Unit 14:

Multi-objective Assessment of Small Hydropower Development

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HyWa-BOKU

Structure of Presentation

- Problem and Objectives
- Methodology
- Application
- Conclusions

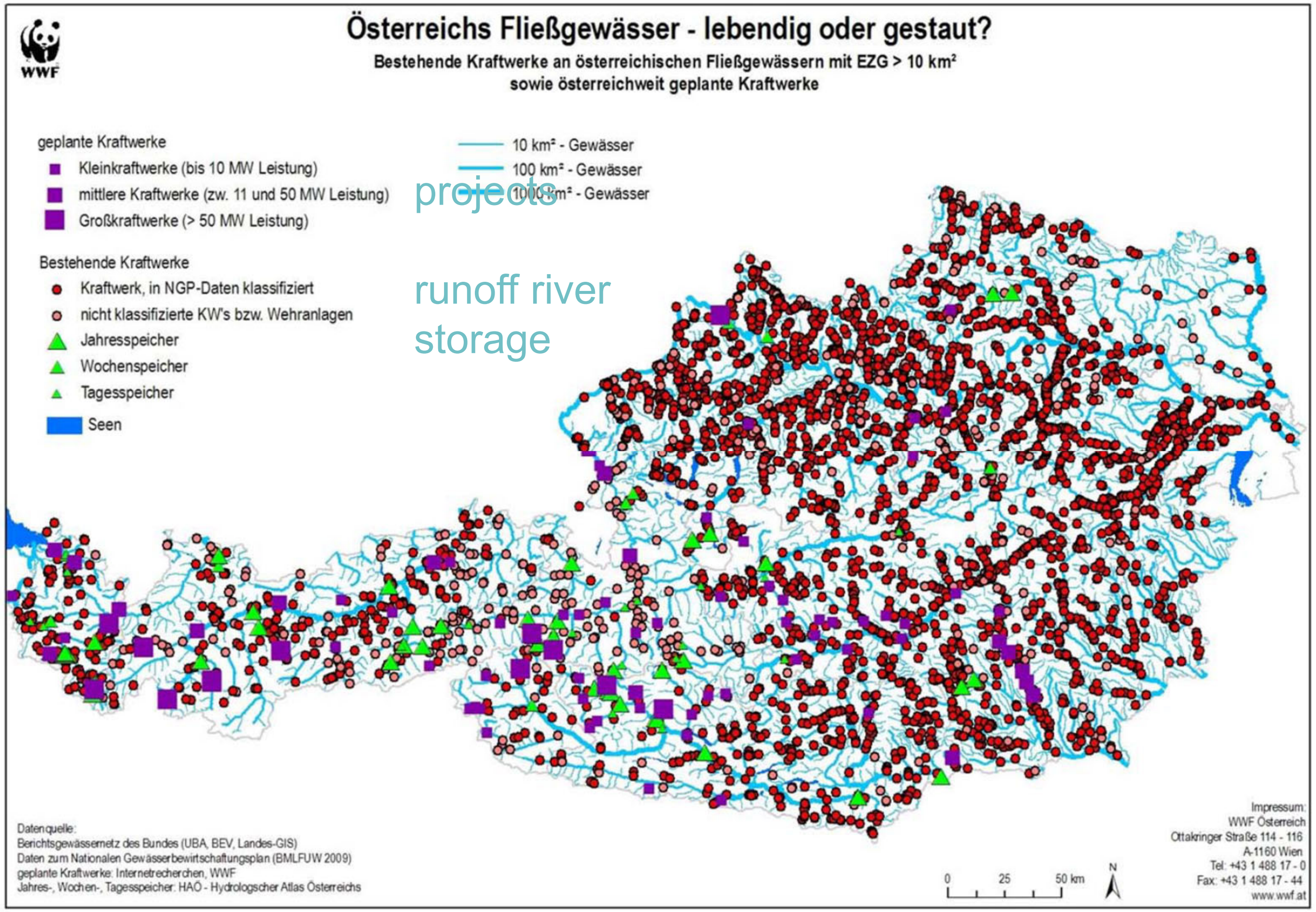
Introduction and Objectives

- hydropower covers more than 60% of electric energy demand of Austria
- There are about 4 000 small hydropower stations
- Their contribution is about 4-6 % of total hydropower generation
- Many power stations are privately owned and operated
- These small schemes generate renewable, clean energy but also adverse environmental impacts

