Storm Water Drainage Design
(Answer Key)

PART I: Let's determine the flow rate when the channel is built with the minimum slope. **Fill in this table**:

Formula	$\frac{1.49}{0.015}$ *n=coefficient for smoothed concrete	$A = b \cdot (y \cdot 0.9)$ *0.9 is to account for a 10% freeboard	$R = \frac{b \cdot (y \cdot 0.9)}{b + 2\,(y \cdot 0.9)}$ **0.71** ft Now calculate $R^{\frac{2}{3}}$	$S = 0.005^{\frac{1}{2}}$ *0.5% is the standard minimum	Solve for Q *multiply answers [1-4]
Answer	1 **99.33** $\frac{1}{s}$	2 **4.05** ft^2	3 **0.796** ft	4 **0.071** $\frac{ft}{ft}$	**22.7** $\frac{ft^3}{s}$
Think About It	Would the rough concrete coefficient be higher or lower than smoothed concrete? **LOWER**	If want to keep the same area but widen the channel what must happen to the height? **SHORTEN**	Does decreasing height (y) affect the wetted perimeter in the same ratio as decreasing width (b)? **NO, divides 2Xs**	Since S is square rooted, will making the slope 1% make the flow twice as fast? **NO, not quite**	Is this rate very fast? NO

Bonus: Determine the maximum slope to stay under the maximum velocity.

Solve for S (slope) when V = 18 $\frac{ft}{s}$ the maximum standard for velocity	$S = \left(18 \cdot \frac{0.015}{1.49} \cdot 0.71 \frac{2}{3}\right)^2$	**Answer: 0.021**
Given the answer, would you recommend a slope greater than the minimum?		

PART II: Determine peak runoff during a typical storm. Fill in this table to calculate Q.

Land Type & Runoff Coefficient	Mock site runoff is ⅛ of the 25 acre campus with a 15% portion of parking lot..	Typical Storm is 0.04 in/hr	Peak Mock Site Runoff into Proposed Channel Design
Urban, Parking Lot; C = 0.9	$A = \frac{25\,acres \cdot 0.15}{8} \cdot 43560 \frac{ft^2}{acre}$	$I = 0.04 \frac{in}{hr} \cdot \frac{1\,ft}{12\,in} \cdot \frac{1\,hr}{3600\,s}$	Multiply together each answer to the left.
	A = **20,418.75** ft^2	I = **0.00000093 ft/s**	Q = **0.017** cfs

NOTE: *0.04 inches per hour is a typical storm with one inch in 24 hours*

PART III: Determine if the channel design can handle a 50 year & 100 year storm. Fill in this table:

50 year storm of 3.4 inch/hour *Use same calculation above to solve for Q but switch 0.04 in/hr above with 3.4 in/hr to solve for I*	100 year storm of 3.8 inch/hour
1.61 cfs	**1.79 cfs**

The channel with a flow rate of 22.7 cfs can handle the 1.61 or 1.79 cfs runoff from a 50 or 100-year storm with significant capacity to spare even with a 10% freeboard. Designers could consider optimizing costs by downsizing the size to handle only 16.8 cfs with a freeboard.

NOTE: *A bonus challenge for students could be to optimize the design to be sized for the 100 year storm.*

Rate of Soil Erosion at Drainage Outfall
(Answer Key)

Another important design consideration when designing storm water drainage is to assess the impact of flow rates on the existing soils at the outfall or exit.

> The Revised Universal Soil Loss Equation (RUSLE) is a model that estimates the average annual rate of soil erosion due to water and considers six main factors that control soil erosion:
>
> Rainfall erosivity (R); Soil erodibility (K); Slope length (L); Slope (S); Cropping (C) ; Conservation practice (P)

In calculating the sediment loading from urban lands in the PLET model from Lesson 4, the following RUSLE coefficients were assigned:

User Defined				
R	K	LS	C	P
239	0.180	0.458	0.215	1.00

The LS in this equation is a factor of the predominant topography of the area, using the length (L) and slope (S).

