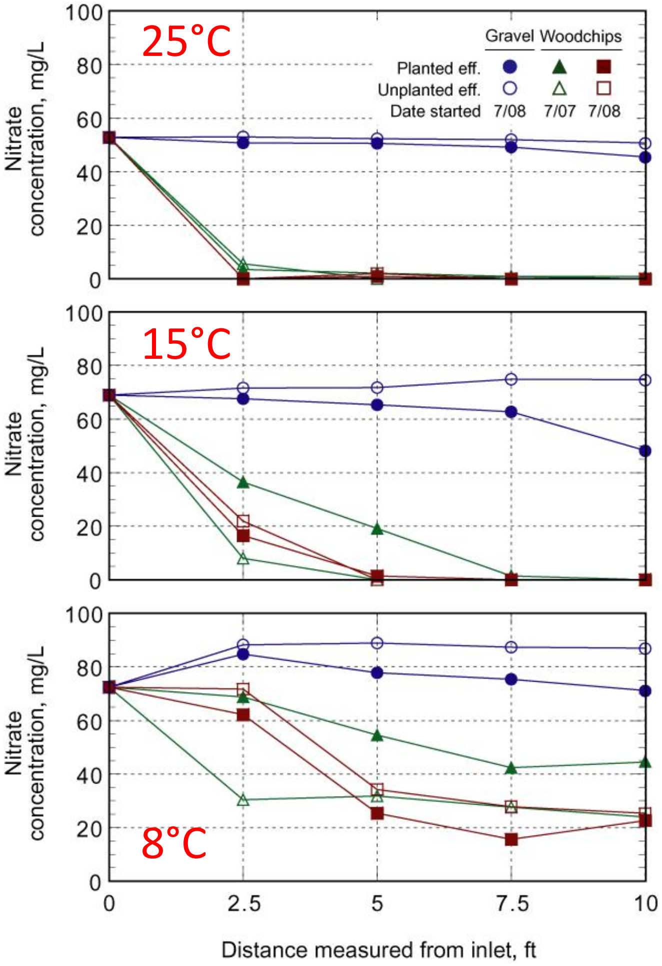
HORIZONTAL SUB-SURFACE FLOW ANOXIC WETLAND FOR NITROGEN REMOVAL



(a)

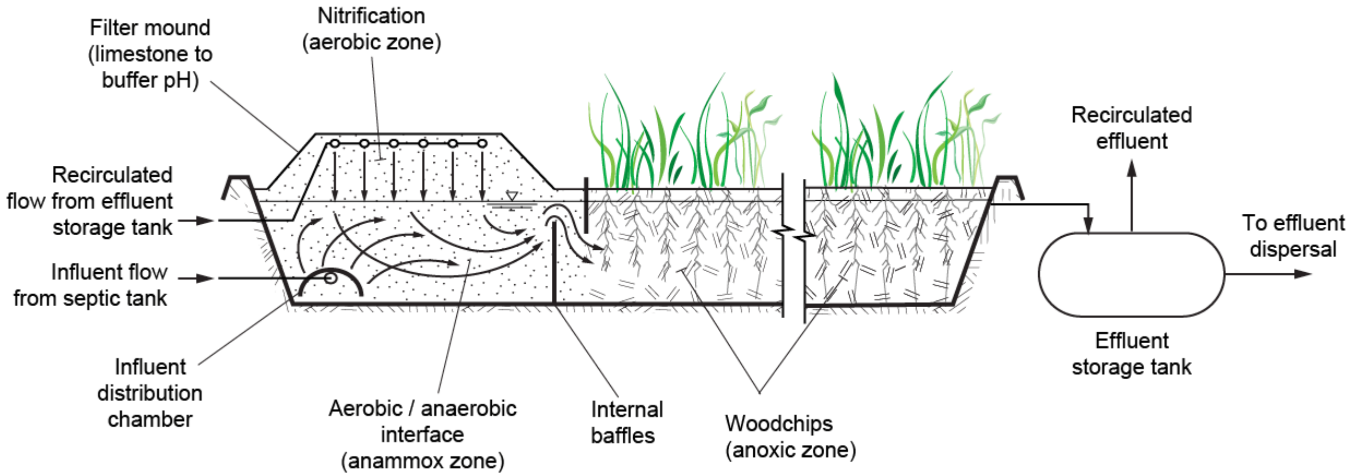
(b)

(c)



