Decentralized Wastewater Treatment Systems:

Processes, Design, Management, and Use

Webinar Series Sponsored by the Conservation Technology Information Center, US EPA, and Tetra Tech

Session 3

Decentralized Wastewater System Design: Part 2

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Decentralized Wastewater Design

- Part 1 – Design Fundamentals
  - Planning and Design Basis
  - Wastewater Characterization
  - Preliminary/Primary Treatment
  - Soil-based Treatment
  - Soil Dispersal Systems
  - Distribution Design for Soil Dispersal

Decentralized Wastewater Design

- Part 2 – Advanced Design Topics
  - – Pumping Systems
  - – Clustered Collection and Treatment
  - – Advanced Treatment
  - – Other Topics
    - Repairs, Expansions, and Retrofits
    - Construction Management and Supervision
    - Operation and Maintenance

Pumping Systems

Types of Pumps

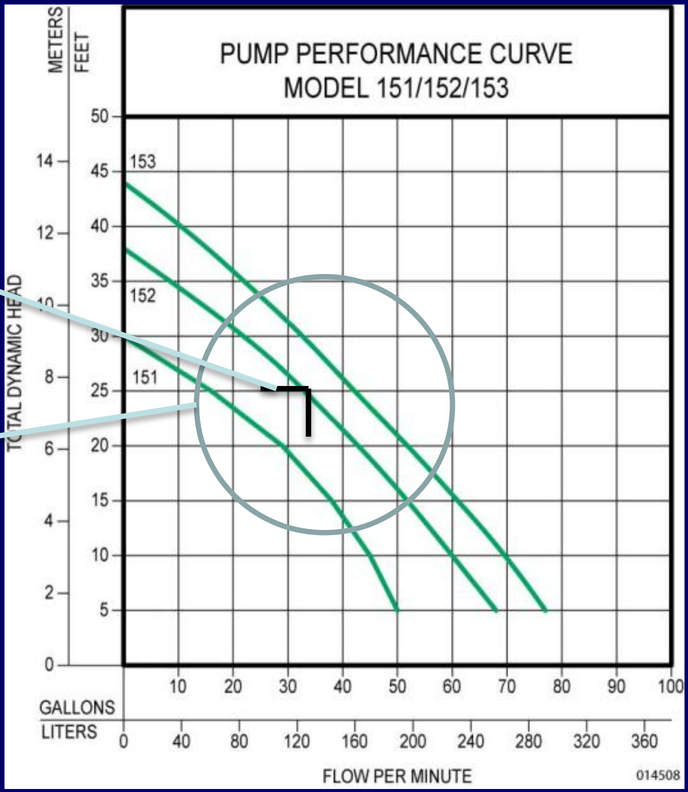
- By application
  - Effluent
  - Solids handling
  - Grinder
- By pump design
  - Centrifugal
  - Submersible
  - Multi-stage/high head
  - Positive displacement

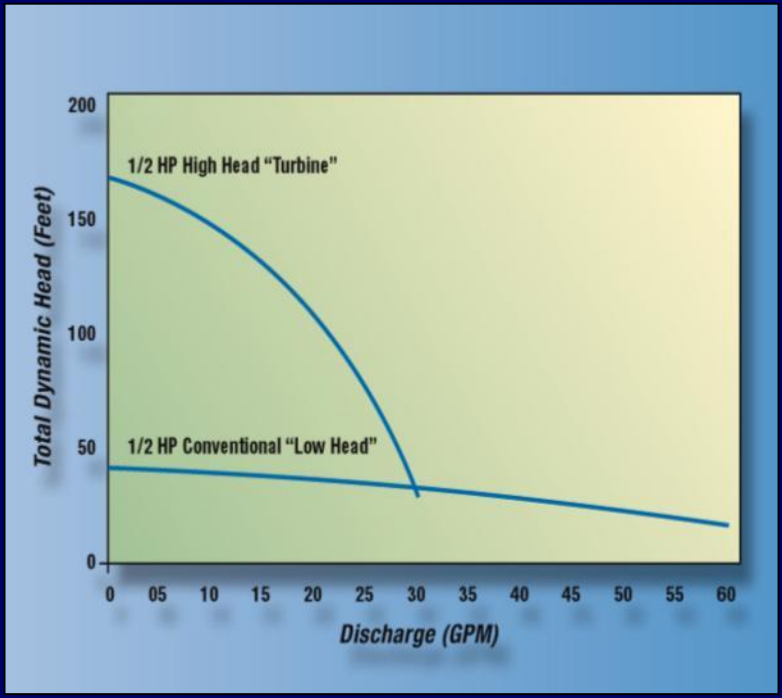
Reading a Pump Curve

- Flow (gpm) versus Total Dynamic Head (feet)
- The pump WILL operate at a point on its curve
- Efficiency typically highest in the shoulder of the curve
- In parallel, flow is additive; in series, TDH is additive

Potential operating point (33 gpm @ 25' TDH)

sweet spot





Calculating Pump Requirements

- **Flow** dictated by distribution system or conveyance demands
- **Total Dynamic Head** (TDH) = PH + SH + FH
  - PH = pressure head at endpoint (e.g., at distribution system)
  - SH = static head (or elevation head) = high point elevation – pump off elevation
  - FH = friction head or headloss = major + minor losses

Friction Head

- Calculate using Darcy equation:

$$h_f = \frac{fLv^2}{2Dg}$$

(Calculation of *f* depends on Reynolds number)

- Or, Hazen-Williams equation:

$$h_f = \frac{0.00113LQ^{1.85}}{D^{4.87}}$$

(Assuming C = 140)

  - h_f = head loss (feet)
  - L = pipe length (feet)
  - Q = flow (GPM)
  - D = pipe inside diameter (inches)

Friction Head

- Friction head = major + minor losses
  - Major losses = friction loss in pipe
    - Direct inputs into either equation (Hazen Williams and Darcy)
  - Minor losses = friction loss due to other obstructions
    - Calculate loss coefficient and use in Darcy formula
    - Or, calculate equivalent length and use in either equation

Fitting Type	**1” Pipe**	**2” Pipe**	**4” Pipe**
90º elbow	5.2	8.5	13.0
45º elbow	1.3	2.7	5.5
Tee, flow through	3.2	7.7	17.0
Tee, flow through stem	6.6	12.0	21.0
Globe valve (open)	29.0	54.0	110.0
Gate valve (open)	0.84	1.5	2.5
Swing check valve	11.0	29.0	38.0

Pump Selection for Pressure Distribution

Example

- LPD system with dosing rate of 30 gpm
- Level drainfield is 120’ away and 10’ higher than pump off elevation
- Assume four 90º elbows, one check valve, one gate valve, and one globe valve

Solution

- Use 2” SCH 40 PVC supply line (v = 2.87 fps @ 30 gpm)
- TDH = PH + SH + FH = 3’ + 10’ + FH

$$h_f = \frac{0.00113\,LQ^{1.85}}{D^{4.87}}$$

- Q = 30 gpm
- D = 2.067”
- L = 120 + 4(8.5) + 1(29) + 1(1.5) + 1(54) = 239’
- FH = 4’
- TDH = 3’ + 10’ + 4’ = 17’

Pump Selection for Pressure Distribution

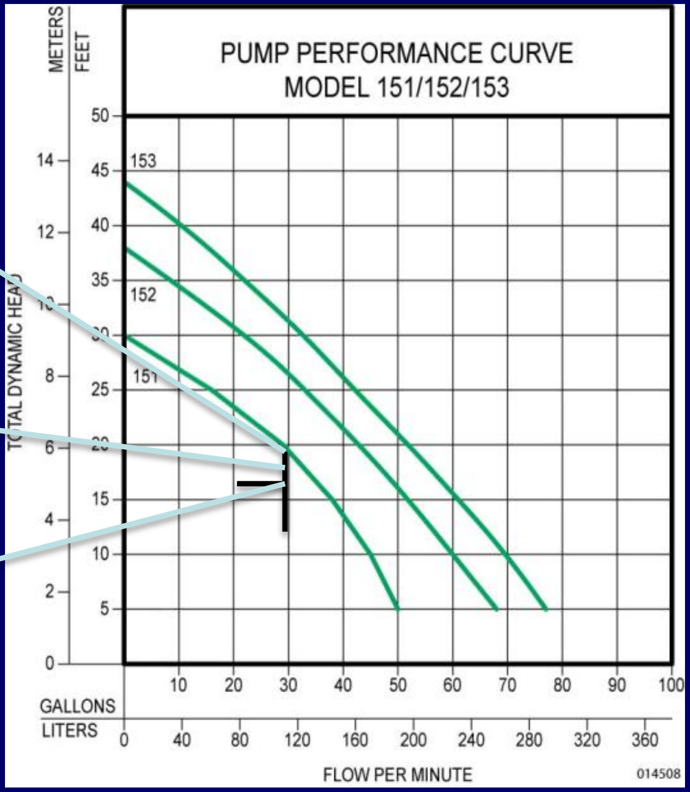
<u>Solution</u>

- 30 gpm @ 17’ TDH

Operating point (30 gpm @ 20’ TDH)

3’ FH induced by pressure control valve

Design requirement (30 gpm @ 17’ TDH)



Determining Operating Point

Example - pumping to a storage tank

- A tank at point B is 120' away from and 10' above the pump at Point A
- Points A and B are connected by a 2" SCH 40 PVC pipe
- Fittings include four elbows, one check valve, one ball valve, and one gate valve

Solution

- Calculate TDH for a range of flow rates
- TDH = PH + SH + FH = 0' + 10' + FH

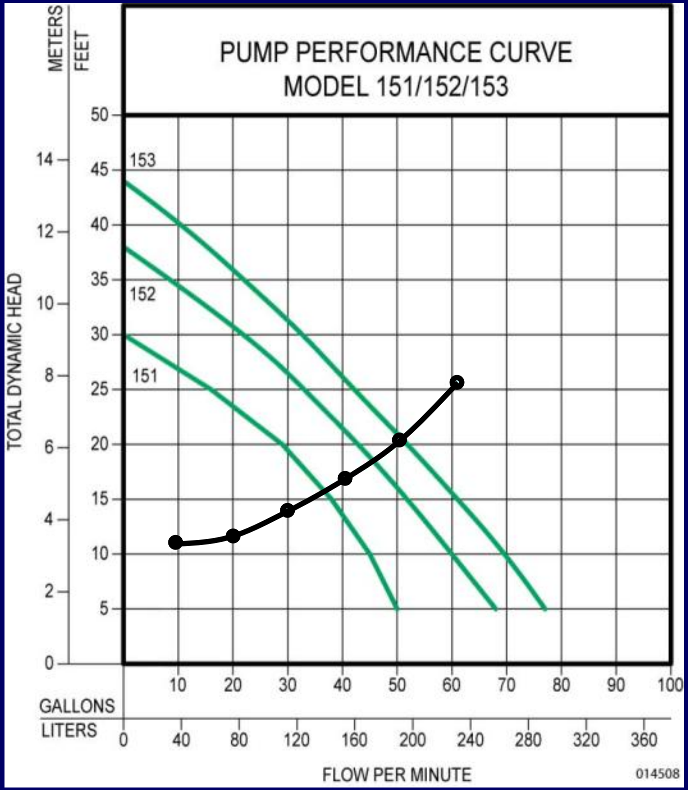
$$h_f = \frac{0.00113\, LQ^{1.85}}{D^{4.87}}$$

- D = 2.067"
- L = 120 + 4(8.5) + 1(29) + 1(1.5) + 1(54) = 239'
- FH = $0.0079Q^{1.85}$

Flow, Q	FH	TDH
10 gpm	0.56'	10.6'
20 gpm	2.0'	12.0'
30 gpm	4.3'	14.3'
40 gpm	7.3'	17.3'
50 gpm	11.0'	21.0'
60 gpm	15.4'	25.4'

