Engineering Hydrology

Week-13

CHAPTER- 7 URBAN HYDROLOGY

Sisay Demeku Derib (PhD, PE)
Sisay.demeku@aastu.edu.et
Addis Ababa Science and Technology University (AASTU),
Department of Civil Engineering
April, 2025

Lecture contents of the last weeks (Week-12)

CHAPTE- 6 RESERVOIR CAPACITY DETERMINATION

- Purposes of constructing reservoirs
- Categories of reservoir
- Common methods to determine the capacity of a reservoir
  - Mass curve (Ripple diagram) method,
  - Sequent peak algorithm,
  - Operation study

Lecture contents of the week (Week-12)

CHAPTE- 7 URBAN HYDROLOGY

7.1 Catchment Response Modifications

7.2 Urban Development Planning

7.3 Drainage Design

Lecture Learning Outcomes

Course Learning Outcomes: After completion of this Lecture, you will be able to:

CLO-1: Apply measurement techniques of the components of the hydrologic cycle, water balance and filling of missed data;

CLO-2: Examine rainfall-runoff relationship and hydrograph;

- Apply flood routing

CLO-3: Examine the probability of occurrence;

;

CLO-4: Analyze the water movement in to, over, and through the soil surface;

CLO-5: Design capacity of reservoir;

CLO-6: **Design runoff volume and time of distribution of the runoff hydrograph from urbanization effect.**

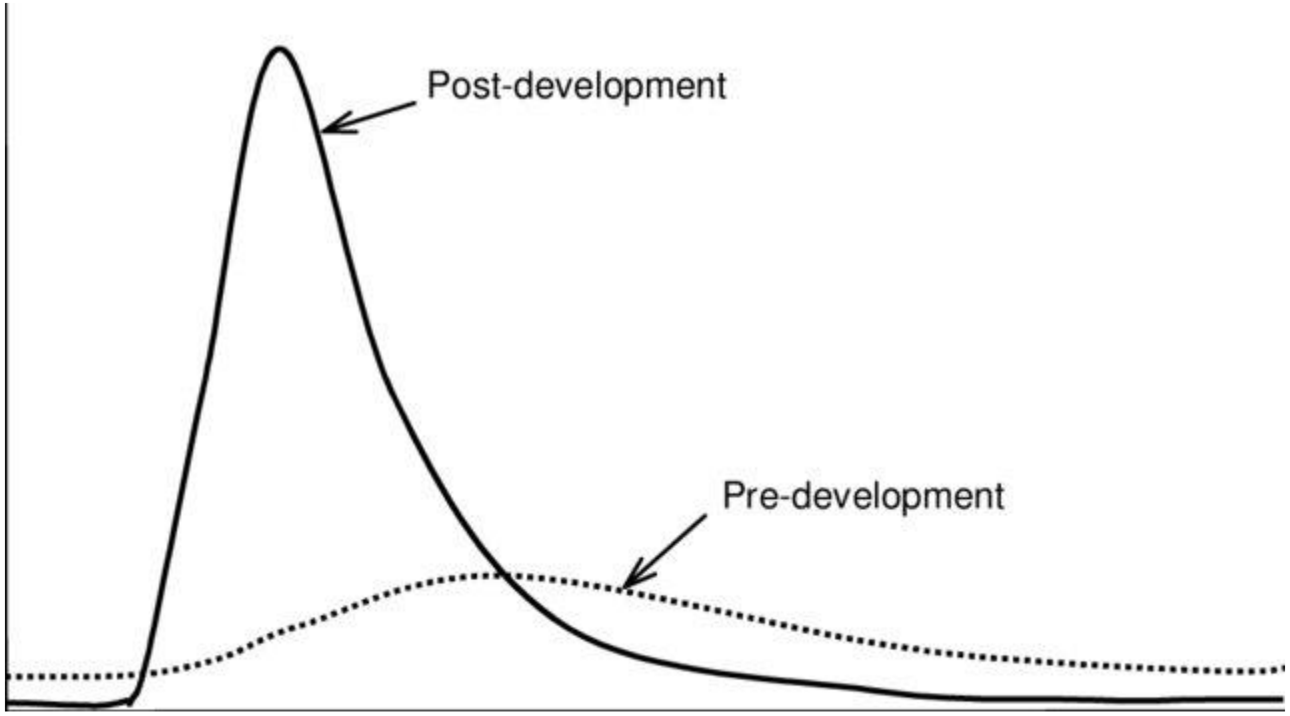
- **Discuss hydrological effects of urbanization**
- **Design urban drainage**

Catchment response urbanization

Urban Hydrology

Urban Hydrology is the scientific application of hydrologic principles and knowledge to the planning and management of urban areas and their surroundings.

