URBAN HYDROLOGY

Hydrology and Floodplain Analysis, Chapter 6

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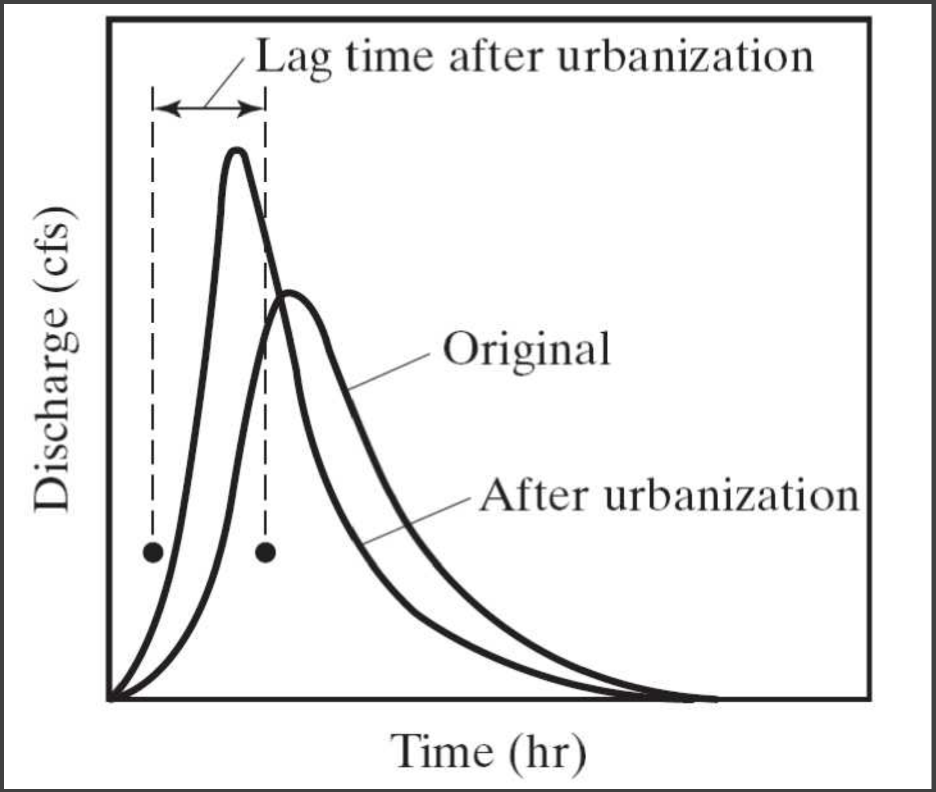
Hydrology and Floodplain Analysis, Chapter 6.1

Characteristics of Urban Hydrology

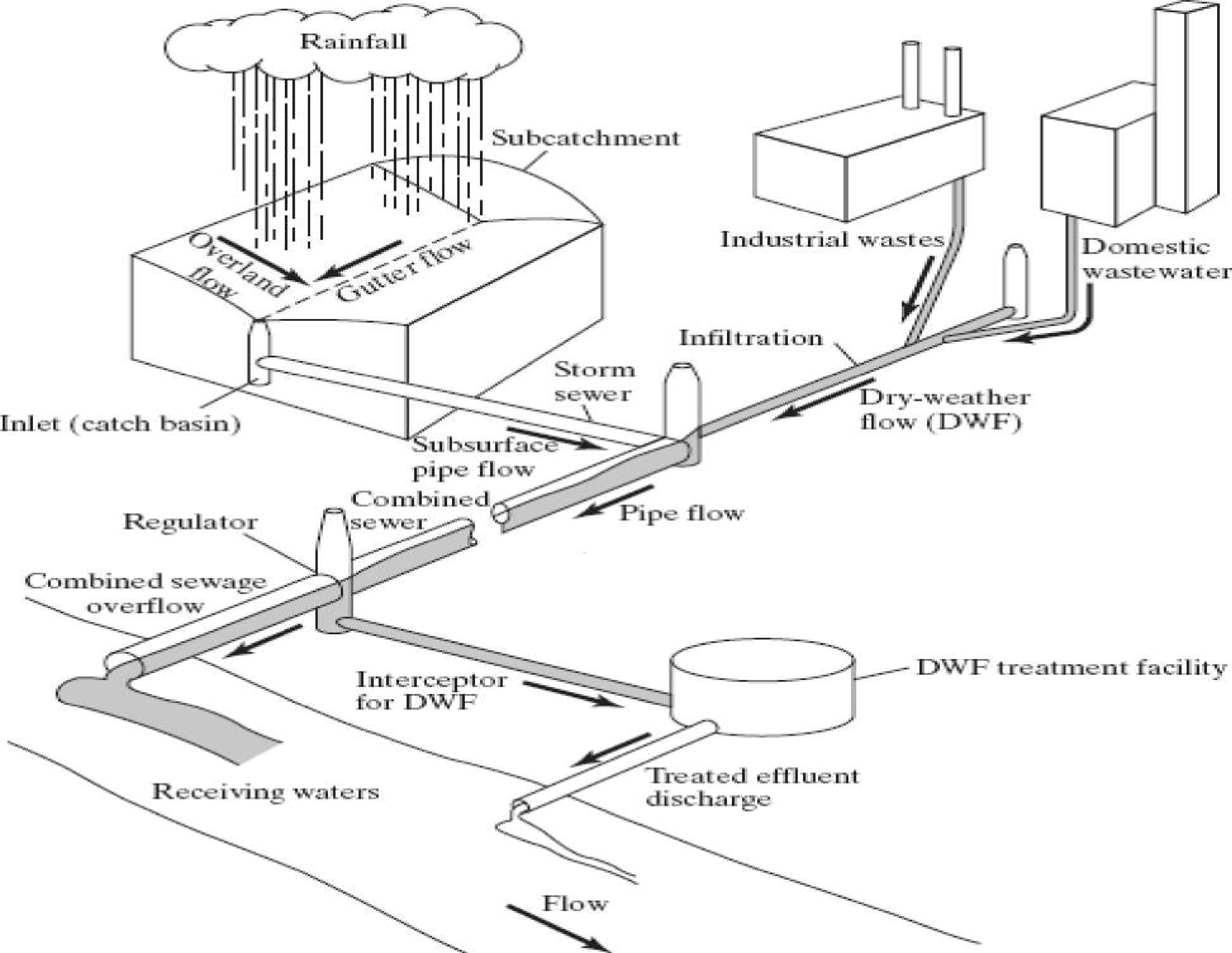
Introduction

- ❖ Urban watersheds characterized by:
  - Impervious surface predominance
  - Man-made drainage systems
- ❖ Results in:
  - Rapid Response of the catchment to the rainfall.
  - Increased runoff volume