Let's explore how the length and slope of the outfall area can influence the rate of erosion when the outfall area of the Mock Site Channel Design is 20 ft x 3 ft

Parameter	User Defined LS (0.458)	0.5% slope with 20 ft length	5.1% slope with 20 ft length
Formula	239(0.180)(**0.458**)(0.215)(1)	239(0.180)(20)(**0.005**)(0.215)(1)	239)(0.180)(20)(**0.051**)(0.215)(1)
Answer (tons/acre/year)	**20.26**	**0.22**	**2.26**

Example calculations: R * K * C * P = tons/acre/year; (239)(0.180)(0.215)(1.00) = ~9.25 tons/acre/year; LS with 0.5% slope is (20)(0.005) = 0.1; (9.25)(0.1) = 0.925 tons/acre/year; LS with 5.1% slope = (20)(0.051) = 1.02; (9.25)(1.02) = 9.435 tons/acre/year

The Cropping or 'C' coefficient is influenced by changes to the surface of the soils.
Estimate the tons of sediment eroding from the outfall area in a year if treated with rip rap that results in a C coefficient of 0.2:

R	**K**	**LS**	**C**	**P**	**ANSWER 1 (tons/acre/year)**	Outfall area in acres is (20)(3)(0.000023) =	(ANSWER 1)(Outfall area in acres) = tons/year
239	0.180	(20)(0.005) = 0.1	0.200	1.00	240.48	0.00138	**~ 0.25 tons/year**

Example calculation: (239)(0.18)((20)(0.005))(**0.2)**(1) = ~ 0.86 tons/acre/year; (0.86 tons/acre/year)(3 ft) (20 ft)(0.00002 acre/ft^2) = 0.247 tons/year

Storm Water Drainage Design
(Calculations)

Determine the flow rate with the given minimum slope.

Parameters:

- Channel width (b): 3 feet
- Channel depth (d_1): 1.5 feet
- Slope (S): 0.5% = 0.005
- Length (L): < 50 feet (using 20 feet for a small-scale design)
- Channel type: Smoothed Rough Concrete (assume Manning's n = 0.015)

Final Design Calculations:

- Width (b): 3 ft
- Flow Depth (d): 1.35 ft
- Flow rate (Q): ~22.8 cfs
- Velocity (V): 5.6 f/s (V = Q/A = 22.8 cfs/ 4.05 ft^2)
- Area of Flow (A): 4.05 ft^2

Step 1: Include Freeboard (Freeboard is usually 10% of flow depth)
Available Depth (d_1) = 1.5ft ⇒ Maximum flow depth (d) = 1.5 - 0.15 = 1.35 ft
Step 2: Cross-Sectional Area (A)
For a rectangle: A=b*d = 3 ft*1.35 ft = 4.05 ft^2
Step 3: Wetted Perimeter (P)
P=b+2d = 3+2(1.35) = 5.7ft
Step 4: Hydraulic Radius (R)
R= A/P = 4.05/5.7 = 0.71 ft
Step 5: Use Manning's Equation.
$Q = VA = 1.49/n*AR^{2/3}*S^{1/2} =$
$Q = 1.49/0.015*4.05\ ft^2*(0.71\ ft)^{2/3}(0.005)^{1/2} = 22.64$ cfs
1.49/0.015 = 99.33
$R^{2/3}=(0.71\ ft)^{2/3}= 0.796$
$S^{1/2}$= sqrt(0.005) = 0.0707
Finally Q = 99.33*4.05 ft^2*0.8ft*0.0707 ≈ 22.8 cfs

Determine the maximum slope design for the maximum flow rate of 18 feet per second.