- In urban hydrology the magnitudes of storms and their frequency of occurrence are of greater importance than annual rainfall totals



Source: storm hydrograph before and after a high degree of urbanization

Catchment response urbanization

- For developed areas several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered.

For example,

- do the impervious areas connect directly to the drainage system? or
- do they outlet onto lawns or other pervious areas where infiltration can occur?

Catchment response …

Factors that must be considered for urban hydrology:

- Rainfall amount and storm distribution
- Drainage area size, shape, and orientation
- Ground cover and soil type
- Slopes of terrain and stream channel(s)
- Antecedent moisture condition
- Storage potential (floodplains, ponds, wetlands, reservoirs, channels, etc.)
- Watershed development potential
- Characteristics of the local drainage system

Catchment response …

The typical hydrologic processes of interest in urban hydrology are related to:

- Precipitation and losses (rainfall abstractions)
- Determination of peak flow rate ---- for **drainage size**,
- Determination of total runoff volume ---- for **storage**
- Runoff hydrograph (flow vs. time)
- Stream channel hydrograph routing and combining of flows
- Reservoir (storage) routing

Catchment response …

- Urban storm water hydrology includes the information and procedures for estimating flow peaks, volumes, and time distributions of storm water runoff.
- The analysis of these parameters is fundamental to the design of storm water management facilities, such as storm drainage systems for conveyance of surface runoff and structural storm water controls for quality and quantity.
- There are a number of variable factors that affect the nature of storm water runoff from the site.

Catchment response …

- An impervious area is considered directly connected if runoff from it flows directly into the drainage system
- It is also considered directly connected if runoff from it occurs as concentrated shallow flow that runs over pervious areas and then into a drainage system
- It is possible that curve number values from urban areas could be reduced by not directly connecting impervious surfaces to the drainage system, but allowing runoff to flow as sheet flow over significant pervious areas.

Catchment response …

The changes made to urban area:

- extensive ground coverage by building
- the paved streets and car parks
- large areas to the impervious surface

These construction of building and urban infrastructures have a direct effect on its surface hydrology.

- Decrease infiltration
- Less evaporation due to low vegetation and surface water coverage
- Increased and immediate runoff.
- Less groundwater recharge

Catchment response …

After major urban development, the following differences in the river flow from that of an equivalent rural catchment can be identified:

1. Higher proportion of rainfall appearing as surface runoff
2. Response of the catchment is accelerated, with a steeper rising limb
3. Flood peak magnitudes are increased
4. In times of low flows, discharges are decreased
5. Water quality in streams and rivers draining urban area is degraded

Catchment response …

- Any slope of the land also greatly enhances the runoff response of a paved area
- In a defined catchment area, the effect on the stream discharge is dependent on the extent on the remaining pervious surfaces, where normal infiltration in to the soil and percolation in to the underlying strata can take place
- Many of these modifications are promoted by structural changes made to drainage channels.
- It is essential to remove rain water quickly from developed areas, and surface water drainage systems are included in modern town extensions.

Catchment response and modifications

- The runoff volume and time distribution of the runoff hydrograph is modified.
- The interaction of in the hydrological components, processes and the need to accommodate the changed hydrological characteristics is **complex**.
- The various hydrograph parameters such as peak discharge, Q_p, time to peak, t_p and lag time are usually related to catchment characteristics like percent:
  - impervious surfaces or proportion of area urbanized,
  - Greenery infrastructures
  - Water bodies
- in order to obtain quantitative rainfall-runoff relationships.

Urban development planning

Hydrological knowledge of the areas is required at two stages in new urban development:

1. The general layout of the new town is being decided during planning stage.
2. H**ydrological involvement** occurs at the detailing stage,
   - The designing of storm water drainage channels and
   - Pipes to carry the surface water in to the rivers
   - Management of excess rainfall for other **economic, social** and **environmental** benefits

- The first two details were the most considered ones in our cases.
- However, the last management details can make the others more sustainable and beneficial.

