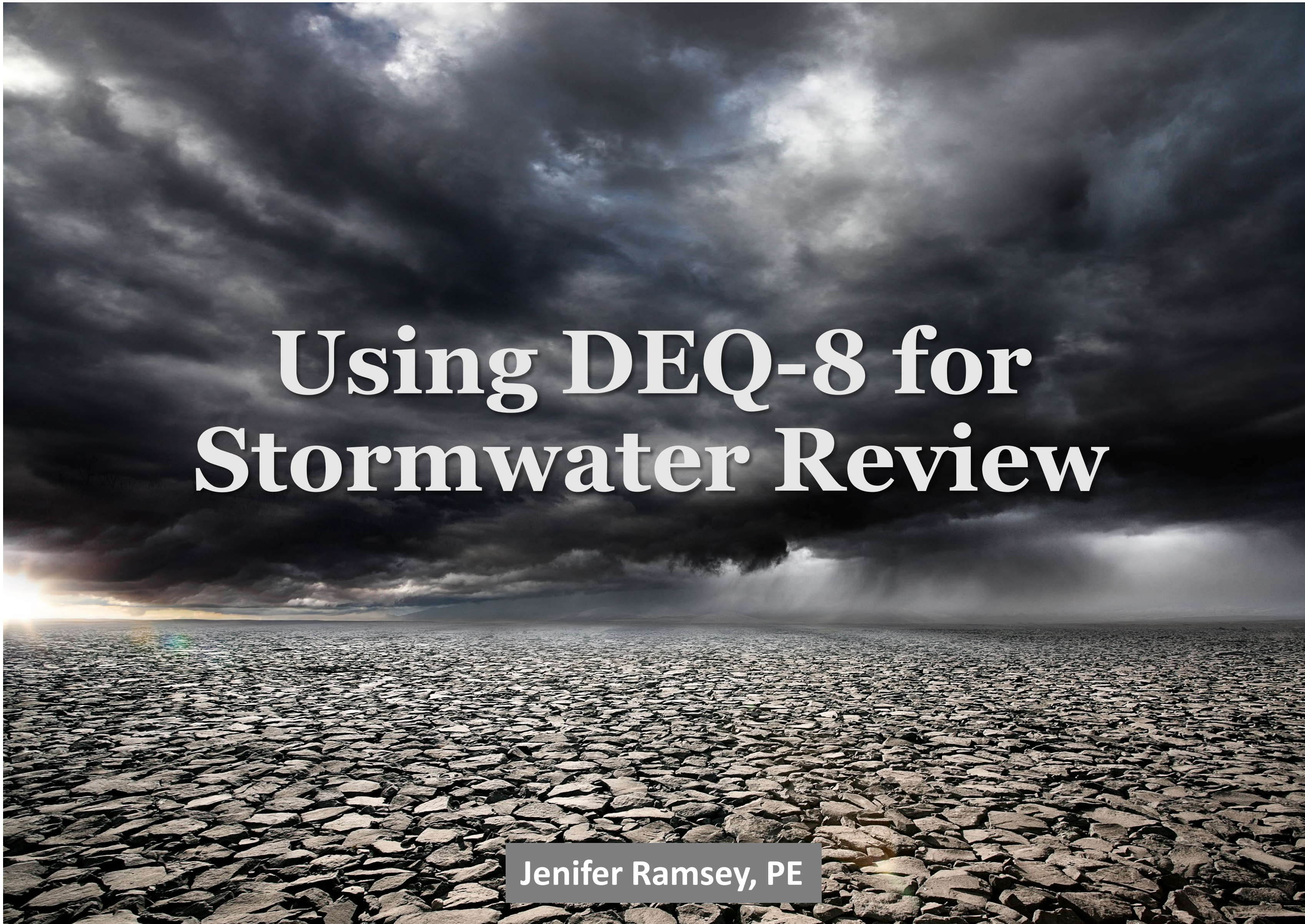
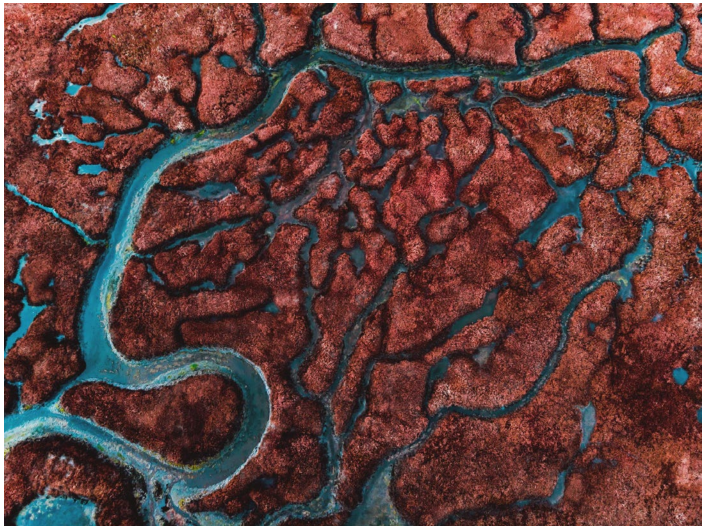


Using DEQ-8 for Stormwater Review

Jenifer Ramsey, PE

Outline

- Definitions
- Quick Summary of DEQ-8 Changes
- What are we really looking for in a stormwater design?
- Using DEQ-8 – Determining rainfall rates with IDF Curve
    - Time of concentration
    - Finding Rainfall Intensity
    - Determining IDF curve values
    - Example – flow through a swale
- Review Tips
- Summary
- Questions



Definitions

- What is an IDF Curve? A graph of rainfall intensity with its duration and frequency of occurrence. It graphically shows the probability (storm event) of a given average rainfall intensity event occurring.
- What is time of concentration? The time it takes for stormwater to collect from the farthest point of a watershed to the final discharge point.
- TR-55, also known as Urban Hydrology for Small Watersheds Technical Release 55, or NRCS TR-55
- **SCS Method is the method used by TR-55** for calculating flows – it is the mathematical method behind the curve numbers and time of concentration (and ultimately the IDF curve)
- **TR-55 = SCS Method** as far as mathematical calculations go
- What is a storm event? It is a flood frequency, being a probability of a flood event of a certain size occurring for any given year.

Figure 9.3-1 — FLOOD FREQUENCY PROBABILITIES

Recurrence Interval (RI)	Probability of event occurring in any given year	Percent chance of event occurring in any given year (Exceedance Probability)
2-year	1 in 2	50%
5-year	1 in 5	20%
10-year	1 in 10	10%
25-year	1 in 25	4%
50-year	1 in 50	2%
100-year	1 in 100	1%
200-year	1 in 200	0.5%
500-year	1 in 500	0.2%

From Chapter 9, Appendix B-2022 of the Montana Department of Transportation Hydraulics Manual (January 2022)

Quick Summary of DEQ-8 Changes

- Additional required information as part of the stormwater reports, such as depth to limiting layer
- Clarification regarding looking at downstream affects (what happens during large storm events) and can require additional information if there are concerns
- Simplified Plan can be used by a greater number of projects with slope restriction removed – can use spreadsheet or calculate retention volume via new formula
- Culverts are required for roads crossing drainages, and must be 12 inches in size minimum
- Some minor overtopping of roadways is now allowed under certain situations
- Groundwater proximity to bottom of retention, detention or infiltration facilities needs to be checked

What are we looking for in a stormwater design?

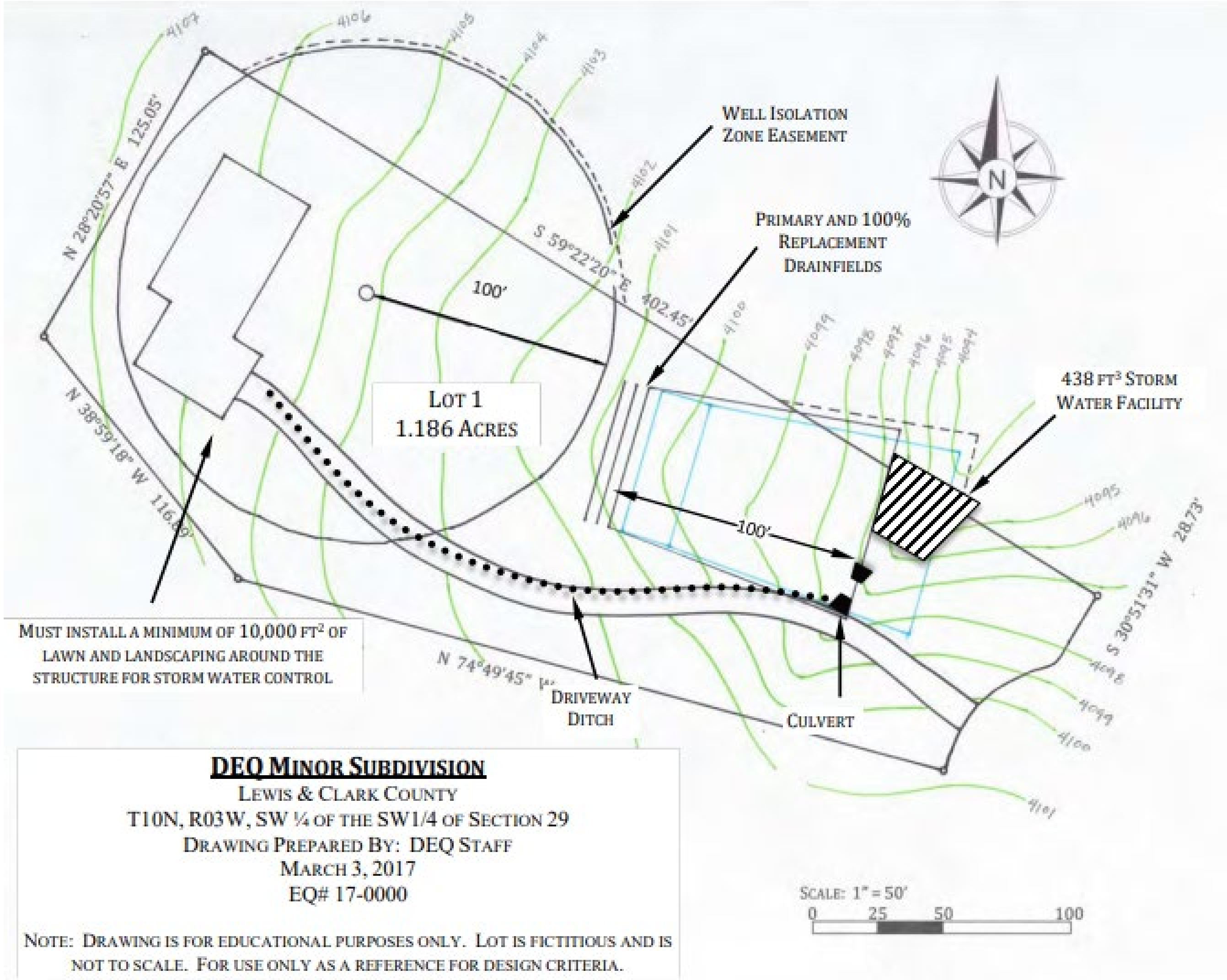
- Will stormwater runoff from development cause flooding
    - What kind of soils are present?
    - How steep is it?
    - What is downstream of the site?
    - Does the stormwater run through or cross any roads or come close to buildings, drainfields or other infrastructure we don't want damaged by a flow of water?

