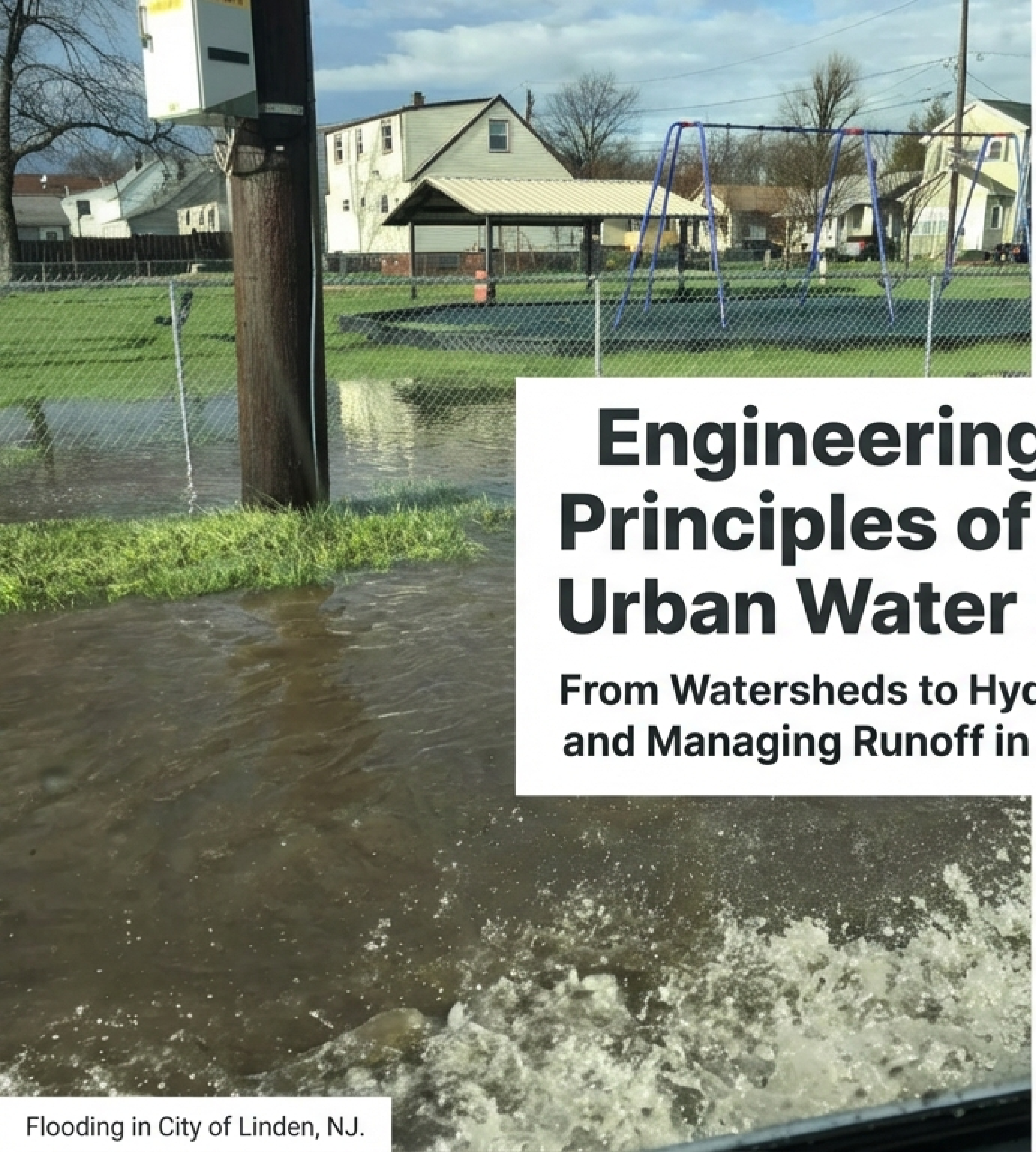
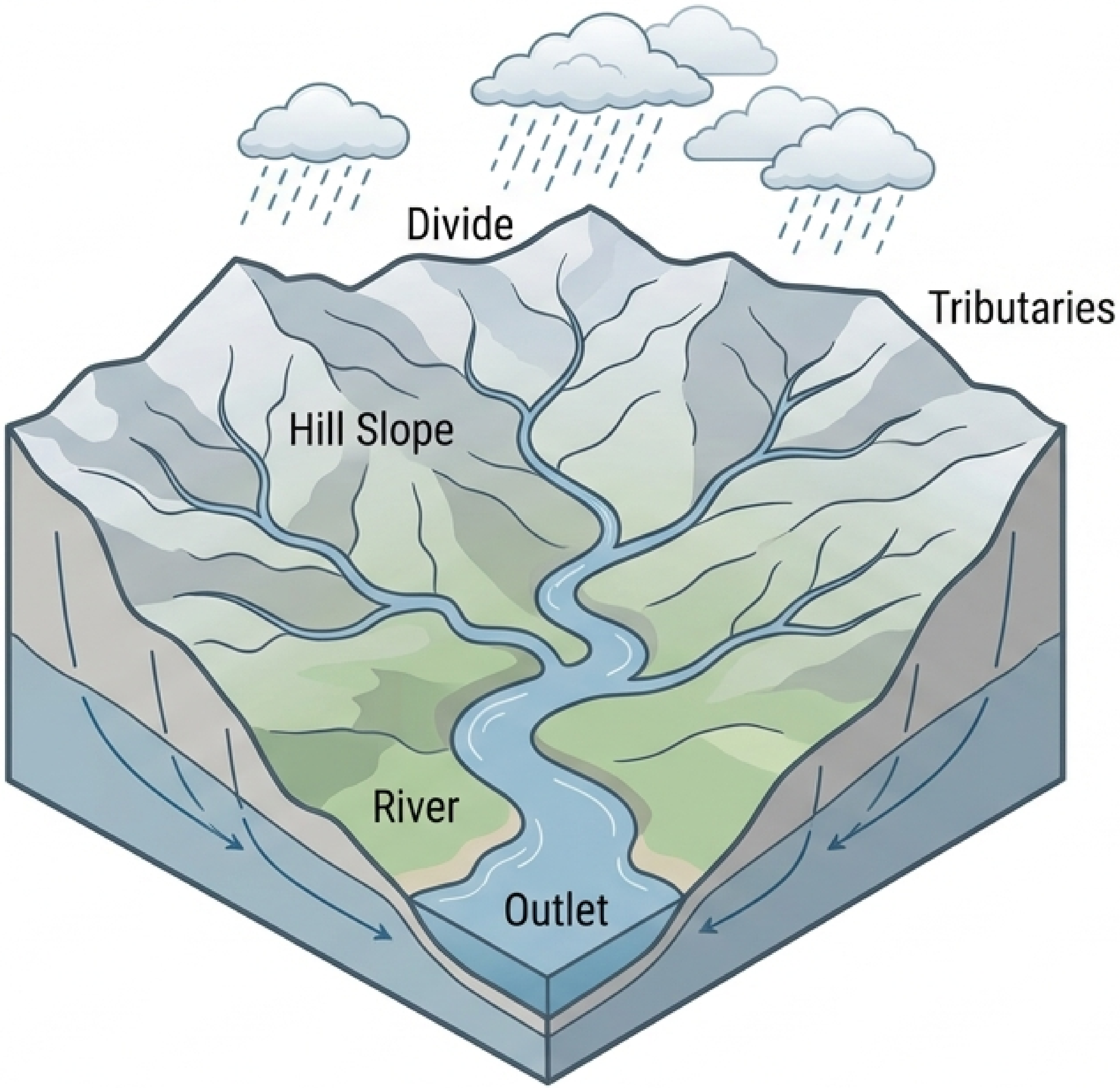