Objectives

- **Most of the SHPs are diversion type plants**
- **Assess the pdf of instream water requirement (ecological discharge)**
- **Find a sound trade-off among hydropower-environment**

Hydropower in Austria



Environmental Impacts of SHP

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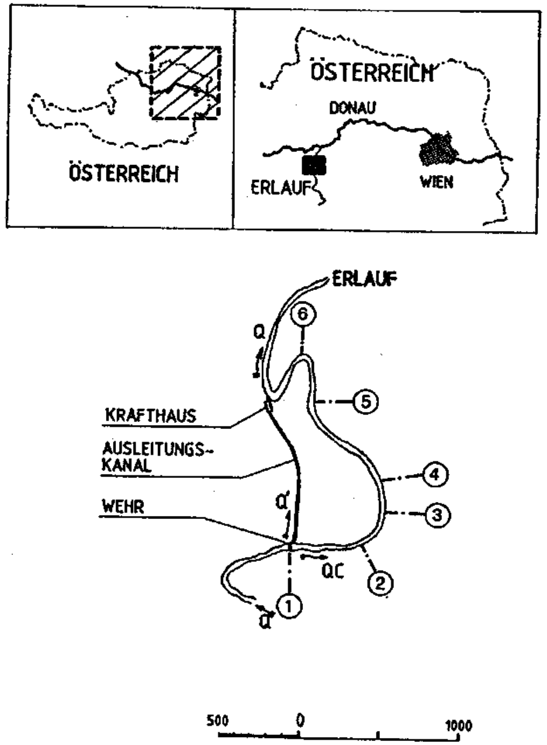
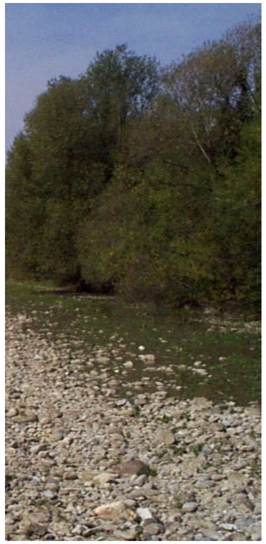




Environmental Impacts of SHP

- **Most of the schemes are diversion type plants**

- **Hydraulic parameters are changed upstream of the weir**
  - **Increase in water depth**
  - **Decrease in flow velocity**
  - **Sedimentation**
  - **Interruption of river continuum**
- **Impacts in the river section downstream of the weir**
  - **Drastically reduced discharge**
  - **Reduced flow velocity**
  - **Change in energy balance (increase in water temperature)**
  - **Change in oxygen balance**
  - **Sedimentation processes**
  - **Increase in algae productivity**

What are the main objectives ?

- **Maximize economic efficiency**
- **Minimize adverse environmental impacts**

Specification of objectives by criteria

- **Economic efficiency**

  annual power generation

  # of shutdown days should be a minimum

Specification of objectives by criteria

- **Economic efficiency**
  - annual power generation
  - # of shutdown days should be a minimum

- **Environmental quality**
  - ensure a minimum water depth
  - preserve the water volume
  - preserve variability in width of the water body
  - avoid major changes in water temperature
  - avoid changes in oxygen concentration