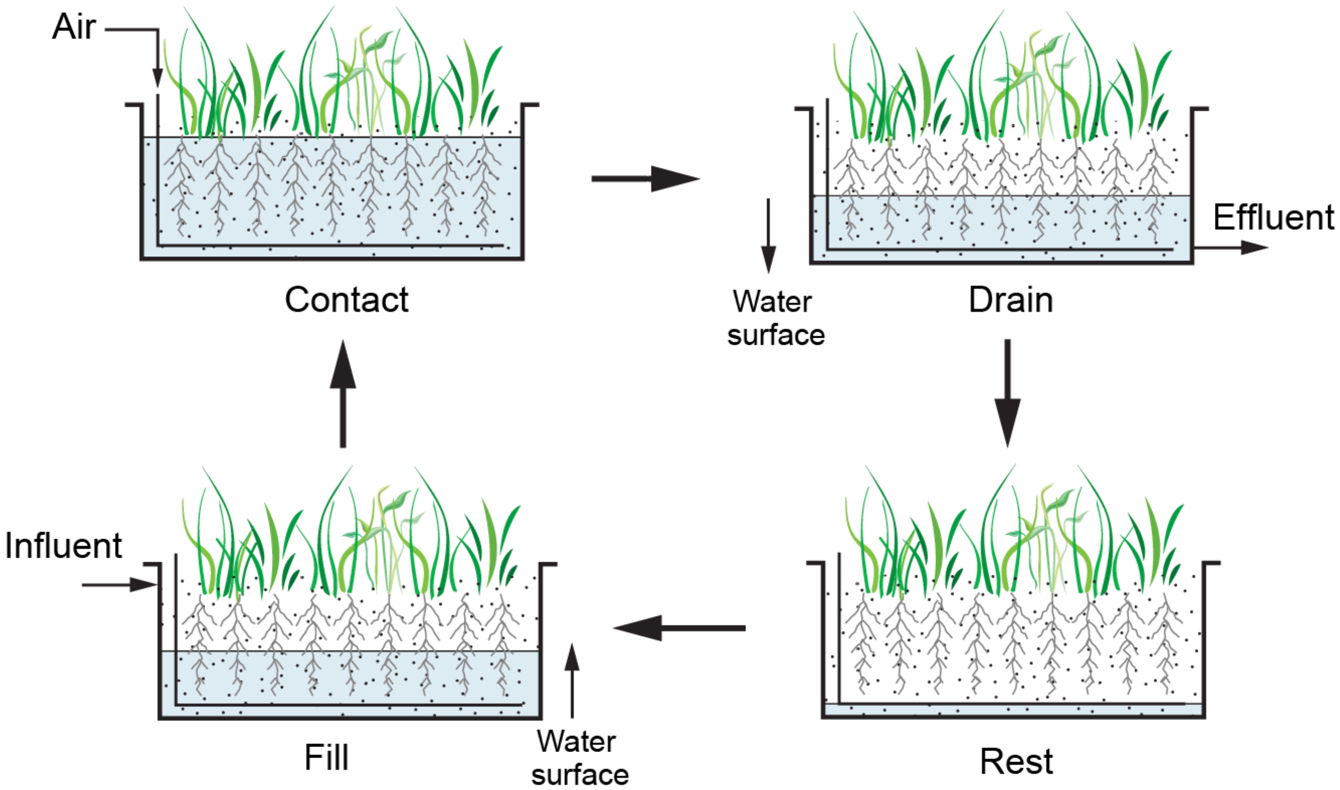
Courtesy Harold Leverenz

HORIZONTAL SUB-SURFACE FLOW ANOXIC WETLAND FOR NITROGEN REMOVAL

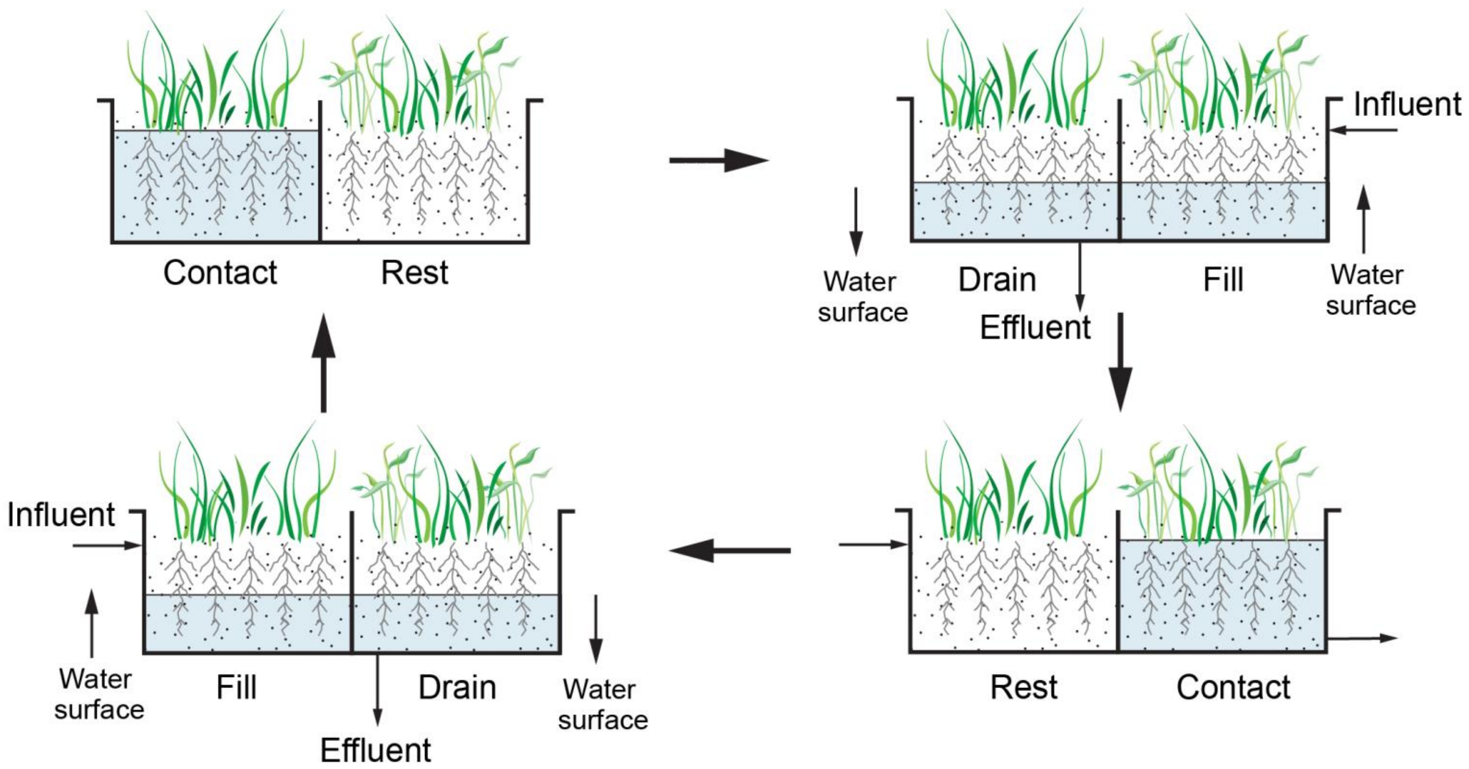


Courtesy Harold Leverenz

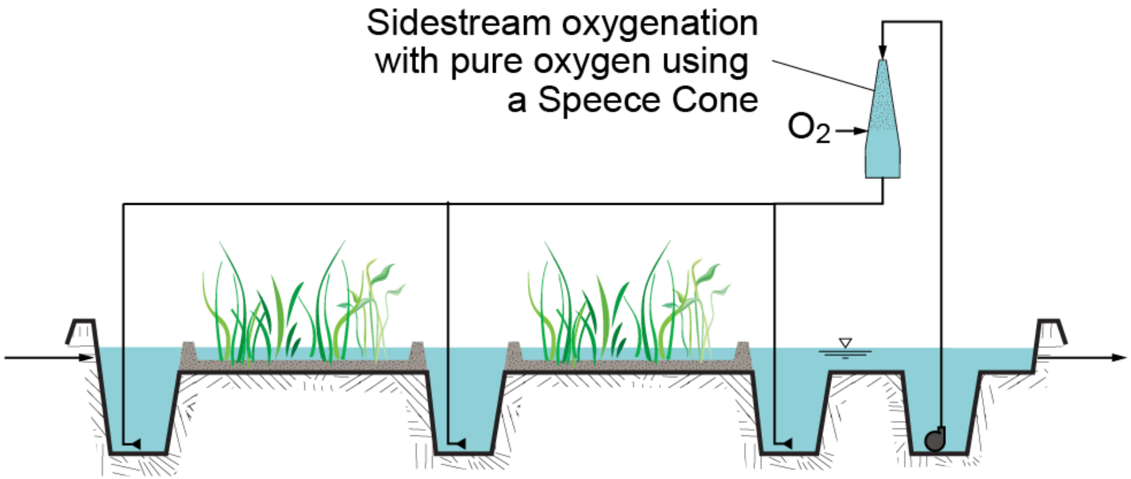