Determining Operating Point

Flow, Q	FH	TDH
10 gpm	0.56’	10.6’
20 gpm	2.0’	12.0’
30 gpm	4.3’	14.3’
40 gpm	7.3’	17.3’
50 gpm	11.0’	21.0’
60 gpm	15.4’	25.4’

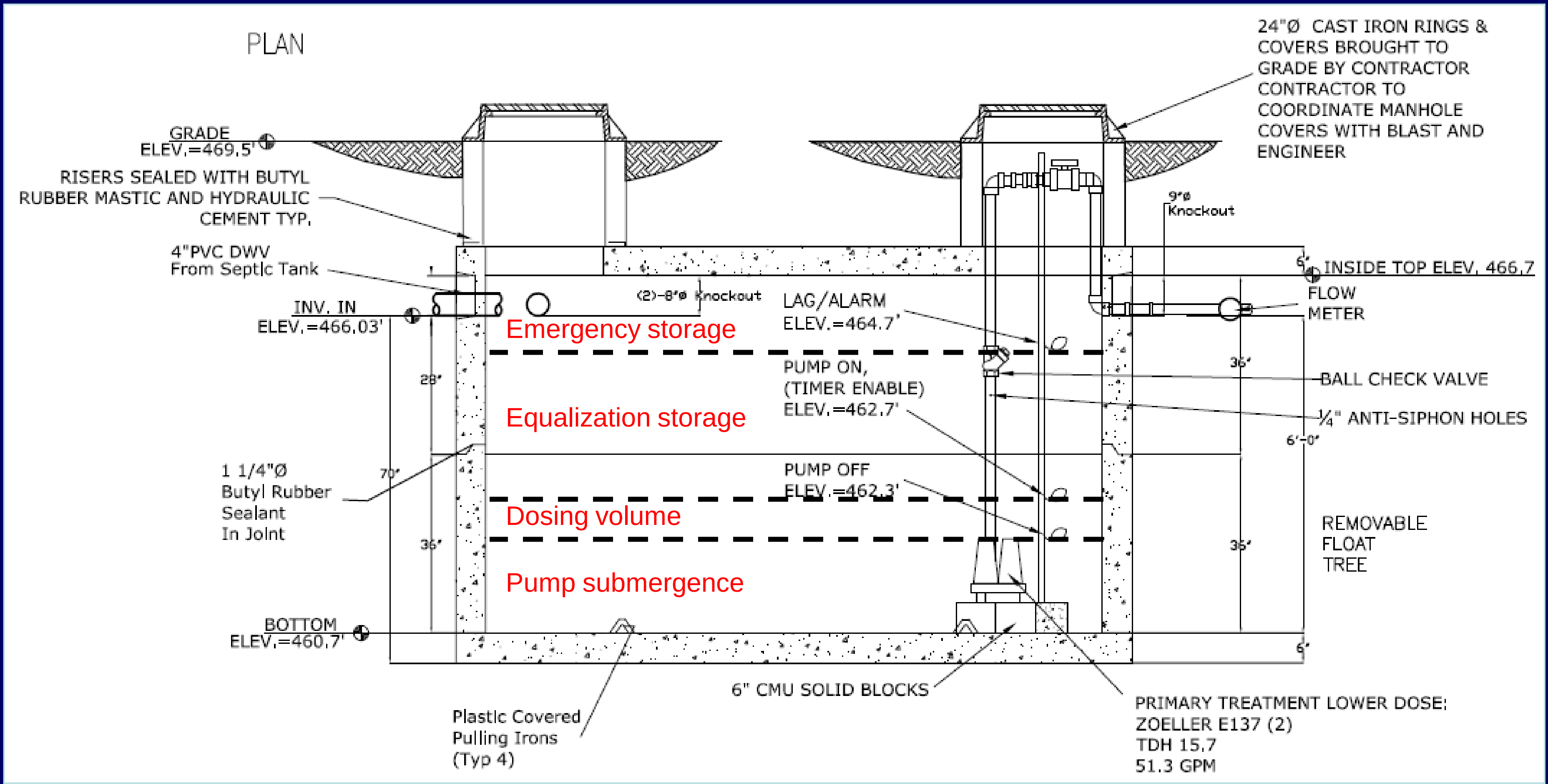


Pump Tanks

- Sizing
  - Pump submergence
  - Dosing volume
  - Storage (equalization and emergency)

- Other Design Considerations
  - Pump and float access/removability
  - Position and accessibility of valves, disconnects, and other appurtenances
  - Control systems
  - Watertightness

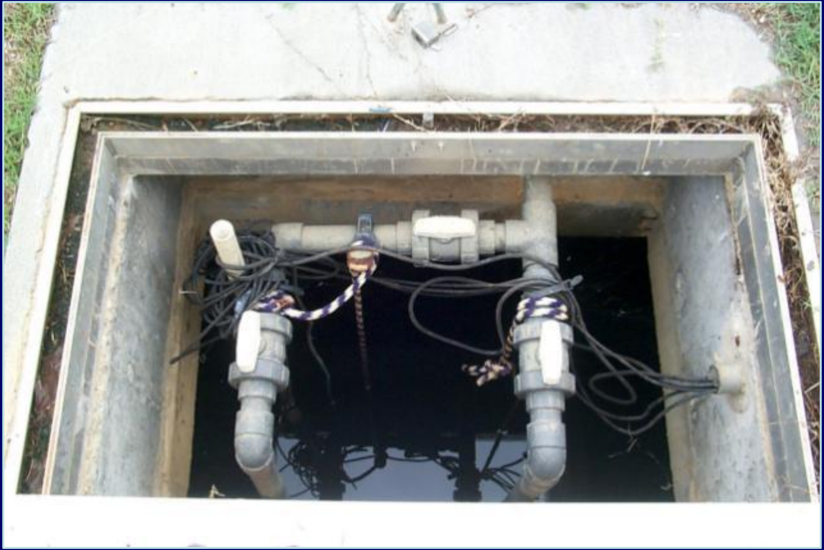
Pump Tanks

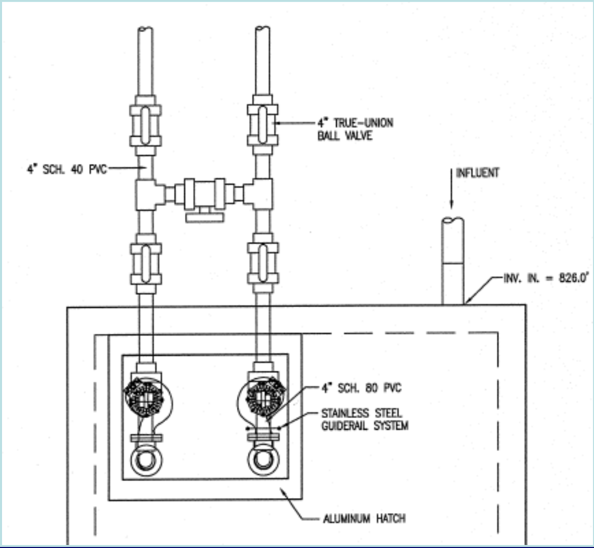


PLAN
24"Ø CAST IRON RINGS & COVERS BROUGHT TO GRADE BY CONTRACTOR
CONTRACTOR TO COORDINATE MANHOLE COVERS WITH BLAST AND ENGINEER
GRADE ELEV.=469.5'
RISERS SEALED WITH BUTYL RUBBER MASTIC AND HYDRAULIC CEMENT TYP.
4"PVC DWV From Septic Tank
INV. IN ELEV.=466.03'
(2)-8"ø Knockout
9"ø Knockout
INSIDE TOP ELEV. 466.7
FLOW METER
LAG/ALARM ELEV.=464.7'
Emergency storage
PUMP ON, (TIMER ENABLE) ELEV.=462.7'
Equalization storage
BALL CHECK VALVE
¼" ANTI-SIPHON HOLES
PUMP OFF ELEV.=462.3'
Dosing volume
Pump submergence
1 1/4"Ø Butyl Rubber Sealant In Joint
REMOVABLE FLOAT TREE
BOTTOM ELEV.=460.7'
6" CMU SOLID BLOCKS
Plastic Covered Pulling Irons (Typ 4)
PRIMARY TREATMENT LOWER DOSE: ZOELLER E137 (2) TDH 15.7 51.3 GPM
28"
70"
36"
6'-0"
6"

Pumping Systems

- Pump tanks





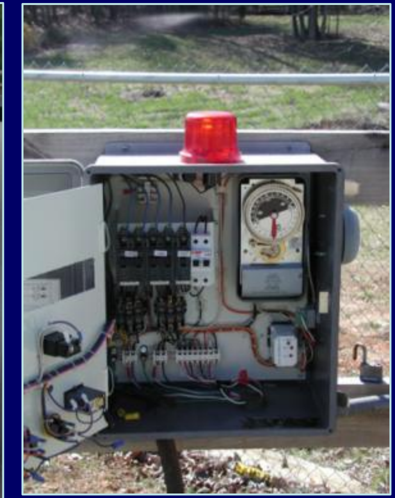
Pumping System Controls

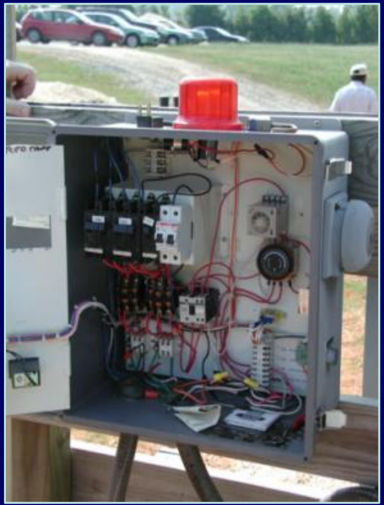
- Simplex, duplex, multiplex
- Demand-based
- Timer-based (flow equalization)
- Useful control features
  - Alternating pumps (lag/lead)
  - Audible/visible alarm
  - Remote notification
  - Cycle counters and elapsed time meters
  - Programmable logic controller (PLC)
  - Weatherproofing (NEMA 4X box, lightning arrestor)