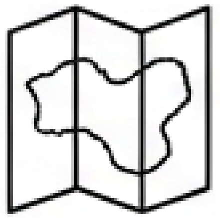
Flooding in City of Linden, NJ.

Engineering the Storm: Principles of Hydrology & Urban Water Management

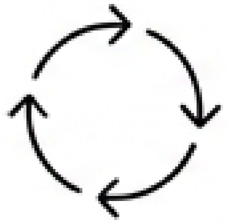
From Watersheds to Hydrographs: Quantifying and Managing Runoff in the Built Environment.



The Fundamental Unit: The Watershed



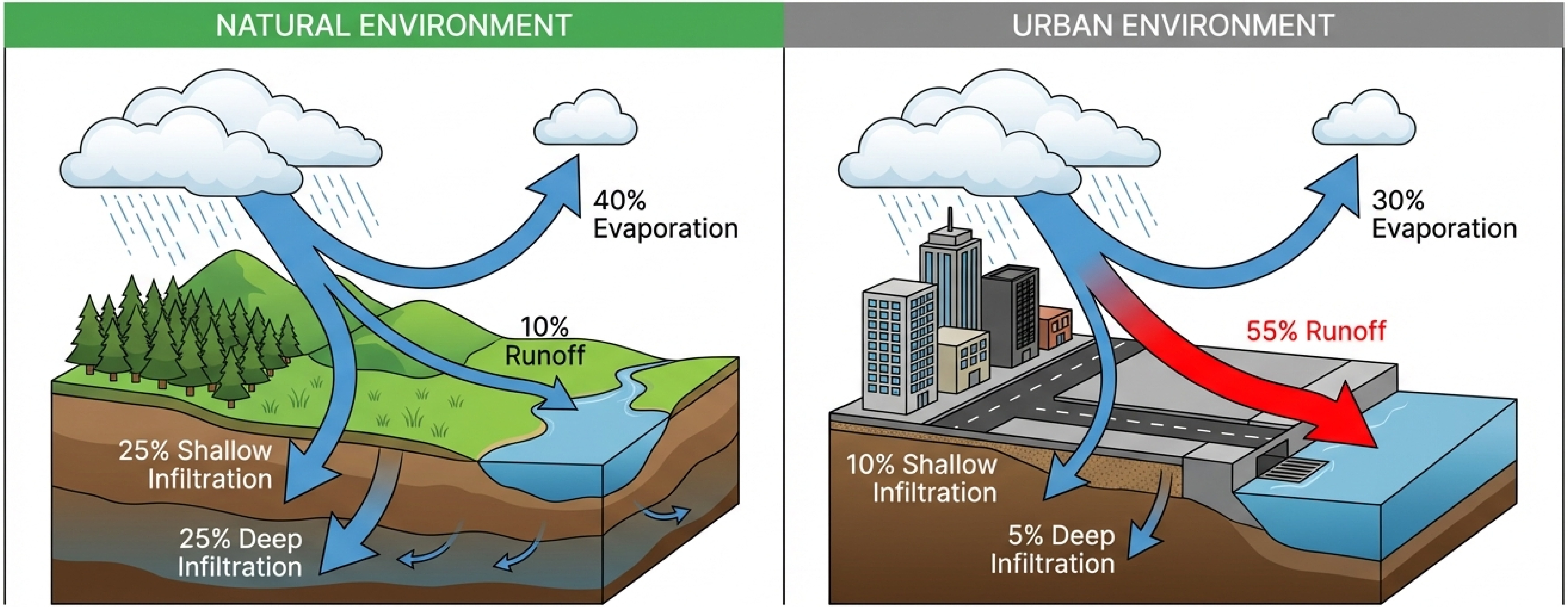
A watershed is an area of land where all of the water that falls under it and drains off of it goes to a common outlet.



