Urban Water Management

Within the module:
Ecology and Water Resources
Summer 2012

April 24 – May 16, 2012

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Part 3

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Overview

Contents today: Drainage

Waste water **plus** storm water

- amount and pollution
- drainage systems
  - → combined systems
  - → separate systems
- dimensioning of pipes
- storage
  - → stormwater overflow tanks
  - → stormwater retention tanks
- dimensioning of tanks

Waste water

Domestic plus industrial plus external

- amount (domestic)

= depending on habitants connected to the sewer system

= equivalent to water consumption
(disposed = delivered)

consumption e.g. 140 l/(C*d)
for design: often higher (safety margin)

Waste water

Domestic plus industrial plus external

- amount (industrial)

  = individual, often expressed in „population equivalents“ (PE)

  $PE_{ind.}$ = waste water of plant / waste water per capita

  Example: discharge of industrial plant: 6000 l/d

  $PE_{ind.} = 6000 / 150 = 40$

- amount (external)

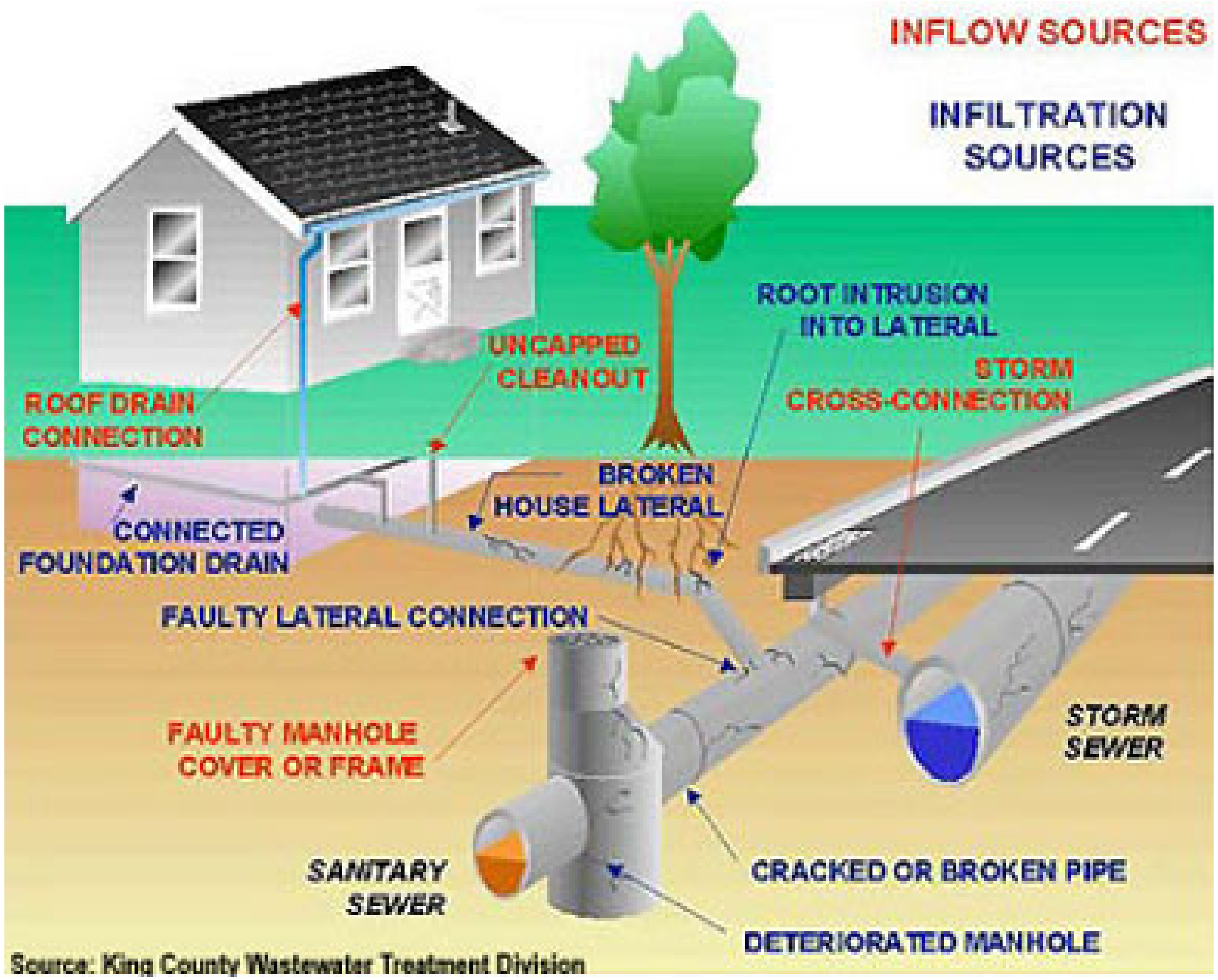
  = water not wanted in the system

  Origin: cracked pipes, incorrect connections etc.

External water

Where does it come from?

2 ways :



Waste water

Domestic plus industrial plus external

- pollution (domestic)

  mean value (rule of the thumb) = 600 mg/l COD
  load per capita: 150 l/d * 600 mg/l = 90 g/d COD

- pollution (industrial)

  = individual, often expressed in „population equivalents“ (PE)

  $PE_{ind.}$ = pollution load of plant / pollution load per capita

  Example: pollution load of industrial plant:
  6000 l/d * 1200 mg/l COD = 7200 g/d COD
  $PE_{ind.}$ = 7200 / 90 = 80

- pollution (extraneaous)