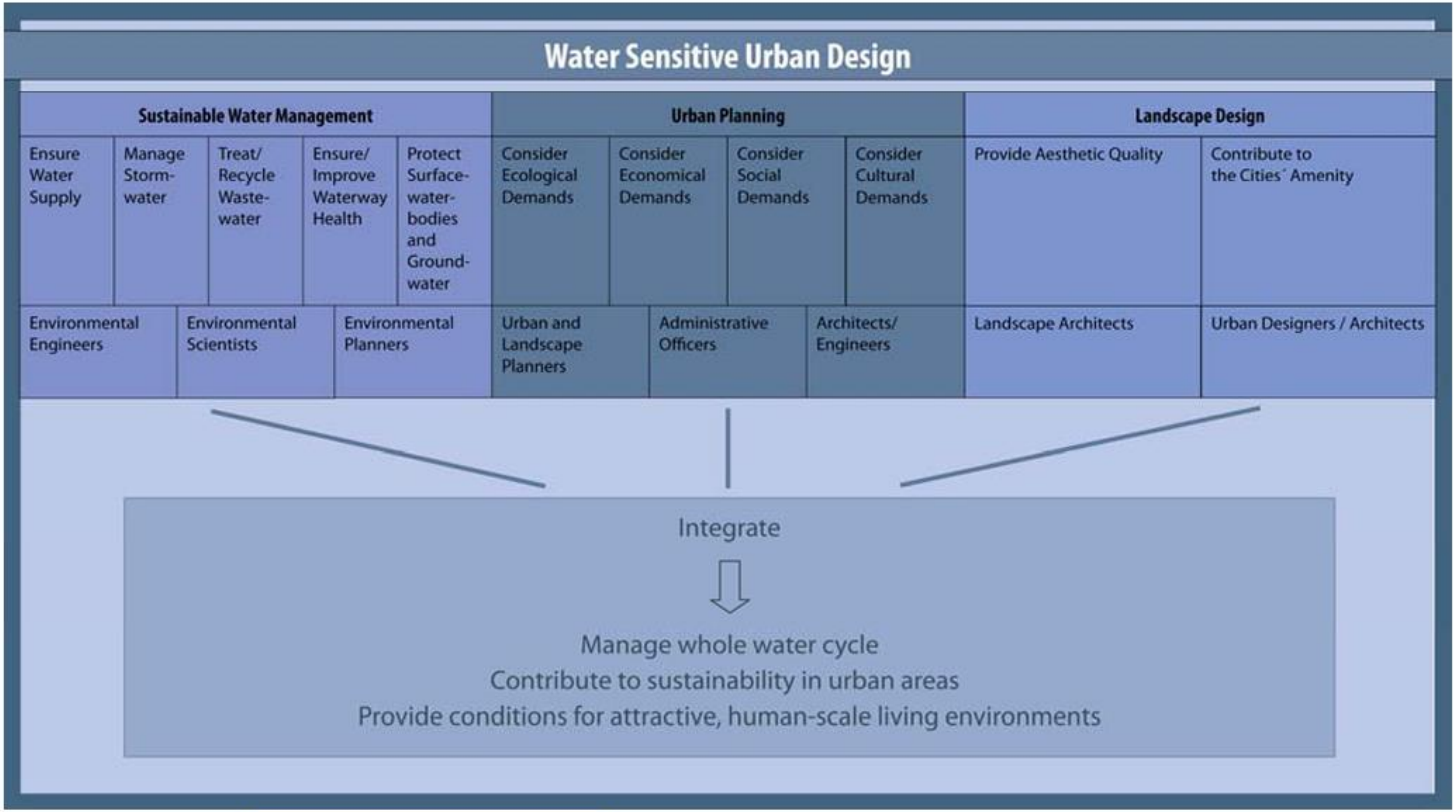
Urban development planning

- The principal objective at the **planning stage** are the determination of:
  - the size of flood,
  - its related return period,
  - the develop a design to accommodate the flood.
- The design of the **drainage system** is satisfactory to assess:
  - the flood magnitude-return period relationship and
  - the subsequent choice of a design flood with future extension and climatic change
  - Consider wastewater management too

Water sensitive urban design

- is the **interdisciplinary** cooperation of water management, urban design, and landscape planning.
- considers the management of entire water systems (drinking water, storm water run-off, waterway health, sewerage treatment and re-cycling),
  - but is concerned mostly with issues of rainwater management (compare www.wsud.melbournewater.com.au).

Water sensitive urban design



Components of Water Sensitive Urban Design (© HCU Hamburg).

Source: Hoyer et al. (2011)

Water sensitive urban design

Left: Fig. 14. Detention pond (dry), Gelsenkirchen, Germany (© J. Eckart).
Right: Fig. 15. Detention pond (wet) in Tanner Springs Park, Portland, Oregon, USA (© J. Hoyer).