Water is in constant motion—evaporation, transpiration, precipitation, and runoff.

In a natural state, the cycle is balanced. In an engineered environment, we must calculate how much of that precipitation becomes 'Direct Runoff" versus how much is lost to infiltration and evaporation.

The Conflict: Urbanization vs. Infiltration



"As we replace soil with concrete, we lose the earth's natural sponge. In New York City, for example, the land is more than 66% impervious. This shift requires precise engineering to handle the excess volume."

Gray vs. Green: A Philosophy of Management

Gray Infrastructure

Single-purpose. Uses pipes to dispose of rainwater quickly.

Green Infrastructure

Multi-functional. Uses vegetation and soil to manage rainwater where it falls.

Core Benefit: By weaving natural processes into the built environment, we achieve stormwater management alongside flood mitigation and air quality improvement.

Input Data: Quantifying Rainfall

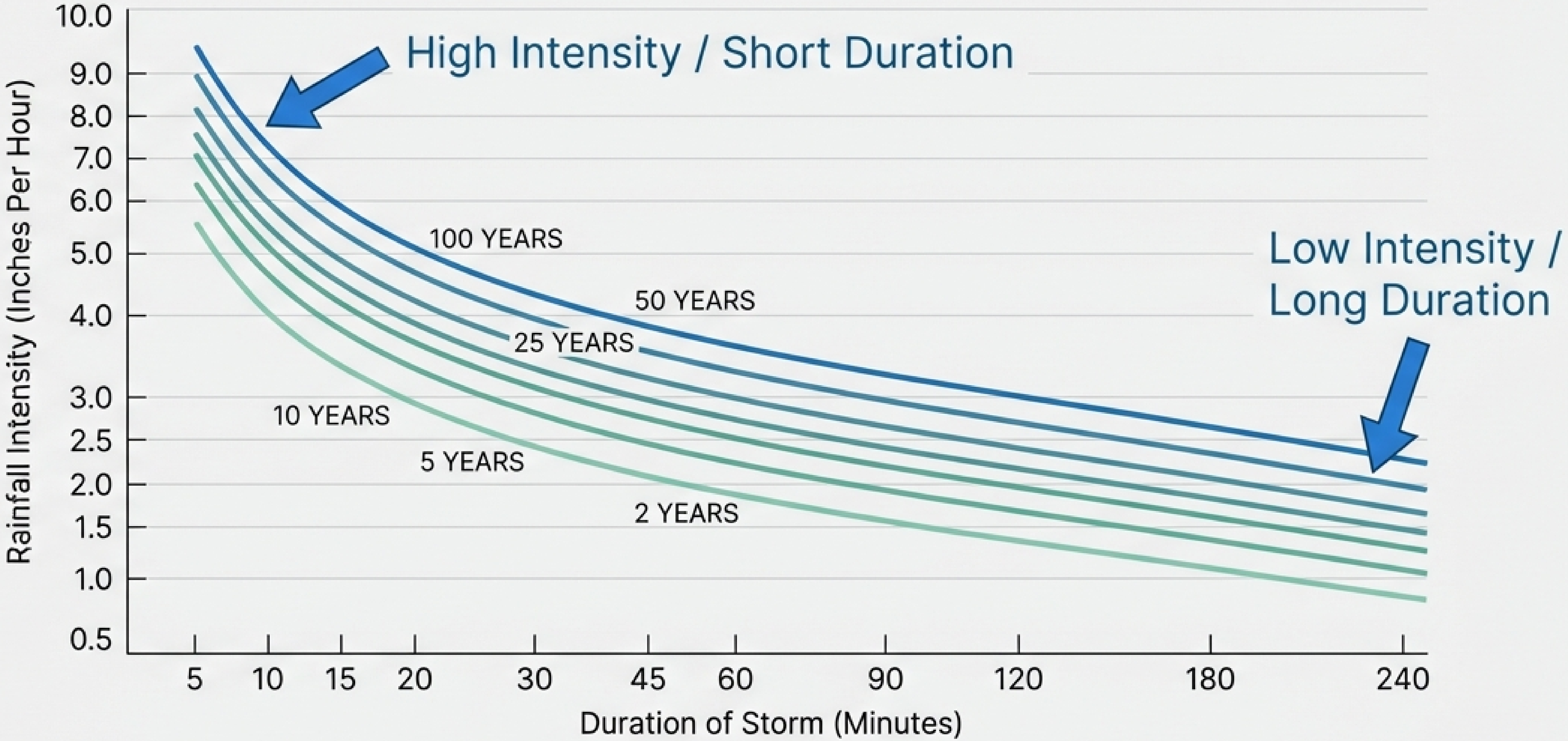
Engineers characterize storms by three metrics: Depth, Duration, and Frequency.