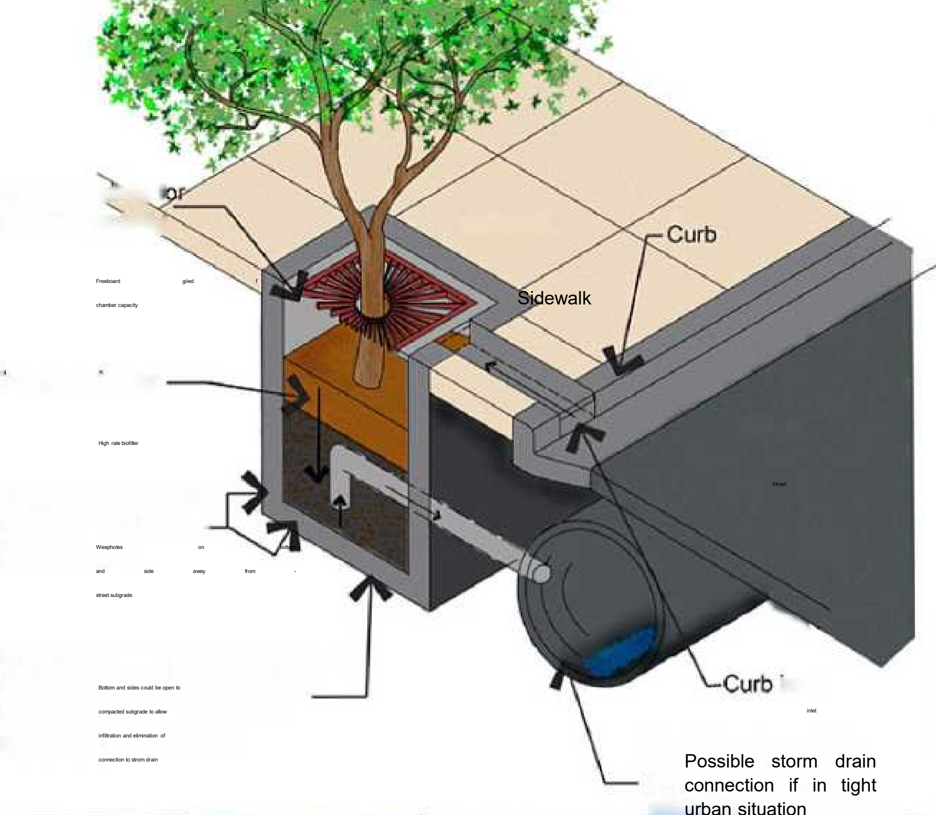
Urban Drainage Systems

- Sewer types:
  - Storm sewer - exclusively storm water removal
    - Part of separated sewage systems
  - Combined sewer - waste and storm water
    - Common in older cities (Boston, Chicago, Atlanta)
    - Diverts domestic and industrial sewage from storm water at interceptor for treatment
    - System overwhelmed during storm events and raw storage is released into receiving water body
  - Usually designed to handle a peak flow
  - Major vs. Minor drainage systems


Rainfall
Subcatchment
Overland flow
Gutter flow
Industrial wastes
Domestic wastewater
Infiltration
Storm sewer
Inlet (catch basin)
Dry-weather flow (DWF)
Subsurface pipe flow
Combined sewer
Pipe flow
Regulator
Combined sewage overflow
DWF treatment facility
Interceptor for DWF
Treated effluent discharge
Receiving waters
Flow

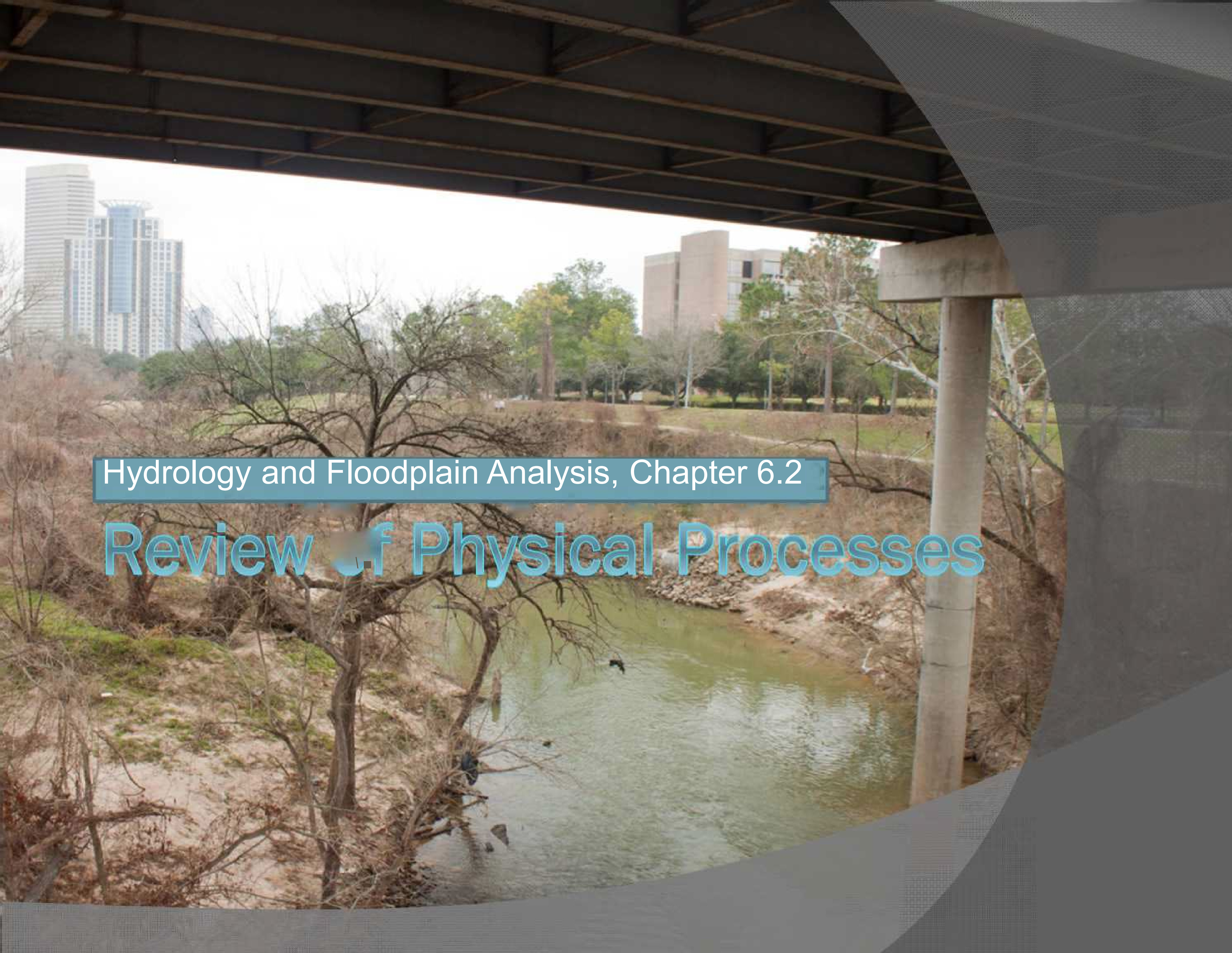
Design Concerns

- Need to control peak flow and maximize depth.
- Hydraulic grade line should not be too high
- Measures required to improve water quality
- Mitigation strategies:
  - Retention and detention in new development
  - Underground or aboveground storage
  - Increasing infiltration and permeable paving
  - Channelizing, floodplain delineation, flood proofing
- Low Impact Development


Curb
Sidewalk
chamber capacity
High rate biofilter
Weepholes on
and side away from
street subgrade
Bottom and sides could be open to
compacted subgrade to allow
infiltration and elimination of
connection to strom drain
Possible storm drain connection if in tight urban situation

Design Objectives

- Control peak flows and maximum depths
- Protect environment
- Reduce urban impact on runoff
- Use of extensive calculation and modeling to determine the watershed parameters which will influence design plans.