Controls


OFF
ON
hrs
OFF
0.6
0.4
0.8
0.2
1.0
0
1.2
OFF
ON
min
OMRON H3CR
ON


RSF #1
PRIMARY





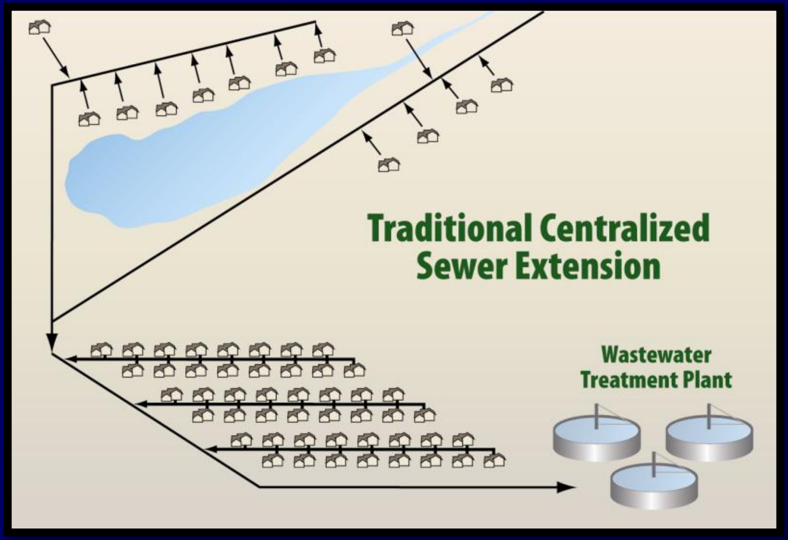

AC 115/120V
Input 12xAC
SIEMENS
ESC
OK
LOGO! 230RCL
Output 8xRelay/10A

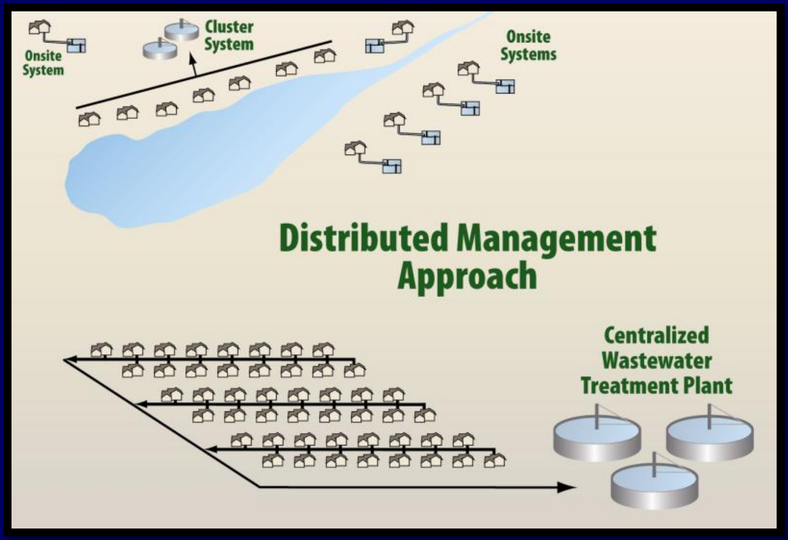

PASS
ESP 12-LX Plus

Cluster Systems

Objectives and Benefits

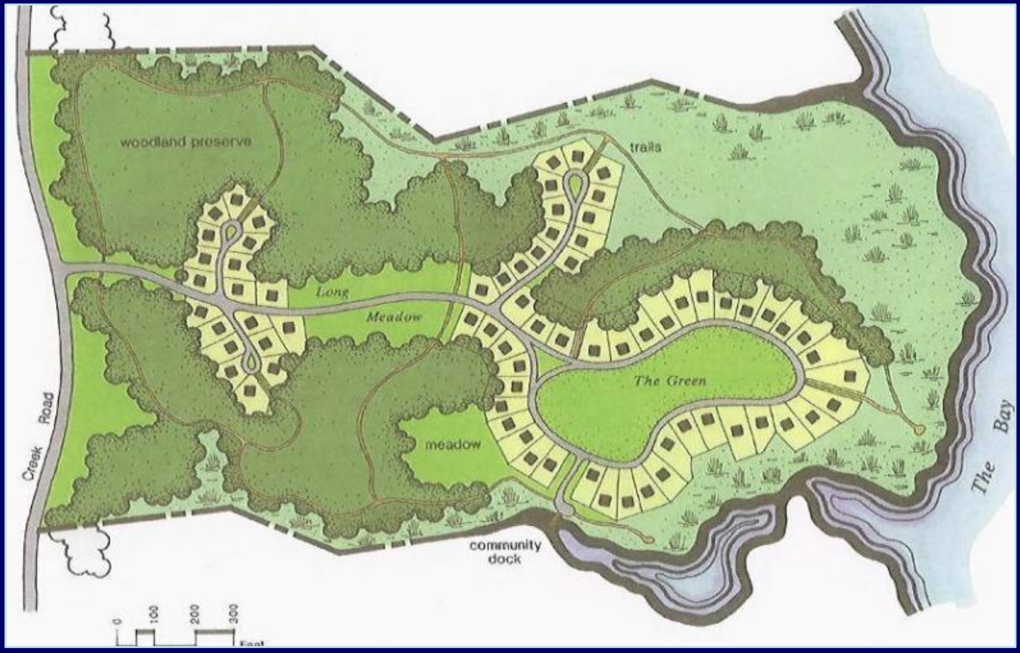
- Versus central sewer
  - Reduced conveyance demands (invest in treatment instead)
  - Incremental funding
  - Positive secondary impacts (growth management, aquifer recharge, etc.)
  - Economically viable water reuse





Objectives and Benefits

- Versus individual onsite systems
  - Economies of scale
  - Advanced treatment more viable, affordable
  - Allows for:
    - Smaller individual lot sizes, compact growth, and open space preservation
    - Prioritization of best soils for effluent dispersal



Collection System Alternatives

- Conventional gravity with lift stations
- Septic tank effluent (STE)
  - STEP
  - STEG
- Pressure sewers
  - STEP
  - Grinder pump
- Vacuum sewer

Conventional Gravity/Lift Stations

- Expensive
- Maintenance intensive
- Pipe slope/scour velocities important
- Moving raw sewage
- High I/I possible
- Most appropriate for large areas of dense development

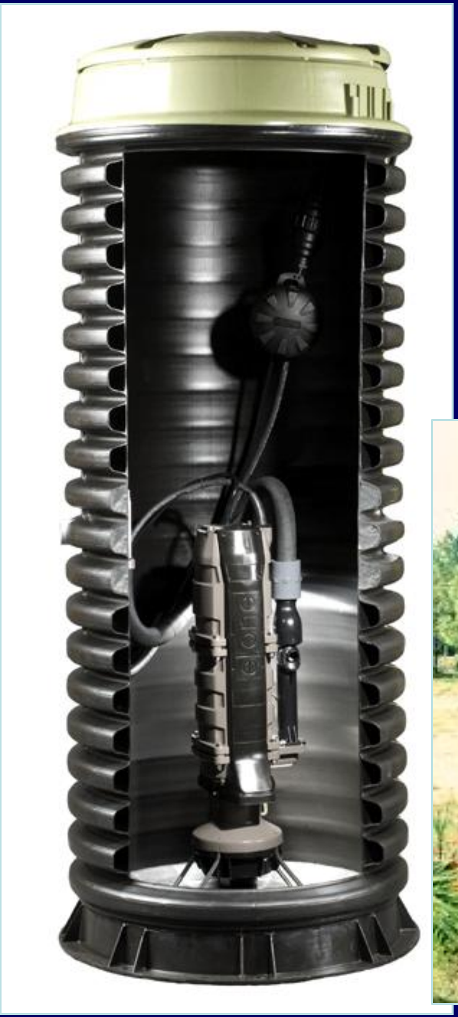



Septic Tank Effluent Sewers

- Septic Tank Effluent Pump (STEP)
- Septic Tank Effluent Gravity (STEG)
- Can mix and match STEP and STEG
- Mains are inexpensive
- Low maintenance
- Low I/I
- Provides onsite storage
- Moving relatively clean, but anaerobic water

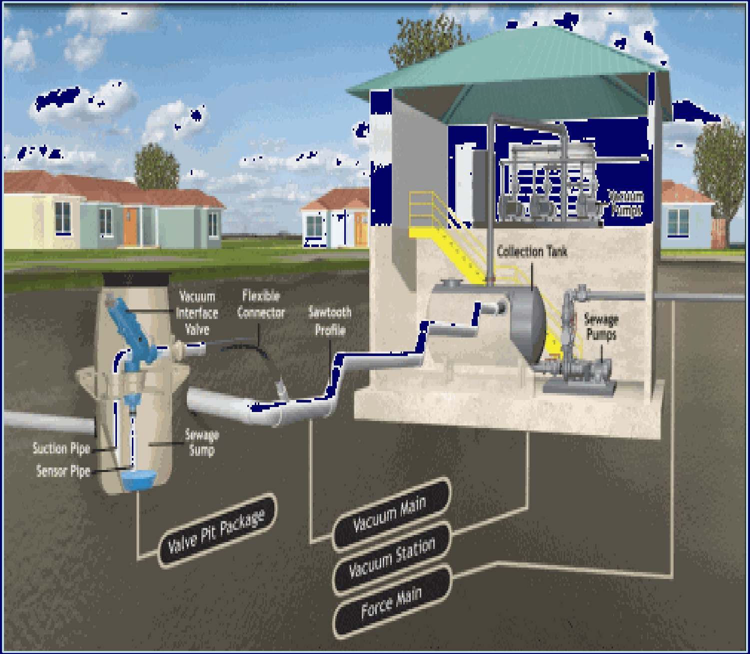
Grinder Pumps

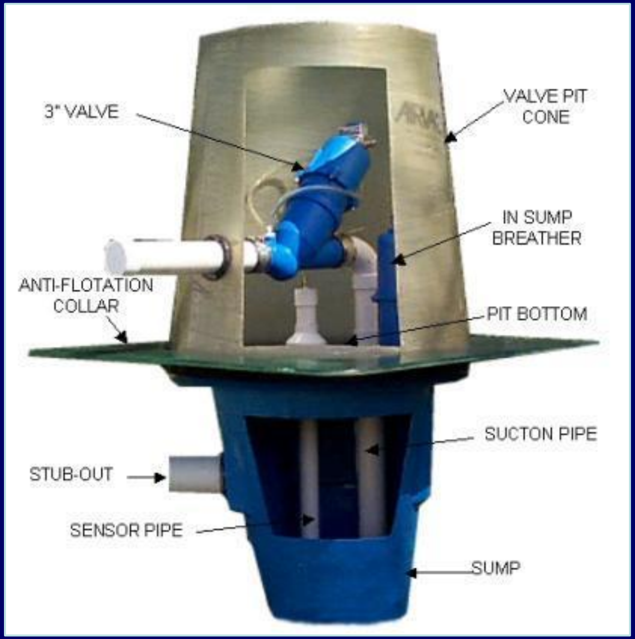
- – Relatively inexpensive mains and connection
- – No need for on-lot pump-outs
- – High strength wastewater
- – Potential settling problems at primary treatment unit
- – Maintaining scour velocity is critical



Vacuum Sewers

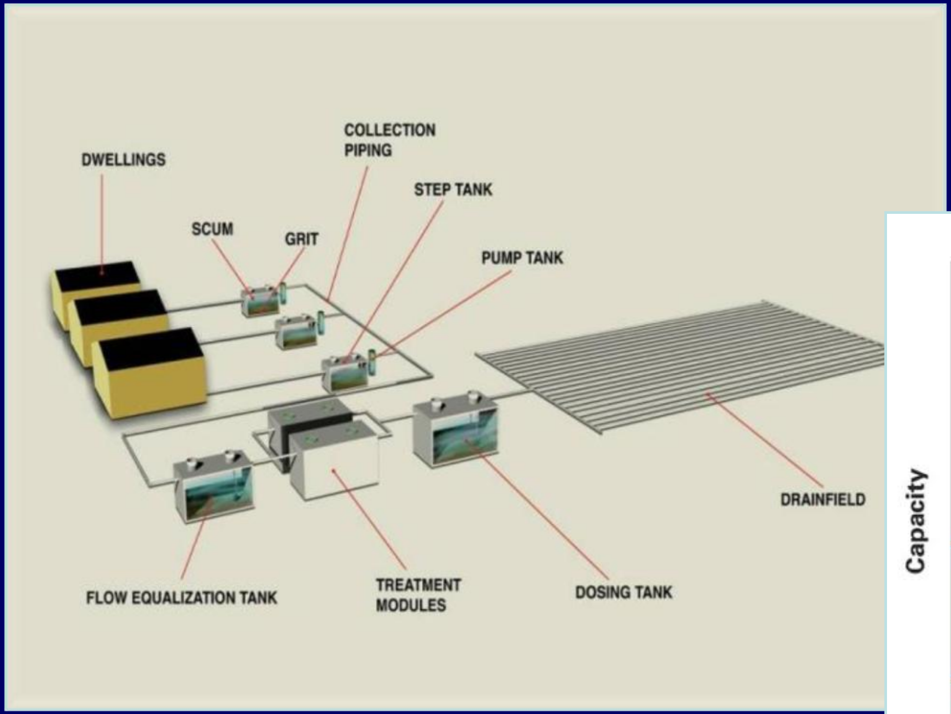
- Similar costs to other alternative sewers
- No need for on-lot pump-outs
- Scour velocity generally not a problem
- Can cluster multiple homes on one vacuum valve
- Requires O&M personnel with special training
- Odor problems rare