  = generally not accounted for, assumed to be „clean“

Waste water

Design runoff

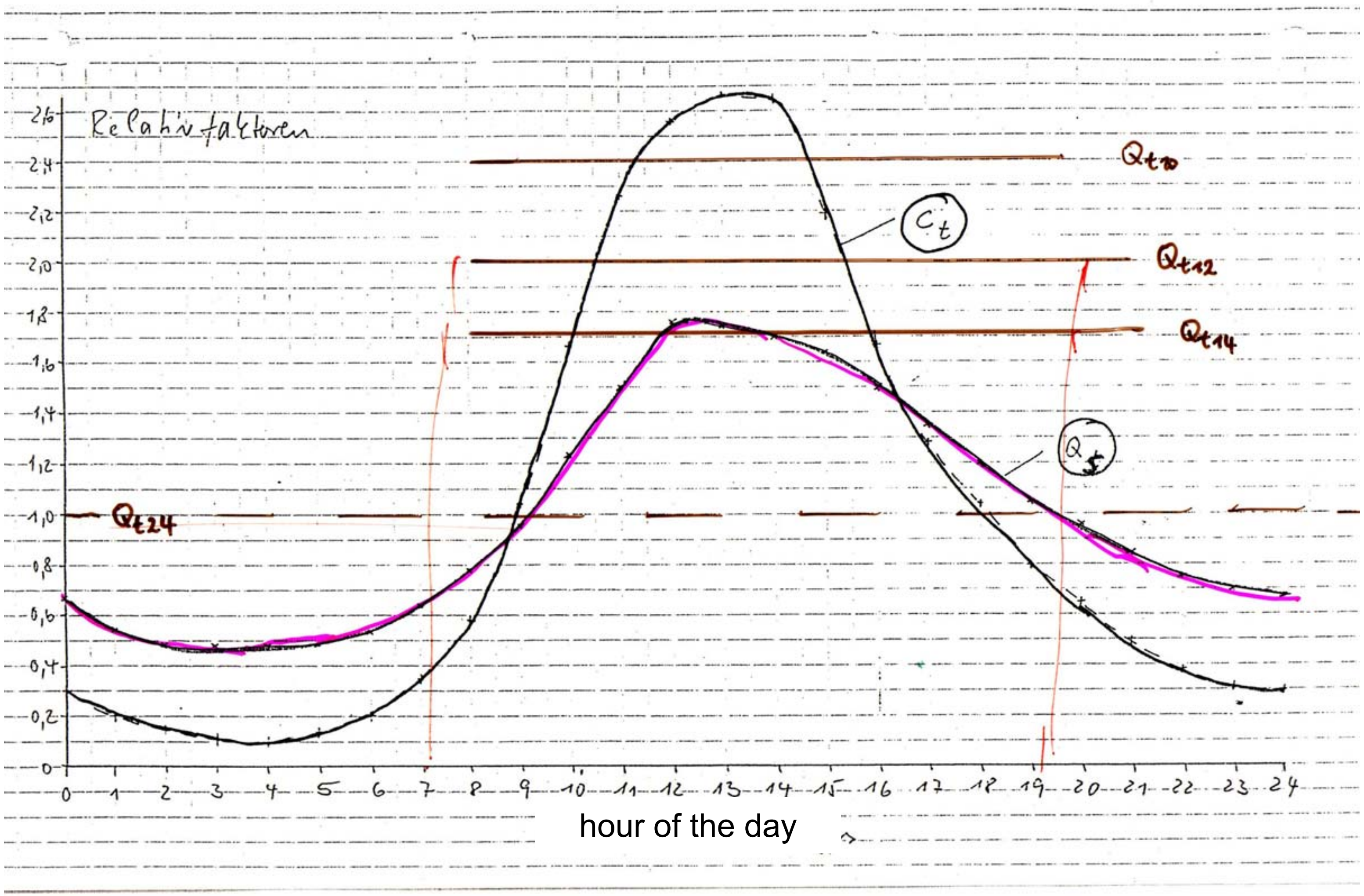
espec. for subcatchments: population density
(counted or assumed) is used
(total or sub-catchment area is easy to obtain)

Q_{d24} = mean discharge per day

Q_{dx} = daily discharge compressed into x hours

Waste water

Daily variations of runoff and concentration



hour of the day

Waste water

Design runoff

espec. for subcatchments: population density (capita per ha)
(counted or assumed) is used
(→ total or sub-catchment area is easy to obtain)

Q_{d24} = mean discharge per day

Q_{dx} = daily discharge compressed into x hours

often used: normalized values (per ha):

$$q_{d24} = l / (C*d) * C / ha * d / 86400\ s = l / (s*ha)$$

with freshwater consumption = 150 l/(C*d) and 50 C/ha:

$$q_{d24} = 150 * 50 * 1 / 86400 = 0{,}0868\ l/(s*ha)$$

rule of the thumb: 0,1 l(s*ha)

Storm water

Design runoff

- no defined design load
- rain is a stochastic entity
- dimensioning not for maximum possible load (inefficient from an economical viewpoint)

- as in hydrology in general:
  - feature / attribute — e.g. water level, volume, runoff

    plus
  - recurrence interval of exceedence — T [a]

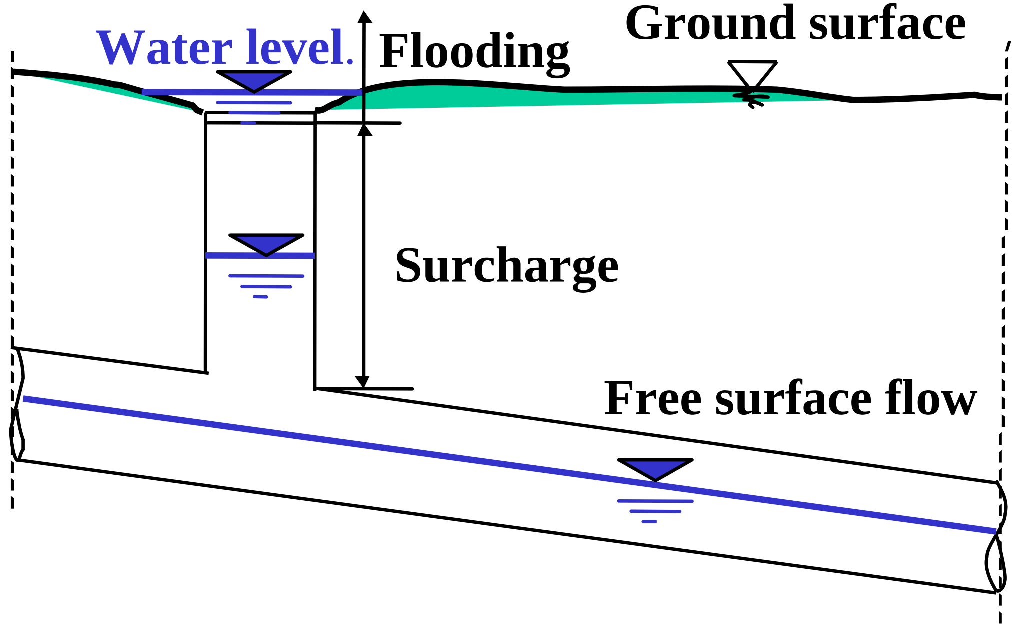
Storm water

Design

- Define: frequency / recurrence interval — of what?
- Find: design runoff
- Choose: appropriate diameter / profile
  (diameter depends on runoff and slope)

