Design Elements to Avoid Hydraulic Failure in Passive Treatment

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HedinEnvironmental

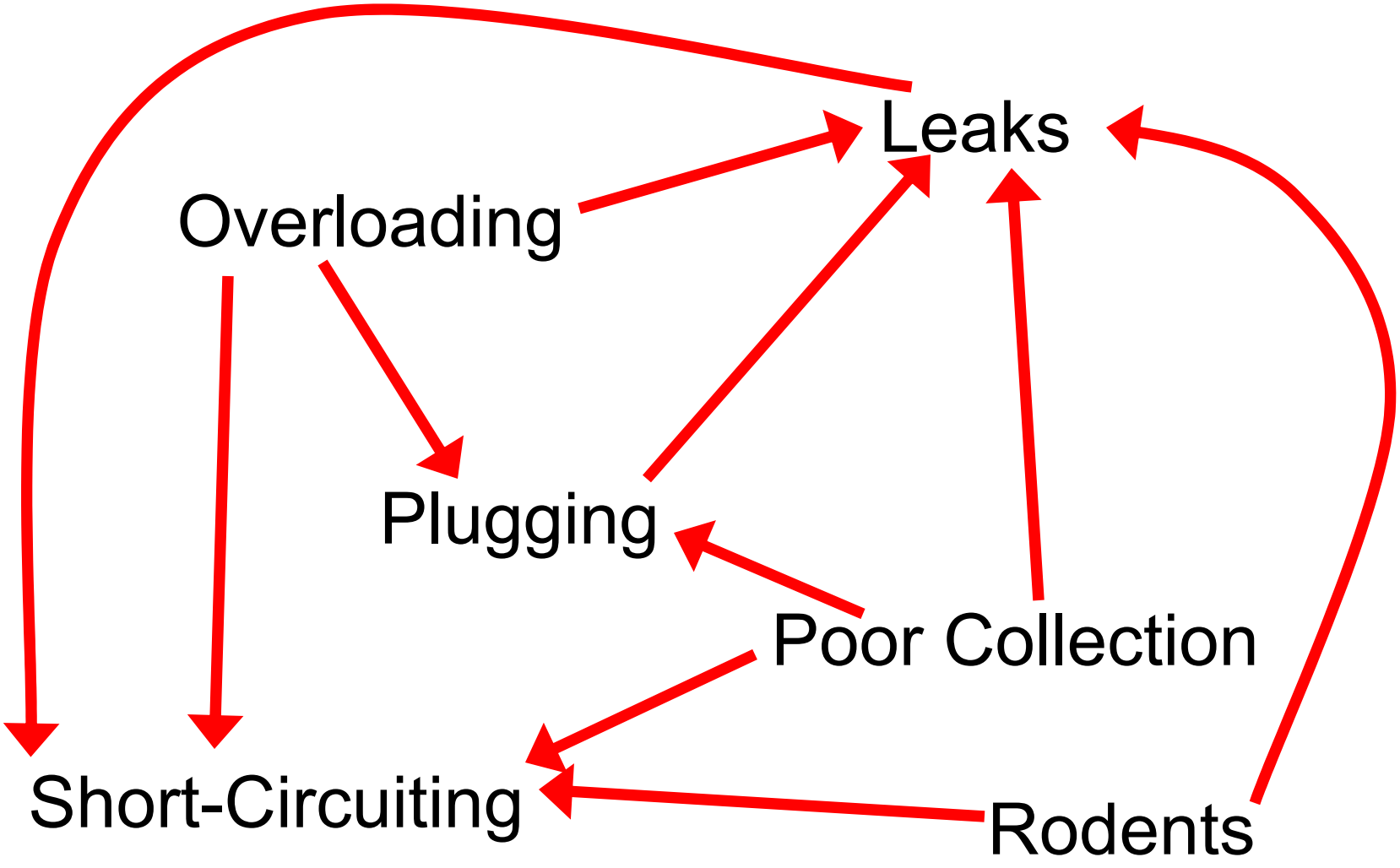
The Game Plan

1. Hydraulic causes of failure
2. Avoiding specific failure modes
3. Flushing theory and design
4. Flushing strategies
5. Design examples
6. Self-flushing results
7. Looking ahead

Culprits

1. Overloading
2. Short-circuiting
3. Plugging
4. Rodents/Vandals
5. Leaks
6. Improper Collection
7. Improper Treatment Type

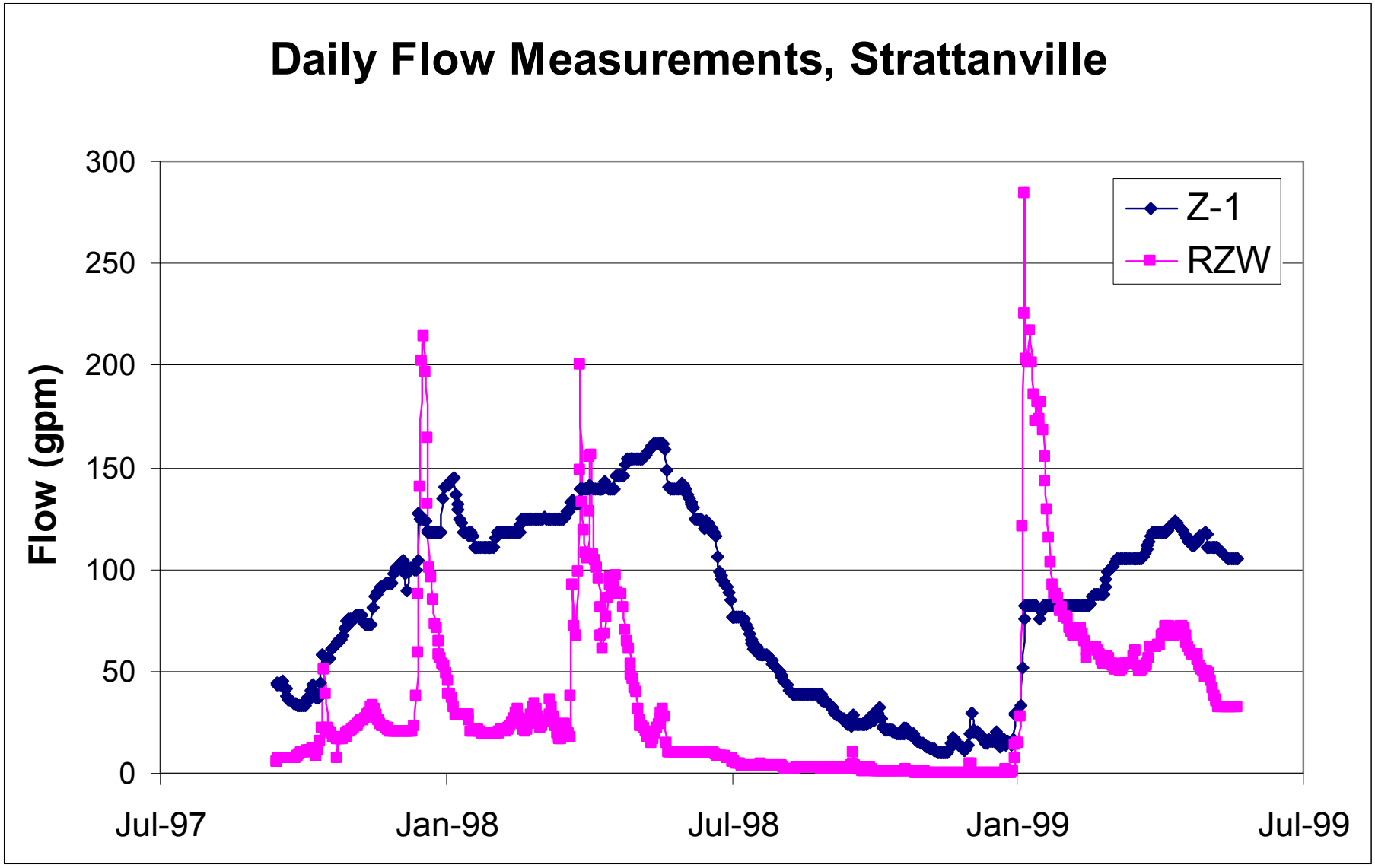
Diagnosis


Leaks
Overloading
Plugging
Poor Collection
Short-Circuiting
Rodents

Overloading

Overloading can…

- Cause physical damage to berms, channels, etc.
- Clog ponds/channels with debris or sediment
- Chemically overwhelm the system (lower retention time)
- Damage the bacteria required for treatment
- Shorten the life of the system or cause failure



Data courtesy of Joe Schueck of DEP BAMR

So What?

