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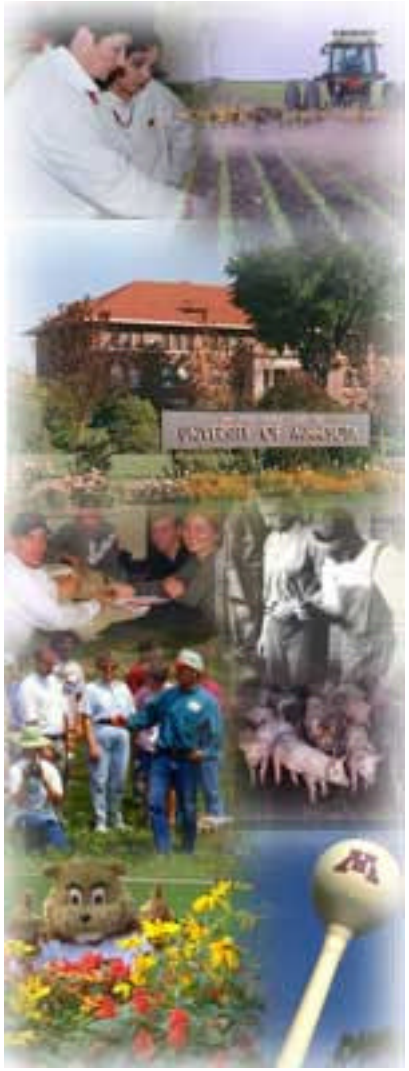
BIOSYSTEMS & AGRICULTURAL ENGINEERING

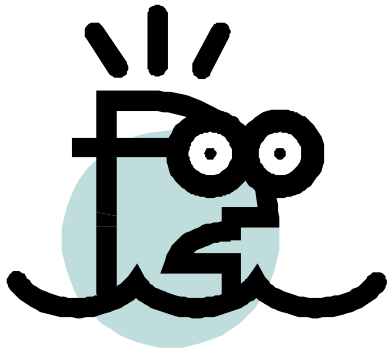


Subsurface (Tile) Drainage Design

Outline

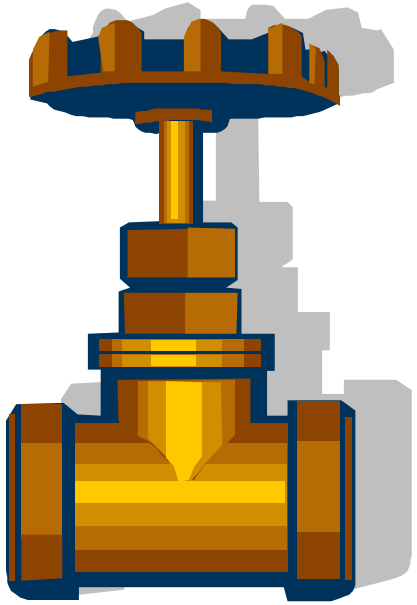
- How drainage works
- Drainage design objectives
- The Design Process:
  - *Outlet*
  - *Layout & location of lines*
  - *Spacing & depth*
  - *Grade*
  - *Drain Sizing*
- Design Tools (throughout)

How Drainage Works

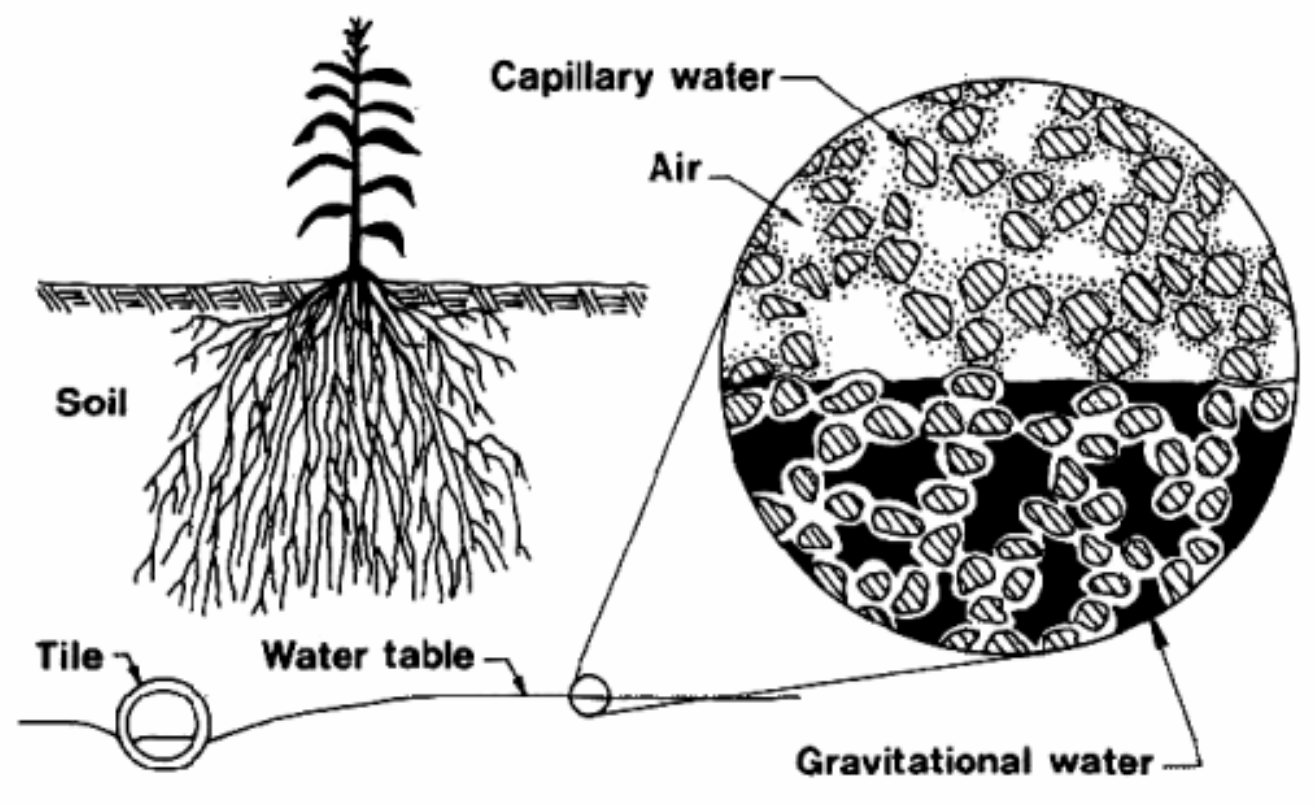


Drainage Fundamentals

- Drainable water
- “Physics” of drain flow
- Influence of design choices



Drainable Water



Drainable Water

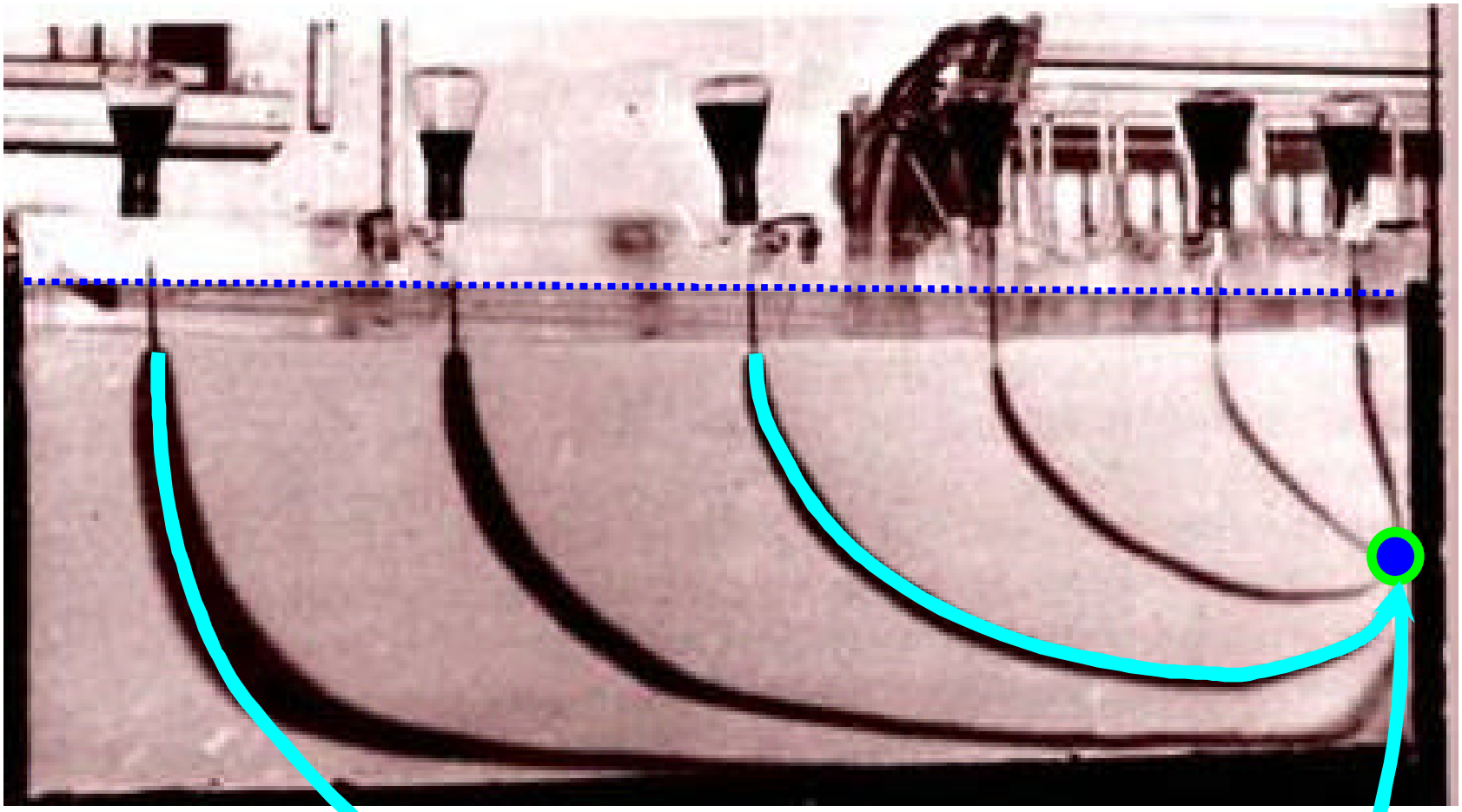
Soil Texture	Field Capacity *(% by vol)*	Wilting Point *(% by vol)*	Drainable Porosity *(% by vol)*
clays, clay loams, silty clays	30-50%	15-24%	3-11%
well structured loams	20-30%	8-17%	10-15 %
sandy	10-30%	3-10%	18-35 %

Example: a 5% drainable porosity means that the watertable drops/rises 100 inches for every 5 inches of water drained.

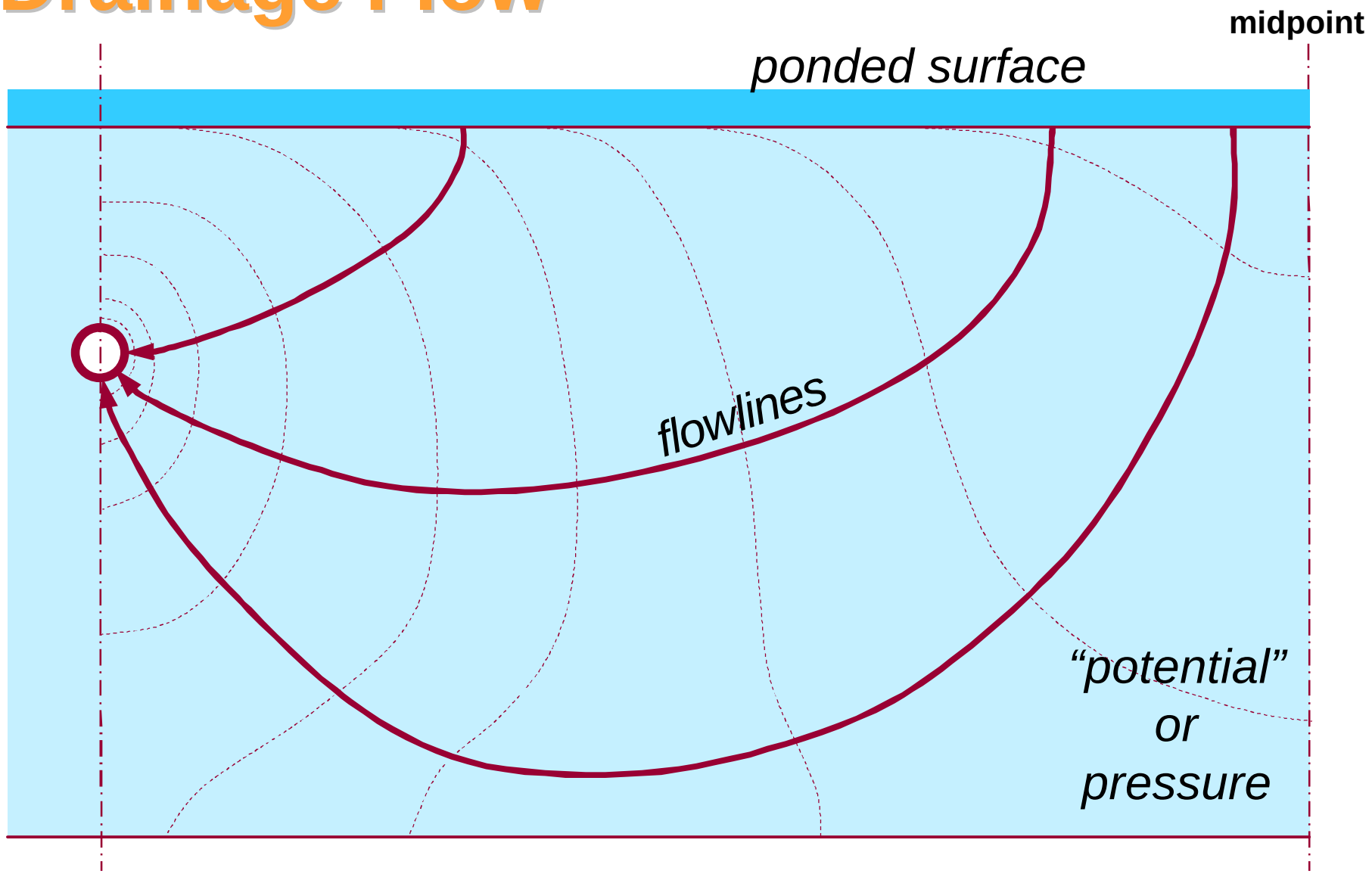
Drainable Water

- Example:A clay loam soil with a watertable at 6” below the soil surface is drained to a watertable depth of 3.5’. How much water was drained from the soil profile?
- Solution: Assuming a Pd of 8%, the volume drained is:
- vol = $8 \times (3.5’ - .5’) \div 100 = 0.24’ = 2.88”$

“Physics” of Drainage Flow



Drainage Flow



Influence of “Design” Choices

- Design choices:
  - *Drain depth*
  - *Drain spacing*
  - *Drain size*
  - *System layout*
  - *Outlet configuration (elev, pumped, natural)*
- Do all of these affect water flow to the drains?

Drainage Design Objectives

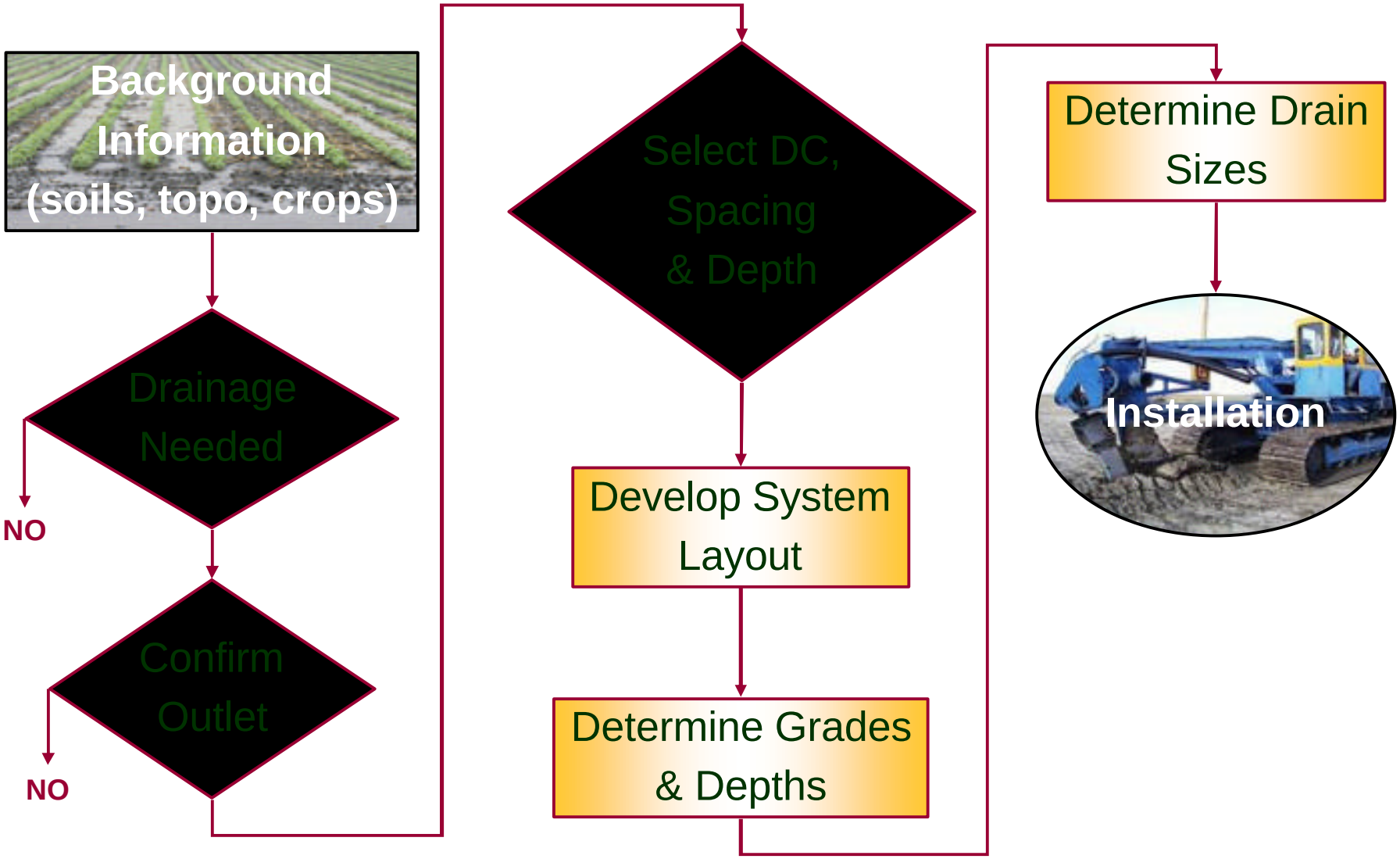
You tell me!

