Hydro-economic model to calculate nodal prices in water distribution networks

- WATERMOD -

Technische Universität Berlin
und Fachgebiet Wirtschafts- und Infrastruktur Politik

Dipl. Wi.-Ing. Markus Siehlow (ms@wip.tu-berlin.de),

Agenda

1) Background
2) Urban and Rural Water Network Modeling
3) Application
4) Conclusion

Background- Germany

- **Price structure does not reflect cost structure (20:80 vs. 80:20)**
- **Annual water consumption per capita very low , especially in Eastern Federal States of Germany, in the European context**
- **Expensive over capacities, especially in water networks which are affected by demographic change**

  → Caused fair price set incentive to consume more water and dimes the revenue risk for water companies

Background- Worldwide

- **Water prices are subsidized or lacking totally in many countries; cost-covering prices are an exception**
- **Low water prices lead to underinvestment in water infrastructure and endanger the security of supply**
- **Prices do not reflect the scarcity of water → wasteful use of water → aggravates water stress in arid countries**

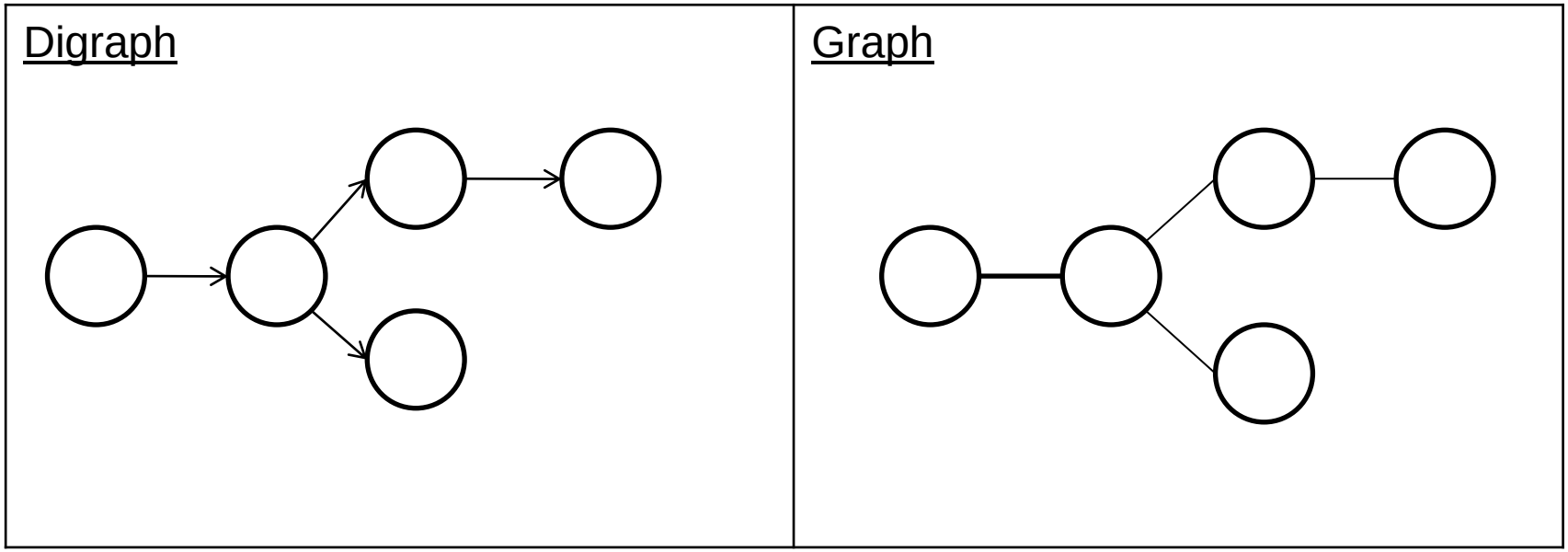
How to calculate a caused –fair water price that internalize the shortage of water?

Agenda

1) Background
2) Urban and Rural Water Network Modeling
3) Application
4) Conclusion

Modeling: Graph vs. Digraph

- **Real urban and rural water networks are modeled as digraph or graph**



- **Nodes: Main Access Points, Tanks, Reservoirs, Waterworks**
- **Edges: Pipelines, Pumps, Throttles**

Modeling: Hydraulic Approaches, Sets and Variables

- **Two hydraulic approaches are considered for modeling:**
  - **Volumetric Approach → Continuity of volume (1st Kirchhoff Law)**
  - **Energetic Approach → Bernoulli Law, Mesh balance**