Source: Hoyer et al. (2011)

Water sensitive urban design

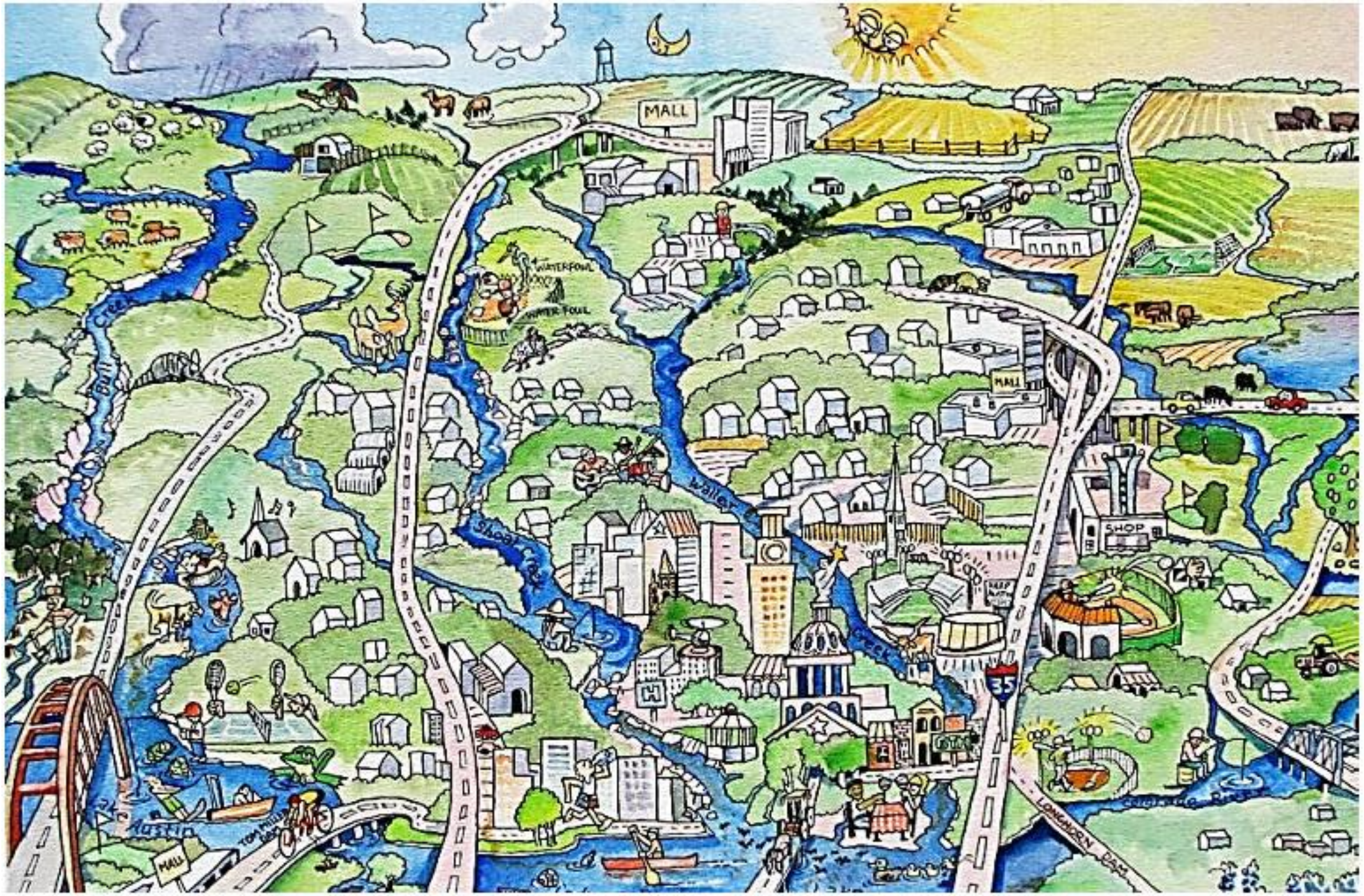
- For the success of decentralized stormwater management in combination with urban design (WSUD), it is important that the solutions are water sensitive:
- they bring stormwater management closer to the natural water cycle), ***functional, aesthetically pleasing, usable and accepted*** by local inhabitants.
- The five topics are defined:
  - Water Sensitivity
  - Aesthetics
  - Functionality
  - Usability
  - Public perception and acceptance

Water sensitive urban design

Low Impact Development (LID), Versus Water sensitive urban design (WSUD)