- Frequency of a limit state, e.g.
  - the pipe surcharging — water level at pipe crown or higher
  - flooding — water level at surface

→ allow exceedence of limit state at recurrence interval / with defined frequency



Water level.
Flooding
Ground surface
Surcharge
Free surface flow

History of urban hydrology and sewer design

Ancient times

- Water supply
- Drainage of waste water
- Stormwater drainage as a by-product

Modern Urban Drainage

1830	Cholerac epidemic in London
1840-50	Sewersystem in London
1842	Great fire in Hamburg
1843	Design of a sewer system

Industrielle Revolution

since 1850: Systematic determination of required diameters depending on

- drained area
- connected habitants

History of urban hydrology and sewer design

1851 **Mulvaney**
Relation between rainfall, runoff and area
Principle of the rational formula

1889 **Kuichling**
Rational Formula
Sewer system for Rochester, NY (1877 - 1889)

1906 **Lloyd-Davies**
Rational formula for the anglo-saxon sphere

1922 **Imhoff:** German version of the rational formula

1940 **Reinhold:** statistical rain data analysis
Definition of time coefficient φ to allow for change of charted base rainfall intensity $r_{15,1}$ (15 min, once a year) dependent on duration and frequency

Rational formula

$$Q_p = C \cdot i_T \cdot A$$

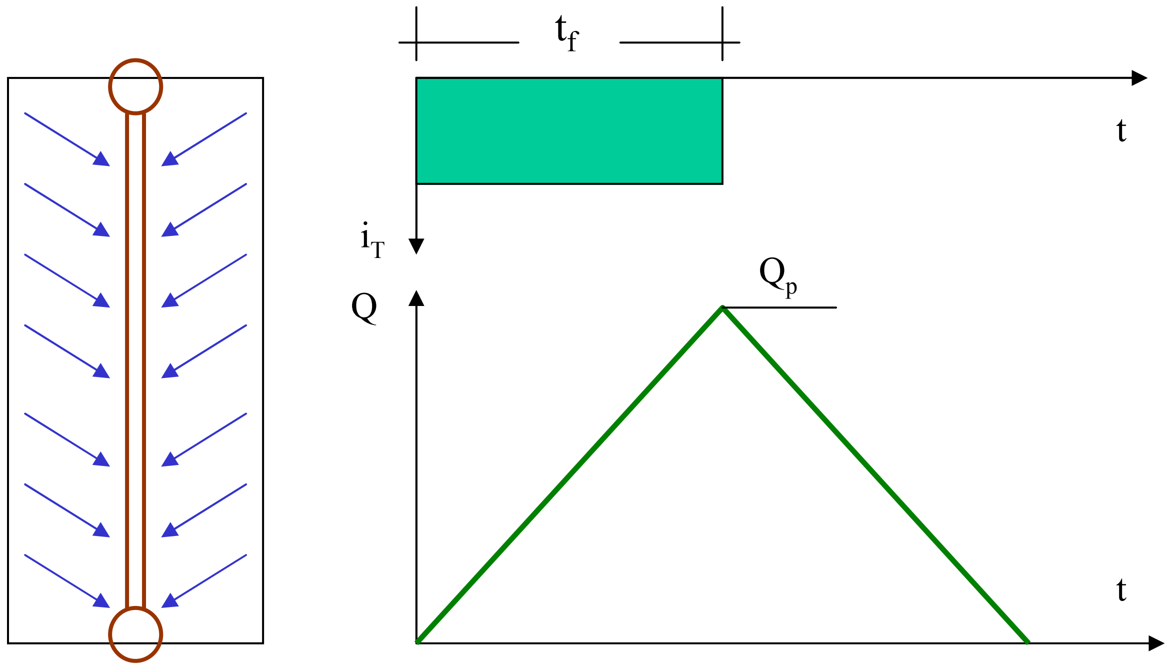
Q_p Design peak flow

C Proportion of effective rainfall

i_T mean rainfall intensity of decisive duration and design frequency

A Catchment area above design point

t_f Time of flow



Storm water

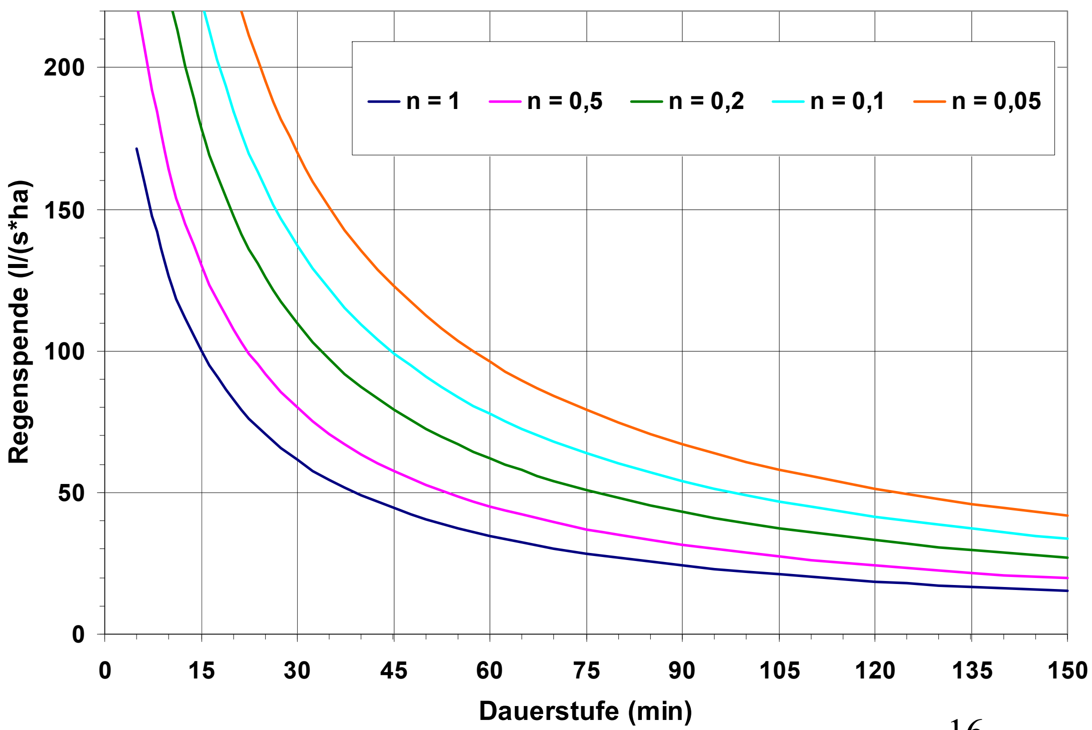
Design

- Design peak flow is dependent on rainfall
- Assumption: rainfall frequency = runoff frequency
- Consequence: rainfall statistics are needed

