ARISTOTLE UNIVERSITY OF THESSALONIKI

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Storm Water Management

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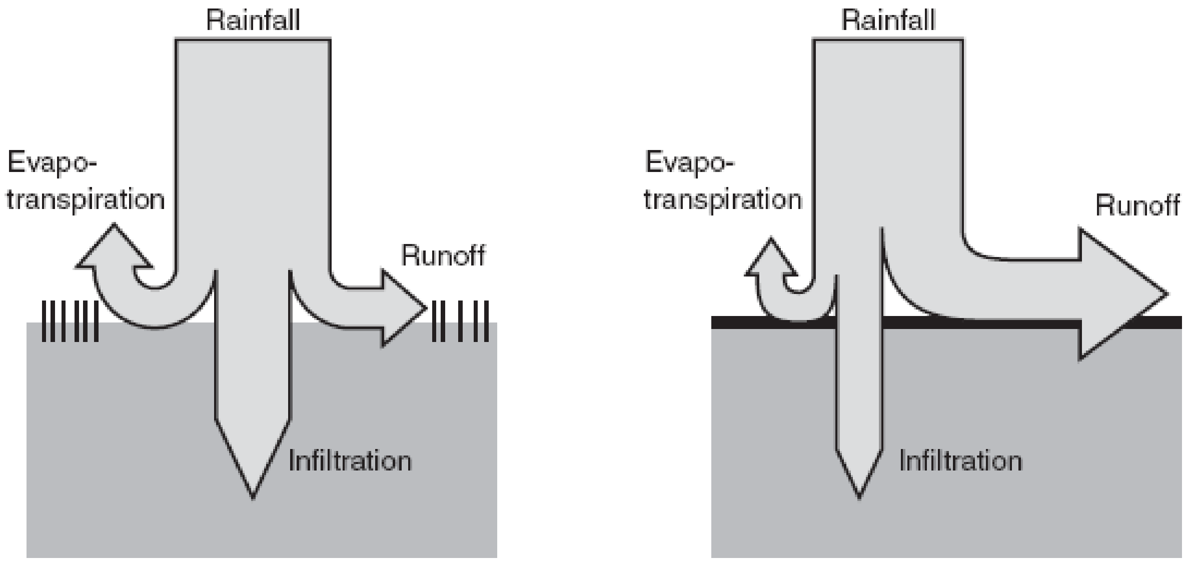
Thursday, 16/12/2021

Urban Drainage Systems

Fig. 1.1 Interfaces with the public and the environment

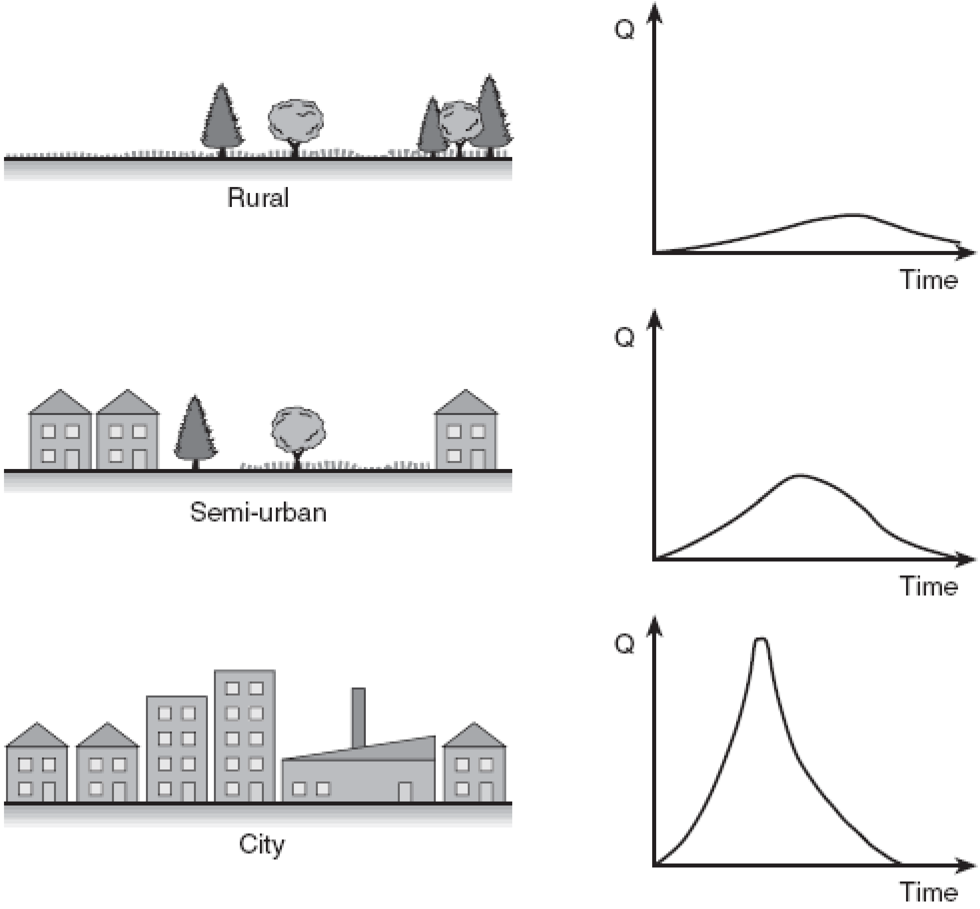


(a) Pre-urbanisation

(b) Post-urbanisation

Fig. 1.2 Effect of urbanisation on fate of rainfall

Effect of urbanization on runoff



Q = rate of runoff

Fig. 1.3 Effect of urbanisation on peak rate of runoff

Combined System

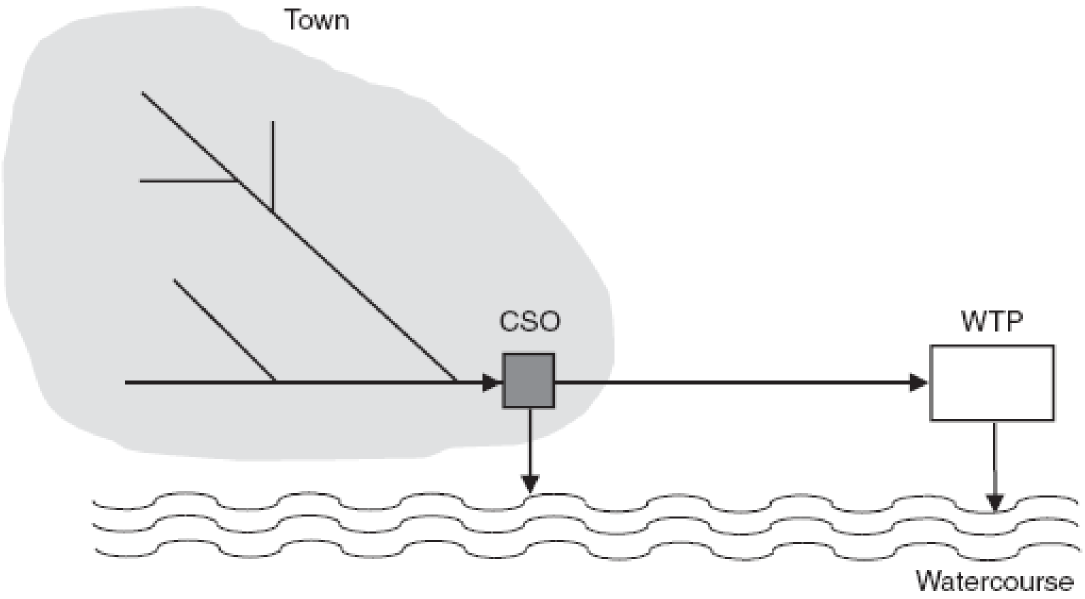


Fig. 2.1 Combined system (schematic plan)

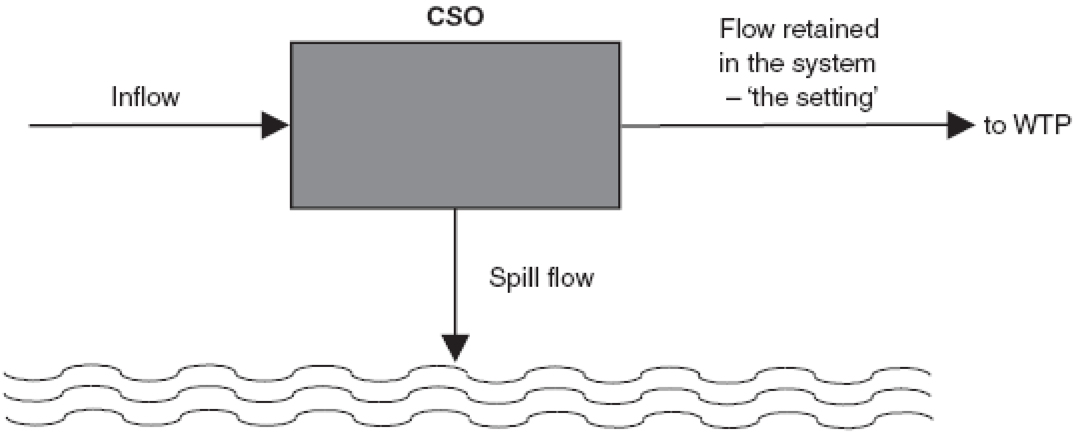


Fig. 2.2 CSO inflow and outflow

Separate System

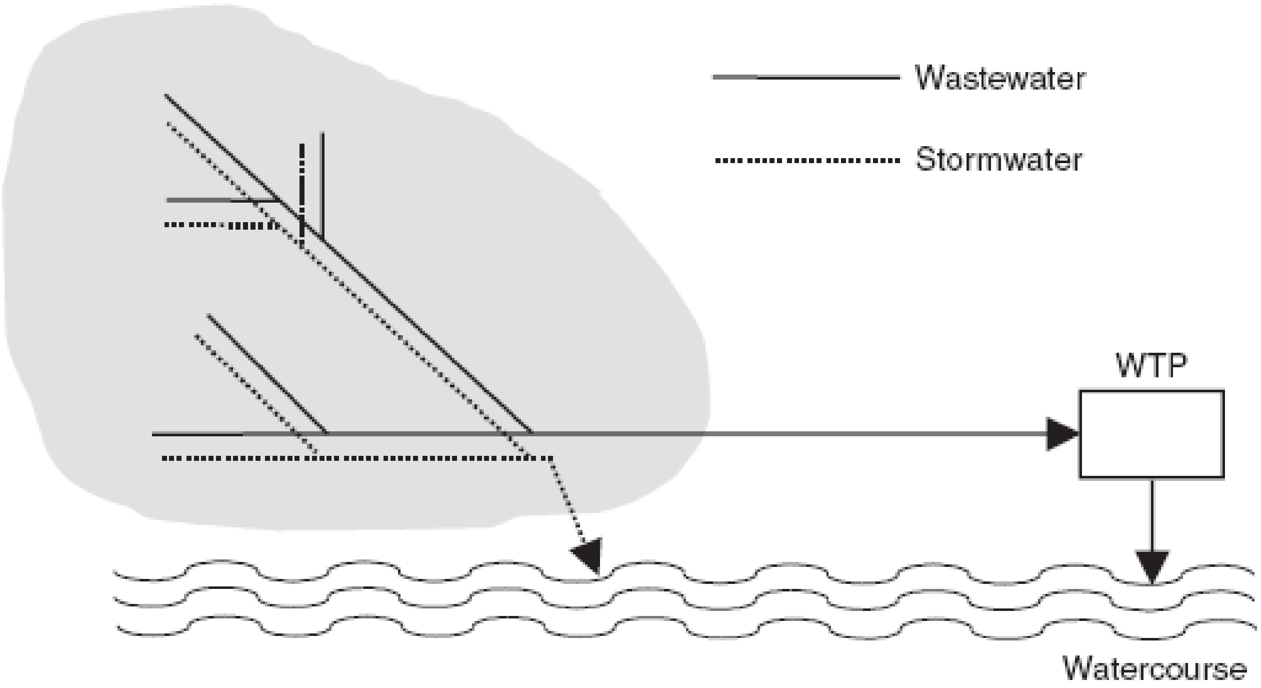
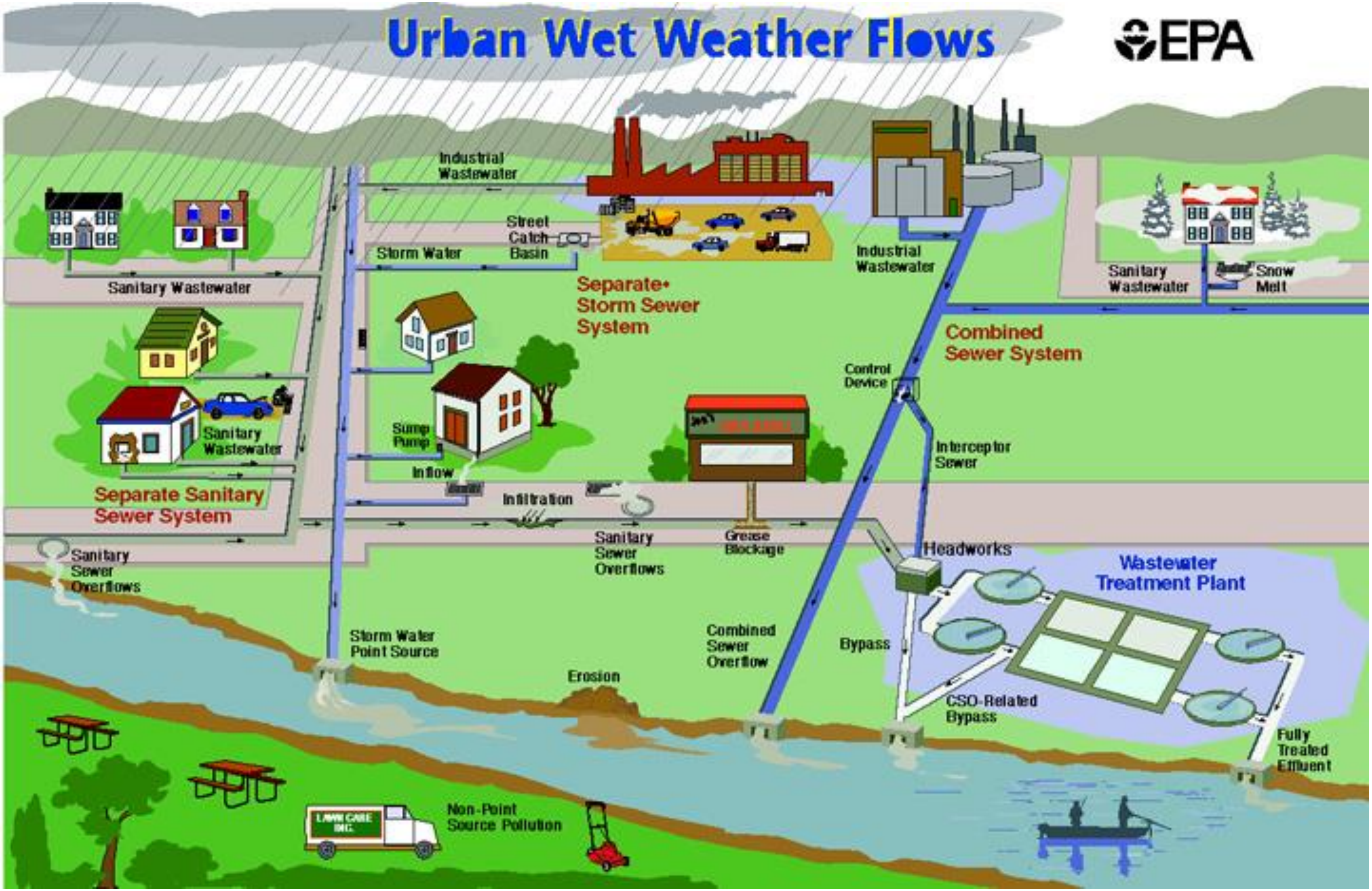
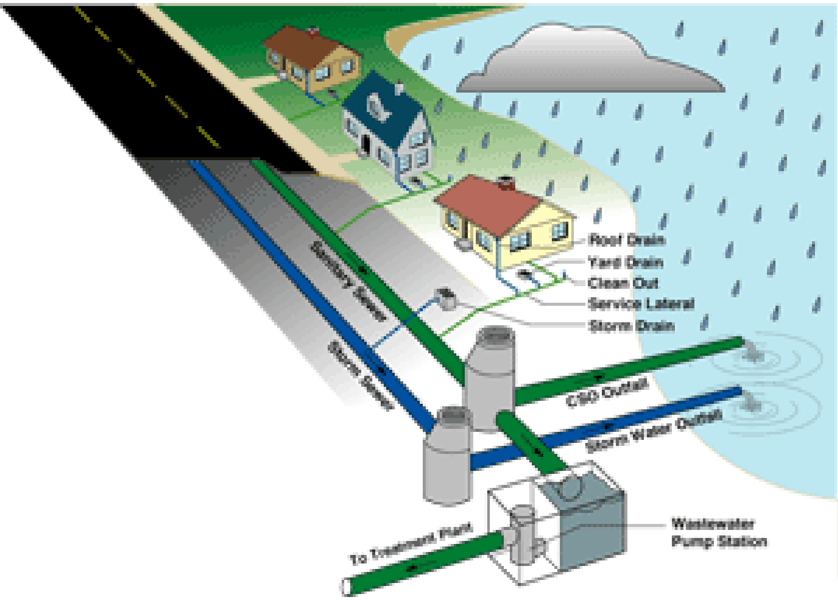


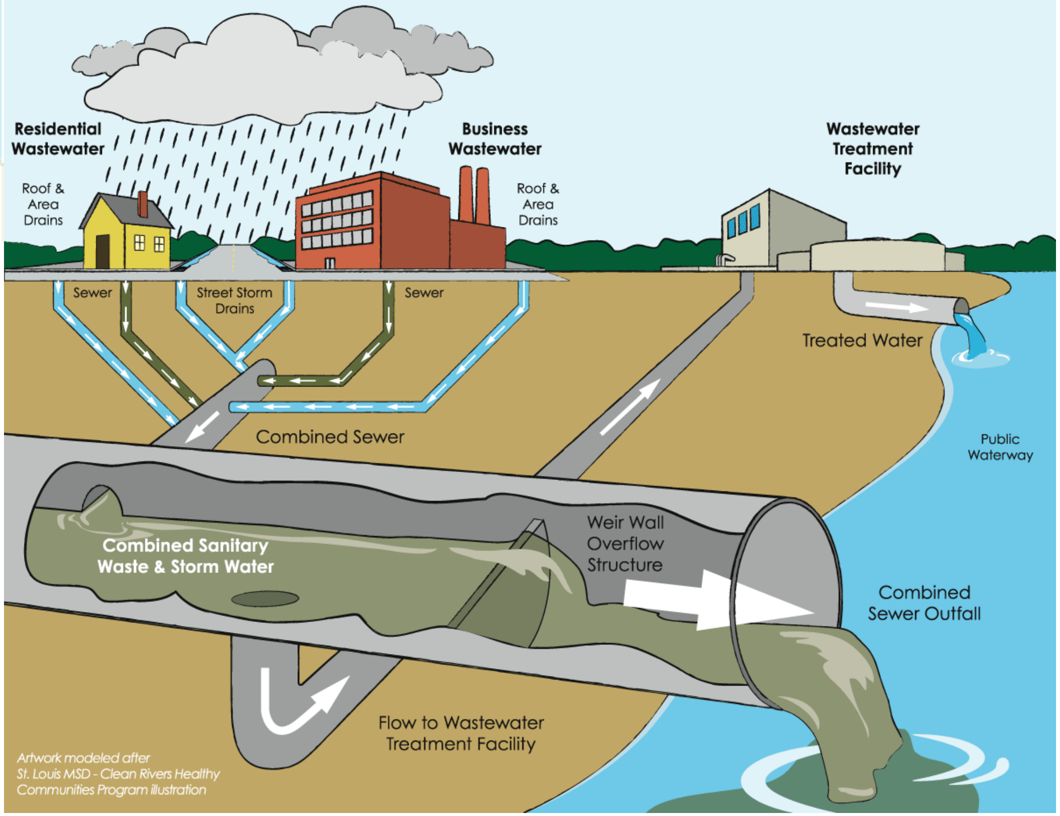
Fig. 2.3 Separate system (schematic plan)

Separate and Combined Drainage system



Separate and Combined Drainage system





Artwork modeled after St. Louis MSD - Clean Rivers Healthy Communities Program illustration

Separate and Combined Drainage system

Separate and combined system, advantages and disadvantages	
Separate system	**Combined system**
Advantages	**Disadvantages**
No CSOs – potentially less pollution of watercourses.	CSOs necessary to keep main sewers and treatment works to feasible size. May cause serious pollution of watercourses.
Smaller wastewater treatment works.	Larger treatment works inlets necessary, probably with provision for stormwater diversion and storage.
Stormwater pumped only if necessary.	Higher pumping costs if pumping of flow to treatment is necessary.
Wastewater and storm sewers may follow own optimum line and depth (for example, stormwater to nearby outfall).	Line is a compromise, and may necessitate long branch connections. Optimum depth for stormwater collection may not suit wastewater.