FILL AND DRAIN (TIDAL) WETLAND WITHOUT OR WITH AERATION



RECIPROCATING FILL AND DRAIN (TIDAL) WETLAND WITHOUT OR WITH AERATION AND ADSORPTIVE MEDIUM



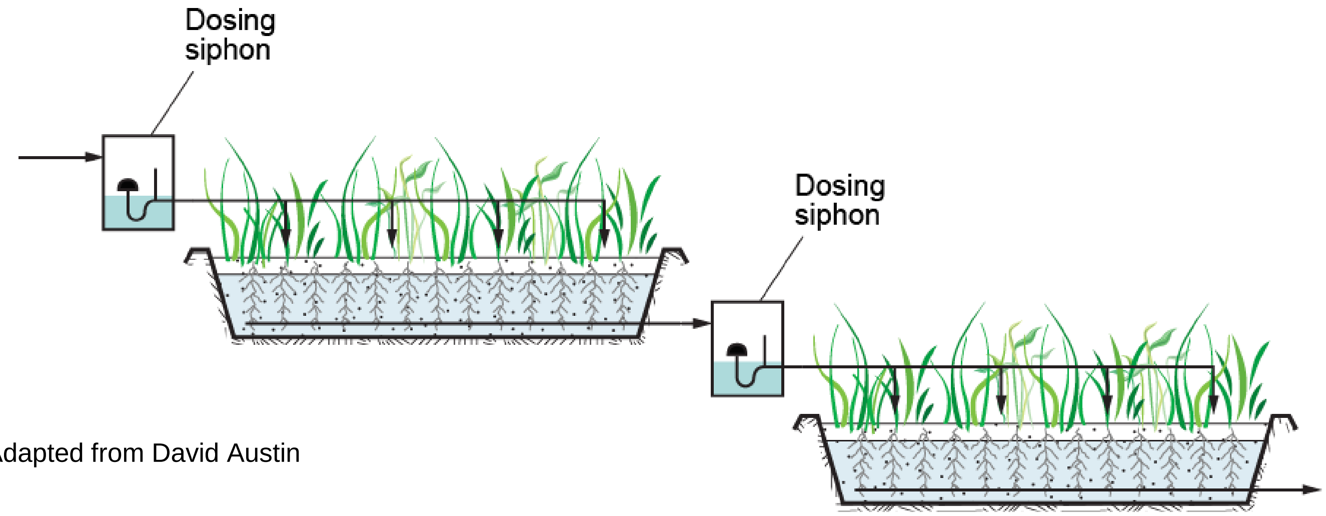
SURFACE FLOW WETLAND WITH SIDESTREAM OXYGENATION FOR NITRIFICATION