- Early awareness of rainfall characteristics:

  mean intensity decreases

  - with frequency
  - with duration

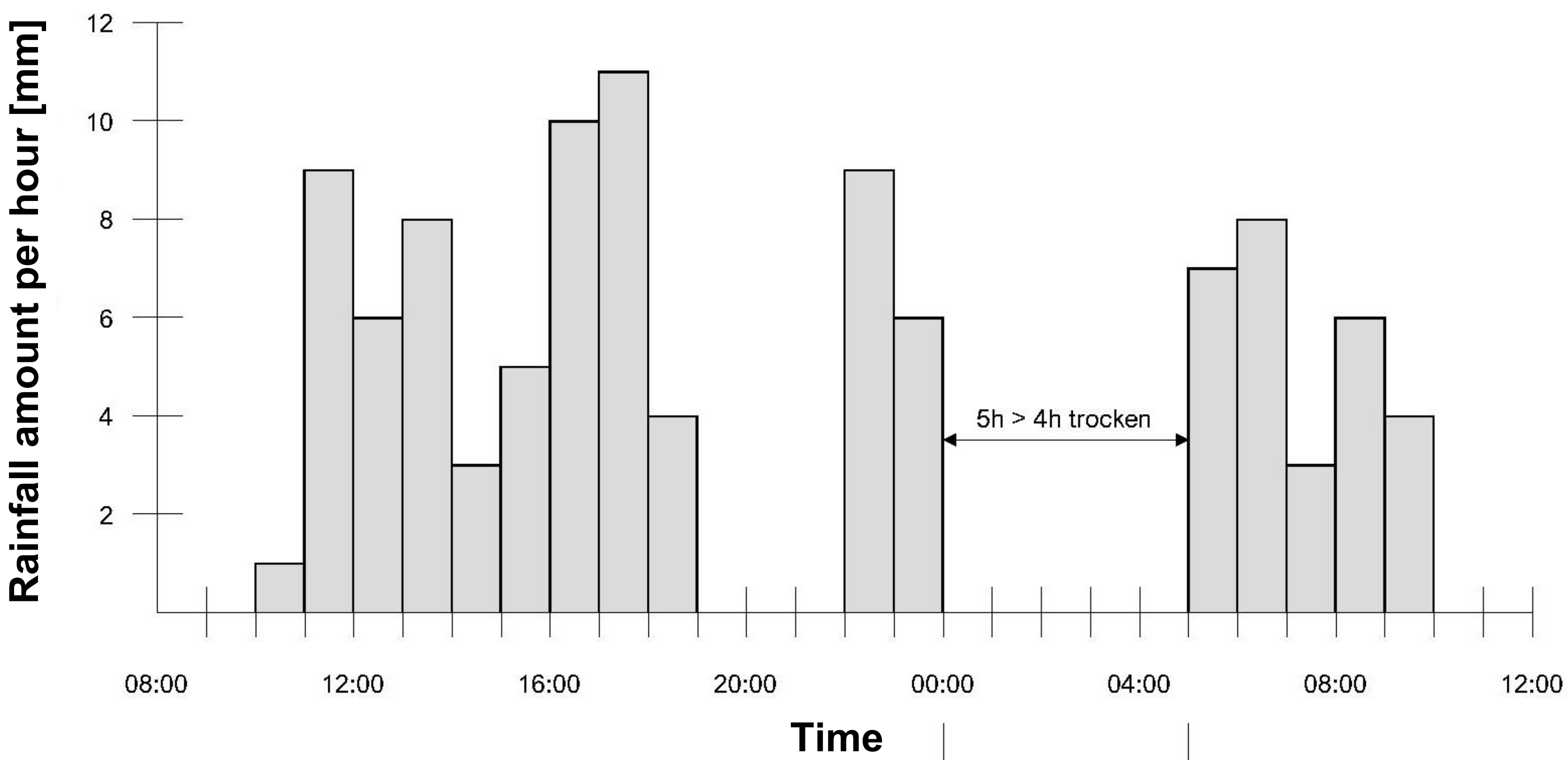


Statistical rainfall analysis

- Needed: long time series of rainfall recordings
- one of the possible ways:
  - choose a duration
  - move duration-wide window over time series sequence of data
  - collect all extreme rainfall sums within window