Separate and Combined Drainage system

Table Separate and combined system, advantages and disadvantages

Separate system	Combined system
Advantages	Disadvantages
Wastewater sewer small, and greater velocities maintained at low flows.	Slow, shallow flow in large sewers in dry weather flow may cause deposition and decomposition of solids.
Less variation in flow and strength of wastewater.	Wide variation in flow to pumps, and in flow and strength of wastewater to treatment works.
No road grit in wastewater sewers.	Grit removal necessary.
Any flooding will be by stormwater only.	If flooding and surcharge of manholes occurs, foul conditions will be caused.

Separate and Combined Drainage system

Table Separate and combined system, advantages and disadvantages

Separate system	**Combined system**
Disadvantages	**Advantages**
Extra cost of two pipes.	Lower pipe construction costs.
Additional space occupied in narrow streets in built-up areas.	Economical in space.
More house drains, with risk of wrong connections.	House drainage simpler and cheaper.
No flushing of deposited wastewater solids by stormwater.	Deposited wastewater solids flushed out in times of storm.
No treatment of stormwater.	Some treatment of stormwater.

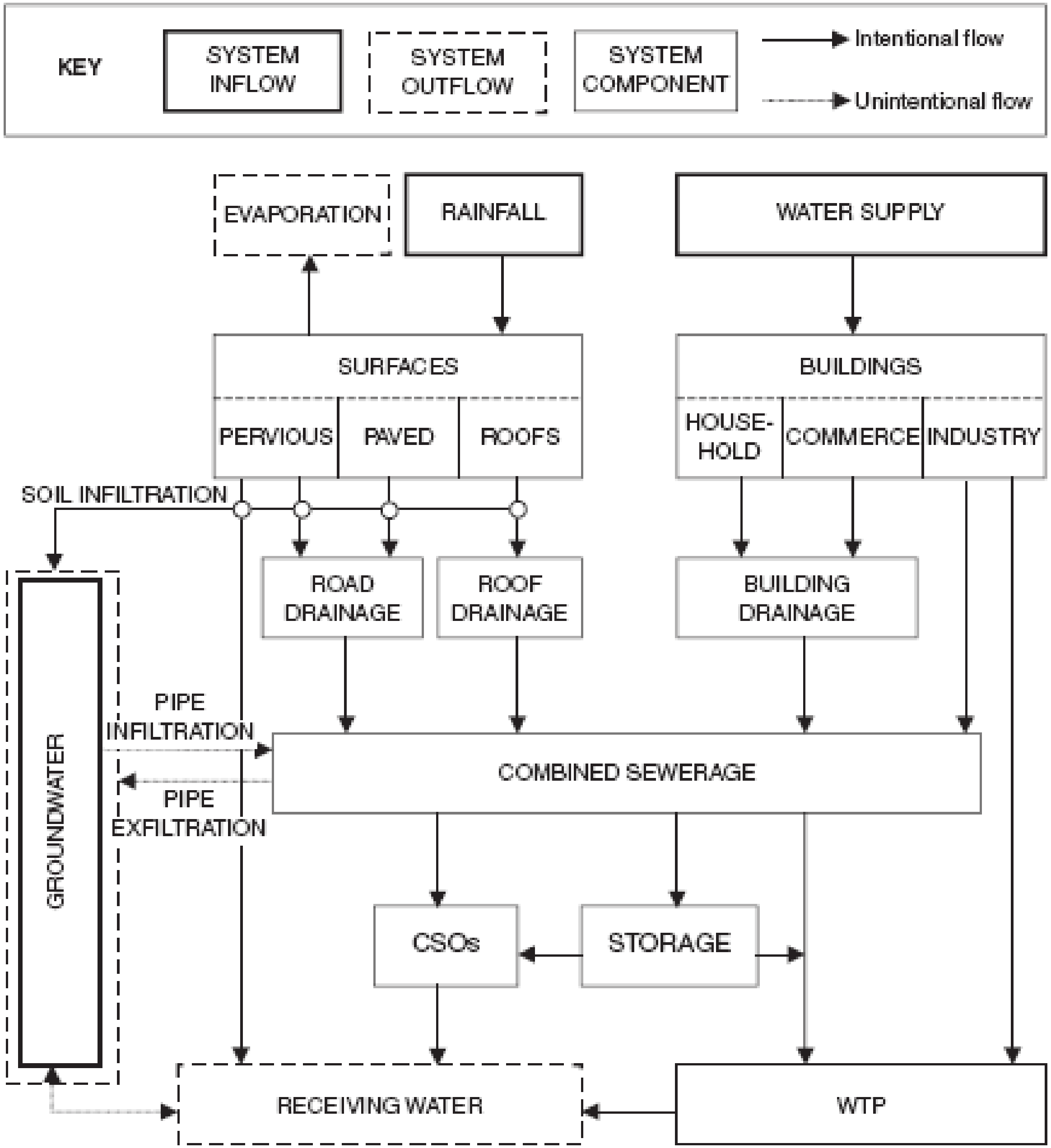


Fig. 2.4 Urban water system: combined sewerage

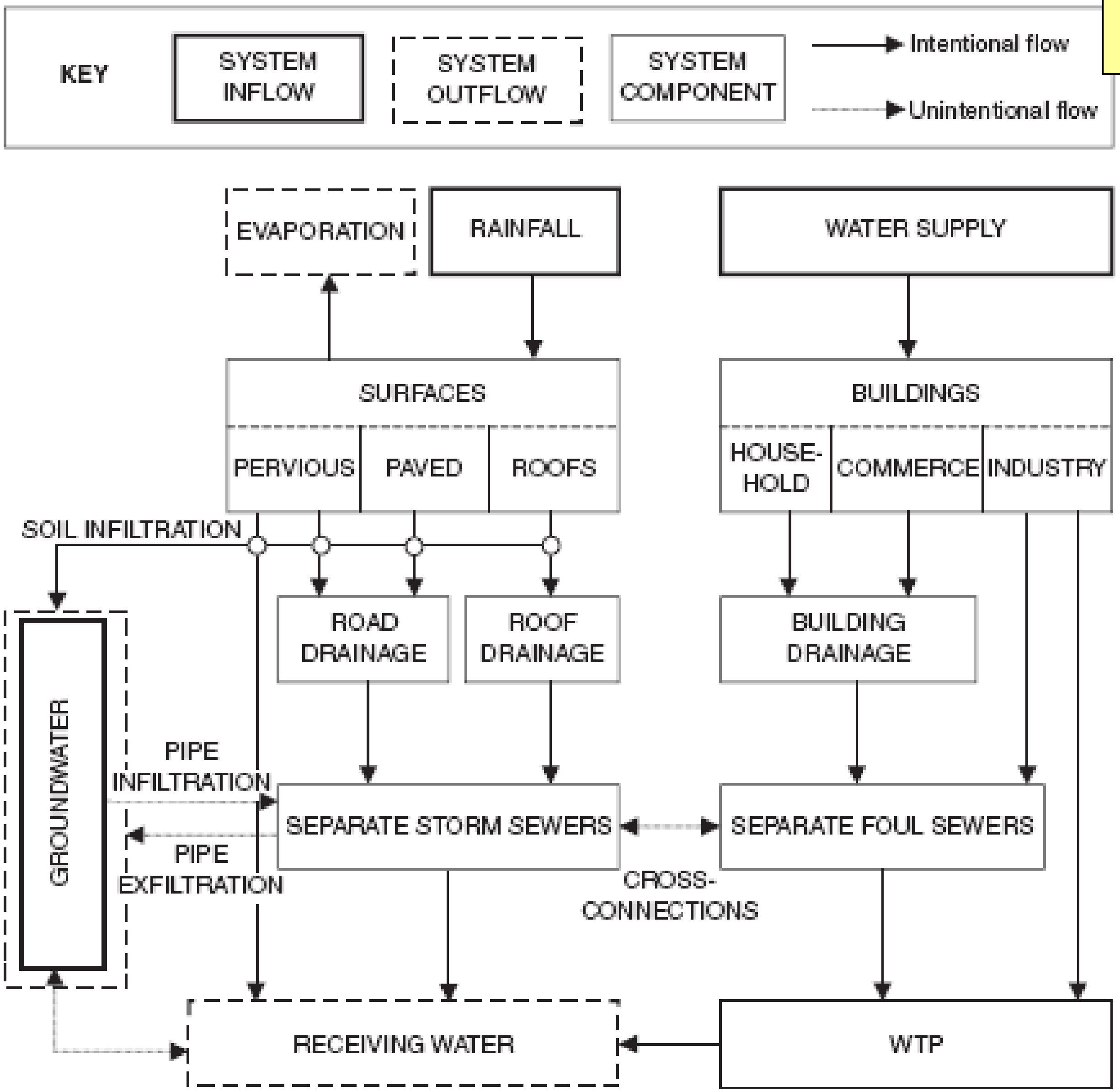
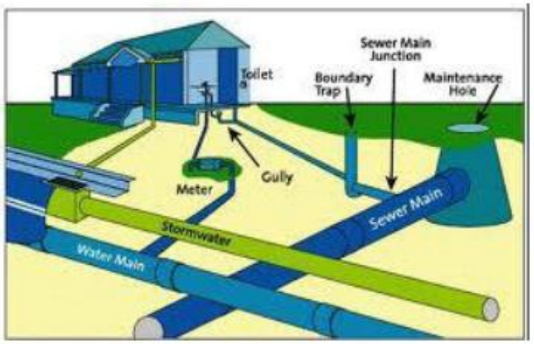
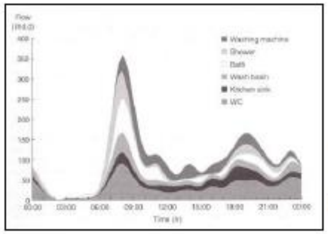


Fig. 2.5 Urban water system: separate sewerage

Design of Urban Drainage Systems

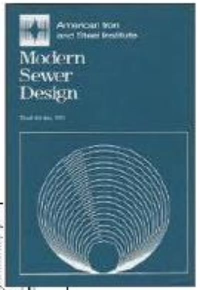
1. Available principles for urban drainage: stormwater and wastewater collection

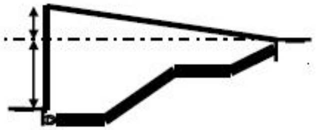




2. How to quantify flows incl. flow variations: stormwater and **wastewater**

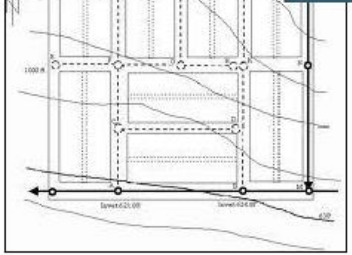
3. Design requirements

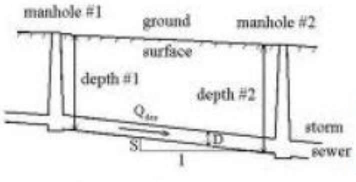




4. Available transport principles: gravity flow, pressurised flow

5. Layout of urban drainage system





Longitudinal Section of Storm Sewer

6. Principles of hydraulic calculations: design pipe dimensions and vertical profile

Foul sewer design

- Terminology: wastewater flow; dry weather flow; wastewater sewer/foul sewer

Design steps for wastewater sewers:

- Determine design capacity: dry weather flow
- Determine appropriate design diameter: max filling rate
- Determine bottom gradient: "self-cleansing" capacity

Foul/wastewater sewer design

Design steps for separate wastewater sewers:

- Determine design capacity: dry weather flow
- Determine appropriate design diameter: max filling rate
  - max filling rate 50% at design flow: allow for future increase + backup in case of system failure

Foul/wastewater sewer design – bottom gradient

Minimum bottom gradient: “self-cleansing” capacity
(esp. critical in more or less flat areas)

- UK: min self-cleansing velocity 0.6 m/s
- Better: min shear stress: $\tau = 0.5\text{-}1.5\ N/m^2$

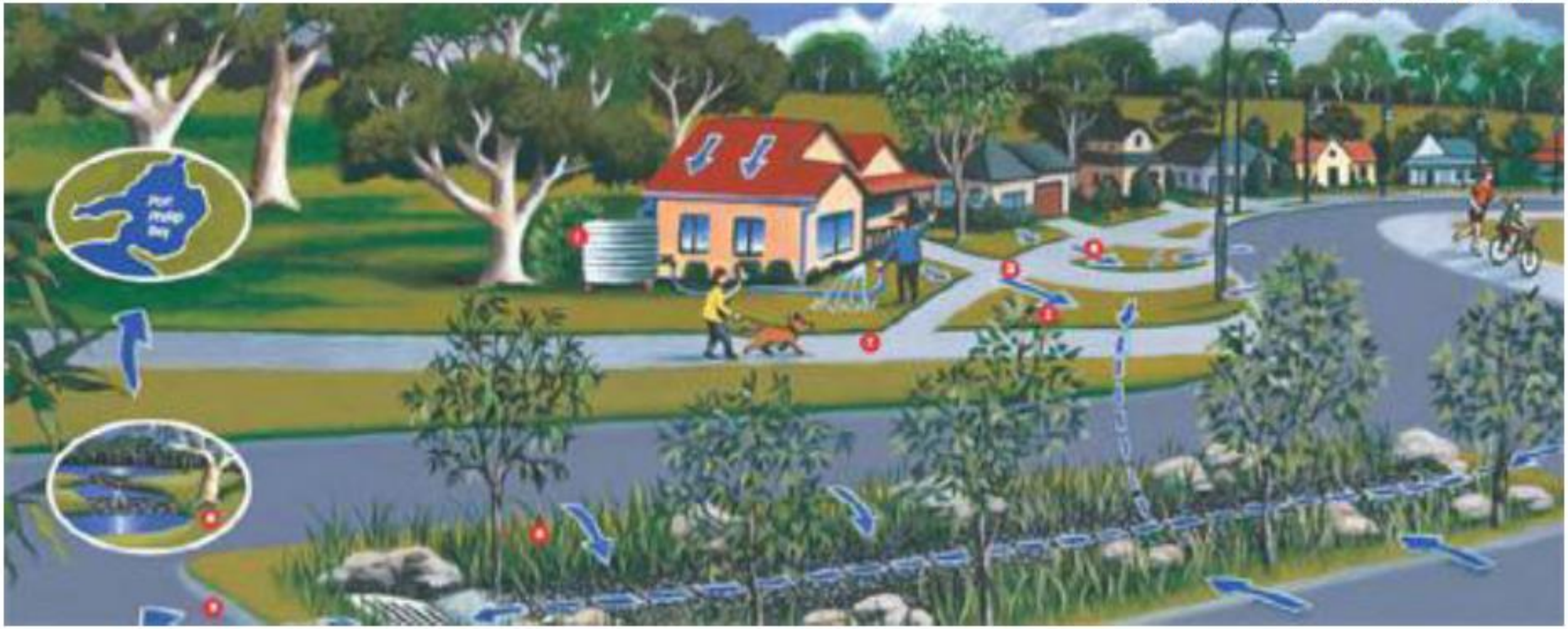
- Rule of thumb: i=1/D (D: pipe diameter in mm)
- Or: min gradient 1:250 (1st section); 1:500 (other sections)

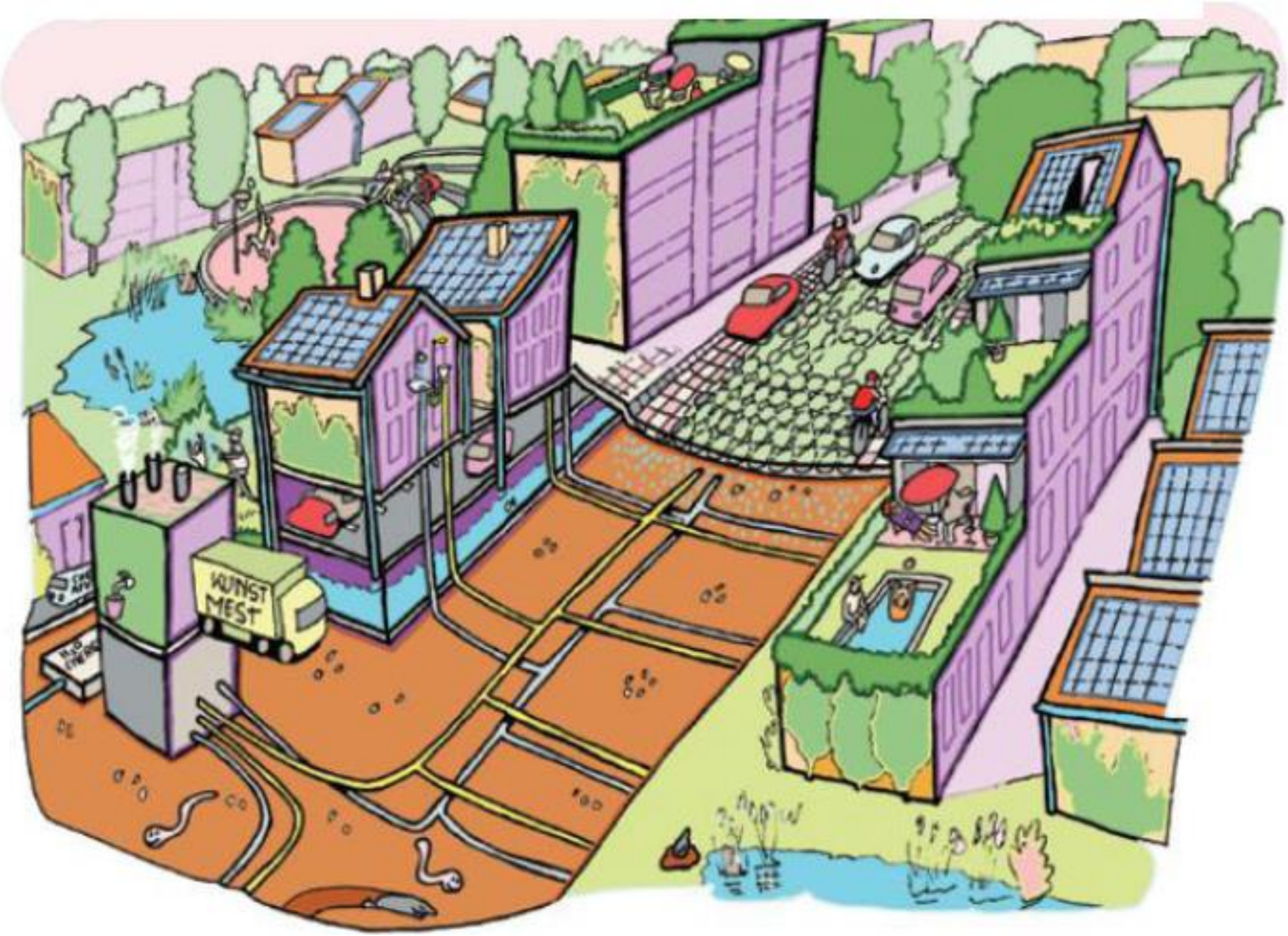
N.B.: 25 years of sewer sedimentation research – unable to predict sedimentation processes!

