# Water management in urban areas

## Design, Computation methods

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# Runoff

- Many processes influence the runoff → simplified model
  - Stochastic
    - Probability input → probability output
  - Parametric
    - Input → mathematic relations → output
  - Deterministic
    - Description of the physical reality
- Water simulation packages
  - Storm Water Management Model (SWMM)
  - STORM ILLUDAS
  - The Wallingford Simulation Package (InfoWorks)
  - MOUSE
  - SOBEK

# Structure of the model

$$\frac{\text{input}}{\text{precipitation p(t)}} \rightarrow \frac{\overline{\text{loss model}}}{} \frac{\text{net}}{\text{precipitation } p_N(t)} \rightarrow \frac{\overline{\text{transformation;routing}}}{} \frac{\text{output}}{\text{runoff q(t)}}$$

# Loss-models

- Percentile
- φ-index
- Exponential loss-model
- Curve-number method

- First loss is estimated with help of:
  - Area characteristics (which ones?)
  - Rainstorm characteristics

# Transformation models

- Transform net precipitation into design run-off
- Various types
  - Deterministic / Parametic
  - Stady state / time dependant
- If needed add more complexity

# Transformation models

## Rational method (Lloyd-Davies)

A simple and consequently rough method

$$Q_p = C*i*A$$

| | |
|---|---|
| $Q_p$ | maximum runoff [$m^3$] |
| C | runoff coefficient |
| i | design precipitation intensity [$m^3 s^{-1} ha^{-1}$] |
| A | catchment of drainage [ha] |

# Transformation models

## Rational method (Lloyd-Davies)

Dimensioning the pipe diameter (iterative)

$$Q_p = i^* A_{paved}$$

1. Determine $A_{paved}$
2. Choose $D_I$
3. Compute velocity $v_i$ (Manning/Colebrook)
4. Compute 'time of concentration' $t_c$ $t_c = t_e + t_v$
5. Choose a return period
6. Derive i from DDF-curve
7. Compute runoff with $Q = i^* A_{paved}$
8. Compute the capacity of the pipe $Q_{cap} = {}^1/_4 v_{i*} \pi^* d_i^2$
9. If $Q > Q_{cap}$ repeat procedure from point 2 with a larger diameter. If $Q < Q_{cap}$ than $d_i$ is the minimal required diameter.

# Transformation models

## Rational method (Lloyd-Davies)

The most essential assumptions

- Steady and homogeneously distributed design precipitation intensity
- Return period of top runoffs is equal to the return period of precipitation events
- Velocity of the runoff wave is equal to the flow velocity in the completely filled pipe.
- Time of concentration is not dependent on the precipitation intensity.
- Runoff-coefficient is not related to the physical processes, but set 1 for paved area and 0 for un-paved area.

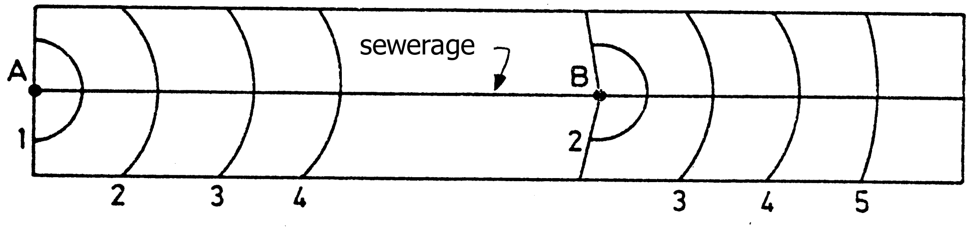
# Transformation models

## Time area method

- Area that contribute to the runoff
- On basis of routing velocity

$$Q(t) = \sum_{i=1}^{n} \Delta A_j I_i$$

$$\text{with } j = \frac{t-(i-1)\Delta t}{\Delta t} \text{ and } t = \Delta t, 2\Delta t, 3\Delta t$$