Flow Rates (gpm)	Z-1
	All Data (607 Points)
Average	84
25th %	39
75th %	118
90th %	139

Avoiding Overloading

- Get good initial data
- No guessing or “visual estimates”
- Monthly for one year plus a high flow event
- Targeting a high flow event
  - Flow may peak during, immediately after, or many days after rainfall/ snowmelt
- Limit the maximum amount of flow

“The Black Box”

- Limits the total amount of flow
- Divides flow equally among treatment cells OR
- Sequences flow into multiple treatment cells
- Directs overflow as desired
- Screens debris
- Adaptable after installation

Short Circuiting

Short Circuiting

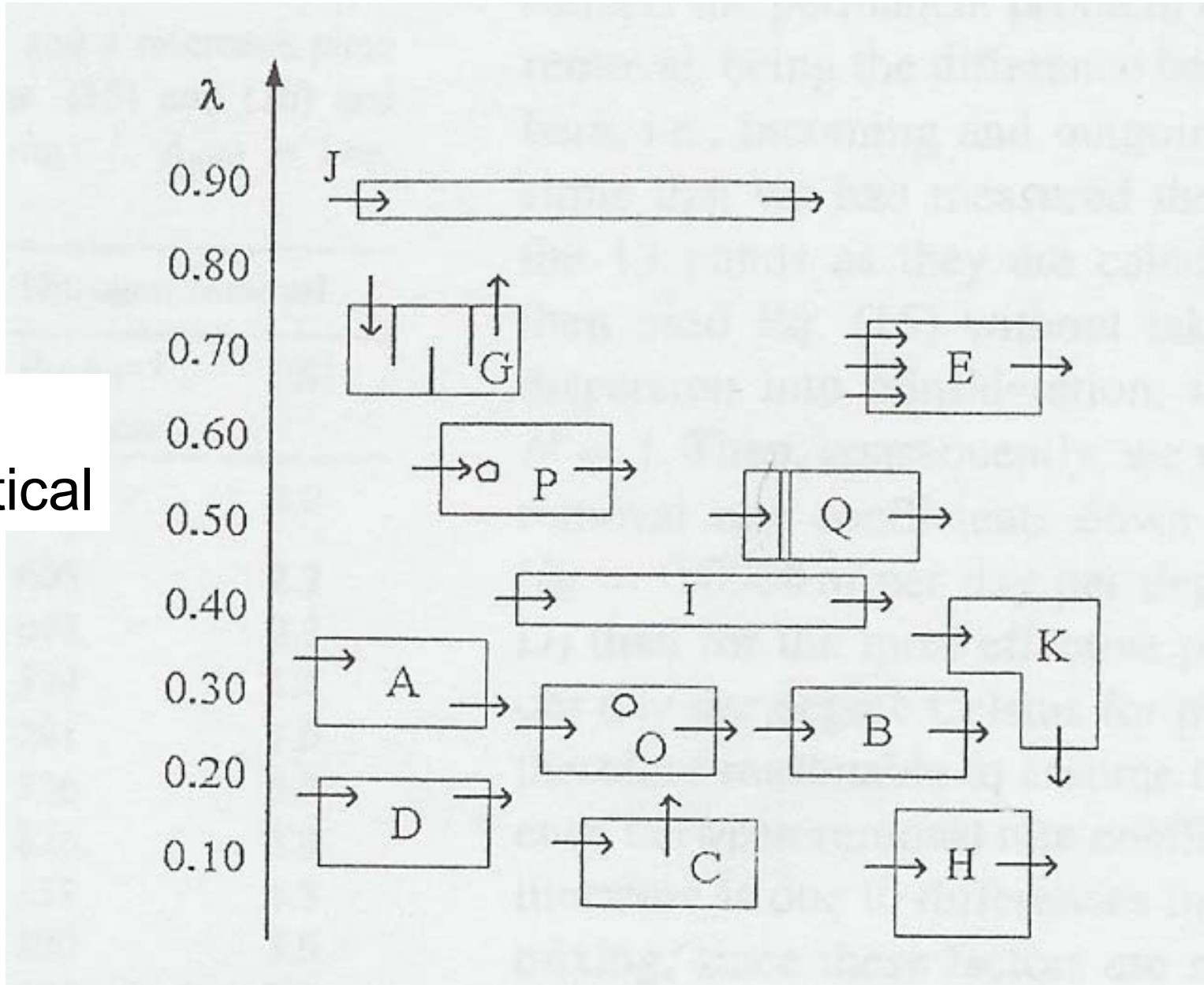
- Can occur in any open or closed system
- Effectively reduces the retention time
- Can cause system failure if an entire “step” is bypassed (Middle Branch)

Minimizing Short Circuiting

- Open Ponds and Wetlands
  - 5:1 Length to Width Ratio
  - Dividing berms or curtains (dry or submerged)
- Closed limestone or compost beds
  - Proper collection and introduction
- Vertical flow systems
  - Uniform, complete compost layer
- All systems: consider the inlet and outlet velocity

From "How hydrological and hydraulic conditions affect performance of ponds." Jesper Persson and Hans B. Wittgren, Ecological Engineering 21 (2003) 259 - 269

$$I = \frac{\text{Actual}}{\text{Theoretical}}$$



Plugging

AH-HA!
I'VE GOT YOU NOW, KID!
AAUGH!
HELP! QUICK!
MOMMM!

HA! I PULLED THE PLUG!
DOWN THE DRAIN WITH YOU!
DIE, FIEND! DIE, DIE!!
AAARRRGHHH

Plugging

- “Loss of permeability”
- Can occur in any type of treatment system
- Can occur in compost, limestone, or pipes
- Metal precipitation
- Compost compaction
- Debris/Rodents/Vandals

Iron + Alkalinity + Oxygen = Orange goo

Aluminum + Alkalinity = White goo

Prevention and Management

- Prevention
  - Proper selection of the type of treatment
  - Proper design (anoxic, etc)
  - Avoid compost compaction (“bulk”)
- Management
  - Occasional “stirring”
  - Component removal and replacement
  - Flushing of solids

Flushing Strategies

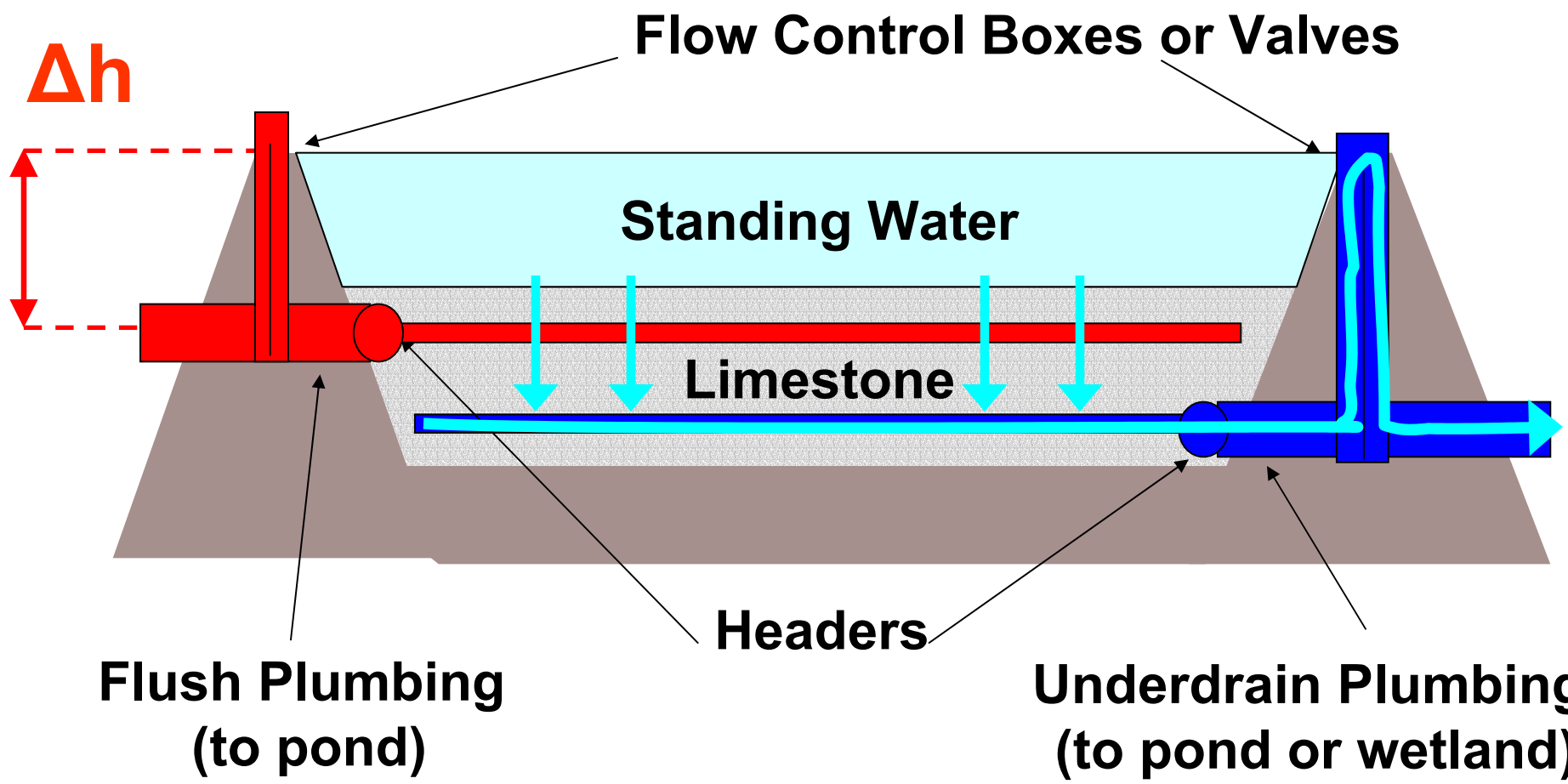
VFPs versus Self-Flush

- Compost over limestone
- Large retention time (days)
- Downflow / Downflush
- Operator controls frequency and duration of flush (several times per year)
- Flush flow rate limited by plumbing network design