Possible Design Objectives

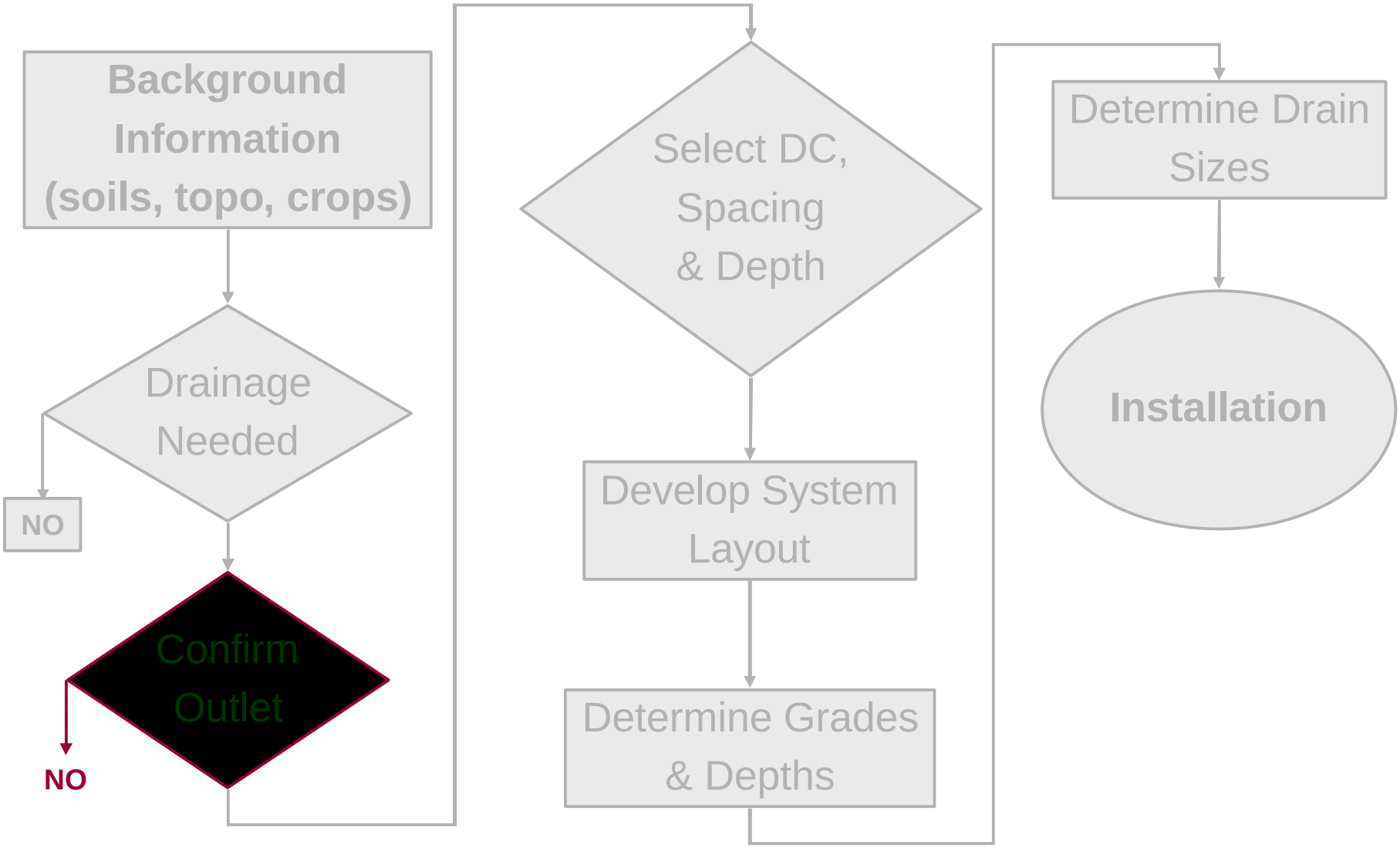
- Remove as much water as quickly and as cheaply as possible
- Design a system that functions with hydraulic efficiency and uniformity
- Design & install a maintenance-free system
- Provide for the agronomic needs of the crop
- Minimize unwanted environmental effects to the extent possible
- Design with future outlet management in mind

The Design Process

Design Process Flowchart



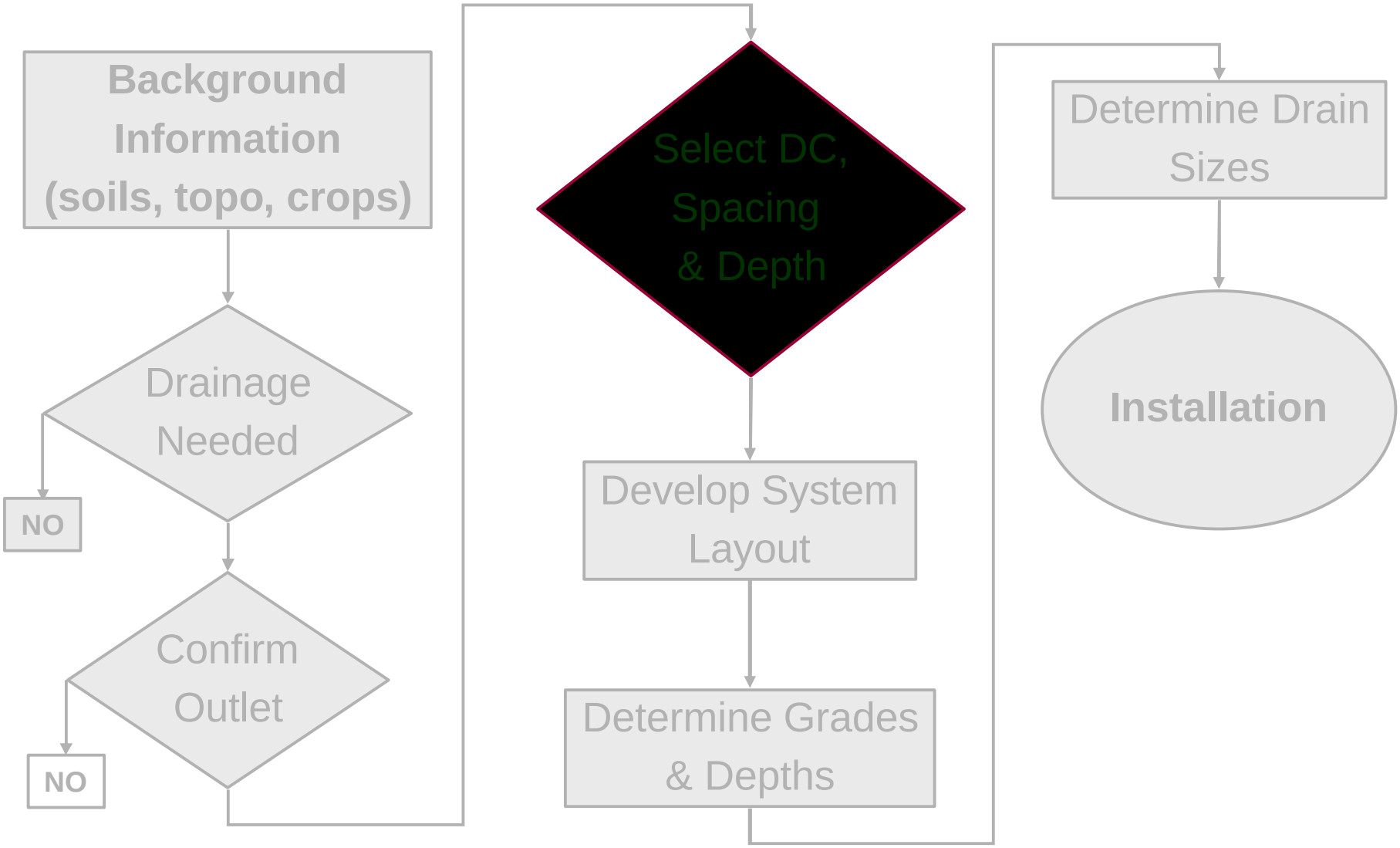
Design Process Flowchart



Outlets

- Ditch, tile main, other?
- Location (right of way issues)
- Capacity (flow and timing issue)
- Rules & regs
- Elevation (physical structure & water surface)

Design Process Flowchart



Drain Spacing & Depth

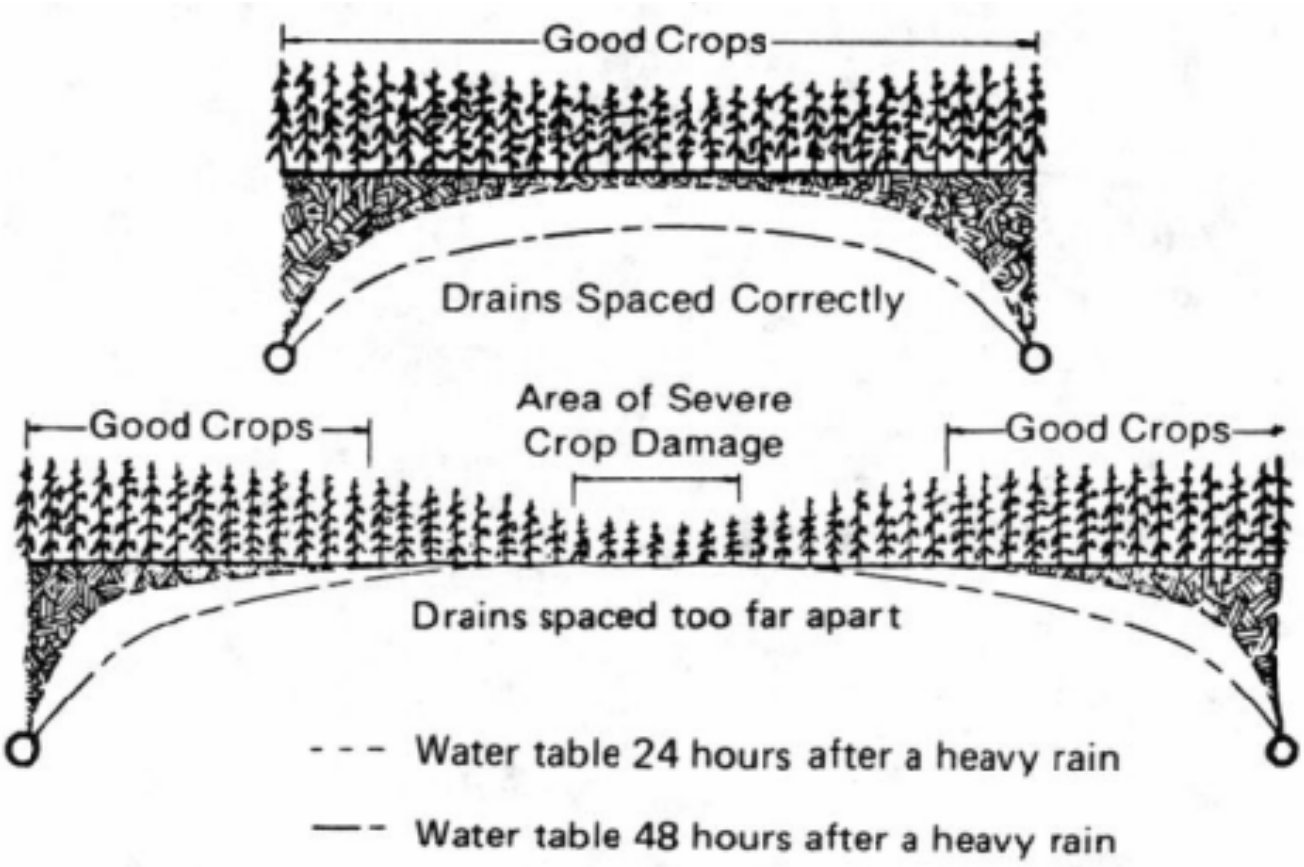
- What are we doing by selecting spacing & depth?
  - *DRAINAGE COEFFICIENT*
- What factors push us wider/narrower, deeper/shallower?
- Importance of uniform drainage

Generalized Drainage Coefficients

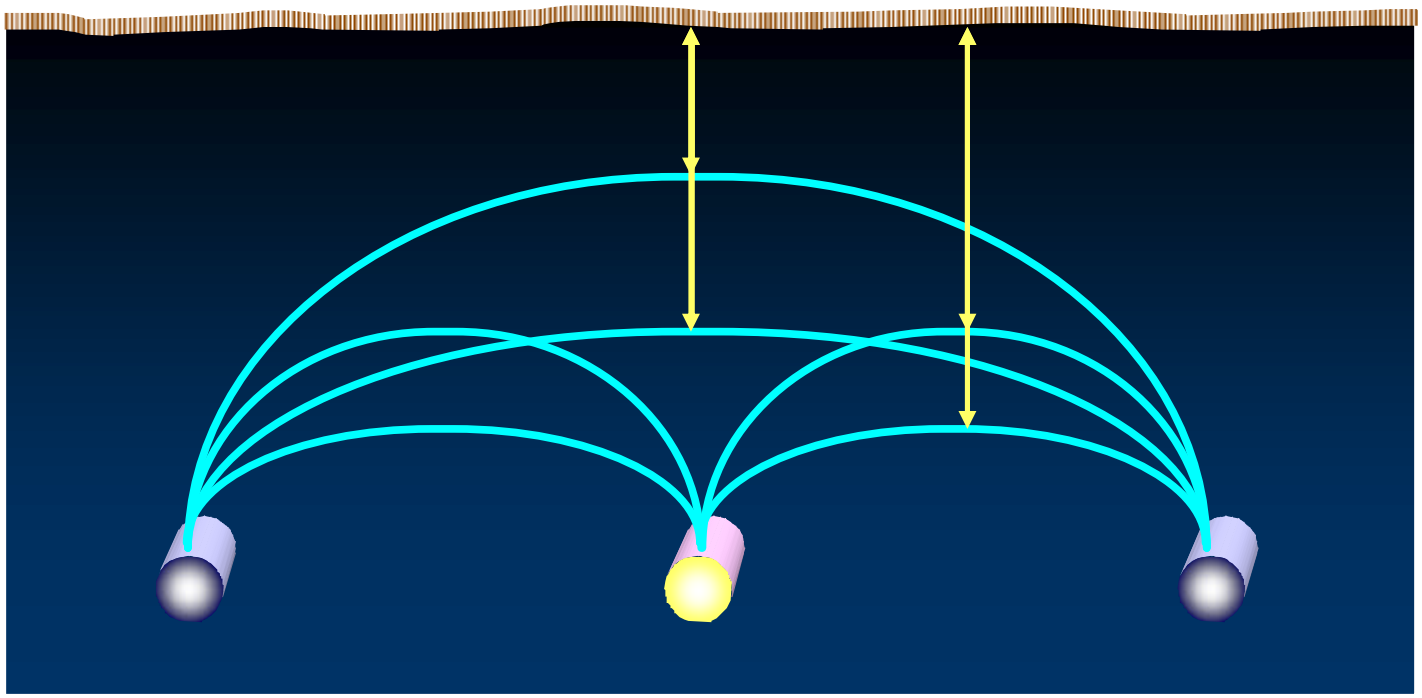
Soil Type	Inches to be removed in 24 hours	
	Field Crops	***Truck Crops***
Mineral	3/8 – ½	½ – ¾
w/ surface inlets	½ – 1	1 – 1-½
Organic	½ – ¾	¾ – 1-½
w/ surface inlets	1 – 1-½	2 – 4

- We don't really know what the "right" number is for our soil, crop, and region
- Risk management for farmer
  - *Protect crop for any condition?*
  - *Protect crop for average condition?*

Drain Spacing: How Close is Close Enough?