A, B: inlet points

runoff time to point A

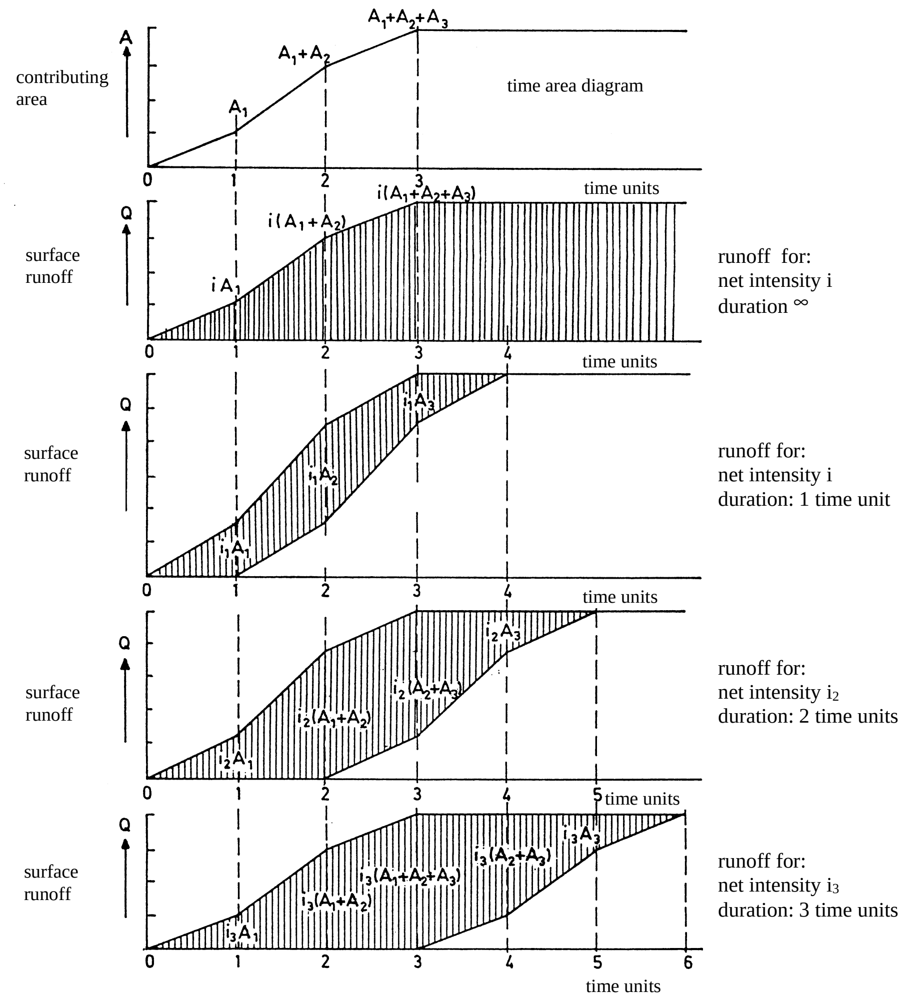
# Transformation models

## Tangent method

- Compensating the increasing surface for reduction of precipitation intensity

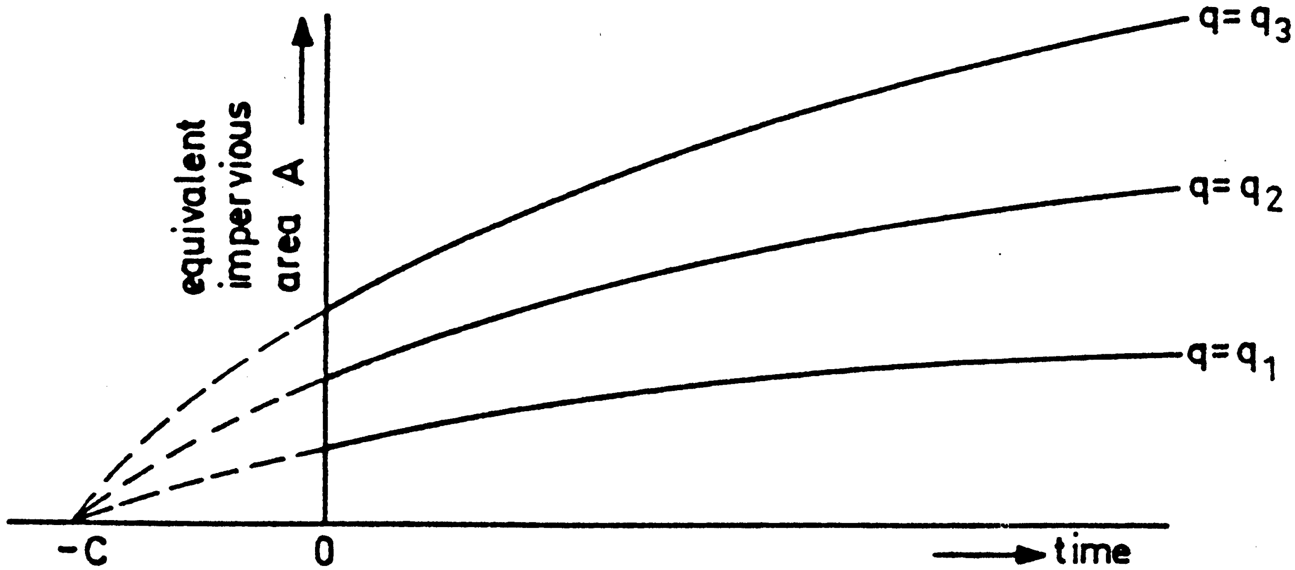
$$i = \frac{B}{(t+C)^n} \quad \& \quad A = \frac{q}{i}$$