- LID minimizes the impact of development (and the subsequent stormwater
- management) on nature.
- The most recent LID manuals re-establish **hydrological targets** for both **retrofit** and **new urban developments,** as well as
  - provide design options to meet and sustain these objectives

Water sensitive urban design

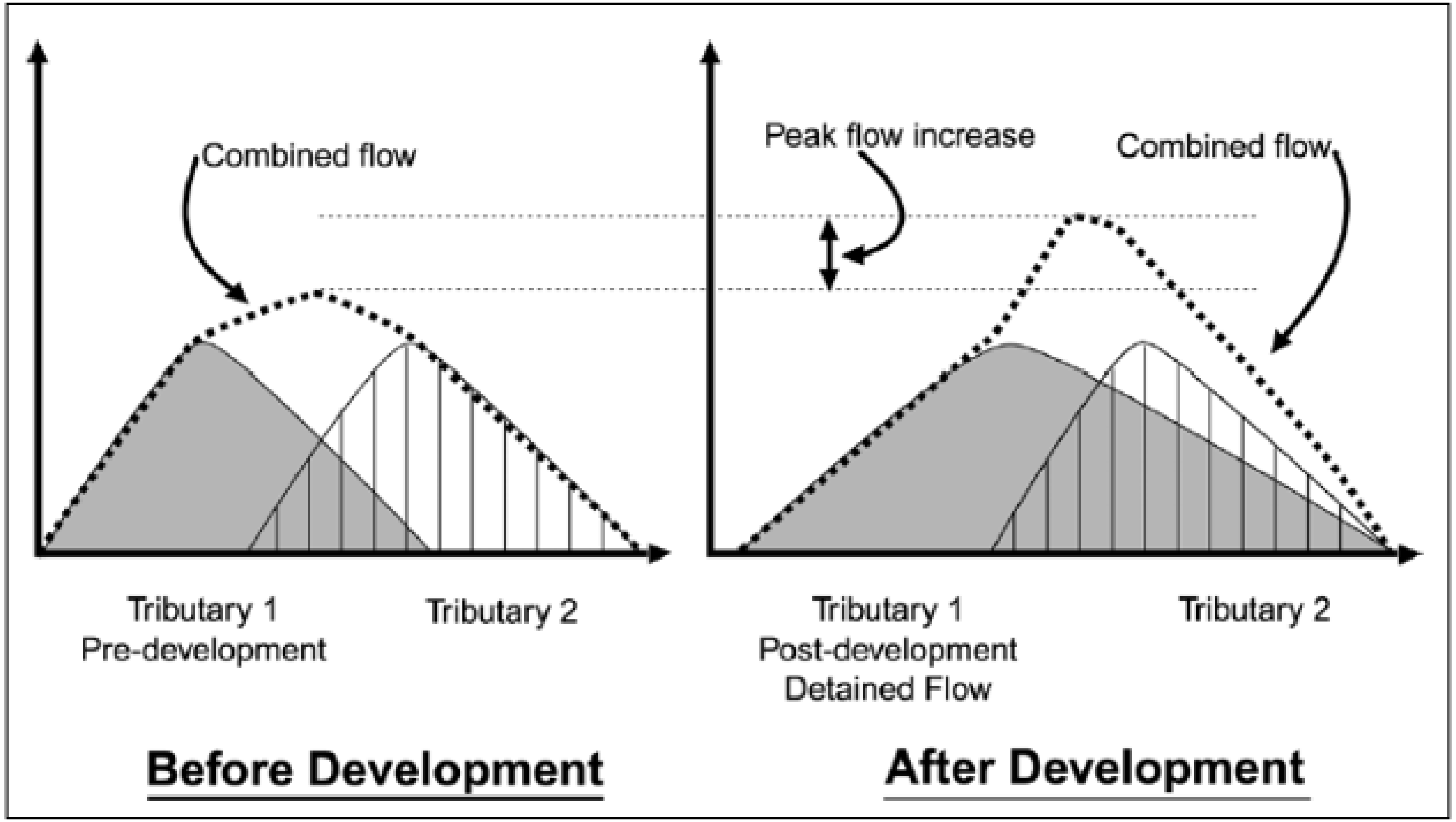


Austin watershed (source: http://www.bing.com/images/search?q=austin+watershed&view

Source: http://www.bing.com/images/search?q=austin+watershed&view

Galan Vivas, J.J. (Undated)

Water sensitive urban design



Source: Galan Vivas, J.J. (Undated)

Effect of Increased Post-Development Runoff Volume with Detention on a Downstream Hydrograph

Storm water drainage design

Basic terminologies:

- **Definition**
  - **Drainage** is the process of water or waste liquids flowing away from somewhere into the ground or down pipes.
  - **Urban drainage** is the process of collecting and transporting wastewater, rainwater/storm water or a combination of both.
  - **Sewage** is water-carried wastes, in either solution or suspension, which is intended to flow away from a community.
  - **Sewage**:- liquid material and
  - **Sewerage**:- pipes, pumps and infrastructure through which sewage flows.