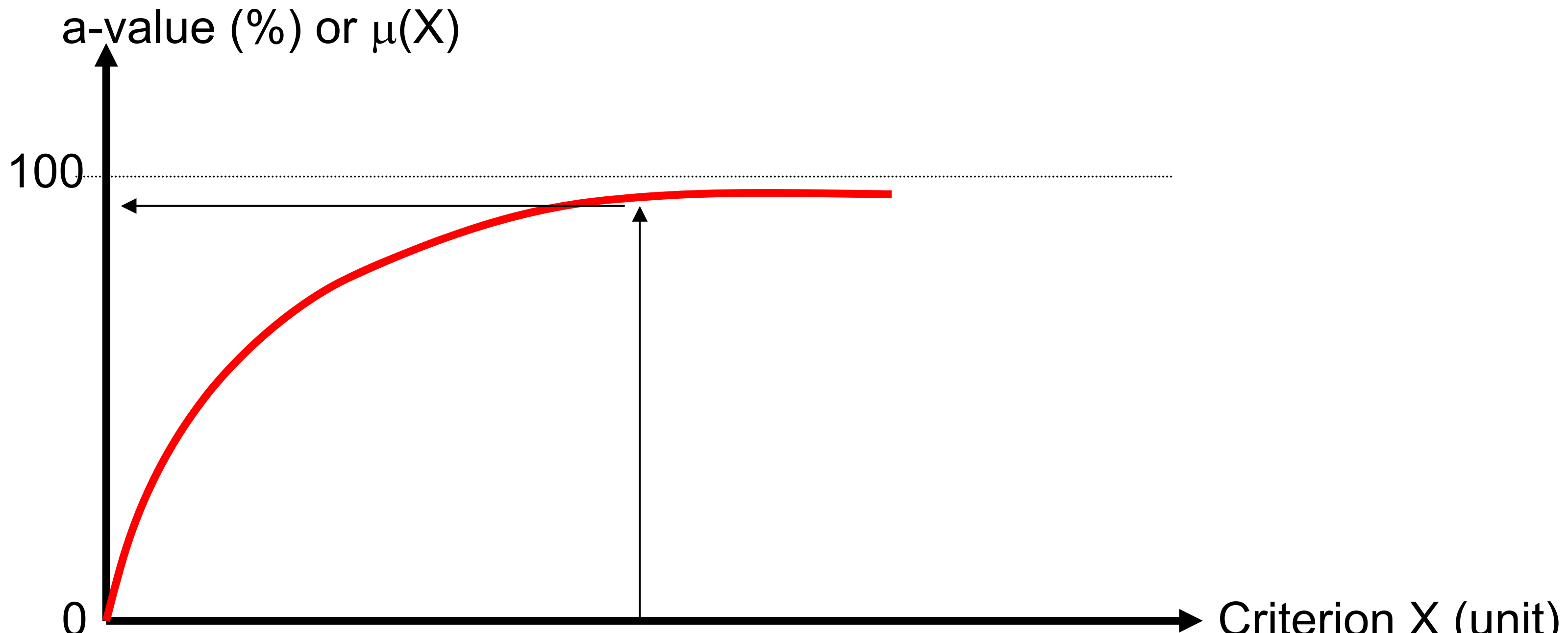
Preferences for ranking alternatives: Weights

• **Economic efficiency**	**0.5**
annual net benefits from power generation (ANB)	0.8
# of shutdown days should be a minimum (OPD)	0.2
• **Environmental quality**	**0.5**
ensure a minimum water depth	0.2
preserve the water volume	0.2
preserve variability in width of the water body	0.2
avoid major changes in water temperature	0.2
avoid changes in oxygen concentration	0.2

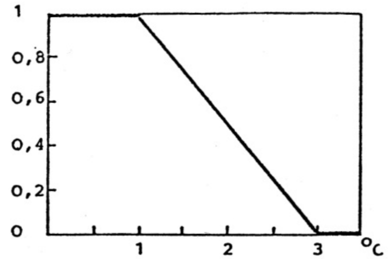
Transforming Outcomes (measured by criteria) into values

How can we evaluate an outcome ?

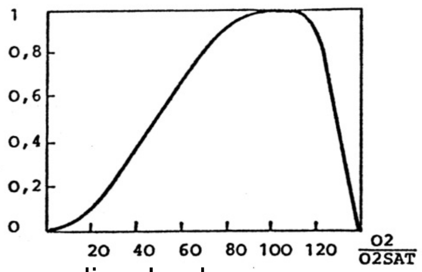
We need to scale the outcomes: (linear, nonlinear)



