Unit 2:
Systems Approach to Risk
Linking Loads with Responses

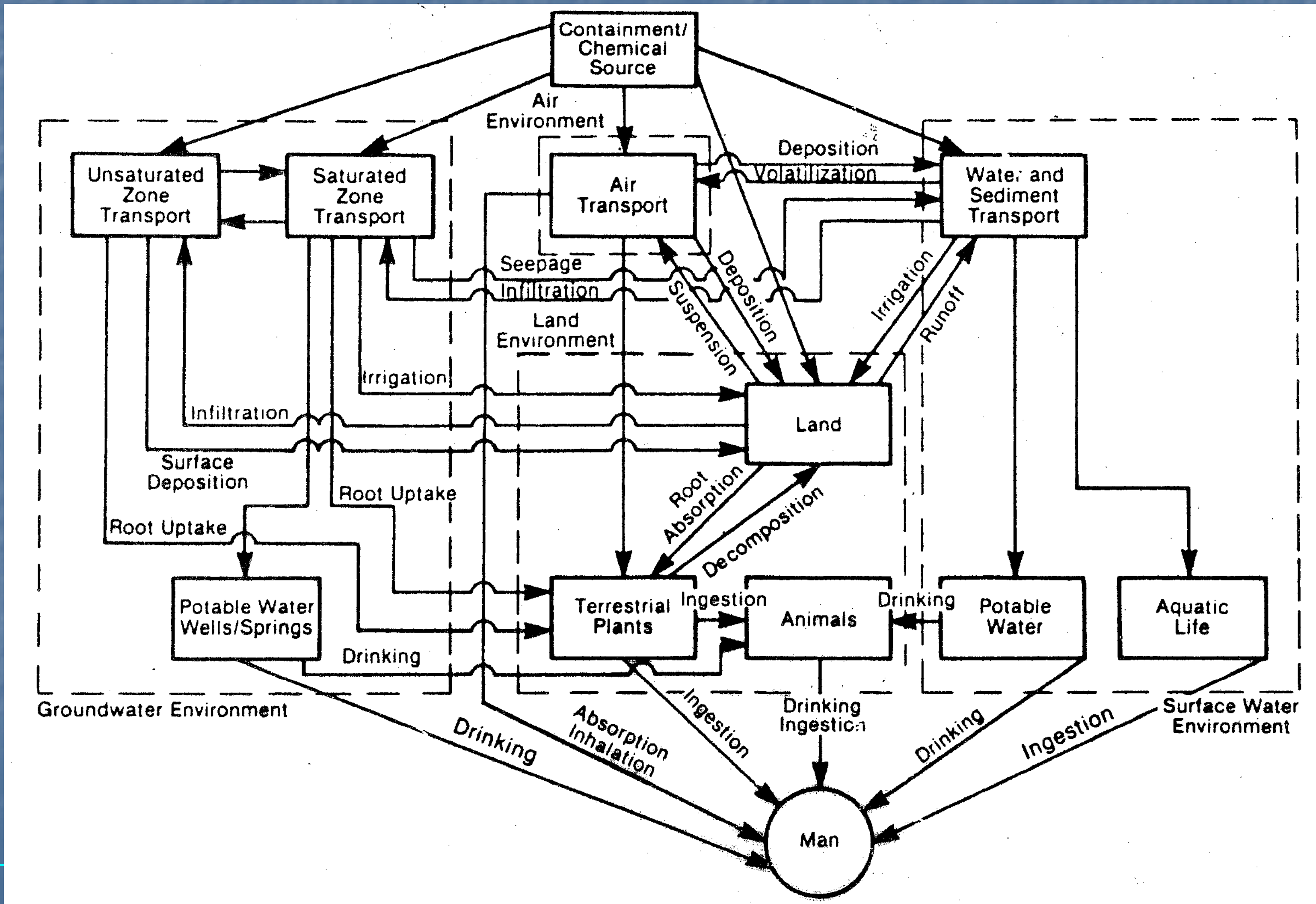
H.P. Nachtnebel

Dept. of Water-Atmosphere-Environment
Univ. of Natural Resources
and Applied Life Sciences
hans_peter.nachtnebel@boku.ac.at