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Review of Physical Processes

Rainfall –Runoff:

- Conversion of rainfall into runoff is simplified because of the high imperviousness of urban areas.
- Infiltration estimates are complicated as the urban soil is very disturbed.
- Difficult to obtain rainfall data.
- Rainfall data should be available at 5 minutes or shorter increment to compute the hydrograph accurately.
- More than three gages are needed for larger catchment

Catchment Description

- Necessary to distinguish between directly connected impervious areas and non-directly connected impervious areas
- Percent impervious estimation:

$$I=9.6PD(0.573-0.017\ln PD$$

I = percent imperviousness

PD = population density (persons/ac)

Calculation of Losses

- ❖ Losses result from depression storage on vegetation and other surface, infiltration and evaporation. For individual storm, evaporation loss is unimportant.

Time of Concentration

- ❖ Travel time of a *wave* to move from the hydraulically most distant point in the catchment to the outlet
- ❖ The time to equilibrium of the catchment under a steady rainfall excess

Wave Speed:

$$c = mV = \alpha m y^{m-1}$$

c = wave speed
V = average velocity of water
y = water depth
m = 5/3 (turbulent) 3 (laminar)

$$\alpha = \frac{k_m \sqrt{S}}{n}$$

Turbulent Flow

$$\alpha = gS / 3v$$

Laminar Flow

S = slope
n = Manning's roughness
g = gravitational acceleration
v = kinematic viscosity

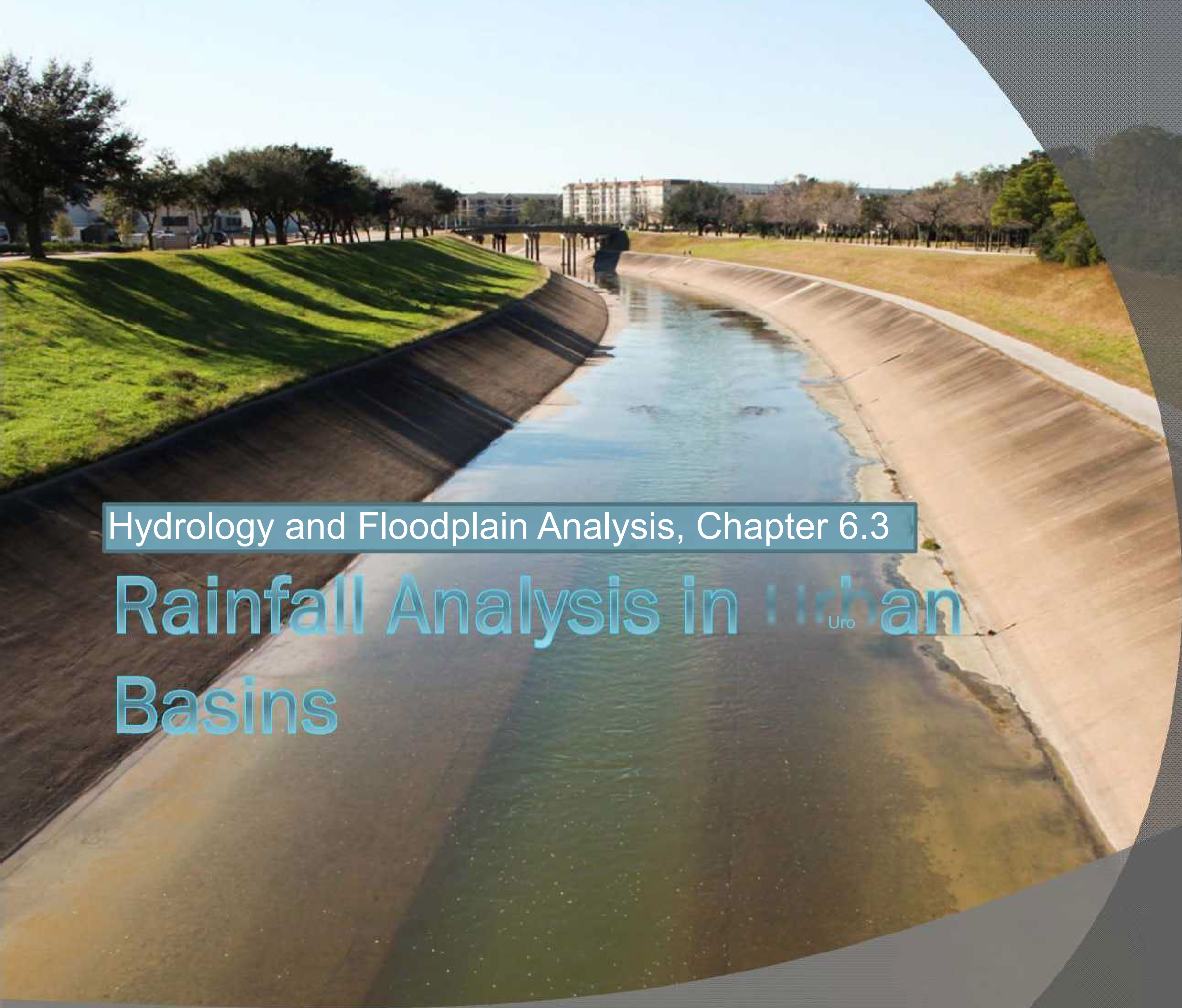
Flow in Catchment:

$$q = yV = \alpha y^m$$

q = flow per unit of width

Time of Concentration: $t_c = \left(\dfrac{L}{\alpha i_e^{m-1}} \right)^{1/m}$

L = length of overland flow plane
i_e = rainfall excess



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Rainfall Analysis in Urban Basins

Data Sources

- Two types of rainfall data:
  - “raw” point data (actual hyetographs)
  - Processed data (frequency information)

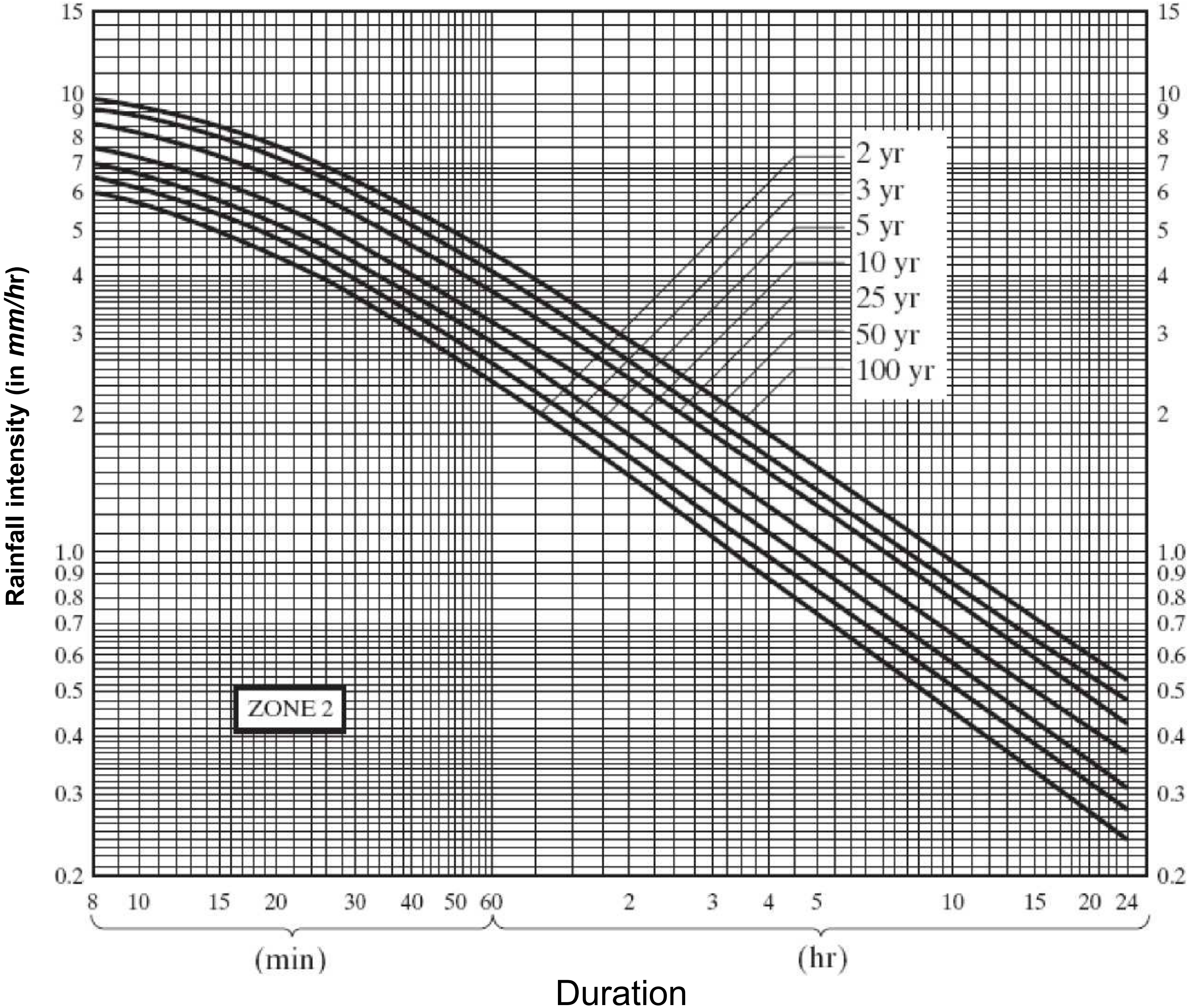
Rainfall Measurement:

- Rainfall measurement in urban areas is very difficult due to the quick response of the catchment to the rainfall.

- In most cases tipping bucket rain gage will provide adequate rainfall data. These are easy to install .

Intensity-Duration-Frequency Curves

- Represent the probability a given rainfall intensity will occur, given a duration
  - Note: duration is not the length of the storm
- Do not represent actual time histories of rainfall
  - Smoothed results of several different storms
  - Hypothetical results if point does not fall on contour


Rainfall intensity (in mm/hr)
Duration
(min)
(hr)
2 yr
3 yr
5 yr
10 yr
25 yr
50 yr
100 yr
ZONE 2
15
10
9
8
7
6
5
4
3
2
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
8
10
15
20
30
40
50
60
2
3
4
5
10
15
20
24

Definition of Storm Event

- For analysis, rainfall time series must be separated into discrete independent events. Then it is ranked by volume or other desired parameters and a conventional frequency analysis is performed.
- A minimum interevent time (MIT) can be defined such that rainfall pulses separated by a time less than this time are considered the same event.

Choice of Design Storm

- Need to know return period and parameter (precipitation runoff volume, etc.)
- Return period of a storm based on rainfall characteristics will not be the same as the return period of the same storm based on runoff characteristics.

Synthetic Design Storm Creation

- Procedure
  - 1. Duration specified
  - 2. Duration depth is obtained from IDF curve
  - 3. Rainfall must be distributed in time to construct the hyetograph
    - Shape varies depending on storm type
    - Natural Resources Conservation Service publishes temporal distributions
      - e.g. SCS type II and type IA

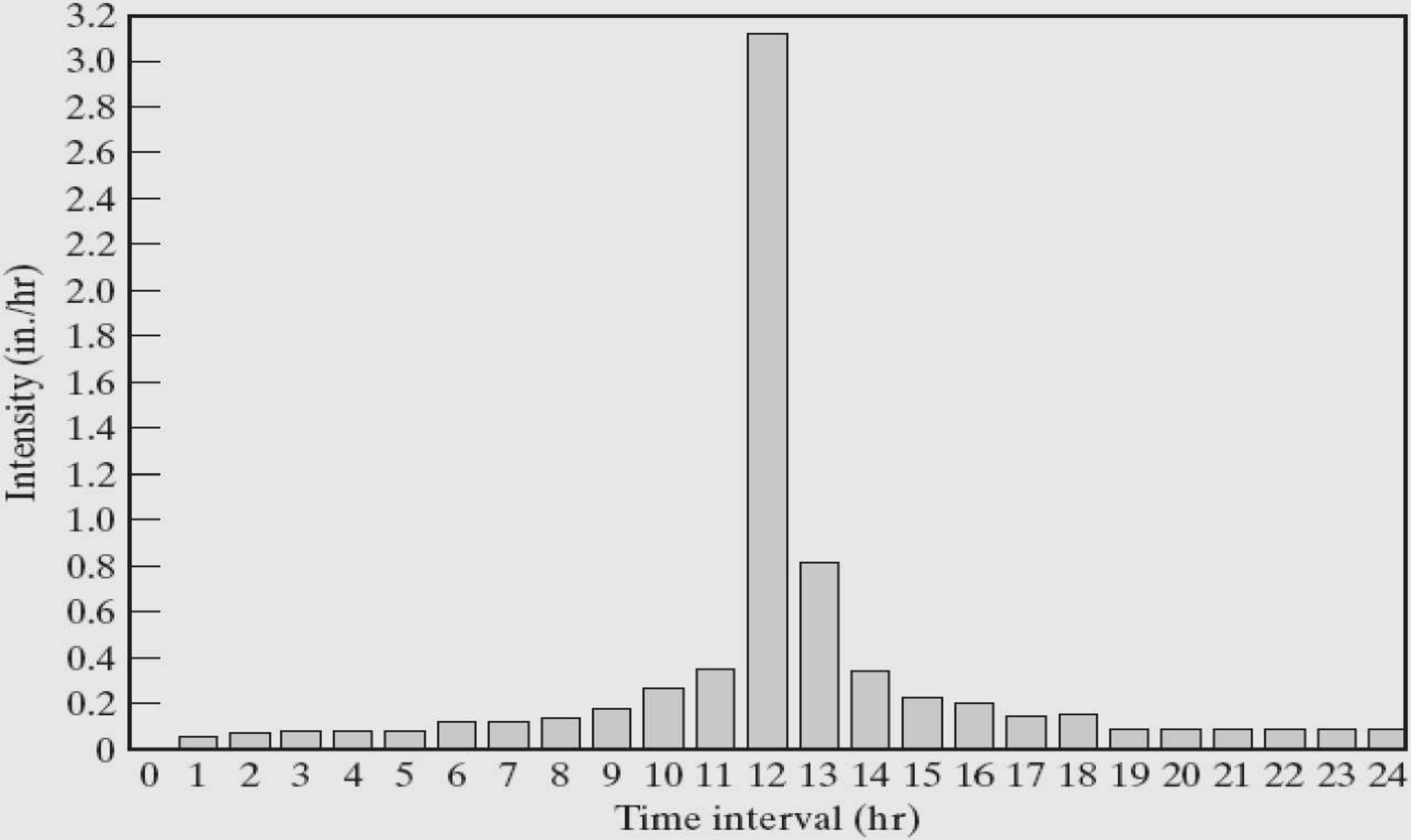
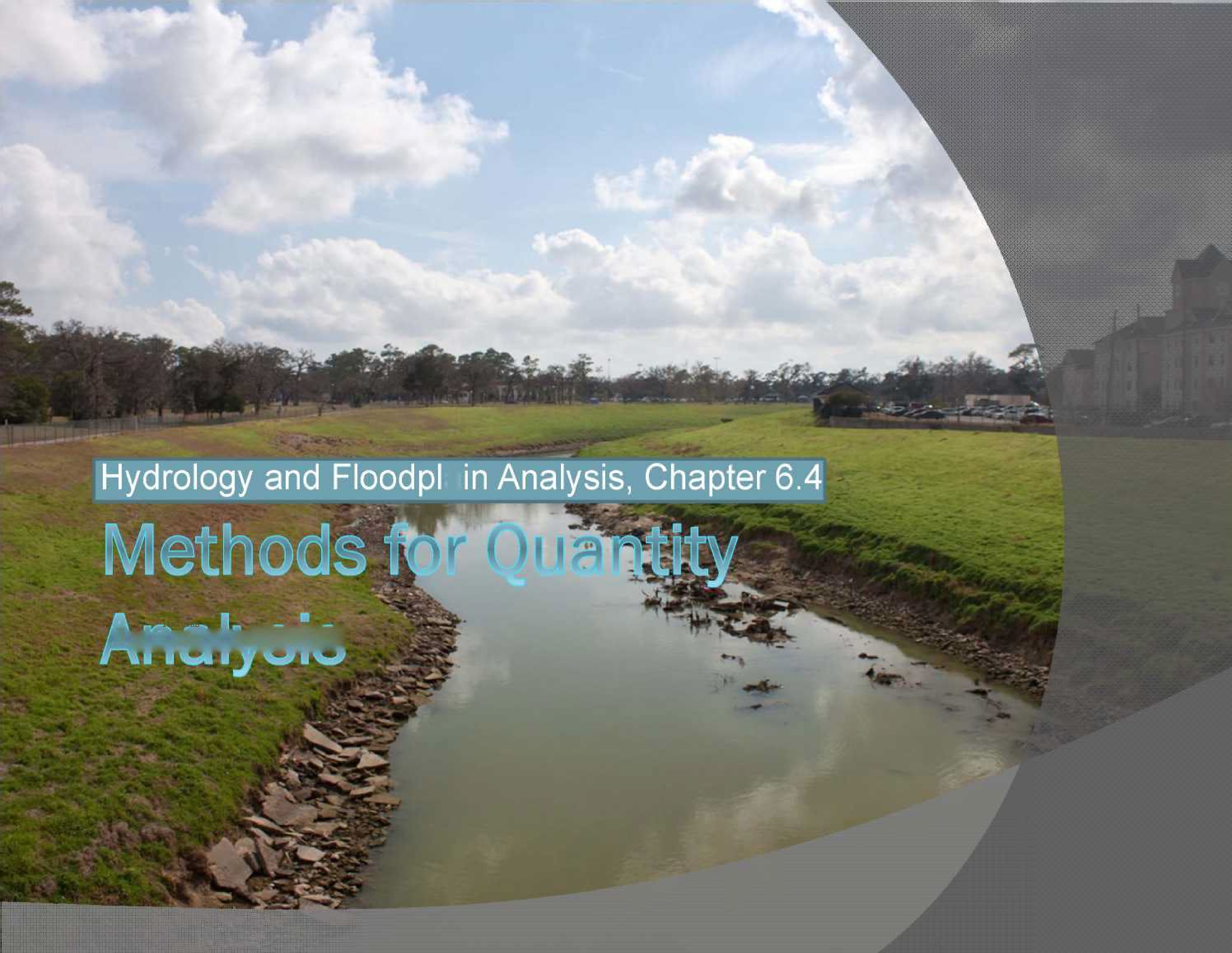