Given:

- Channel width (b): 3 feet
- Flow Depth (d): 1.35 ft
- Channel type: Smoothed Rough Concrete (assume Manning's n = 0.015)
- Max Velocity Vmax = 18 ft/s

Manning's Velocity Equation:

$$V = 1.49/n*R^{2/3}S^{1/2}$$

Solving for S, you get:

$$S = (V*n/1.49*R^{2/3})^2$$

Calculate Hydraulic Radius, R:
Cross-sectional area: A=b*d = 3 ft*1.35 ft = 4.05 ft^2
Wetted perimeter: P = b+2d = (3+2)(1.35) = 5.7ft
Hydraulic radius: R = A/P = 4.05/5.7 = 0.71 ft

Solving for Slope:
$S = (18*0.015/1.49*(0.71)^{2/3})^2 = (0.144)^2 = 0.021$

The maximum slope to keep flow velocity ≤ 18 ft/s within the safe flow area which includes a freeboard is: S = 0.021 or 2.1%

Estimate Storm Water Runoff

Rational Method:
Q = C*I*A
Where:

- Q: peak runoff (cfs)
- C: runoff coefficient (dimensionless) = 0.9 (paved/urban area)
- I: rainfall intensity (in/hr) 0.04 in/hr (typical storm, 1" per 24 hour)
- A: drainage area (ft2) = 20,419 ft^2

Step 1: Convert intensity to ft/s:
I = 0.04 in/hr * 0.08 ft/in * 0.0003 hr/s = ~ 0.00000096 ft/s (note: these are rounded up)
Step 2: Calculate Q:
Q= 0.9*0.00000096 ft/s * 20,419 ft^2 = 0.018 cfs
Result: The runoff is 0.18 cfs, much less than the channel's 26 cfs peak rate, which means this design is very safe under these assumptions.

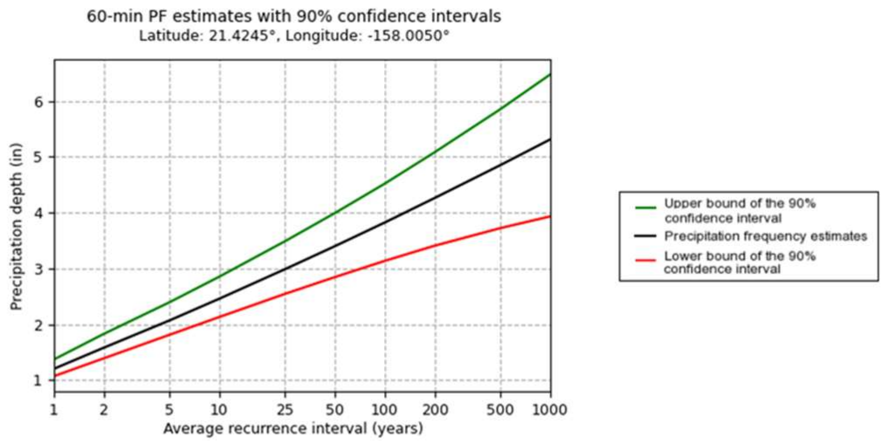
Final Verdict:

- Runoff expected in a 24hr storm of 1": ~0.18 cfs
- Channel capacity with freeboard: ~22.8 cfs
- Full capacity (no freeboard): ~26 cfs
- Freeboard included: 0.15 ft
- Conclusion: Design is more than sufficient and allows for future increases or extreme events.

Storm Water Drainage Design
(Calculations Cont.)

Estimate Runoff for a 50 and 100 year storm

According to NOAA Atlas 14, the 1-hour rainfall intensity for a 50 year storm in Waipahu is approximately 3.4 inches per hour and 3.8 inches per hour for a 100 year storm.



Step 1: Rainfall Intensity for a 50 and 100-Year Storm

I = (3.4 in/hr)(0.08 ft/in)(0.0003 hr/s) = 0.0000816 ft/s (50 year)

I = (3.8 in/hr)(0.08 ft/in)(0.0003 hr/s) = 0.0000912 ft/s (100 year)

Step 2: Calculate Peak Runoff (Q)

Q = (0.9)(0.000816 ft/s)(20,419 ft^2)= ~1.50 cfs (50 year)

Q = (0.9)(0.000912 ft/s)(20,419 ft^2)= ~1.68 cfs (100 year)

Step 3: Compare with Channel Capacity

Previously, we calculated the channel's capacity:

- Without freeboard: ~26 cfs
- With 0.15 ft freeboard: ~ 22.8 cfs

Conclusion: The channel can handle the 1.50 or 1.68 cfs runoff from a 50 or 100-year storm with significant capacity to spare even with a 10% freeboard.