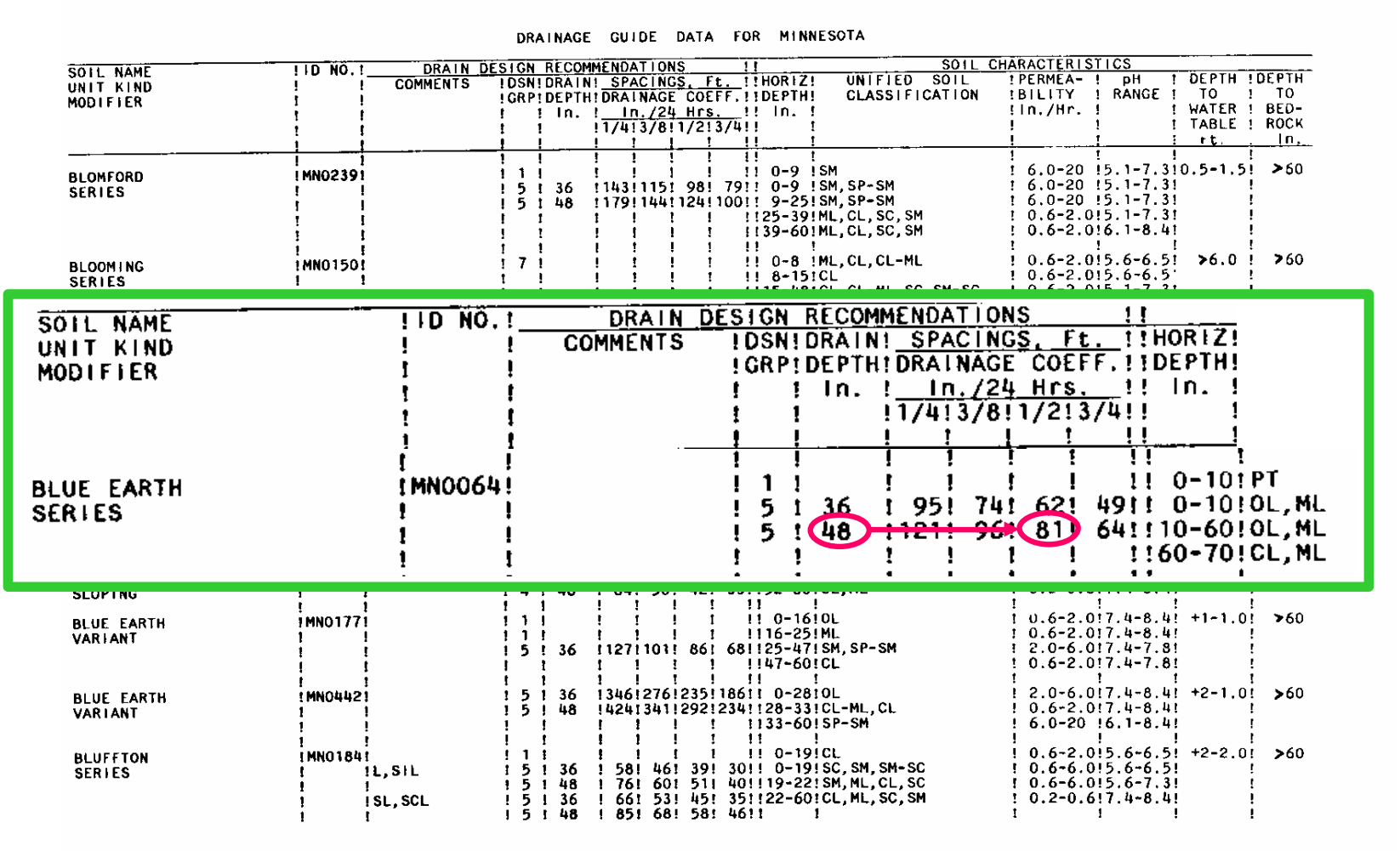


Drain Spacing: But how close is too close?



- Issue is both economic and environmental

Minnesota Drainage Guide



DRAINAGE GUIDE DATA FOR MINNESOTA

SOIL NAME UNIT KIND MODIFIER	ID NO.	DRAIN DESIGN RECOMMENDATIONS COMMENTS	DSN GRP	DRAIN DEPTH In.	SPACINGS, Ft. DRAINAGE COEFF. In./24 Hrs. 1/4	3/8	1/2	3/4	HORIZ DEPTH In.	UNIFIED SOIL CLASSIFICATION	SOIL CHARACTERISTICS PERMEABILITY In./Hr.	pH RANGE	DEPTH TO WATER TABLE ft.	DEPTH TO BED-ROCK In.
BLOMFORD SERIES	MN0239		1						0-9	SM	6.0-20	5.1-7.3	0.5-1.5	>60
			5	36	143	115	98	79	0-9	SM, SP-SM	6.0-20	5.1-7.3		
			5	48	179	144	124	100	9-25	SM, SP-SM	6.0-20	5.1-7.3		
									25-39	ML, CL, SC, SM	0.6-2.0	5.1-7.3		
									39-60	ML, CL, SC, SM	0.6-2.0	6.1-8.4		
BLOOMING SERIES	MN0150		7						0-8	ML, CL, CL-ML	0.6-2.0	5.6-6.5	>6.0	>60
									8-15	CL	0.6-2.0	5.6-6.5		

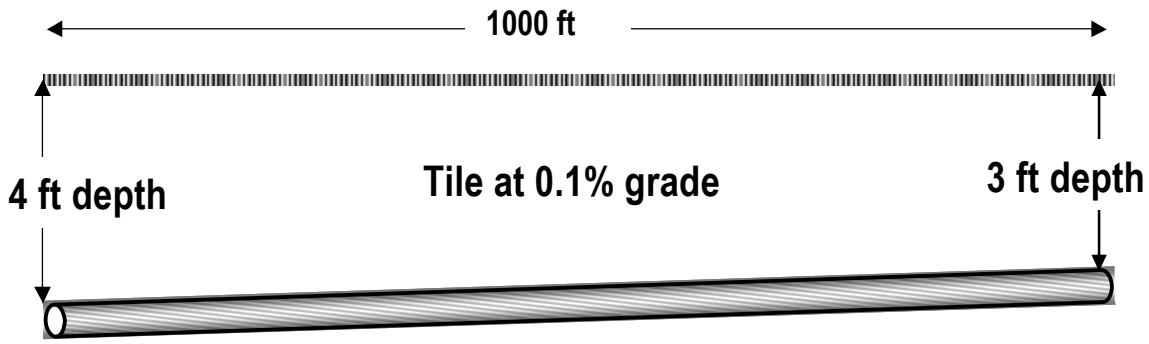
SOIL NAME UNIT KIND MODIFIER	ID NO.	DRAIN DESIGN RECOMMENDATIONS COMMENTS	DSN GRP	DRAIN DEPTH In.	SPACINGS, Ft. DRAINAGE COEFF. In./24 Hrs. 1/4	3/8	1/2	3/4	HORIZ DEPTH In.	
BLUE EARTH SERIES	MN0064		1						0-10	PT
			5	36	95	74	62	49	0-10	OL, ML
			5	48	121	96	81	64	10-60	OL, ML
									60-70	CL, ML

SOIL NAME UNIT KIND MODIFIER	ID NO.	DRAIN DESIGN RECOMMENDATIONS COMMENTS	DSN GRP	DRAIN DEPTH In.	SPACINGS, Ft. DRAINAGE COEFF. In./24 Hrs. 1/4	3/8	1/2	3/4	HORIZ DEPTH In.	UNIFIED SOIL CLASSIFICATION	SOIL CHARACTERISTICS PERMEABILITY In./Hr.	pH RANGE	DEPTH TO WATER TABLE ft.	DEPTH TO BED-ROCK In.
SLOPING														
BLUE EARTH VARIANT	MN0177		1						0-16	OL	0.6-2.0	7.4-8.4	+1-1.0	>60
			1						16-25	ML	0.6-2.0	7.4-8.4		
			5	36	127	101	86	68	25-47	SM, SP-SM	2.0-6.0	7.4-7.8		
									47-60	CL	0.6-2.0	7.4-7.8		
BLUE EARTH VARIANT	MN0442		5	36	346	276	235	186	0-28	OL	2.0-6.0	7.4-8.4	+2-1.0	>60
			5	48	424	341	292	234	28-33	CL-ML, CL	0.6-2.0	7.4-8.4		
									33-60	SP-SM	6.0-20	6.1-8.4		
BLUFFTON SERIES	MN0184		1						0-19	CL	0.6-2.0	5.6-6.5	+2-2.0	>60
		L, SIL	5	36	58	46	39	30	0-19	SC, SM, SM-SC	0.6-6.0	5.6-6.5		
			5	48	76	60	51	40	19-22	SM, ML, CL, SC	0.6-6.0	5.6-7.3		
		SL, SCL	5	36	66	53	45	35	22-60	CL, ML, SC, SM	0.2-0.6	7.4-8.4		
			5	48	85	68	58	46						

- Assumes WT at 1 ft within 1 day after rainfall

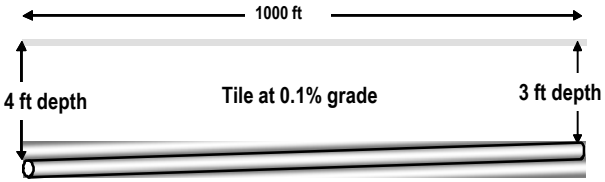
Drain Spacing & Depth

- Design for uniform depth throughout system (depends on layout)
- Depth will of course vary on flat and rolling topography



Drain Spacing & Depth

- For the previous soil:



SOIL NAME / UNIT KIND / MODIFIER	ID NO.	COMMENTS	DSN GRP	DRAIN DEPTH In.	SPACINGS, Ft. DRAINAGE COEFF. In./24 Hrs. 1/4	3/8	1/2	3/4	HORIZ DEPTH In.	
BLUE EARTH	MN0064		1						0-10	PT
SERIES			5	36	95	74	62	49	0-10	OL,ML
			5	48	121	96	81	64	10-60	OL,ML
									60-70	CL,ML

- A foot of depth means a significant change in DC!

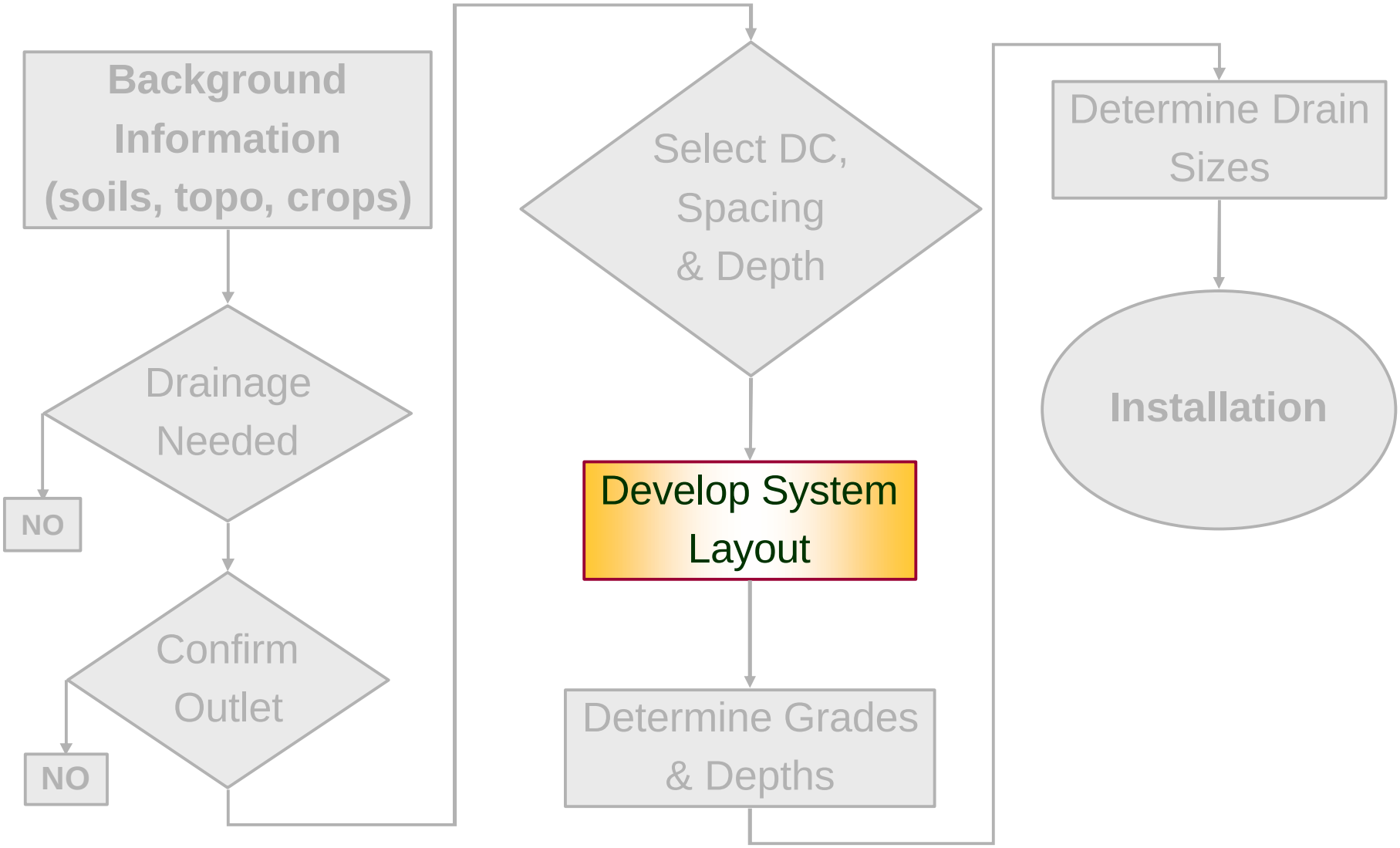
Spacing & Depth

- Many combinations of depth/spacing are possible
- Resources:
  - *Mn Drainage Guide*
  - *Local experience, (farmers, contractors)*
  - *Extension*
- Two important issues:
  - *How narrow is economically justified?*
  - *Moving from deeper/wider to shallower/narrower may have important environmental benefits*

Depth of Cover Requirements

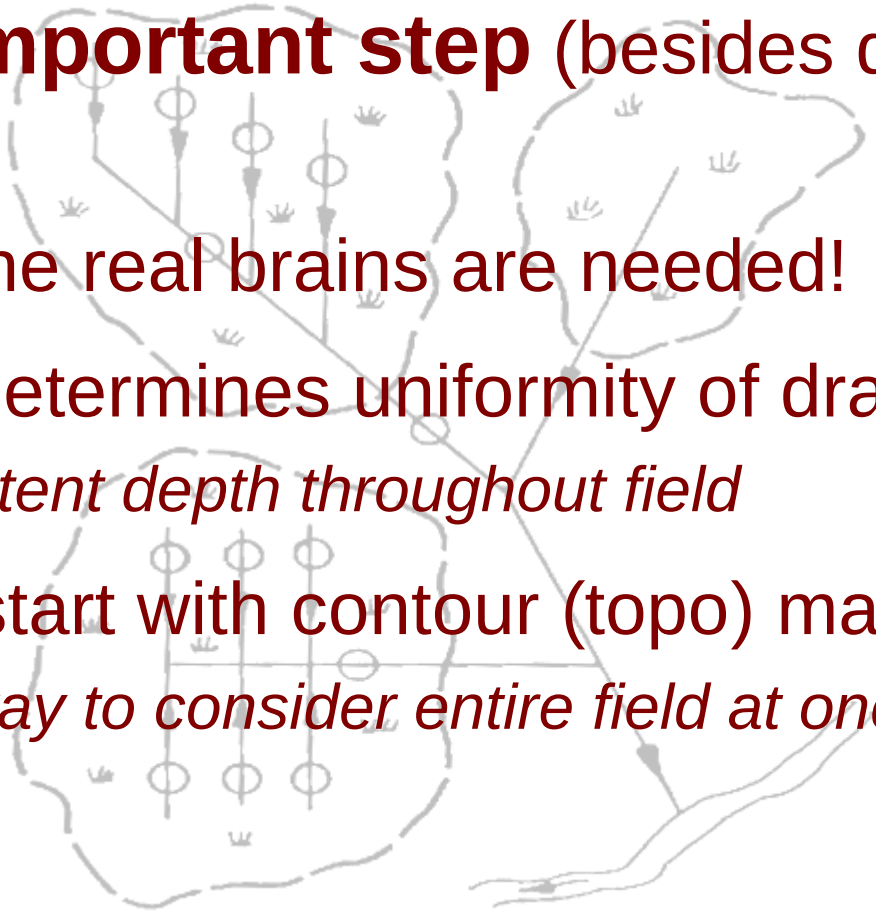
- For a well-bedded drain:
- 2 feet minimum cover for 3, 4, 5 & 6 in pipe
- 2.5 feet minimum cover for 8, 10,12, 15, & 18 in pipe