Using DEQ-8 – Determining rainfall rates with IDF Curve

- Steps
  - Determine the time of concentration for the pre-development and post-development conditions
  - Look up the precipitation intensity for Atlas 14
  - Find the storm recurrence interval of interest (2-year storm event, 10-year storm event, etc)
  - Find the rainfall intensity for the storm duration based on the time of concentration
  - Interpolate the final value if needed

Time of Concentration

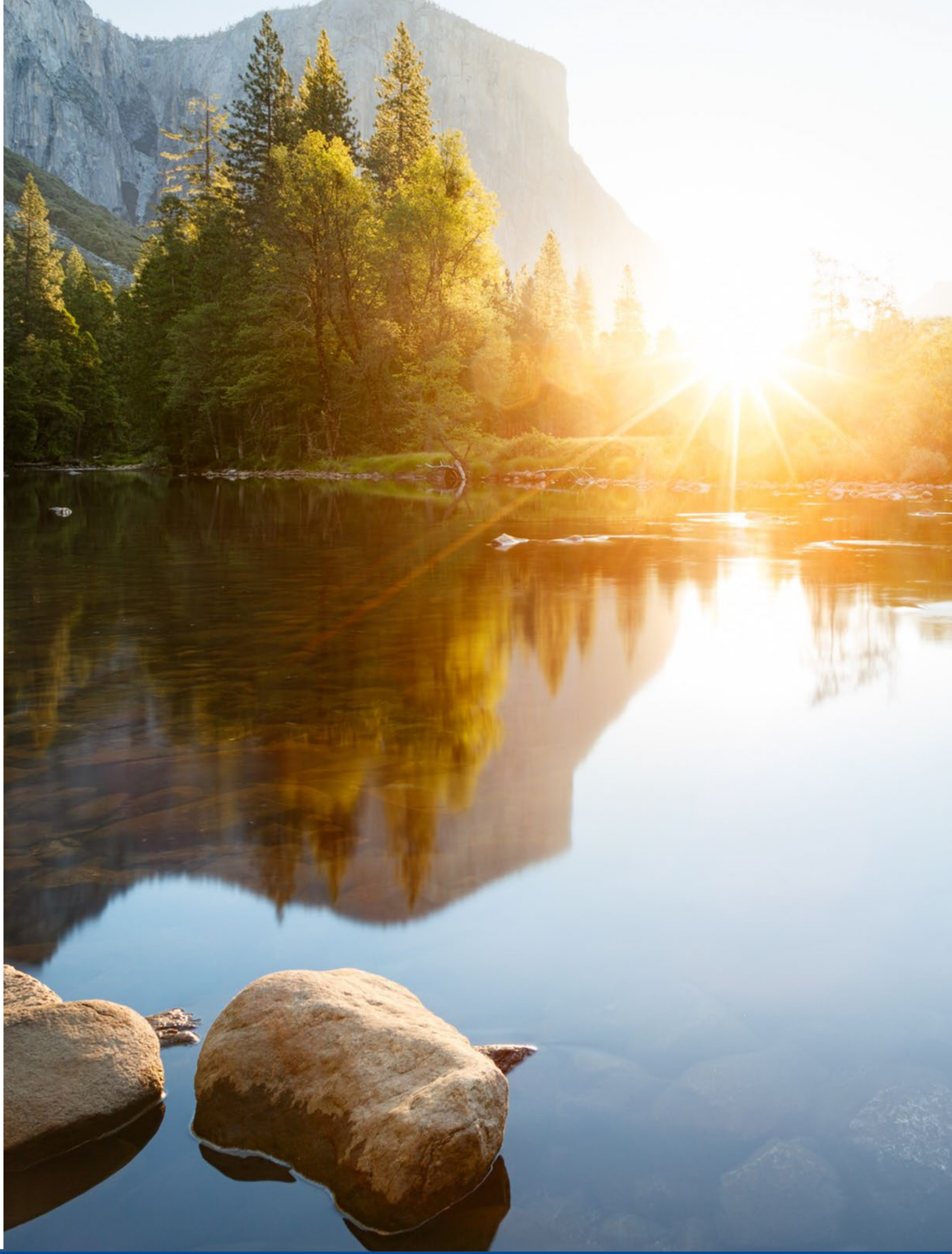
- Determines the time it takes for drop of water to get from one end of the basin to the other
- It is a ***<u>time!</u>*** (velocity over a distance)
    - Determined by adding up the time for sheet flow, shallow flow, and concentrated flow
    - The shortest total time allowed is 5 minutes



WELL ISOLATION ZONE EASEMENT
PRIMARY AND 100% REPLACEMENT DRAINFIELDS
438 FT³ STORM WATER FACILITY
LOT 1
1.186 ACRES
100′
100′
N 28°20'57" E 125.05'
S 59°22'20" E 402.45'
N 38°59'18" W 116.6'
N 74°49'45" W
S 30°51'31" W 28.73'
MUST INSTALL A MINIMUM OF 10,000 FT² OF LAWN AND LANDSCAPING AROUND THE STRUCTURE FOR STORM WATER CONTROL
DRIVEWAY DITCH
CULVERT
DEQ MINOR SUBDIVISION
LEWIS & CLARK COUNTY
T10N, R03W, SW ¼ OF THE SW1/4 OF SECTION 29
DRAWING PREPARED BY: DEQ STAFF
MARCH 3, 2017
EQ# 17-0000
NOTE: DRAWING IS FOR EDUCATIONAL PURPOSES ONLY. LOT IS FICTITIOUS AND IS NOT TO SCALE. FOR USE ONLY AS A REFERENCE FOR DESIGN CRITERIA.
SCALE: 1" = 50'
0 25 50 100

Time of Concentration

- Sheet flow
  - Thin sheet of flow less than 1 inch in depth
  - Limited to 300 feet in length
  - **Empirical equation**



Time of Concentration

Sheet Flow

$$T_{t-sheet\ flow} = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}s^{0.4}}$$

Where:

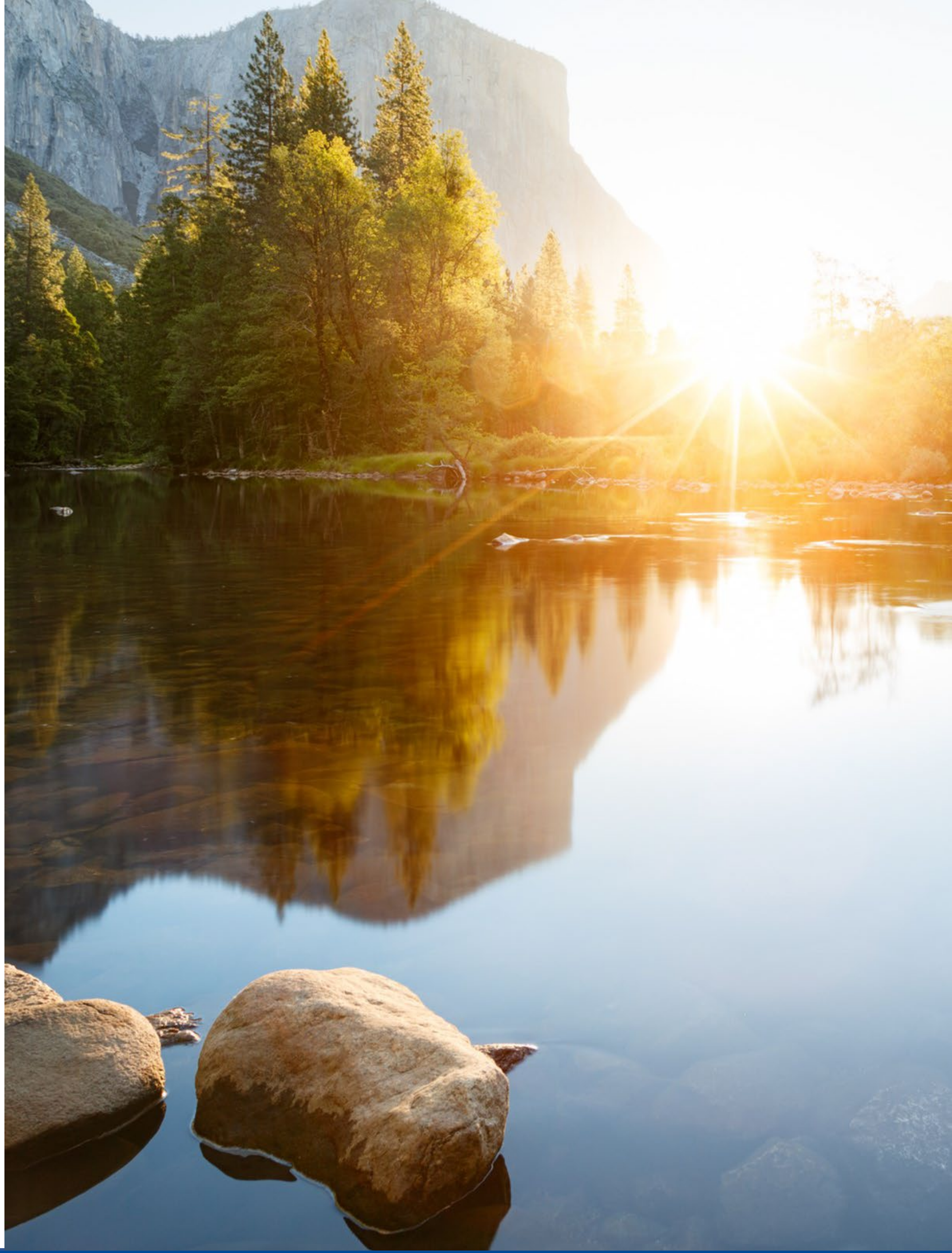
T_t = travel time (hr),
n = Manning's roughness coefficient
L = flow length (ft, max of 300 ft)
P_2 = 2-year, 24-hour rainfall (in)
s = slope of hydraulic grade line (land slope, ft/ft)