Methodology

- Events (hazards) X may appear at location x at time t and can be described by its magnitude (intensity) z and the respective coordinates $X(z,x,t)$
- Impacts D may appear with some delay at $t+\Delta t$ at another location $x+\Delta x$ and are described by a set of criteria CR (economic, social and environmental impacts) $D(CR, x+\Delta x, t+\Delta t)$
- To assess the risk we have to combine both and we need models to link hazards with impacts

Linking hazards and impacts: Environmental transport processes



Linking loads and impacts

- A hazard can be described by its occurrence (intensity, location, time)
- The impacts are described by people affected (#), damages (€), impacted cultural heritage (# and degree), in a certain region within a time period
- Models are needed to link hazard and impacts

Living in a dynamic environment

- We realize some impacts from hazardous events (may be observed at several locations and at different times)
- We take measures to reduce the impacts
- As a consequence, we change the state of the environment
- And observe responses…..

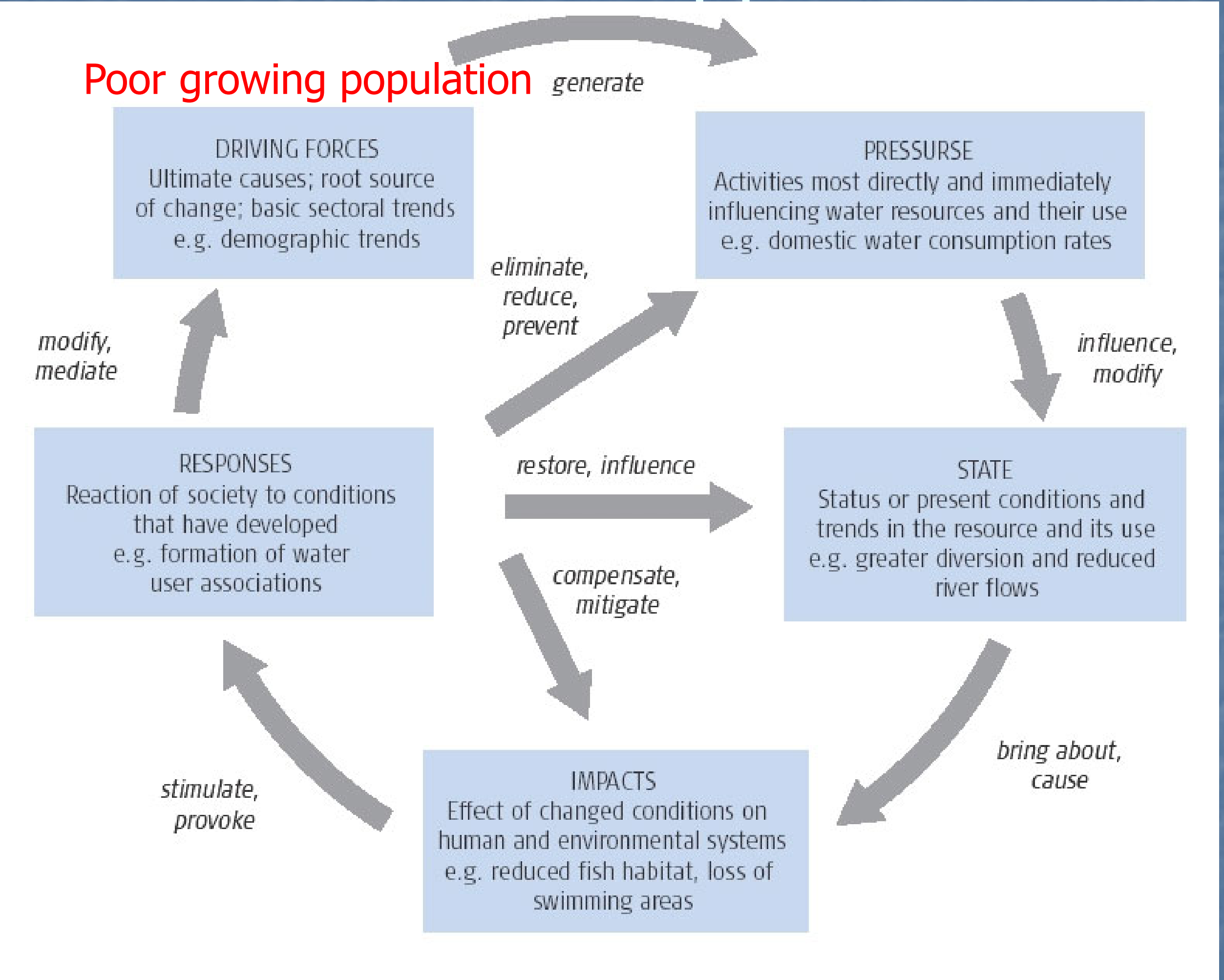
- A framework is needed to describe this process