Cluster Treatment Systems

- Dispersed (onsite) primary treatment
- Phased/modular installation
- Advanced treatment (next topic)



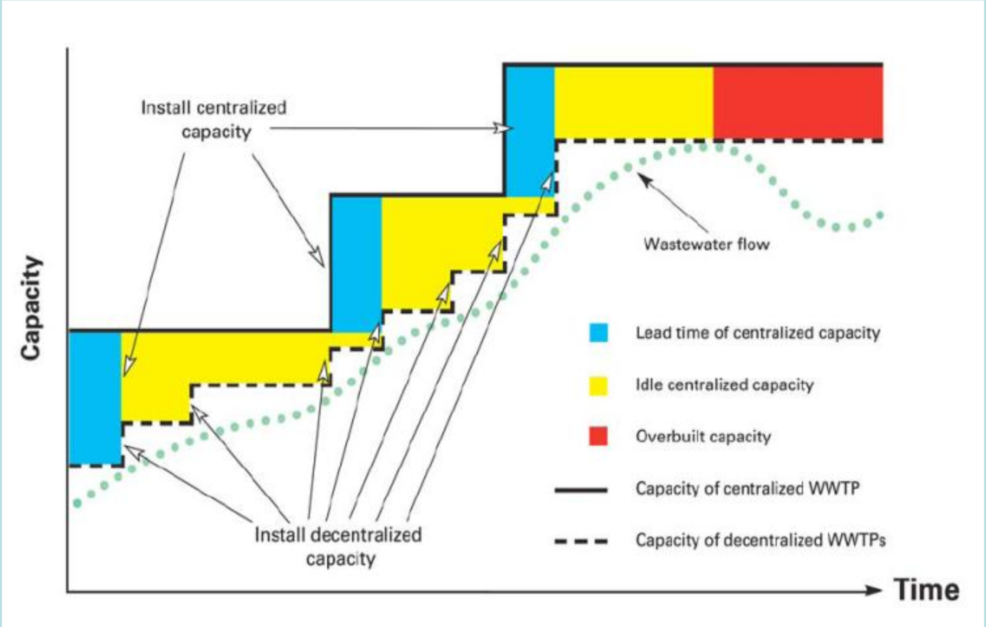
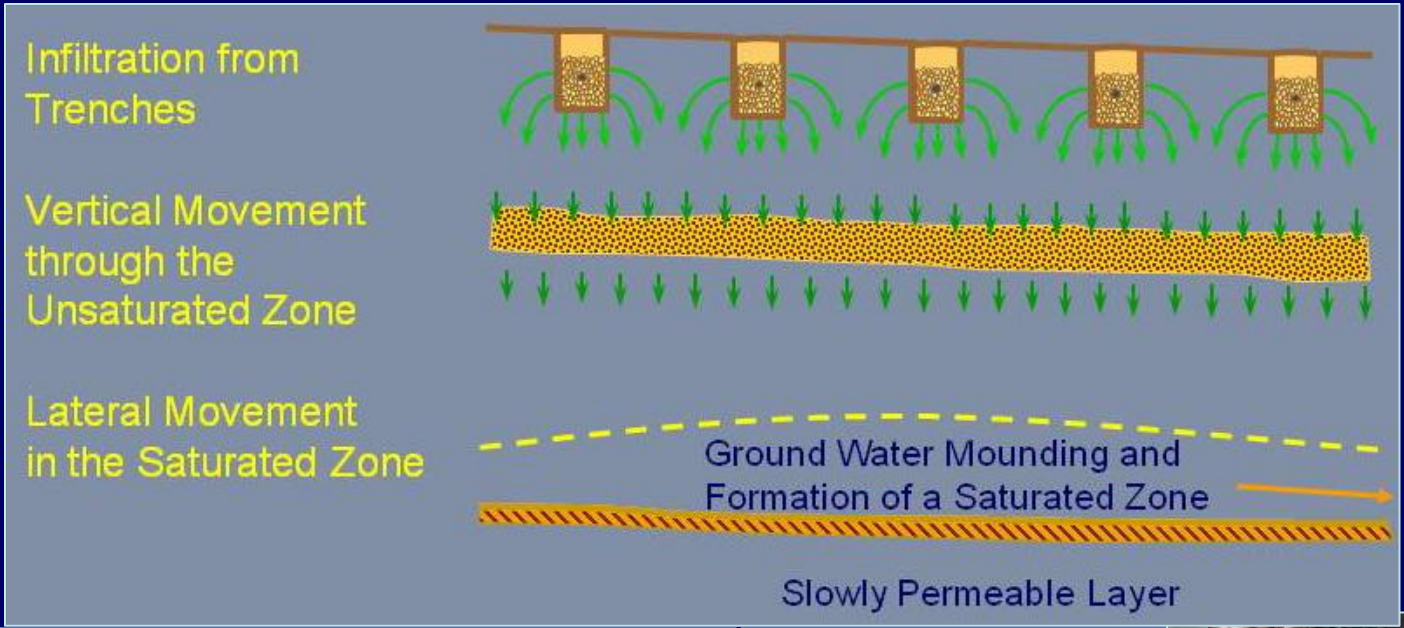


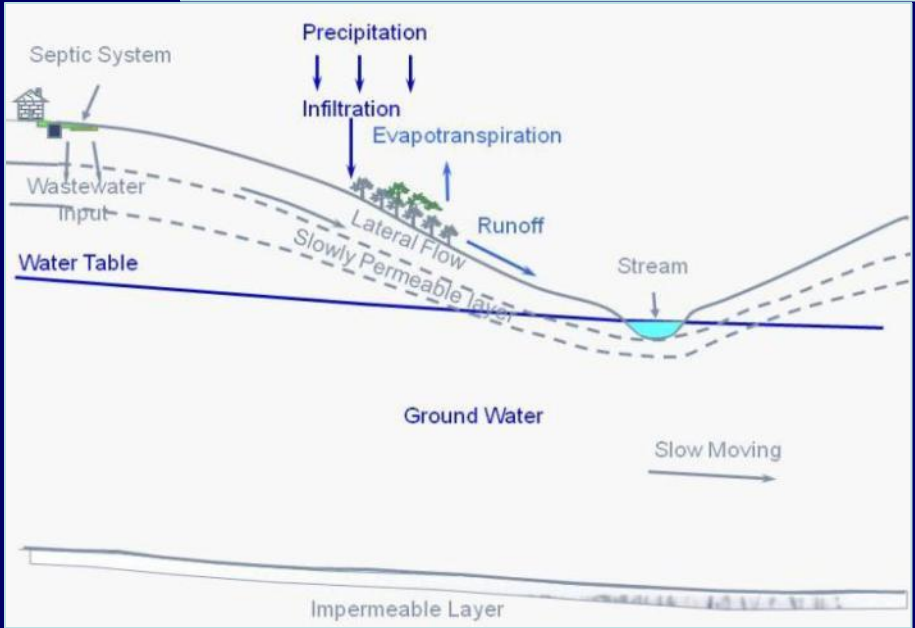
Figure 8-1: Flow Versus Capacity for Centralized and Decentralized Wastewater Systems. WWTP stands for Wastewater Treatment Plant.

Cluster Soil Dispersal Systems

- Hydrogeology and groundwater monitoring
- Multiple fields/zones
- Storage requirements

Hydrogeology and Groundwater Monitoring

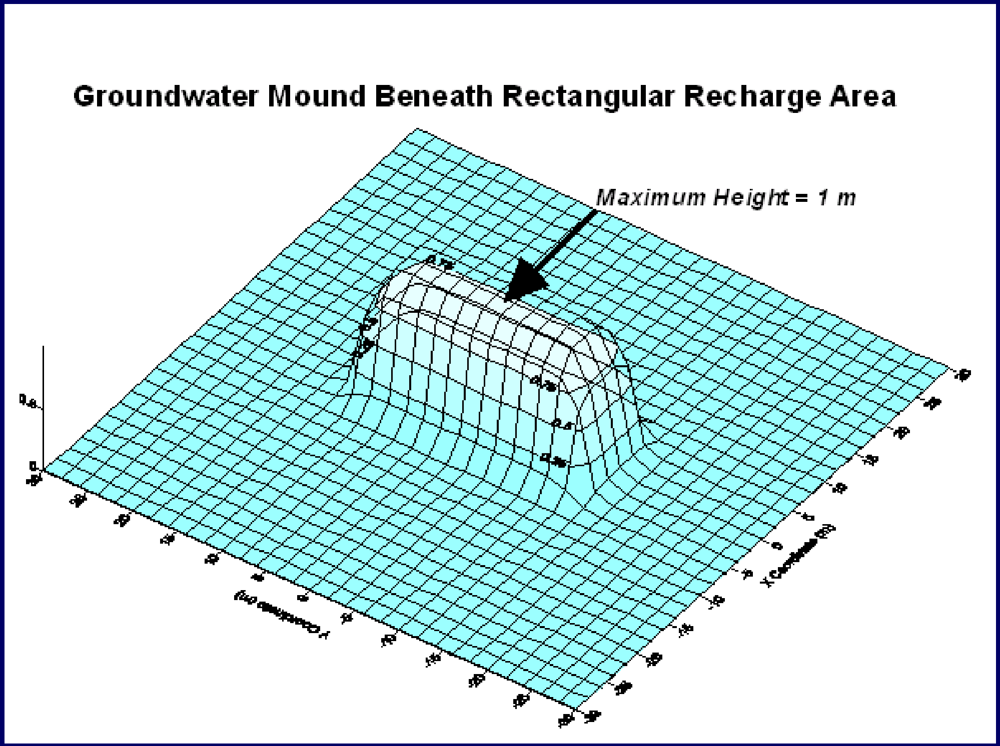




Hydrogeologic Assessment

- Groundwater mounding
  - Hantush equation
  - Various computer programs

- Lateral flow
  - Hand calculate using Darcy's Law



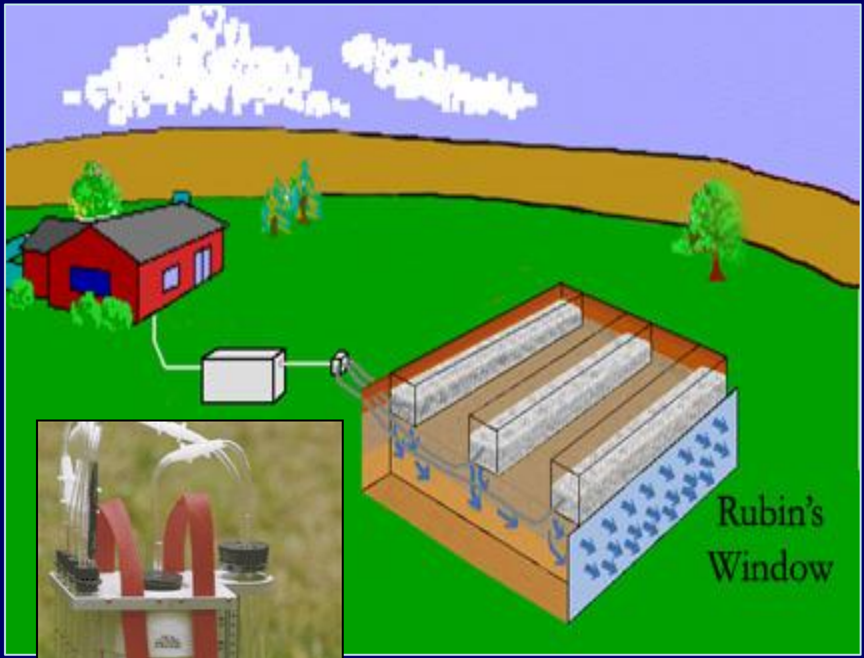
http://www.aqtesolv.com/mounding_analysis.htm