Storm water drainage design

Basic terminologies:

- **Storm water** is rainwater (or water resulting from any form of precipitation) that has fallen on a built-up area.
  - If storm water were not drained properly, it would cause inconvenience ***damage, flooding*** and further ***health risks***.
  - It contains some pollutants, originating from rain, the air or the catchment surface.
- The word sewerage refers to the whole infrastructure system: pipes, manholes, structures, pumping stations and so on.
- There are basically two types of conventional sewerage system:
  - a combined system in which wastewater and storm water flow together in the same pipe, and
  - a separate system in which wastewater and storm water are kept in separate pipes.

Storm water drainage design

The **factors affecting** the quantity of **storm water flow** are

1. **Area** of the catchment
2. **Slope and shape** of the catchment area
3. **Porosity** of the soil
4. **Obstruction** in the flow of water as trees, fields, gardens..
5. **Initial state** of catchment area with respect to wetness
6. **Intensity and duration** of rainfall
7. Atmospheric **temperature** and **humidity**
8. Number and size of **ditches** present in the area

Quantity estimation of storm water

- The runoff **will be maximum** when the duration of rainfall is equal to the time of concentration and is called as **critical rainfall duration.**
- The time of concentration is equal to sum of inlet time and time of travel.
    - Time of concentration = Inlet time + time of travel

$$T_c = T_i + T_t$$

Quantity Estimation of Storm Water

Inlet Time:

- The time required for the rain in falling on the most **remote point** of the tributary area to flow across the ground surface along the ***natural drains or gutters*** up **to inlet of sewer** is called inlet time.

- The inlet time 'T_i' can be estimated using the following relationships similar. It will have different values for different catchments

$$T_c = T_i + T_t$$

$$T_i = [0.885 \frac{L^3}{H}]^{0.385}$$

$Ti = [0.885\ L^3/H]^{0.385}$

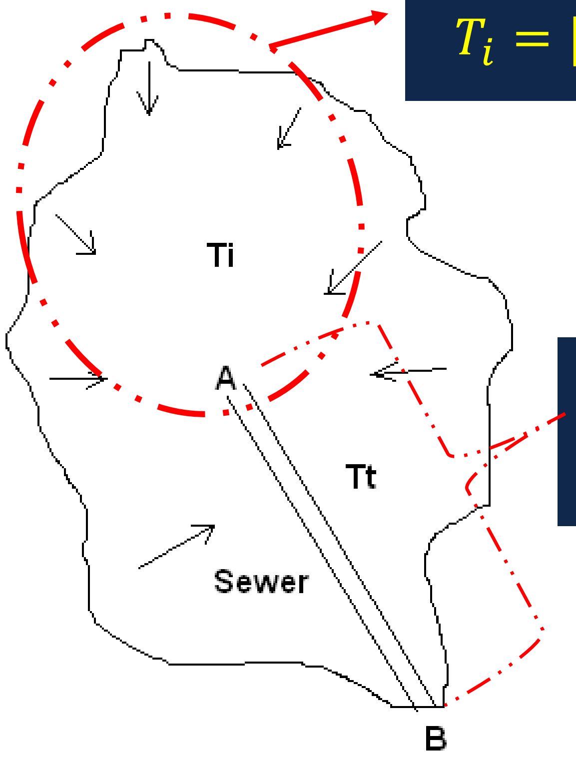
Where,

Ti = Time of inlet, minute

L = Length of overland flow in Kilometer from critical point to mouth of drain

H = Total fall of level from the critical point to mouth of drain, meter

Quantity Estimation of Storm Water



$$T_i = [0.885 \frac{L^3}{H}]^{0.385}$$

$$T_t = \frac{L}{v}$$

Time of Travel:

- The time required by the water to flow in the drain channel from **the mouth to the point under consideration** is called as time of travel