Figure : SCS type II , 5-yr 24-hr design storm

Historical Storms

- Use rainfall data from storm that created peak flow of desired return interval

- Ideal method for design
  - No assumptions about hyetograph shape
  - Popular with the public
    - Design to prevent a readily remembered flood event



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Methods for Quantity Analysis

Rational Method for Peak Flows

- Dates from 1850s
- One of the simplest methods

$$Q_p = k_c C i A$$

- Q_p = peak flow (cfs or m^3/s)
- C = runoff coefficient
- i = rainfall intensity (in/hr or mm/hr)
- A = catchment area (ac or ha)
- k_c = conversion factor

Rational Method Cont.

- Rational method should not be used on areas larger than a few hundred acres
- Losses are factored into coefficient "C"
  - Problem with rational method: losses are always a fraction of rainfall
    - do not change with conditions
- Weighted average for areas with multiple "C" values
- Impact of t_c on rational method

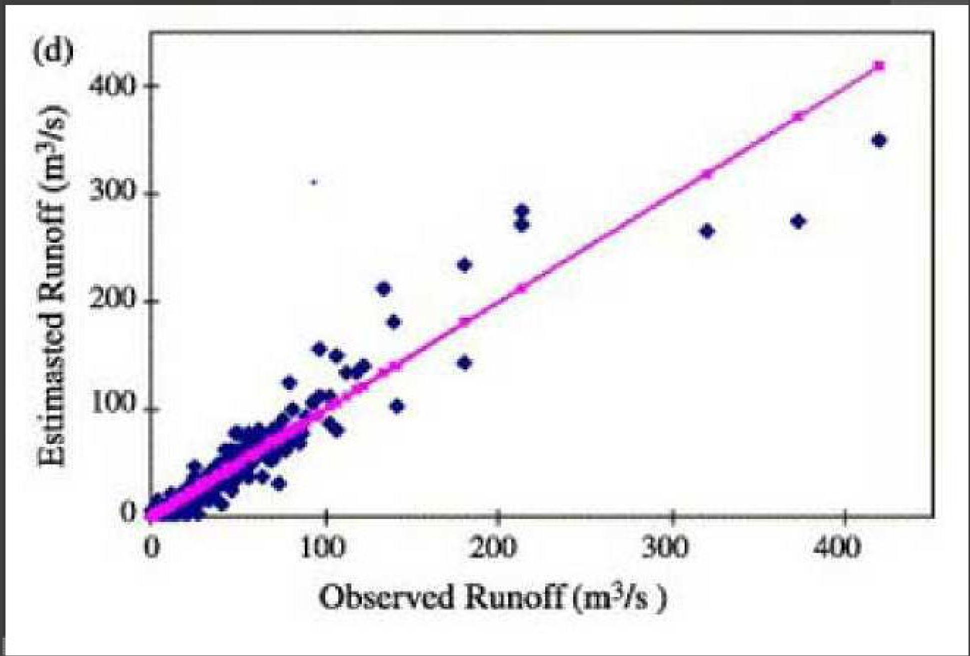
Description of Area	Runoff Coefficients
Business	
Downtown areas	0.70–0.95
Neighborhood areas	0.50–0.70
Residential	
Single-family areas	0.30–0.50
Multi-units, detached	0.40–0.60
Multi-units, attached	0.60–0.75
Residential (suburban)	0.25–0.40
Apartment dwelling areas	0.50–0.70
Industrial	
Light areas	0.50–0.80
Heavy areas	0.60–0.90
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yard areas	0.20–0.40
Unimproved areas	0.10–0.30
Streets	
Asphalt	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Drives and walks	0.75–0.85
Roofs	0.75–0.95
Lawns, sandy soil	
Flat, 2%	0.05–0.10
Average, 2%–7%	0.10–0.15
Steep, 7%	0.15–0.20
Lawns, heavy soil	
Flat, 2%	0.13–0.17
Average, 2%–7%	0.18–0.22
Steep, 7%	0.25–0.35

Coefficient and Regression Methods

- Usually preformed with large, nonurban catchments
- Used to relate independent events (i.e. rainfall and runoff)