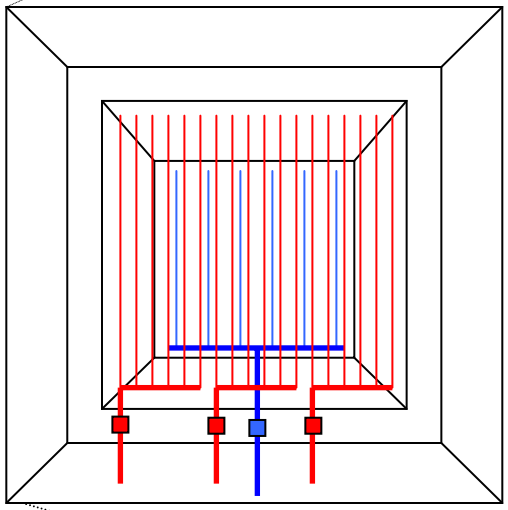
- Usually just limestone
- Low retention time (hours)
- Upflow / Downflush
- Design (capacity and flow rate) controls frequency and duration of flush (several times per day)
- Flush flow rate limited by siphon

Designed and operated based on “best guesses” because few studies on solids removal, life cycle costs, cost/effectiveness, etc.

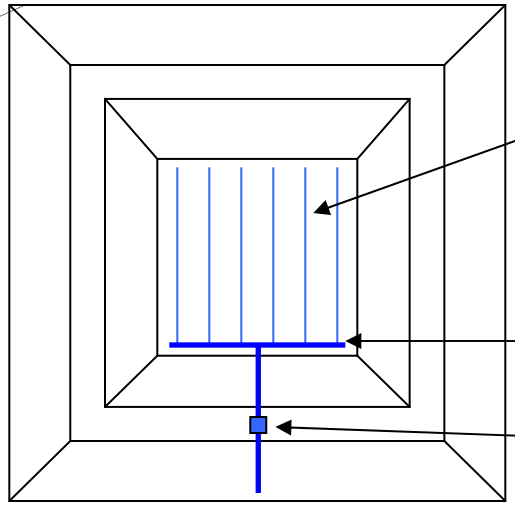
VFP Basics


Δh
Flow Control Boxes or Valves
Standing Water
Limestone
Headers
Flush Plumbing
(to pond)
Underdrain Plumbing
(to pond or wetland)

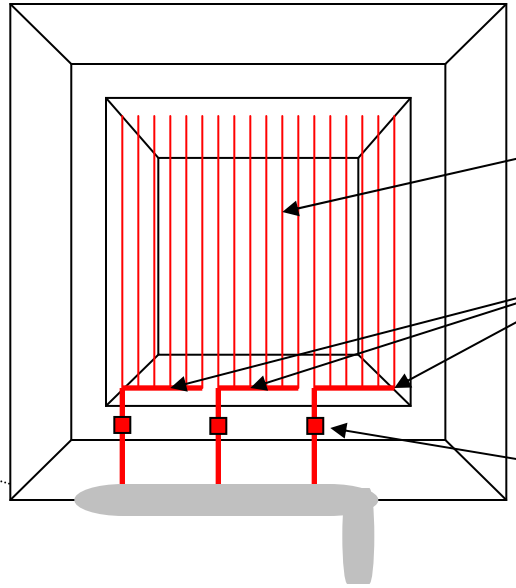
VFP Plan View



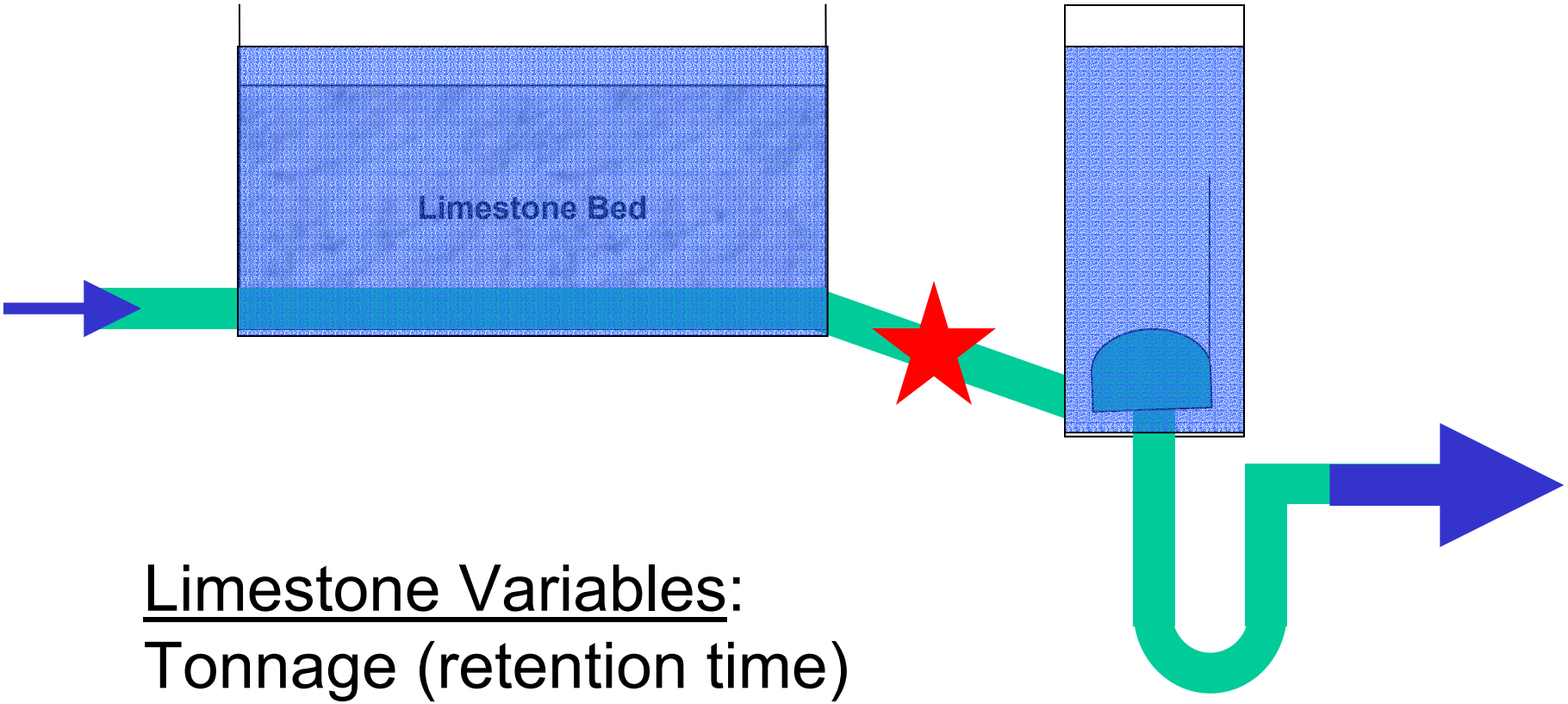
Underdrain Plumbing



Flush Plumbing



Self Flushing Basics



Limestone Variables:
Tonnage (retention time)
Size of aggregate
Depth and area
Plumbing design