Lateral Flow Analysis

- Adaptation of Darcy's Law
- $Q_{site} = K_{sat} \times S \times A$
  - Q_{site} = site conveyance capacity
  - K_{sat} = effective hydraulic conductivity of vadose zone
  - S = slope of hydraulic gradient or ground surface
  - A = cross-sectional area of "flow window" = w x d

- Generally start using conservative assumptions and then refine as necessary

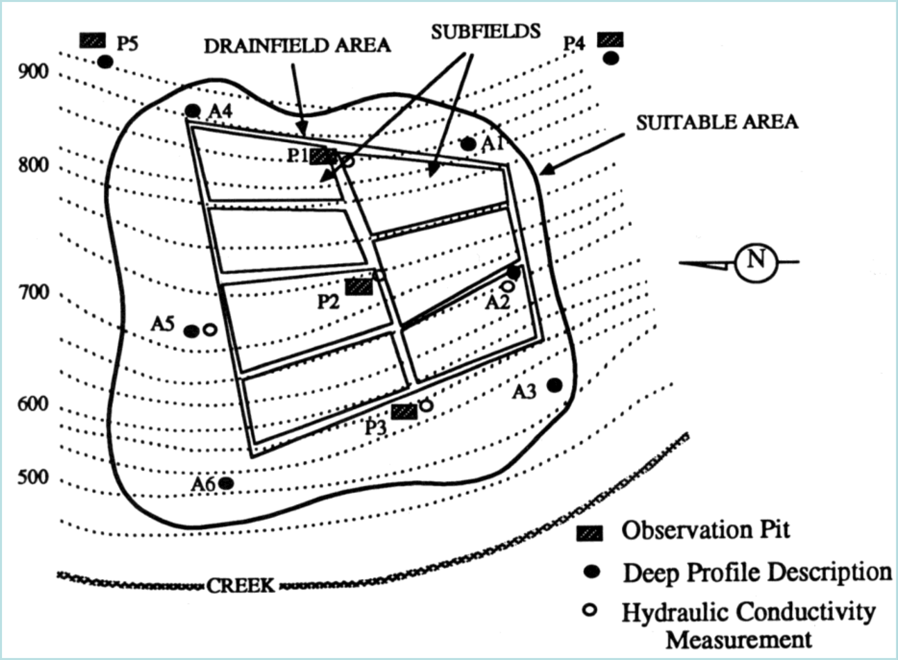
- Ensure that $Q_{site} > Q_{system}$



Lateral Flow Analysis

- Year-round school with Q_{system} = 4,670 gpd
- LPD at 0.1 gpd/sf (46,700 sf) with seven zones

		K_{sat} (gpd/sf)		
Horizon	Depth (in)	Mean	Low	High
Bt	19-25	2.7	0.7	5.3
BC	46-87	0.5	0.06	1.5
C	91-121	3.0	0.3	7.6



Deep Boring: depth to Cr horizon > 180” (15’)

Lateral Flow Analysis

Solution

- Assume
  - Cr is at 15’ and completely impermeable
  - 18” trench bottom depth
  - 24” separation below trench bottom
  - Flow westward toward creek
- Calculate d = max. saturated thickness = 180” - 18” - 24” = 138” = 11.5’
- Estimate slope from topo, S = 0.12
- Estimate flow window width, w = 300’
- Use K_{sat} = 0.5 gpd/sf

$Q_{site} = K_{sat} \times S \times A$

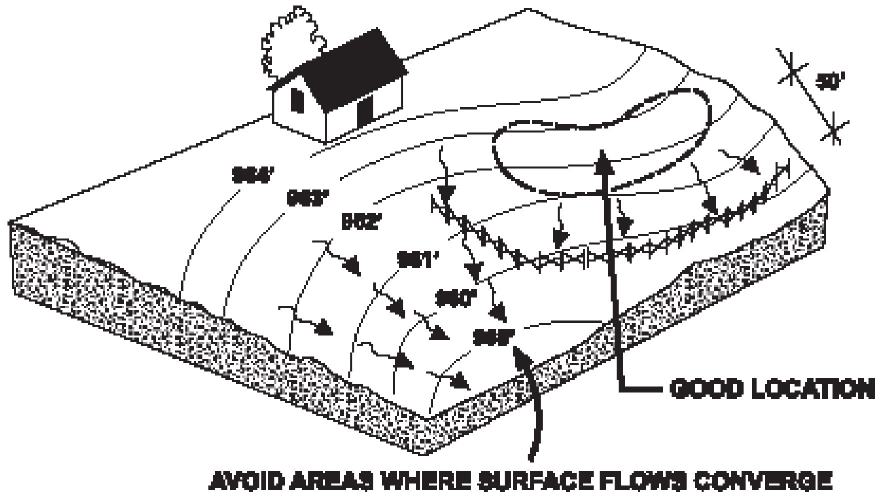
Q_{site} = (0.5 gpd/sf) x (0.12 ft/ft) x (300’ x 11.5’) = 207 gpd

$Q_{site} < Q_{system}$ (4,670 gpd)

Lateral Flow Analysis

- Flow may be in another direction or in more than one direction
- Hydraulic gradient may be different than ground slope
- Using K_{sat} for BC horizon may be overly conservative
- Restrictive horizon (Cr) may be deeper
- Restrictive horizon may not be totally impermeable
- Reconfigure/relocate drainfields
- Use flow equalization
- Don’t forget to check flow out of infiltrative surface and through vadose zone

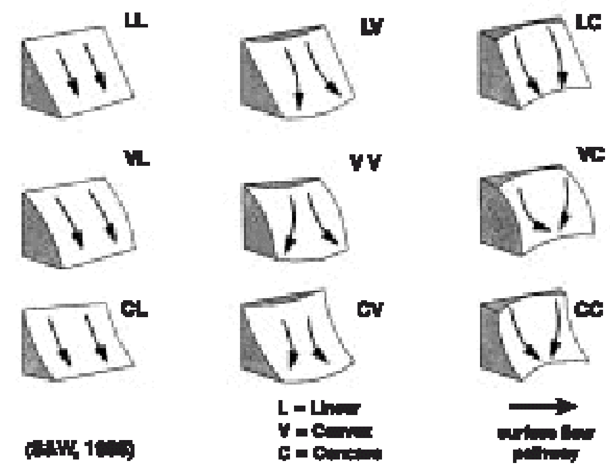
Siting and System Layout



Source: Purdue University, 1990.

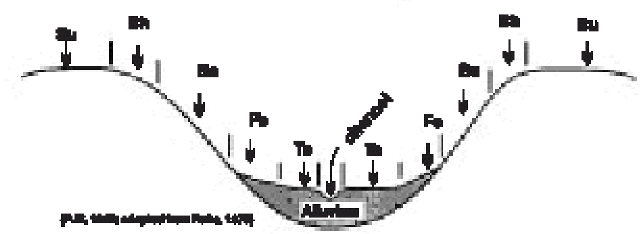
- Try not to stack lines (minimize linear loading rate)
- If stacking lines, split into independently-dosed zones or fields and “rotate” them
- Layout horizontally along contour rather than vertically down contour

Slope Shape - Slope shape is described in two directions: up and down slope (perpendicular to the contour), and across slope (along the horizontal contour); e.g., *linear, convex*, or *LV*.



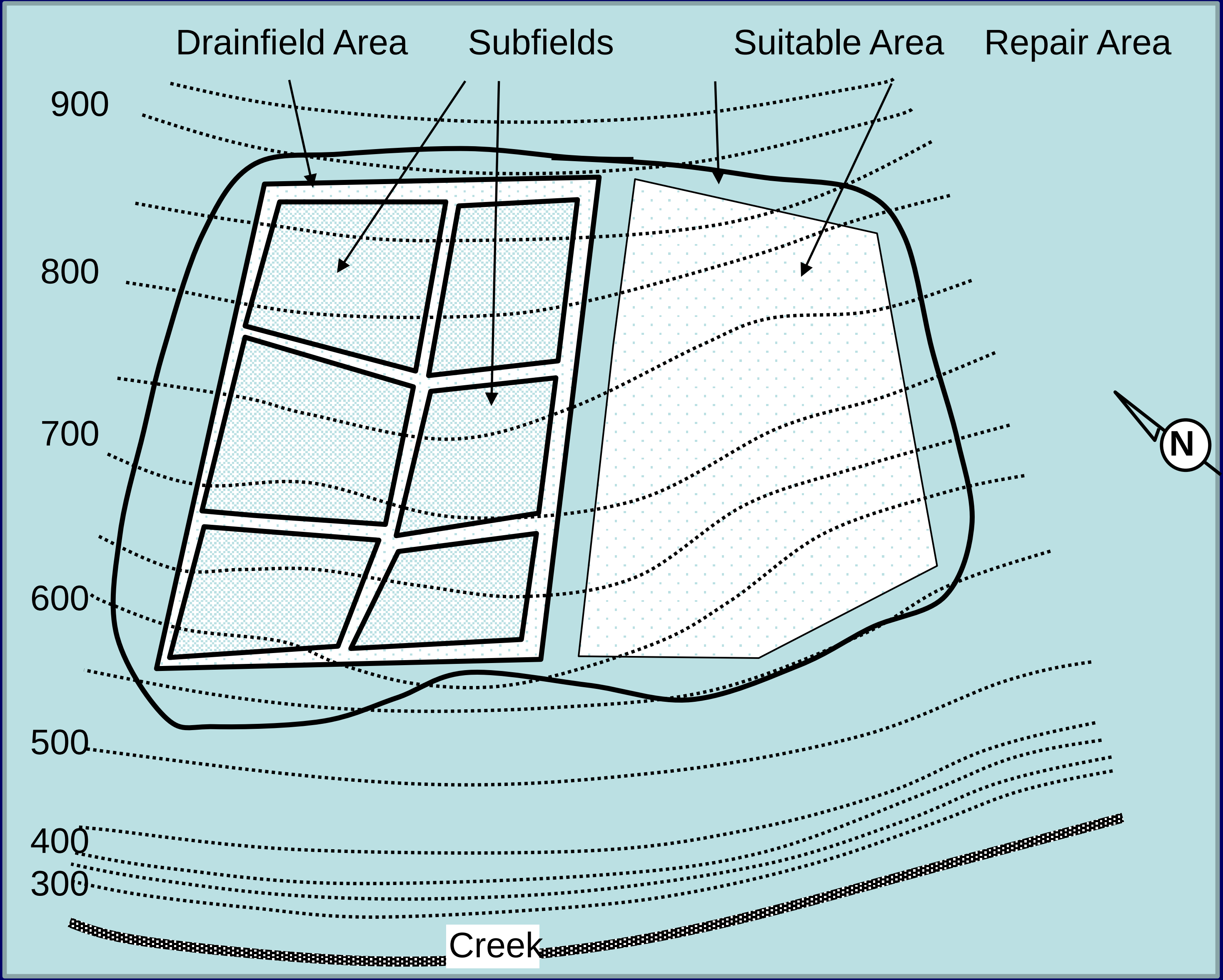
Hillslope - Profile Position (Hillslope Position in PDP) - Two-dimensional descriptions of parts of line segments (slope position) along a transect that runs up and down the slope; e.g., *backslope* or *BS*. This is best applied to transects or points, not areas.