Time of Concentration

- Sheet Flow (con’t)
  - So, can’t I use other storm events for sheet flow (like 10-year or 100-year)?
  - **NO** – empirical equation is one developed based on experimental data and observations, NOT based on a theory that can be applied universally

Time of Concentration

- Shallow flow
  - Flow depths are approximately 1 inch to 6 inches (0.1 to 0.5 feet)



Time of Concentration

Shallow Concentrated Flow

$$T_t = \frac{L}{3600V}$$

Where: T_t = time of concentration (hr),
L = flow length (ft)
V = velocity, ft/s

Unpaved: $V = 16.1345 * \sqrt{s}$

Paved: $V = 20.2382 * \sqrt{s}$

Where: V = average velocity, ft/s
S = slope of hydraulic grade line (watercourse slope), ft/ft

Time of Concentration

- Concentrated Flow
  - Determine velocity using Chezy-Manning Equation
  - Use Shallow Concentration equation to get time of concentration
  - Lots of online calculators available for Chezy-Manning or Mannings equation (open channel flow)

Time of Concentration

Chezy-Manning Equation to get velocity

$$Q = VA = \frac{1.486}{n} * A * R^{2/3} * S^{1/2}$$

$$V = \frac{1.486}{n} * R^{2/3} * S^{1/2}$$

Where:

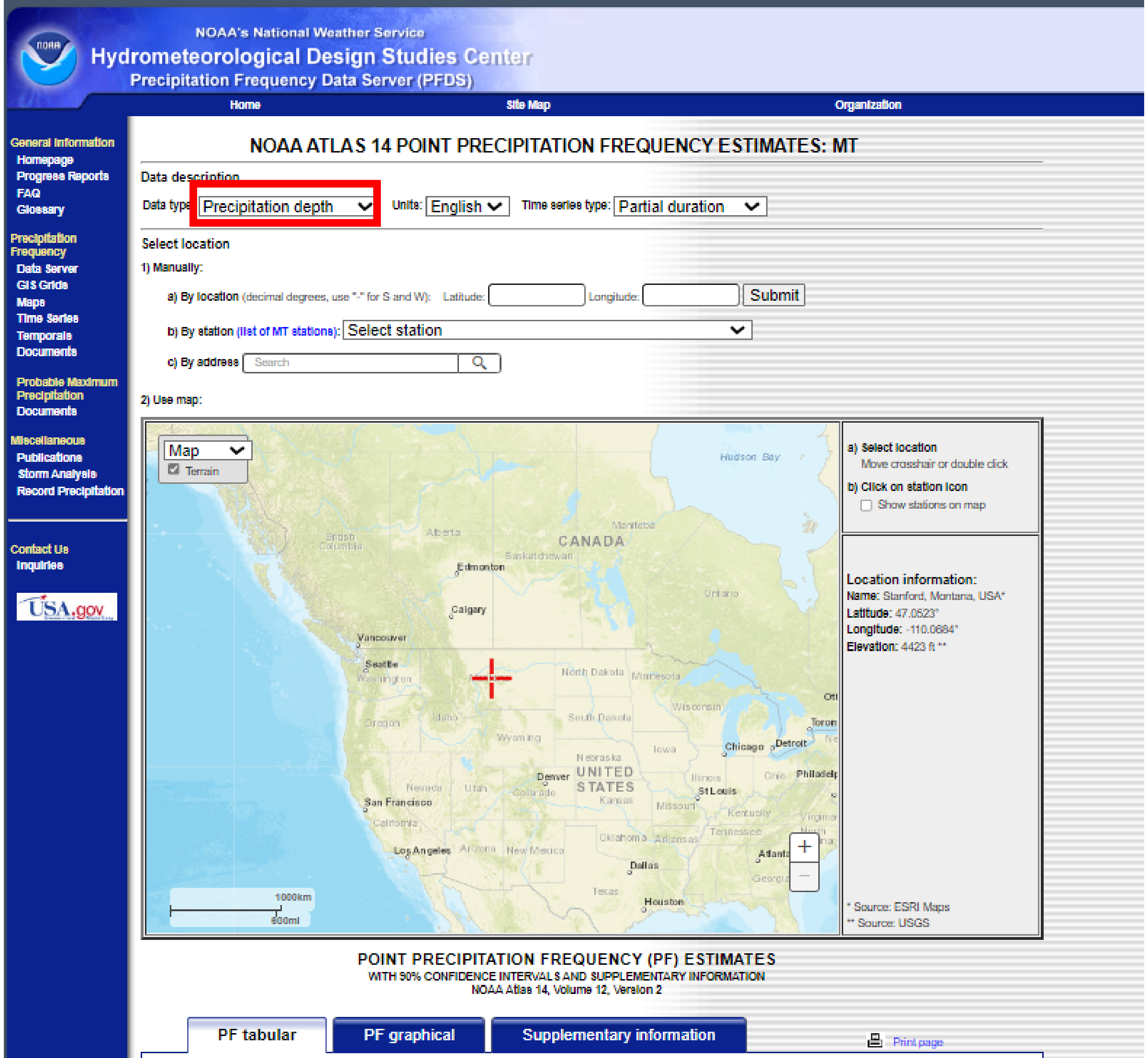
Q = channel flow (cfs)
V = velocity (ft/s)
n = Manning's roughness coefficient
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft)
S = channel slope (ft/ft)
WP = wetted perimeter
R = A/WP

Finding Rainfall Intensity

- Using NOAA's Atlas 14
  - Go to the Atlas 14 site
  - Select "Precipitation Intensity"
  - Look at the 2-year storm event column (or 10-year or 100-year)
  - Select the storm with the duration that is equal to your time of concentration (or interpolate between two values)
  - That value is the rainfall intensity for that storm event

Rainfall

- NOAA has published Atlas 14, Volume 12 for Idaho, Montana, and Wyoming
  - This updates and replaces Atlas 2
  - Available at https://hdsc.nws.noaa.gov/pfds/pfds_map_cont.html



PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years) 1	2	5	10	25	50	100	200	500	1000
5-min	0.169 (0.143-0.197)	0.240 (0.206-0.284)	0.357 (0.305-0.431)	0.457 (0.382-0.558)	0.597 (0.476-0.740)	0.707 (0.538-0.885)	0.819 (0.586-1.05)	0.934 (0.620-1.24)	1.09 (0.656-1.53)	1.21 (0.688-1.77)
10-min	0.235 (0.199-0.274)	0.333 (0.286-0.393)	0.496 (0.422-0.598)	0.634 (0.530-0.774)	0.829 (0.661-1.03)	0.981 (0.747-1.23)	1.14 (0.813-1.45)	1.30 (0.861-1.72)	1.51 (0.910-2.12)	1.68 (0.955-2.46)
15-min	0.273 (0.231-0.318)	0.386 (0.333-0.457)	0.576 (0.491-0.695)	0.737 (0.616-0.899)	0.963 (0.767-1.19)	1.14 (0.868-1.43)	1.32 (0.945-1.69)	1.51 (1.00-1.99)	1.76 (1.06-2.46)	1.95 (1.11-2.85)
30-min	0.332 (0.282-0.388)	0.471 (0.405-0.557)	0.702 (0.598-0.847)	0.898 (0.750-1.10)	1.17 (0.935-1.45)	1.39 (1.06-1.74)	1.61 (1.15-2.06)	1.84 (1.22-2.43)	2.14 (1.29-3.00)	2.38 (1.35-3.48)