Approaches to urban drainage: a short history

20th century: integrated urban water management, water sensitive urban design

Source: Melbourne Water

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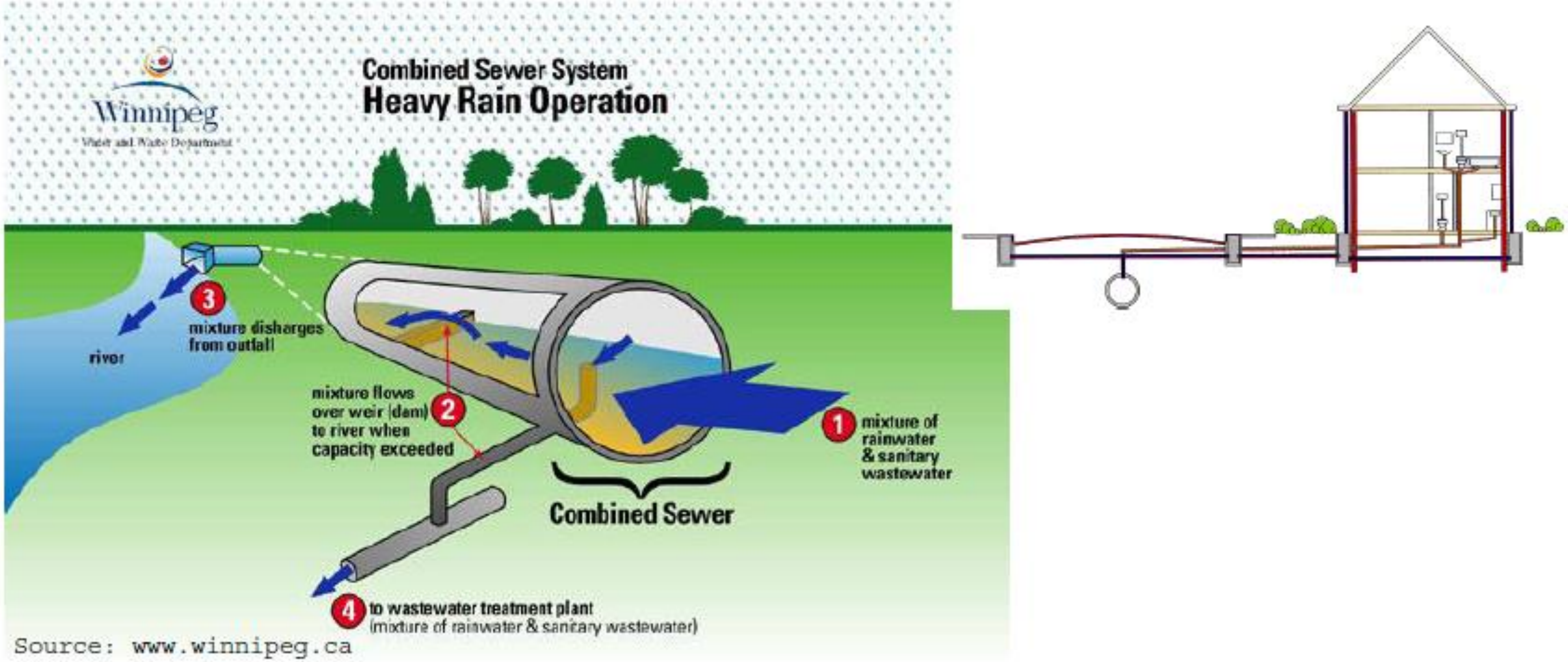
MEST

Combined Systems

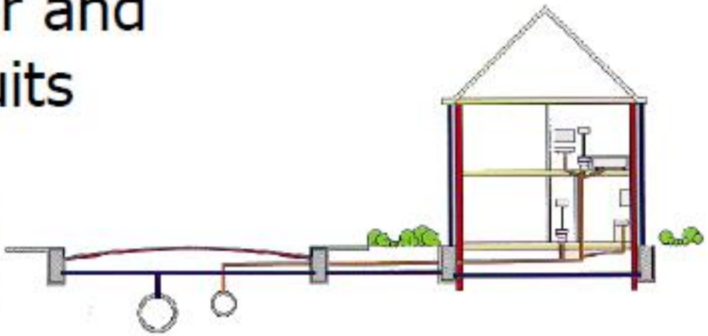
Combined sewer system: Wastewater and rainwater through 1 conduit/pipe

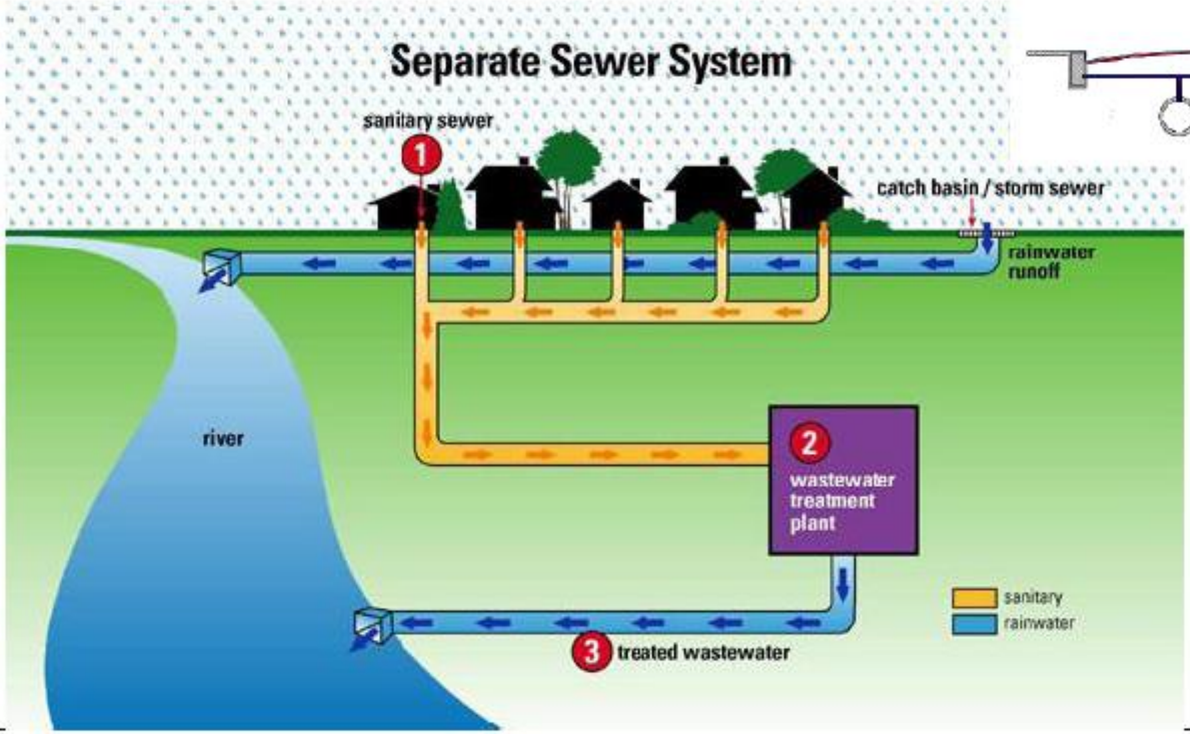


Source: www.winnipeg.ca

Separate Systems

Separate sewer system: Wastewater and rainwater through 2 separate conduits

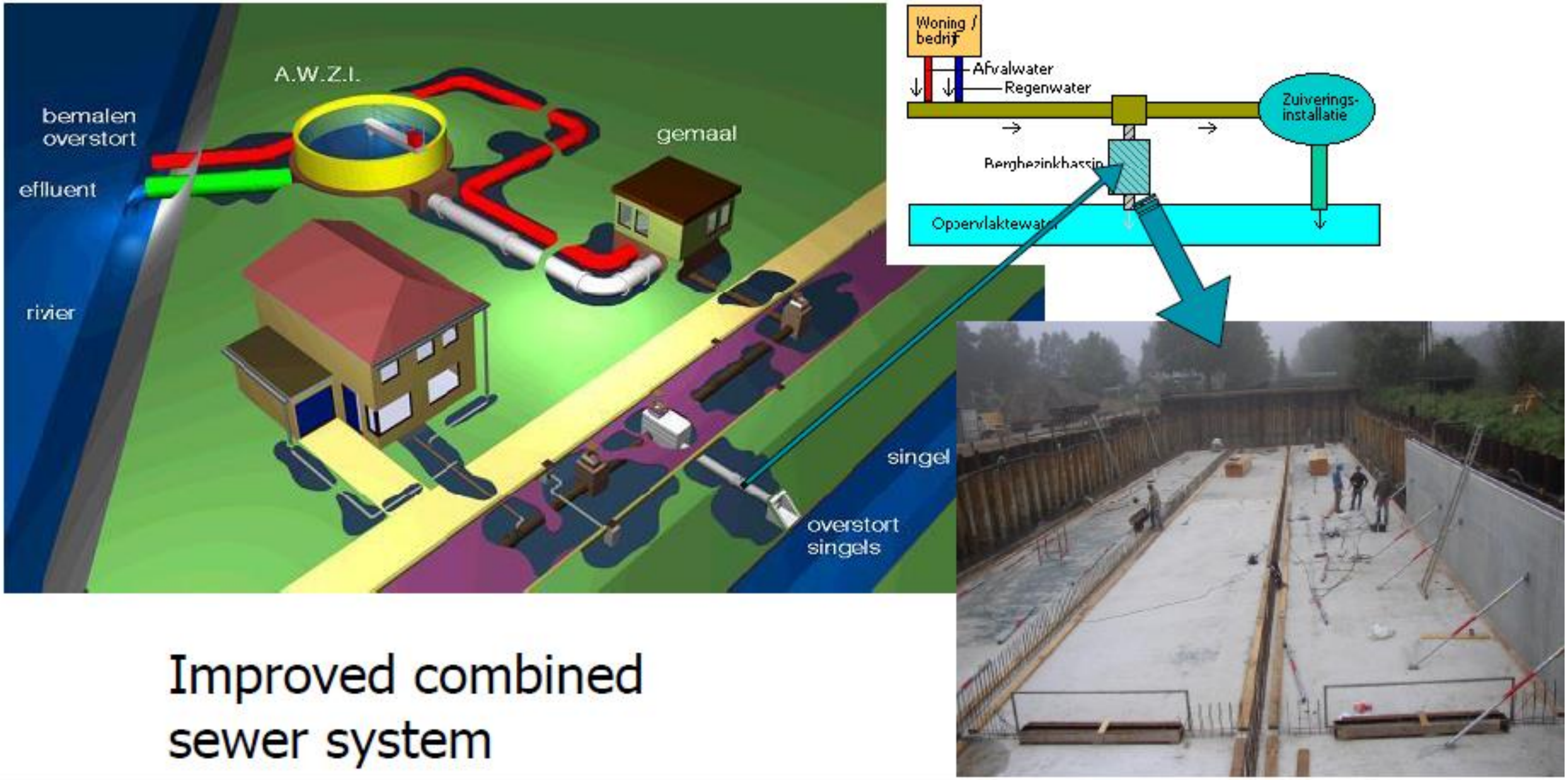




Typical stormwater drainage channel Singapore

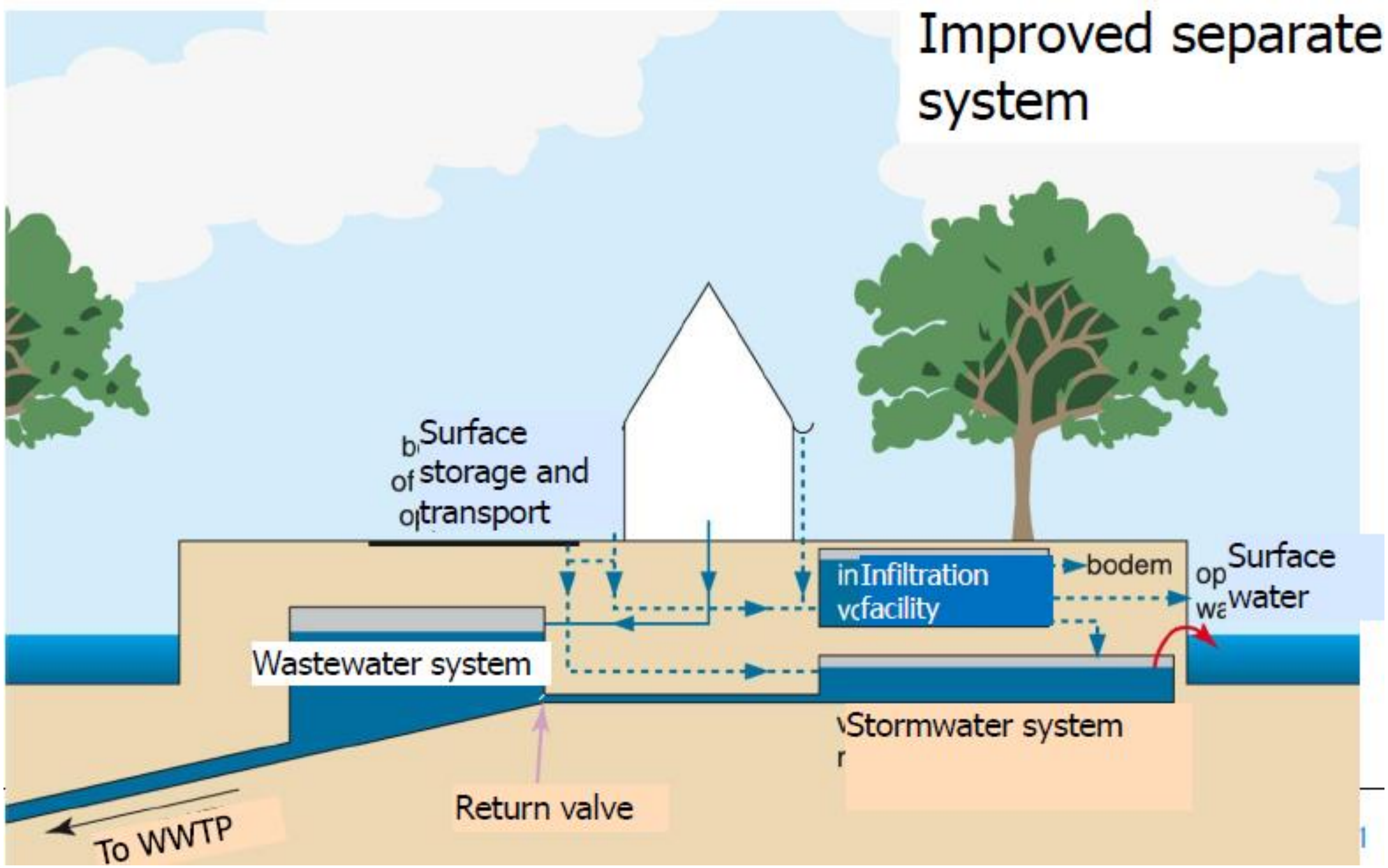
Stormwater drainage, Campus IT Bandung

Combined Systems



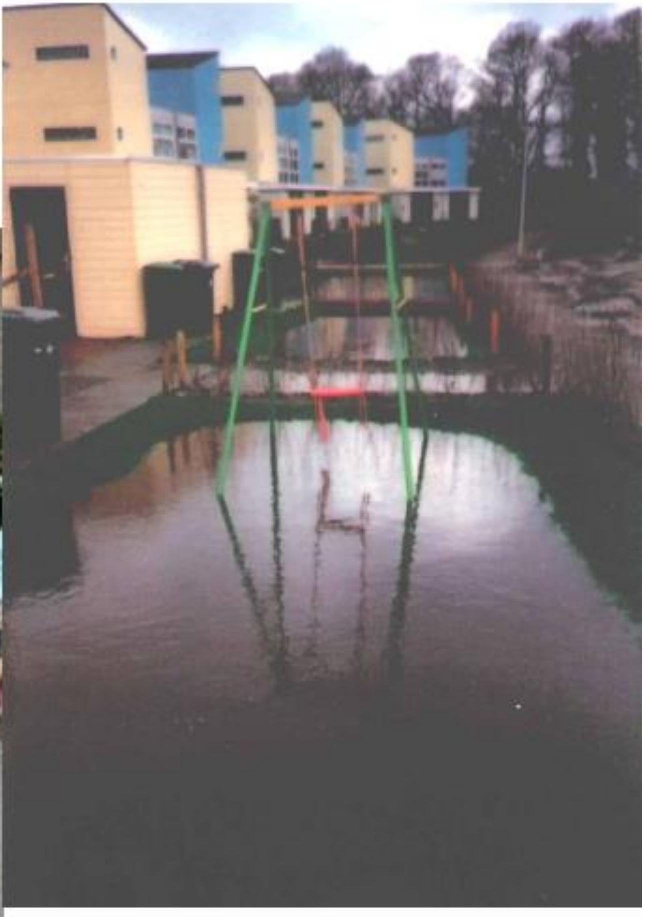
Improved combined
sewer system

Separate Systems



Stormwater handling

(Unintended) Surface storage



- Store rainwater and delay flow to sewer system and surface water

Stormwater handling

(Intended) Surface storage: Water squares

Remarks:

- Wash-off pollution from urban surfaces; Surface condition after emptying storage ?
- Health aspects ?

Photo: Rotterdam City

Stormwater handling

Underground storage

- Store rainwater
- Delay flow to sewer system and surface water

Photo: Rotterdam City

Stormwater handling

Infiltration: permeable pavements

- Infiltrate rainwater

Stormwater handling

Infiltration zone, swale (NL: wadi)

- Store and infiltrate rainwater

Stormwater handling

Infiltrating sewer

- Store and infiltrate rainwater

Stormwater handling

Green roofs

g

Photo: TU Delft

Photo: Rotterdam City

Of course there are downsides to every system type...

Source: www.tidydrivederby.co.uk

Photo: City of Lewiston

...downsides of every system type...

Design and Analysis of Sewer systems

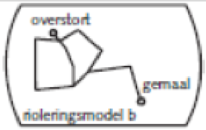
Robust method stationary modelling

IDF curves

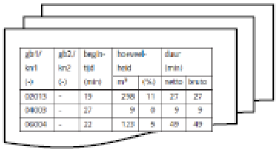
Rainfall runoff modelling

Rational method

Branched networks (few loops)



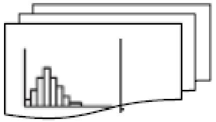
Stationary hydraulic calculations



Water levels in nodes

Storm event dynamic modelling

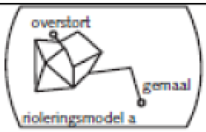
Design storms



Rainfall runoff modelling

Hydrodynamic model calculations

Detailed branched and looped networks

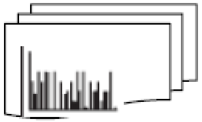


Dynamic hydraulic calculations

Q-t diagram per node per storm event

Rainfall series dynamic modelling

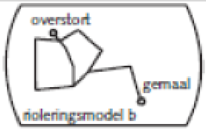
Standard rainfall series



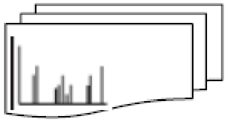
Rainfall runoff modelling

Hydrodynamic model calculations

Simplified branched and looped networks



Dynamic hydraulic calculations



Q-t diagram per node for series of storm events

Rainfall-Runoff modelling

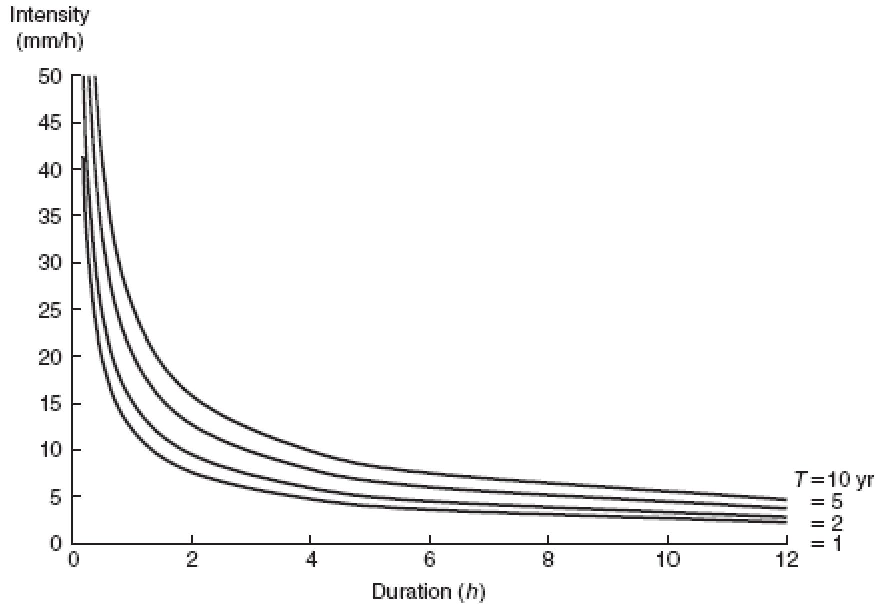


Fig. 5.2 Typical intensity-duration-frequency curves

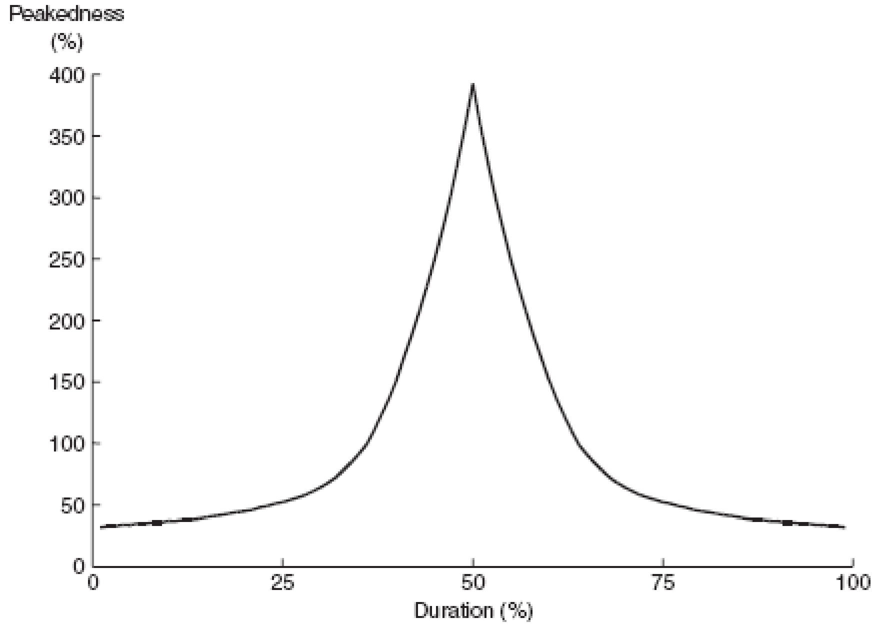


Fig. 5.6 FSR 50 percentile summer storm profile

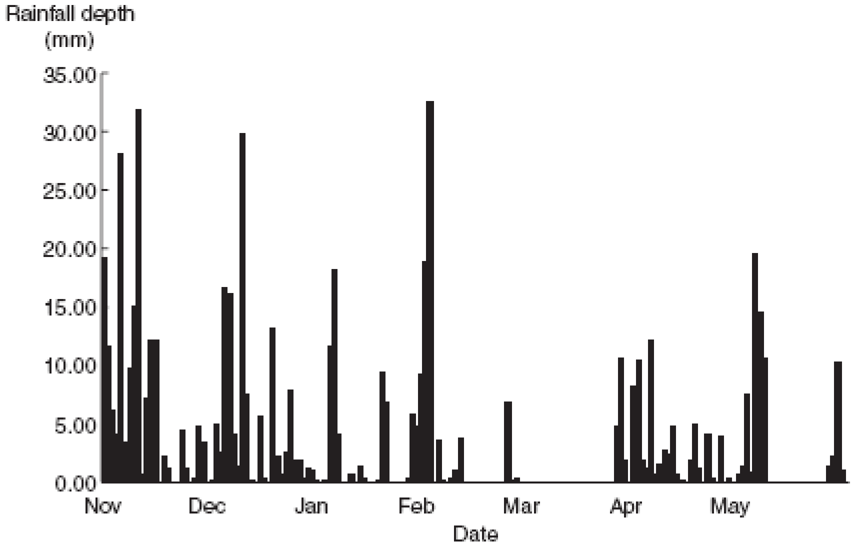


Fig. 5.7 Time–series rainfall (6 months of daily data)