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.5 (0.01-0.92)	4.7 (0.21-1.03)	3.1 (0.57-1.06)	5.4 (0.91-1.19)	7.1 (0.04-1.88)	9.6 (0.51-1.08)	11.3 (1.34-1.12)	12.5 (0.74-1.88)	10.7 (0.09-1.50)	12.2 (0.89-1.17)
10-min	0.00 (0.07-1.02)	0.05 (0.51-1.35)	1.15 (0.31-1.89)	1.20 (0.53-1.87)	1.67 (0.36-1.83)	1.83 (0.38-1.73)	1.36 (1.67-2.20)	1.89 (0.64-2.23)	1.88 (0.01-2.99)	1.95 (0.38-2.54)
15-min	0.81 (0.07-1.26)	10.3 (0.61-1.81)	15.5 (0.42-1.99)	16.7 (0.36-2.11)	1.83 (0.28-1.95)	2.33 (0.06-2.85)	1.95 (1.05-2.93)	2.73 (0.01-2.93)	2.34 (0.88-2.58)	28.7 (0.97-3.57)
15-min	0.20 (0.07-1.34)	0.30 (0.61-1.96)	1.53 (0.85-2.02)	2.00 (0.01-2.70)	2.33 (0.74-2.02)	3.90 (2.26-2.76)	2.21 (1.83-2.76)	2.69 (1.03-3.37)	3.09 (2.68-3.28)	3.94 (9.42-4.03)
30-min	0.08 (0.07-1.55)	0.60 (0.39-2.03)	0.75 (0.03-2.29)	2.33 (0.16-2.74)	2.98 (1.03-2.33)	4.28 (3.83-3.33)	3.66 (3.38-3.38)	3.85 (3.33-3.78)	3.96 (1.79-3.91)	4.85 (1.89-5.07)
60-min	0.99 (0.03-1.07)	0.70 (0.73-2.41)	9.07 (0.73-2.56)	2.56 (0.99-3.03)	3.16 (0.61-3.54)	5.80 (3.01-3.88)	4.73 (2.21-4.50)	3.35 (3.56-4.00)	4.91 (5.01-4.14)	5.53 (5.15-6.19)
2-hr	0.99 (0.01-1.04)	0.99 (0.91-2.07)	1.25 (0.06-2.60)	1.91 (0.51-2.07)	2.57 (3.79-4.04)	4.20 (1.39-4.10)	5.35 (6.31-5.72)	4.25 (4.99-5.58)	5.07 (5.88-5.23)	6.06 (5.56-7.78)
3-hr	0.99 (0.07-1.07)	1.09 (0.18-2.82)	1.56 (0.12-2.82)	1.56 (0.31-3.18)	2.44 (3.23-3.80)	3.88 (3.08-4.13)	7.39 (6.31-5.38)	5.35 (5.63-5.83)	5.89 (5.61-6.67)	7.15 (6.78-7.59)
6-hr	1.00 (0.08-1.08)	1.10 (0.17-2.03)	1.91 (0.34-2.84)	2.01 (0.31-3.57)	2.93 (6.25-3.87)	3.44 (3.71-4.08)	8.50 (6.31-6.63)	5.65 (6.76-6.64)	6.87 (6.31-6.57)	8.33 (6.51-8.87)
12-hr	0.94 (0.10-1.98)	1.21 (0.23-1.89)	2.45 (0.26-2.39)	2.51 (0.53-3.09)	3.88 (3.03-4.02)	4.27 (4.37-5.03)	8.51 (6.31-8.06)	6.71 (6.23-7.80)	6.89 (1.91-8.96)	9.77 (6.31-9.04)
24-hr	1.00 (0.01-1.84)	1.57 (0.21-1.23)	2.65 (0.39-2.56)	2.73 (6.31-3.66)	3.83 (8.31-4.33)	4.55 (8.33-5.03)	8.51 (6.31-8.06)	1.05 (6.35-8.54)	7.0 (10.11-9.28)	10.7 (10.11-13.08)
2-day	1.33 (0.29-1.13)	1.78 (0.25-2.35)	2.31 (0.25-3.96)	2.98 (3.61-4.02)	3.38 (8.26-5.76)	5.13 (6.26-6.31)	8.35 (6.35-6.66)	10.8 (6.81-8.76)	11.8 (12.91-11.81)	13.7 (13.97-18.83)
3-day	1.37 (0.13-1.57)	1.95 (0.26-2.39)	2.38 (0.34-3.49)	3.08 (0.35-4.09)	4.20 (3.85-5.84)	5.30 (6.85-6.06)	6.85 (7.01-6.92)	17.5 (4.69-8.52)	12.1 (12.01-11.99)	18.0 (13.97-18.99)
4-day	1.80 (0.17-2.02)	1.93 (0.56-3.06)	2.40 (0.51-4.04)	3.55 (0.31-4.54)	4.48 (3.33-5.73)	5.73 (6.61-6.32)	6.17 (7.72-6.13)	21.0 (3.52-8.64)	13.6 (13.39-12.04)	21.5 (14.76-20.99)
7-day	1.83 (0.06-2.30)	2.10 (0.34-3.36)	2.35 (0.05-4.01)	3.56 (0.76-4.53)	4.67 (5.35-5.73)	5.86 (8.55-6.36)	6.39 (6.36-6.04)	24.8 (3.65-6.60)	18.8 (16.36-12.81)	25.5 (18.76-22.58)
10-day	2.17 (0.16-2.69)	2.24 (0.21-3.79)	2.67 (0.85-4.54)	3.98 (0.67-5.08)	4.19 (3.99-5.29)	6.71 (3.75-6.16)	7.33 (7.83-6.87)	26.3 (8.08-6.32)	26.8 (15.71-11.81)	37.8 (28.35-25.23)
20-day	2.29 (0.22-2.57)	2.46 (0.53-3.33)	2.80 (0.81-5.01)	3.77 (8.73-5.60)	5.98 (6.62-5.56)	6.33 (3.97-6.30)	7.25 (8.63-7.03)	31.3 (3.58-9.83)	25.6 (20.68-13.46)	38.5 (23.35-37.89)
30-day	2.90 (0.29-3.10)	2.43 (8.57-3.52)	3.33 (0.91-5.36)	4.18 (0.76-5.73)	5.98 (3.91-6.83)	6.75 (3.58-4.78)	8.10 (6.63-7.08)	67.8 (8.27-8.92)	30.3 (26.56-14.62)	44.7 (20.31-26.93)
45-day	2.30 (0.25-2.38)	2.45 (0.32-3.88)	3.70 (0.51-4.81)	4.73 (0.93-5.86)	5.77 (3.59-6.15)	6.96 (3.57-4.12)	7.83 (8.76-8.19)	99.5 (9.89-9.58)	35.3 (24.65-15.31)	54.0 (34.39-48.88)
60-day	3.18 (0.13-1.98)	3.35 (8.37-3.89)	4.21 (0.72-4.54)	5.30 (0.95-6.22)	6.98 (2.20-6.38)	7.20 (2.39-4.34)	8.25 (8.06-9.33)	10.7 (8.59-10.02)	40.8 (28.50-15.34)	60.7 (38.58-70.99)