Time of Travel (T_t) = Length of drain (m)/ velocity (m/s) in drain

$$T_t = \frac{L}{v}$$

$$T_c = T_i + T_t$$

$$T_c = [0.885 \frac{L^3}{H}]^{0.385} + \frac{L}{v}$$

Drainage design

- The engineering **hydrologist** is fully concerned with evaluating the runoff from sub areas to be drained in order to design the necessary storm water sewers.
- The peak runoff from the selected design storm determines the size sewer pipe.
- At the head of the catchment sub area, the required pipe size **may be quite small**,
- At downstream, as the sewer receives water from **a growing** are through a series of junctions, the pipe size gradually needs to be **increased.**

Drainage design

- The problem of estimating the runoff from the storm rainfall is very much dependent on the character of the catchment surface.
- The degree of urbanization (extent of impervious area) greatly affects the volume of runoff obtained from a given rainfall.
- Retention of rainfall by initial wetting of surfaces and absorption by vegetation and pervious areas reduces the amount of storm runoff.
- These surface conditions also affect the time distribution of the runoff.
- Thus the computational method used to obtain the runoff from the rainfall should allow for the characteristics of the surface are to be drained.

Impervious areas

- These comprises the roof areas and large expanses of paved surfaces of city centers and industrial sites, in which there is very little or even no part of the ground surface into which rainfall could infiltrate.
- The calculation of the runoff from these relatively small catchments is the most straight forward, since the area can be easily defined and measured.
- Over such limited areas, the storm rainfall can be assumed to be uniformly distributed with 100% runoff occurring.

Drainage design

- The response of the impervious surface is rapid, resulting in a short time of concentration of the flow in the drainage system.
- The rational formula can thus provide the peak drainage Q.

$$Q_{(l/s)} = \frac{A_{(m^2)} * i_{(mm/h)}}{3600}$$

Drainage design

- At the outset of the design procedure, the selected return period for a design storm will have been decided.
- Storm water sewers are usually designed for 1 in 1, 1 in 2 or 1 in 5 year storm return periods.
- The type of pipe will also have been chosen; the internal roughness governs the flow characteristics, and roughness coefficient.
- Velocities and discharges for standard sized pipes can be found from published tables, assuming full bore conditions, a hydraulic gradient equal to the pipe gradient and appropriate roughness coefficient.

Drainage design

- Referring to figure 6.1, the design procedure begins with the choice of a trial pipe size for pipe 1.0, say 150 mm is chosen (the smallest used in practice) (Refer Table 2 on the next slide).
- From published tables and for k_s = 0.6 for a normal concrete pipe, the velocity and discharge for a gradient of 1 in 65 are noted, 1.26 m/s and 23.0 l/s, respectively.
- A flow greater than 23.0 l/s would result in surcharging.

Drainage design

Pipe No	Level Diff. (m)	Pipe Leng. (m)	Grad. (1 in)	Trial Pipe Dia (mm)	Pipe		Time of Flow (min)	Time of Conc. (min)	Rate of Rain (mm/h)	Imp. A Cum. (ha)	Storm, Q (l/s)	Comm.
					v (m/s)	Q (l/s)						
1.0	1.00	65.00	65.00	150.00	1.26	23.00	0.86	2.86	67.50	0.15	28.13	S
				225.00	1.64	67.50	0.66	2.66	69.20		28.83	PF
1.1	0.90	70.00	78.00	225.00	1.50	61.70	0.78	3.44	63.20	0.25	43.89	PF
2.0	1.50	60.00	40.00	150.00	1.61	29.40	0.62	2.62	69.50	0.20	38.61	S
				225.00	2.10	86.00	0.48	2.48	70.70		39.28	PF
1.2	0.90	50.00	56.00	225.00	1.77	72.80	0.47	3.91	60.20	0.53	88.63	S
				300.00	2.13	156.00	0.39	3.83	60.70		89.36	PF

Table 2: Rational method Drainage Design

Drainage design

- The time of flow along the pipe is next calculated from the velocity and length of pipe and comes to 0.86 min. the time of concentration at the end of the first pipe is then 0.86 min plus an assumed allowance of 2 min, for the time of entry, which is assumed to cover the lag time between the beginning of the storm rainfall and the entry of the overland flow in to the leading manhole.
- With the time of concentration of the drainage to the end of the first pipe known, the design return period rainfall intensity (i) over this duration to give the peak flow an be obtained from intensity-duration-frequency data.
- The storm peak discharge is then calculated using equation 6.1 for comparison with the un surcharged full bore pipe flow.