Storm Event

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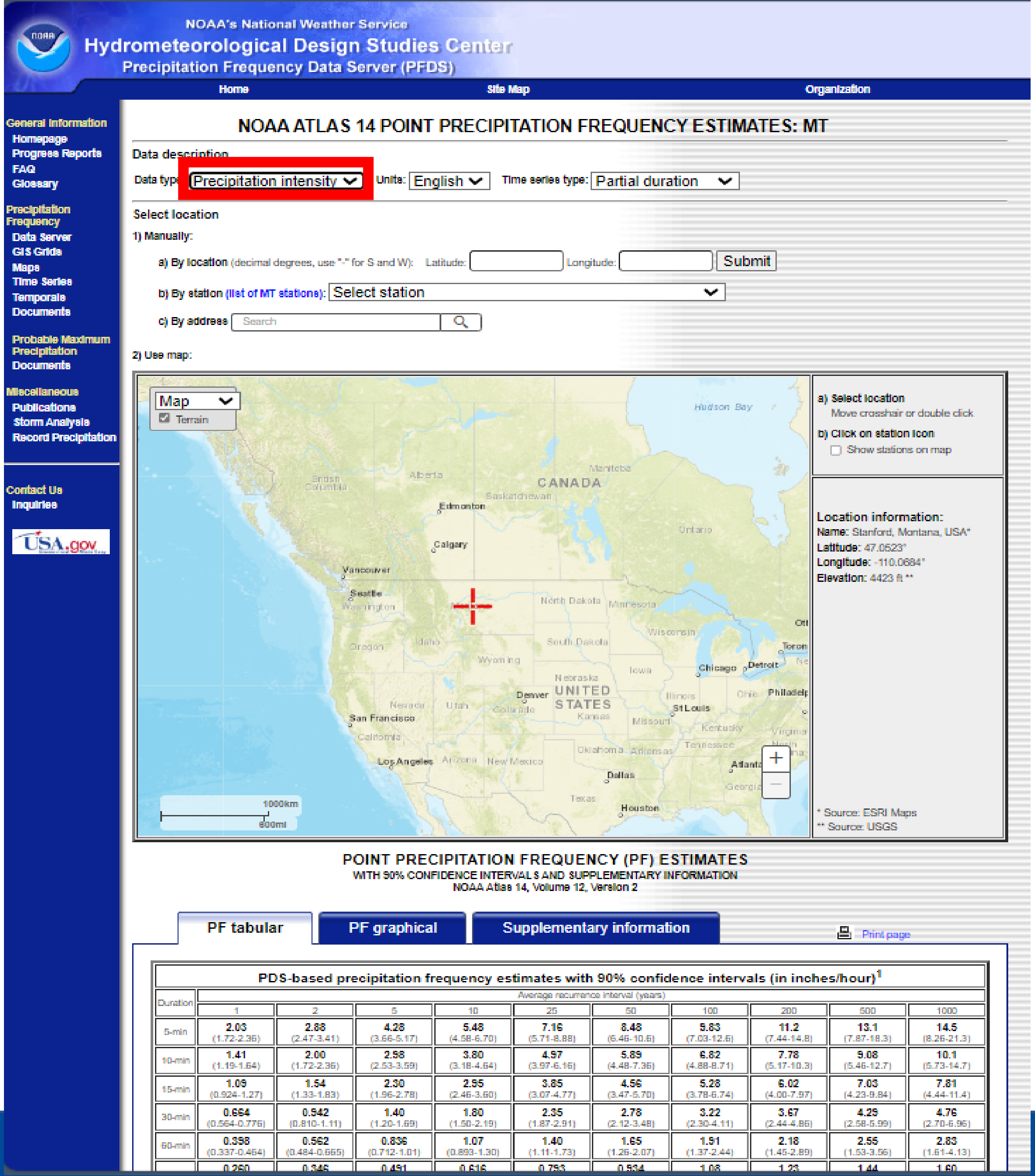
PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.156** (0.136-0.178)	**0.216** (0.191-0.250)	**0.313** (0.274-0.368)	**0.393** (0.337-0.467)	**0.501** (0.413-0.605)	**0.583** (0.462-0.713)	**0.664** (0.495-0.829)	**0.745** (0.521-0.965)	**0.851** (0.547-1.17)	**0.929** (0.574-1.34)
10-min	**0.216** (0.189-0.247)	**0.300** (0.265-0.346)	**0.435** (0.380-0.510)	**0.545** (0.468-0.647)	**0.695** (0.572-0.839)	**0.809** (0.640-0.988)	**0.921** (0.687-1.15)	**1.03** (0.722-1.34)	**1.18** (0.759-1.62)	**1.29** (0.797-1.86)
15-min	**0.251** (0.220-0.287)	**0.348** (0.308-0.402)	**0.505** (0.441-0.593)	**0.633** (0.544-0.752)	**0.807** (0.665-0.975)	**0.940** (0.744-1.15)	**1.07** (0.798-1.34)	**1.20** (0.839-1.56)	**1.37** (0.882-1.88)	**1.50** (0.926-2.16)
30-min	**0.306** (0.268-0.350)	**0.424** (0.375-0.491)	**0.615** (0.538-0.723)	**0.772** (0.663-0.917)	**0.984** (0.810-1.19)	**1.14** (0.907-1.40)	**1.30** (0.973-1.63)	**1.46** (1.02-1.90)	**1.67** (1.08-2.30)	**1.82** (1.13-2.63)
60-min	**0.366** (0.320-0.418)	**0.506** (0.448-0.585)	**0.733** (0.641-0.861)	**0.919** (0.789-1.09)	**1.17** (0.964-1.41)	**1.36** (1.08-1.66)	**1.55** (1.16-1.94)	**1.74** (1.22-2.25)	**1.99** (1.28-2.73)	**2.17** (1.34-3.13)
2-hr	**0.477** (0.422-0.537)	**0.627** (0.559-0.715)	**0.870** (0.768-1.01)	**1.07** (0.929-1.25)	**1.34** (1.13-1.60)	**1.55** (1.26-1.87)	**1.76** (1.36-2.17)	**1.97** (1.44-2.53)	**2.25** (1.51-3.06)	**2.45** (1.59-3.52)
3-hr	**0.561** (0.502-0.627)	**0.713** (0.640-0.804)	**0.960** (0.852-1.10)	**1.16** (1.02-1.34)	**1.45** (1.23-1.70)	**1.66** (1.37-1.98)	**1.88** (1.49-2.30)	**2.10** (1.59-2.68)	**2.39** (1.70-3.24)	**2.61** (1.79-3.73)
6-hr	**0.719** (0.650-0.796)	**0.876** (0.793-0.975)	**1.14** (1.02-1.28)	**1.36** (1.20-1.54)	**1.66** (1.43-1.91)	**1.90** (1.60-2.22)	**2.14** (1.76-2.58)	**2.38** (1.90-3.00)	**2.71** (2.08-3.64)	**2.97** (2.20-4.19)
12-hr	**0.893** (0.809-0.983)	**1.06** (0.966-1.18)	**1.36** (1.22-1.52)	**1.61** (1.43-1.81)	**1.97** (1.72-2.25)	**2.26** (1.94-2.62)	**2.56** (2.14-3.04)	**2.87** (2.35-3.55)	**3.30** (2.60-4.34)	**3.64** (2.79-5.02)
24-hr	**1.09** (0.988-1.20)	**1.28** (1.17-1.42)	**1.62** (1.47-1.81)	**1.92** (1.72-2.15)	**2.36** (2.07-2.67)	**2.71** (2.33-3.11)	**3.07** (2.59-3.62)	**3.45** (2.85-4.23)	**4.00** (3.19-5.20)	**4.43** (3.44-6.03)
2-day	**1.29** (1.17-1.42)	**1.52** (1.38-1.67)	**1.91** (1.73-2.13)	**2.26** (2.01-2.53)	**2.75** (2.41-3.12)	**3.15** (2.71-3.62)	**3.56** (3.00-4.20)	**3.99** (3.29-4.90)	**4.60** (3.66-5.98)	**5.07** (3.94-6.91)



PDS-based precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	2.03 (1.72-2.36)	2.88 (2.47-3.41)	4.28 (3.66-5.17)	5.48 (4.58-6.70)	7.16 (5.71-8.88)	8.48 (6.46-10.6)	9.83 (7.03-12.6)	11.2 (7.44-14.8)	13.1 (7.87-18.3)	14.5 (8.26-21.3)
10-min	1.41 (1.19-1.64)	2.00 (1.72-2.36)	2.98 (2.53-3.59)	3.80 (3.18-4.64)	4.97 (3.97-6.16)	5.89 (4.48-7.36)	6.82 (4.88-8.71)	7.78 (5.17-10.3)	9.08 (5.46-12.7)	10.1 (5.73-14.7)
15-min	1.09 (0.924-1.27)	1.54 (1.33-1.83)	2.30 (1.96-2.78)	2.95 (2.46-3.60)	3.85 (3.07-4.77)	4.56 (3.47-5.70)	5.28 (3.78-6.74)	6.02 (4.00-7.97)	7.03 (4.23-9.84)	7.81 (4.44-11.4)
30-min	0.664 (0.564-0.776)	0.942 (0.810-1.11)	1.40 (1.20-1.69)	1.80 (1.50-2.19)	2.35 (1.87-2.91)	2.78 (2.12-3.48)	3.22 (2.30-4.11)	3.67 (2.44-4.86)	4.29 (2.58-5.99)	4.76 (2.70-6.96)
60-min	0.398 (0.337-0.464)	0.562 (0.484-0.665)	0.836 (0.712-1.01)	1.07 (0.893-1.30)	1.40 (1.11-1.73)	1.65 (1.26-2.07)	1.91 (1.37-2.44)	2.18 (1.45-2.89)	2.55 (1.53-3.56)	2.83 (1.61-4.13)
	0.260	0.346	0.491	0.616	0.793	0.934	1.08	1.23	1.44	1.60