$$A = \frac{q(t+C)^n}{B}$$



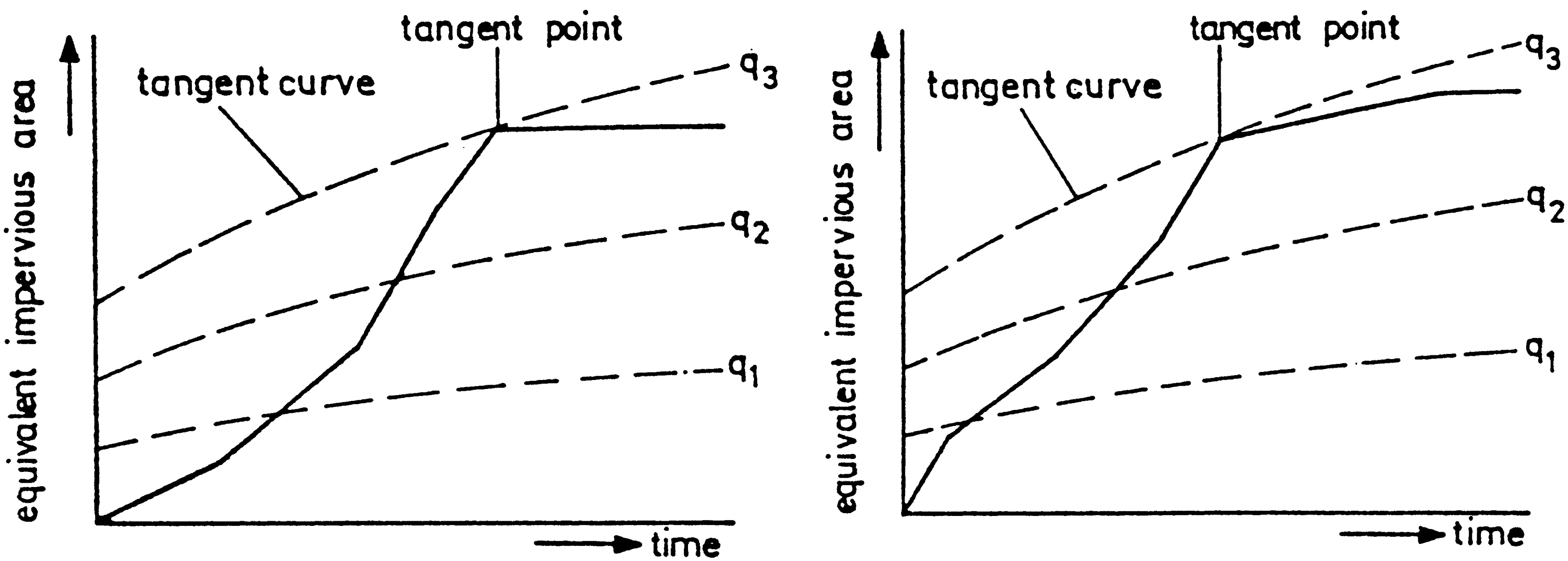
# Transformation models

## Tangent method



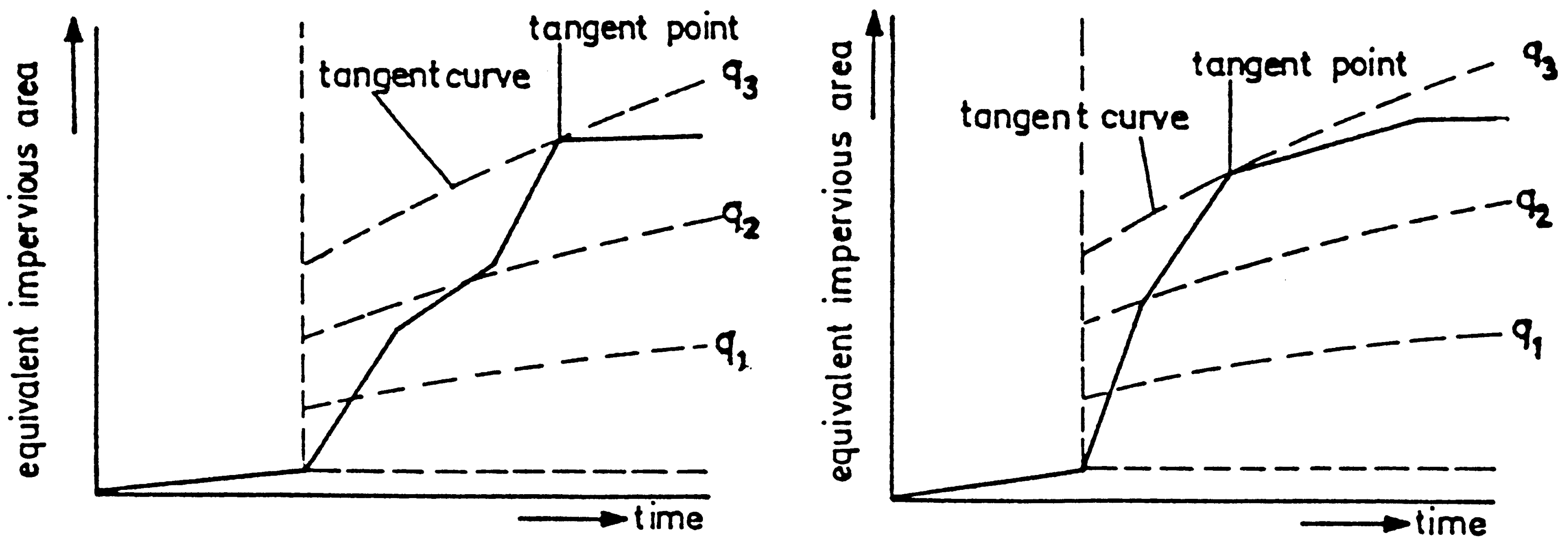
# Transformation models

## Tangent method



# Transformation models

## Tangent method



# Transformation models

## Unit-hydrograph-method

- Instantaneous Unit Hydrograph (IUH): $\Delta t \rightarrow 0$
- Transform Unit Hydrograph (TUH): $\Delta t > 0$

Assume linear precipitation-runoff process and use net precipitation

$$Q(t) = \sum_{i=1}^{n} h\{\Delta t, t-(i-1)\Delta t\} I_i \Delta t$$

$h\{\Delta t, t-(i-1)\Delta t\}$ = TUH at time $t-(i-1)\Delta t$

$I_i$ = net precipitation intensity at $i^{th}$ time step $\Delta t$

# Transformation models

## Unit-hydrograph-method

UH estimations:

- Matrix inversion
- Quadratic programming
- Deterministic modelling
  - Linear reservoir