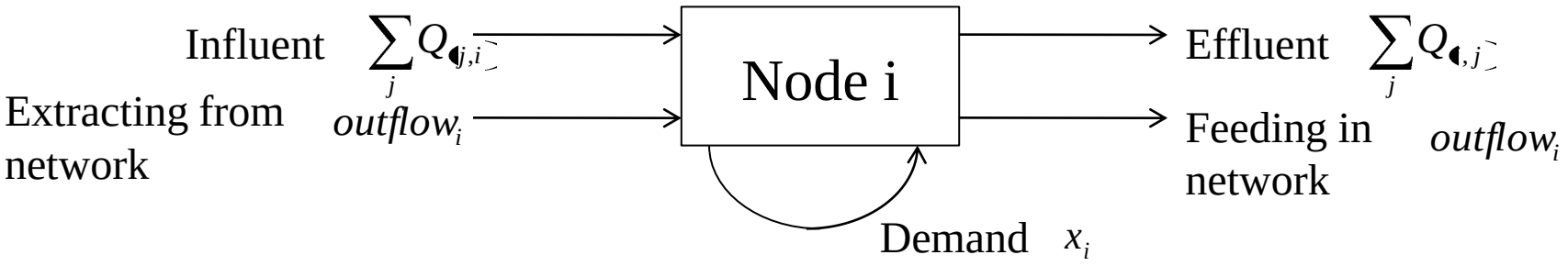
Economic Objective: Objective Function of Modeling

- **Aim of modeling:**

1. **Cost minimization**
2. **Welfare maximization**

- **Two cost components exist:**
  - **Variable Treatment costs depends on used chemistry, fees for withdrawal etc.**
  - **Variable Transport costs depends on pumping height and discharge through pump**

Volumetric Approach



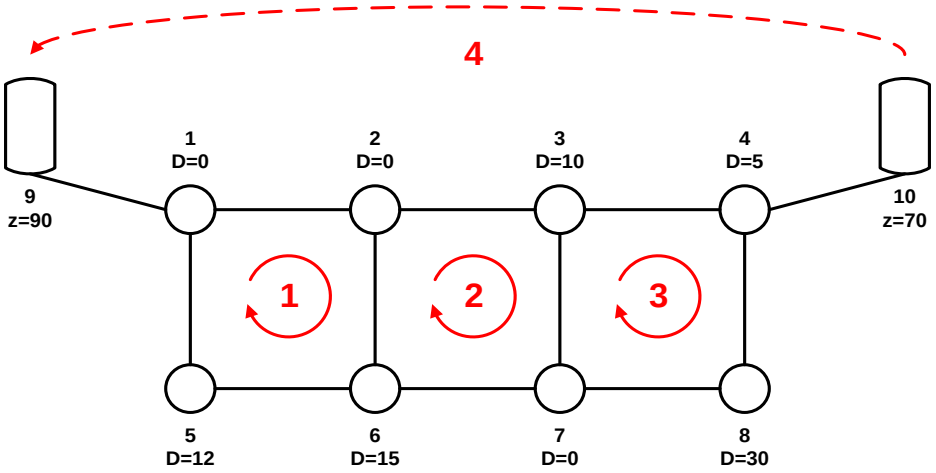
- **Volume continuity is set up for each node:**
- **Fed and extracted water in the network are limited**
  - Recharge rate in water sources (reservoir)
  - Storage capacity
- **Discharge can only be realized in defined pipelines**
- **Discharge is limited on pipelines**
- **Flows in pipelines are only allowed in one direction for each moment**

Energetic Approach: Bernoulli Equation and Mesh Balance

- **Reservoirs are nodes with known energy level: Energetic level is equal to geodetic level of free surface**

- **Estimating energy level of residual nodes → Bernoulli equation**
  - **Hydraulic losses parameter depends on material and diameter of pipeline → Moody diagram is used**

- **Balance is set up for each mesh**
  - **Real mesh: Pipelines are arranged as circuit**
  - **Pseudo mesh: Nodes with known energy level are connected by pipeline (communicating vessels)**