Siphon Variables:
Height of Trigger
Rate of Flush

Figure 2A

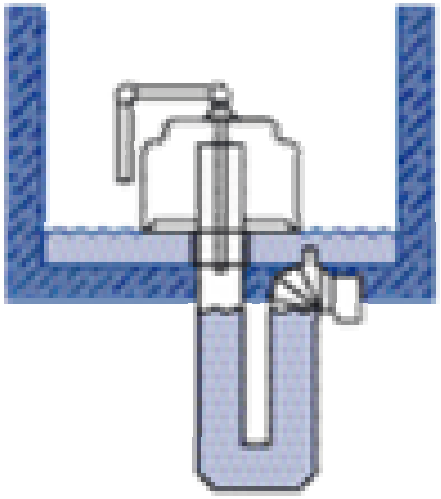


Figure 2B

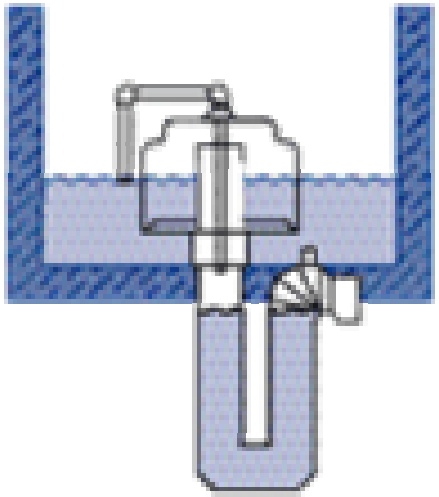


Figure 2C

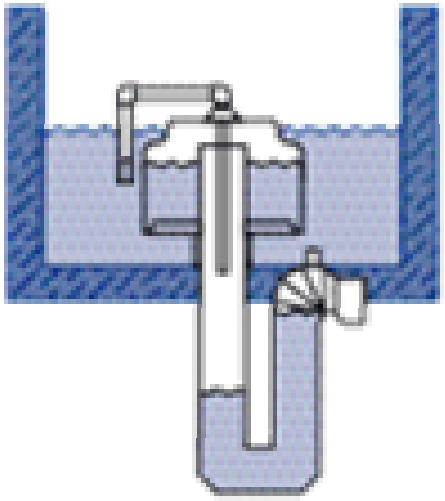


Figure 2D

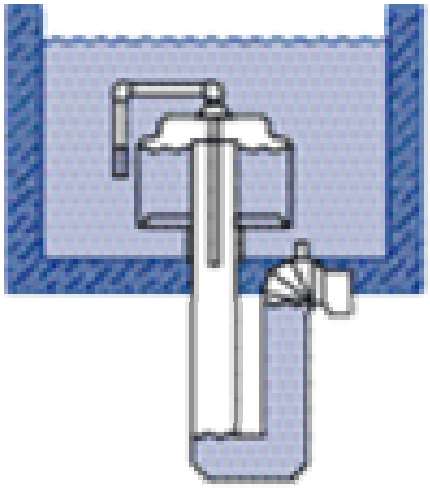


Figure 2E

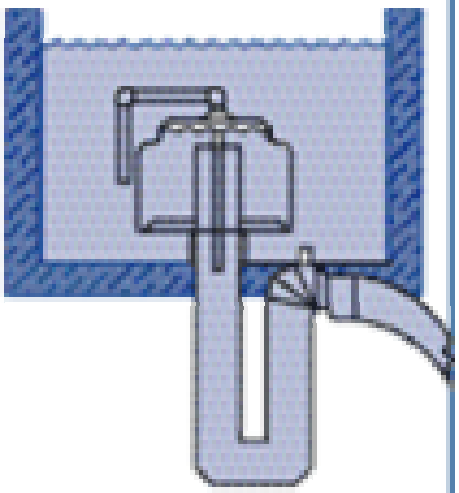
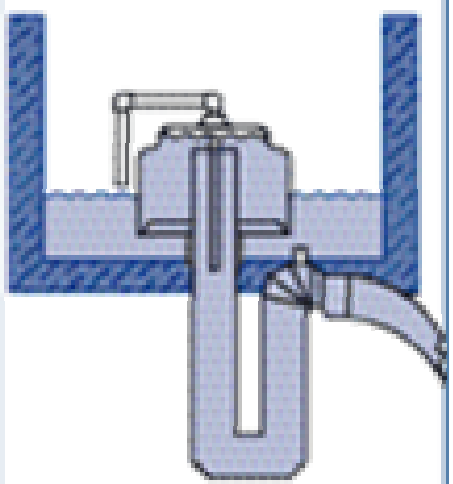


Figure 2F



Figures courtesy of Fluid Dynamic Siphons, Inc (www.siphons.com)

Q_f

- Flow rate during the flush
- Larger flow rate is more likely to move particles
- Individual orifices have small areas of influence
- Systems compared based on the “superficial velocity”

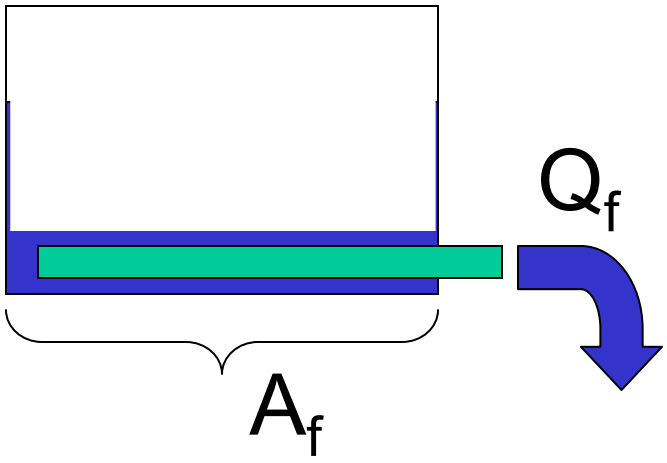
Superficial Velocity

$$V_s = \frac{Q_f}{A_f}$$

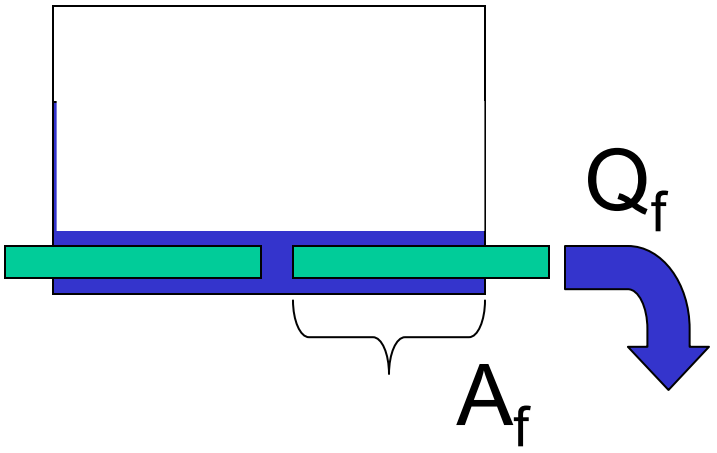
Flush Flow Rate (gpm or m^3/sec)

Area being flushed (ft^2 or m^2)