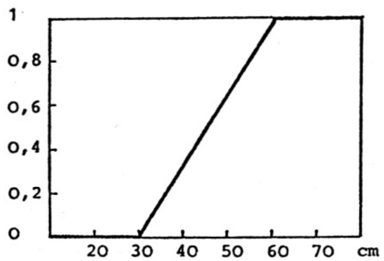
Transforming outcomes into values



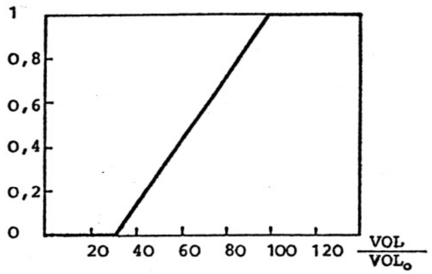
Change in water temperature



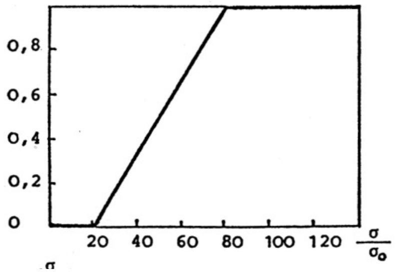
dissolved oxygen concentration



Maximum water depth

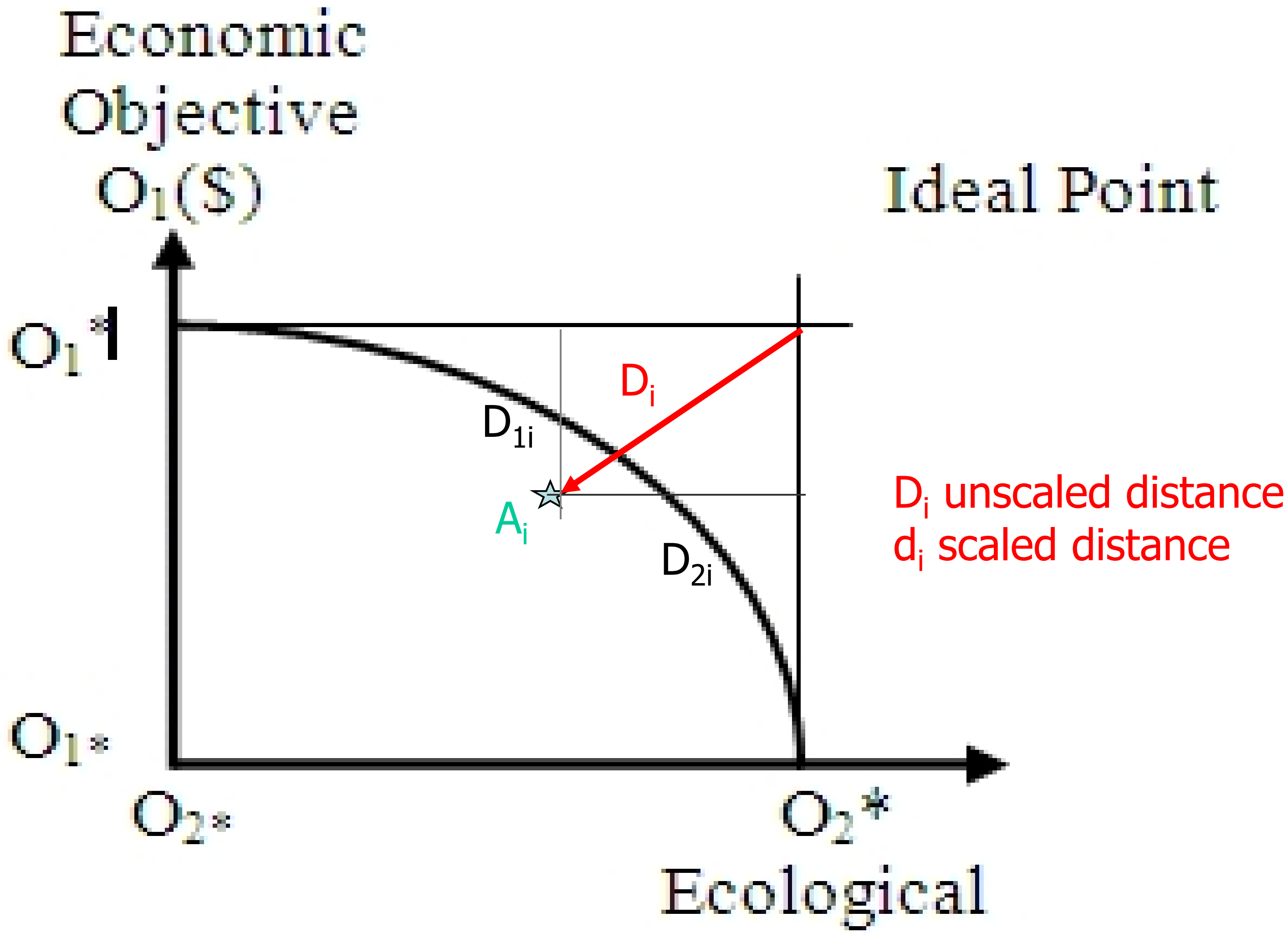


remaining water volume



Variability in river width

Selection of Favourable Solutions



Identification of Favourable Solutions

$$d_{i,j} = 1 - a_{i,j}$$

Distance with respect to one criterion

$$L_i(p) = \Sigma(w_j \cdot d_{i,j}^{p})^{1/p}$$

Overall distance

Wj weights
P trade-off factor

Aggregation of Outcomes

- **How to aggregate different outcomes ?**
- **Which trade-offs ?**
  - *** Trade-off among environmental indicators is p_2=3-4**
  - *** Trade-off among economic indicators p_1=2**
  - *** Trade-off among economic and ecological objectives is q=2**

- **Hierarchical ranking**

What are the Main Decision Variables ?