$R = CR(P - DS)$

R = runoff depth
P = rainfall depth
CR = slope of fitted line
DS = depression storage



Linear and Nonlinear Reservoirs

- ❖ Catchment surfaces can be conceptualized as reservoirs
- ❖ Surface storage is spatially lumped
  - Conceptualized as a "tank"
  - Lumped storages can be distributed over area to incorporated spatial variation and then "linked" by routing routines
- ❖ Allows for conversion of rainfall into runoff

- ❖ Continuity Equation:

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

Weir Outflow

$$Q = C_w L_w (h - h_0)^{1.5}$$

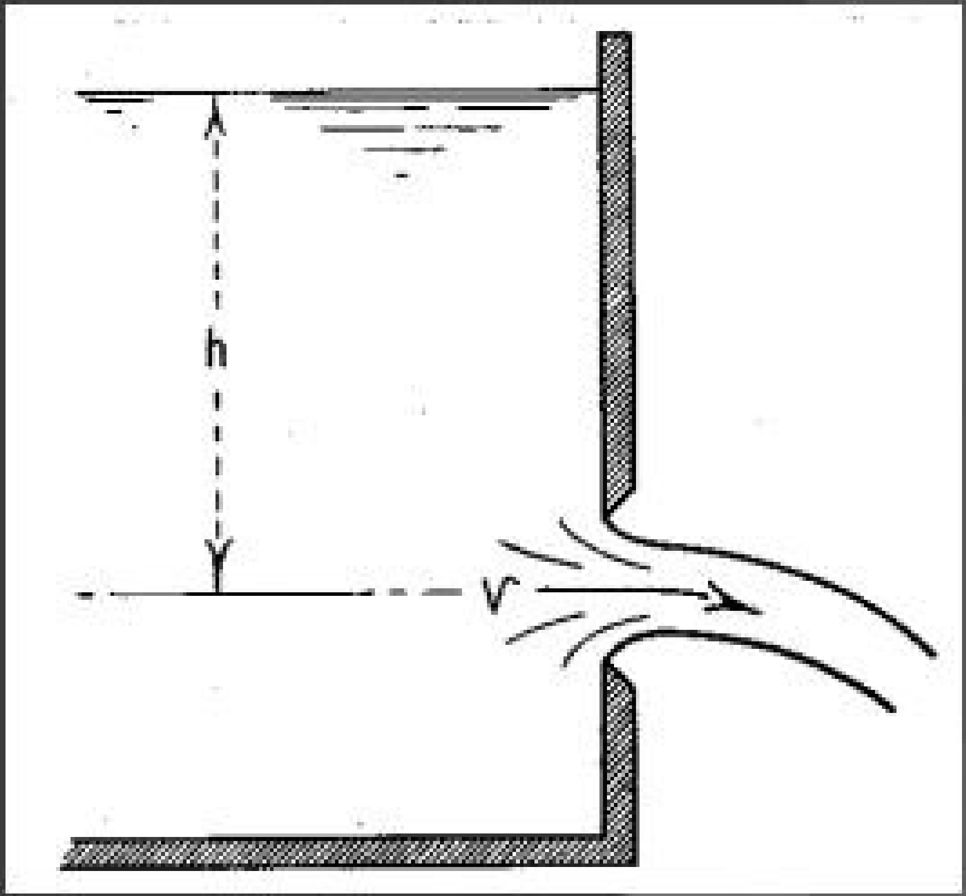
L_w = Weir length (perpendicular to flow)
h = Water surface elevation upside of weir crest
h_0 = Weir crest elevation
C_w = Weir coefficient :

$$C_w = C_e (2/3)\sqrt{2g}$$

C_e = effective discharge coefficient
g = gravitational acceleration

Orifice Flow

$$Q = C_d A_0 \sqrt{2g(h - h_0)}$$



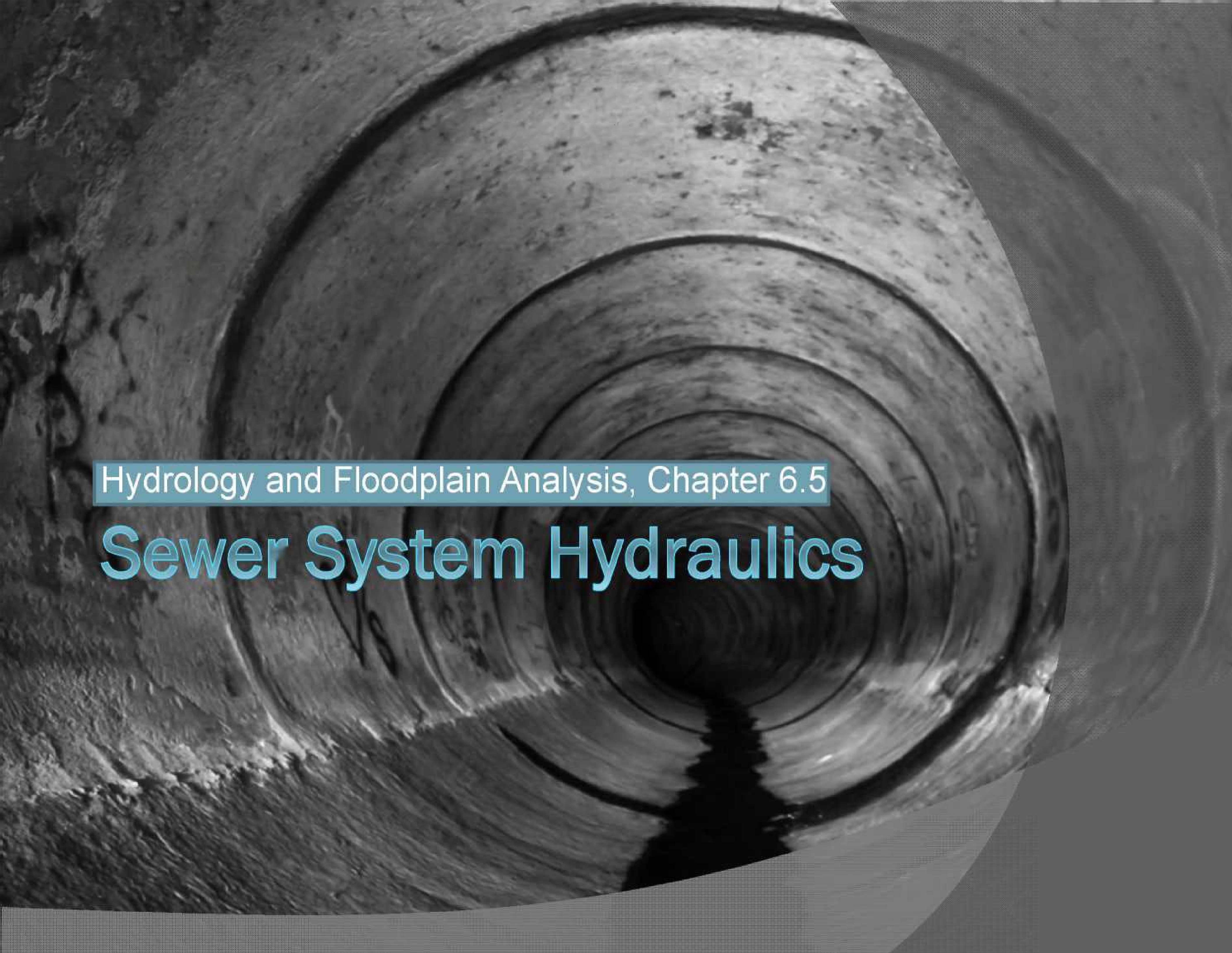
C_d = discharge coefficient
A_0 = area of orifice
h = water surface elevation
h_0 = elevation of orifice centerline

