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A mathematical approach to find long-term strategies for the implementation of resource orientated sanitation
Focus and Background

- **Industrialised / developed countries**
  - High standard of water supply and disposal
  - (water) infrastructure already built

- **Urban Water Management**
  - regional water and nutrient cycle
  - technical aspects

- **Transformation of existing water infrastructures**
  - problems resulting e.g. from demographic and climate change cause a conceptual alteration in urban water management
  - from predominantly centralised end-of-pipe solutions
  - towards more resource orientated closed-loop systems
Focus and Background

- **How** can sustainable drainage and sanitation devices be implemented in existing systems in an optimal way?
  - extensive financial and construction efforts
  - a conversion can only be realised successively over a long period

**Development of optimised strategies for transformation → mathematical approach**
Mathematical Model

**Initial situation**
- Present state
  - Analysis
  - Evaluation
- Activities
  - Useful life-span
  - Installation period
  - Economical costs
  - Functioning
  - Standards in regulations
  - Environment
  - Ecological costs
- Impact
- Network feasibility
  - Balances
- Optimised strategy for realisation

**Mathematical model**
- Choice of activities
  - Optimal choice and combination of activities to reach future state
  - Determination of temporal and spatial sequence of activities with minimal costs and impact

**Aim**
Mathematical Model

- **Initial Situation**
  - Present State
  - Analysis
  - Evaluation
  - Constraints
  - Requirements
  - Future State

- **Mathematical Model**
  - Activities
    - Installation period
    - Useful life-span
    - Economical costs
    - Functioning
    - Standards in regulations
    - Environment
    - Ecological costs

- **Objective Functions**
  - Precendence constraints
  - Network feasibility
  - Balances
  - Optimised strategy for realisation

- **Aim**
  - Choice of activities

Mathematical model for realisation of mini-misa-tion with constraints of economical costs, ecological costs, and useful life-span.
Application

- Suburb of Kaiserslautern: KL-Siegelbach
  - Rural catchment of 90 ha area
  - 3,000 inhabitants
  - heterogeneous forms of housing / use
  - 70% drained by combined sewer system (3 overflow devices), 30% drained by (modified) separate sewer systems
  - wastewater is transported to central WWTP of Kaiserslautern (220,000 p.e.)
  - effects on WWTP not included in this study
future state

future state and conditions

- example of future state for implementation
  - stormwater runoff and wastewater should not be mixed any more,
    achieve natural stormwater management
  - decentralised treatment of blackwater
  - greywater should be treated centrally in WWTP
objective functions

- **period of consideration**
  - 50 years of conversion + 30 years of ‘maintenance’
  - total project costs with 3 % interest rate
  - budget 2.5 million € / time step (5 years)

- **weights objective functions**
  - weight economic costs \( C(1) \) : ecologic costs \( C(2) \)
    - Scenario 0: 1 : 0
    - Scenario 1: 1 : 0.2
    - Scenario 2: 1 : 0.4
    - Scenario 3: 1 : 1
    - Scenario 4: 1 : 2
    - Scenario 5: 0 : 1
Results – objective function values

- **Ecologic costs C(2)**
  - different criteria (at present 11) count to these costs
  - main fields of criteria
    - adaption of natural water balance
    - resources protection
    - emissions
    - immission
  - each criterion is scaled to an interval from 0 (no detriment) to 1 (highest detriment)

The graph shows the relationship between economic costs and ecologic costs for different scenarios (S0 to S5). Each scenario has a different weightage of economic costs to ecologic costs:

- S0: C(1):C(2) = 1:0
- S1: C(1):C(2) = 1:0.2
- S2: C(1):C(2) = 1:0.4
- S3: C(1):C(2) = 1:1
- S4: C(1):C(2) = 1:2
- S5: C(1):C(2) = 0:1

The graph illustrates how the minimal economic costs change with different ecologic cost ratios.
Results – portions $C_i(2)$ of $C(2)$

- Economic costs [million €/5]
- Emissions [-]
- Immissions [-]
- Water balance [-]
- Resources protection [-]

Scenario S3
Scenario S5

Annotation: Ecologic costs of 16 would represent an extrapolation of the present state.
Results – time schedule

total period under consideration [years]

SC1
- SUDS
- transport
- DESAR

SC2
- SUDS
- transport
- DESAR

SC3
- SUDS
- transport

SC4
- SUDS
- transport
- DESAR

SC5
- SUDS
- transport
- DESAR

SC6
- SUDS
- transport
- DESAR
to reach one future state many different optimal strategies are possible:

- the subjective weighting of the two costs is essential
- it is also essential to specify which impact in C(2) has to be considered for an optimal transformation strategy
- only the discussion of local deciders with engineers can lead to definite choice of solution (→ difficult!)

→ potential of the approach in making possible to show all impacts in detail when calculating different scenarios
→ big potential for complex systems!