Rainfall-Runoff

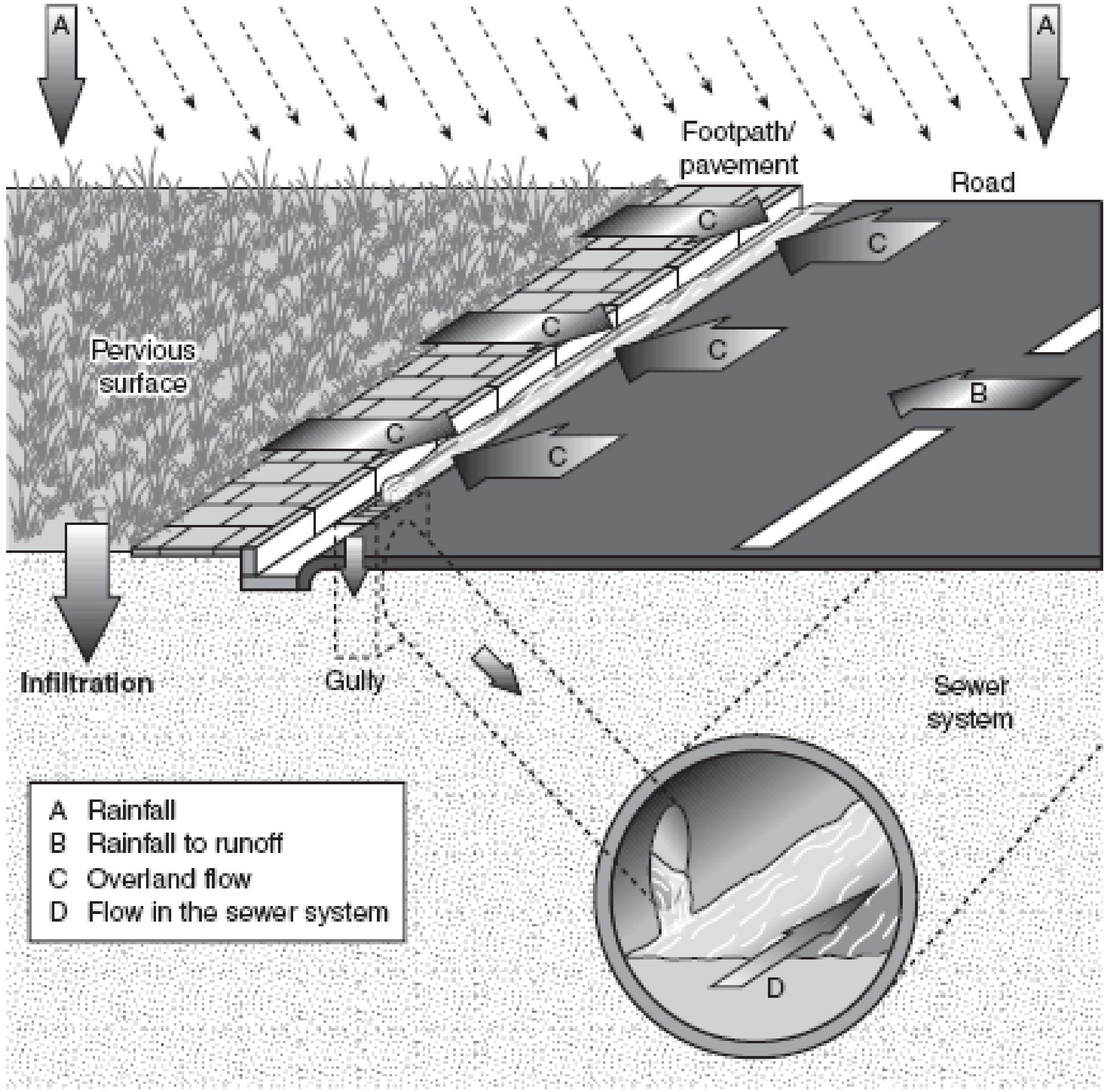


Fig. 6.1 Stormwater runoff generation processes

Rational Method

Steady Flow

$$Q_n = i \times \sum_{m=1}^{n} C_m A_m$$

Q_n=discharge at a location with n upstream areas (l/s)

i= critical rainfall intensity (l/s/ha η mm/h) with return period T and concentration time t

C_m=runoff coefficient for the watershed corresponding to area m

A_m= watershed surface corresponding to area m (ha)

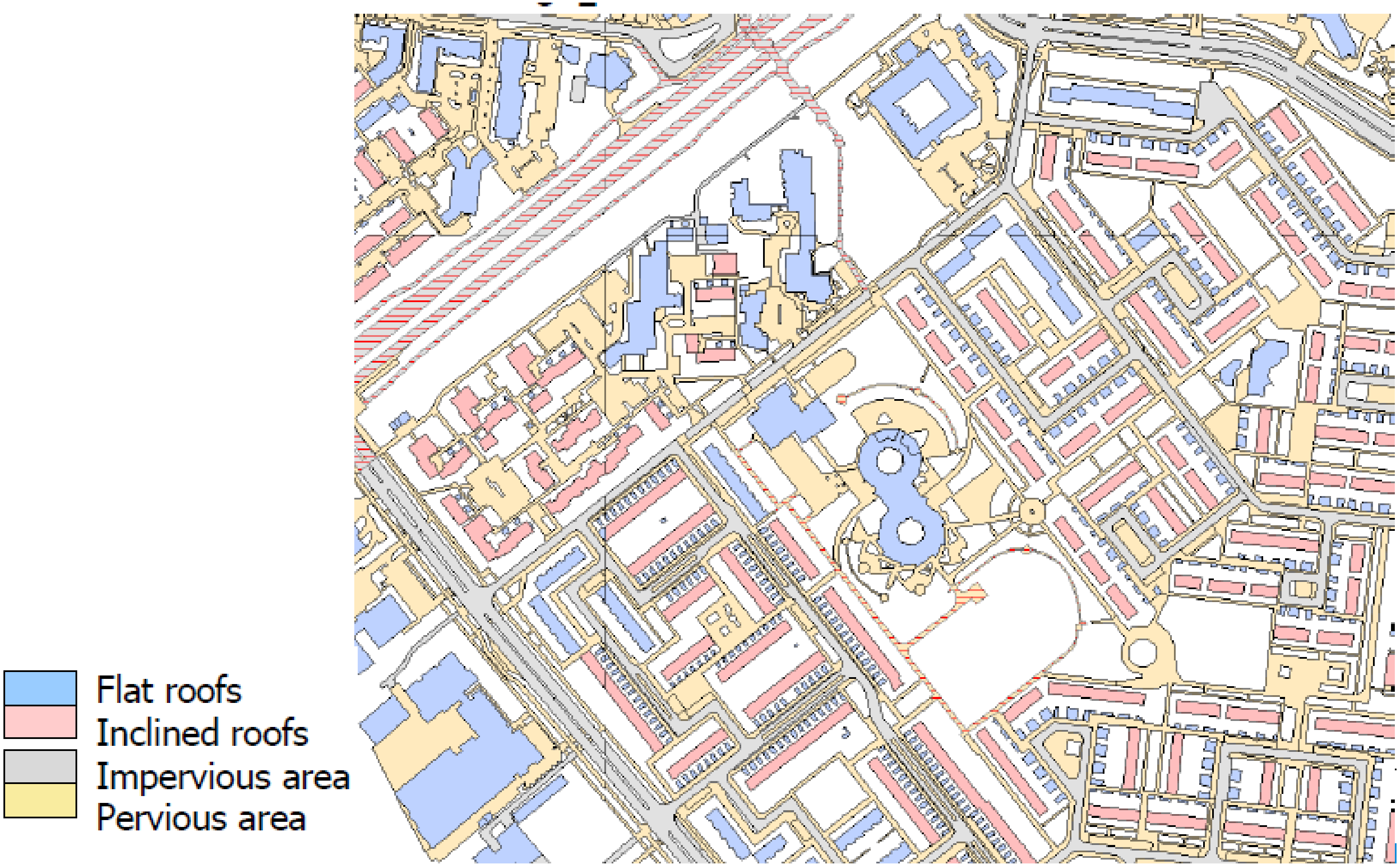
Rational Method

Assumptions:

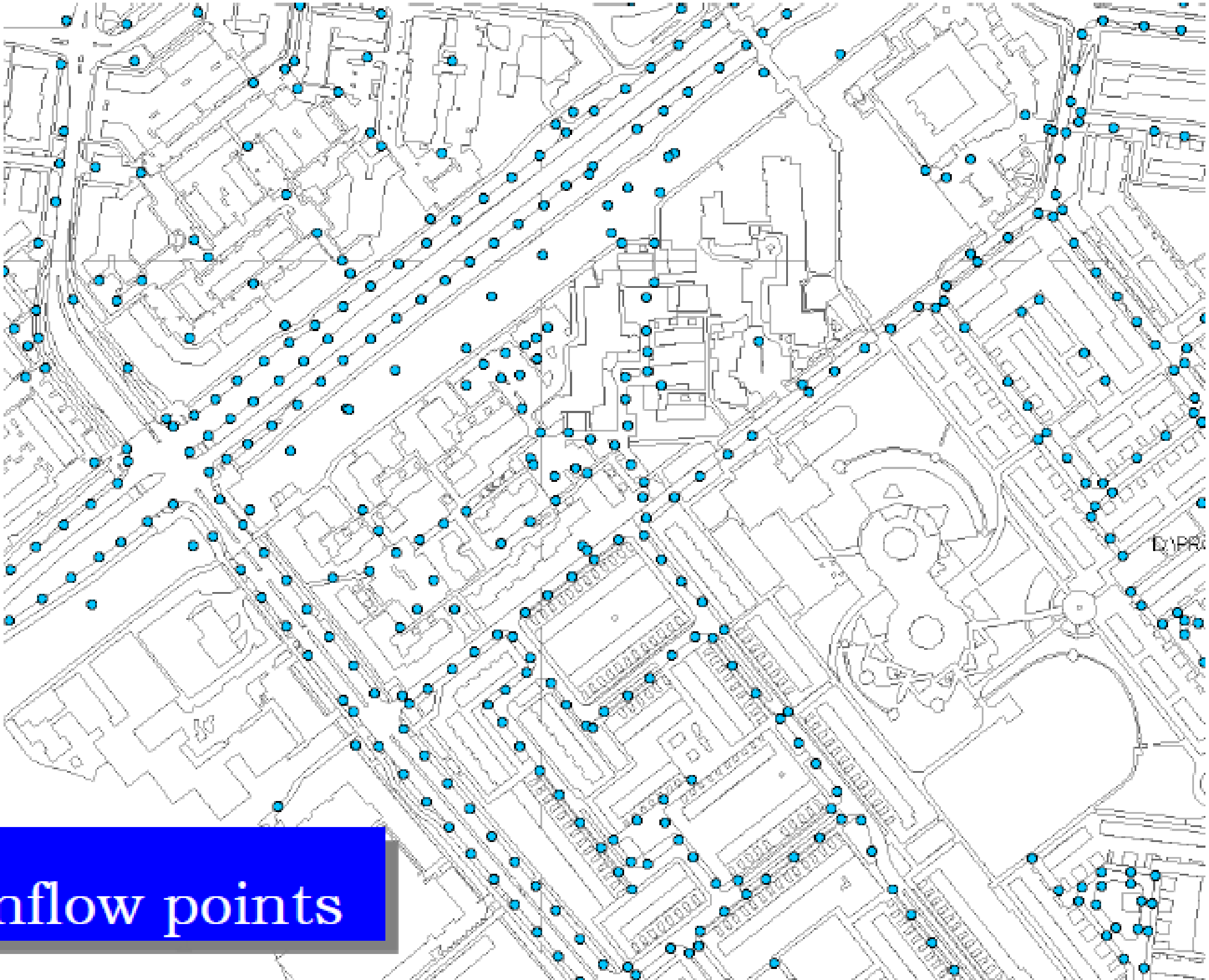
- Uniform rainfall in the whole area of the watershed
- Watershed permeability is constant for the whole duration of the storm
- Flow is with constant velocity for the time t_c
- Steady flow for $t_{storm}>t_c$

Runoff Coefficient c

Depends on the watershed characteristics

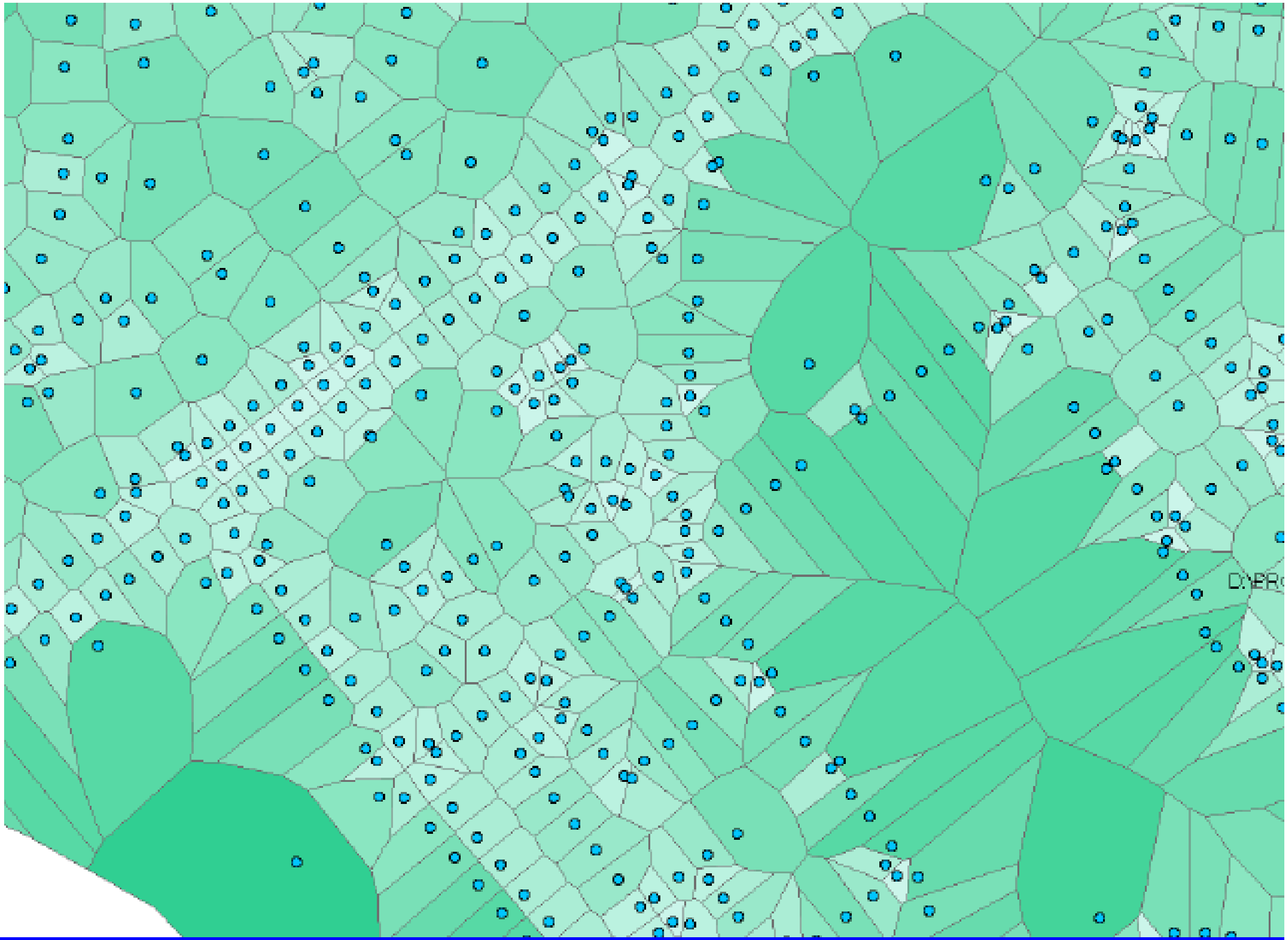


Inflow Points-Manholes

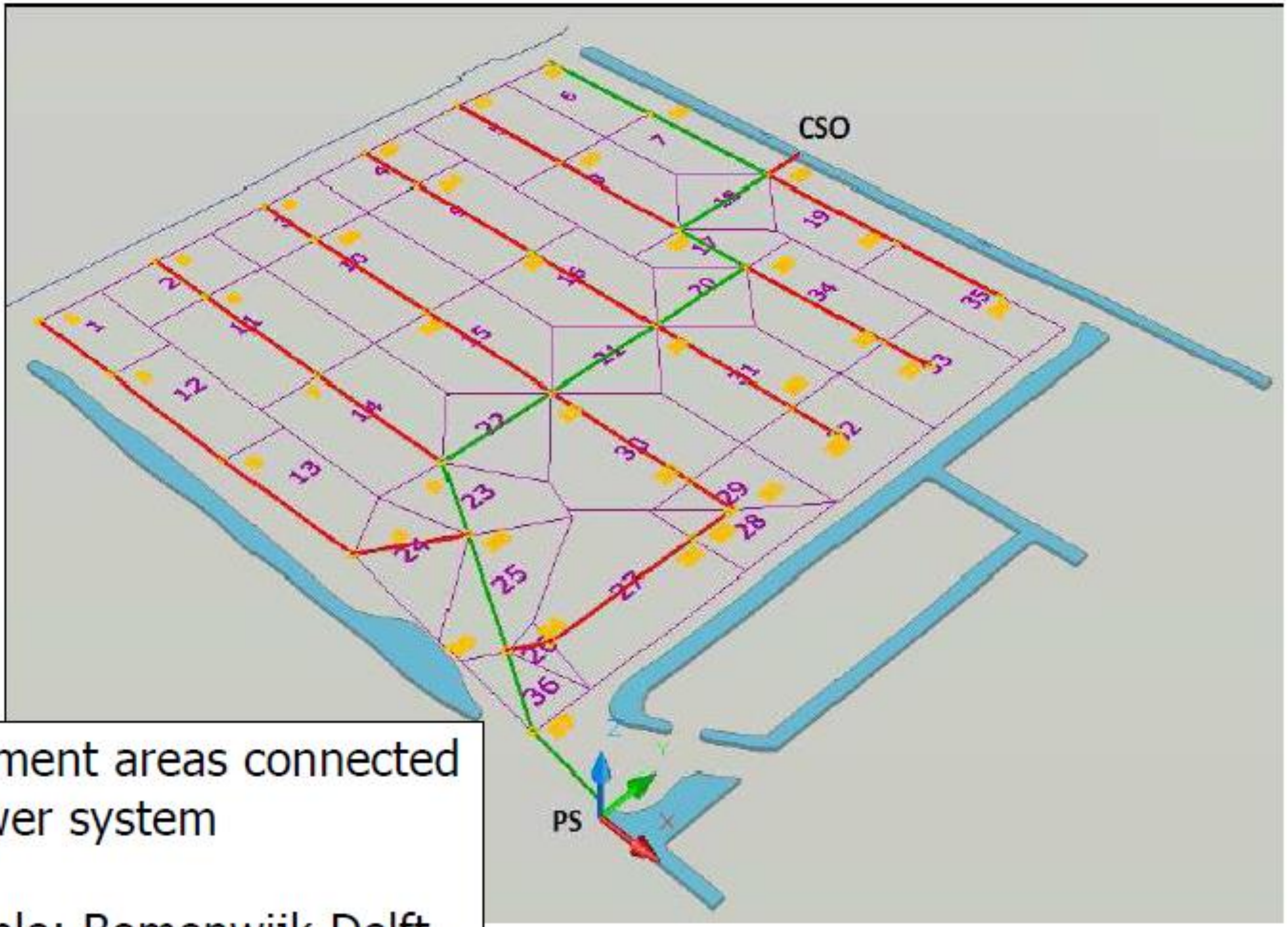


Inflow points

Contributing area per inflow point



Contributing area per inflow point (manhole)



Catchment areas connected to sewer system

Example: Bomenwijk Delft

Concentration Time

The required time for runoff from the most remote point of the catchment to the inflow point

Two Components

-entrance time

(t_e)

-Flow time (t_f)