The Gold Standard: NOAA Atlas 14 is the authoritative source for precipitation frequency estimates.

Key Concept: A “100-year storm” doesn’t happen every 100 years; it has a 1% chance of occurring in any given year.

The IDF Curve: Intensity-Duration-Frequency



Key Insight: Rainfall intensity is inversely proportional to duration. A 5-minute burst is far more intense than a 24-hour drizzle. This relationship dictates how we design pipes and basins.

Effective Precipitation: What Actually Runs Off?

$$P_e = P - \text{Losses}$$

P_e = Effective Precipitation (Runoff Depth)

P = Total Rainfall

Losses: Interception, Depression Storage, Infiltration, Evaporation

Method 1: The Rational Method

Used for peak discharge (Q_p) in small areas.

Method 2: The NRCS (SCS) Curve Number Method

Used for volume and flow in larger, complex watersheds.

Method 1: The Rational Method

$$Q_p = CiA$$

- Q_p: Peak Discharge (cfs)
- C: Runoff Coefficient (dimensionless (dimensionless surface impermeability)
- i: Rainfall Intensity (in/hr)
- A: Drainage Area (acres)

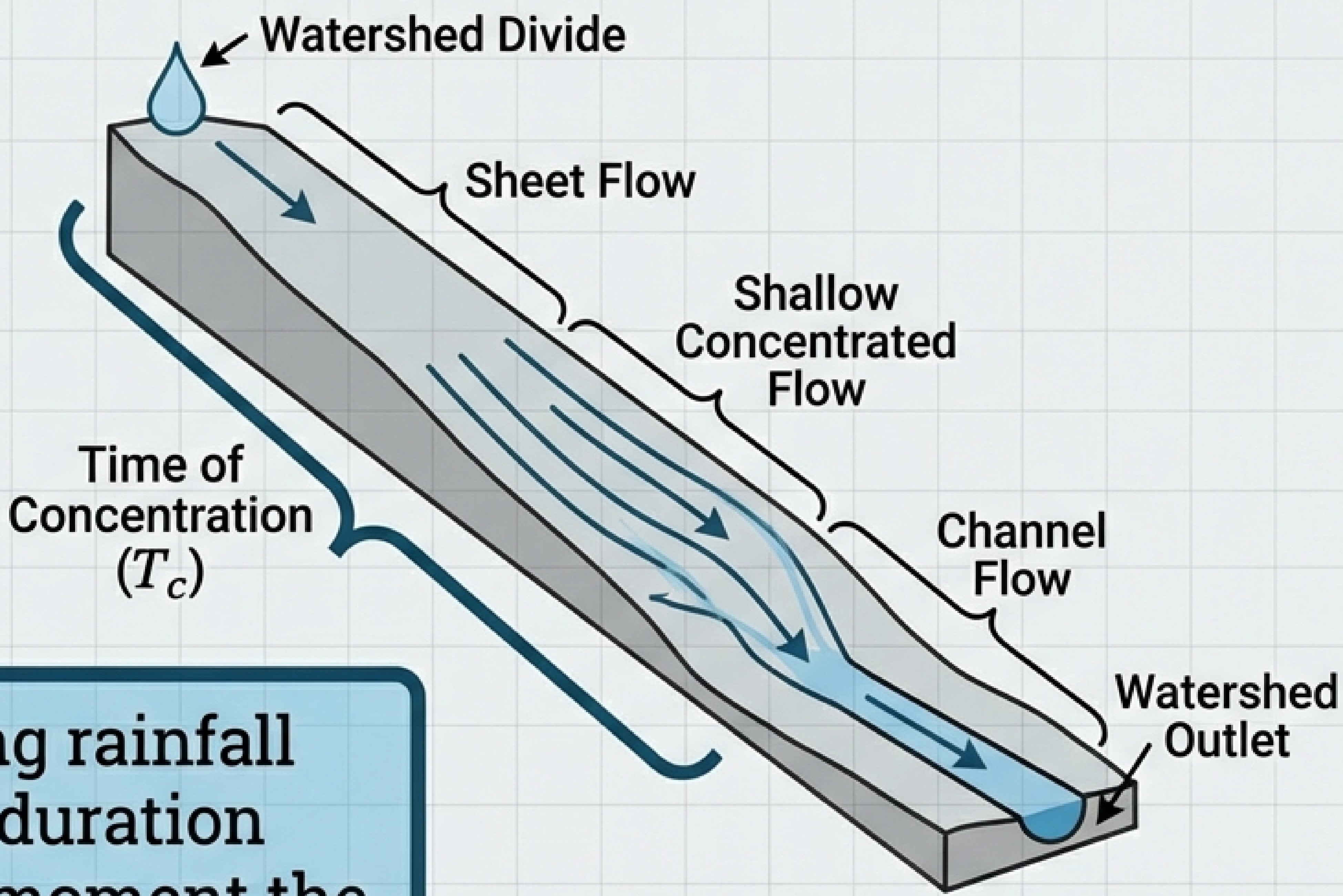
Typical Runoff Coefficients

Description of Area	Runoff Coefficient
Business: Downtown areas	0.70–0.95
Business: Neighborhood areas	0.50–0.70
Residential: Single-family areas	0.30–0.50
Residential: Multiunits, attached	0.60–0.75
Residential: Residential, suburban	0.25–0.40
Industrial: Light areas	0.50–0.80
Parks, cemeteries	0.10–0.25
Pavement: Asphalt or concrete	0.70–0.95
Roofs	0.75–0.95
Lawns, sandy soil: Flat, 2%	0.05–0.10
Lawns, sandy soil: Average, 2%–7%	0.10–0.15
Lawns, heavy soil: Flat, 2%	0.13–0.17

Source: ASCE (1992).

Critical Parameter: Time of Concentration (T_c)

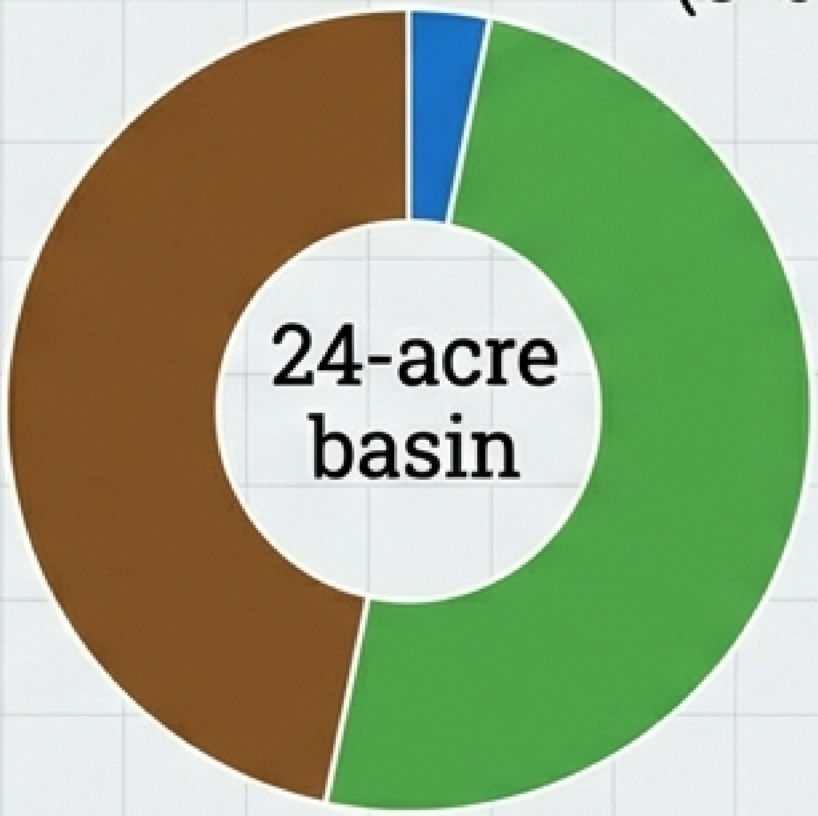
Definition: The longest time required for a drop of water to travel from the most remote point of the watershed divide to the watershed outlet.