Statistical rainfall analysis

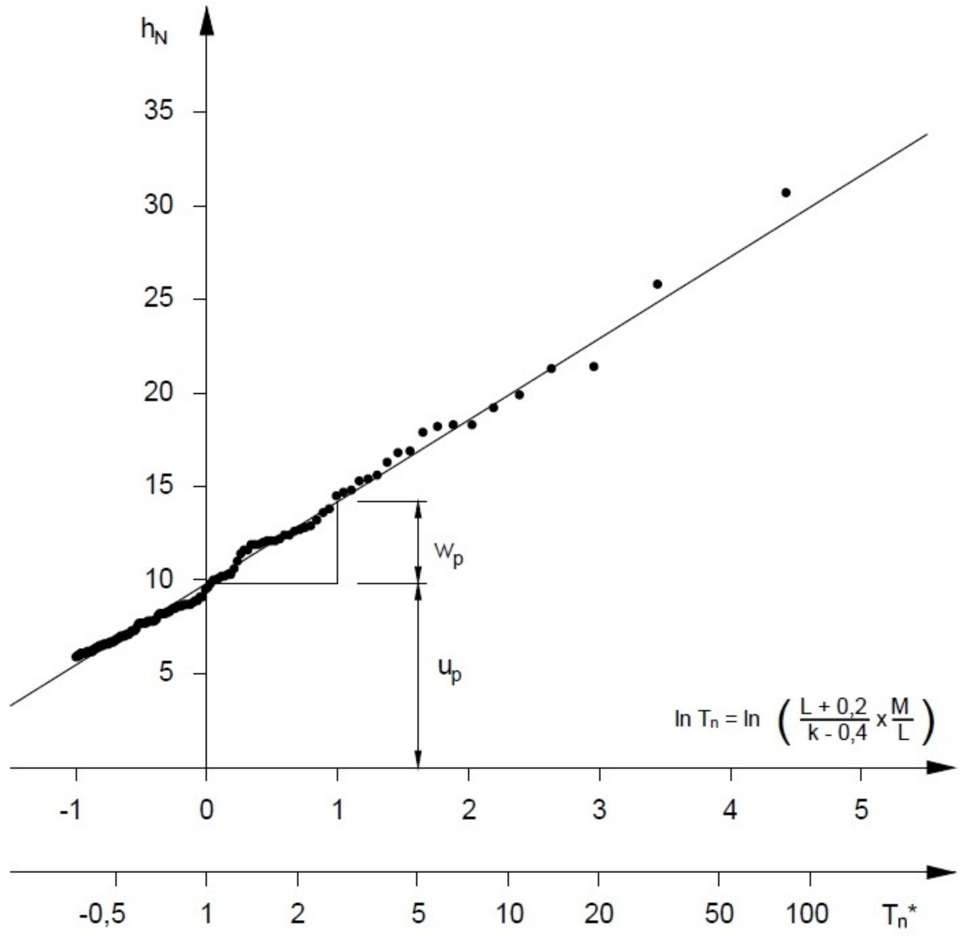
Overlapping rainfall sums



a)	0	0	1	9	6	8	3	5	10	11	4	0	0	0	9	6	0	0	0	0	0	7	8	3	6	4	0	0
b)	1	10	16	23	17	16	18	26	25	15	4	0	9	15	15	6	0	0	0	7	15	18	17	13	10	4	0	0

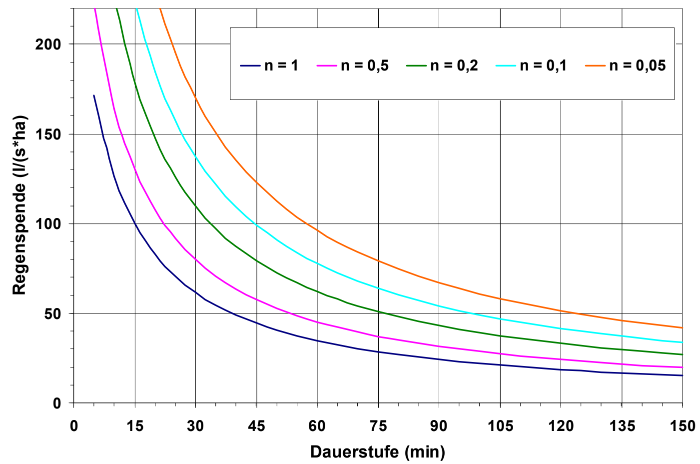
Statistical rainfall analysis

- Needed: long time series of rainfall recordings
- one of the possible ways:
  - choose a duration
  - move duration-wide window over time series sequence of data
  - collect all extreme rainfall sums within window
  - analyse statistically



Statistical rainfall analysis

- Needed: long time series of rainfall recordings
- one of the possible ways:
  - choose a duration
  - move duration-wide window over time series sequence of data
  - collect all extreme rainfall sums within window
  - analyse statistically
  - repeat for other durations
  - smooth parameters over duration
  - result: Intensity-Duration-Frequency curves → IDF curves



Statistical rainfall

1940 Reinhold

$$r_{D,f} = r_{15,1} \cdot \left\{ \frac{38}{D+9} \cdot \left(\frac{1}{\sqrt[4]{f}} - 0{,}369 \right) \right\}$$

time coefficient φ

1990/97 KOSTRA
„Coordinated statistical and regionalisation analysis “

Statistical rainfall amounts for:
D = 15, 60 min, 12, 24, 48, 72 h
f = 1, 0.1, 0.01 (0.5, 0.2) [1/a]

Rainfall statistics

KOSTRA demonstration

Open channel flow

Velocity:

$$v = \frac{4 \cdot Q}{\pi \cdot D^2}$$

$f = \lambda$ = friction factor v = velocity
D = diameter
(substitute with $4 * R_H$ for non-circular profiles)

Darcy-Weisbach:

$$I_e = I_b = I_s = f \cdot \frac{1}{D} \cdot \frac{v^2}{2g}$$

energy gradient = **b**ed slope = **s**urface slope → stationary flow

Prandtl-Colebrook:

$$\frac{1}{\sqrt{f}} = -2 \log_{10}\left(\frac{\varepsilon}{3{,}71 \cdot D} + \frac{2{,}51}{\mathrm{Re}\sqrt{f}}\right)$$

ε = k_b = roughness height
Re = Reynolds number

$$\mathrm{Re} = v \cdot \frac{D}{\upsilon}$$

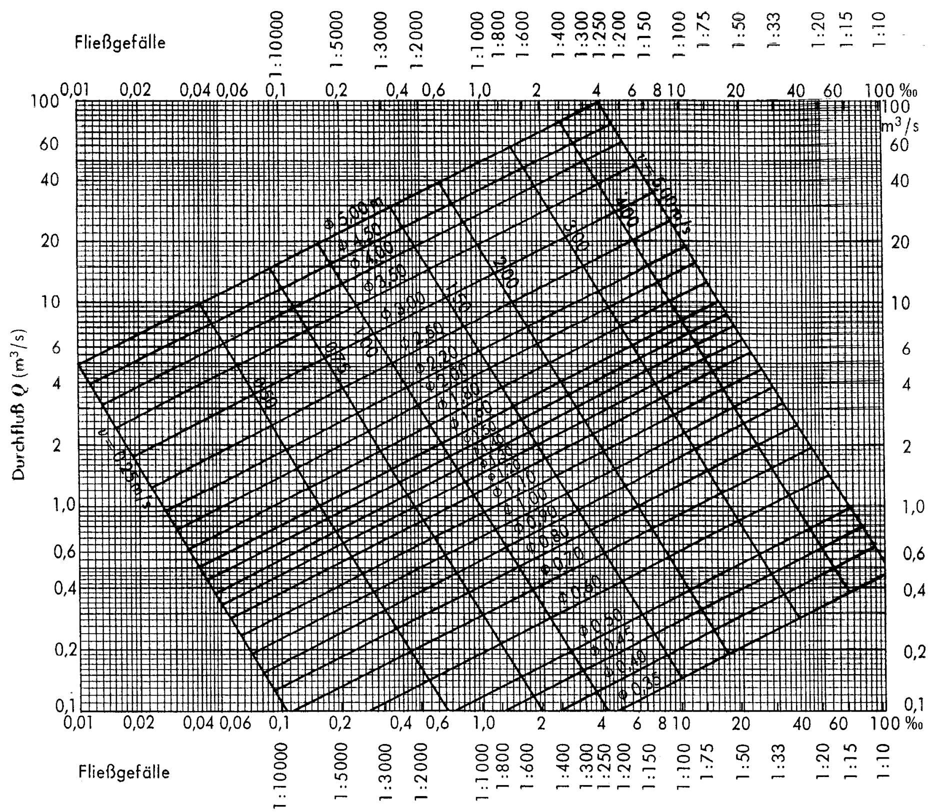
υ = kinematic viscosity

Dimensioning of pipes

wanted:	**diameter D**	
given:	**design runoff Q**	
given or choose:	**gradient**	should not be less than 0,01 % (1 in 10.000)
	roughness height	typically $k_b = 0{,}25 \ \dots \ 1{,}5$ [mm]