$t_c = t_e + t_f$

Return Period (years)	Entrance time (min)
1	4-8
2	4-7
3	3-6

Entrance Time and Flow Time

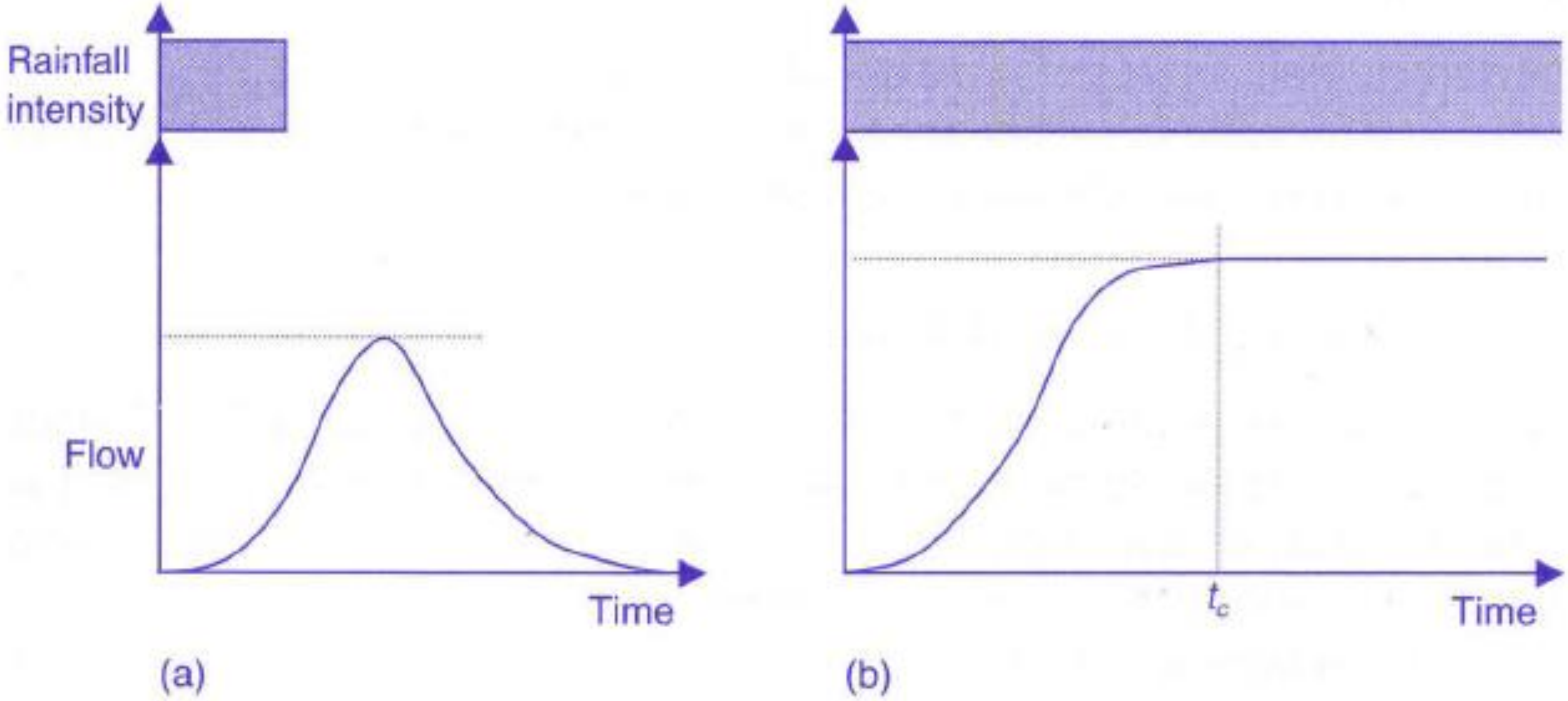
The entrance time depends on

- surface roughness
- slope and length of water path
- rainfall intensity

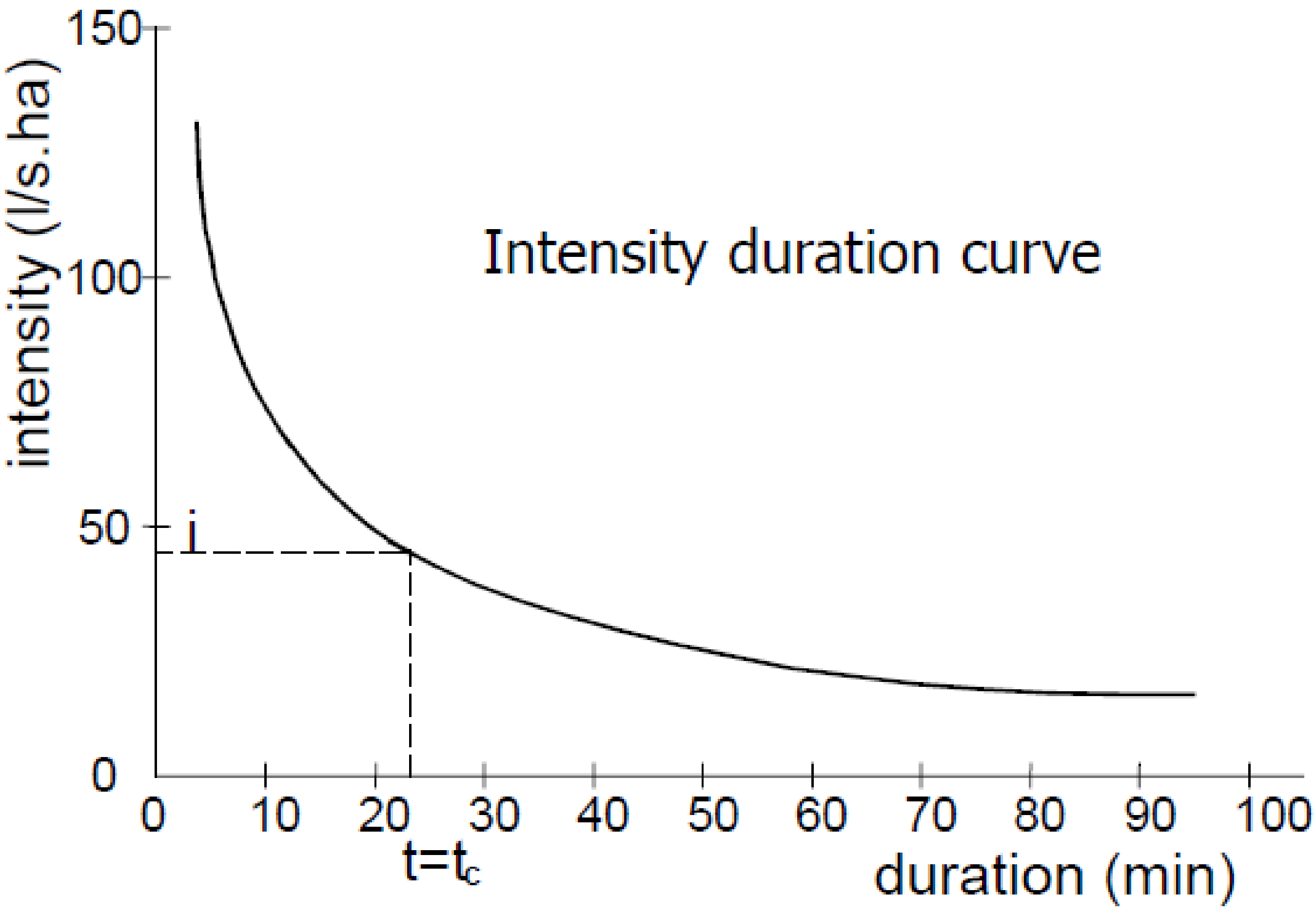
The flow time depends on

- hydraulic characteristics of the pipe (e.g flow velocity)
- length of water path

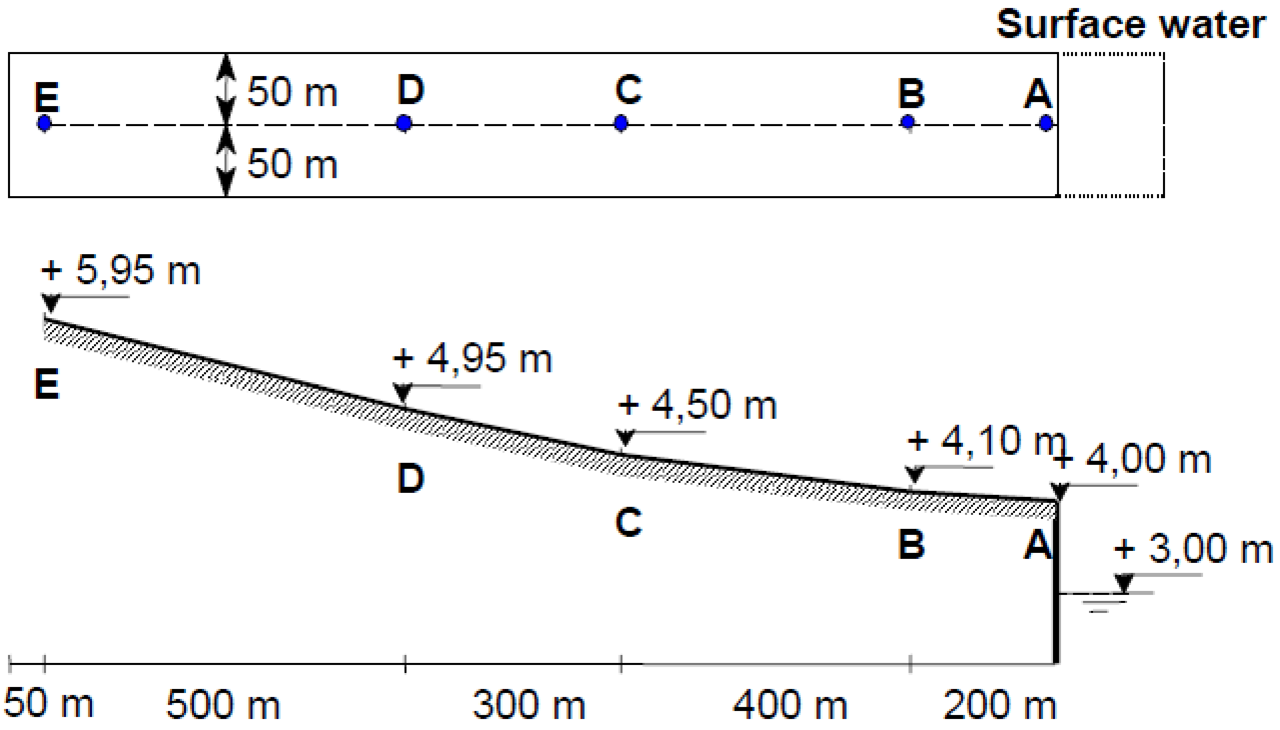
Rational Method-Stationary conditions



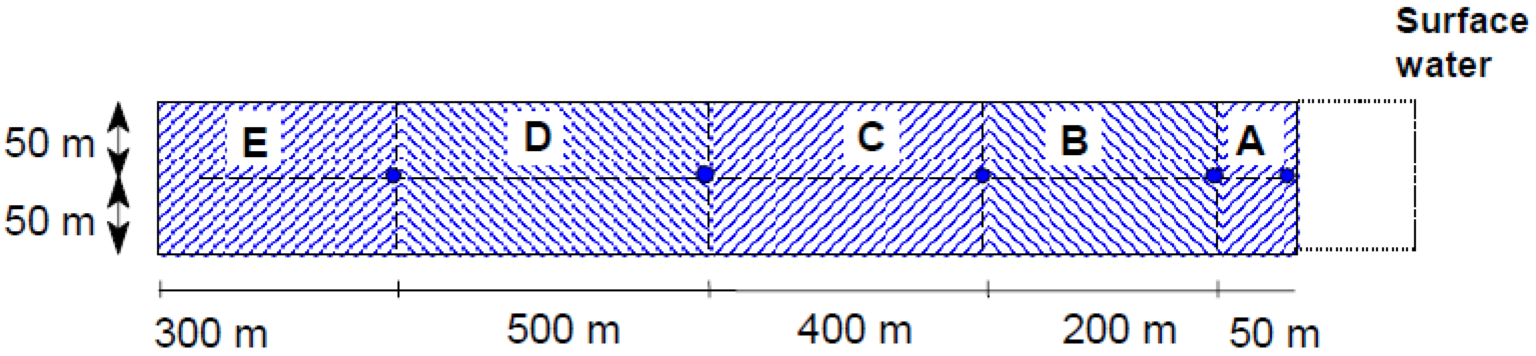
Critical Intensity of rainfall



Example – Design Flow

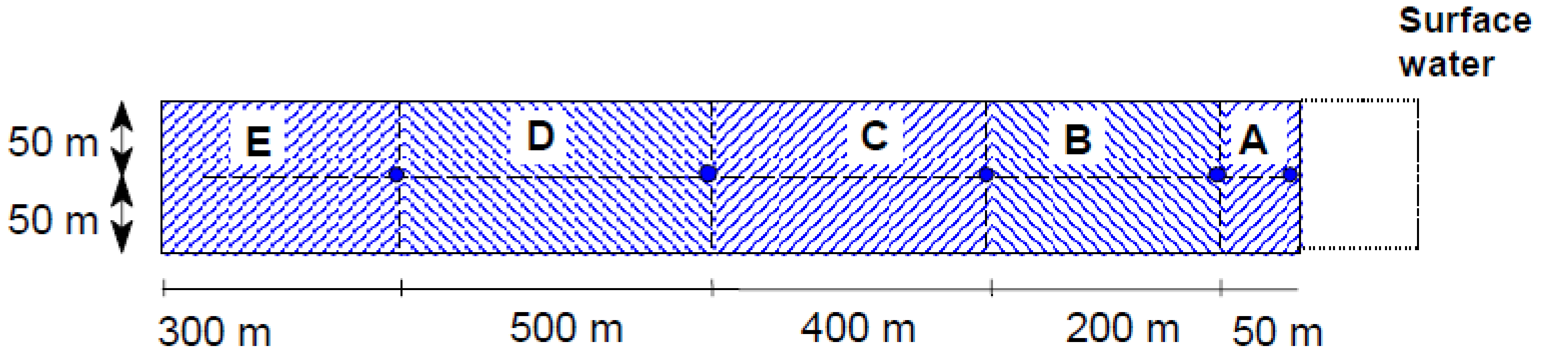


Example – Design Flow



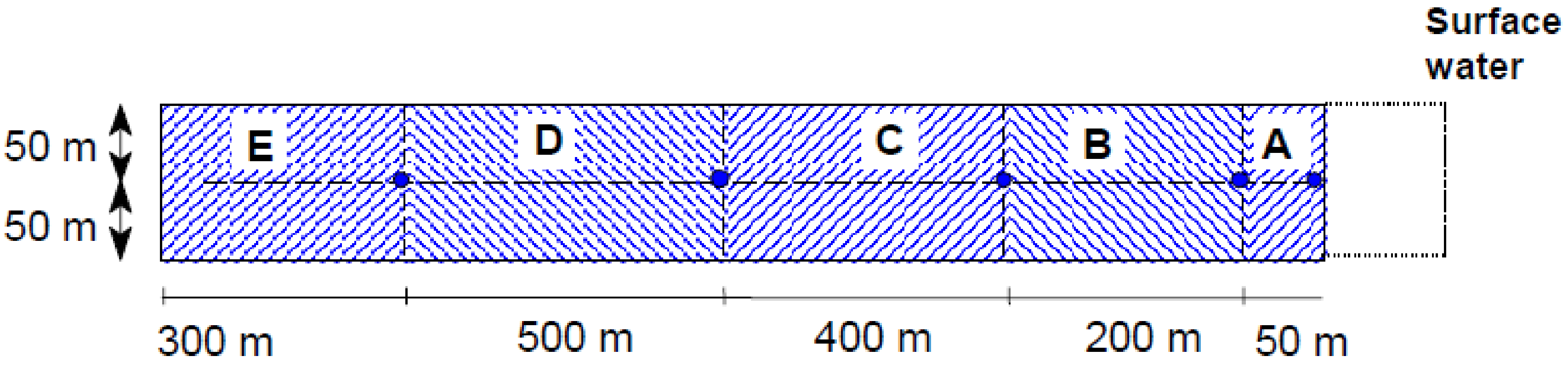
Area	A	B	C	D	E
Area per node (ha)	0.5	2	4	5	3
Impervious area (%)	50	60	40	30	30
Impervious area per node (ha)					
Cum. Area per node (ha)					

Example – Design Flow



Area	A	B	C	D	E
Area per node (ha)	0.5	2	4	5	3
Impervious area (%)	50	60	40	30	30
Impervious area per node (ha)	0.25	1.2	1.6	1.5	0.9
Cum. Area per node (ha)	5.45	5.2	4.5	2.4	0.9

Example – Design Flow

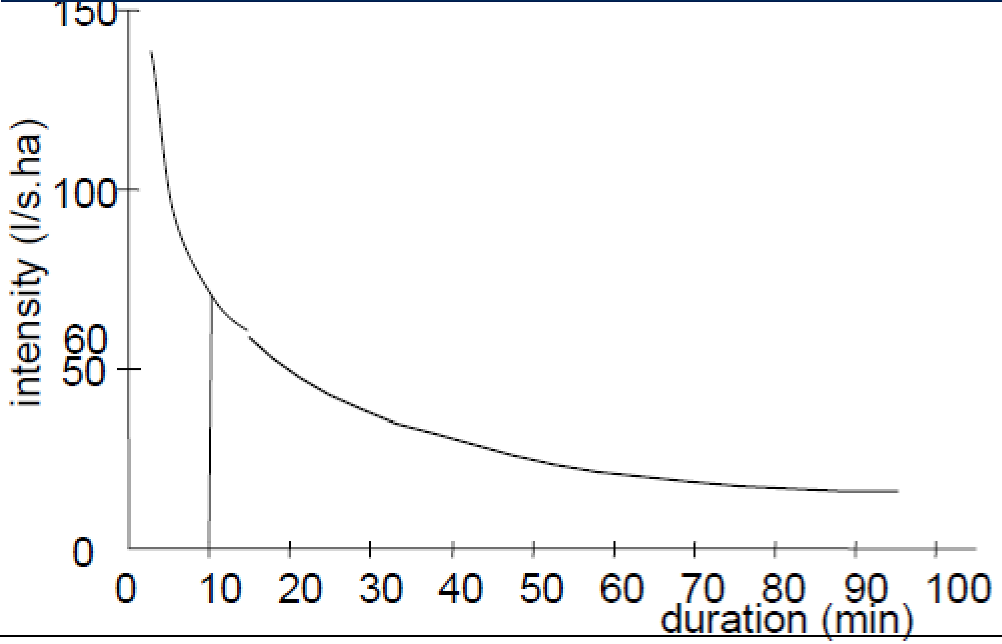


Assume flow velocity 1 m/s

Area	**A**	**B**	**C**	**D**	**E**
Time of concentration (min)	29	28	25	18.3	10

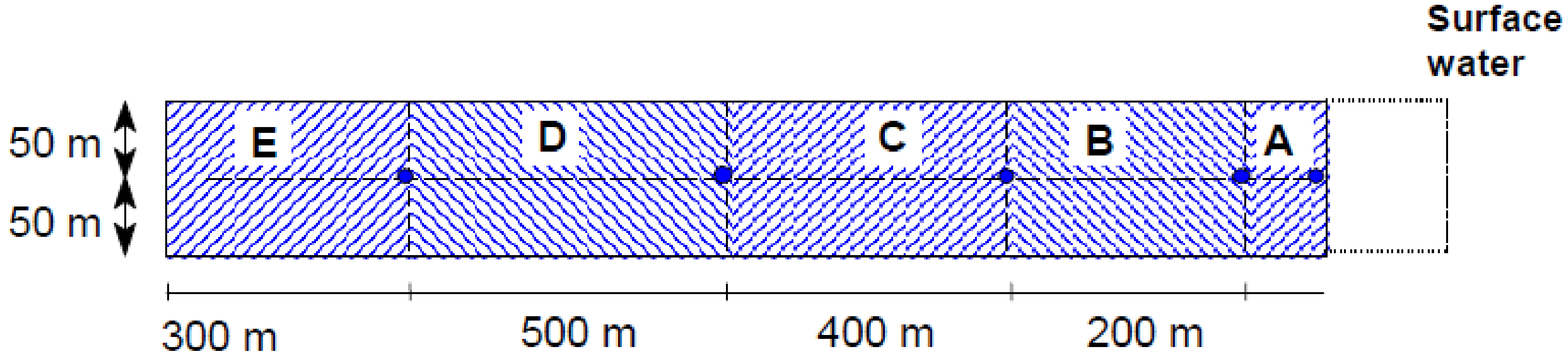
Example – Design Flow

Area	**A**	**B**	**C**	**D**	**E**
Time of concentration (min)	29	28	25	18.3	10
Rainfall intensity (l/s/ha)	40	40	45	50	70