Drainage design

- The first trial pipe of 150 mm diameter would clearly be surcharged, so the calculations are repeated with the next size pipe, diameter 225 mm.
- the calculated storm discharge, 28.8 l/s would be easily contained by larger pipe
- The calculations proceed for each pipe in turn, with the previous time of concentration being added to the new time of flow to give the combined times of concentration at the end of sequential pipes.
- The drainage areas are also accumulated. It will be noted that the 2.0 min time of entry is also added to the flow time of pipe 2.0 since it is at the start of a branch of pipeline.
- The time of concentration for the last pipe, is then the sum of the time of concentration of pipe 1.1 and the flow time of pipe 1.2. the extra contribution from the greatly increased area drained by the tributary pipe results in a much larger discharge requiring the next size larger pipe, 300 mm diameter.

Quantity Estimation of Storm Water

1. Rational method

- Storm water quantity, Q, can be estimated by rational method:

$$Q = \frac{C * I * A}{360}$$

  - Where: Q = Quantity of storm water, m^3/sec
  - C = Coefficient of runoff
  - I = intensity of rainfall (mm/hour) for the duration equal to time of concentration, and
  - A = Drainage area in hectares

- *OR*

$$Q = 0.278*C*I*A$$

Where, Q is **m^3/s**; I is **mm/hour**, and A is area in **square kilometre**

Quantity Estimation of Storm Water

Runoff Coefficient:

- is a fraction, which is multiplied with the quantity of total rainfall to determine the quantity of rain water, which will reach the sewers.

- The runoff coefficient depends upon the
  - **porosity** of soil cover,
  - **wetness** and
  - ground **cover**.

- The overall runoff coefficient for the catchment area can be worked out as follows:

$$C = \frac{\sum_1^n A_n C_n}{\sum_1^n A_n} = \frac{A_1 C_1 + A_2 C_2 + \cdots + A_n C_n}{A_1 + A_2 + \ldots + A_n}$$

  - Where A_1, A_2……. An areas with C_1, C_2…C_n as their coefficient of runoff respectively.

Quantity Estimation of Storm Water

Table 3.2 Runoff coefficient for different type of cover in catchment

Type of Cover	Coefficient of runoff
Business areas	0.70 – 0.90
Apartment areas	0.50 – 0.70
Single family area	0.30 – 0.50
Parks, Playgrounds, Lawns	0.10 – 0.25
Paved Streets	0.80 –0.90
Water tight roofs	0.70 – 0.95

Quantity Estimation of Storm Water

Examples 1

1. Determine designed discharge for a combined system serving population of 50000 with rate of water supply of 135 LPCD. The catchment area is 100 hectares and the average coefficient of runoff is 0.60. The time of concentration for the design rainfall is 30 min and the relation between intensity of rainfall and duration is I = 1000/(t + 20).

Given:

P=50000
D=135l/c/d
A=100ha

C=0.6
T_c=30 min
I=1000/(t+20)

Required:

$Q\ (m^3/s) = ?$

Solution: Designed drain discharge = waste sewage + storm sewage

- **Assume:** Estimation of sewage quantity considering 80% of the water supplied will result in wastewater generation,
- The quantity of sanitary sewage = 50000 x 135l/c/d x(1m³/1000lit) x 0.80 = 5400 m³/day = 0.0625 m³/sec
- Considering peak factor of 2.5, the design discharge for sanitary sewage = 0.0625 x 2.5 = **0.156 m³/sec**

Quantity Estimation of Storm Water

- Estimation of **storm water discharge**
  - Intensity of rainfall, I = 1000/(t + 20)
  - Therefore, I = 1000/(30 + 20) = 20 mm/h
  - Hence, storm water runoff, Q = C.I.A/360
  - = 0.6 x 20 x 100/(360) = **3.33 m^3/sec**

- Therefore, design discharge for combined sewer = 3.33 + 0.156 = **3.49 m^3/sec** …….. #

Home assignment:

Make sure that you can write, select, compare on the following topics:

- Flood routing
- Importance of flood routing
- Types of flood routing
- Techniques of flood routing
- Mathematical representation of flood routing

References

Galan Vivas, J.J. Undated. Urban Hydrology and Storm Water Management, PPT, iWater_3rd International Event, Aalto University

Hoyer, J., W. Dickhaut, L. Kronawitter, and B. Weber. 2011. Water Sensitive Urban Design – Principles and Inspiration for Sustainable Stormwater Management in the City of the Future, Manual, jovis Verlag GmbH, Berlin.

Thank you very much for your active attendance!!

Prepared By: Sisay Demeku Derib (PhD, Practicing Hydraulics Engineer, Assistant Prof.)
Affiliated to: Addis Ababa Science and Technology University –AASTU, Department of Civil Engineering
----
Scopus WOS ORCID ResearchGate Google Scholar LinkedIn YouTube