- If the entire pond is flushed, Vs ~ rate of water level drop

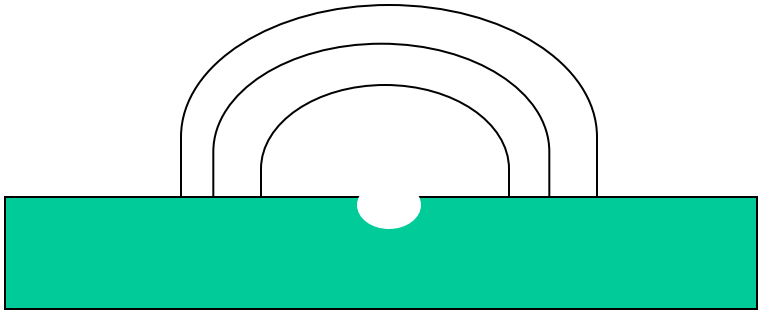


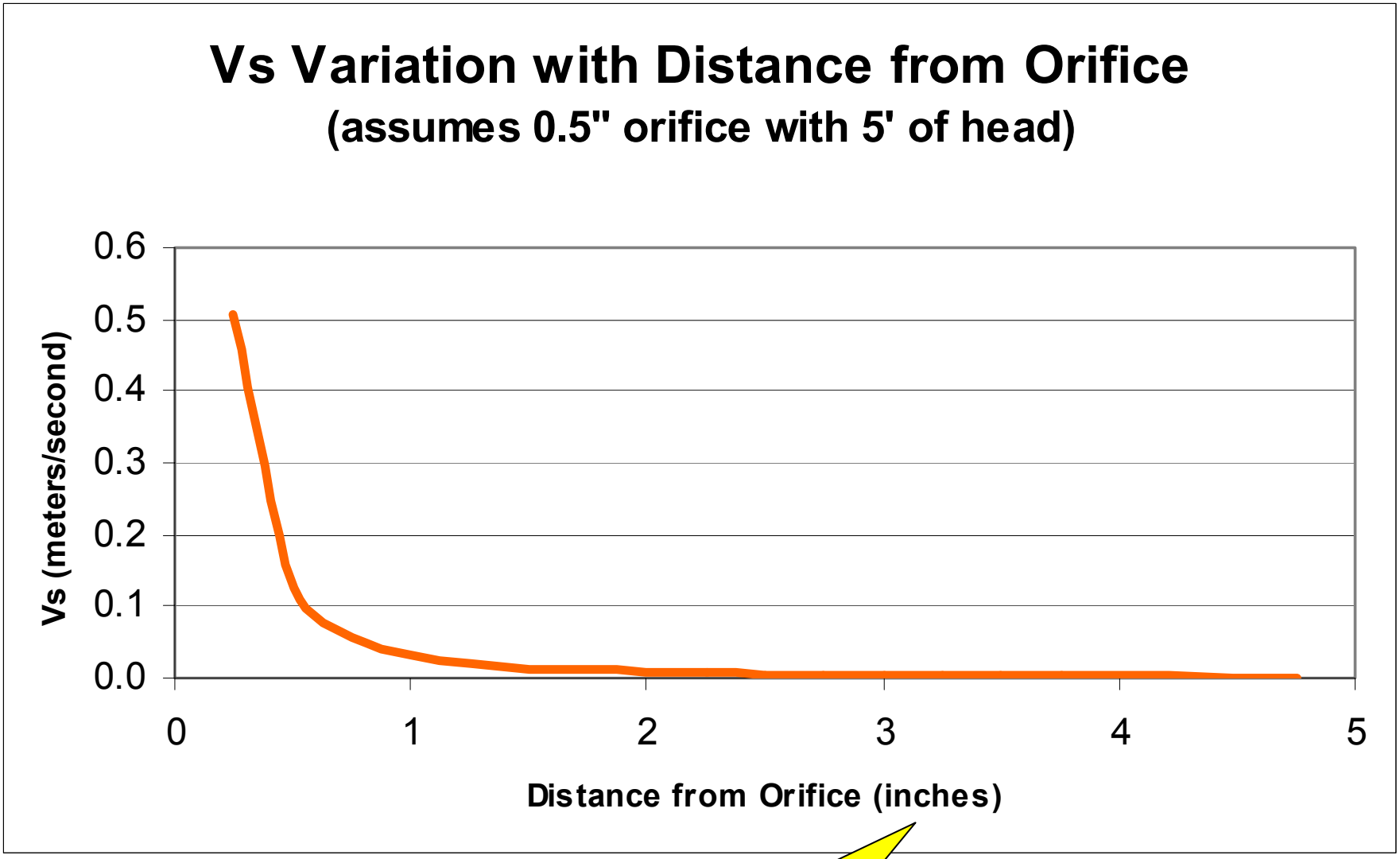
- Not the case if pond has "zones"



The “Small” View

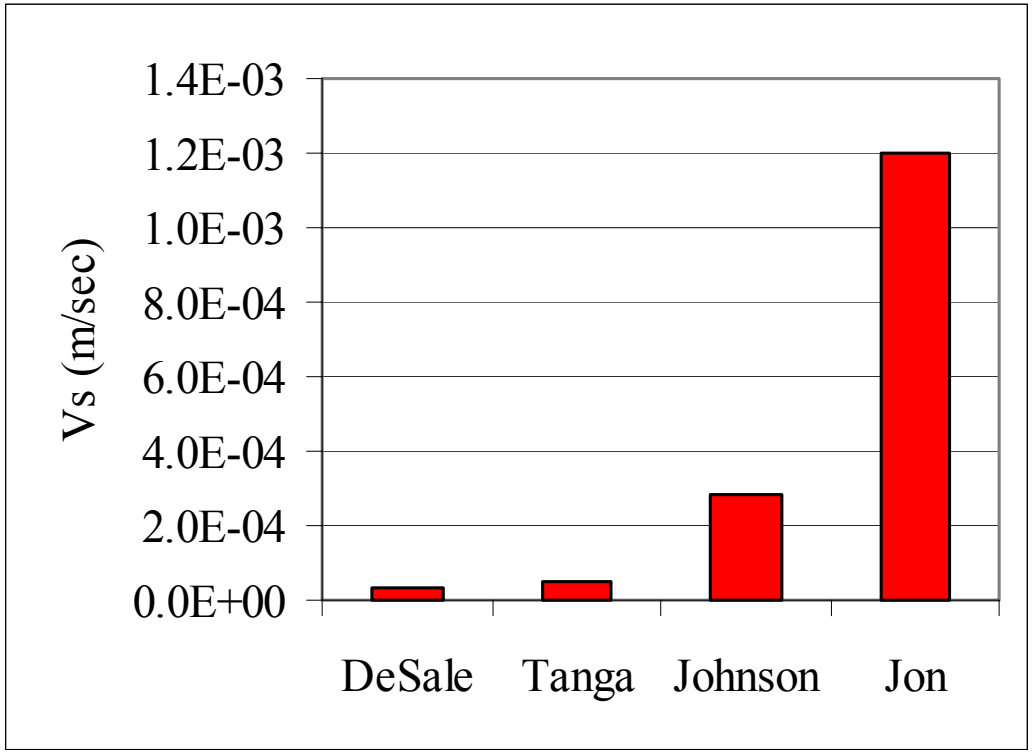
- Water is flushed through orifices, usually 0.5” diameter
- Under 5 feet of head, about 7 gpm/orifice
- Assuming a “dome of influence:”




Vs Variation with Distance from Orifice
(assumes 0.5" orifice with 5' of head)
Vs (meters/second)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3
4
5
Distance from Orifice (inches)
Note: inches, not feet

What Vs is out there

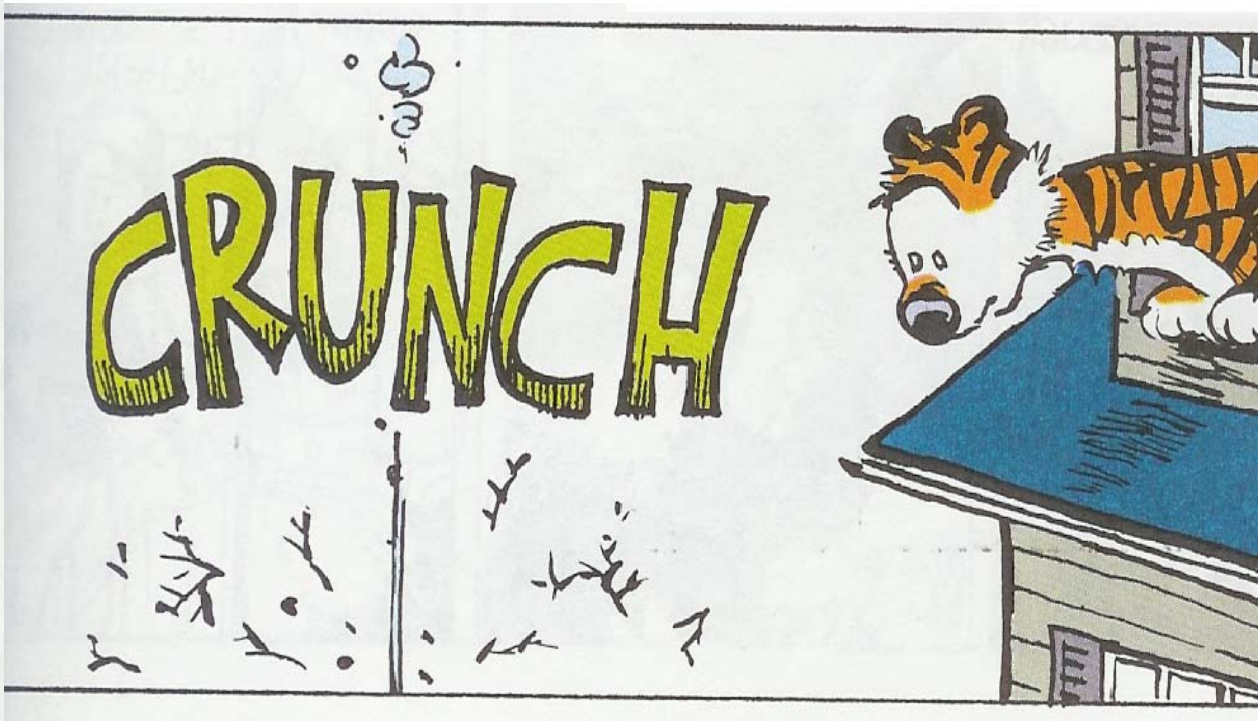
System
DeSale II (Butler County, PA)
Tangascootack I (Clinton County, PA)
Johnson Run (Elk County, PA)
Jonathan Run (Centre County, PA)