Wide Rectangular Channel

- Overland flow can be approximated with this Manning's equation form

$$Q = W \frac{k_m}{n} (h - DS)^{5/3} S^{1/2}$$

W = width of (overland) flow
n = Manning's Roughness
DS = depression storage (depth)
S = slope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Sewer System Hydraulics

Flow Routing

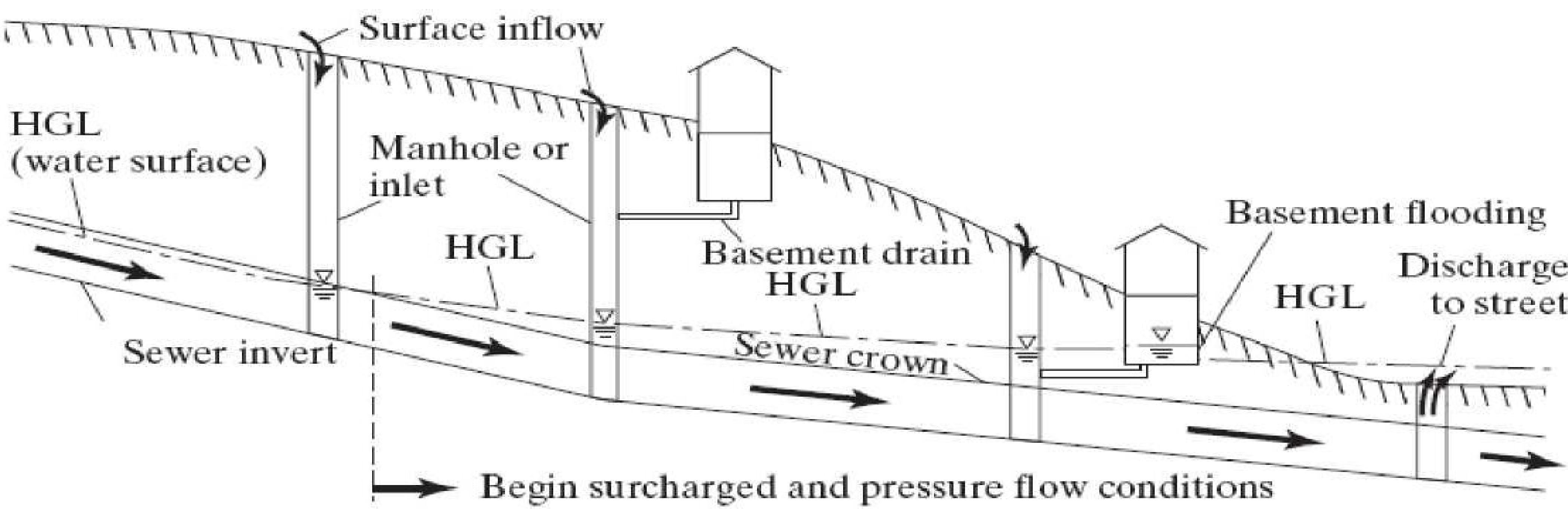
- Similar to any other channel network, but with known and regular geometry
- For simple systems:
  - Kinematic wave, Muskingum, nonlinear reservoir, diffusion routing have been applied
- Modeling difficulty is easily increased beyond this point

Saint Venant Equations

- Simpler routing methods only apply to:
  - Networks where backwater is unimportant
  - Dendritic networks (branching of downstream network does not depend on flow conditions downstream)
- More complex scenarios require complete Saint Venant Equations
- Best accomplished through computer modeling:
  - SWMM5, HEC-RAS

Surcharging

- Occurs when the hydraulic grade line (HGL) is above the sewer crown
- Can cause basement flooding and blown man covers
- Presents significant modeling challenges



Internal Hydraulic Structures

Side Flow Weirs

$$Q = 3.32 L^{0.83} h^{1.67}$$

Q = side-flow weir discharge, cfs

L = weir length (in direction of main channel flow), ft

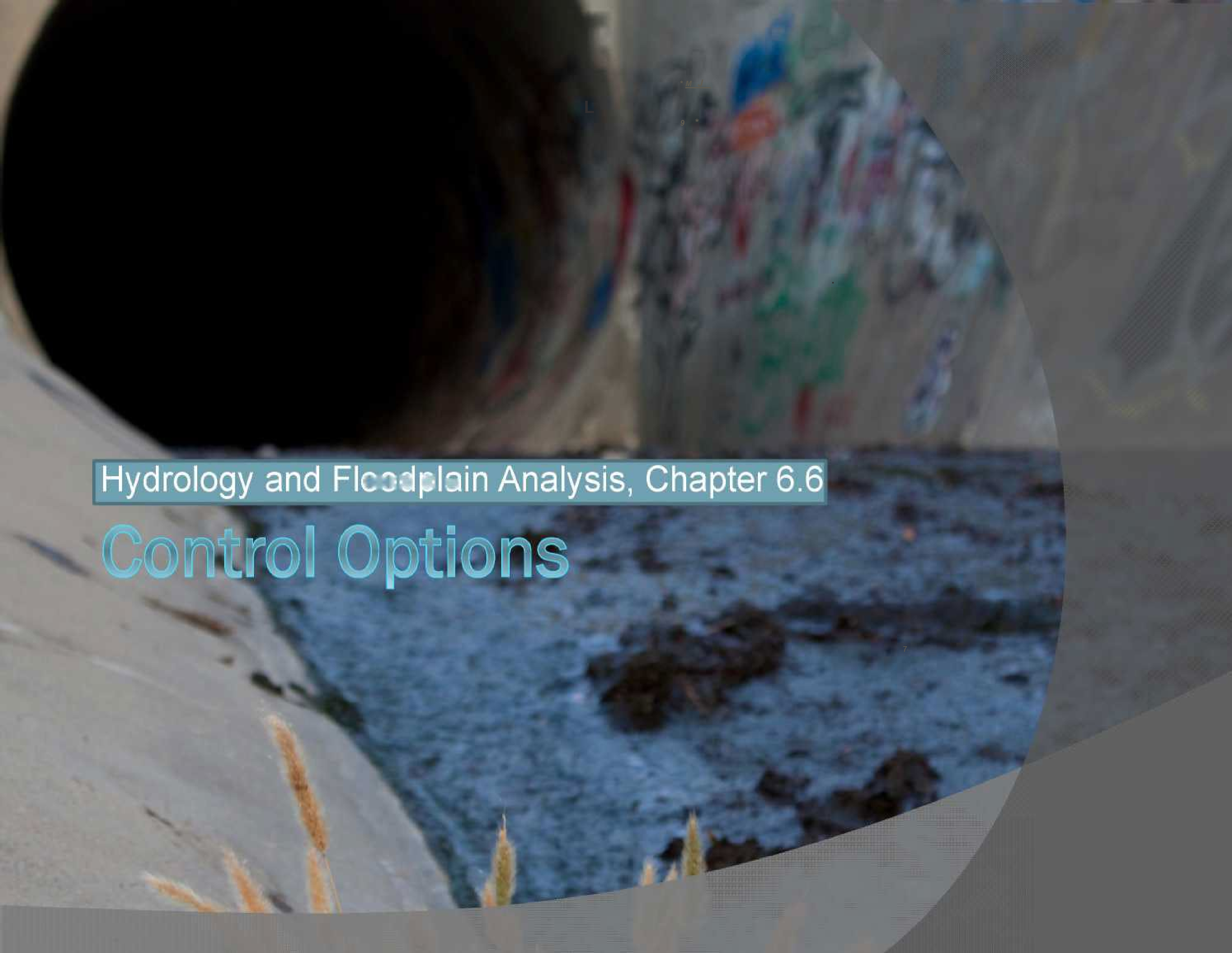
h = head on lower (downstream) end of weir, ft