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PDS-based precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**1.87** (1.63-2.14)	**2.59** (2.29-3.00)	**3.76** (3.29-4.42)	**4.72** (4.04-5.60)	**6.01** (4.96-7.26)	**7.00** (5.54-8.56)	**7.97** (5.94-9.95)	**8.94** (6.25-11.6)	**10.2** (6.56-14.0)	**11.1** (6.89-16.1)
10-min	**1.30** (1.13-1.48)	**1.80** (1.59-2.08)	**2.61** (2.28-3.06)	**3.27** (2.81-3.88)	**4.17** (3.43-5.03)	**4.85** (3.84-5.93)	**5.53** (4.12-6.90)	**6.20** (4.33-8.03)	**7.08** (4.55-9.73)	**7.73** (4.78-11.1)
15-min	**1.00** (0.880-1.15)	**1.39** (1.23-1.61)	**2.02** (1.76-2.37)	**2.53** (2.18-3.01)	**3.23** (2.66-3.90)	**3.76** (2.98-4.59)	**4.28** (3.19-5.34)	**4.80** (3.36-6.22)	**5.48** (3.53-7.53)	**5.99** (3.70-8.63)
30-min	**0.612** (0.536-0.700)	**0.848** (0.750-0.982)	**1.23** (1.08-1.45)	**1.54** (1.33-1.83)	**1.97** (1.62-2.38)	**2.29** (1.81-2.80)	**2.61** (1.95-3.26)	**2.93** (2.04-3.79)	**3.34** (2.15-4.59)	**3.65** (2.26-5.26)
60-min	**0.366** (0.320-0.418)	**0.506** (0.448-0.585)	**0.733** (0.641-0.861)	**0.919** (0.789-1.09)	**1.17** (0.964-1.41)	**1.36** (1.08-1.66)	**1.55** (1.16-1.94)	**1.74** (1.22-2.25)	**1.99** (1.28-2.73)	**2.17** (1.34-3.13)
2-hr	**0.238** (0.211-0.268)	**0.313** (0.279-0.357)	**0.435** (0.384-0.503)	**0.535** (0.464-0.625)	**0.672** (0.563-0.798)	**0.776** (0.629-0.936)	**0.880** (0.680-1.09)	**0.985** (0.717-1.26)	**1.12** (0.756-1.53)	**1.23** (0.794-1.76)
3-hr	**0.186** (0.167-0.208)	**0.237** (0.213-0.267)	**0.319** (0.283-0.365)	**0.387** (0.338-0.447)	**0.481** (0.408-0.565)	**0.554** (0.456-0.660)	**0.626** (0.496-0.766)	**0.699** (0.529-0.891)	**0.796** (0.567-1.08)	**0.869** (0.595-1.24)
6-hr	**0.120** (0.108-0.132)	**0.146** (0.132-0.162)	**0.189** (0.169-0.213)	**0.226** (0.199-0.256)	**0.277** (0.238-0.319)	**0.316** (0.267-0.371)	**0.356** (0.293-0.430)	**0.397** (0.317-0.500)	**0.453** (0.347-0.608)	**0.495** (0.367-0.699)
12-hr	**0.074** (0.067-0.081)	**0.088** (0.080-0.097)	**0.112** (0.101-0.125)	**0.133** (0.119-0.150)	**0.163** (0.142-0.186)	**0.187** (0.160-0.217)	**0.212** (0.177-0.252)	**0.237** (0.194-0.294)	**0.273** (0.216-0.360)	**0.301** (0.231-0.416)
24-hr	**0.045** (0.041-0.049)	**0.053** (0.048-0.058)	**0.067** (0.061-0.075)	**0.080** (0.071-0.089)	**0.098** (0.086-0.111)	**0.112** (0.097-0.129)	**0.127** (0.108-0.150)	**0.143** (0.118-0.176)	**0.166** (0.132-0.216)	**0.184** (0.143-0.251)
2-day	**0.026** (0.024-0.029)	**0.031** (0.028-0.034)	**0.039** (0.035-0.044)	**0.047** (0.041-0.052)	**0.057** (0.050-0.065)	**0.065** (0.056-0.075)	**0.074** (0.062-0.087)	**0.083** (0.068-0.101)	**0.095** (0.076-0.124)	**0.105** (0.082-0.143)
3-day	**0.019** (0.017-0.021)	**0.023** (0.021-0.025)	**0.029** (0.026-0.032)	**0.034** (0.030-0.038)	**0.041** (0.036-0.047)	**0.047** (0.041-0.055)	**0.053** (0.045-0.063)	**0.060** (0.049-0.073)	**0.068** (0.054-0.089)	**0.075** (0.058-0.103)

Determining the IDF Curve values

- Determine Time of Concentration for Site
  - Site has a swale and a culvert
  - Length of Sheet Flow = 150 feet
  - Drains into driveway swale. Swale is 120 feet long.
  - Elevation at top of sheet flow path = 4,106 ft
  - Elevation at bottom of sheet flow path = 4,101 ft
  - Elevation at start of swale at the bottom (shallow concentrated flow) = 4,100 ft
  - Elevation at end of swale at the bottom = 4,094 ft

Determining Time of Concentration (Con’t)

- Find the slope for the sheet flow:

$$s = \frac{\Delta h}{L} \therefore s = \frac{4{,}106 - 4{,}101}{155}$$

$$= 0.0323 \frac{ft}{ft}$$

Determining Time of Concentration (Con't)

- Calculate Sheet Flow

n = ?

L = 155

P_2 = ?

s = 0.0323

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}}$$

Where:
T_t = time of concentration (hr),
n = Manning's roughness coefficient
L = flow length (ft, max of 300 ft)
P_2 = 2-year, 24-hour rainfall (in)
s = slope of hydraulic grade line (land slope, ft/ft)

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NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES: MT

Data description

Data type: Precipitation depth | Units: English | Time series type: Partial duration

Select location

1) Manually:

a) By location (decimal degrees, use "-" for S and W): Latitude: Longitude: Submit

b) By station (list of MT stations): Select station

c) By address Search

2) Use map:

a) Select location
Move crosshair or double click

b) Click on station icon
Show stations on map

Location information:
Name: Stanford, Montana, USA*
Latitude: 47.0523°
Longitude: -110.0684°
Elevation: 4423 ft **

* Source: ESRI Maps
** Source: USGS

POINT PRECIPITATION FREQUENCY (PF) ESTIMATES

WITH 90% CONFIDENCE INTERVALS AND SUPPLEMENTARY INFORMATION

NOAA Atlas 14, Volume 12, Version 2

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PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years) 1	2	5	10	25	50	100	200	500	1000
5-min	0.169 (0.143-0.197)	0.240 (0.206-0.284)	0.357 (0.305-0.431)	0.457 (0.382-0.558)	0.597 (0.476-0.740)	0.707 (0.538-0.885)	0.819 (0.586-1.05)	0.934 (0.620-1.24)	1.09 (0.656-1.53)	1.21 (0.688-1.77)
10-min	0.235 (0.199-0.274)	0.333 (0.286-0.393)	0.496 (0.422-0.598)	0.634 (0.530-0.774)	0.829 (0.661-1.03)	0.981 (0.747-1.23)	1.14 (0.813-1.45)	1.30 (0.861-1.72)	1.51 (0.910-2.12)	1.68 (0.955-2.46)
15-min	0.273 (0.231-0.318)	0.386 (0.333-0.457)	0.576 (0.491-0.695)	0.737 (0.616-0.899)	0.963 (0.767-1.19)	1.14 (0.868-1.43)	1.32 (0.945-1.69)	1.51 (1.00-1.99)	1.76 (1.06-2.46)	1.95 (1.11-2.85)
30-min	0.332 (0.282-0.388)	0.471 (0.405-0.557)	0.702 (0.598-0.847)	0.898 (0.750-1.10)	1.17 (0.935-1.45)	1.39 (1.06-1.74)	1.61 (1.15-2.06)	1.84 (1.22-2.43)	2.14 (1.29-3.00)	2.38 (1.35-3.48)

PF tabular | PF graphical | Supplementary information | Print page

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.156** (0.136-0.178)	**0.216** (0.191-0.250)	**0.313** (0.274-0.368)	**0.393** (0.337-0.467)	**0.501** (0.413-0.605)	**0.583** (0.462-0.713)	**0.664** (0.495-0.829)	**0.745** (0.521-0.965)	**0.851** (0.547-1.17)	**0.929** (0.574-1.34)
10-min	**0.216** (0.189-0.247)	**0.300** (0.265-0.346)	**0.435** (0.380-0.510)	**0.545** (0.468-0.647)	**0.695** (0.572-0.839)	**0.809** (0.640-0.988)	**0.921** (0.687-1.15)	**1.03** (0.722-1.34)	**1.18** (0.759-1.62)	**1.29** (0.797-1.86)
15-min	**0.251** (0.220-0.287)	**0.348** (0.308-0.402)	**0.505** (0.441-0.593)	**0.633** (0.544-0.752)	**0.807** (0.665-0.975)	**0.940** (0.744-1.15)	**1.07** (0.798-1.34)	**1.20** (0.839-1.56)	**1.37** (0.882-1.88)	**1.50** (0.926-2.16)
30-min	**0.306** (0.268-0.350)	**0.424** (0.375-0.491)	**0.615** (0.538-0.723)	**0.772** (0.663-0.917)	**0.984** (0.810-1.19)	**1.14** (0.907-1.40)	**1.30** (0.973-1.63)	**1.46** (1.02-1.90)	**1.67** (1.08-2.30)	**1.82** (1.13-2.63)
60-min	**0.366** (0.320-0.418)	**0.506** (0.448-0.585)	**0.733** (0.641-0.861)	**0.919** (0.789-1.09)	**1.17** (0.964-1.41)	**1.36** (1.08-1.66)	**1.55** (1.16-1.94)	**1.74** (1.22-2.25)	**1.99** (1.28-2.73)	**2.17** (1.34-3.13)
2-hr	**0.477** (0.422-0.537)	**0.627** (0.559-0.715)	**0.870** (0.768-1.01)	**1.07** (0.929-1.25)	**1.34** (1.13-1.60)	**1.55** (1.26-1.87)	**1.76** (1.36-2.17)	**1.97** (1.44-2.53)	**2.25** (1.51-3.06)	**2.45** (1.59-3.52)
3-hr	**0.561** (0.502-0.627)	**0.713** (0.640-0.804)	**0.960** (0.852-1.10)	**1.16** (1.02-1.34)	**1.45** (1.23-1.70)	**1.66** (1.37-1.98)	**1.88** (1.49-2.30)	**2.10** (1.59-2.68)	**2.39** (1.70-3.24)	**2.61** (1.79-3.73)
6-hr	**0.719** (0.650-0.796)	**0.876** (0.793-0.975)	**1.14** (1.02-1.28)	**1.36** (1.20-1.54)	**1.66** (1.43-1.91)	**1.90** (1.60-2.22)	**2.14** (1.76-2.58)	**2.38** (1.90-3.00)	**2.71** (2.08-3.64)	**2.97** (2.20-4.19)
12-hr	**0.893** (0.809-0.983)	**1.06** (0.966-1.18)	**1.36** (1.22-1.52)	**1.61** (1.43-1.81)	**1.97** (1.72-2.25)	**2.26** (1.94-2.62)	**2.56** (2.14-3.04)	**2.87** (2.35-3.55)	**3.30** (2.60-4.34)	**3.64** (2.79-5.02)
24-hr	**1.09** (0.988-1.20)	**1.28** (1.17-1.42)	**1.62** (1.47-1.81)	**1.92** (1.72-2.15)	**2.36** (2.07-2.67)	**2.71** (2.33-3.11)	**3.07** (2.59-3.62)	**3.45** (2.85-4.23)	**4.00** (3.19-5.20)	**4.43** (3.44-6.03)
2-day	**1.29** (1.17-1.42)	**1.52** (1.38-1.67)	**1.91** (1.73-2.13)	**2.26** (2.01-2.53)	**2.75** (2.41-3.12)	**3.15** (2.71-3.62)	**3.56** (3.00-4.20)	**3.99** (3.29-4.90)	**4.60** (3.66-5.98)	**5.07** (3.94-6.91)

