Briefing on Stormwater Hydrology

Principles and Analysis

Executive Summary

This briefing presents a systematic overview of stormwater hydrology, with emphasis on:

- The influence of **urbanization** on watershed response
- The role of **Green Infrastructure (GI)** as a multi-benefit strategy
- Standardized methods for **rainfall analysis**, **runoff estimation**, and **peak discharge calculation**
- Use of **hydrographs** and **hydrologic routing** for stormwater system design

Urban development fundamentally alters the natural water balance by:

- Increasing surface runoff
- Reducing infiltration and groundwater recharge
- Accelerating watershed response

Two major approaches are used to estimate runoff:

1. **Runoff Coefficient Method** (simple, empirical)
2. **NRCS (SCS) Curve Number Method** (physically based, widely adopted)

Peak discharge is commonly computed using:

- **Rational Method** (small watersheds)
- **NRCS Graphical Method (TR-55)** (larger, complex watersheds)

Hydrologic routing methods, particularly the **Modified Puls** technique, are used to evaluate detention storage and flood attenuation. The overarching theme is a **data-driven, physically consistent framework** for managing stormwater impacts.

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1. Foundational Concepts in Stormwater Management

1.1 Green Infrastructure (GI)

Green Infrastructure integrates natural processes into the built environment to manage rainfall near its source.

Definition

Green infrastructure is an approach that communities can use to maintain healthy waters, provide multiple environmental benefits, and support sustainable communities.

Key Characteristics

- Uses vegetation, soils, and natural storage
- Infiltrates, evapotranspires, and reuses rainfall
- Reduces dependence on pipes and conveyance systems

Multiple Benefits

- Flood mitigation
- Water quality improvement
- Urban heat reduction
- Habitat creation
- Energy savings
- Enhanced public spaces

1.2 Watersheds and the Hydrologic Cycle

Watershed

A watershed is the land area that drains precipitation to a common outlet.

Key features:

- Divides
- Hillslopes
- Tributaries
- Sub-basins
- Surface water and groundwater pathways

Large-scale example: Mississippi River Basin with Missouri, Ohio, and Arkansas–Red–White sub-basins.

Hydrologic Cycle Components

- Precipitation
- Infiltration
- Surface runoff
- Evaporation
- Transpiration / Evapotranspiration
- Groundwater flow

Modern water-cycle concepts explicitly include **human influences** such as urban runoff, reservoirs, irrigation, and industrial withdrawals.

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2. Hydrologic Impacts of Urbanization

Urbanization increases impervious cover and disrupts natural hydrologic pathways.

2.1 Changes in Water Distribution

Land Cover	ET (%)	Runoff (%)	Shallow Infiltration (%)	Deep Infiltration (%)
Natural cover	40	10	25	25
10–20% impervious	38	20	21	21
35–50% impervious	35	30	20	15
75–100% impervious	30	55	10	5

As imperviousness increases:

- Runoff increases sharply
- Infiltration and recharge decline

2.2 Effects on Hydrographs

Urbanization causes:

- Higher peak discharge
- Greater runoff volume
- Shorter time to peak

Stormwater BMPs (e.g., rain gardens, bioretention) are designed to reverse these trends by promoting infiltration and storage.

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3. Rainfall Data for Hydrologic Design

Hydrologic design relies on rainfall described by:

- Depth
- Duration
- Frequency
- Temporal distribution

3.1 Rainfall Depth–Frequency

NOAA Atlas 14 provides 24-hour rainfall depths for various return periods.

Example (selected NJ counties):

County	2-yr (in)	10-yr	25-yr	100-yr
Atlantic	3.31	5.16	6.46	8.90
Bergen	3.34	5.07	6.28	8.47
Ocean	3.42	5.33	6.68	9.20

3.2 Rainfall Distribution (NRCS)

Synthetic 24-hour distributions:

- Type I
- Type IA
- Type II
- Type III

New Jersey uses **Type III** distribution.

3.3 Intensity–Duration–Frequency (IDF)

IDF or DDF curves describe:

$$\text{Rainfall Intensity} = f(\text{Duration,Return Period})$$

Modern curves are derived from NOAA Atlas 14 data.

4. Effective Precipitation (Runoff)

Effective precipitation (Pe) is rainfall that becomes direct runoff.

4.1 Runoff Coefficient Method

$$P_e = C\,P \quad \text{or} \quad i_e = C\,i$$

Typical C values:

Surface Type	C
Downtown commercial	0.70–0.95
Single-family residential	0.30–0.50
Pavement	0.70–0.95
Lawns, sandy soil	0.05–0.10
Lawns, heavy soil	0.25–0.35

4.2 NRCS Curve Number (CN) Method

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S}$$

$$S = \frac{1000}{CN} - 10$$

CN depends on:

- Land use
- Hydrologic soil group
- Antecedent moisture

Soil Groups:

- A: High infiltration
- B: Moderate infiltration
- C: Low infiltration
- D: Very low infiltration

Composite CN is computed for mixed land use.

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5. Peak Discharge Estimation

5.1 Rational Method

$$Q_p = C\, i\, A$$

Where:

- Qp = peak discharge (cfs)
- C = runoff coefficient
- i = rainfall intensity (in/hr)
- A = area (acres)

Time of concentration (Tc) governs selection of i.

5.2 NRCS Graphical Method (TR-55)

$$Q_p = q_u \, A \, P_e$$

Where:

- qu = unit peak discharge
- A = drainage area (mi²)
- Pe = effective precipitation (in)

Adjustment factor Fp accounts for pond/swamp storage.

6. Hydrographs and Hydrologic Routing

6.1 Hydrographs

A hydrograph plots discharge versus time.

Key information:

- Peak flow
- Runoff volume
- Timing

NRCS dimensionless unit hydrograph is commonly used.

6.2 Hydrologic Routing

Based on continuity:

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

Reservoir (Level-Pool) Routing

- Modified Puls Method
- Used for detention basins and reservoirs

Channel Routing

- Muskingum Method
- Accounts for prism and wedge storage

Final Conceptual Summary

Stormwater hydrology integrates:

- Rainfall characterization
- Runoff generation
- Peak flow estimation
- Flow routing and storage

Together, these tools support **predictive, defensible, and sustainable stormwater design** in urbanizing watersheds.