- Restructering of the river bed upstream
- Length of the diversion
- **Instream water requirements**
- Restructuring of the diverted section

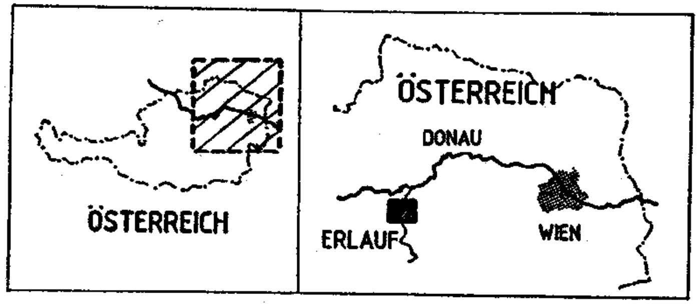
Generation of alternatives

- **Here, only the instream requirements (minimum remaining discharge Qp in the old river bed) is considered**
- **An infinite # of alternatives exists**

Generation of alternatives: Models and data

- Outcomes were monitored during several days
- Data were used to calibrate/validate models
- Models were used to simulate other flow conditions

The Case Study



A small hydropower station in Lower Austria

There are more than 2000 SHPs in Austria

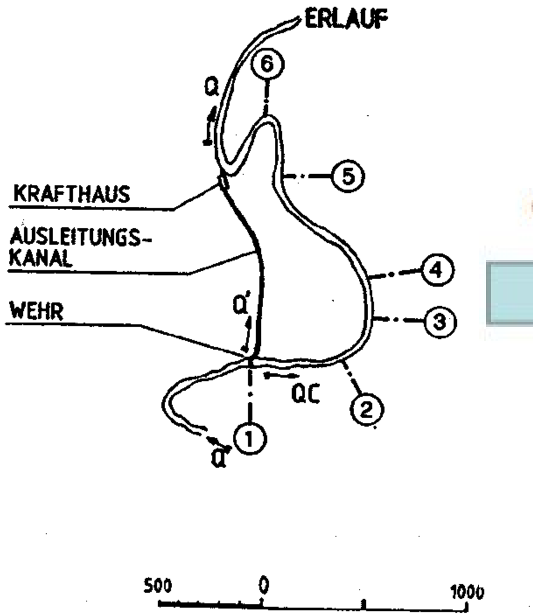
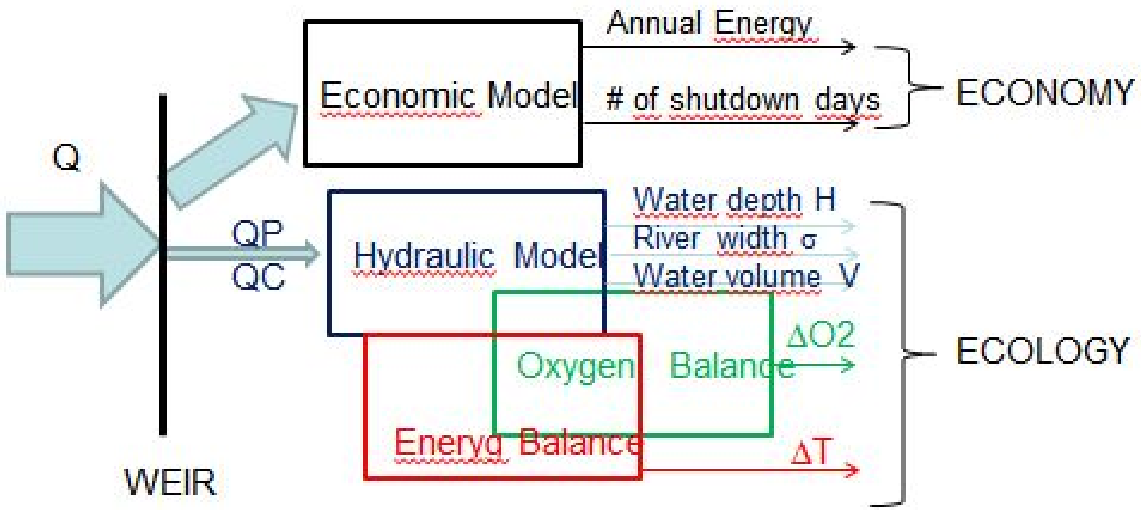
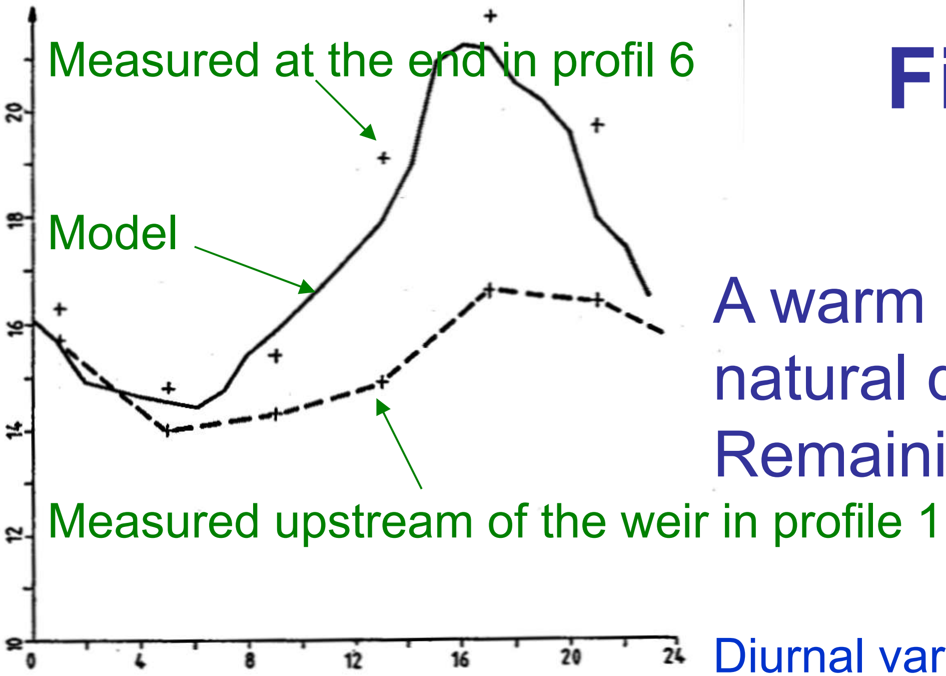