Other Internal Structures

- ❖ Grate inlet:
  - Gradually varied flow analysis

- ❖ Tide grates:
  - Installed to prevent backflow
  - Orifice flow

- ❖ Pumps
  - Head vs. discharge rating curve for pumps



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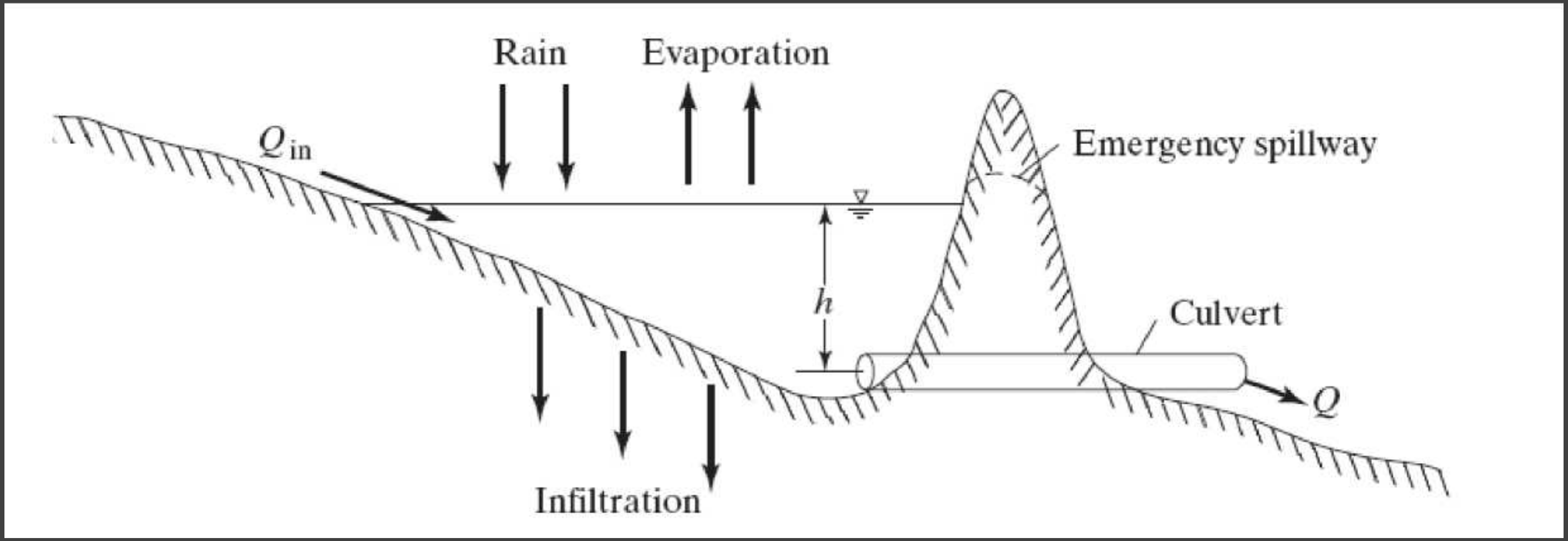
Control Options

Detention / Retention

- Detention
  - Detaining or slowing runoff and releasing it over 24 to 72 hours
- Retention
  - Runoff not released, allowed to infiltrate or evaporate




Other Methods

- ❖ Increased infiltration
  - Permeable pavement, parking lots, increased vegetated areas
    - o Only useful for smaller storms
- ❖ Inlet Restrictions
  - Useful to prevent surcharge and basement flooding
- ❖ Floodplain zoning
- ❖ Floodproofing

T.S. Allison Highway 59

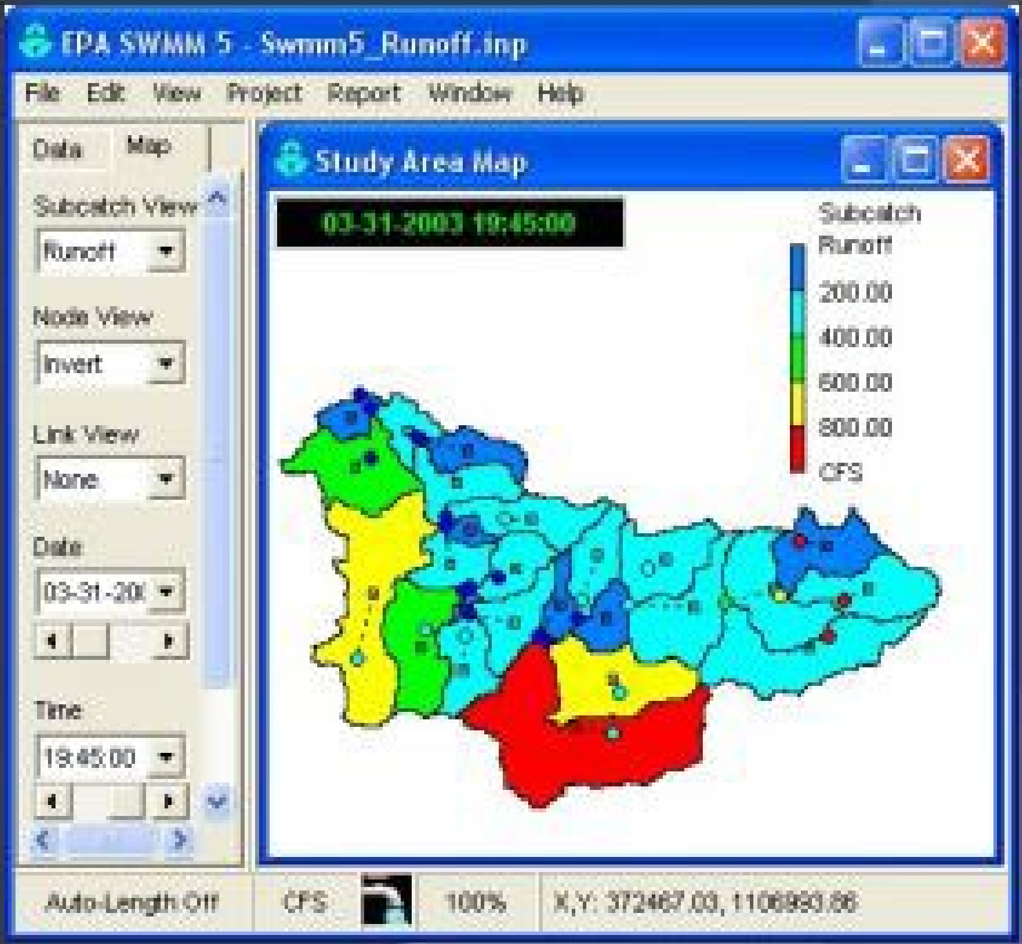
T.S. Allison Flooding

FLOOD PREVENTION- TMC

SWMM

Storm Water Management Model (SWMM)

- First developed by EPA in 1971
- Models storm water runoff and drainage systems
- Typical applications:
  - Rainfall-runoff simulations
  - Drainage design (storm sewers, pipe network) for flood control
  - Floodplain mapping (FEMA-approved)
  - Low impact development (LID) studies (College Park, MD; State College, PA; College Station, TX)



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