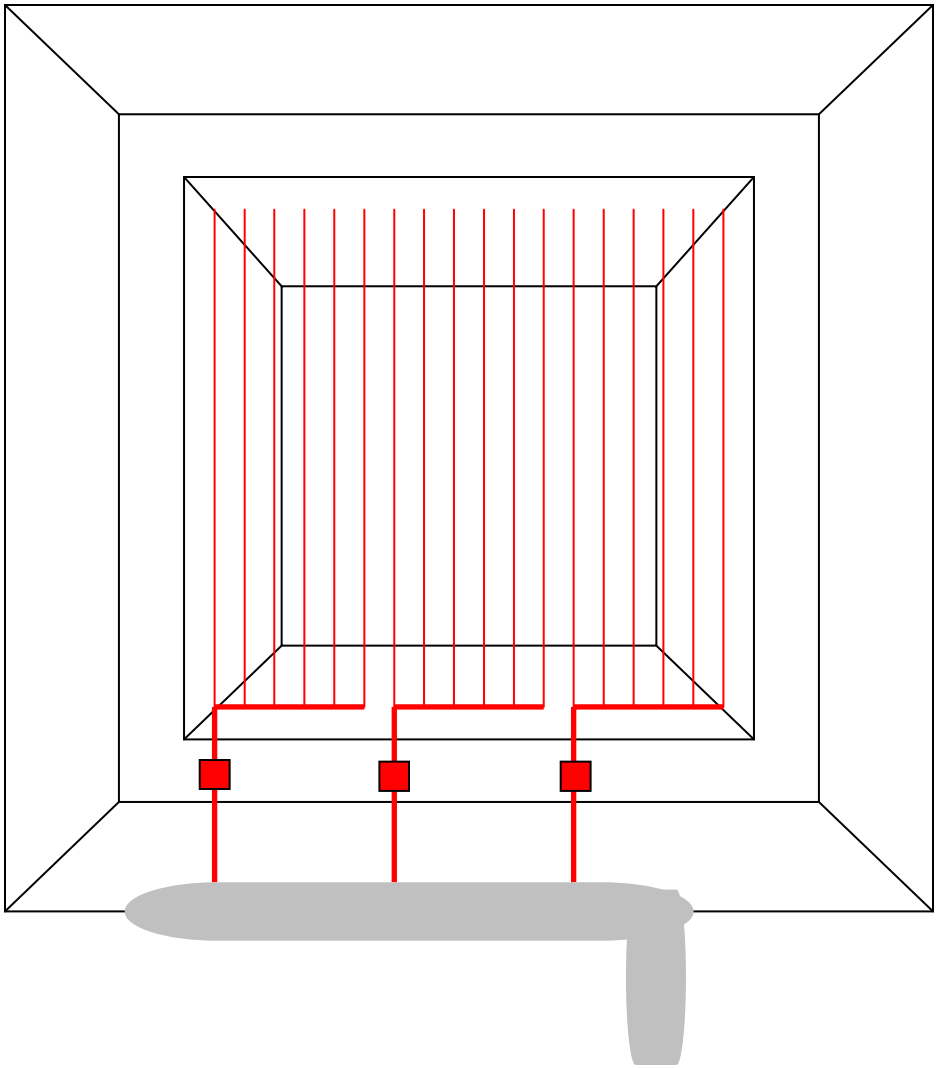
Uses and Limits of Vs

- Can be used to compare “apples to apples”
- Gives a basis of evaluating alternative designs
- Vs required to move AMD particles is not known; may vary based on influent chemistry, time between flushes, etc.
- Until more is known, maximize Vs

Gravity Flow Design



Limits to flush flow rate



Plumbing Suspects:

1. Orifice size and number
2. Lateral size
3. Header/valve size

Other Potential Culprits:

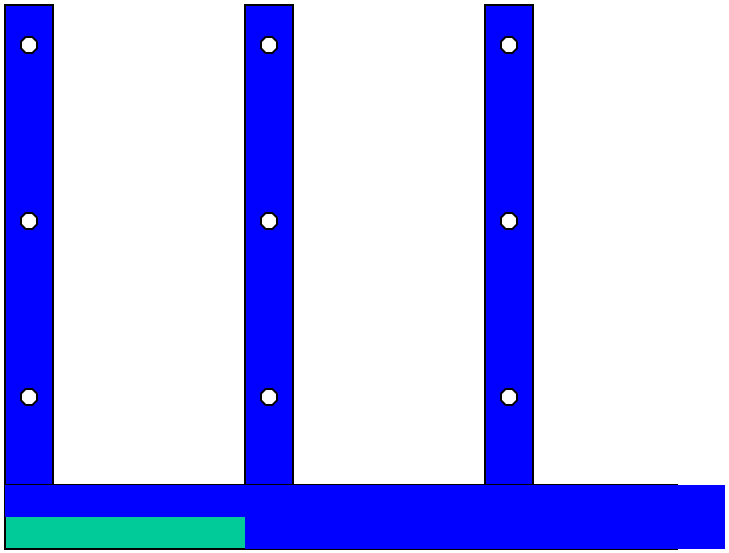
4. Plugged compost
5. Plugged limestone

Design Goals

- Maximize Q . . .
- . . . and have it be consistent throughout system (decrease preferential flow). . .
- . . . to maximize solids removal.
- Orifices, laterals, and headers designed together

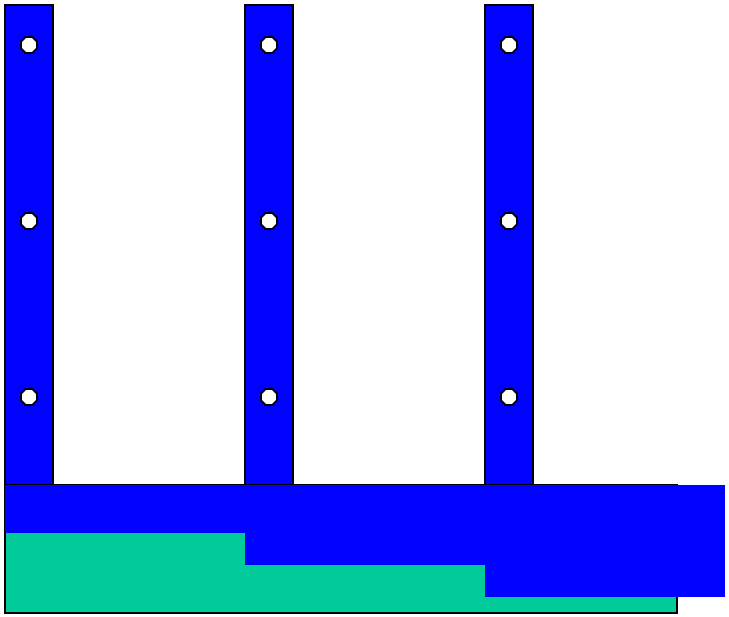
Headers and Laterals

Header Size Controls Flow



Results:
Pressurized flow.
Driving head varies.
Laterals flow unequally.

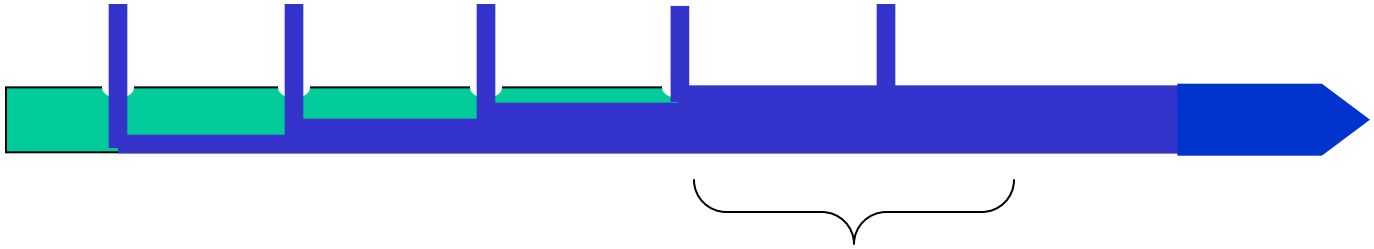
Lateral Size Controls Flow



Results:
Drainage by gravity flow.
Driving head consistent.
Laterals flow equally.

Laterals and Orifices

Lateral Size Controls Flow



Result:
Pressurized flow. Orifices flow unequally.

Orifice Size/Spacing Control Flow

Result:
Drainage by gravity flow. All orifices flow equally.

Design Examples

VFP Design

1. Start with basic VFP parameters
2. Select a desired Vs value
3. Calculate Qf for various numbers of zones (Qf = Vs x Af) and select header size
4. Pick orifice size and calculate the flow per orifice
5. Calculate number of orifices (# = Qf/Qo)

1. 20,000 square feet total (70’ by 285’)
2. Vs = 0.0006 ft/sec (0.000056 m/sec)
3. 1 zone = 5,400 gpm
   2 zones = 2,700 gpm
   3 zones = 1,800 gpm
   4 zones = 1,350 gpm √
4. At 5’ of head, a 0.5” diameter orifice flows 7 gpm
5. 1,350 gpm / 7 gpm = 193 orifices / zone

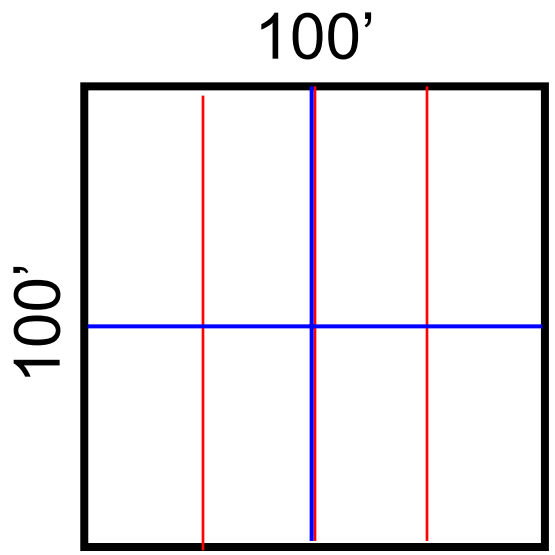
VFP Design, cont.