Solution:

by iterative calculation or tables or nomograms

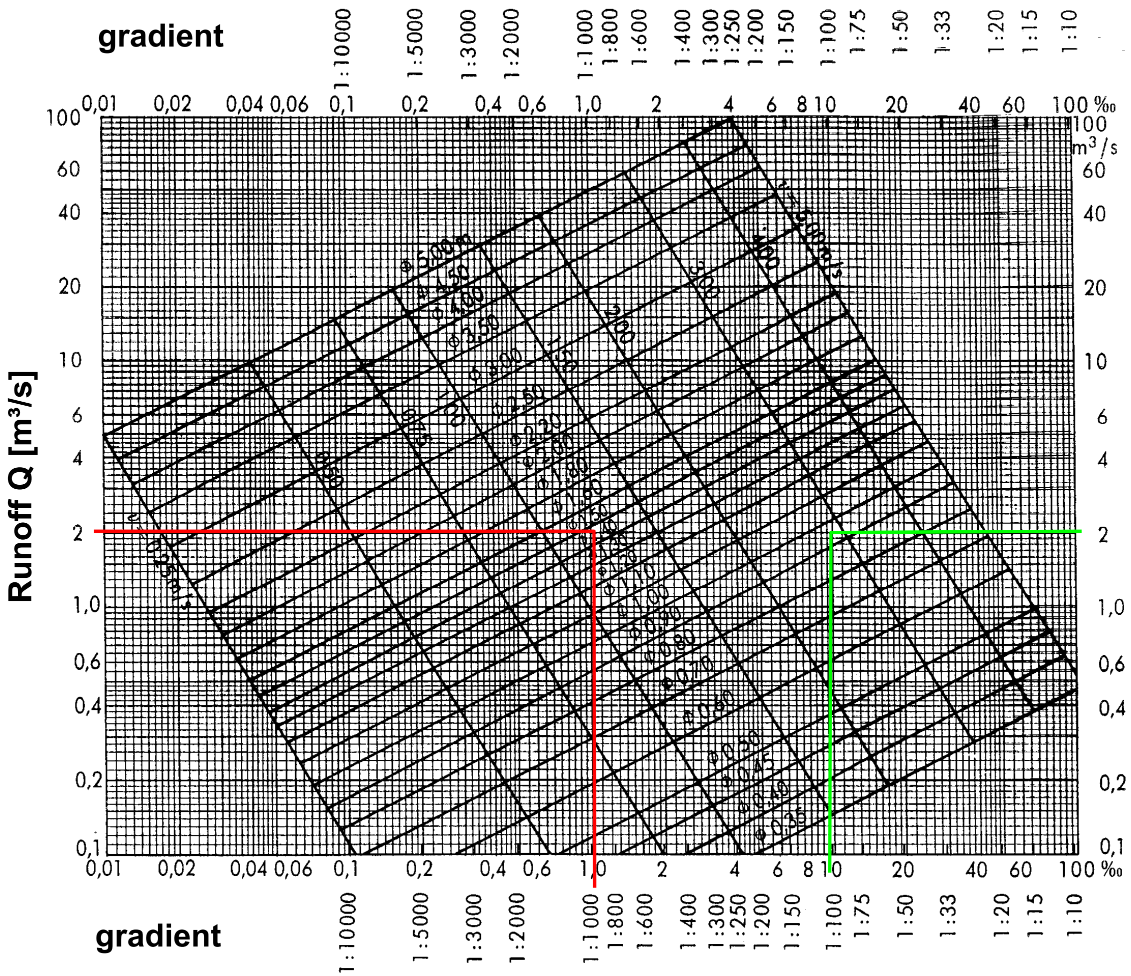


Dimensioning of pipes

wanted: diameter D
given: design runoff Q
given or choose: gradient, roughness height