Position	Code
summit	SU
shoulder	SH
backslope	BS
footslope	FS
toeslope	TS

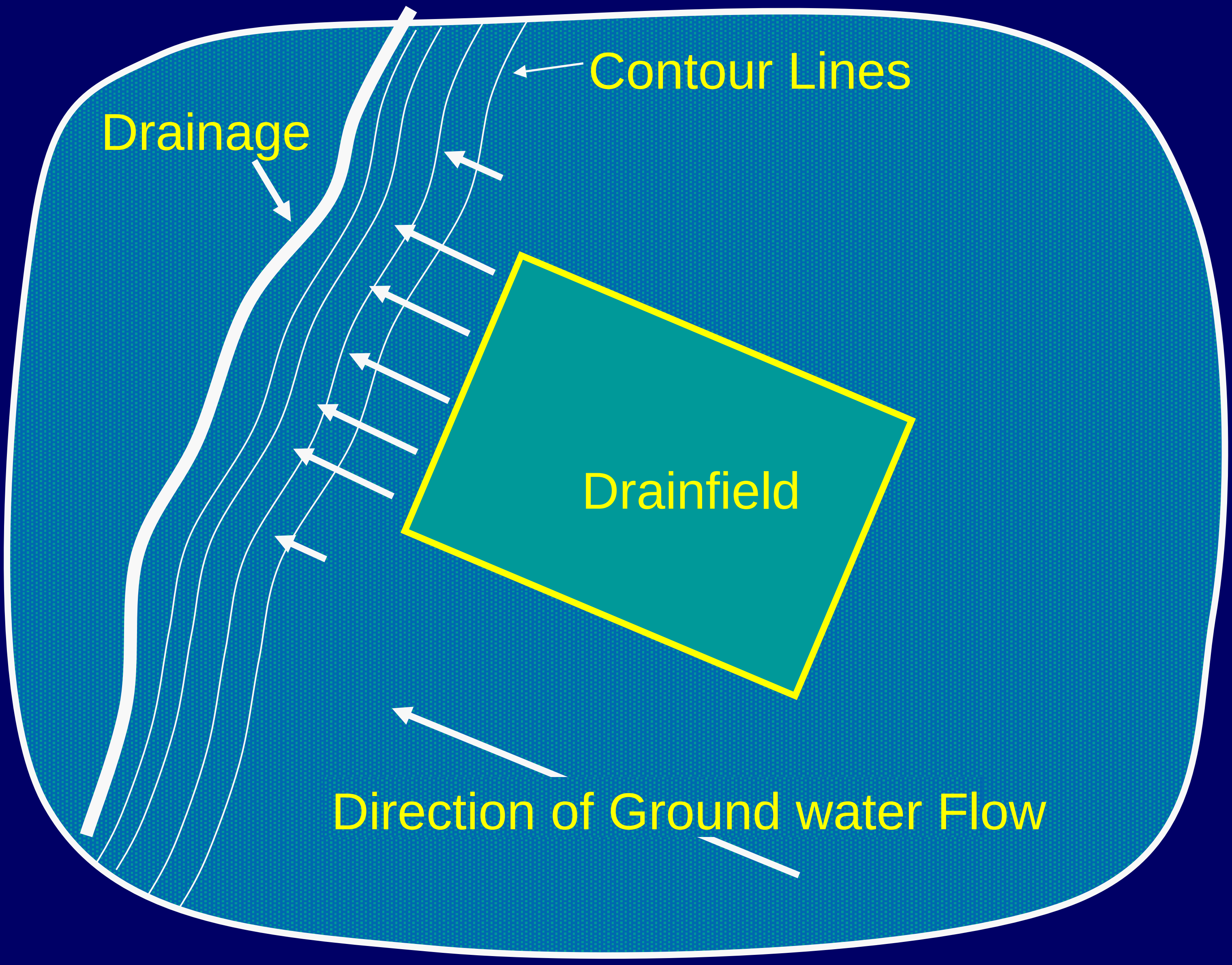


Source: NRCS, 1998.