Design Process Flowchart



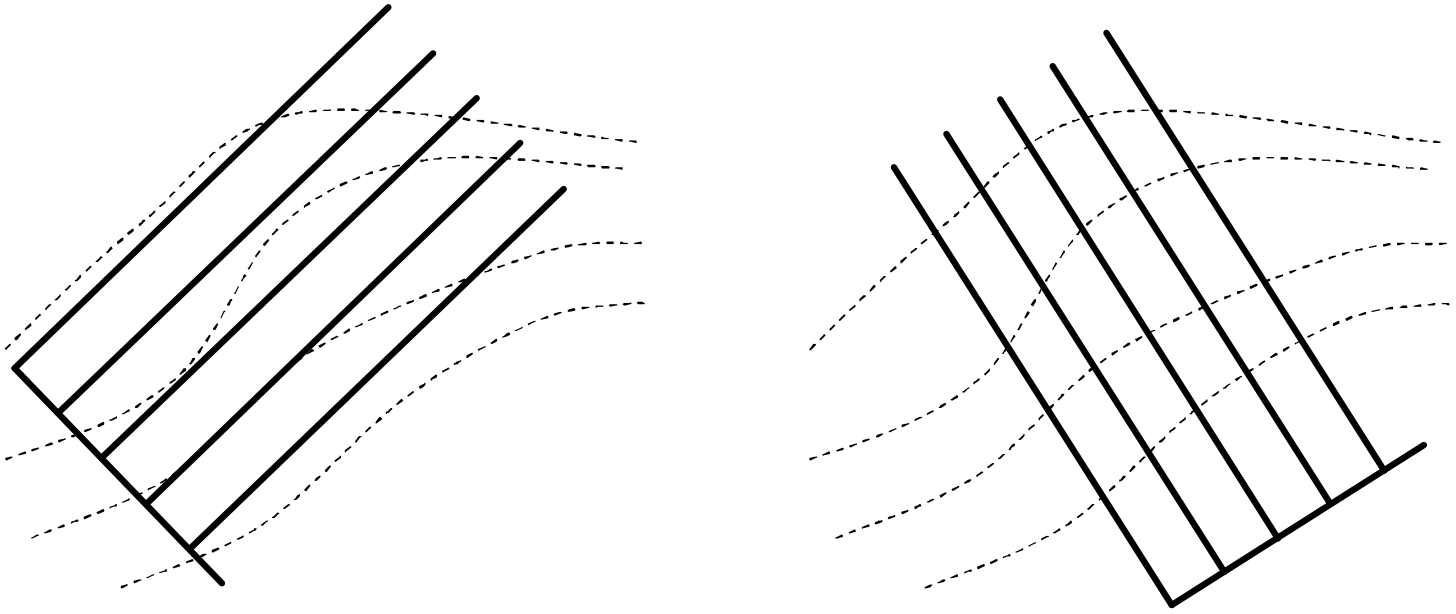
Layout

- **Most important step** (besides determining an outlet!
- Where the real brains are needed!
- Layout determines uniformity of drainage
  - *Consistent depth throughout field*
- Should start with contour (topo) map of field
  - *Only way to consider entire field at once*



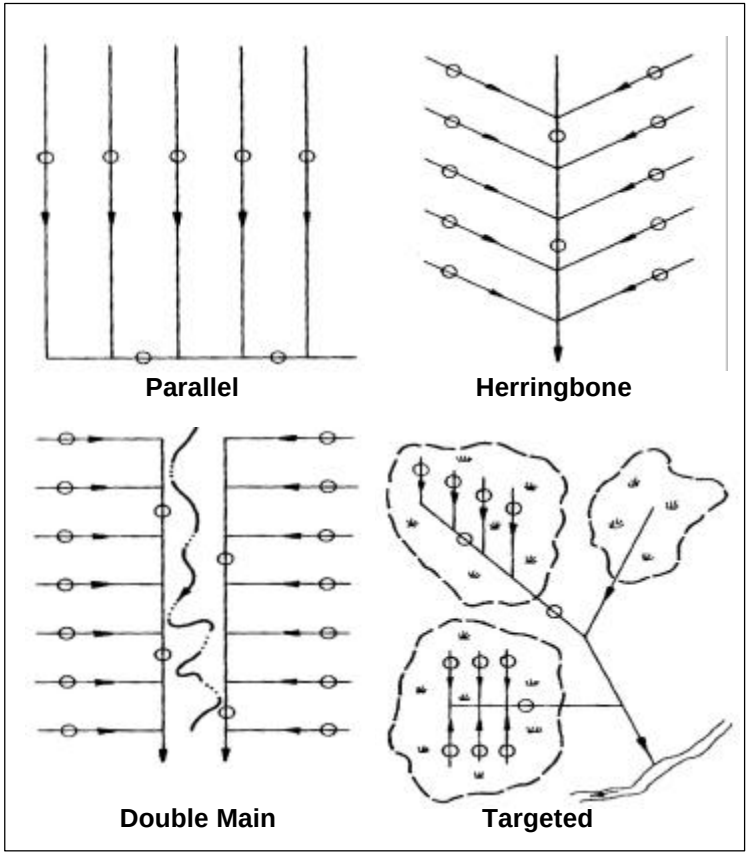
Layout

- Put (sub)mains on steepest grades
- Field laterals more on contours (intercept water)

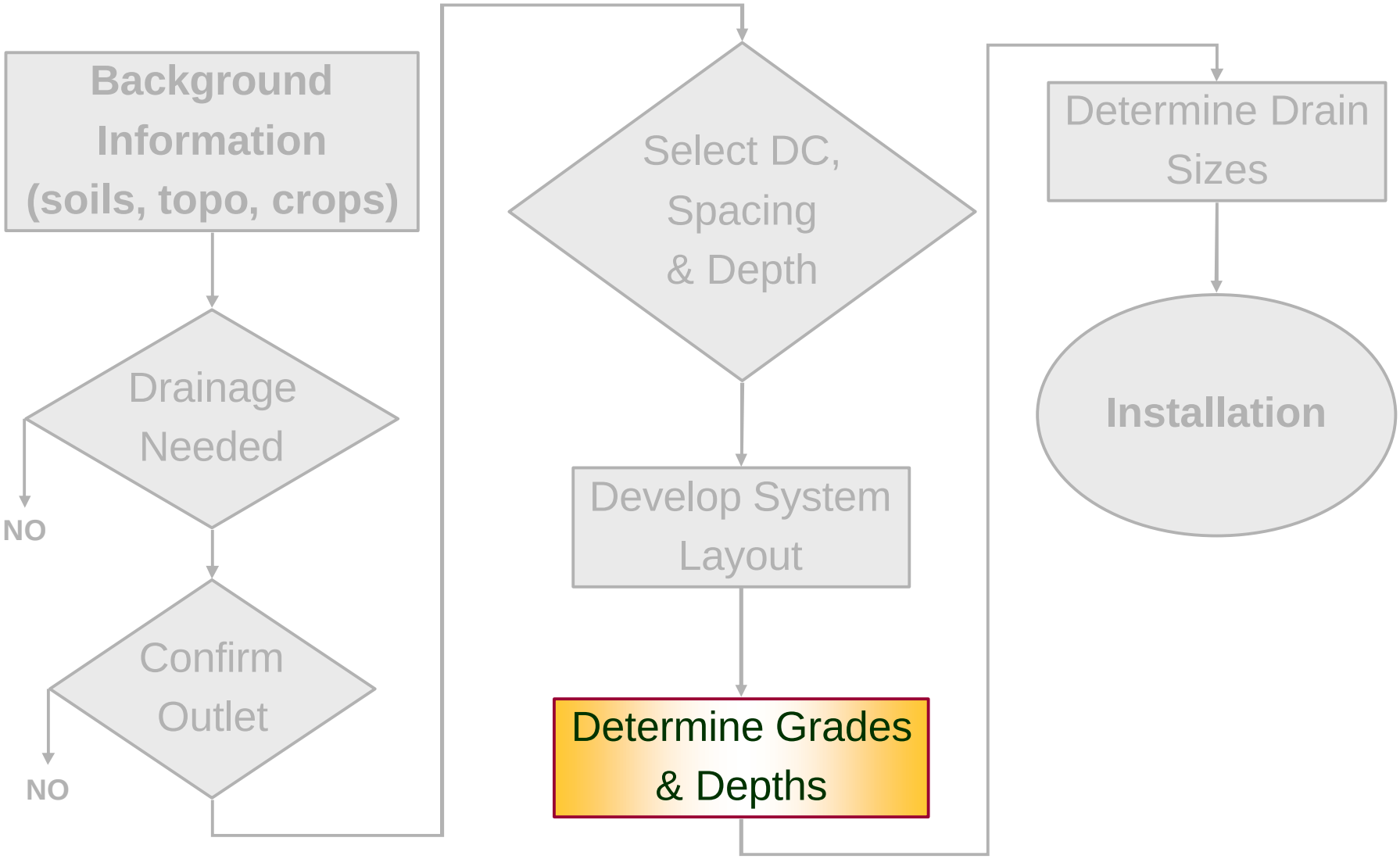


Layout

- Consider & plan for future needs
- Make maps of everything:
  - *As designed*
  - *As built*



Design Process Flowchart



Tile Grades

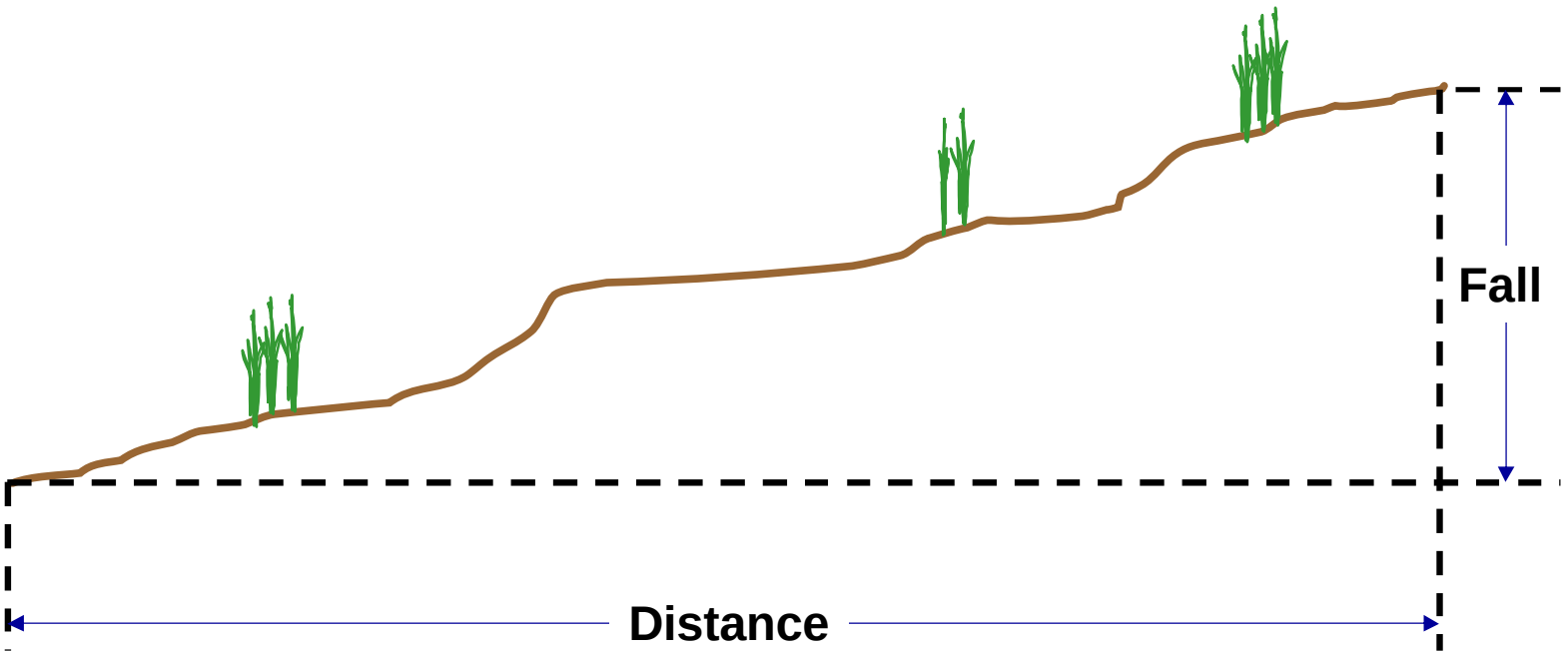
- Enough grade to:
  - *Keep the water moving*
  - *Keep sediment suspended in the water*
- Flat grades
  - *Shallower average depth, less digging*
  - *More prone to sediment build up*
  - *Installation errors more costly*
- Steep grades -- Higher Velocities
  - *Increase tile capacity*
  - *Too steep -- very high velocities can cause tile failure by "suckholes" or "blowouts" when soil is actually pulled into the tile line*
- Watch out for steep-to-flat grade changes….blowouts!

Minimum Grades

Drain Inside Diameter (inches)	Drains not subjected to fine sand or silt *(min velocity 0.5 ft/s)*		Drains where fine sand or silt may enter *(min velocity 1.4 ft/s)*	
	Tile	***Tubing***	***Tile***	***Tubing***
3	0.08	0.10	0.60	0.81
4	0.05	0.07	0.41	0.55
5	0.04	0.05	0.30	0.41
6	0.03	0.04	0.24	0.32
8 – 12 [Ψ]		0.07		
12 and larger [Ψ]		0.05		

[Ψ] recommendation for these drain sizes are from the Minnesota Drainage Guide.

Difference Between “Fall” & “Grade”



$$\%\ \text{grade} = \frac{\text{fall}}{\text{distance}} \times 100\%$$

Grade

1% Grade = 1 ft/100ft = .01 ft/ft

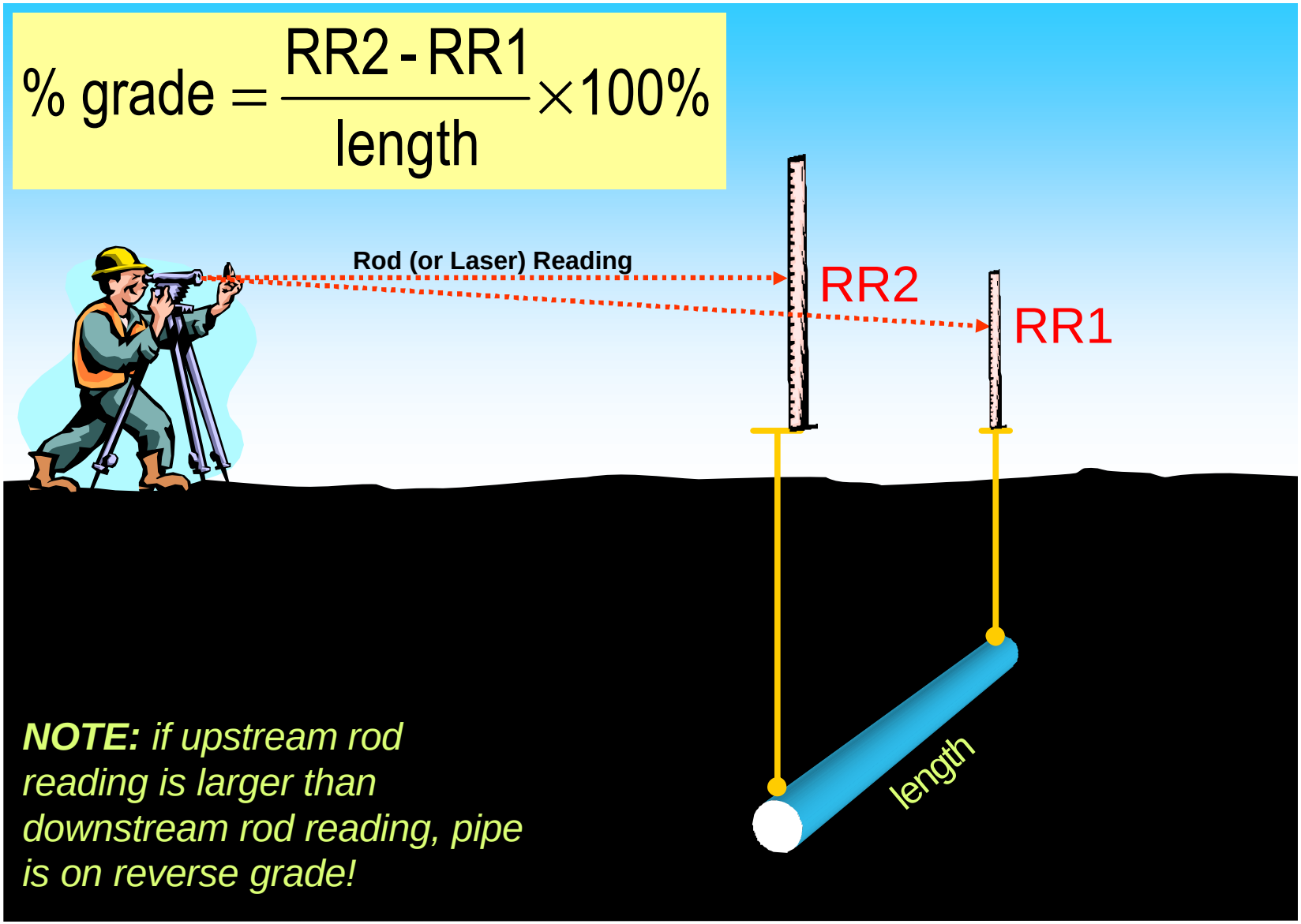
6 ft fall/mile = what % grade?