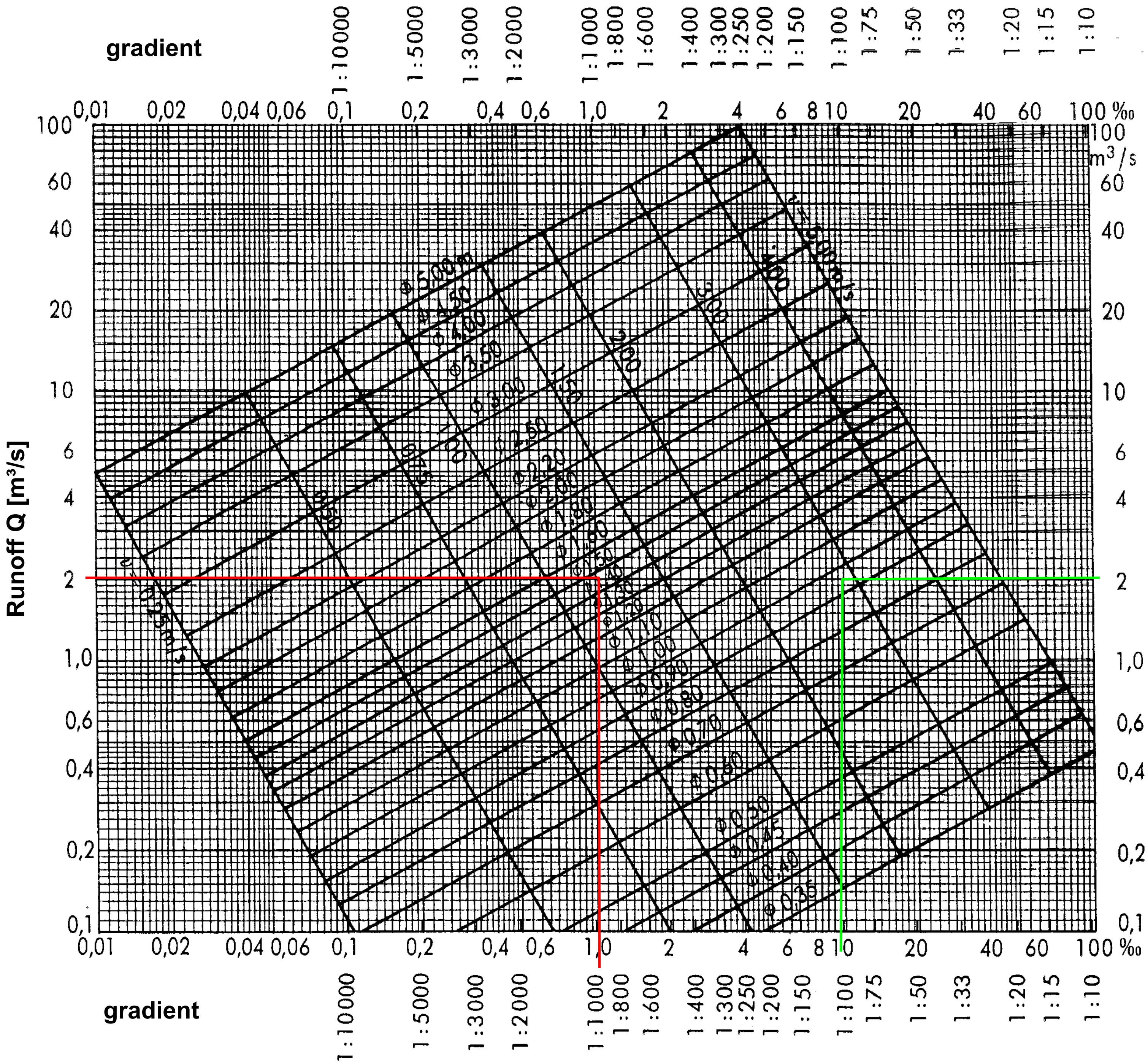
Example:

Q = 2,0 m³/s
a) 0,1 %   b) 1,0%
k_b = 1,5 mm



a) d = 1,50 m
v = 1,25 m/s

b) d = 1,00 m
v = 2,9 m/s


gradient
Runoff Q [m³/s]
m³/s
‰
1:10000
1:5000
1:3000
1:2000
1:1000
1:800
1:600
1:400
1:300
1:250
1:200
1:150
1:100
1:75
1:50
1:33
1:20
1:15
1:10
0,01
0,02
0,04
0,06
0,1
0,2
0,4
0,6
1,0
2
4
6
8
10
20
40
60
100

Design principles

sufficient minimum velocity

v > 0,2 m/s to avoid deposition
and to keep the settleable solids in suspension
→ gradient: I > 0,01% (1 in 10000)

appropriate diameter and profile

sufficient water depths at minimum flow
(during the night)