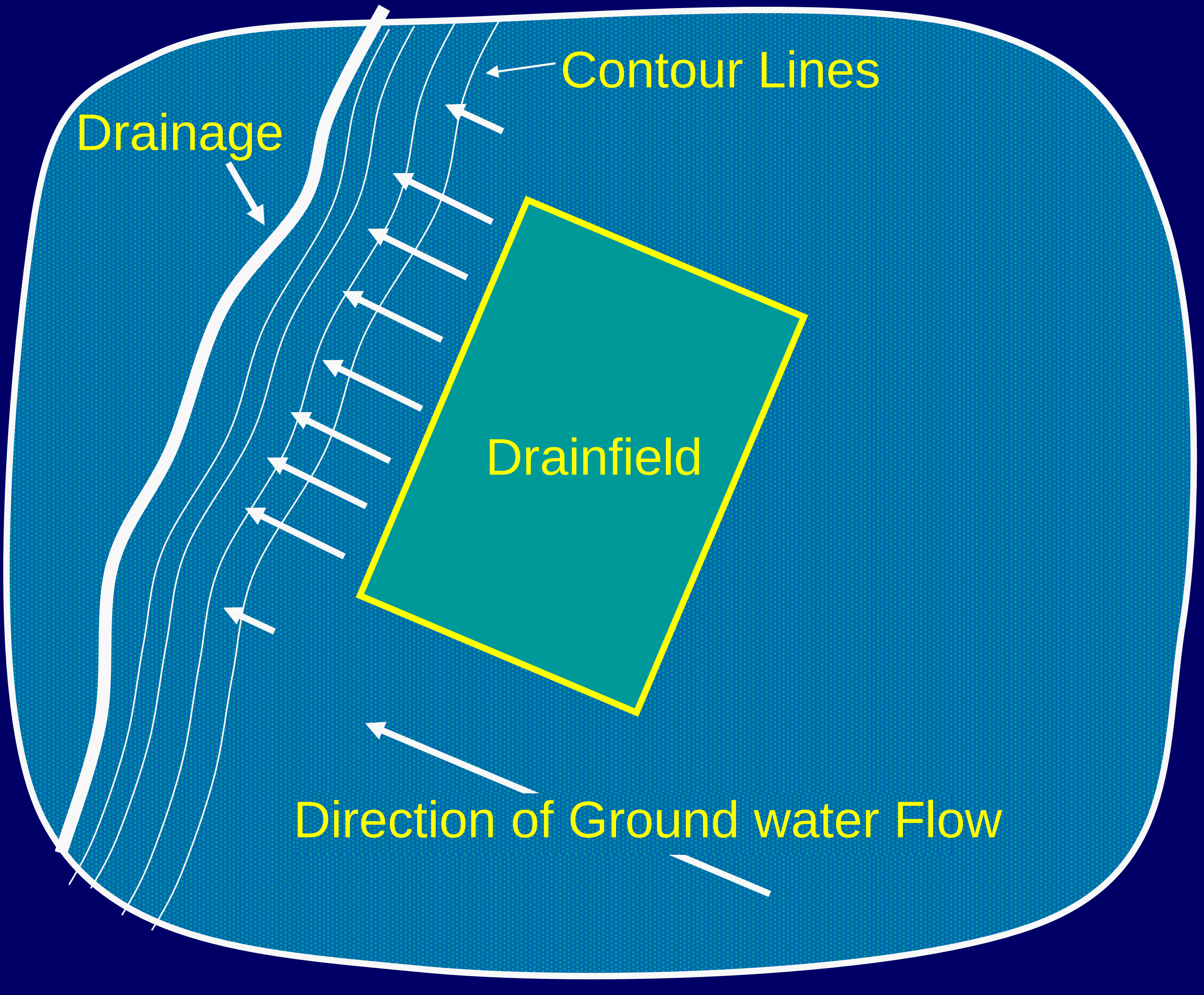
Siting and System Layout



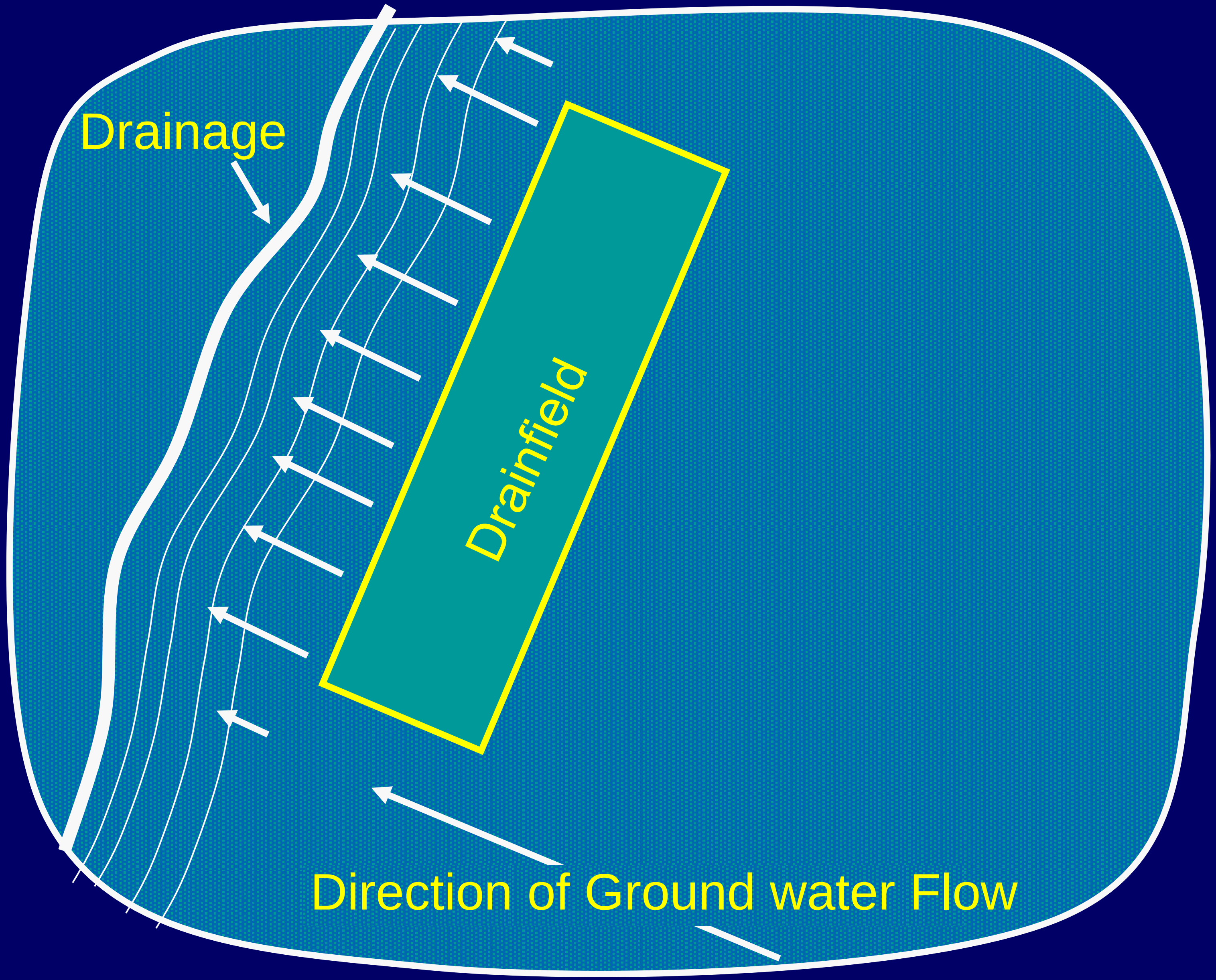
Siting and System Layout



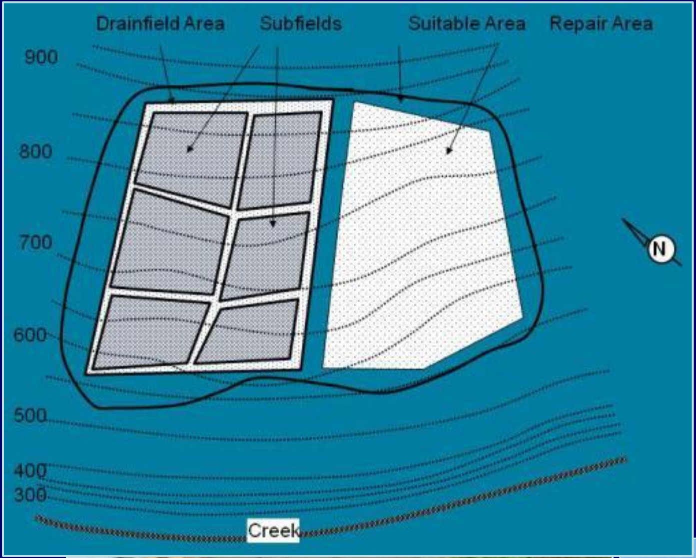
Siting and System Layout

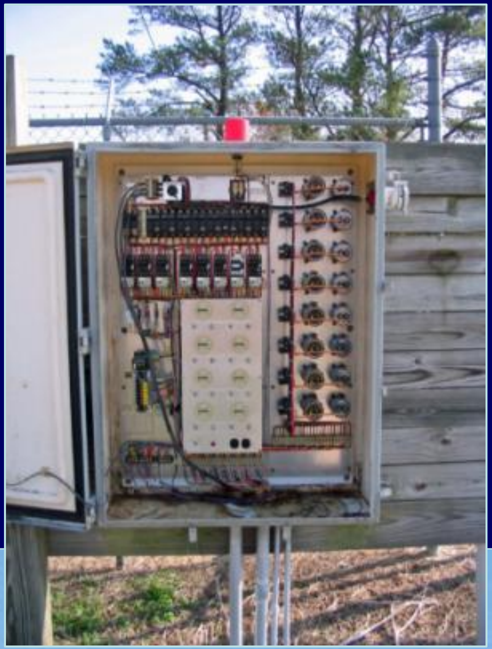


Siting and System Layout



Multiple Fields/Zones





Storage

- Irrigation design based on *water balance*
- Some reuse applications
- Storage for rainy weather or frozen conditions
- Use of a conjunctive system may alleviate storage needs

1.05 acres, 2700 gpd flow with stormwater

		Allowable Application Rate		Stormwater Additions			Irrigation Water		Storage Requirements	
							Additional	Cumulative	Change in	Cumulative
Month	Days/mo.	Lw	Lw	Rainfall	ET	Stormwater	Wa	Wa	Storage	Storage
	(days/mo)	(in/mo)	(gal/mo)	(in/mo)	(in/d)	(gal/mo)	(gal/mo)	(gal/mo)	(gal/mo)	(gal)
October	31	2.89	82394	3.5	0.08	4504	83700	88204	5810	5810
November	30	1.93	55024	2.97	0.05	6492	81000	87492	32467	38278
December	31	1.28	36493	3.36	0.03	10731	83700	94431	57938	96216
January	31	1.07	30506	3.17	0.03	9892	83700	93592	63086	159302
February	28	1.33	37918	3.32	0.05	8479	75600	84079	46160	205462
March	31	2.23	63577	3.72	0.09	4107	83700	87807	24230	**229692**
April	30	3.99	113755	2.84	0.13	-4681	81000	76319	-37436	192256
May	31	4.35	124019	4.02	0.16	-4151	83700	79549	-44470	147786
June	30	4.74	135137	3.81	0.17	-5697	81000	75303	-59834	87952
July	31	4.04	115180	4.51	0.17	-3356	83700	80344	-34837	53115
August	31	3.28	93513	3.88	0.15	-3400	83700	80300	-13213	39902
September	30	3.61	102921	3.52	0.12	-353	81000	80647	-22274	17628
totals	365	34.74	990438	42.6	1.23	22566	985500	1008066	17628	1273398
averages			2714			1880	2700	4580		85.1
										days storage

"Allowable Application Rate" taken from water balance for original design, based on soil scientist's recommendations.
"Stormwater Additions" calculated using average rainfall and ET values (attached) and the total surface area of both wetlands.
"Irrigation Water" based on proposed daily flow of 2,700 gpd and stormwater additions caclulated earlier.
"Storage Requirements" calculated based on cumulative water added to system minus allowable application rates.

Advanced Treatment

Advanced Treatment

- Sometimes called “pretreatment”
- Treatment objectives
  - Reduce stress on drainfield/biomat formation
  - Allow higher application rate
  - Protect receiving water quality
- Treatment standards
  - Varies by state/locality
  - *Preliminary/primary* – protect downstream processes
    - Low solids/FOG, high organics
  - *Secondary* – precondition wastewater for improved STU performance
    - Low solids/FOG/organics, high nutrients/pathogens
  - *Tertiary/advanced* – improved receiving water quality
    - Nutrient removal, disinfection

Preliminary/Primary Treatment

- Preliminary treatment
  - Removal of materials that can damage downstream treatment units (e.g., grit, grease, large solids, rags)
  - Includes screens, bar racks, grease traps, etc.

- Primary treatment
  - Removal of influent solids – settleable and floatable
  - Includes septic tanks, primary clarifiers
  - In decentralized treatment, preliminary and primary treatment are usually accomplished together in a single unit

Secondary Treatment

- Biological transformation of dissolved organics into solids, gasses, and dissolved by-products
- Includes separation of biological solids from liquid phase
- Suspended growth systems
  - Activated sludge (conventional, extended aeration, SBR, etc.)
  - Membrane bioreactor (MBR)
- Attached growth systems (fixed media filters)
  - Trickling filters, RBCs, etc. (secondary)
  - Sand filters, SSF wetlands, peat/textile filters, etc. (adv. sec.)
- Custom versus proprietary units

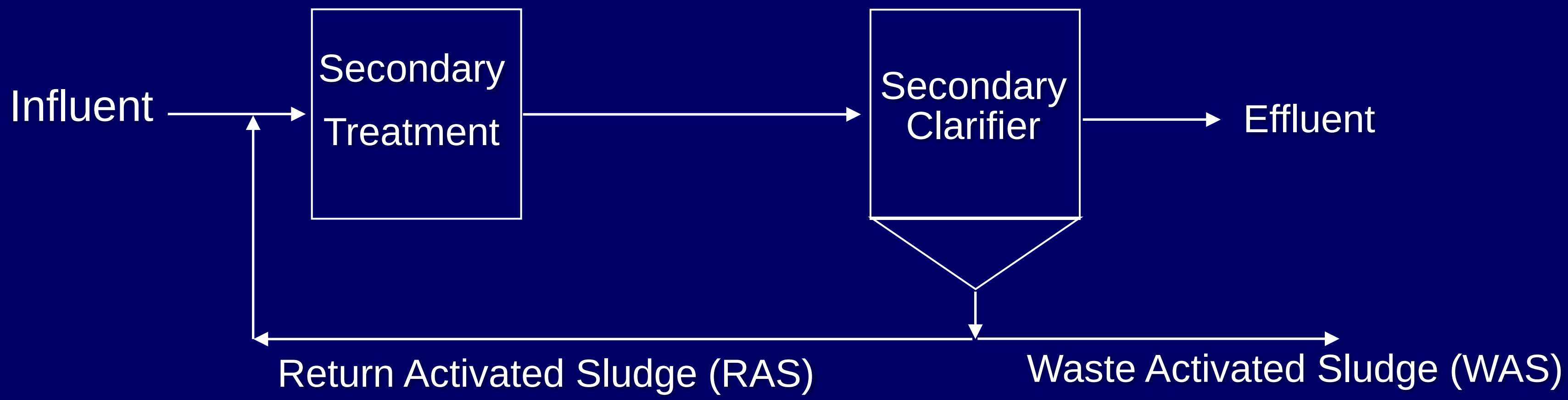
Suspended Growth



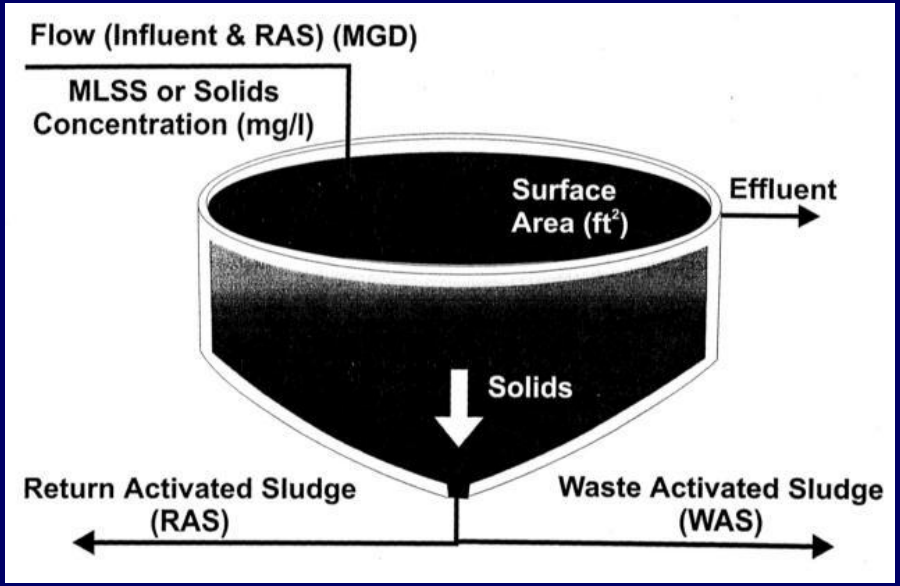





Activated Sludge



- Hydraulic Retention Time (HRT) = Reactor Volume / Flow Rate
- Sludge Retention Time (SRT) = Sludge Mass in Reactor / Sludge Wasting Rate
- Organic Loading Rate = Organic Mass per Time / Reactor Volume
- Food to Mass Ratio (F:M) = Organic Mass per Time / Biomass in Reactor
- Lots of other considerations



Activated Sludge

Table 8-16
Typical design parameters for commonly used activated-sludge processes[a]

Process name	Type of reactor	SRT, d	F/M kg BOD/kg MLVSS·d	Volumetric loading: lb BOD/1000 ft^3·d	Volumetric loading: kg BOD/m^3·d	MLSS, mg/L	Total τ, h	RAS, % of influent[a]
High-rate aeration	Plug flow	0.5–2	1.5–2.0	75–150	1.2–2.4	200–1000	1.5–3	100–150
Contact stabilization	Plug flow	5–10	0.2–0.6	60–75	1.0–1.3	1000–3000[b] 6000–10000[c]	0.5–1[b] 2–4[c]	50–150
High-purity oxygen	Plug flow	1–4	0.5–1.0	80–200	1.3–3.2	2000–5000	1–3	25–50
Conventional plug flow	Plug flow	3–15	0.2–0.4	20–40	0.3–0.7	1000–3000	4–8	25–75[f]
Step feed	Plug flow	3–15	0.2–0.4	40–60	0.7–1.0	1500–4000	3–5	25–75
Complete mix	CMAS	3–15	0.2–0.6	20–100	0.3–1.6	1500–4000	3–5	25–100[f]
Extended aeration	Plug flow	20–40	0.04–0.10	5–15	0.1–0.3	2000–5000	20–30	50–150
Oxidation ditch	Plug flow	15–30	0.04–0.10	5–15	0.1–0.3	3000–5000	15–30	75–150
Batch decant	Batch	12–25	0.04–0.10	5–15	0.1–0.3	2000–5000[d]	20–40	NA
Sequencing batch reactor	Batch	10–30	0.04–0.10	5–15	0.1–0.3	2000–5000[d]	15–40	NA
Countercurrent aeration system (CCAS™)	Plug flow	10–30	0.04–0.10	5–10	0.1–0.3	2000–4000	15–40	25–75[f]

[a] Adapted from WEF (1998); Crites and Tchobanoglous (1998).