Impact Assessment (Linking Decisions With Outcomes)

- Several approaches have been applied.

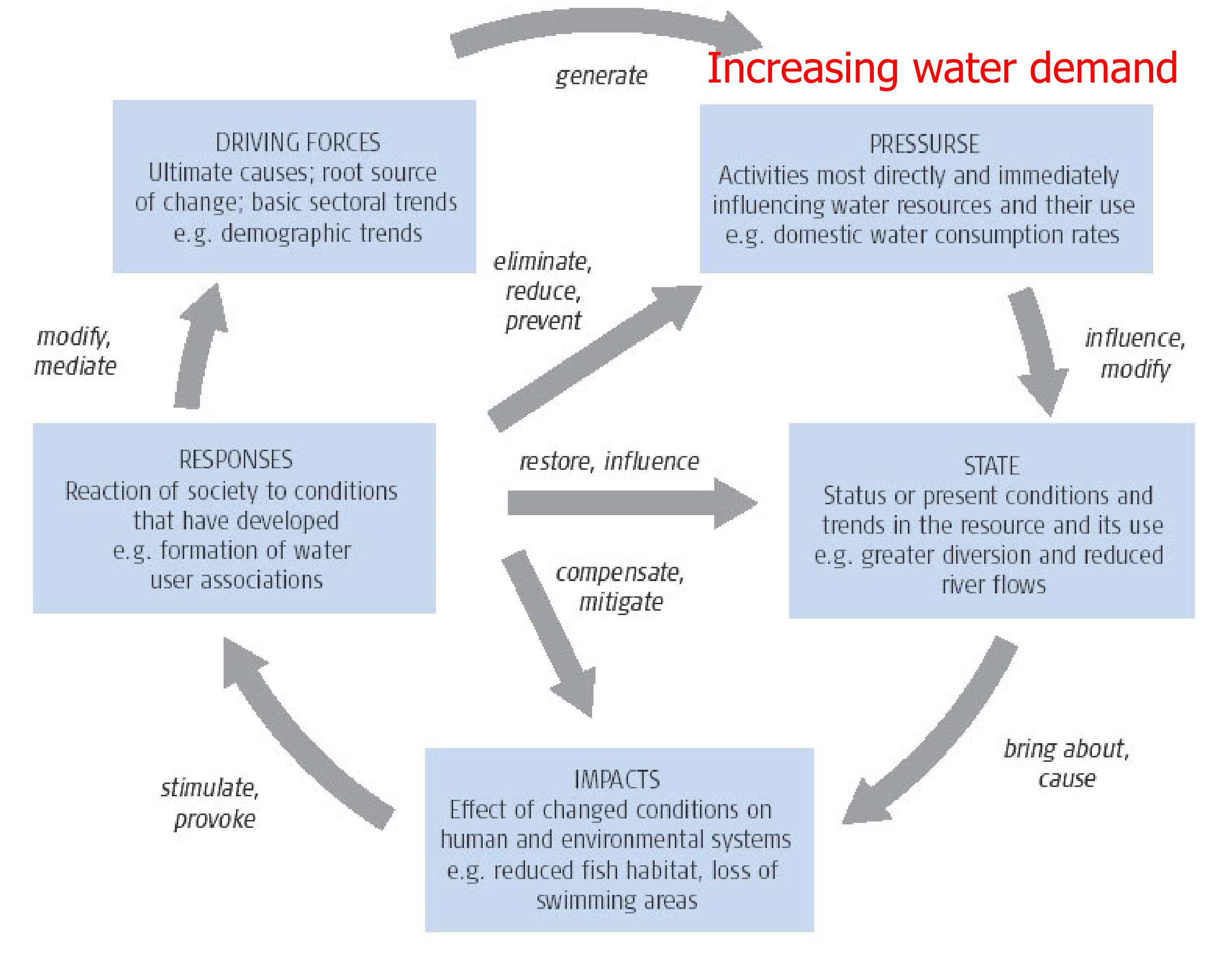
  Examples:
  DPSIR : a methodology used by EEA
  State Space Approach (classical scientific approach)