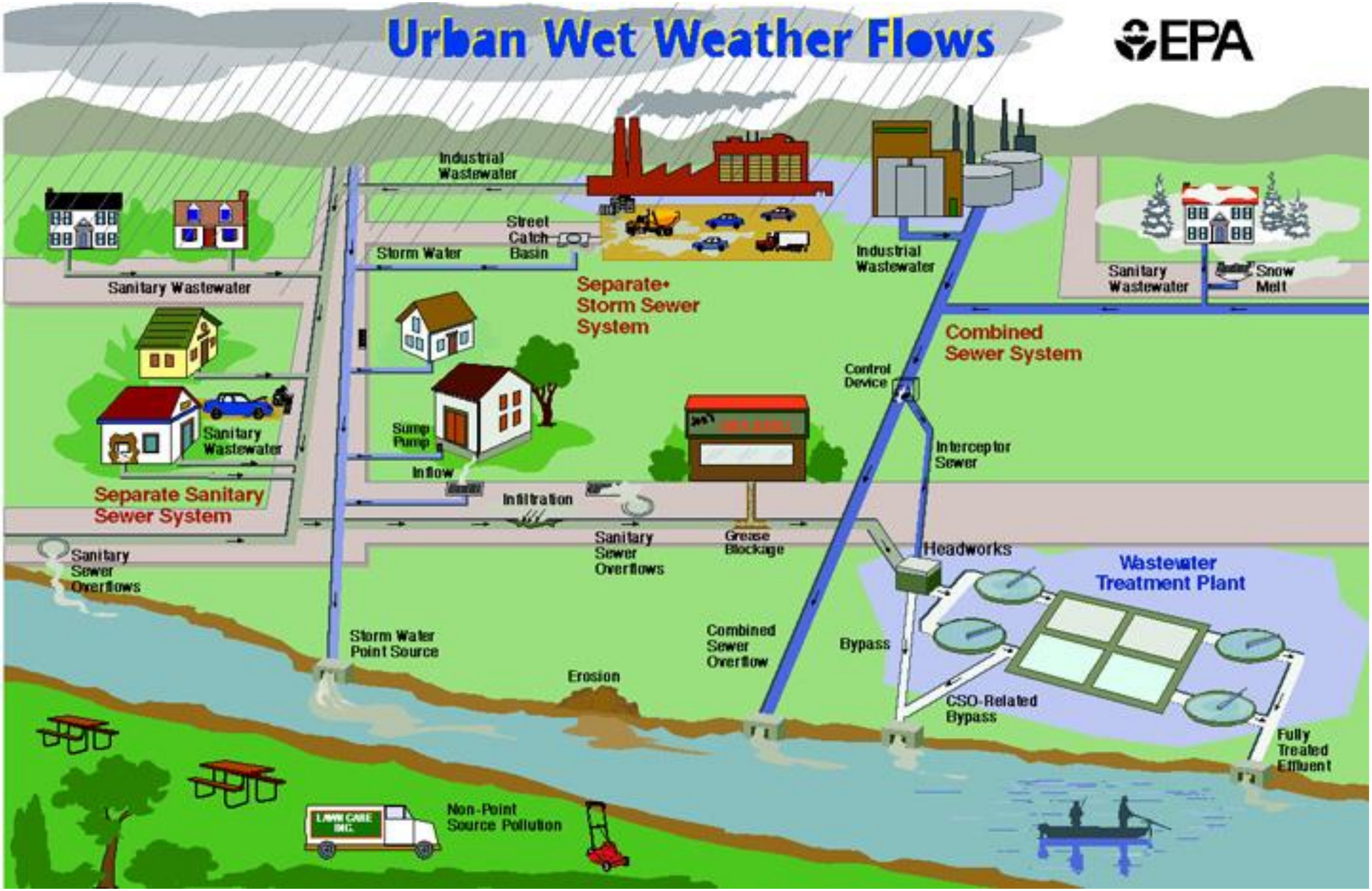


Example – Design Flow

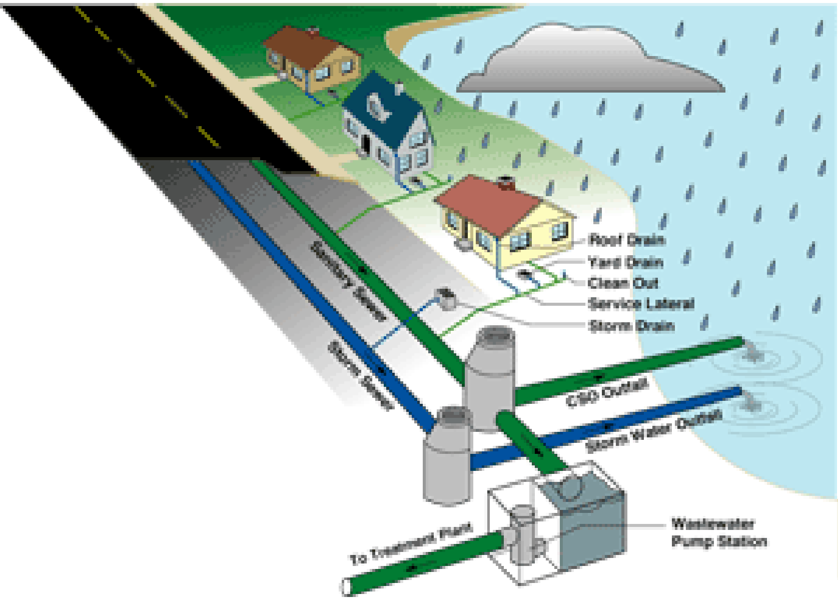
Area	**A**	**B**	**C**	**D**	**E**
Time of concentration (min)	29	28	25	18.3	10
Rainfall intensity (l/s/ha)	40	40	45	50	70
Cumulative area (ha)	5.45	5.2	4.5	2.4	0.9
Design flow (l/s)	218	208	202	120	63

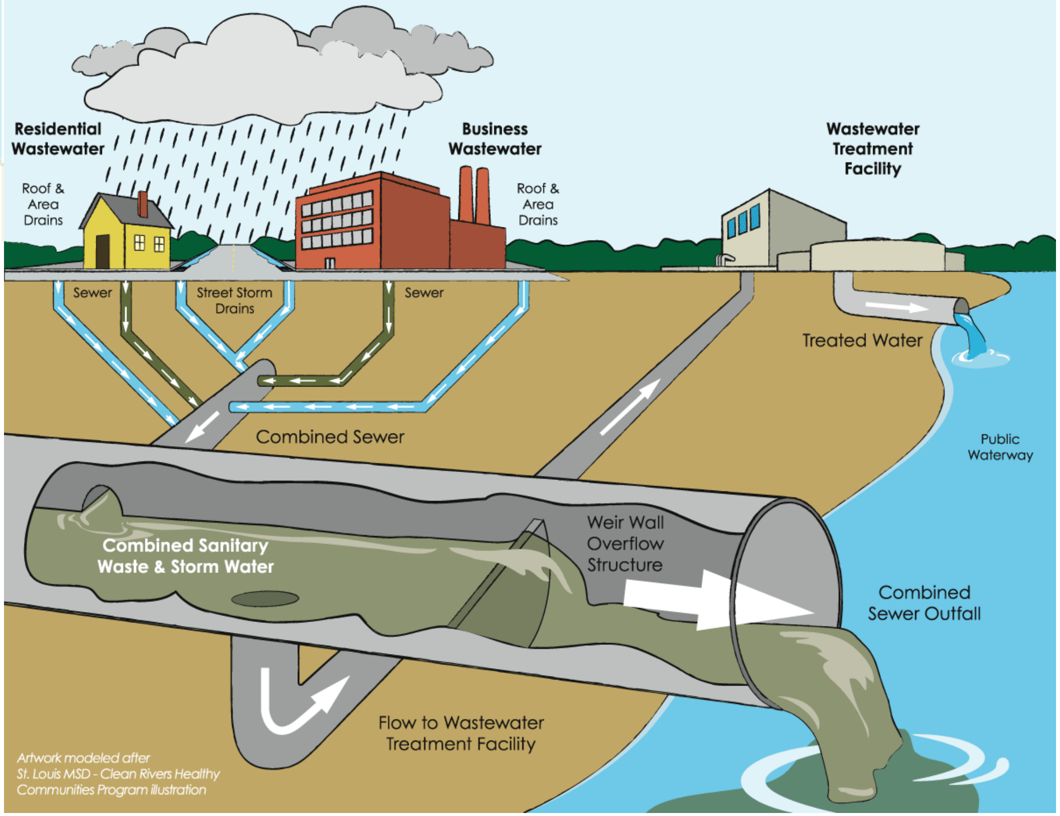


Χωριστικό και Παντοροικό Δίκτυο



Χωριστικό και Παντοροικό Δίκτυο



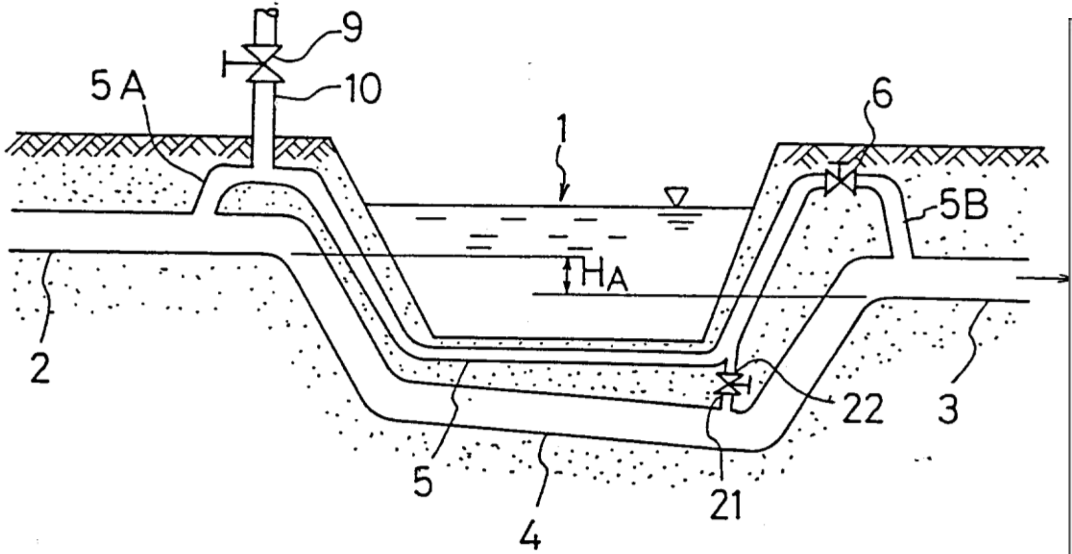


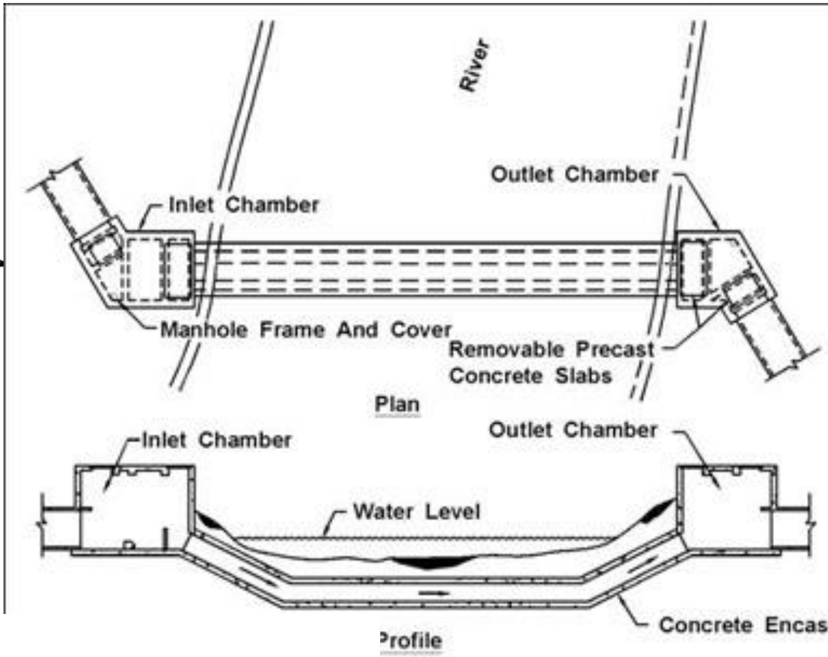
Artwork modeled after St. Louis MSD - Clean Rivers Healthy Communities Program illustration

DESIGN

1. Inverted Siphons
2. Overflow Structures
3. Manholes

1. INVERTED SIPHONS





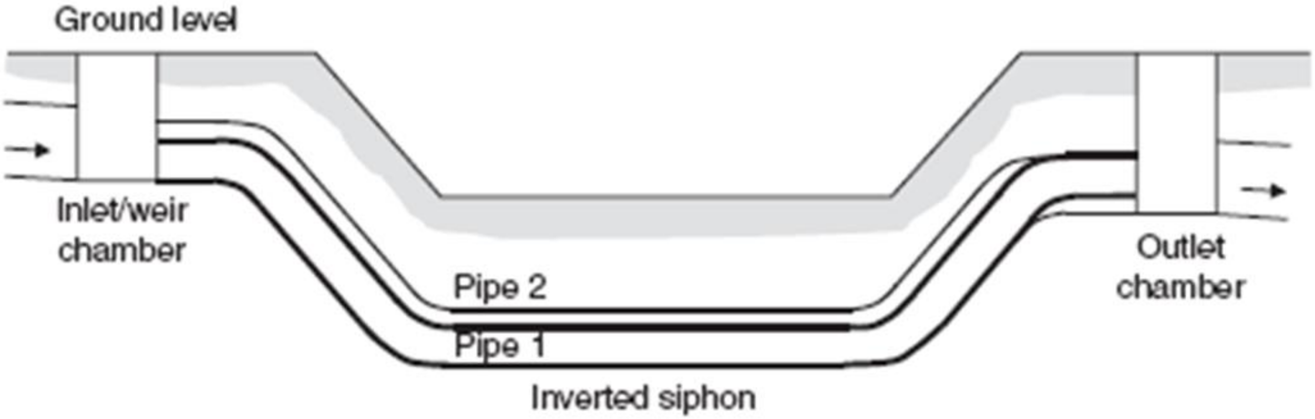


Fig. 9.12 Inverted siphon for wastewater, vertical section (schematic)

INVERTED SIPHONS

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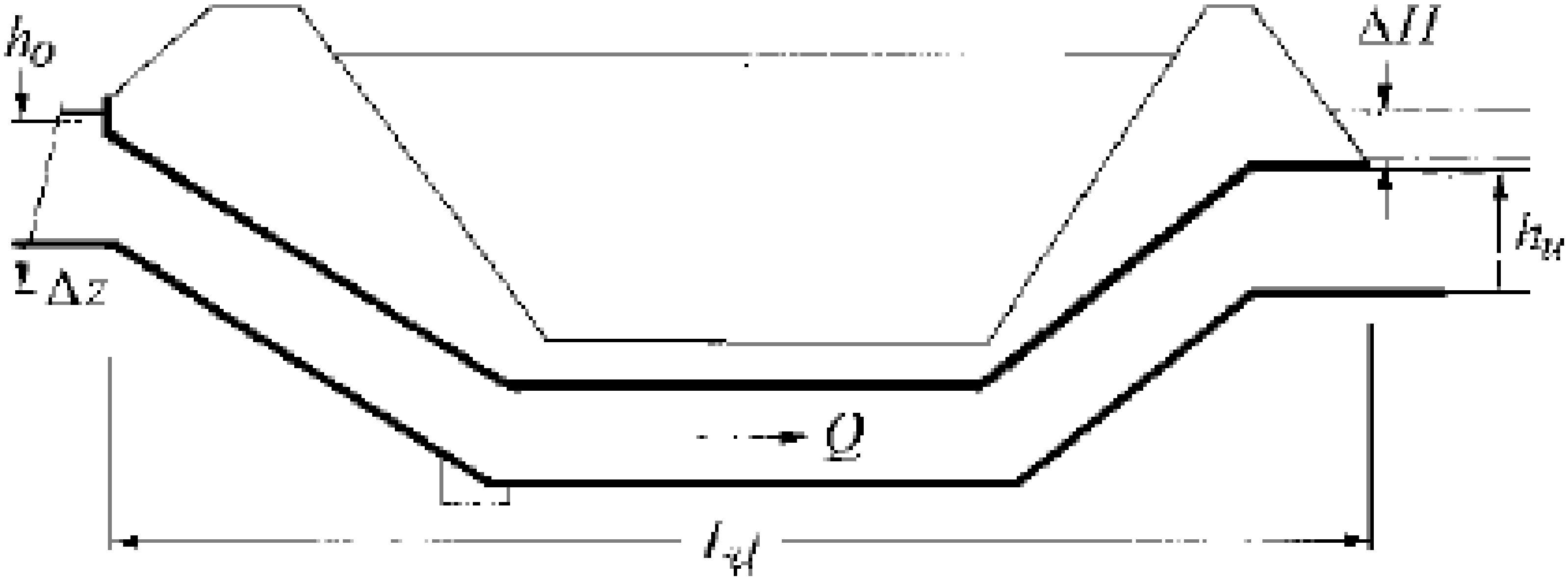
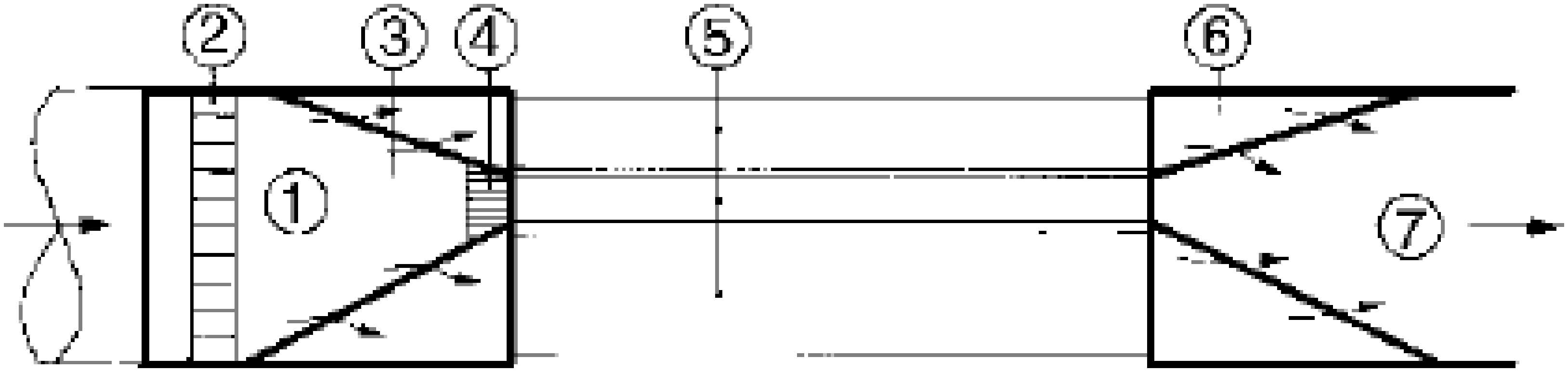


Because the discharge ratio of the night minimum and the rainfall maximum are different by a factor of typically 20 or more, a single siphon pipe in a combined sewer system is inadequate. Therefore a series of parallel siphon pipes with gradated diameters is selected to satisfy both capacity and minimum velocity requirements. Often, a rainwater outlet is located upstream from an inverted siphon such that the structure has to be designed for the maximum dry weather discharge.

COMPONENTS OF INVERTED SIPHONS



Components of inverted siphon ① intake structure, ② trash rack, ③ sideweir, ④ fine trash rack, ⑤ siphon pipes, ⑥ siphon outlet, ⑦ outlet works

The inverted siphon consists of the inlet structure, the pipe series and the outlet structure. The inlet structure contains sideweirs of staggered crest elevations. The approach flow discharge is thus divided on the various pipes to satisfy the flow conditions. A trash rack of a 0.05–0.10 m free passage width located upstream from the sideweirs prevents clogging of the siphon pipes. The area of the trash rack can be enlarged with a box design accessible also during flood conditions. The siphon pipe with the minimum diameter should have a velocity of at least 0.60 m/s for the discharge during the night minimum flow. The minimum diameter should be 0.30 m for combined sewer systems (SIA 1981) and 0.25 m for a separated sewer system.

The siphon pipes are usually horizontal. The transition from the inlet should be at least 1:3 sloping, and 1:6–1:1 for the ascending transition. At the lowest point, the pipe should be connected with a pump sump and a valve for maintenance. The siphon profile is often circular, and it can be rectangular for larger structures.

The outlet works of the inverted siphon, and the downstream sewer should involve minimum energy losses. As for the inlet, the outlet is staggered to prevent a backflow into the siphon pipes. For security reasons, inverted siphons are often protected with a downstream rack.

INVERTED SIPHONS –Hydraulic Design

For given minimum discharge Qm, dry weather discharge QT and critical treatment discharge QK, the uniform and critical flow depths are determined in the approach flow and the downstream sewers (SIA 1981).

For supercritical approach flow, a sufficient submergence at the inlet should move the hydraulic jump into the upstream sewer. Head losses involve the following elements:

$$(h_\varphi = \xi \frac{U^2}{2g}, \quad \xi\text{=coefficient of local losses})$$

Trash rack loss ξ_R (=0.5)

Inlet loss ξ_e (=0.4)

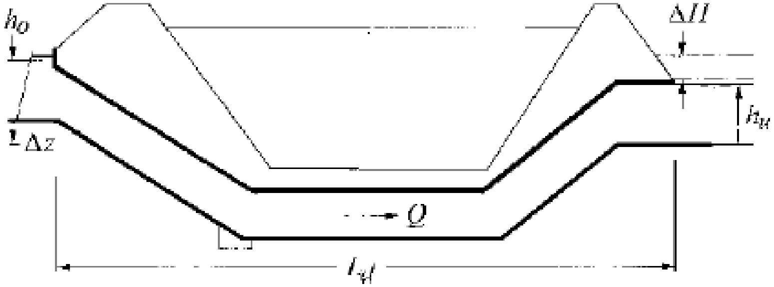
Bend loss ξ_k (4*0.15=0.6)

Expansion loss ξ_E (=0.5) and

Outlet loss equal to zero.