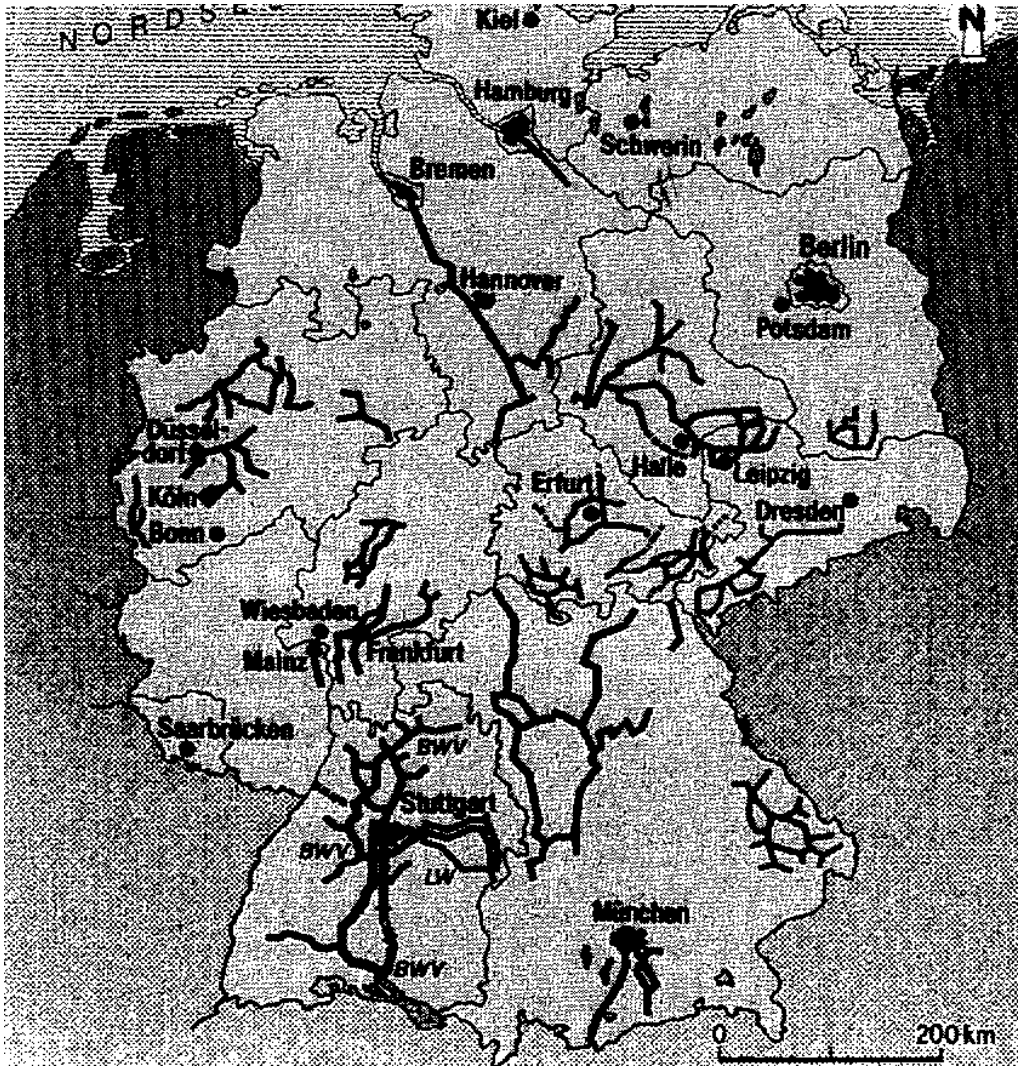
Energetic Approach: Pressure, Pumps and Throttles

- **Pressure**
  - **Guarantee of minimum pressure (supply pressure)**
  - **Guarantee that maximum pressure is not exceed**
- **Pumping height is limited by maximum pumping height depending on discharge**
- **Pumping and throttling only possible along flow direction**
- **Throttling is only realizable in one direction for each mesh at any time point**

Agenda

1) Background
2) Urban and Rural Water Network Modeling
3) Application
4) Conclusion

Bulk Provider in Germany



Source: Nabel (1996)

Agenda

1) Background
2) Urban and Rural Water Network Modeling
3) Application
4) Conclusion

Conclusion (1)

Urban Water Networks can be abstracted as graph or digraph

- **Nodes: Main Access Points, Tanks, Reservoirs, Waterworks**
- **Edges: Pipelines, Pumps, Throttles**

Network Components

- Pipelines:
  - Flows are realized through this component
  - Hydraulic losses depends on discharge
  - Various forms of connections are possible: series and parallel connection, real meshes
- Reservoirs:
  - Energy level is equal to geodetic level
- Pumps and Throttles:
  - Using for feeding and destruction of pressure height

- **Two hydraulic approaches are considered:**
  - **Volumetric Approach → Continuity of discharge**
  - **Energetic Approach → Bernoulli equation, mesh balance**

Conclusion (2)

- **Results of Modeling are nodal prices, scarcity rents, estimated demand**
- **Change from actual to nodal pricing lead to an increasing of demand**
- **Scarcity rent can be used for fix costs covering → Decreasing of base price**