Determining Time of Concentration (Con't)

- Calculate Sheet Flow

$n = ?$

$L = 155$

$P_2 = 1.28$ in

$s = 0.0323$

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}}$$

Where:

T_t = time of concentration (hr),
n = Manning's roughness coefficient
L = flow length (ft, max of 300 ft)
P_2 = 2-year, 24-hour rainfall (in)
s = slope of hydraulic grade line (land slope, ft/ft)

Mannings n from FHA Urban Drainage Design:
https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif24006.pdf

Table 4.2. Manning's roughness coefficient (n) for overland sheet flow (FHWA 2002).

Surface Description	n
Smooth asphalt	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Brick with cement mortar	0.014
Vitrified clay	0.015
Cast iron	0.015
Corrugated metal pipe	0.024
Cement rubble surface	0.024
Fallow (no residue)	0.05
Cultivated soils: Residue cover # 20%	0.06
Cultivated soils: Residue cover > 20%	0.17
Cultivated soils: Range (natural)	0.13
Short grass prairie	0.15
Dense grasses	0.24
Bermuda grass	0.41
Woods: Light underbrush *	0.40
Woods: Dense underbrush *	0.80

*When selecting n, consider cover to a height of about 1 inch (30 mm). This is only part of the plant cover that will obstruct sheet flow.

Note that the closer "n" is to one, the more "rough" the surface

Table 4.4. Typical range of Manning's coefficient (n) for channels and pipes.

Conduit Category	Conduit Material	Manning's n *
Closed conduits	Concrete pipe	0.010 - 0.015
	CMP	0.011 - 0.037
	Plastic pipe (smooth)	0.009 - 0.015
	Plastic pipe (corrugated)	0.018 - 0.025
Pavement/gutter sections	Concrete, asphalt	0.012 - 0.016
Small open channels	Concrete	0.011 - 0.015
	Rubble or riprap	0.020 - 0.035
	Vegetation	0.020 - 0.150
	Bare soil	0.016 - 0.025
	Rock cut	0.025 - 0.045
Natural channels/streams (top width at flood stage less than 100 ft (30 m)	Fairly regular section	0.025 - 0.050
	Irregular section with pools	0.040 - 0.150

*Lower values usually apply to well-constructed and maintained (smoother) pipes and channels.

Determining Time of Concentration (Con't)

- Calculate Sheet Flow

n = 0.15
L = 155
P_2 = 1.28 in
s = 0.0323

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} s^{0.4}}$$

Where:
T_t = time of concentration (hr),
n = Manning's roughness coefficient
L = flow length (ft, max of 300 ft)
P_2 = 2-year, 24-hour rainfall (in)
s = slope of hydraulic grade line (land slope, ft/ft)

$$T_{t-sheet\ flow} = \frac{0.007(0.15 * 155)^{0.8}}{(1.28)^{0.5} 0.0323^{0.4}} = 0.303\ hours\ or\ 18\ minutes$$

Determining Time of Concentration (Con't)

- Find the slope for the channel:

$$s = \frac{\Delta h}{L} \therefore s = \frac{4{,}100 - 4{,}094}{120}$$

$$= 0.05\frac{ft}{ft}$$

Determining Time of Concentration (Con't)

- With a Swale – Velocity using shallow flow equation

L = 120

3600 is seconds

in an hour

V = ?

s = 0.05 ft/ft

$$T_t = \frac{L}{3600V}$$

Where: T_t = time of concentration (hr),
L = flow length (ft)
V = velocity, ft/s

$$V = 16.1345 * \sqrt{s} = 16.1345 * \sqrt{0.05} = 3.6\ ft/sec$$

Velocity equation for unpaved surface

Determining Time of Concentration (Con't)

- With a Swale – Velocity using shallow flow equation

L = 120

3600 is seconds in an hour

V = 3.6 ft/sec

s = 0.05 ft/ft

$$T_t = \frac{L}{3600V}$$

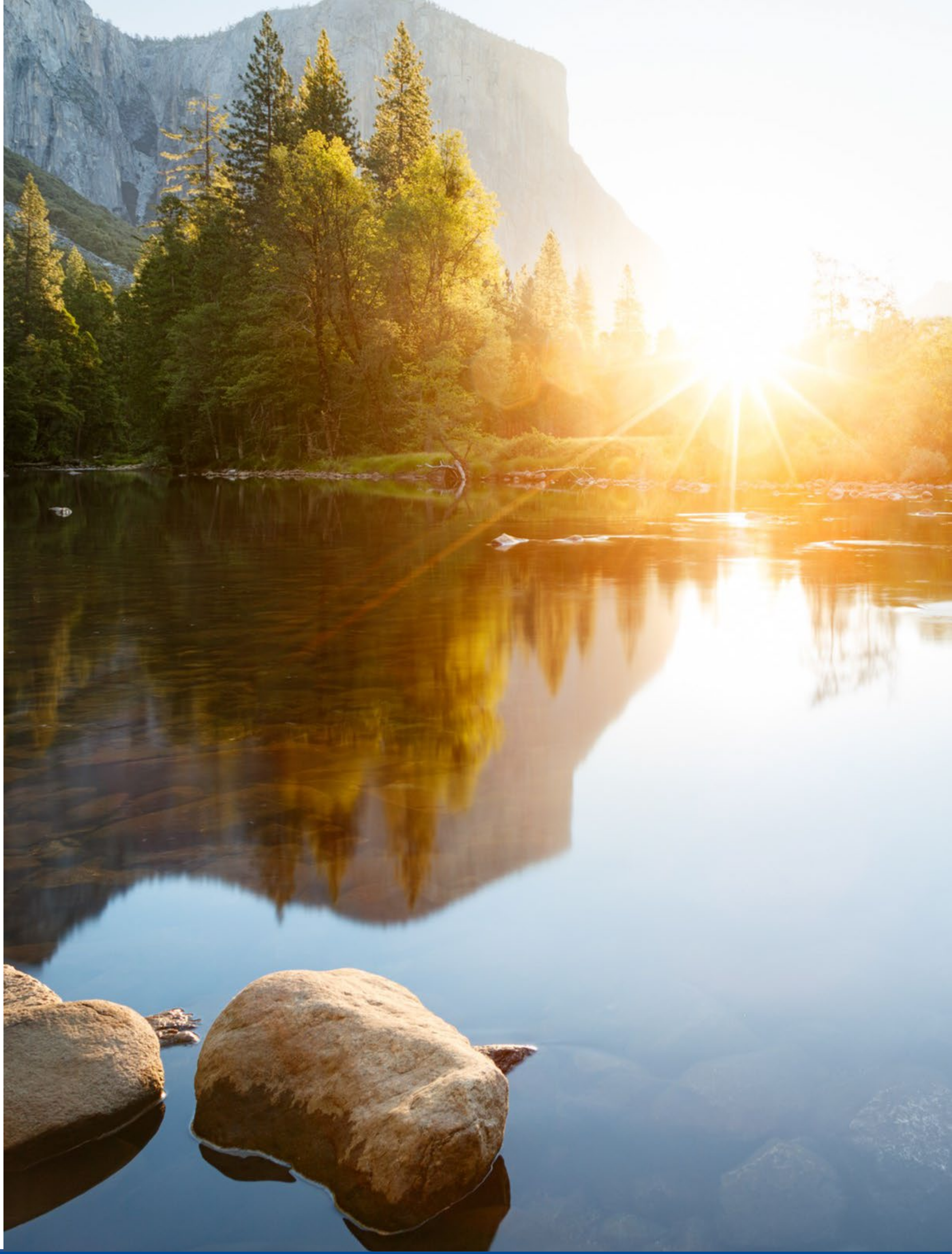
Where: T_t = time of concentration (hr),
L = flow length (ft)
V = velocity, ft/s

$$T_{t-shallow\ concentrated\ flow} = \frac{L}{3600V} = \frac{120}{3600 * 3.6}$$
$$= 0.009\ hours\ or\ 1\ minutes$$

Determining Time of Concentration (Con’t)

- Total Time of Concentration is –

Sheet flow plus shallow flow plus concentrated flow (if any)



Determining Time of Concentration (Con't)

- With a Swale – Total Time of Concentration

$$T_{total} = T_{t-sheet\ flow} + T_{t-shallow\ concentrated\ flow}$$

$$T_{total} = 18\ mins + 1\ mins = 19\ minutes$$

Determining Time of Concentration (Con't)

- With a Swale – Total Time of Concentration
  - Wait…so what about that concentrated flow Chezy-Manning thing?
  - And when do we use it instead of the velocity equation used here for the shallow flow?
  - You would use the Chezy-Manning equation to find the velocity of flow in a channel when the depth exceeds 6 inches, since that is when you can't use the simpler velocity equation
  - You can use the Chezy-Manning equation instead of the simpler velocity equation for any depth

Determining Time of Concentration (Con't)

- With a Swale – Velocity using Chezy-Manning Equation

n = 0.15

V = ?

S = 0.05 ft/ft

A = ?

WP = ?