Abb. 2. Umleitungskraftwerk an der Erlauf (NÖ)

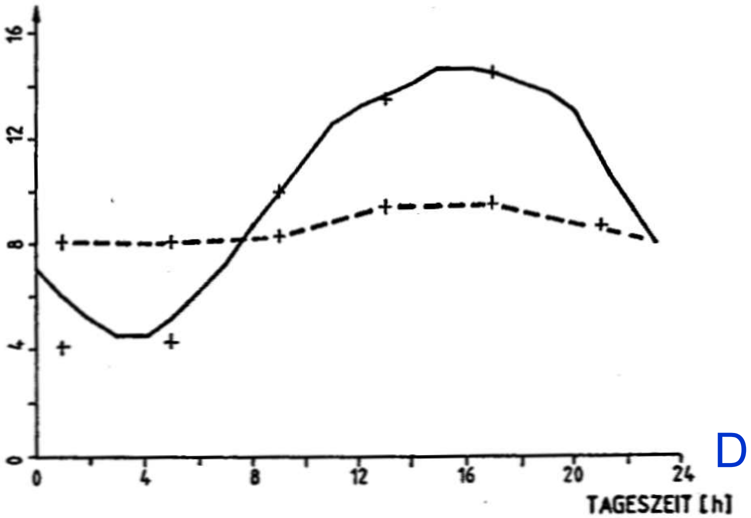


Field Measurements and Model Results

A warm summer day:
natural discharge is about 8.7 m^3/s
Remaining discharge is about .18 m^3/s



Diurnal variation of temperature (T°)



Diurnal variation of dissolved oxygen (mg/l)

Approach

- Model simulate different remaining discharges (alternatives)
- Outcomes are evaluated by utility functions (membership functions)
- Individual values are aggregated by using weights (w) and trade-offs (p)
- Graphical representation
- Distances are calculated
- Ranking