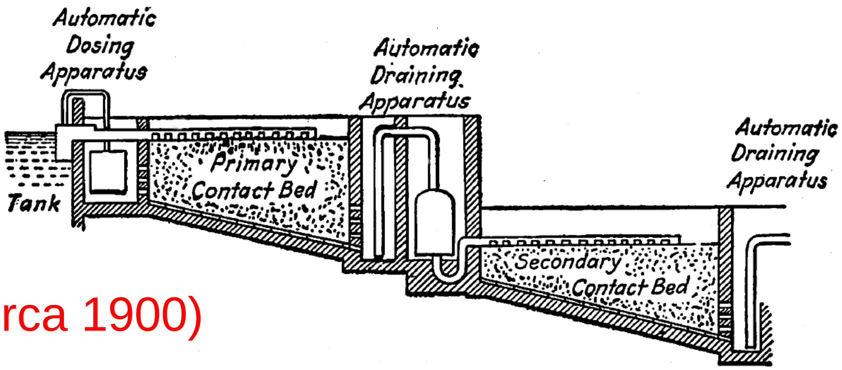
Dick Speece

Adapted from David Austin

TWO-STAGE FILL AND DRAIN (TIDAL) WETLAND WITH ADSORPTIVE MEDIM



Adapted from David Austin



(Circa 1900)

FIG. 115.—Arrangement of double contact beds.