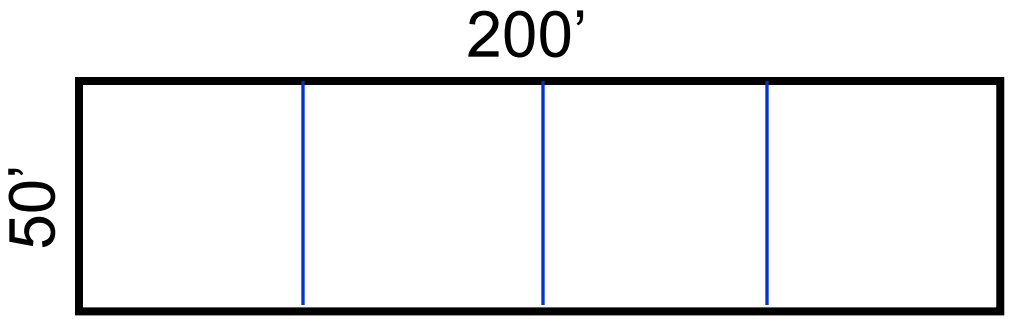
6. Evenly distribute the orifices	6. 1 orifice every 25 square feet
7. Based on 5’ spacing, calculate number of laterals and flow/lateral	7. 70 feet / 5 feet = 14 laterals with 95 gpm / lateral
8. Select a lateral size	8. 4” laterals

Final design: 20,000 square foot VFP (70’ x 285’) divided into 4 zones with 4” laterals spaced 5’ apart, into 12” headers

A Note About L:W Ratios

- Sometimes dictated by site conditions
- Does not affect header sizes
- Does affect lateral sizes
- Zones can be divided several ways





Self-Flushing Design

1. Start with average and high flow values	1. 60 gpm average, 100 gpm high flow
2. Select desired time between flushes	2. 20 hours at average flow (12 hours at high)
3. Calculate required tonnage of limestone	3. 1,200 tons

Vol. of Pores = $\frac{60\ \text{gal}}{\text{min}} \times \frac{60\ \text{min}}{\text{hour}} \times 20\ \text{hours} \times \frac{1\ \text{ft}^3}{7.48\ \text{gals}} \times \frac{1\ \text{CY}}{27\ \text{ft}^3} = 357\ \text{CY}$

Tons of LS = 357 CY pores $\times \frac{1\ \text{CY LS}}{0.4\ \text{CY pores}} \times \frac{1.35\ \text{tons LS}}{1\ \text{CY LS}} =$ **1,200 tons**

Self-Flush Design, cont.

4. Decide on the number of flush ponds
4. 2 (600 tons of limestone per pond)
5. Select a siphon design (flow rate and depth)
5. a. 2,000 gpm @ 5’
   b. 1,500 gpm @ 8’
6. Check Vs

a. 600 tons of limestone 5’ deep covers 2,400 ft^2.
At 2,000 gpm flush, **Vs = 0.0018 ft/sec**

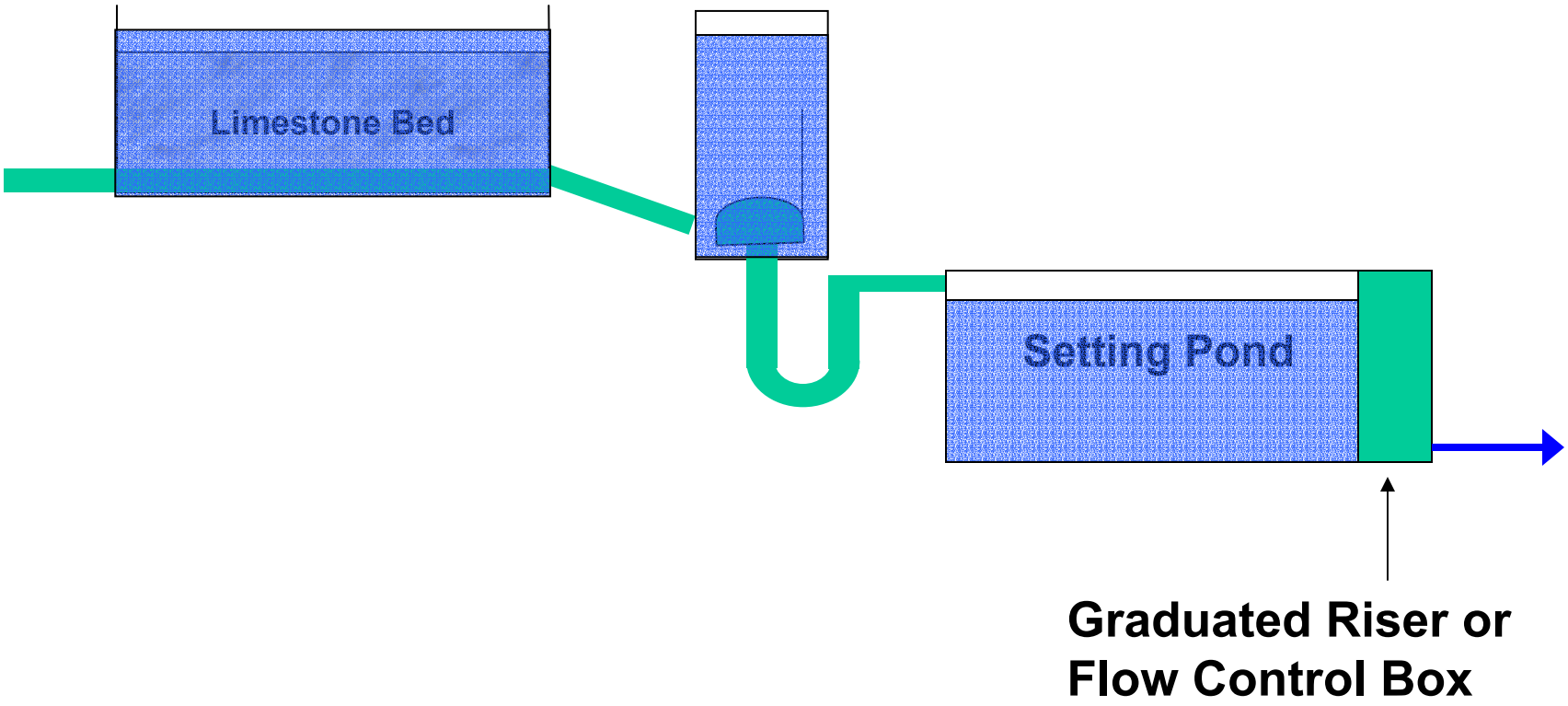
b. 600 tons of limestone 8’ deep covers 1,500 ft^2.
At 1,500 gpm flush, **Vs = 0.0022 ft/sec**

7. Design plumbing to over-supply the siphon unit

Self-Flushing Design Tips

- Average retention time = ½ flush interval
- Place siphon bell below bottom of tank by one pipe diameter
- Minimize volume in plumbing/siphon housing
- Larger limestone flushes better, smaller limestone makes alkalinity faster
- Timed release of flush water