$$\% \text{ grade} = \frac{6}{5{,}280} \times 100\% = 0.11\%$$

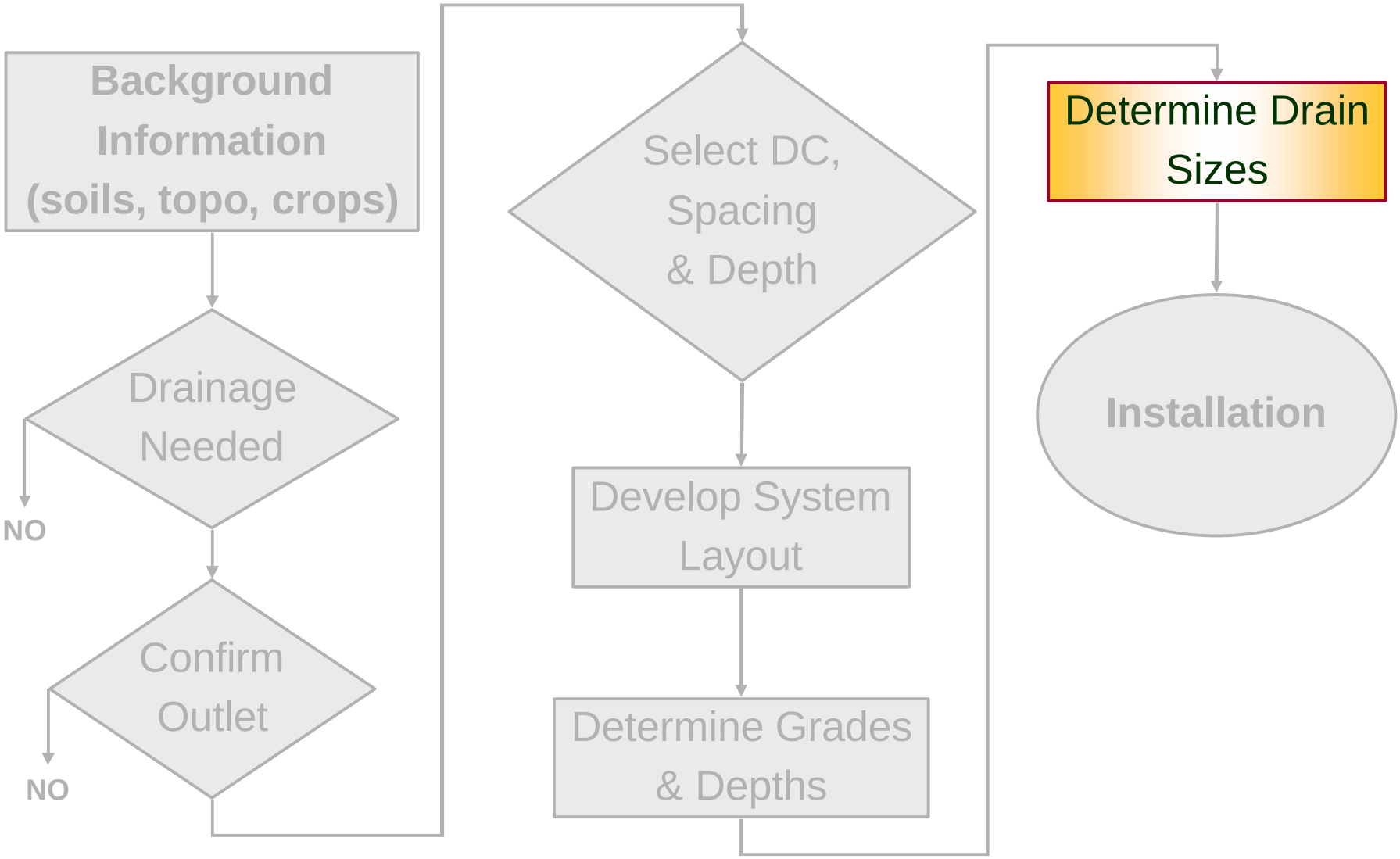
$$\% \text{ grade} = \frac{\text{fall}}{\text{distance}} \times 100\%$$

Checking Grade

$$\% \text{ grade} = \frac{RR2 - RR1}{\text{length}} \times 100\%$$



Design Process Flowchart



Drain Sizing

- What 3 things determine flow capacity of a drain pipe?
  - *Grade (determined from topography)*
  - *Material (plastic-single & dual wall, cement)*
  - *Size - we determine*
- Typical Procedure
  - *Grade, material, and DC set*
  - *Determine drain size with tools or tables*
  - *Just bookkeeping with acres-drained*

Tile Sizing - Velocity Important Too!

Drain Inside Diameter (inches)	Drains not subjected to fine sand or silt *(min velocity 0.5 ft/s)*		Drains where fine sand or silt may enter *(min velocity 1.4 ft/s)*	
	Tile	***Tubing***	***Tile***	***Tubing***
3	0.08	0.10	0.60	0.81
4	0.05	0.07	0.41	0.55
5	0.04	0.05	0.30	0.41
6	0.03	0.04	0.24	0.32
8 – 12 [Ψ]		0.07		
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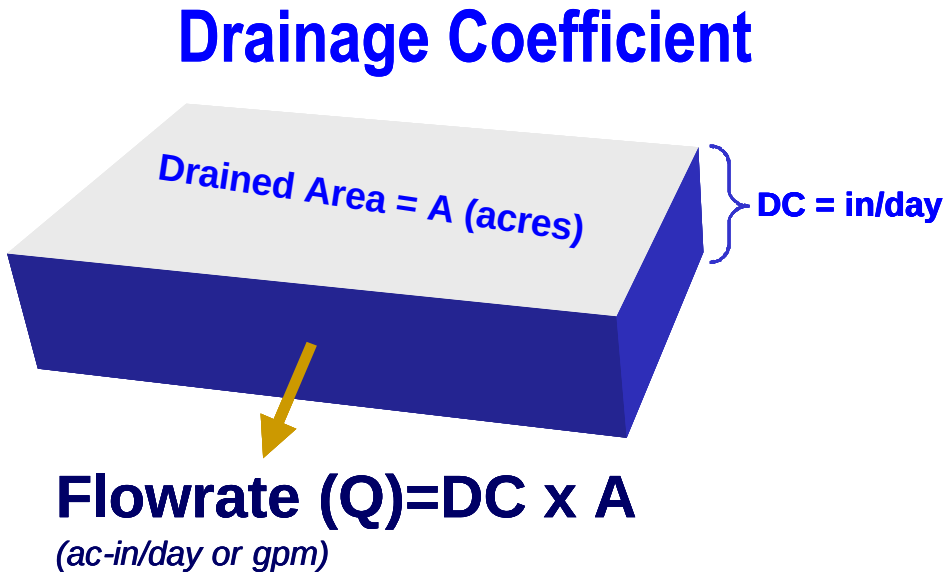
[Ψ] recommendation for these drain sizes are from the Minnesota Drainage Guide.

Tile Sizing - Calculating Flow



Drain Size-Acres Drained Equation

$$FLOW = DC \times Area = \frac{11.05}{n} \times \left(\frac{D}{12} \right)^{2.67} \times \sqrt{grade}$$

- Mannings Equation
- Also used for flow in ditches

n = .009 smooth interior pipe
.015 3” to 8” sizes
.017 9” to 12”
.020 > 12”

Solve for Acres Drained or Pipe Size

- Acres Drained

$$\text{Area} = \frac{11.05}{n \times DC} \times \left(D/12 \right)^{2.67} \times \sqrt{\%\text{grade}/100}$$

- Pipe Size (inches)

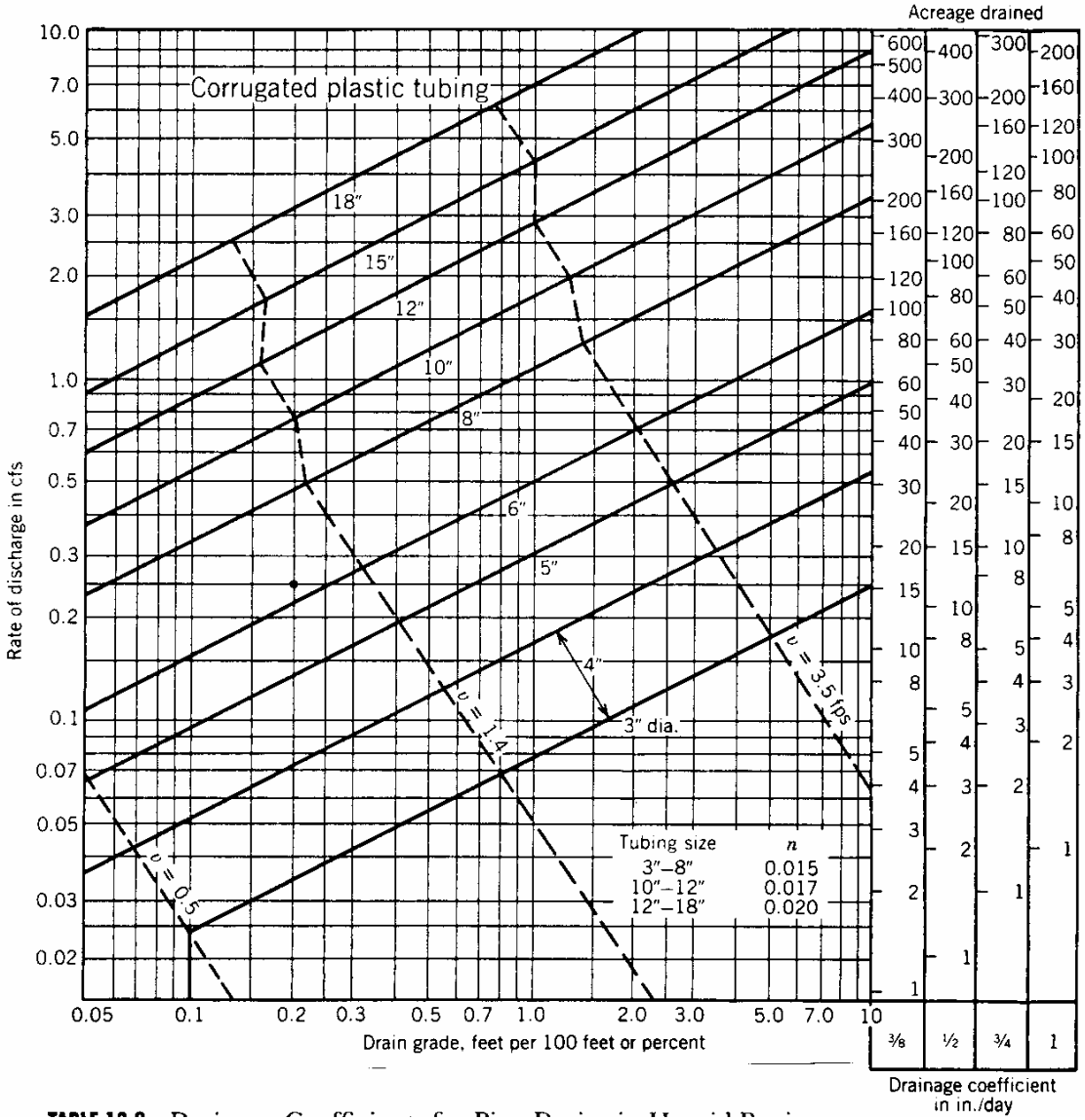
$$\text{Diameter}(D) = 12 \times \left[\frac{n \times DC \times \text{Area}}{11.05 \times \sqrt{\%\text{grade}/100}} \right]^{0.375}$$

Can I use 2 Smaller Pipes?

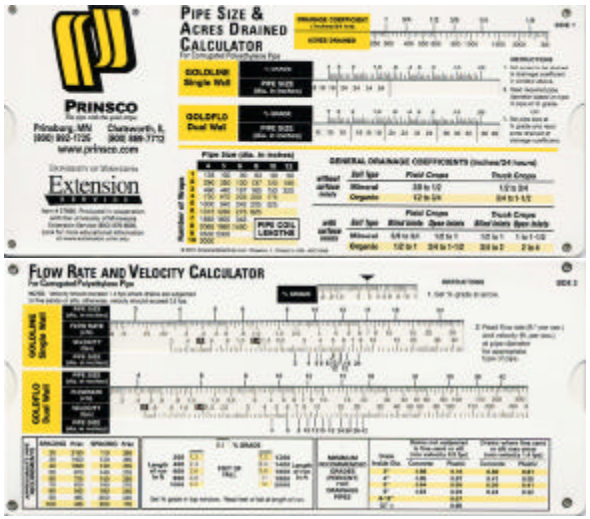
Flow Capacity of Size at Left						
	4	**6**	**8**	**10**	**12**	**15**
4	-	3	6.3	10	16	25
6	-	-	2.2	3.4	5.5	8.5
8	-	-	-	1.5	2.5	4
10	-	-	-	-	1.6	2.5
12	-	-	-	-	-	1.5
15	-	-	-	-	-	-

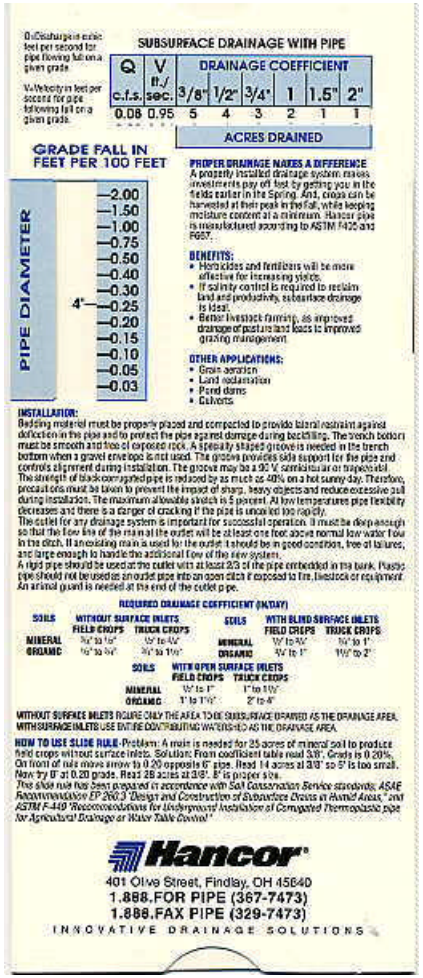
Design Tools

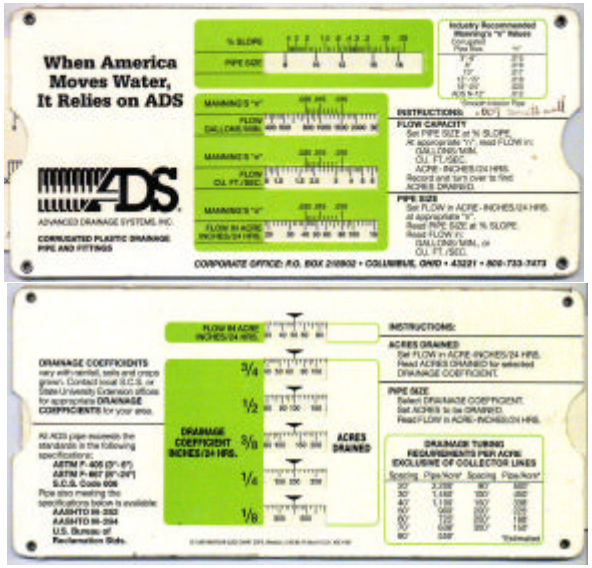
Nomograph


Acreage drained
Corrugated plastic tubing
18″
15″
12″
10″
8″
6″
5″
4″
3″ dia.
v = 3.5 fps
v = 1.4
v = 0.5
Rate of discharge in cfs
Drain grade, feet per 100 feet or percent
Drainage coefficient in in./day
Tubing size
n
3″–8″ 0.015
10″–12″ 0.017
12″–18″ 0.020