Calculation of the Distance

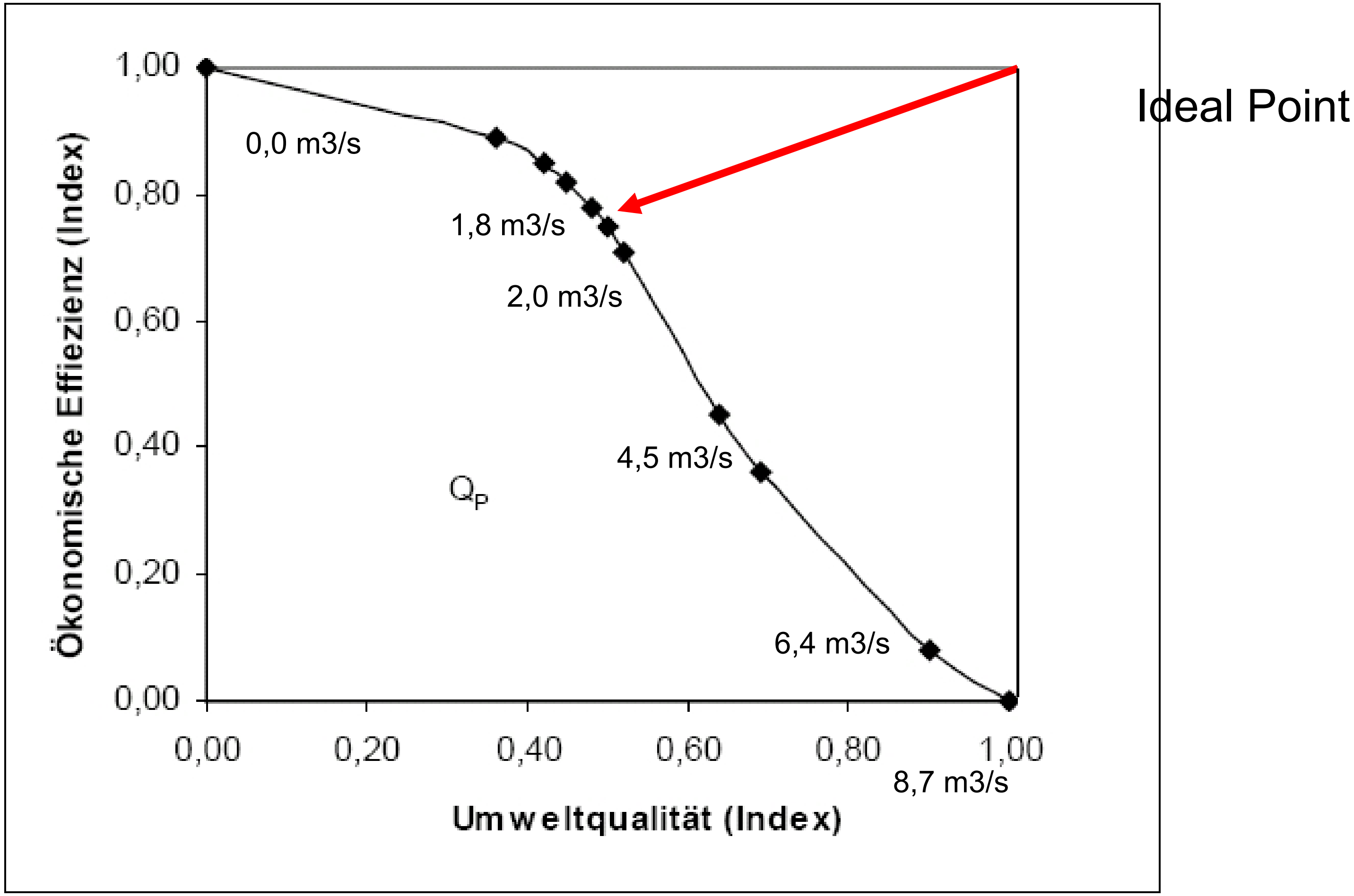
- **For each alternative (characterised by a QPi) the distance to the ideal point is calculated**

$$Z_1 = \left\{ \alpha_{1,1} \left| \frac{ANB^+ - ANB}{ANB^+ - ANB_-} \right|^{P_1} + \alpha_{1,2} \left| \frac{OPD_+ - OPD}{OPD_+ - OPD_-} \right|^{P_1} \right\}^{1/P_1}$$