Design Rule: When determining rainfall intensity (i), we set the storm duration equal to T_c. T_c represents the moment the entire basin contributes to the flow.

Case Study: Rational Method in Action

The Scenario



T_c = 30 minutes

The Calculation

Step 1. Weighted C Calculation

$$\text{Composite } C = \frac{(0.9 \times 0.5) + (0.35 \times 11.5) + (0.25 \times 12)}{24} = 0.31$$

Step 2: Determine Intensity (i)

From IDF Curve @ 30 min duration:
i = 3.7 in/hr

Step 3: Calculate Peak Discharge (Q_p)

$Q_p = 0.31 \times 3.7 \times 24 =$ **27.5 cfs**

Method 2: The NRCS (SCS) Curve Number Method

Calculating Volume based on Soil and Land Use

Instead of a simple “C”, we use a Curve Number (CN) derived from Land Use + Hydrologic Soil Group.

- Soil Group A: High infiltration (Sand)
- Soil Group D: Low infiltration (Clay)

Potential Maximum Retention:

$$S = 1000/CN - 10$$

Effective Runoff:

$$Pe = (P - 0.2S)^2/(P + 0.8S)$$

Runoff Curve Numbers

	Soil Group			
	A	B	C	D
Open space (lawns, parks, etc.)				
Poor condition	68	79	86	89
Fair condition	49	69	79	84
Good condition	39	61	74	80
Residential districts by average lot size				
1/8 acre or less	77	85	90	92
1/4 acre	61	75	83	87
1/3 acre	57	72	81	86
1/2 acre	54	70	80	85
1 acre	51	68	79	84
2 acres	46	65	77	82

Case Study: NRCS Method in Action

400-acre basin, Middlesex, NJ. Soil Group B. Rainfall (P) = 6.36 inches.

Step 1: Calculate Weighted Curve Number

Based on mixed land use (Impervious, Wooded, Meadow, Residential), the weighted average CN is determined to be **61.7**.

Step 2: Calculate Potential Retention (S)

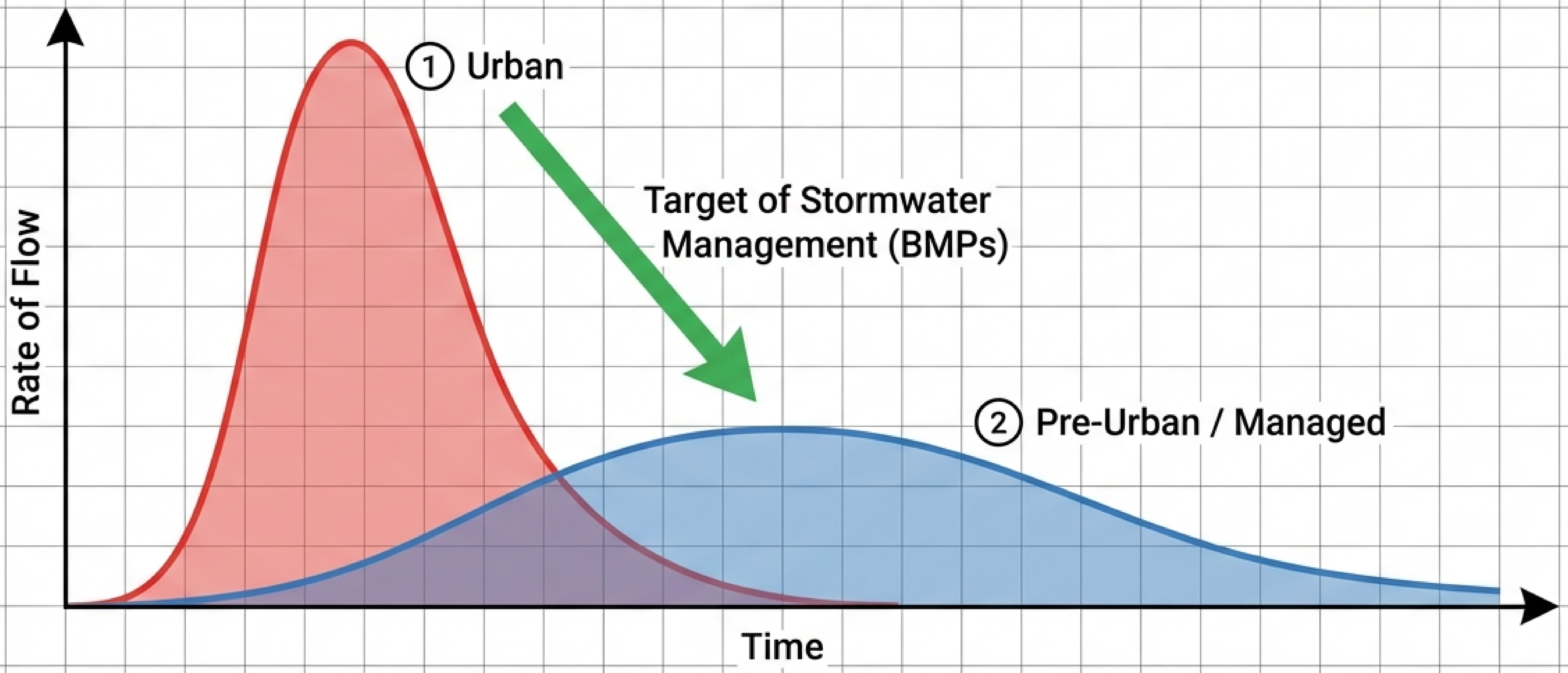
$$S = \frac{1000}{61.7} - 10 = \mathbf{6.21\ inches}$$

Step 3: Calculate Effective Runoff (Pe)

$$P_e = \frac{(6.36 - 0.2(6.21))^2}{6.36 + 0.8(6.21)} = \mathbf{2.31\ inches}$$

Result: Out of 6.36 inches of rain, the soil absorbs ~4 inches. The infrastructure must handle the remaining 2.31 inches of runoff.