Advanced Treatment

- Use "10-State Standards" for oxygen demand stoichiometry.
  - 1.2 to 1.5 lbs. O_2 / lb. BOD
  - 4.6 lbs. O_2 / lb. NH_3-N
- Use these numbers to calculate actual oxygen requirements (AOR), but need to correct for field conditions (e.g., temperature, elevation, type of aeration device).

$$SOR = \frac{(AOR)(C_{20})}{\alpha(\Theta^{T-20})[(\beta)(C_s) - C_w]}$$

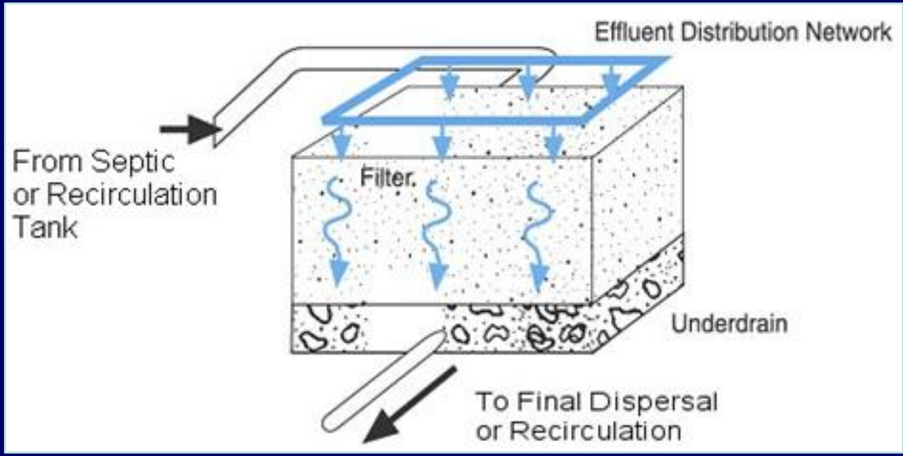
- C_{20} = Dissolved oxygen solubility at standard conditions of 20° C and atmospheric pressure = 9.09 mg/l
- T = temperature of water
- C_s = oxygen solubility at T and actual pressure (refer to oxygen sat. tables)
- C_w = operating oxygen concentration
- α and β are constants depending on the aeration equipment used
- Θ is a temperature constant, 1.024

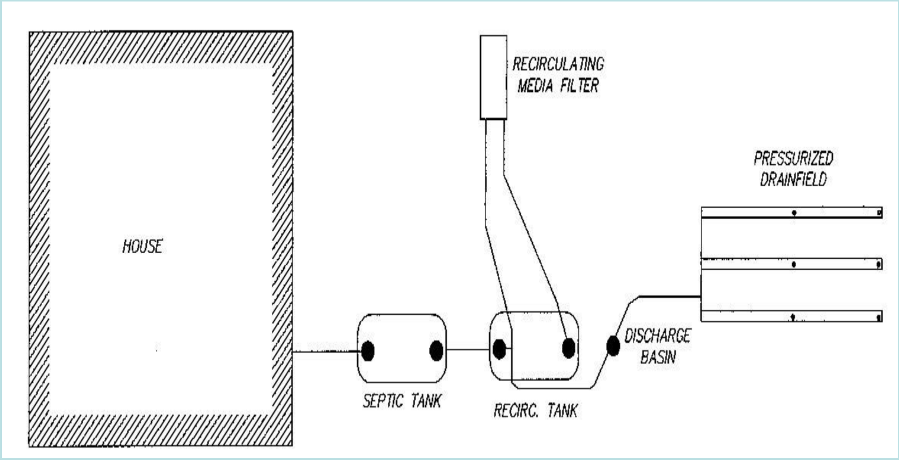
Attached Growth

Attached Growth

Fixed Media Filters

- Hydraulic loading (surface loading rate)
  - Intermittent (single-pass) sand filter = 1-1.5 gpd/sf
  - Recirculating sand filter = 2-5 gpd/sf
- Organic loading (surface loading rate)
  - Intermittent (single-pass) sand filter = 0.0005-0.002 lb BOD/sf-d
  - Recirculating sand filter = 0.002-0.008 lb BOD/sf-d





- Media depth = 1-3 feet (for sand filters)
- Recirculation ratio = 2:1-5:1
- Media specs important
- Supplemental air *may* be necessary

Tertiary Treatment

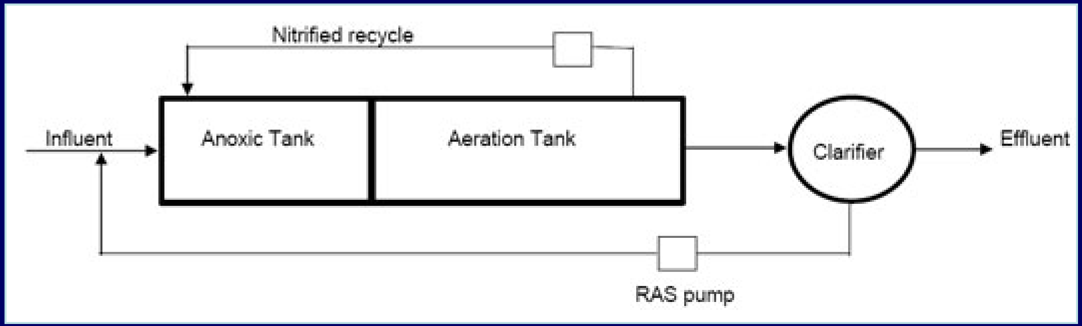
- Anything beyond standard secondary treatment
- Examples
  - Biological or physiochemical nutrient removal
  - Mechanical filtration (e.g., spin filters, high-rate media filters, microfiltration)
  - Disinfection – chlorination, ultraviolet (UV)
  - Soil-based treatment (sorption of P, viruses, metals, etc.)
  - Other pretreatment as needed for special wastewaters (e.g., acid neutralization units)

Biological Nutrient Removal

- Phosphorus removal
  - Soil matrix is an effective treatment unit
  - External to STU, use anaerobic selectors prior to aerobic treatment or chemical precipitation (generally not practical for decentralized)
- Nitrogen removal (two-step process)
  - Nitrification (aerobic conversion of TKN to NO_3)
  - Denitrification (anoxic conversion of NO_3 to N_2)
  - Basic process is aerobic followed by anoxic treatment
  - However, process also requires
    - Organic carbon (BOD) – can be supplemented using various carbon sources (besides those naturally present in the wastewater)
    - Alkalinity – sometimes added via limestone, bicarbonate, etc.

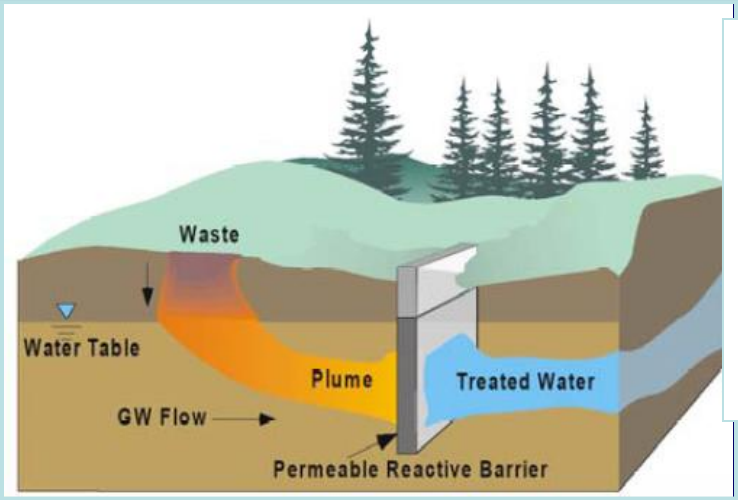
Biological Nitrogen Removal

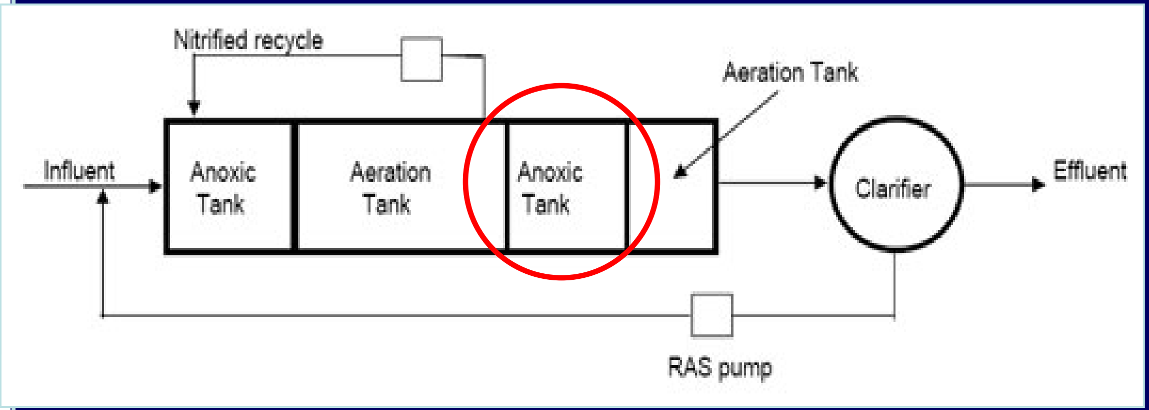
- Recirculating/alternating systems



Modified Ludzack-Ettinger (MLE) Process

- Sequential systems ("post-denitrification")





Disinfection

Residuals Management

- Anaerobic/septic solids = septage
- Aerobic/biological solids = biosolids or sludge
- Solids removal particularly critical for proper operation of suspended growth systems
- Typically hauled to a large, centralized plant
  - Organics reduction (digestion, composting, etc.)
  - Pathogen reduction (thermal treatment, lime stablization, etc.)
  - Volume reduction (thickening, dewatering, drying, etc.)
  - Reuse (land application) or disposal (landfill or incineration)

Other Topics

Repairs

- Failure analysis
  - Hydraulic failure
  - Treatment failure
  - Management failure
- Common problems
  - System components in disrepair
  - Distribution network clogged
  - Soil-trench interface clogged
  - Hydraulic overload
  - Organic overload
- Malfunction analysis methods
  - Visual analysis, manual testing of controls/valves/etc.
  - Drawdown testing, look for lateral ponding
  - Trench monitoring well inspection, auger next to trench
  - Check water usage, flow rates, leaky fixtures, infiltration
  - Test influent/effluent quality, audit facility operations




Expansions/Retrofits

- Performance analysis
- Comprehensive system inspection
- Existing use/flow analysis
- Future use/flow analysis
- Assessment of existing system components
- Repurpose or repair system components
- Design for resiliency

Construction Management and Supervision

- Prepare clear construction documents (plans and specifications)
- Clearly spell out what items require submittals
- Clearly spell out when engineering or regulatory inspection required
- Clearly spell out testing requirements and documentation
- Convene pre-construction meeting between owner, contractor, engineer/architect, soil scientist, and regulators
- Coordinate final inspection with regulators
- Prepare as-built drawings to go with certification

Operation and Maintenance

- All treatment system designs should include a detailed O&M manual
- Standard frequency of inspection for routine items
  - Complexity of system
  - Size of system
- Detail OM&M requirements for any novel items
- Provide inspection forms (customized) or platform

Upcoming Webinar Sessions

Date	Topics (All @ 12 noon EST)	Presenter
November 9	*Overview of Centralized and Decentralized Treatment*	*Barry Tonning*
November 16	*Decentralized Treatment: Processes & Technologies*	*Jim Kreissl*
November 23	*Focus on Wastewater System Design: Part 1*	*Vic D'Amato*
November 30	*Focus on Wastewater System Design: Part 2*	*Vic D'Amato*
December 7	*Management Approaches for Wastewater Systems*	*Juli Beth Hinds & Khalid Alvi*
December 14	*Integrated Water Resource Management*	*Vic D'Amato*