pipe crown line continuation when diameter increases

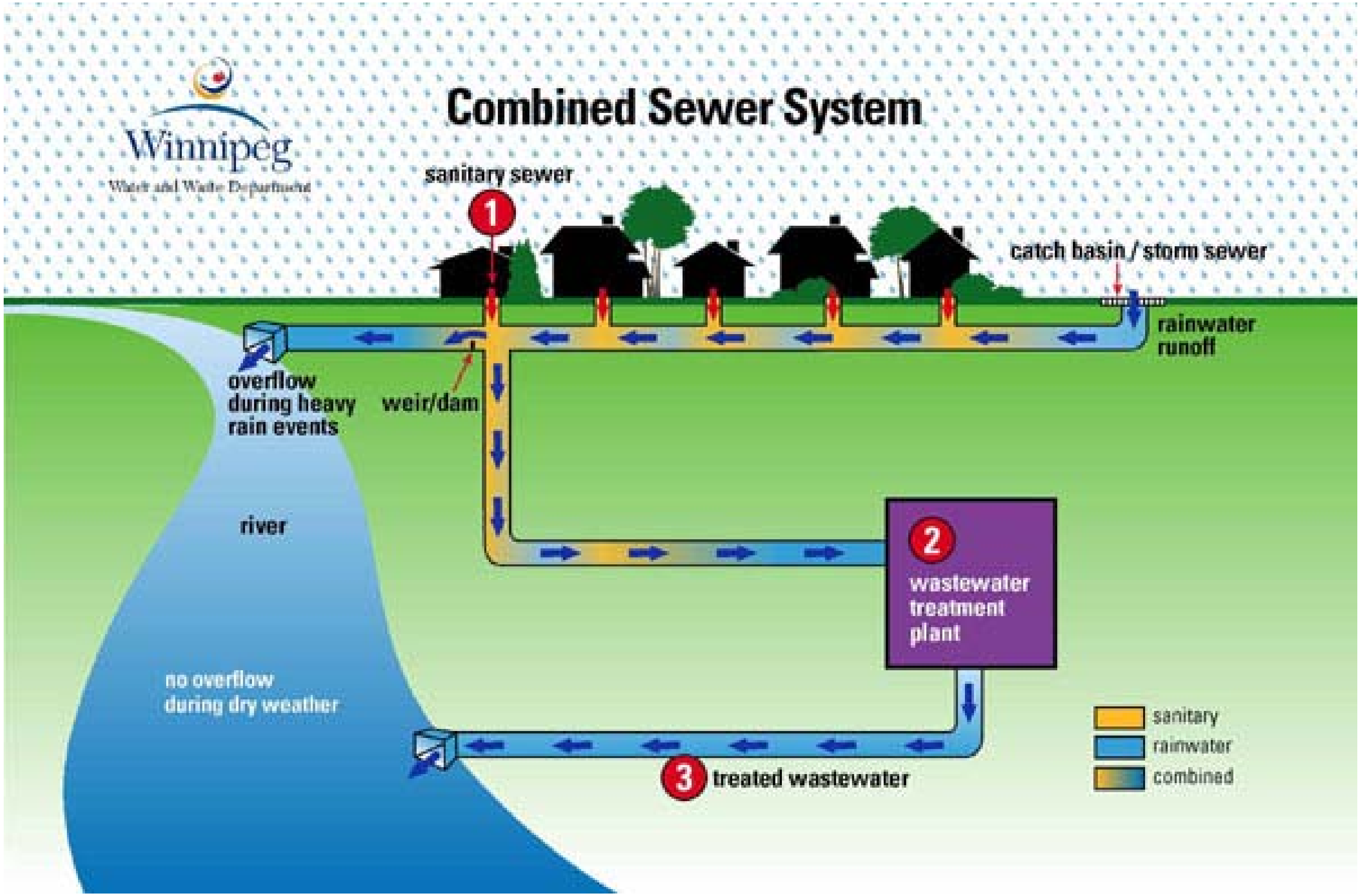
or

pipe base line continuation when diameter decreases

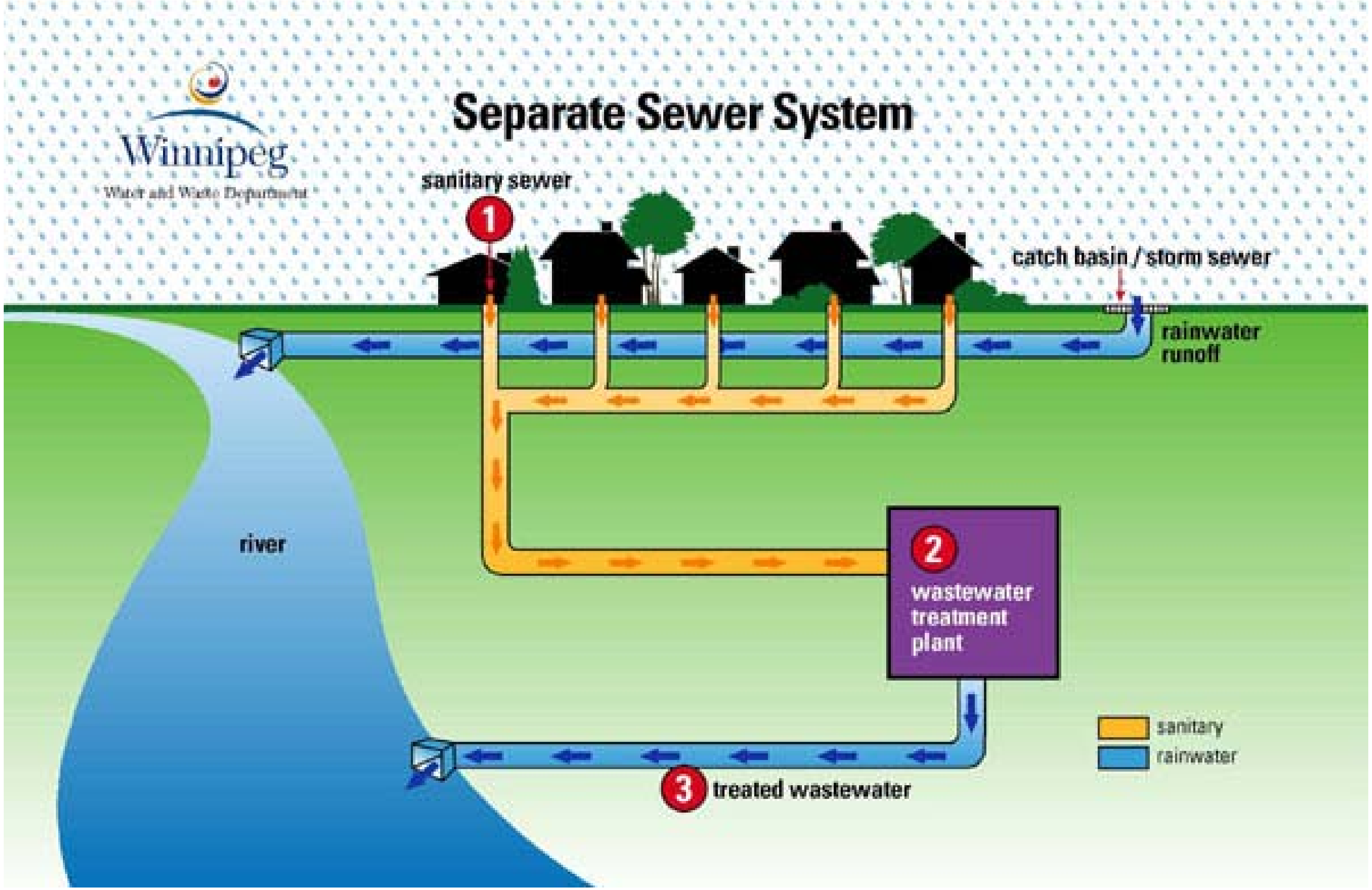
Drainage systems

Drainage systems

Drainage systems



Drainage systems



Drainage systems

Separate systems

a) the sanitary sewer system

- Design load: well defined by
  - water consumption
  - connected habitants
  - additional dischargers (industry)
- uncertainty: external water
- branched system with treatment plant as endpoint
- impact on receiving waters
  - quasi stationary flow
  - quasi stationary concentrations of pollutants

Drainage systems

Separate systems

b) the storm water sewer system

- Design load: dependent on
  - rainfall statistics
  - design frequency
  - connected area
- distributed system with multiple endpoints
- impact on receiving waters
  - hydraulics
  - pollution

Drainage systems

Seperate systems: storm water sewer system

Impact on receiving waters

- Hydraulic impact
  - direct discharge of stormwater runoff into the river
    - → high peak flows
    - → hydraulic stress
  - counter action: storm water detention tanks / basins
    - → temporary storage of storm water
    - → reduction of peak flow
- Pollution
  - generally no treatment
  - storm water is <u>not</u> clean

Drainage systems

Storm water pollution

- For impervious areas (example: Germany):

  assumed wash-off:

  600 kg COD per ha per year

  with annual rainfall = 800 mm
  and storm water runoff = 560 mm

  → mean storm water concentration:

$$C_r = \frac{600\ kg/(ha/a)}{560\ l/m^2} = 107\ mg/l \quad COD$$

- actual concentration varies
  - from event to event
  - within the event

Drainage systems

Combined systems

- Design load: combined loads from
  - waste water
  - storm water
- distributed system with multiple endpoints (overflow outlets)
- impact on receiving waters
  - hydraulics
  - pollution
  - quasi-stationary as well as sporadic

Drainage systems

Combined systems

- Design load:
  - waster water **plus** storm water
- Treatment plant has limited capacity,
  generally 2 .. 3 times dry weather flow
- Excess runoff in the sewer system:
  - has to be disposed by „overflow“
    into receiving waters (river)
  - at the treatment plant or on the way
- Combined sewer overflow is a non-neglectable pollution source
  = waste water diluted by storm water
- generally no bio-chemical treatment

intended, designed and appropriately constructed

No treatment at all ???