DPSIR Approach



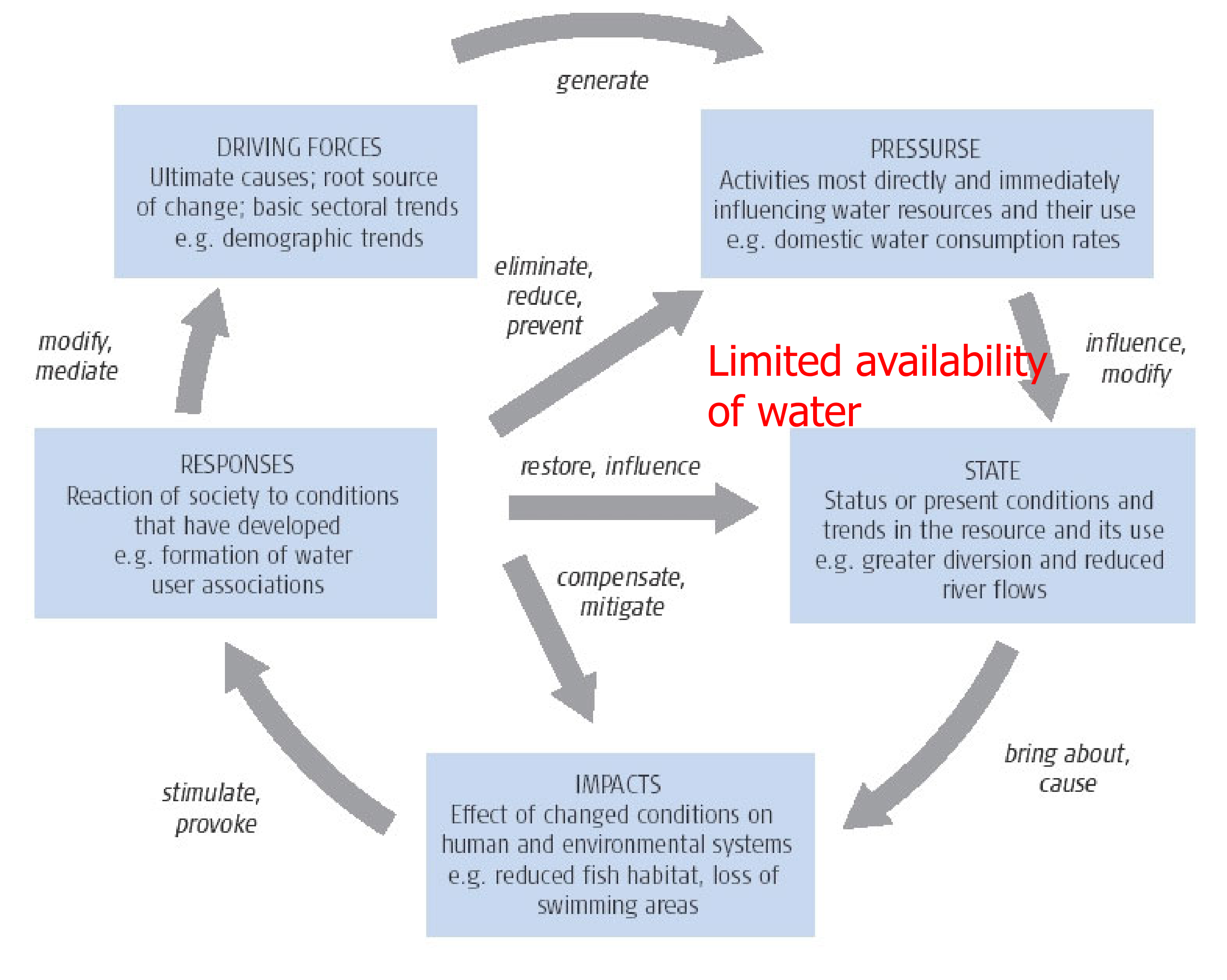
Source: Costantino et al., 2003.