R = ?

$$Q = VA = \frac{1.486}{n} * A * R^{2/3} * S^{1/2}$$

$$V = \frac{1.486}{n} * R^{2/3} * S^{1/2}$$

Where:

Q = channel flow (cfs)
V = velocity (ft/s)
n = Manning's roughness coefficient
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft)
S = channel slope (ft/ft)
WP = wetted perimeter
R = A/WP

Determining Time of Concentration (Con't)

- With a Swale – Velocity using Chezy-Manning Equation
  - Assume swale is 200 feet long, with a slope of 0.028 ft/ft.
  - Swale is trapezoid, with a 1-foot-wide bottom, 3:1 slopes and is 1.5 feet deep, with a water depth of up to 1 foot
  - What is the area and wetted perimeter and hydraulic radius of the swale so we can find velocity?

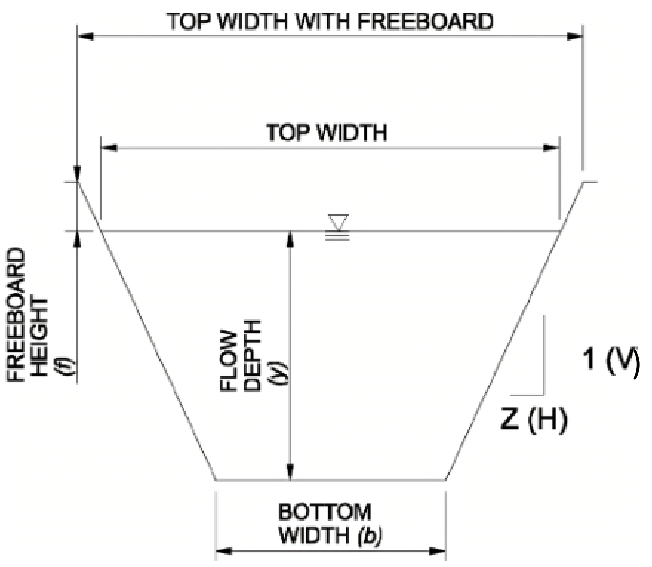
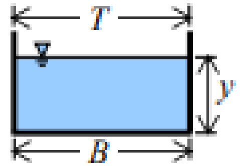
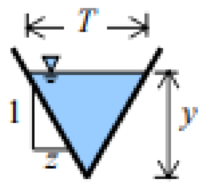
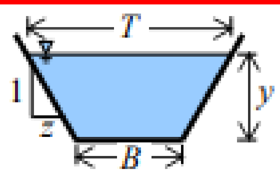
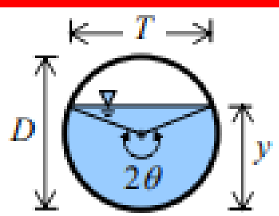


TABLE Q3(b). Open channel flow section geometries

Section	Area A	Top width T	Wetted perimeter P
 Rectangular	By	B	$B + 2y$
 Triangular	zy^2	$2zy$	$2y\sqrt{1+z^2}$
 Trapezoidal	$By + zy^2$	$B + 2zy$	$B + 2y\sqrt{1+z^2}$
 Circular	$\frac{D^2}{8}(2\theta - \sin 2\theta)$	$D\sin\theta$	θD

Determining Time of Concentration (Con't)

- With a Swale – Velocity using Chezy-Manning Equation

B = 1 ft

y = 1 ft (depth)

z = 3

$$A = By + zy^2 = 1\,ft * 1\,ft\ + 3\,ft * (1ft)^2\ = 4\,ft^2$$

$$WP = B + 2y\sqrt{1+z^2}$$
$$= 1 + 2 * 1\sqrt{1+3^2} = 7.32\,ft$$

$$R = \frac{A}{WP} = \frac{4\,ft^2}{7.32\,ft} = 0.55ft$$

- Remember – online calculators will do this!

Determining Time of Concentration (Con’t)

- With a Swale – Velocity using Chezy-Manning Equation

n = 0.15

V = ?

S = 0.05 ft/ft

A = 4 ft^2

WP = 7.32 ft

R = 0.55 ft

$$Q = VA = \frac{1.486}{n} * A * R^{2/3} * S^{1/2}$$

$$V = \frac{1.486}{n} * R^{2/3} * S^{1/2}$$

Where:
Q = channel flow (cfs)
V = velocity (ft/s)
n = Manning's roughness coefficient
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft)
S = channel slope (ft/ft)
WP = wetted perimeter
R = A/WP

$$Q = VA = \frac{1.486}{n} * A * R^{2/3} * S^{1/2}$$

$$V = \frac{1.486}{n} * R^{2/3} * S^{1/2}$$

Where:
Q = channel flow (cfs)
V = velocity (ft/s)
n = Manning's roughness coefficient
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft)
S = channel slope (ft/ft)
WP = wetted perimeter
R = A/WP

$$V = \frac{1.486}{n} * R^{2/3} * S^{1/2} = \frac{1.486}{0.15} * 0.55^{2/3} * 0.028^{1/2} = 1.08\ f/s$$

Determining Time of Concentration (Con't)

- With a Swale – Velocity using Chezy Manning equation

L = 200 ft

3600 is seconds in an hour

V = 1.08 ft/sec

$$T_t = \frac{L}{3600V}$$

Where: T_t = time of concentration (hr),
L = flow length (ft)
V = velocity, ft/s

$$T_{t-shallow\ concentrated\ flow} = \frac{L}{3600V} = \frac{200}{3600 * 1.08} = 0.051\ hours\ or\ 3.1\ minutes$$

Determining Time of Concentration (Con't)

- With a Culvert – Velocity using Chezy Manning equation
  - What about velocity through a culvert?
  - Still would use Chezy Manning equation, same way as swale, only would need internal angle (see open channel geometries table)
  - Online calculators will do this

Developing the IDF Curve values

- Determine Rainfall Intensity (IDF Curve value)
  - Go to NOAA Atlas 14 website
  - Select "Precipitation Intensity" from upper left hand drop down menu
  - Choose your location
  - Use the time of concentration as the storm duration (so 19-minute storm in our example)
  - Interpolate value if needed
  - Value found is the rainfall intensity is in/hr

Developing the IDF Curve values

- Interpolate IDF Curve Values

  - Rainfall during the 2-year storm event (recurrence) with a duration of 19 minutes is what we want for the rainfall intensity value
  - 19-minute duration storm is not directly presented, so we need to interpolate between closest two duration storms – the 15-minute and the 30-minute

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NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES: MT

Data description

Data type: Precipitation intensity | Units: English | Time series type: Partial duration

Select location

1) Manually:

a) By location (decimal degrees, use "-" for S and W): Latitude: Longitude: Submit

b) By station (list of MT stations): Select station

c) By address Search

2) Use map:

a) Select location
Move crosshair or double click

b) Click on station icon
Show stations on map

Location information:
Name: Stanford, Montana, USA*
Latitude: 47.0523°
Longitude: -110.0684°
Elevation: 4423 ft **

* Source: ESRI Maps
** Source: USGS

POINT PRECIPITATION FREQUENCY (PF) ESTIMATES

WITH 90% CONFIDENCE INTERVALS AND SUPPLEMENTARY INFORMATION
NOAA Atlas 14, Volume 12, Version 2

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PDS-based precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	2.03 (1.72-2.36)	2.88 (2.47-3.41)	4.28 (3.66-5.17)	5.48 (4.58-6.70)	7.16 (5.71-8.88)	8.48 (6.46-10.6)	9.83 (7.03-12.6)	11.2 (7.44-14.8)	13.1 (7.87-18.3)	14.5 (8.26-21.3)
10-min	1.41 (1.19-1.64)	2.00 (1.72-2.36)	2.98 (2.53-3.59)	3.80 (3.18-4.64)	4.97 (3.97-6.16)	5.89 (4.48-7.36)	6.82 (4.88-8.71)	7.78 (5.17-10.3)	9.08 (5.46-12.7)	10.1 (5.73-14.7)
15-min	1.09 (0.924-1.27)	1.54 (1.33-1.83)	2.30 (1.96-2.78)	2.95 (2.46-3.60)	3.85 (3.07-4.77)	4.56 (3.47-5.70)	5.28 (3.78-6.74)	6.02 (4.00-7.97)	7.03 (4.23-9.84)	7.81 (4.44-11.4)
30-min	0.664 (0.564-0.776)	0.942 (0.810-1.11)	1.40 (1.20-1.69)	1.80 (1.50-2.19)	2.35 (1.87-2.91)	2.78 (2.12-3.48)	3.22 (2.30-4.11)	3.67 (2.44-4.86)	4.29 (2.58-5.99)	4.76 (2.70-6.96)
60-min	0.398 (0.337-0.464)	0.562 (0.484-0.665)	0.836 (0.712-1.01)	1.07 (0.893-1.30)	1.40 (1.11-1.73)	1.65 (1.26-2.07)	1.91 (1.37-2.44)	2.18 (1.45-2.89)	2.55 (1.53-3.56)	2.83 (1.61-4.13)
[illegible]	0.260	0.346	0.491	0.616	0.753	0.934	1.08	1.23	1.44	1.60