Calculators-Slide Charts



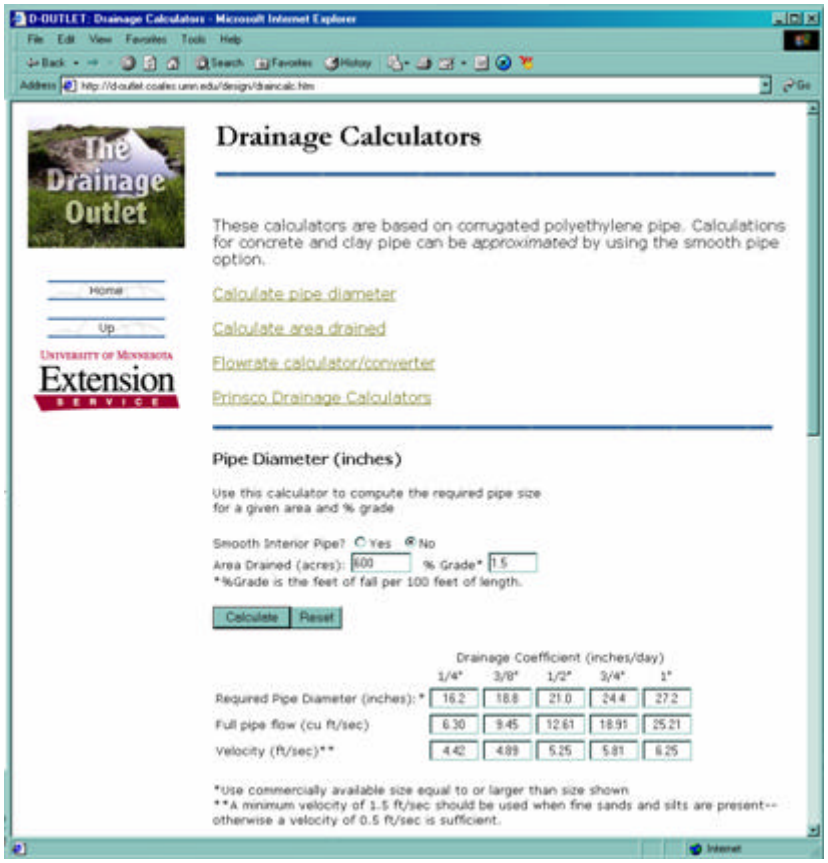


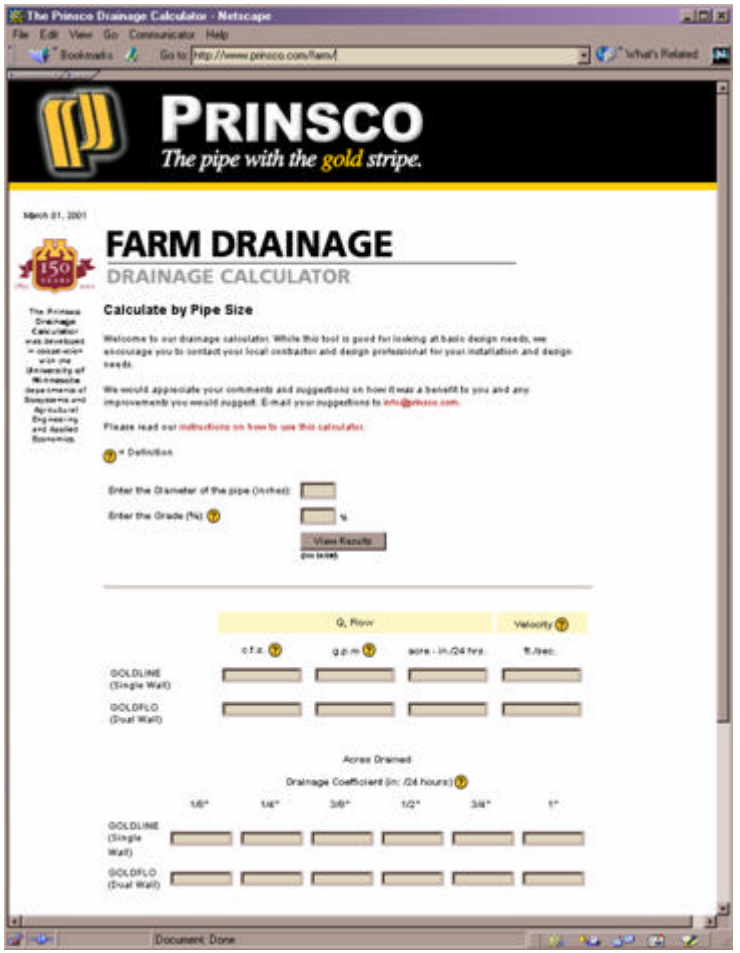


Design Charts & Tables

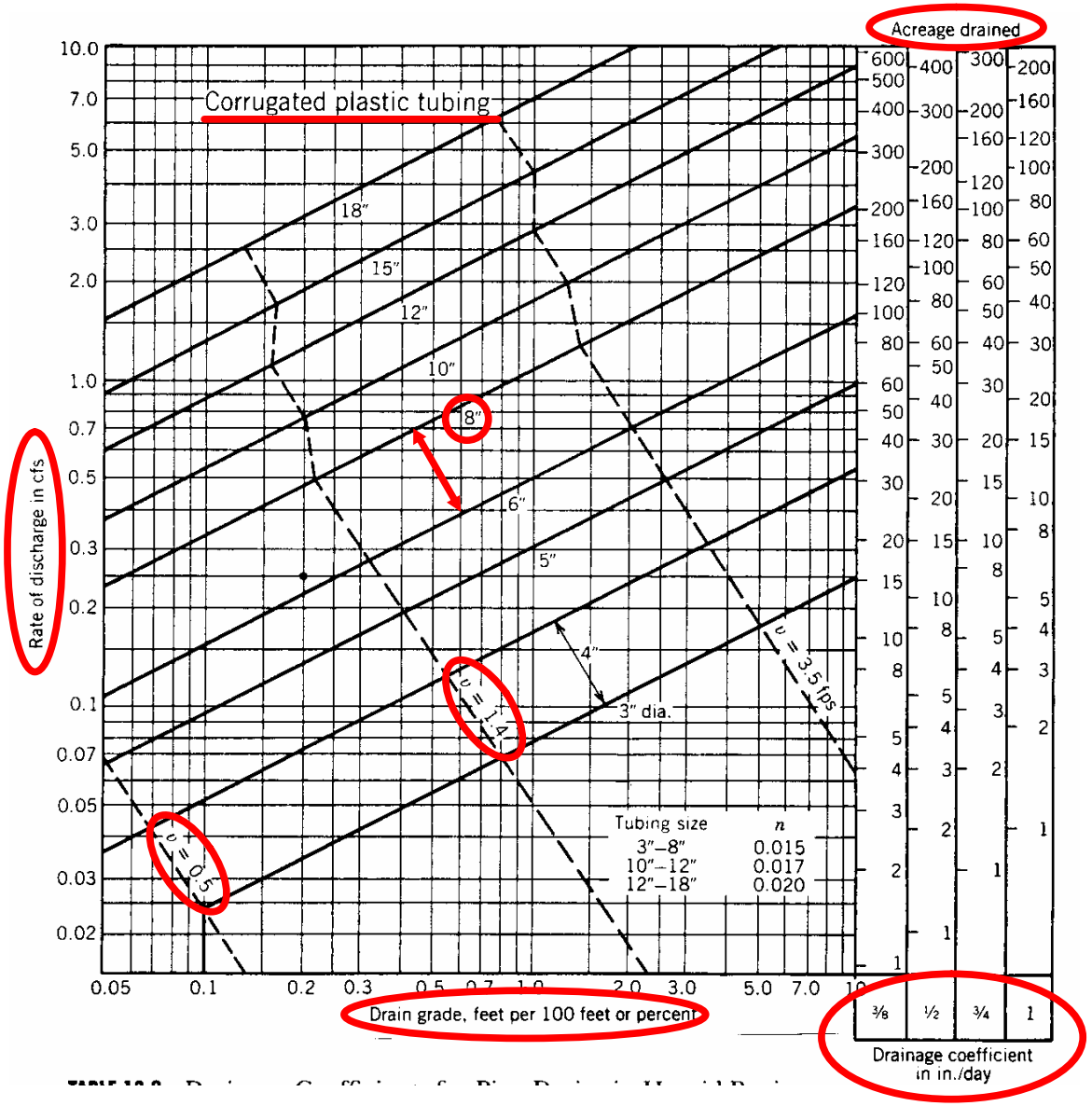
Grade (%)	Drain Size (inches)							
	4	5	6	8	10	12	15	18
0.1	2.5	4.5	7.3	16	25	41	63	103
0.2	3.5	6.4	10.4	22	36	58	89	145
0.3	4.3	7.8	12.7	27	44	71	110	178
0.4	5.0	9.0	14.6	32	50	82	126	206
0.6	6.1	11.0	17.9	39	62	101	155	252
0.8	7.0	12.7	20.7	45	71	116	179	291
1	7.9	14.2	23.2	50	80	130	200	325
1.5	9.6	17.4	28.4	61	98	159	245	398
2	11.1	20.1	32.8	71	113	184	283	460