DPSIR Approach



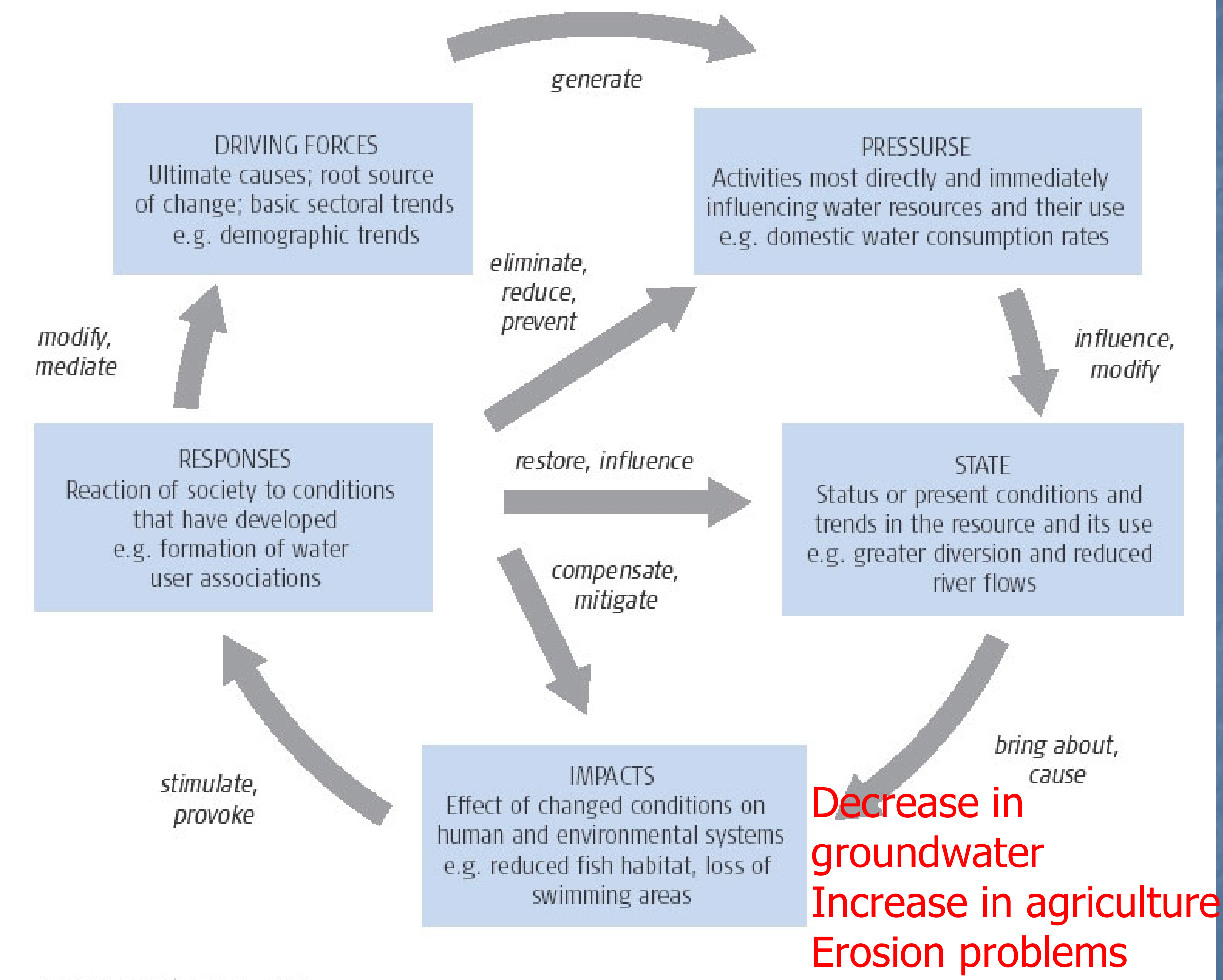
Source: Costantino et al., 2003.