PF tabular | PF graphical | Supplementary information

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PDS-based precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]										
Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**1.87** (1.63-2.14)	**2.59** (2.29-3.00)	**3.76** (3.29-4.42)	**4.72** (4.04-5.60)	**6.01** (4.96-7.26)	**7.00** (5.54-8.56)	**7.97** (5.94-9.95)	**8.94** (6.25-11.6)	**10.2** (6.56-14.0)	**11.1** (6.89-16.1)
10-min	**1.30** (1.13-1.48)	**1.80** (1.59-2.08)	**2.61** (2.28-3.06)	**3.27** (2.81-3.88)	**4.17** (3.43-5.03)	**4.85** (3.84-5.93)	**5.53** (4.12-6.90)	**6.20** (4.33-8.03)	**7.08** (4.55-9.73)	**7.73** (4.78-11.1)
15-min	**1.00** (0.880-1.15)	**1.39** (1.23-1.61)	**2.02** (1.76-2.37)	**2.53** (2.18-3.01)	**3.23** (2.66-3.90)	**3.76** (2.98-4.59)	**4.28** (3.19-5.34)	**4.80** (3.36-6.22)	**5.48** (3.53-7.53)	**5.99** (3.70-8.63)
30-min	**0.612** (0.536-0.700)	**0.848** (0.750-0.982)	**1.23** (1.08-1.45)	**1.54** (1.33-1.83)	**1.97** (1.62-2.38)	**2.29** (1.81-2.80)	**2.61** (1.95-3.26)	**2.93** (2.04-3.79)	**3.34** (2.15-4.59)	**3.65** (2.26-5.26)
60-min	**0.366** (0.320-0.418)	**0.506** (0.448-0.585)	**0.733** (0.641-0.861)	**0.919** (0.789-1.09)	**1.17** (0.964-1.41)	**1.36** (1.08-1.66)	**1.55** (1.16-1.94)	**1.74** (1.22-2.25)	**1.99** (1.28-2.73)	**2.17** (1.34-3.13)
2-hr	**0.238** (0.211-0.268)	**0.313** (0.279-0.357)	**0.435** (0.384-0.503)	**0.535** (0.464-0.625)	**0.672** (0.563-0.798)	**0.776** (0.629-0.936)	**0.880** (0.680-1.09)	**0.985** (0.717-1.26)	**1.12** (0.756-1.53)	**1.23** (0.794-1.76)
3-hr	**0.186** (0.167-0.208)	**0.237** (0.213-0.267)	**0.319** (0.283-0.365)	**0.387** (0.338-0.447)	**0.481** (0.408-0.565)	**0.554** (0.456-0.660)	**0.626** (0.496-0.766)	**0.699** (0.529-0.891)	**0.796** (0.567-1.08)	**0.869** (0.595-1.24)
6-hr	**0.120** (0.108-0.132)	**0.146** (0.132-0.162)	**0.189** (0.169-0.213)	**0.226** (0.199-0.256)	**0.277** (0.238-0.319)	**0.316** (0.267-0.371)	**0.356** (0.293-0.430)	**0.397** (0.317-0.500)	**0.453** (0.347-0.608)	**0.495** (0.367-0.699)
12-hr	**0.074** (0.067-0.081)	**0.088** (0.080-0.097)	**0.112** (0.101-0.125)	**0.133** (0.119-0.150)	**0.163** (0.142-0.186)	**0.187** (0.160-0.217)	**0.212** (0.177-0.252)	**0.237** (0.194-0.294)	**0.273** (0.216-0.360)	**0.301** (0.231-0.416)
24-hr	**0.045** (0.041-0.049)	**0.053** (0.048-0.058)	**0.067** (0.061-0.075)	**0.080** (0.071-0.089)	**0.098** (0.086-0.111)	**0.112** (0.097-0.129)	**0.127** (0.108-0.150)	**0.143** (0.118-0.176)	**0.166** (0.132-0.216)	**0.184** (0.143-0.251)
2-day	**0.026** (0.024-0.029)	**0.031** (0.028-0.034)	**0.039** (0.035-0.044)	**0.047** (0.041-0.052)	**0.057** (0.050-0.065)	**0.065** (0.056-0.075)	**0.074** (0.062-0.087)	**0.083** (0.068-0.101)	**0.095** (0.076-0.124)	**0.105** (0.082-0.143)
3-day	**0.019** (0.017-0.021)	**0.023** (0.021-0.025)	**0.029** (0.026-0.032)	**0.034** (0.030-0.038)	**0.041** (0.036-0.047)	**0.047** (0.041-0.055)	**0.053** (0.045-0.063)	**0.060** (0.049-0.073)	**0.068** (0.054-0.089)	**0.075** (0.058-0.103)

Developing the IDF Curve values

- Interpolate IDF Curve Values
  - 15-minute storm for the 2-year storm event is 1.39 inches/hr
  - 30-minute storm for the 2-year storm event is 0.848 inches/hr

D_1 = 15-minute storm
D_2 = 30-minute storm
D_3 = 19-minute storm
P_1 = 1.39 in/hr
P_2 = 0.848 in/hr
P_3 = ? in/hr

$$P_1 + \frac{(P_1 - P_2)}{(D_1 - D_2)} * (D_3 - D_1) = P_3$$

Developing the IDF Curve values

- Interpolate Final IDF Curve Value

D_1 = 15-minute storm
D_2 = 30-minute storm
D_3 = 19-minute storm
P_1 = 1.39 in/hr
P_2 = 0.848 in/hr
P_3 = ? in/hr

$$P_1 + \frac{(P_1 - P_2)}{(D_1 - D_2)} * (D_3 - D_1) = P_3$$

$$1.39 + \frac{(1.39 - 0.848)}{(15 - 30)} * (19 - 15) = \boxed{1.25\ inch/hour}$$

Developing the IDF Curve values

- Final IDF Curve Value

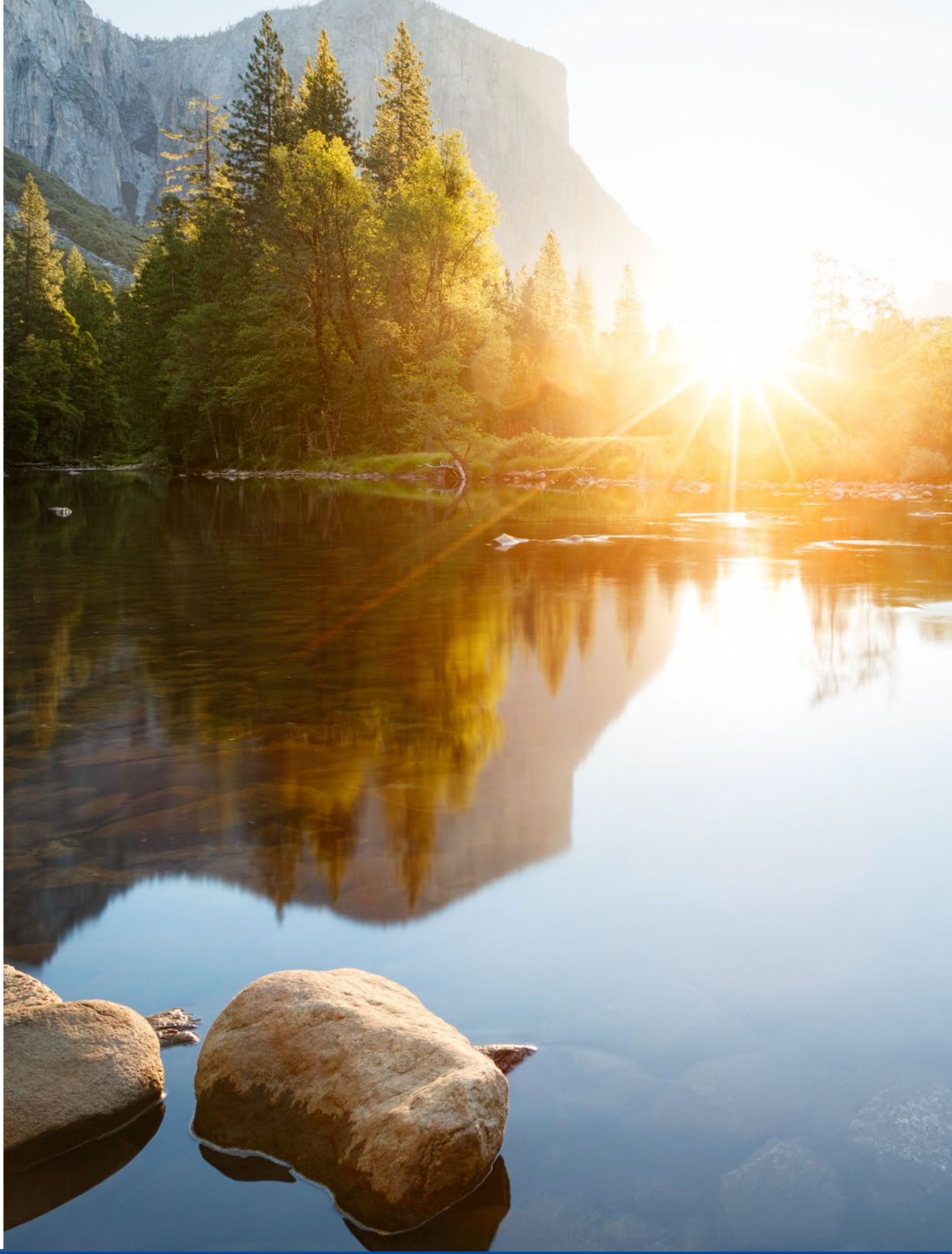
So for the 2-year storm event, where the time of concentration is 19 minutes, the IDF Curve value is:

<u>1.25 inches/hour = **i**</u> (rainfall intensity at the time of concentration)

This is the rainfall intensity used to calculate the flowrates (such as with Q = C * **i** * A)

Review Tips

- Recommendations to keep in mind when reviewing stormwater



Review Tips (con’t)

- Check the TR-55/SCS Method results against the Rational Method (DEQ-8 spreadsheets)
  - How much difference can you allow? Per the TR-55 documentation:

“The procedure (TR-55) should not be used to perform final design if an error in storage of 25 percent cannot be tolerated . . ..”

(for 1000 cf of storage, you would have plus or minus 250 cf)

Review Tips (con't)

- Does the time of concentration make sense? (Is the pre-development time more than post-?)
- Is the rainfall rate within the range listed in Atlas 14?
- What kind of velocities are the flowrates? (4 ft/s starts moving solids – erosion an issue?)
- Do not be afraid to use online calculators for open channel flow
- DEQ-8 has examples – this presentation is based on Appendix F in DEQ-8

Summary

- This is a lot of information – use this presentation and Appendix F in DEQ-8 for help
- Stormwater is based on ranges of numbers and probabilities with margins of error
- Many design decisions for stormwater are based on best judgement, <u>documentation is important</u>
- Always feel free to ask questions

Questions?

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