$$Z_2 = \left\{ \sum \alpha_{2,i} \cdot \left(\mu_1 \left(X^+ \right) - \mu_1 \left(X \right) \right)^{P_2} \right\}^{1/P_2}$$

$$Z_0 = \left\{ \beta_1 Z_1^q - \beta_2 Z_2^q \right\}^{1/q}$$

Graphical representation of alternatives



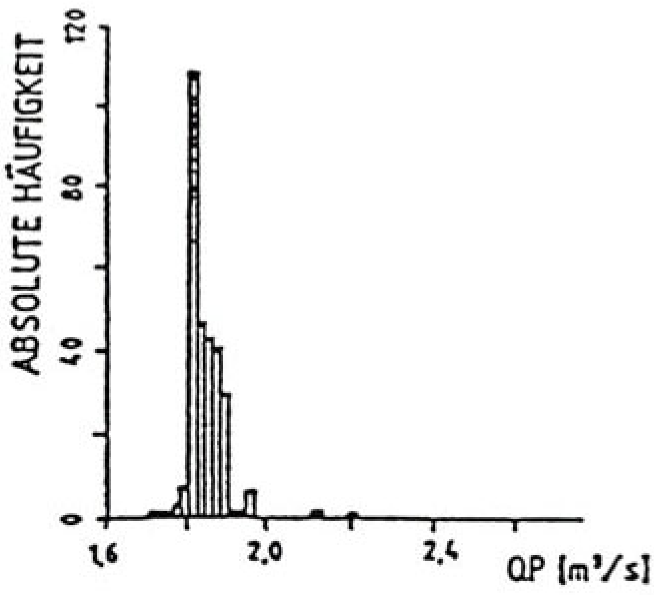
Consideration of uncertainties

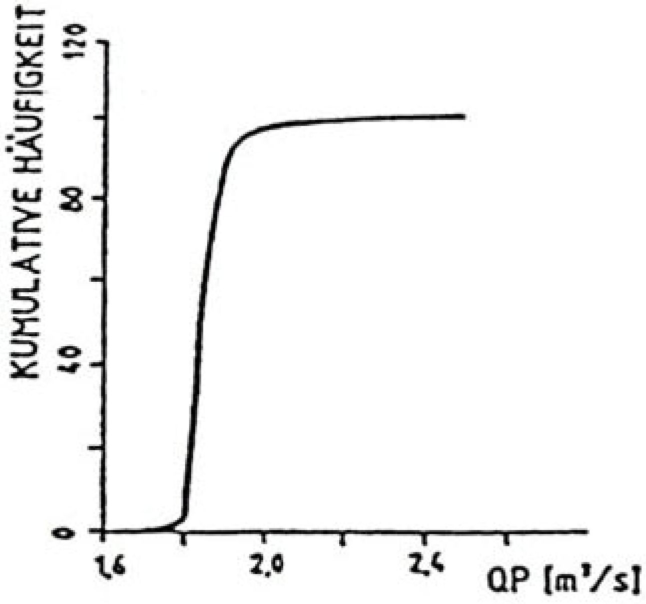
- Uncertainties (natural variability in input)
- Uncertainties in model (parameters,…)
- Uncertainty in impacts (is something missing ?)
- Uncertainty in preferences (w, p, q)

- Can be considered by simulations

Example: uncertainty in input

- **300 different hydro-meteorological conditions are generated and the procedure is repeated. QP has a pdf!**





Compromise Solutions

- **Compromise solutions require a minimum discharge Q_p of about 1,7-2,2 m^3/s**
- **Prescribed discharge is 50 l/s**
- **Mean annual discharge 13,5 m^3/s**
- **The smallest observed discharge in 30 years was 1,87 m^3/s**

Summary and Conclusions:

- **Example: SHP and instream water requirements**
- **Multi-objective context**
  economy and ecology
- **Compromise (composite) programming was applied**
- **Allocation equal weights to Economy and Ecology results in a compromise solution (Q_P= 1.9 m^3/s)**
- **Several models were developed (hydraulic, economic, environmental impact model)**
- **The uncertainty in the input and in preferences was analysed**

Summary and Conclusions

- **Uncertainty in input yields a range 1.7 m³/s $<Q_P<$ 2.25 m³/s**
- **Uncertainty in the weights**
- **Yields stable solutions**
- **Minimum of Q_P is about minimum observed**