SOME THOUGHTS ON WETLAND MODELING, INTENSIFICATION, AND UNKNOWNS

- While simple in concept, wetlands are complex from a process modeling standpoint.
- The intensification of wetlands will continue in response to more restrictive discharge requirements, land area constraints, and the need to reuse water
- Much remains to be known about the use of constructed wetlands for water quality improvement:

A CHALLENGE FOR ALLOF US!

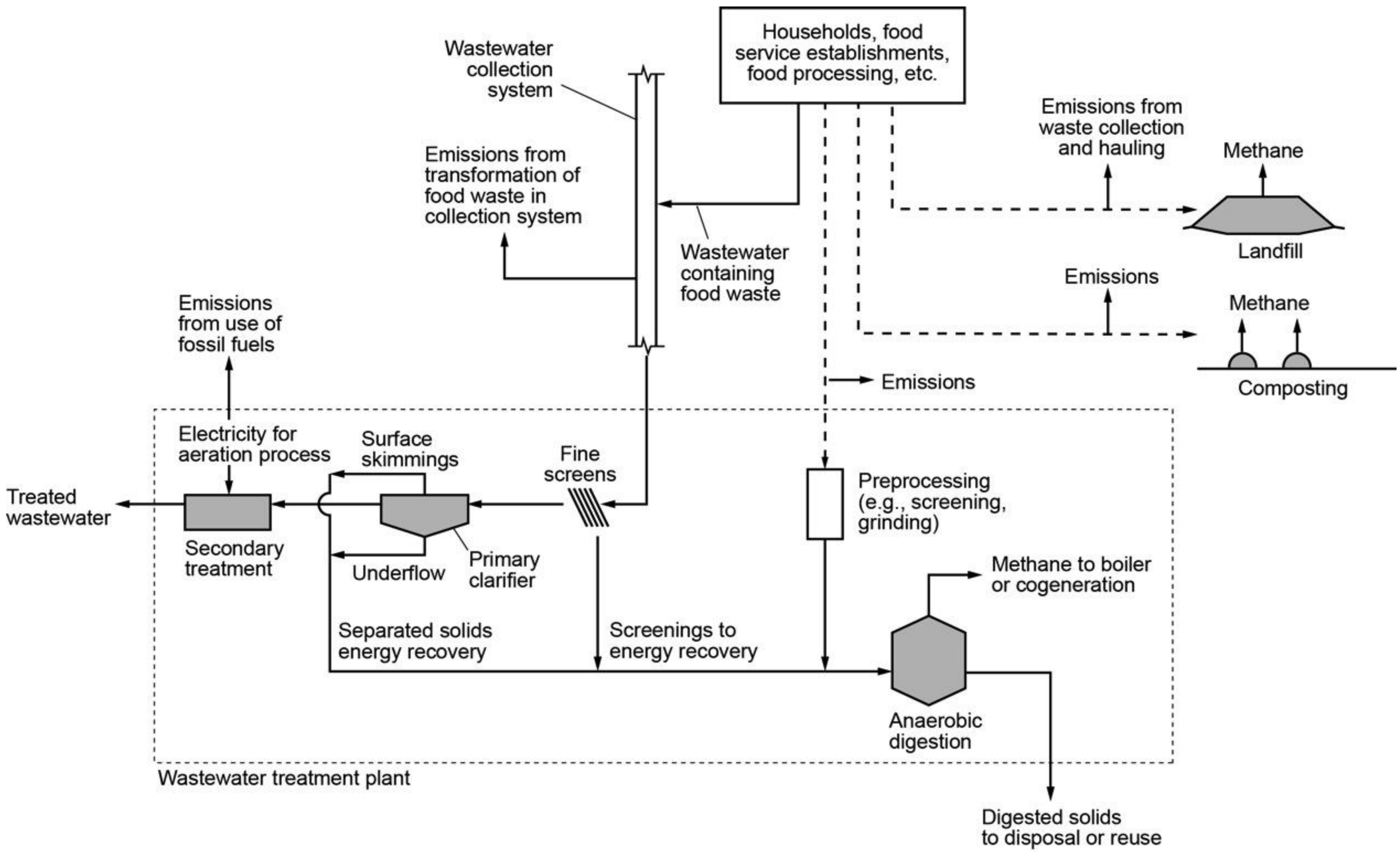
CLOSING THOUGHT: A REMINDER

WASTEWATER is a RENEWABLE RECOVERABLE SOURCE of POTABLE WATER, RESOURCES, and ENERGY

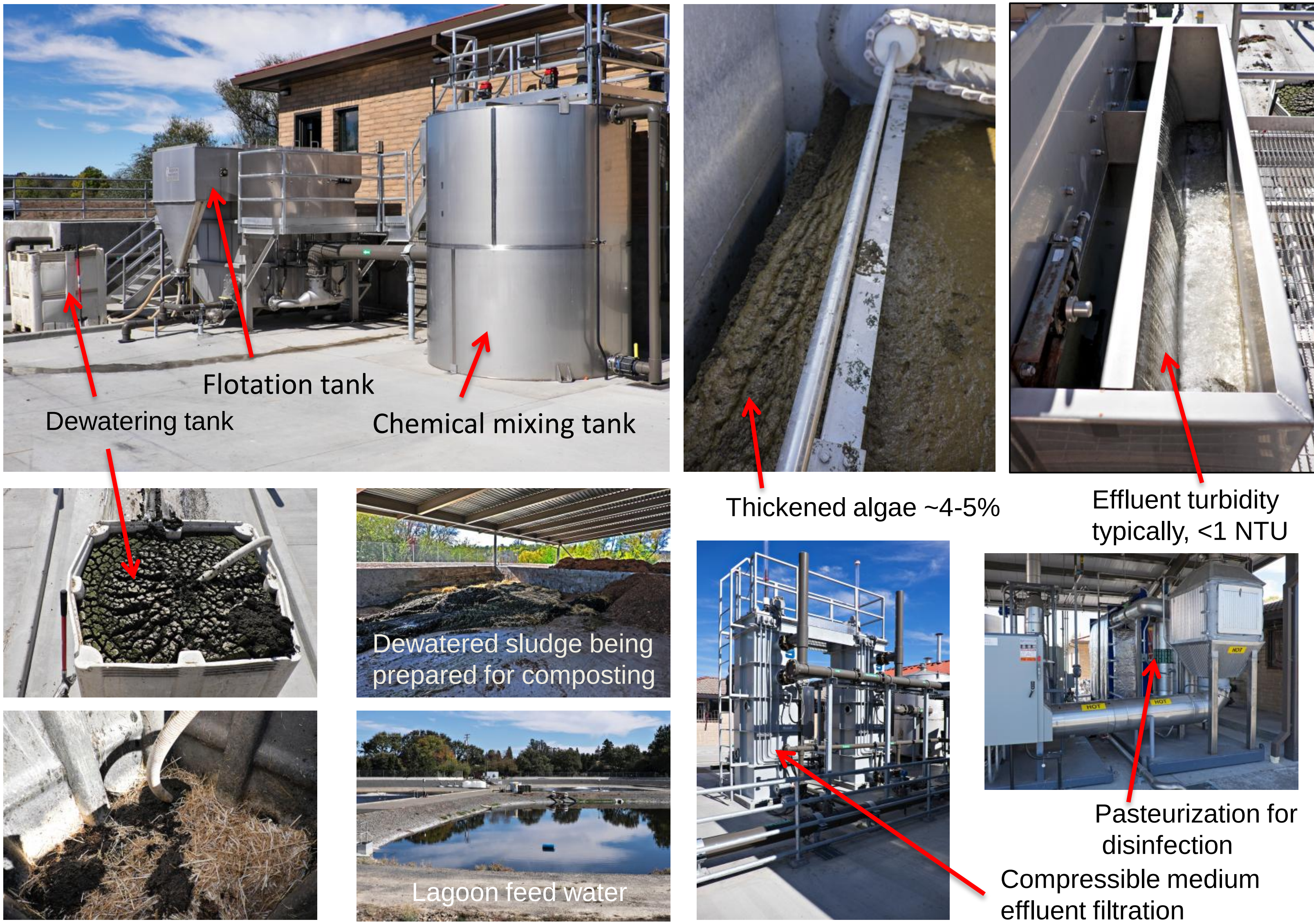
THANK YOU

FOR LISTENING

FOOD WASTE MANAGEMENT OPTIONS



CHARGED BUBBLE FLOTATION FOR ALGAL POND EFFLUENT REUSE



Algae dewatered on straw bed