Visualizing the Storm: The Hydrograph

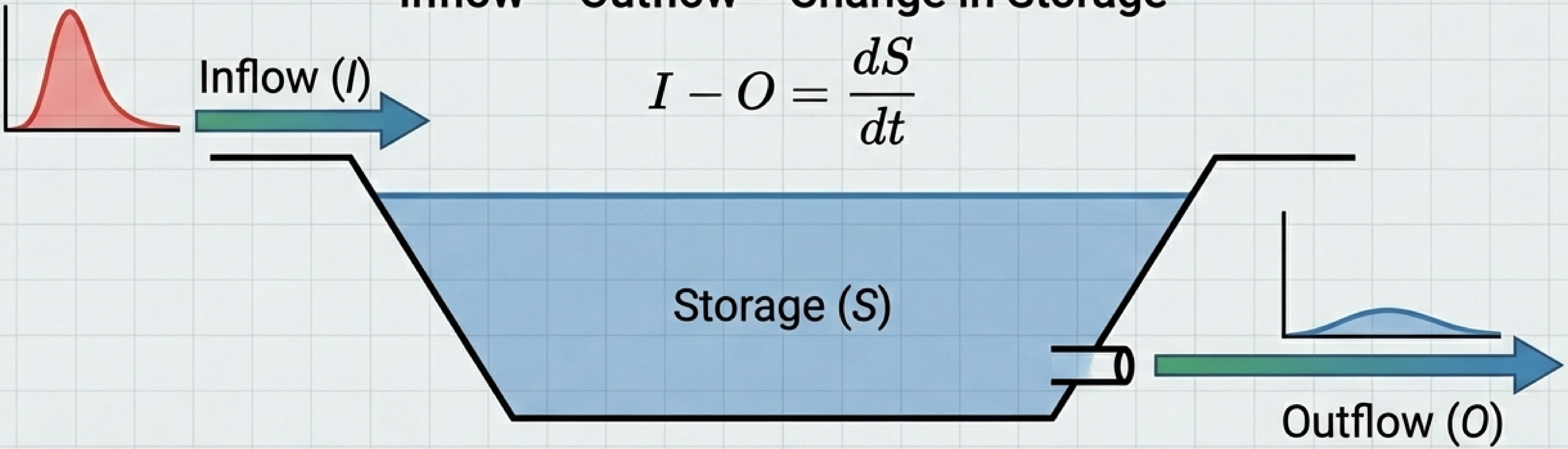


Hydrologic Routing: Managing the Flow

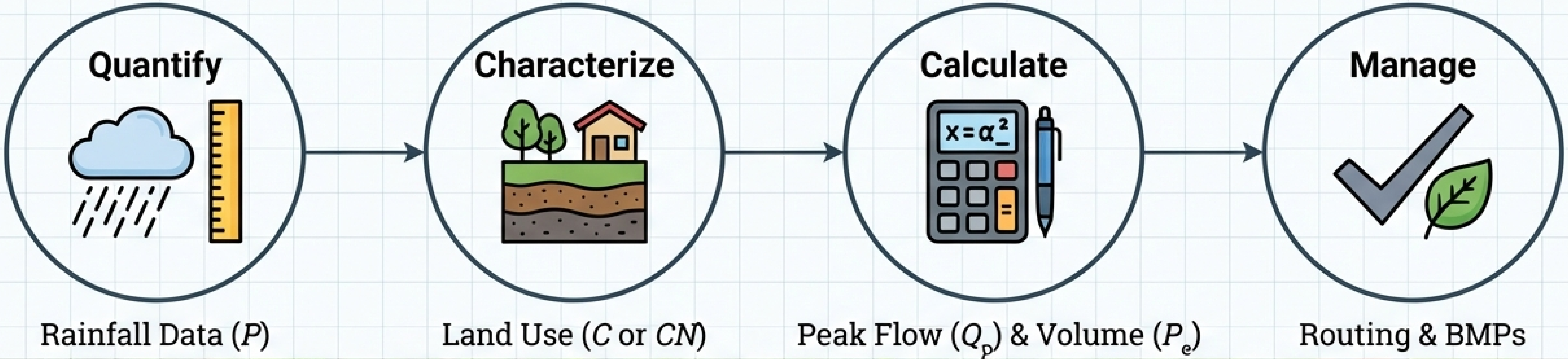
We use detention basins to flatten the hydrograph. This process is modeled using the "Level Pool Routing" method.

Inflow – Outflow = Change in Storage

$$I - O = \frac{dS}{dt}$$



Summary: The Hydrologic Design Cycle



Effective stormwater design is not just about moving water away—it's about restoring the natural balance to protect our communities and environment.