Loss due to friction (ξ_f)

INVERTED SIPHONS –Hydraulic Design



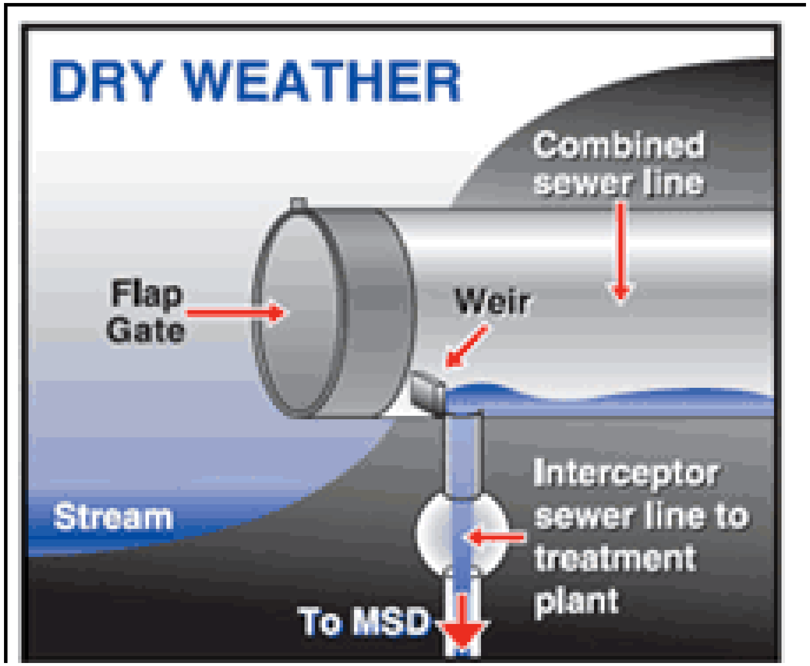
Energy Equation:

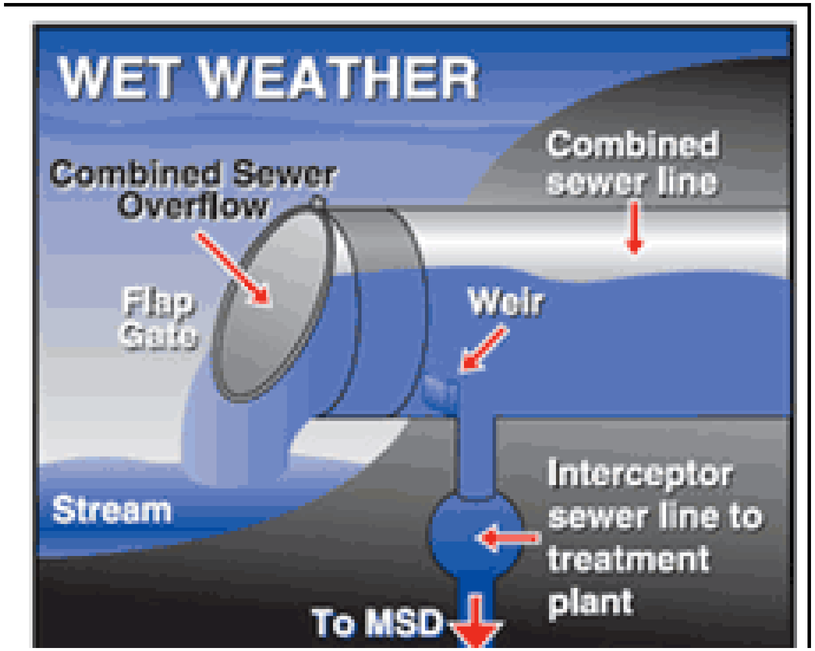
$$h_o + \Delta z + \frac{U_o^{\,2}}{2g} = h_u + \frac{U_u^{\,2}}{2g}(1+\Sigma\xi)$$

The discharge for the ith pipe and $\Delta h = h_o + \Delta z - h_u$ is

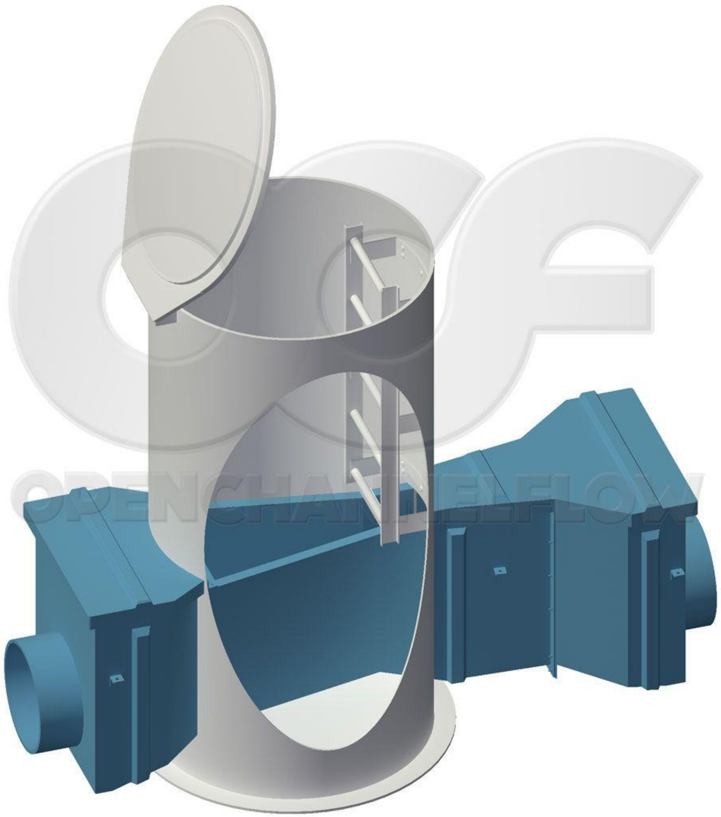
$$Q_i = A_i U_i = A_i \left[\frac{2g\Delta h}{\Sigma\xi} \right]^{1/2}$$

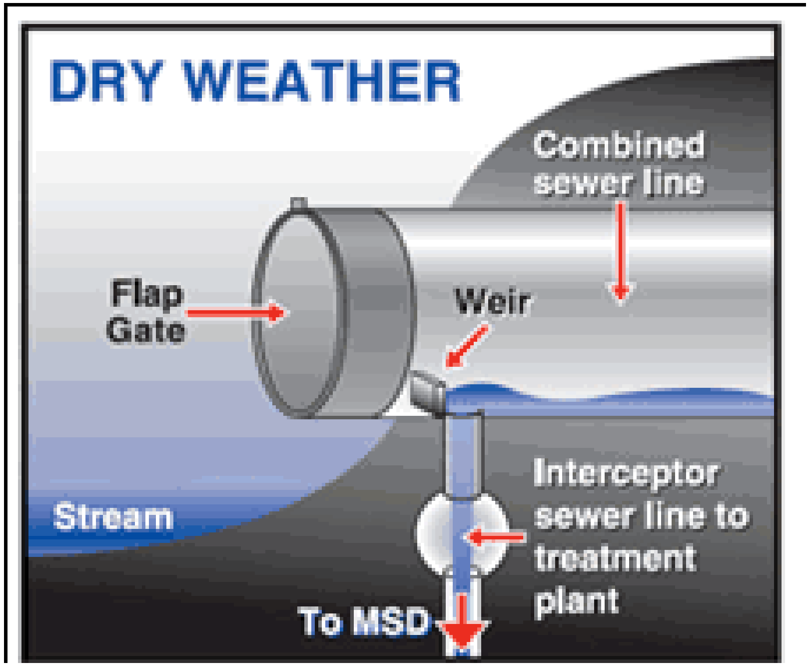
Overflows for Combined Sewers

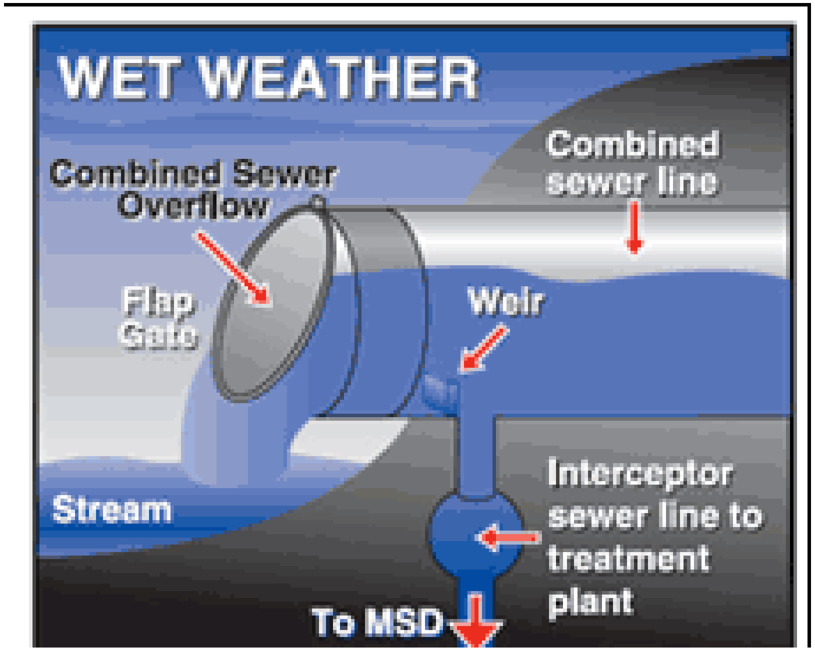




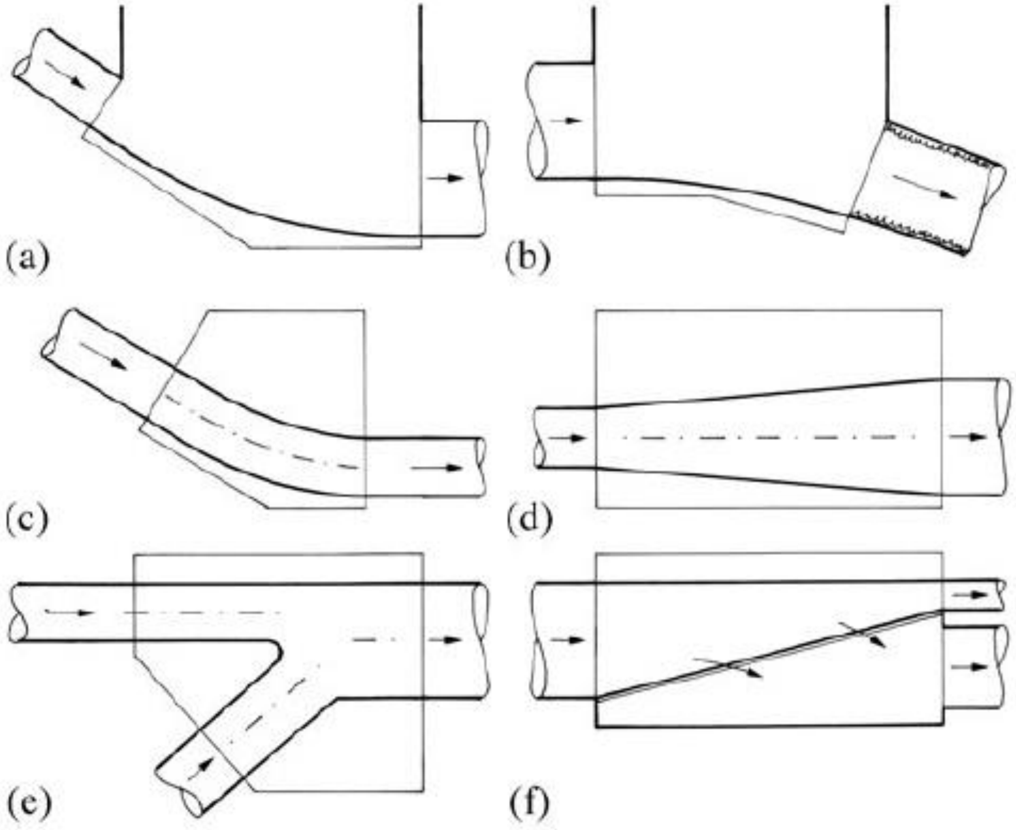
MANHOLES


OPENCHANNELFLOW


DRY WEATHER
Combined sewer line
Flap Gate
Weir
Stream
Interceptor sewer line to treatment plant
To MSD

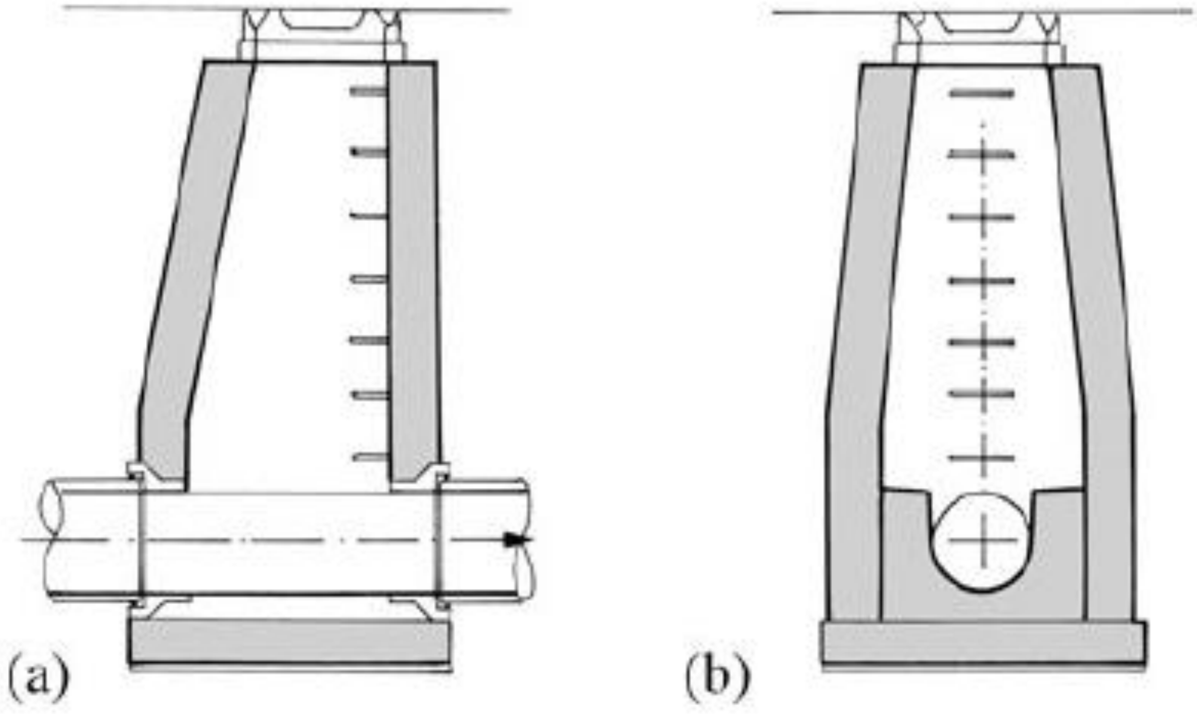

WET WEATHER
Combined sewer line
Combined Sewer Overflow
Flap Gate
Weir
Stream
Interceptor sewer line to treatment plant
To MSD

Manholes



They serve for (a) Maintenance and rehabilitation, (b) Reconstruction of damaged sewers, (c) Inspection of larger sewers, (d) Design of special manholes, (e) Aeration and deaeration of flow, and (f) Emergency overflow during clogging.

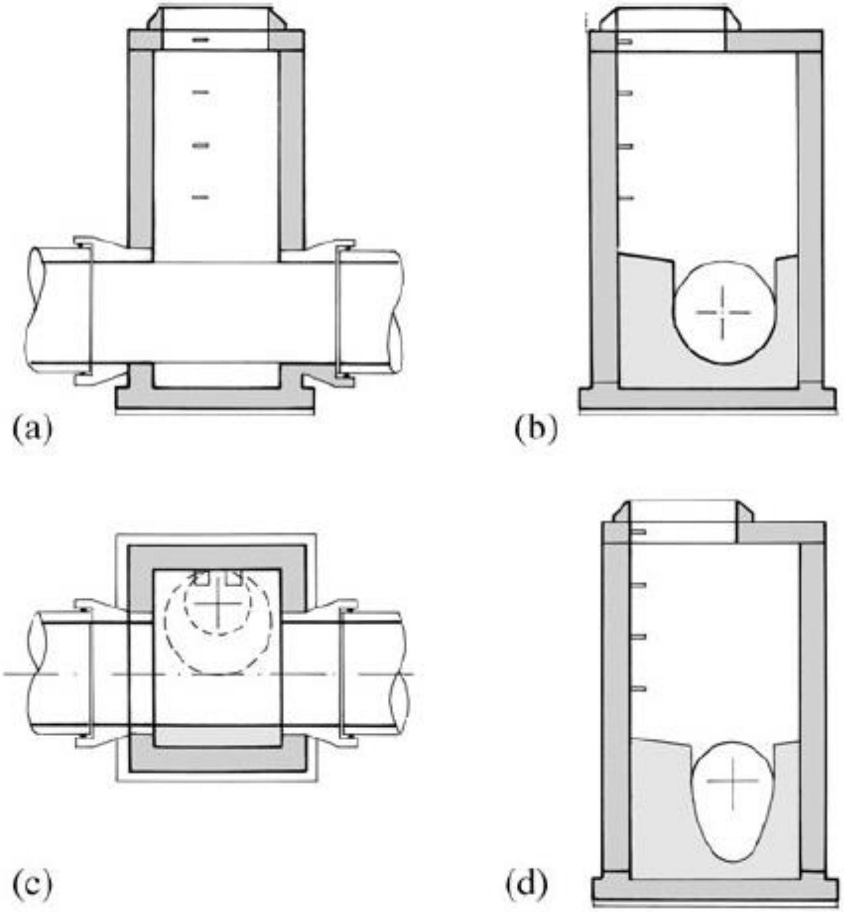
Standard Manhole



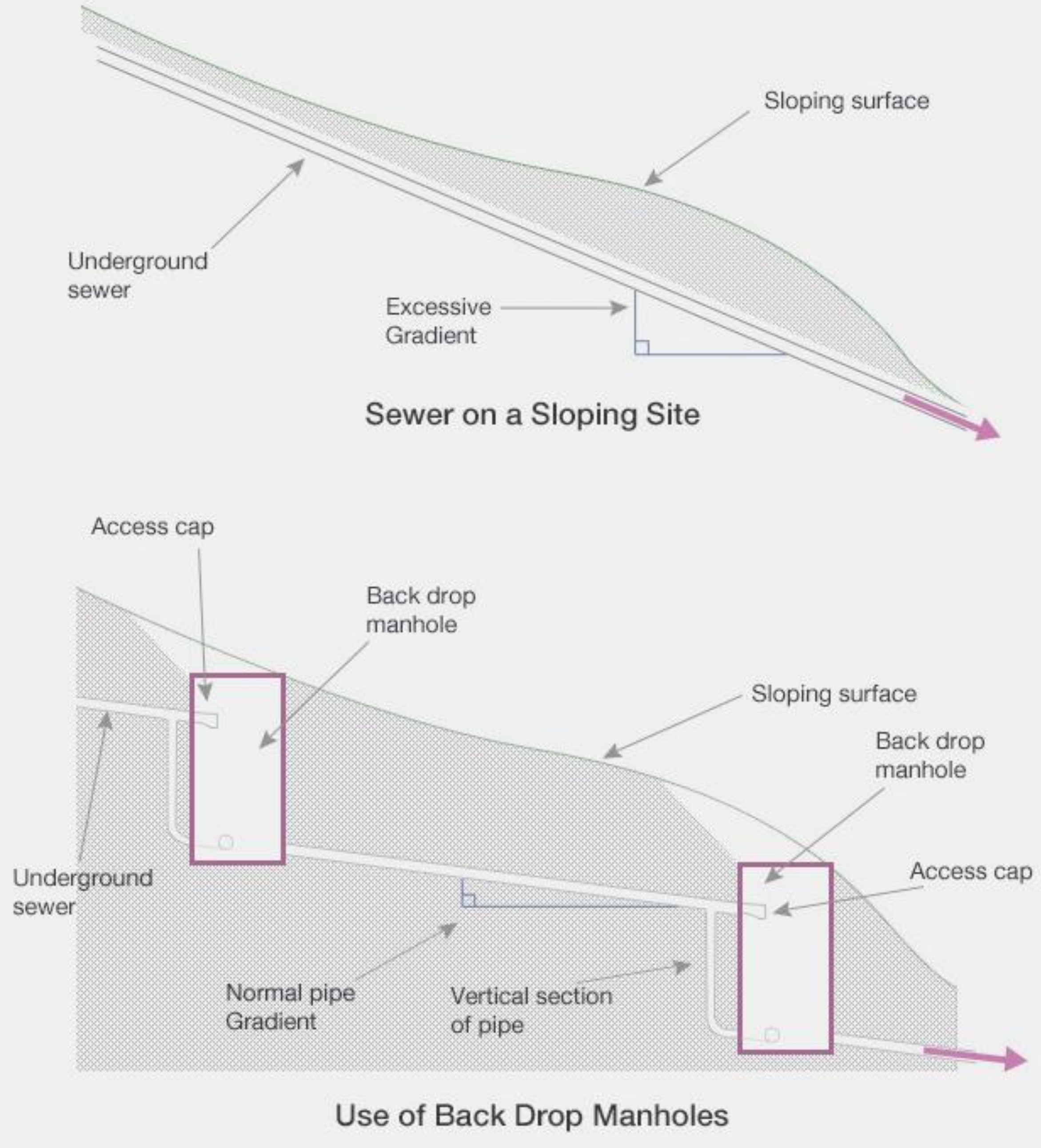
Standard manhole up to D = 0.50 m according to ATV (1978).
(a) Longitudinal section, (b) transverse section with 100% benches

Standard manhole for diameters in excess of D = 0.50 m according to ATV (1978) for a circular sewer (a) longitudinal section, (b) transverse section.