Timed Release



Note: Pond usually sized to hold several flush volumes

A Word About Recharging

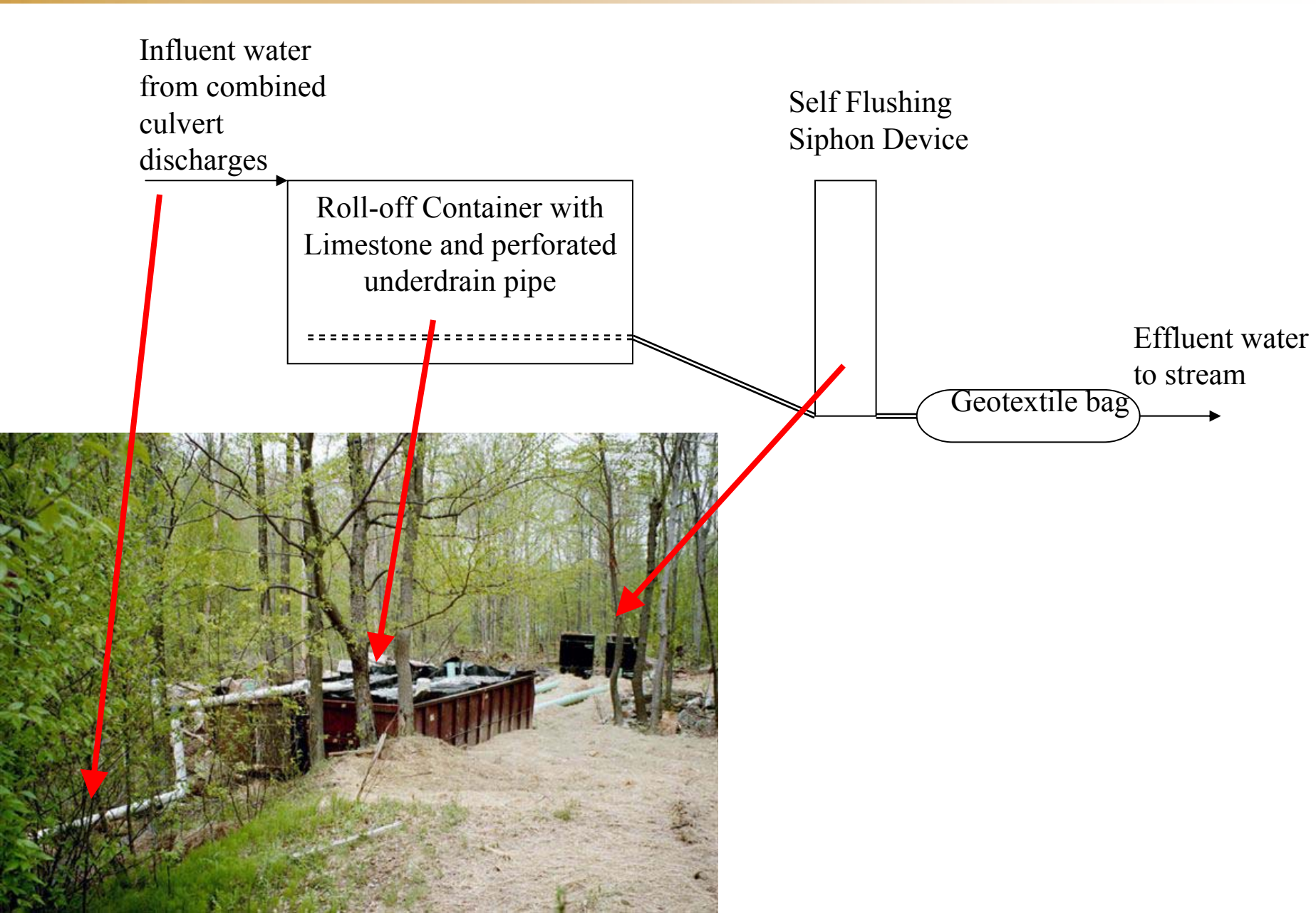
- Limestone is consumed according to the following:

$$(\text{DNet Acid}_{(\text{out} - \text{in})} \times \text{Flow} \div \text{LS Purity}) \times \text{Conversions} = \text{Pounds Per Day Limestone}$$

- Additional limestone “reserve” can be placed above the “wetted zone” for use as limestone beneath dissolves
- Without recharging, performance declines over time

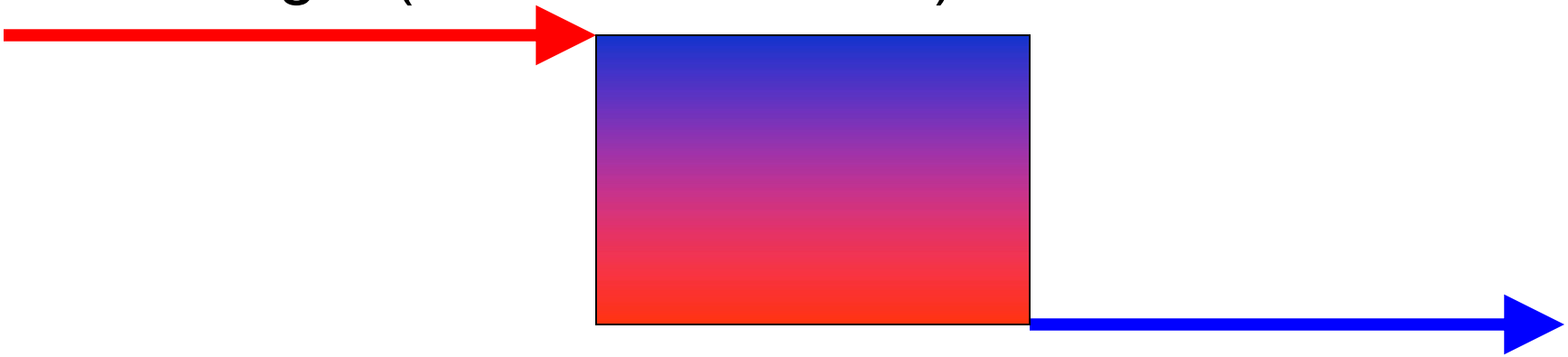
Self-Flushing Results

Jonathan Run



Pilot Scale Results

pH = 3.5
Net Acid = 304
Al = 49 mg/L (total as dissolved)



pH = 5 to 6
Net Acid = -10 to 100
Al = 20 - 40 mg/L total
= 0 – 5 mg/L dissolved

Flushing Performance

- Tanga and DeSale II Flushing events removed ~ 1 % of total solids in limestone
- Jonathan Pilot Systems converted all Al to particulate and flushed 50 – 100% of solids (average = 80%)
- No flushing studies on Johnson or other gravity flow design VFPs
- Follow-up study of Jon Run system being funded by PennDOT—stay tuned!

Looking Forward

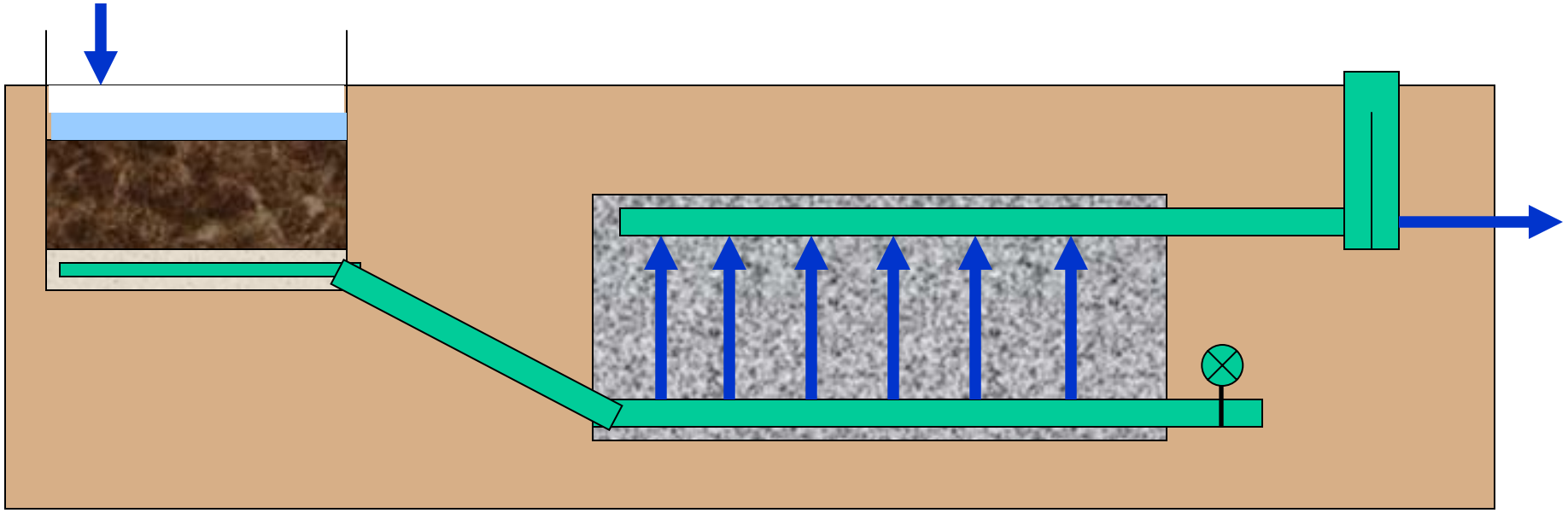
The Next Generation: Audenreid

- 120’ diameter tanks, 10’ of limestone
- 9,000 gpm flush rate
- Operator can adjust flush depth from 0 – 5’

The Next Generation: Punxy

- Separate beds for compost and limestone
- Limestone is 8’ deep, upflow, downflush

Design Advantages



- Thicker components mean a smaller footprint (more flushing head, higher Vs)
- Separate components will simplify maintenance
- Limestone is upflow / downflush
- Ability to develop driving head over time

06/16/2005

Cost Considerations

- Gravity-flow flush network for VFPs
  - Costs an additional $1.50 - 2.00 (installed) per square foot of VFP
  - Complicates rebuilding the system
  - Bigger pipes and valves, more $$$
- Self-flushing systems
  - Cost an additional $2,500 – 6,000 per unit
  - Low retention times mean less limestone up-front but more frequent “recharging”
- “The Black Box” = $3,500

What's Next?

- Monitoring and studies of existing systems
- Flushing studies on VFPs with various Vs values and designs
- Finding the limits of self-flushing treatment
  - Chemistry limits
  - Effective lifespan
  - Most cost/effective Vs value

For More Information….

www.hedinenv.com

- Technical Papers posted
- Project photos and information
- Contact staff

www.siphons.com

Dr. Rose's Talk, Tuesday, 12:40 PM

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Any Questions ?