On-line Calculators

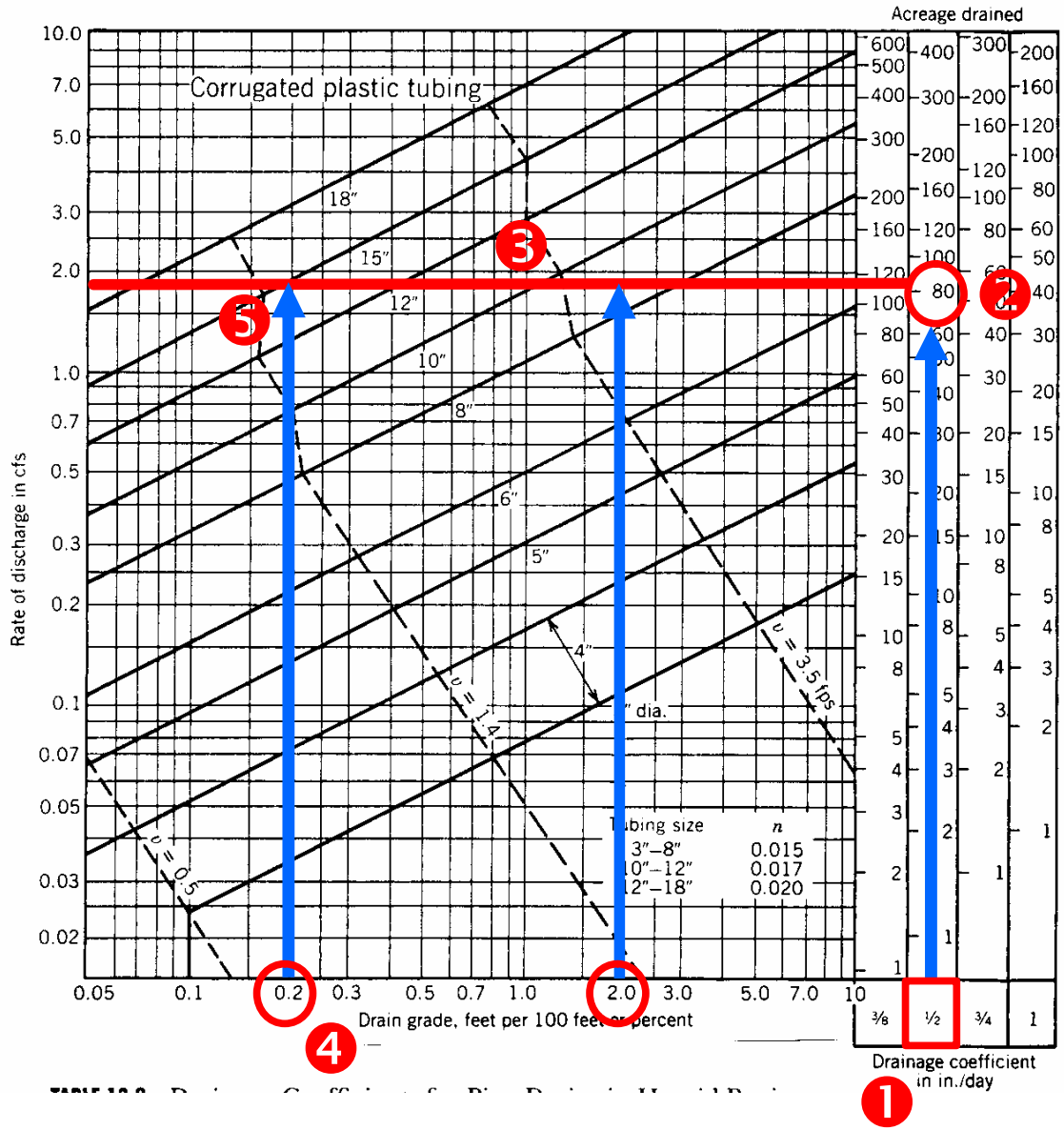




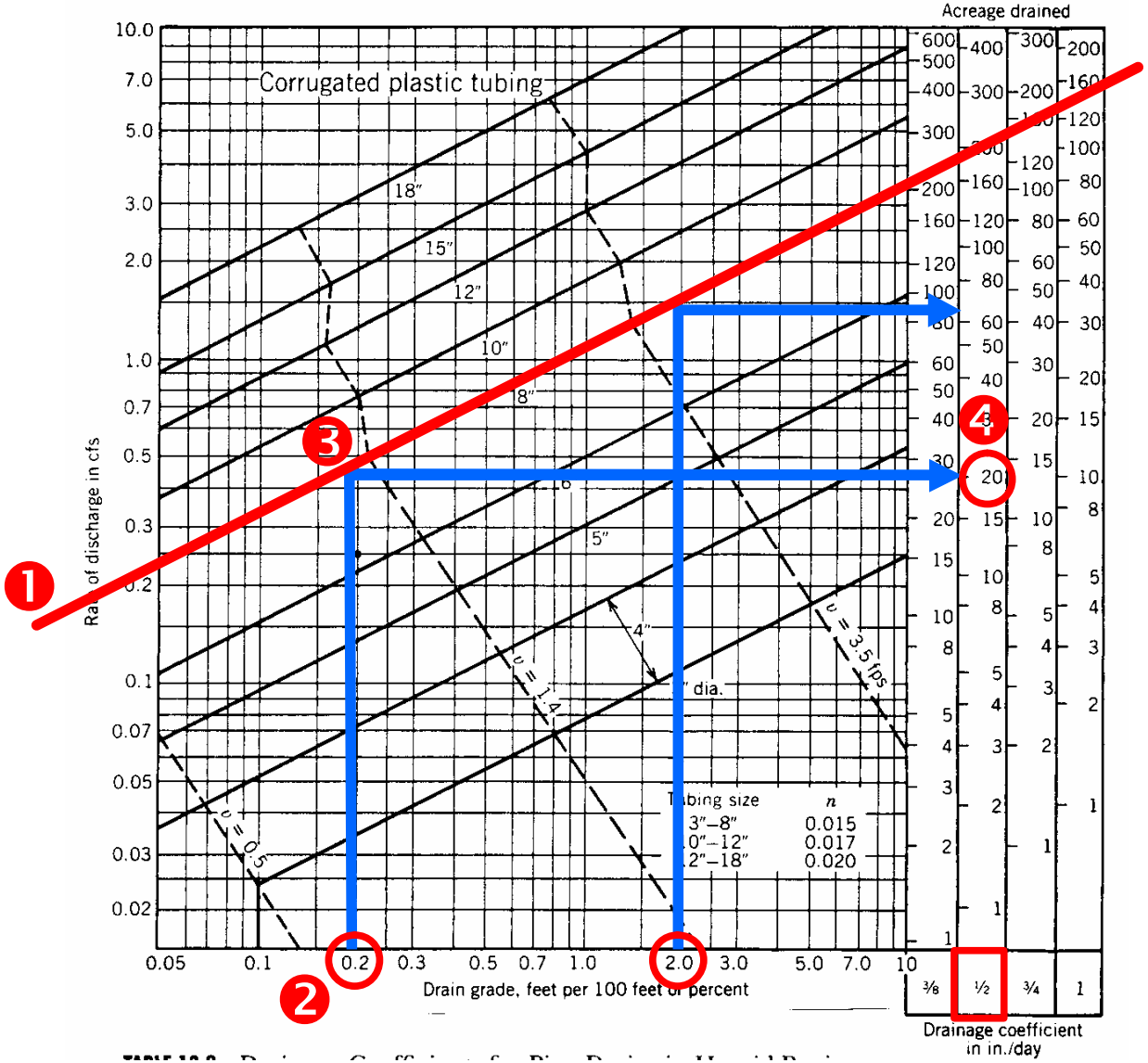
Nomograph - How to Use It



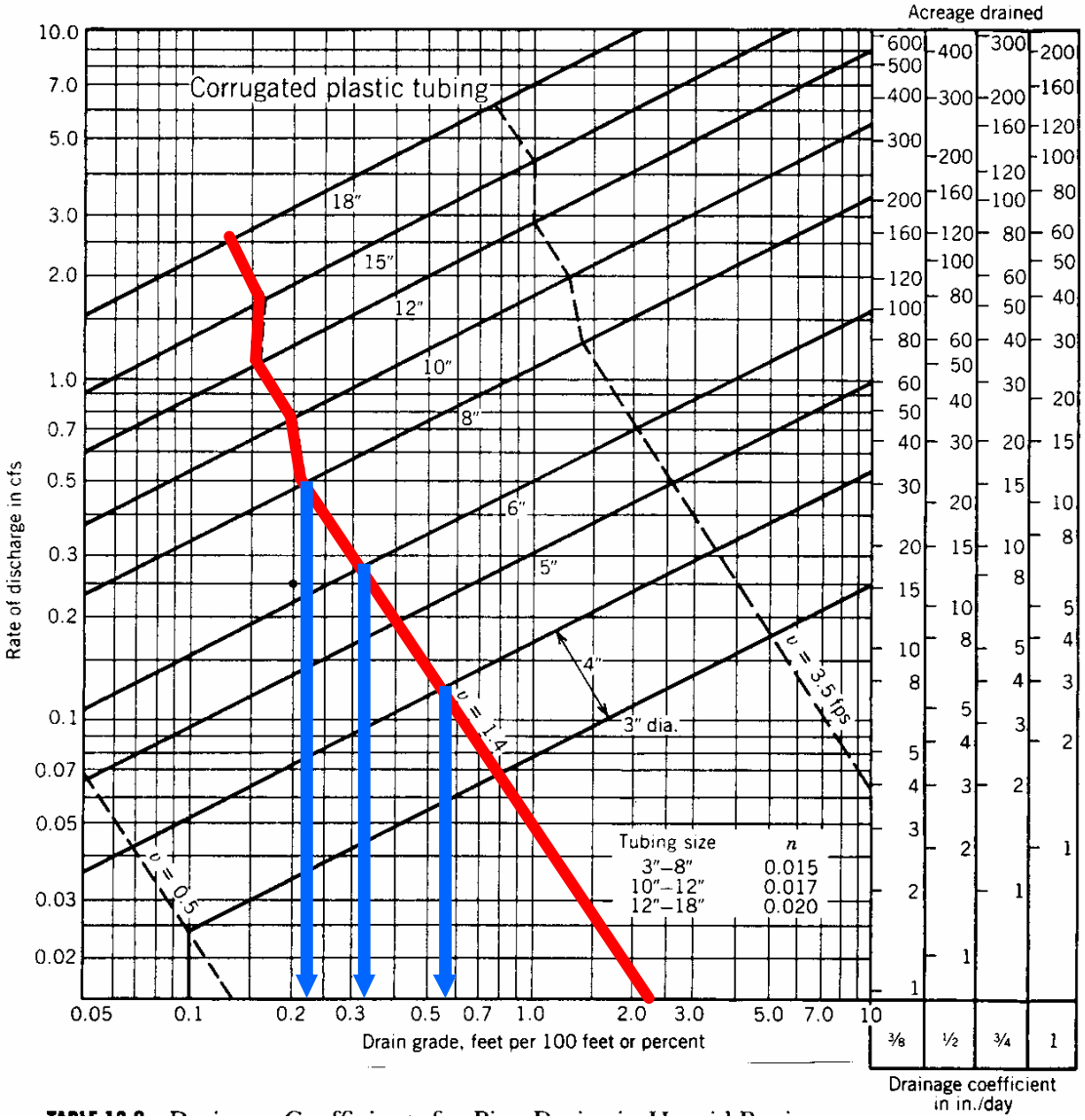
Nomograph - Finding Drain Size



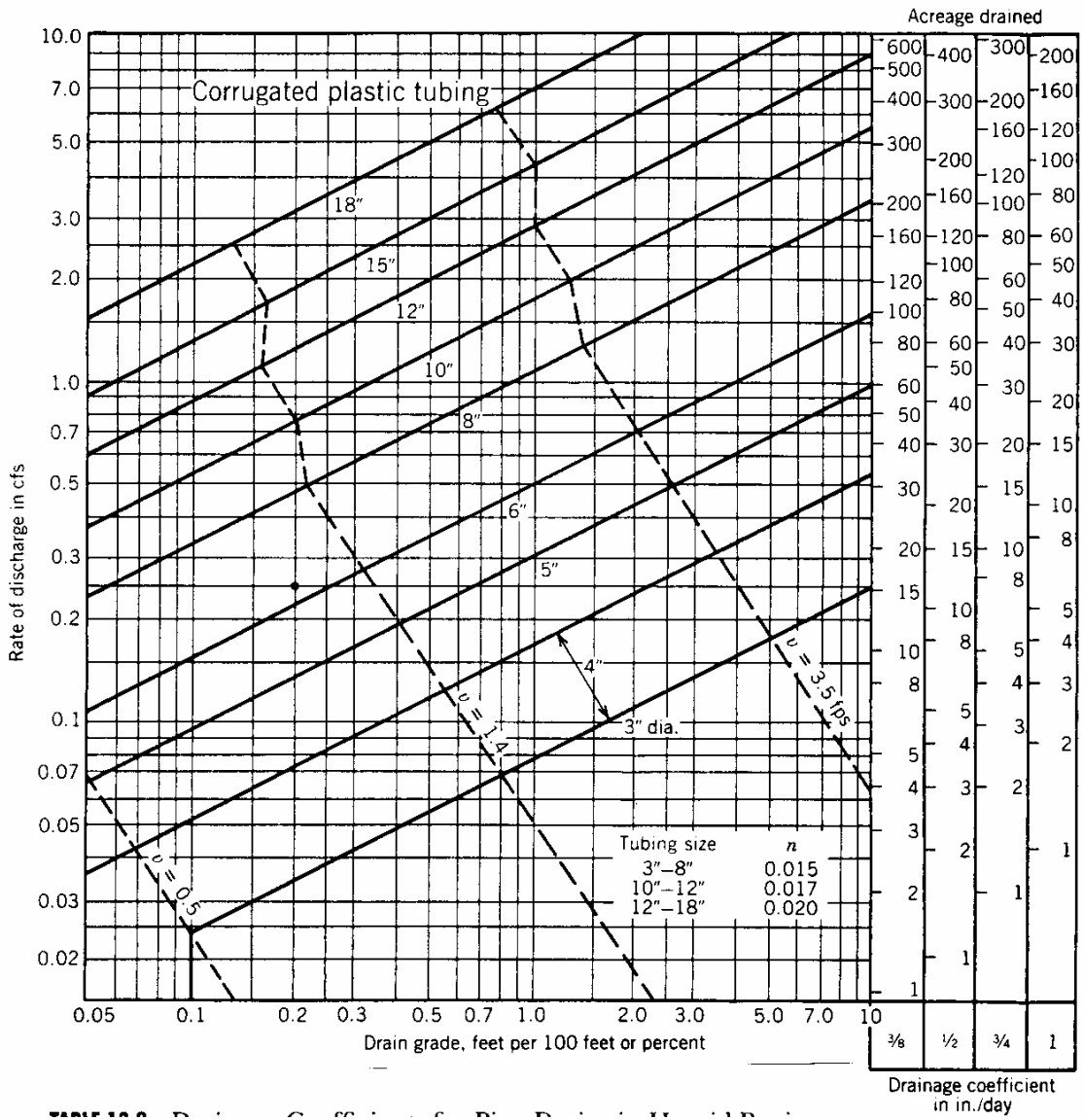
Nomograph – Acres Drained



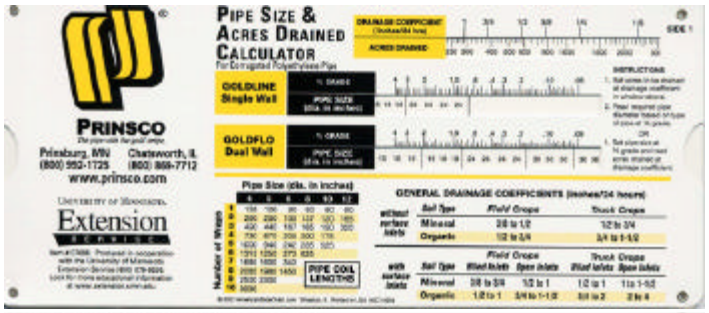
Nomograph - Minimum Grade

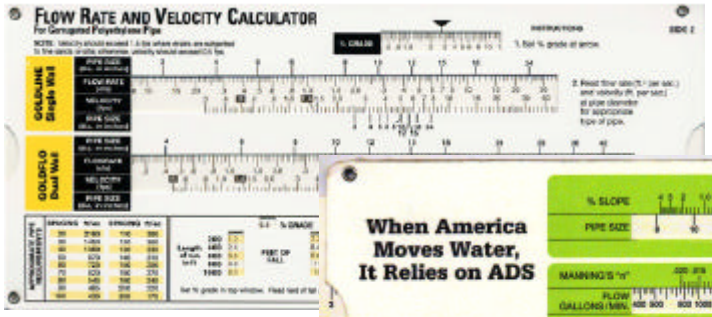


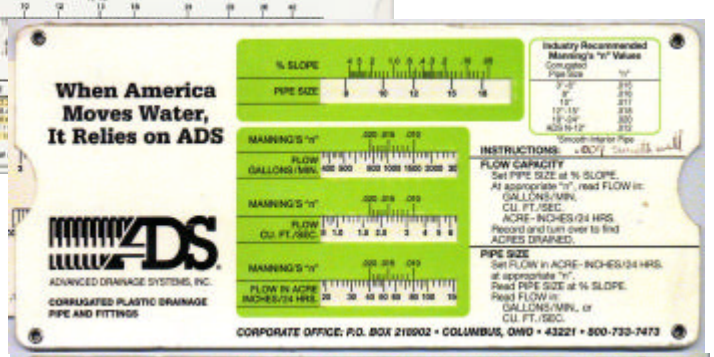
Nomograph - Example

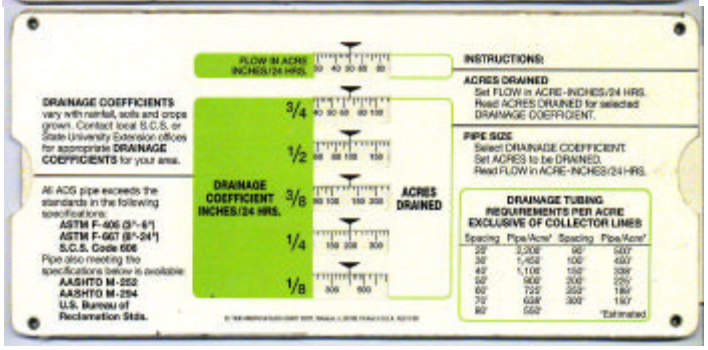


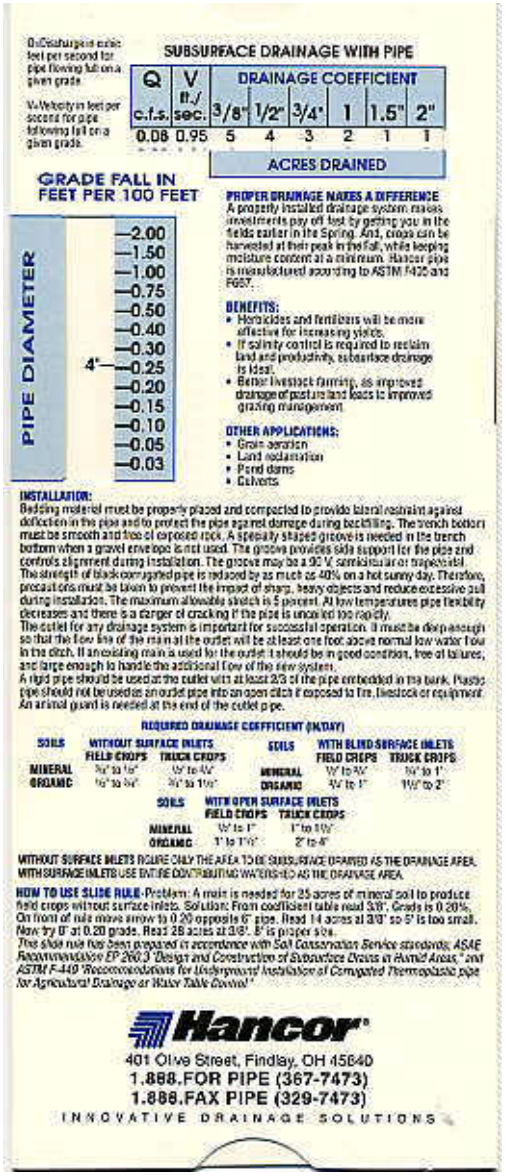
Slide Rules/Charts



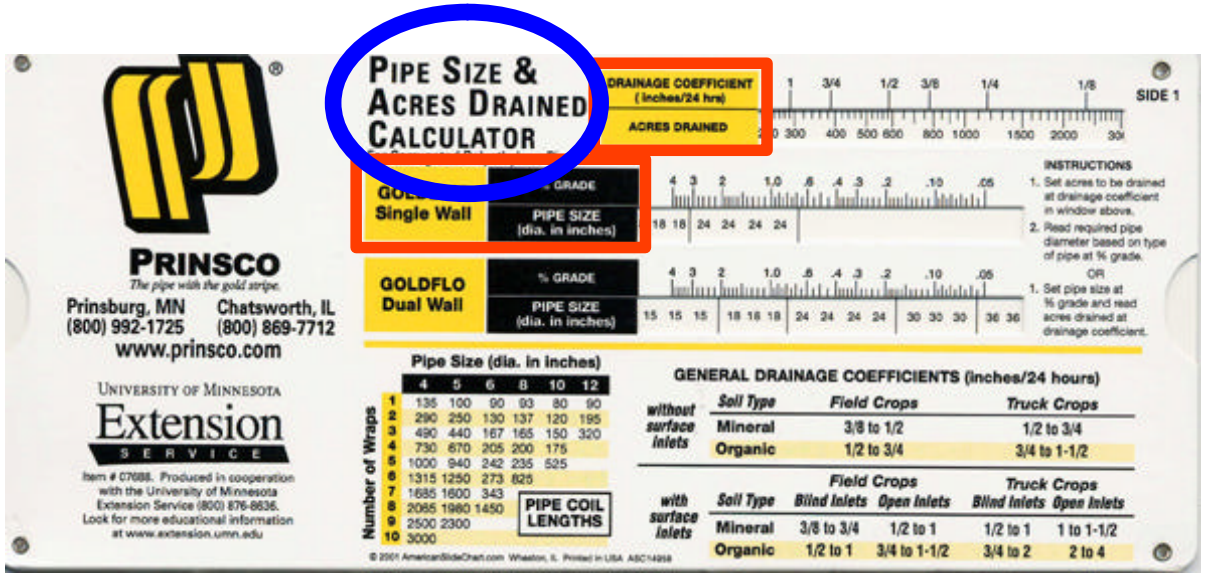


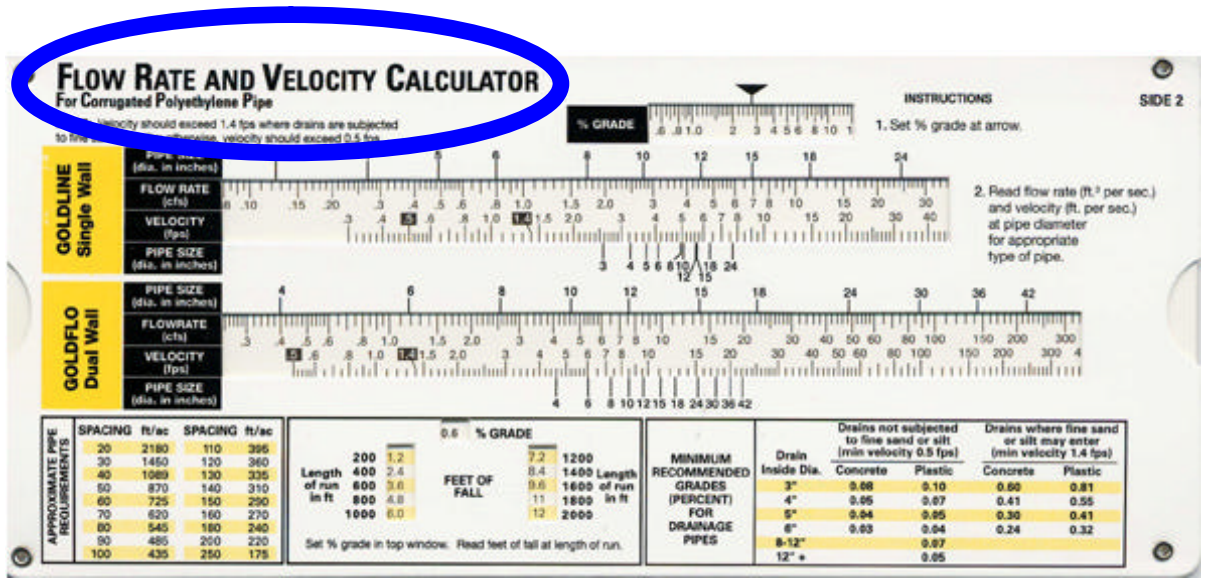






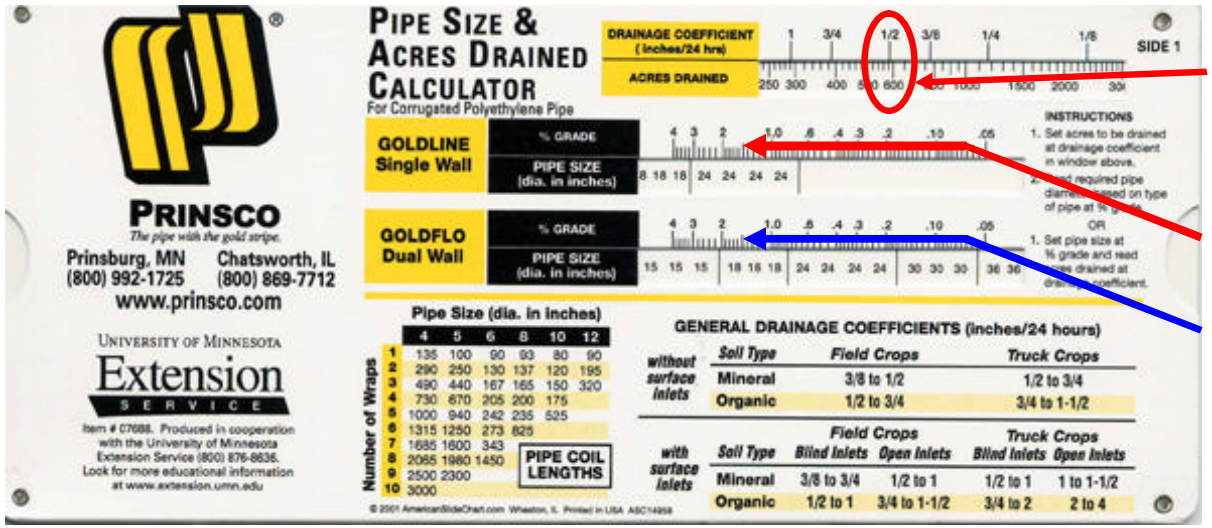
Prinsco-UofM Slide Rule





Prinsco-UofM Slide Rule

- pipe size ➔ acres drained



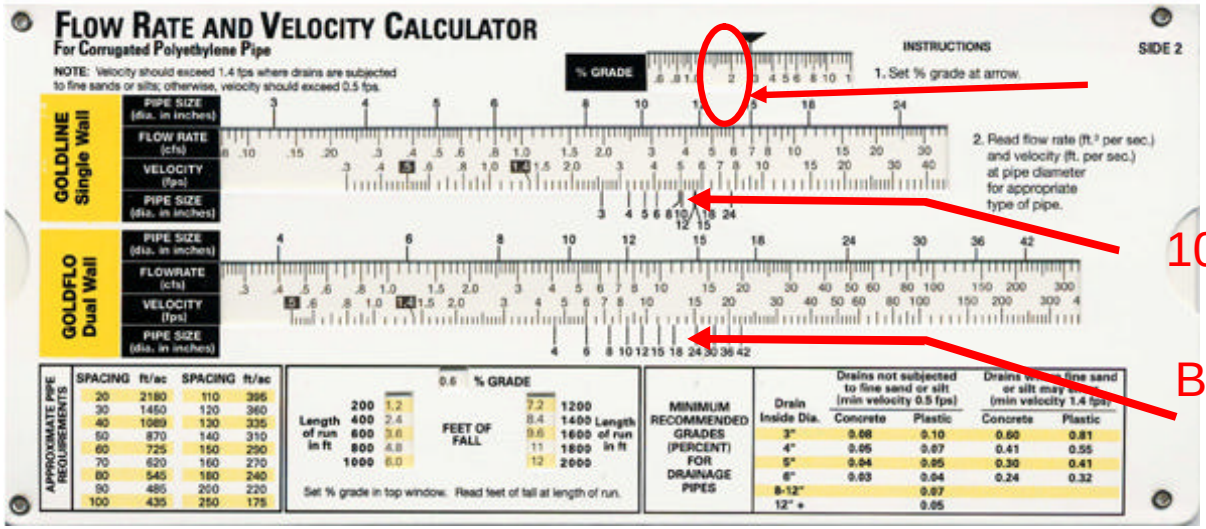
600 acres at ½” drain. coefficient

1.5% grade – 24”

dual wall – 18”