Egg-shaped sewer manhole with (c) plan and (d) transverse section



Drop Manholes

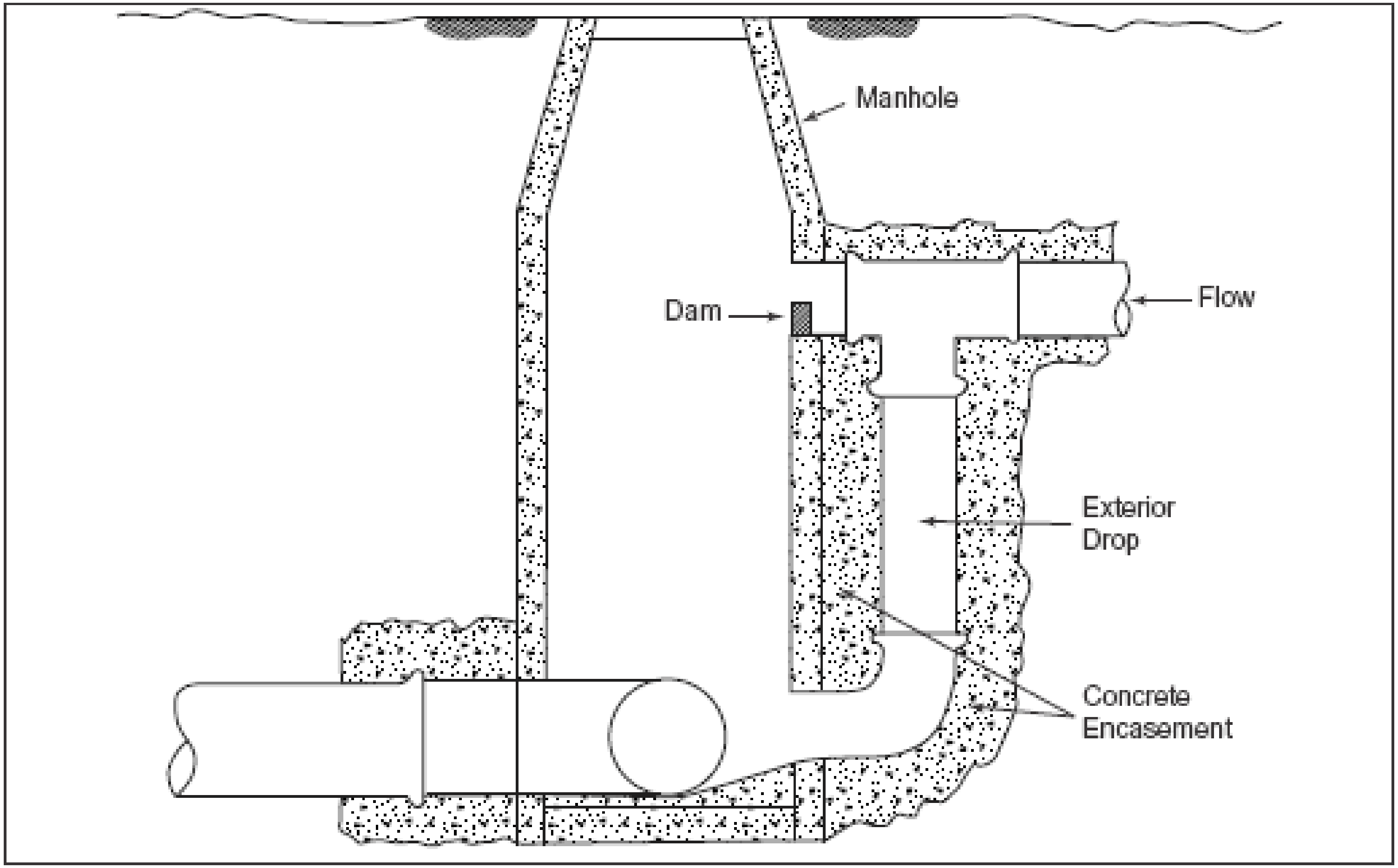


Sewer on a Sloping Site

Use of Back Drop Manholes

Drop Manholes

Figure 2.4 Typical Drop Manhole (Sanitary Sewer)



Locations for Drop Manholes

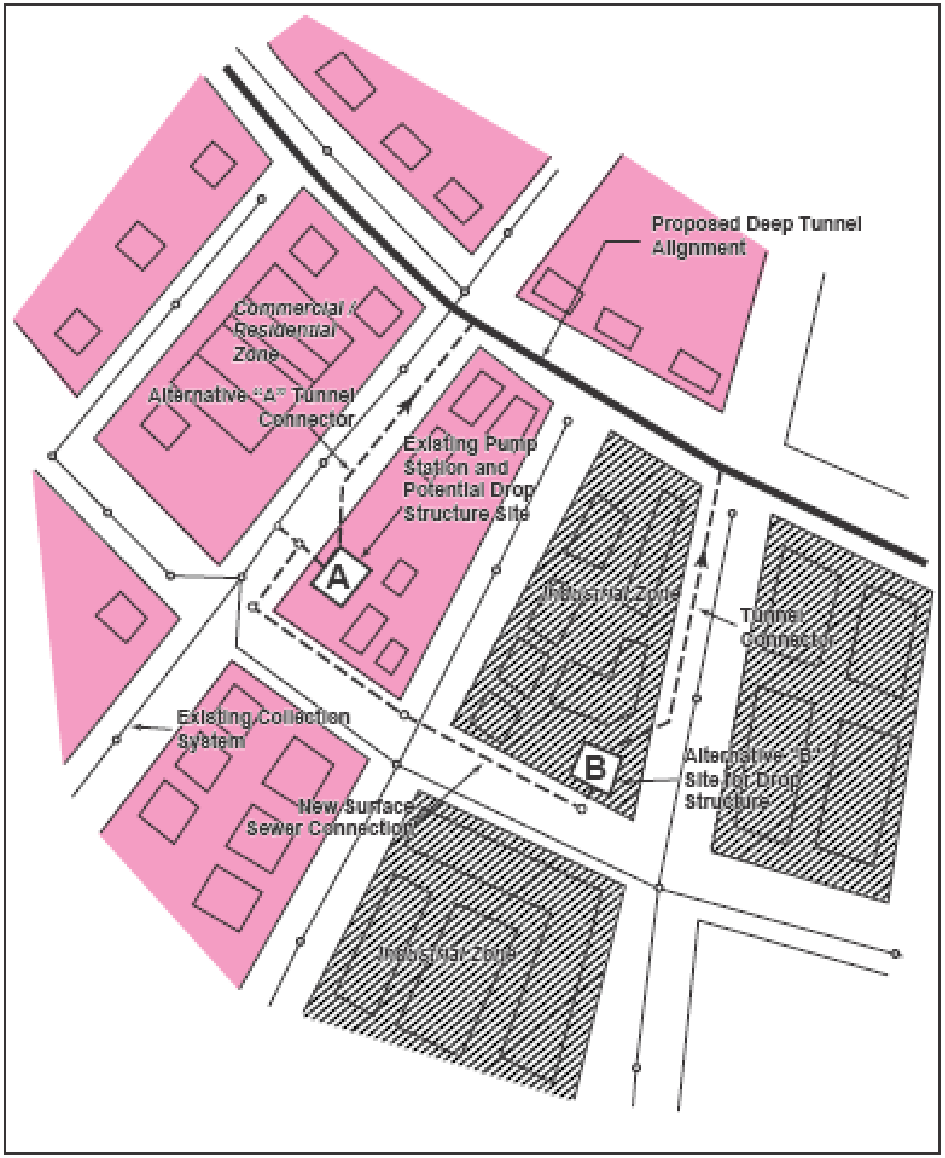
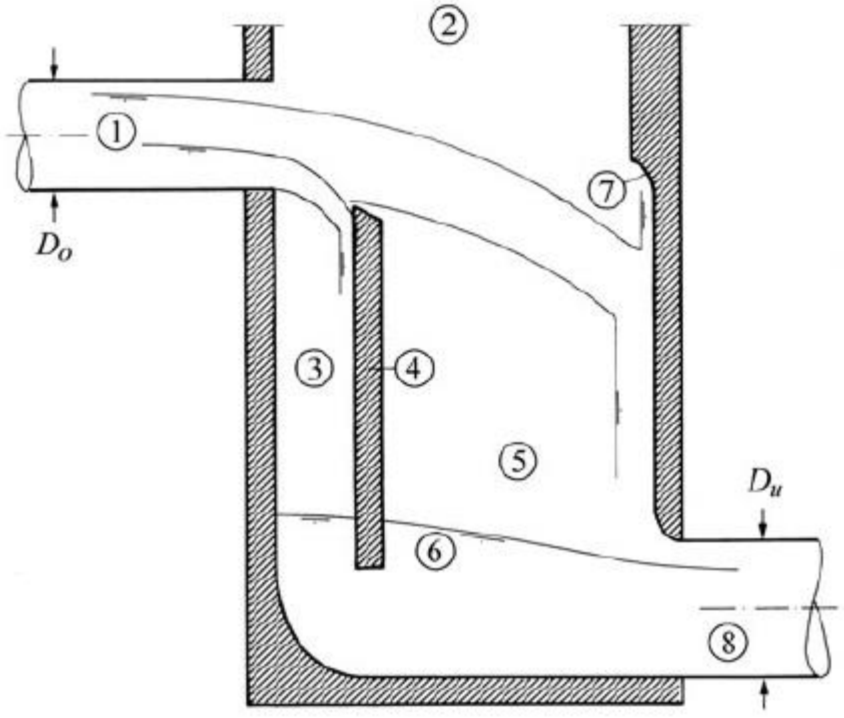


Fig. 8. Circular water jet falling down into the energy dissipation chamber of the Wiggen drop shaft during a minor rain event. The total drop head is 11.2 metres. (Photo: Hohl)

Drop Manholes

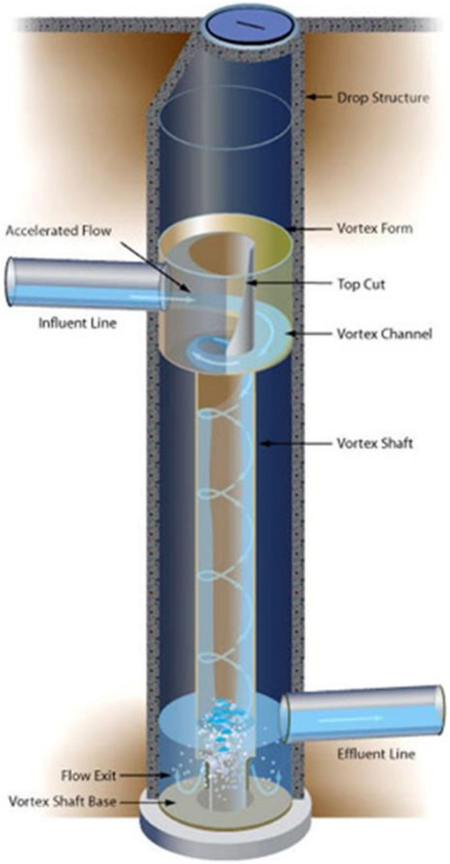
Drop manhole according to SIA (1980) with

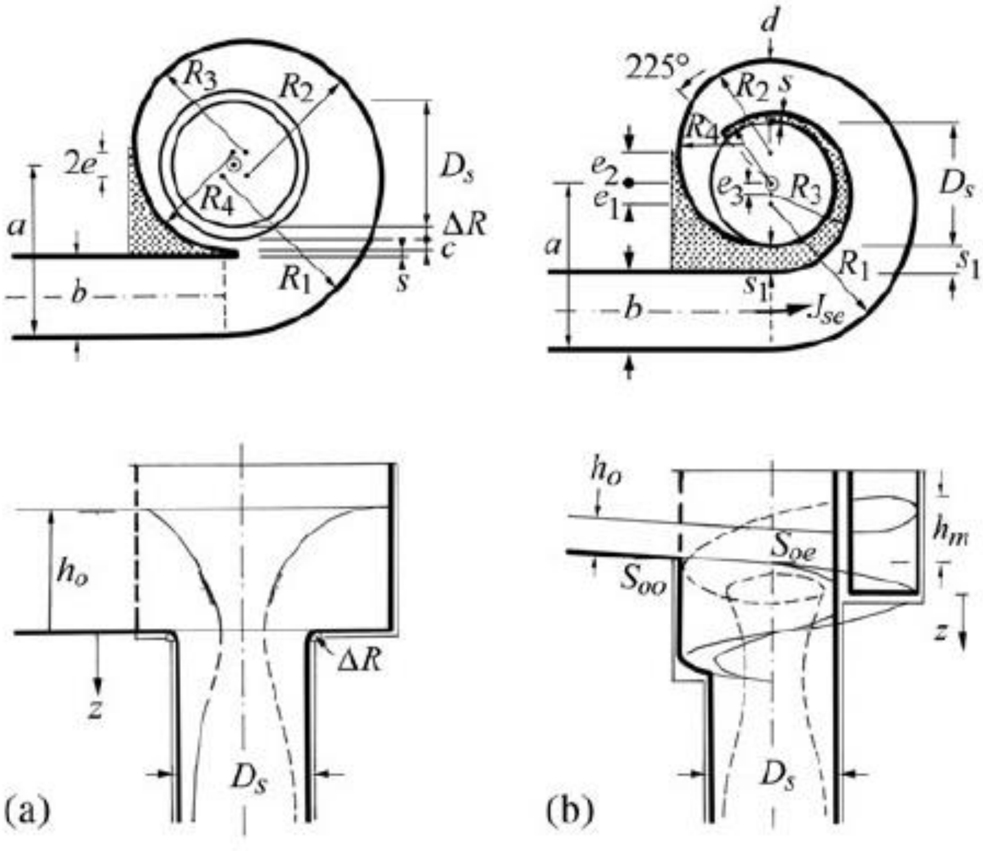
① approach sewer, ② access, ③ dry-weather drop, ④ impact wall, ⑤ drop chamber, ⑥ water cushion, ⑦impact nose, ⑧ outlet



Drop Manholes-Vortex Drop

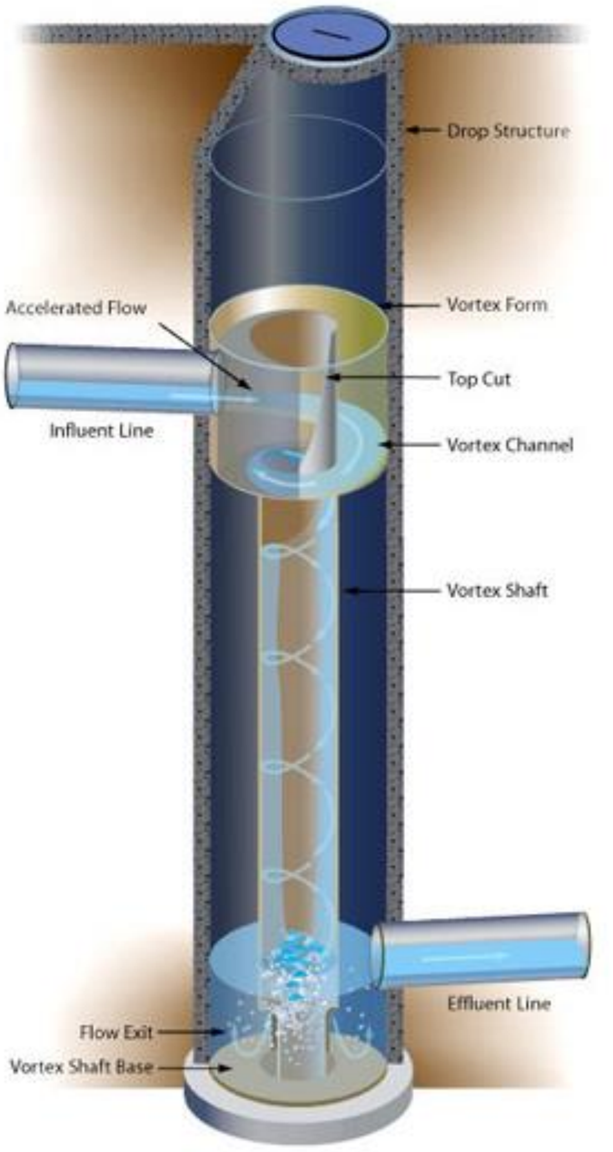
Contrary to a drop manhole, a vortex drop involves a significant energy dissipation by wall friction. This favourable effect is due to a superposition of rotational with translatory flow components causing a helicoidal flow across the shaft. Further, the water moves essentially along the shaft walls, whereas the air moves in a central air core with a pressure slightly above the atmosphere. Thus, the shaft flow is separated into a fluid and a gas phase, resulting in a stable annular flow pattern.





(a) (b)

Vortex Drop



Vortex drops apply, provided:

- Elevation difference between inlet and outlet is at least 5–10 m, depending on the shaft diameter,
- Approach flow is either stably subcritical ($Fr < 0.7$) or stably supercritical ($Fr > 1.5$), and
- Steeply sloping sewer is no economical solution.

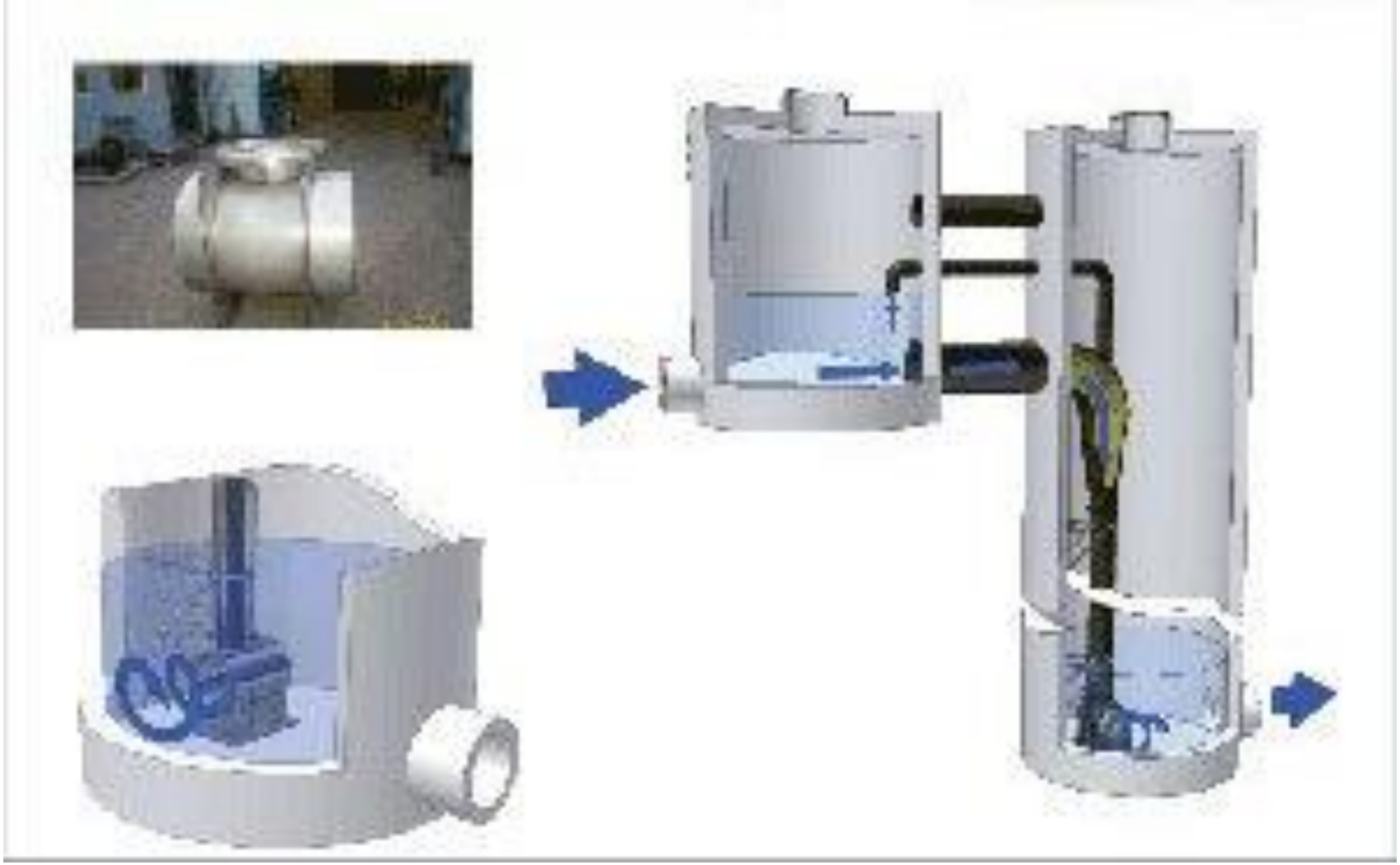
The outflow of a steep sewer is supercritical, whereas the outflow of a vortex drop is generally subcritical. This difference in concept may be determining in the selection of the optimum structure.

The design of a vortex drop depends essentially on the approach flow conditions.

The computation involves three items:

- Intake structure,
- Vertical shaft, and
- Outlet structure.

Vortex Drop



Vortex Drop