$$q = \frac{1}{k} S \qquad \& \qquad \frac{dS}{dt} = p - q \qquad \& \qquad q(0) = 0$$

$$q = p\{1 - \exp(-t/k)\}$$

$$q = Q_0 \exp(-(t - T)/k)$$ if $q=Q_0$ at $t=T$

Instantaneous unit inflow t=0 and $Q_0 = \frac{S_0}{K} = \frac{1}{K}$

$$\text{IUH} = h(\Delta t = 0, t) = \left(\frac{1}{k}\right)\exp(-t/k)$$

# Transformation models

## Unit-hydrograph-method

### Nash model

cascade of n identical linear reservoirs with constant k

$$q_i = \frac{1}{k}\int_0^t e^{\frac{t-\tau}{k}} q_{i-1}(\tau)d\tau$$

with $q_0(t) = p(t)$

$$q_1 = \frac{1}{k}\exp\left(\frac{-t}{k}\right) \quad \rightarrow \quad q_2 = \left(\frac{t}{k^2}\right)\exp\left(\frac{-t}{k}\right) \quad \rightarrow \quad \text{etc}$$

IUH:

$$h\{\Delta t = 0, t\} = \frac{1}{k\Gamma(n)}\left(\frac{t}{k}\right)^{n-1}\exp\left(\frac{t}{k}\right)$$

with $\Gamma$(n) being a gamma-fuction