Prinsco-UofM Slide Rule

- grade/pipe size ➔ flowrate/velocity



0.1% grade

10” pipe < 1.4 fps

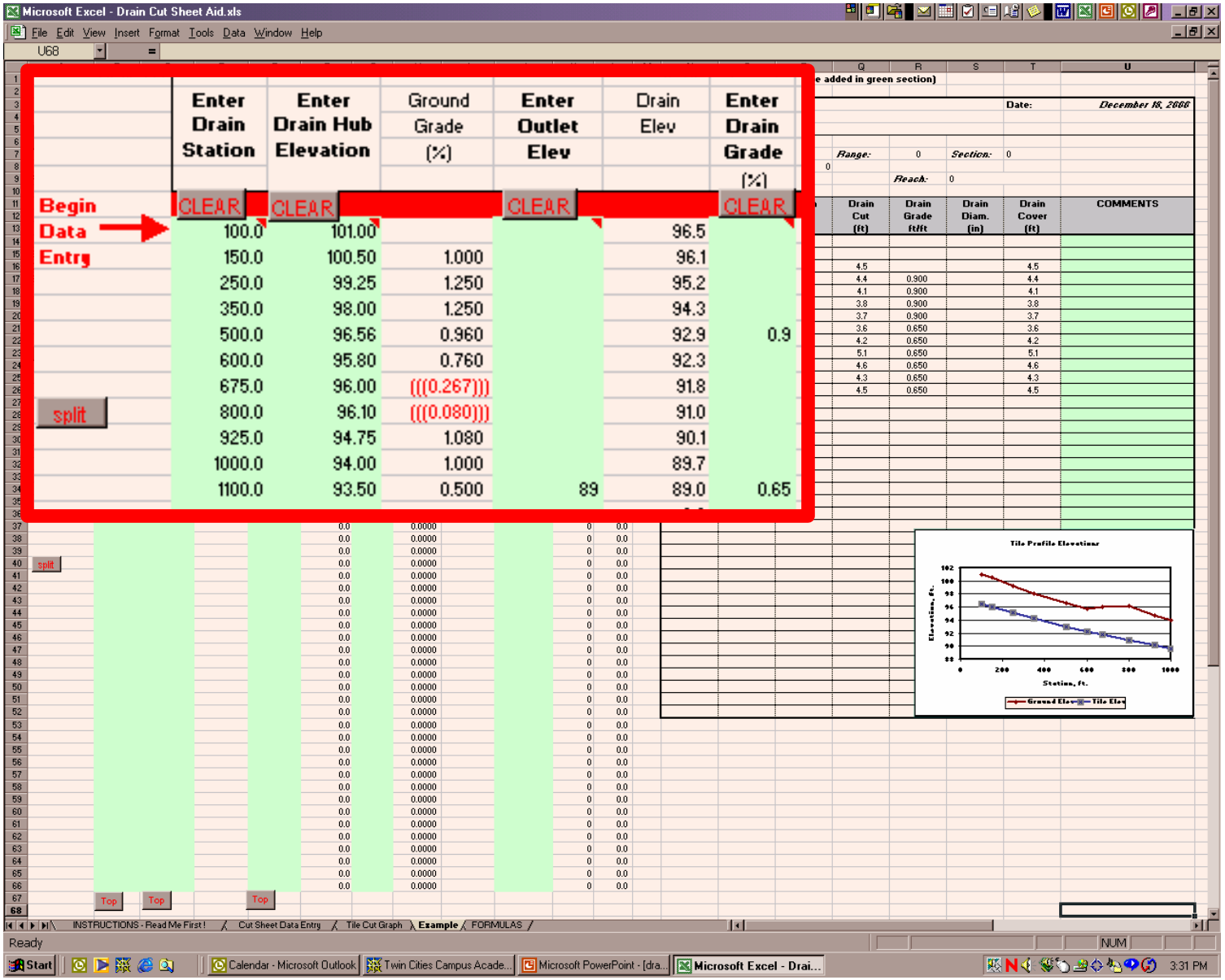
But 10” pipe > 1.5 fps if dual wall

Drain Sizing - Grade & Size

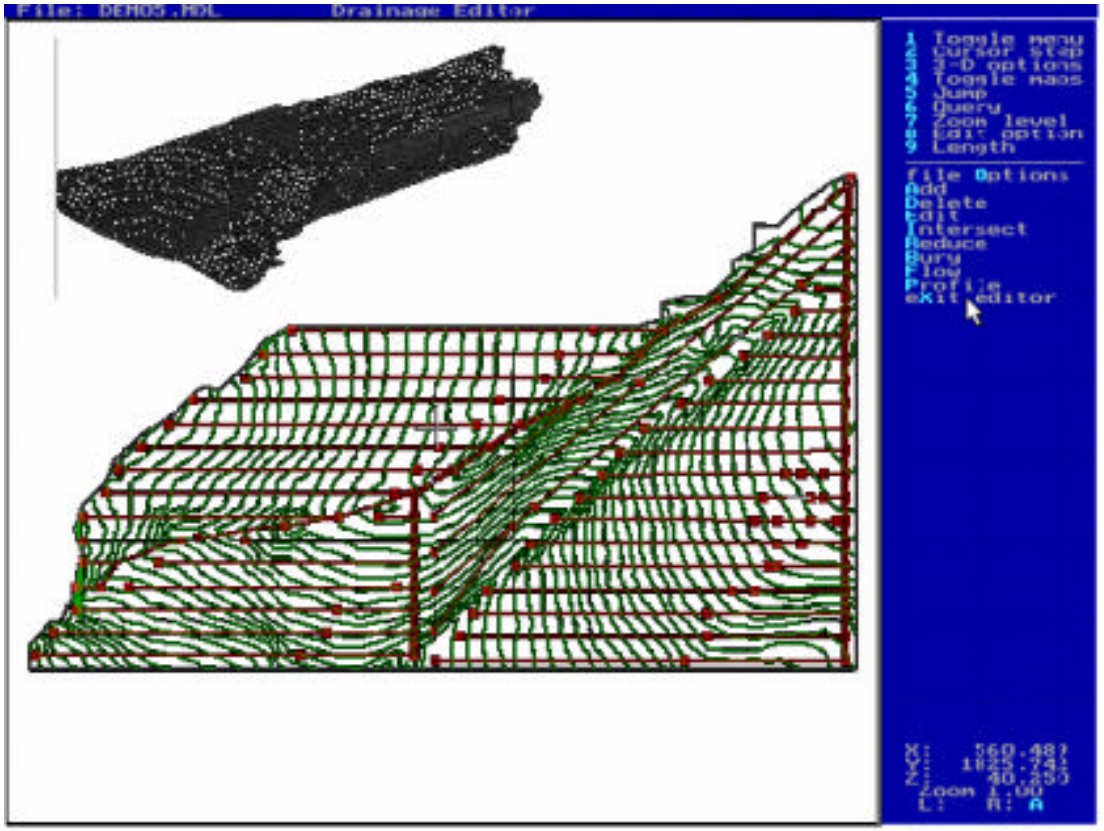
- Always round up to next larger size
- Don't create bottlenecks in system

Potential Acres Drained by Selected Tile Sizes and Grades *Drainage Coefficient = ½-inch/day*						
% Grade	4"	5"	6"	8"	10"	12"
.10	2	4.5	8	15	25	40
.25	4	7.5	12	25	40	65
.50	6	11	17	36	58	92
1.00	8	14	23	50	80	130
2.00	12	20	32	72	118	185

Spreadsheets

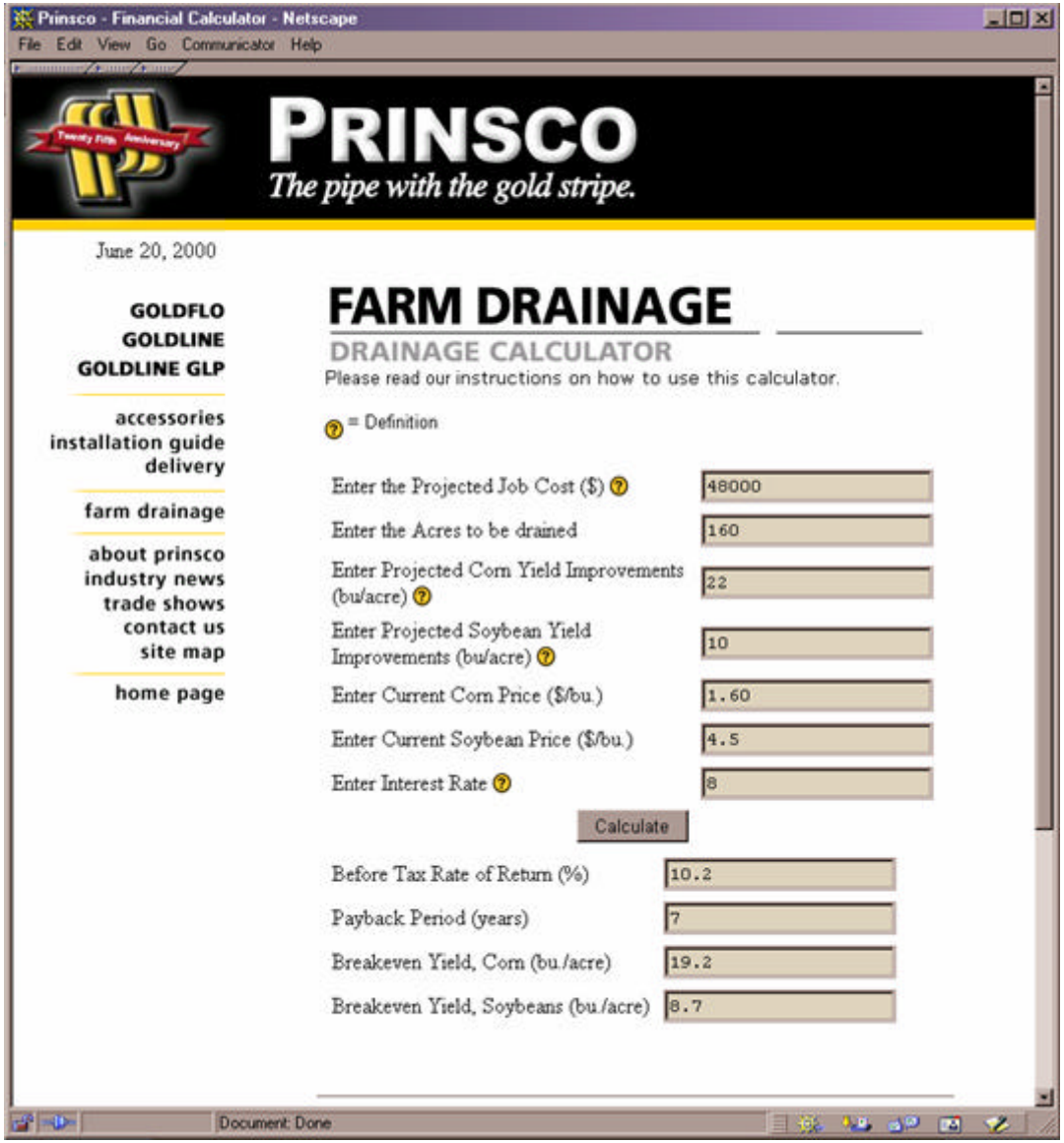


Computer Aided Drainage

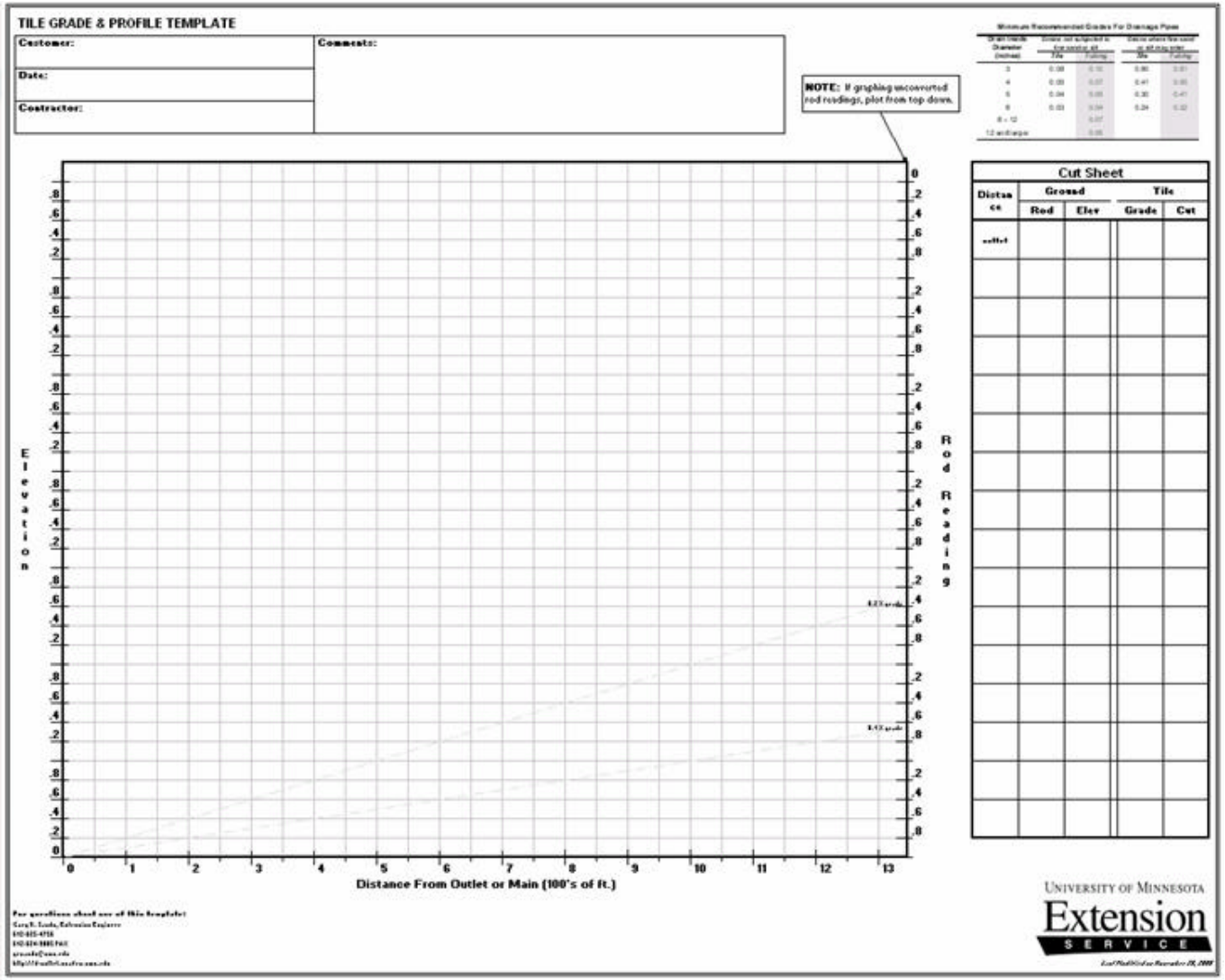


Questions?

On-line Calculators



Cut & Profile Datasheet



Internet Resources