DPSIR Approach



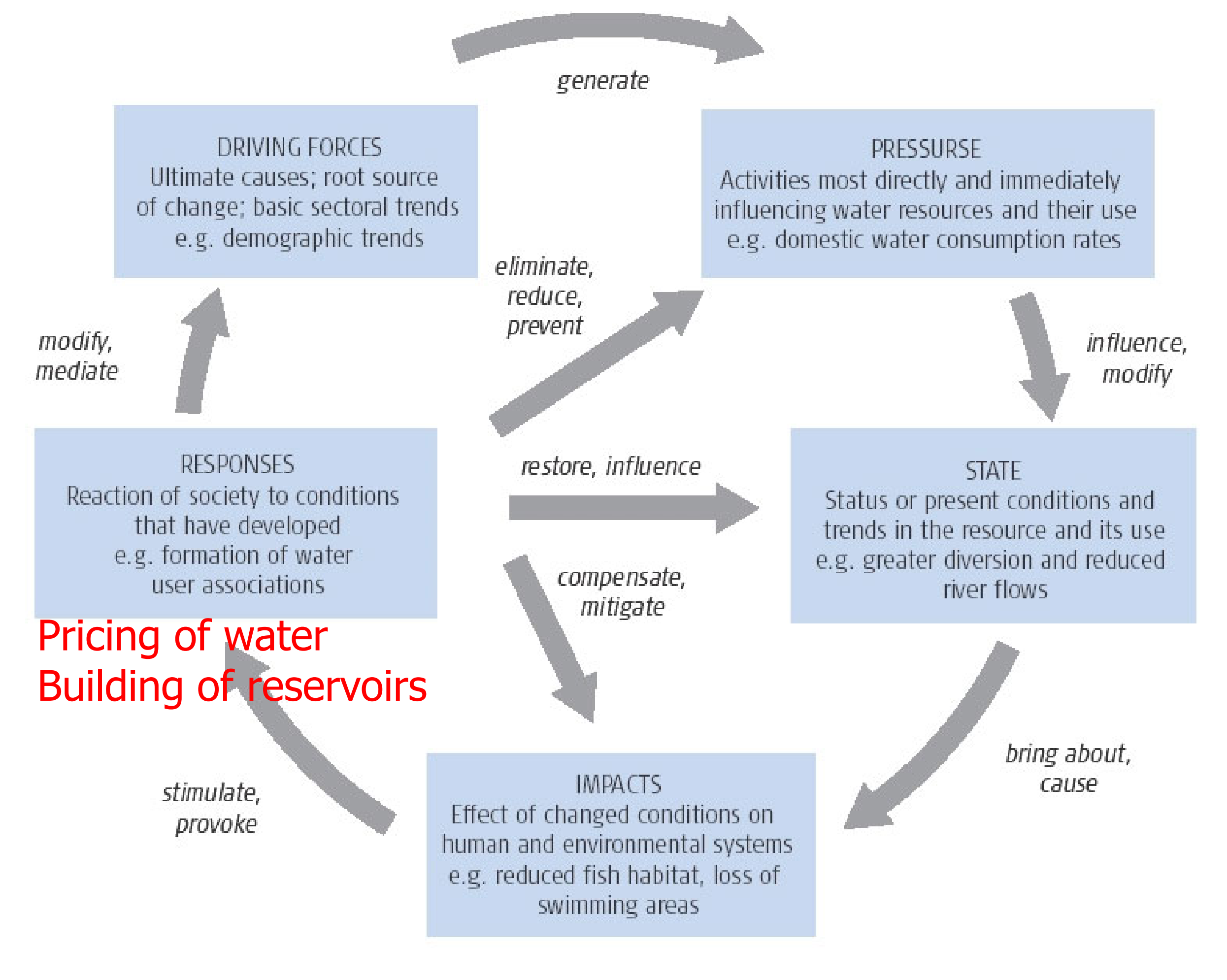
Source: Costantino et al., 2003.

DPSIR Approach

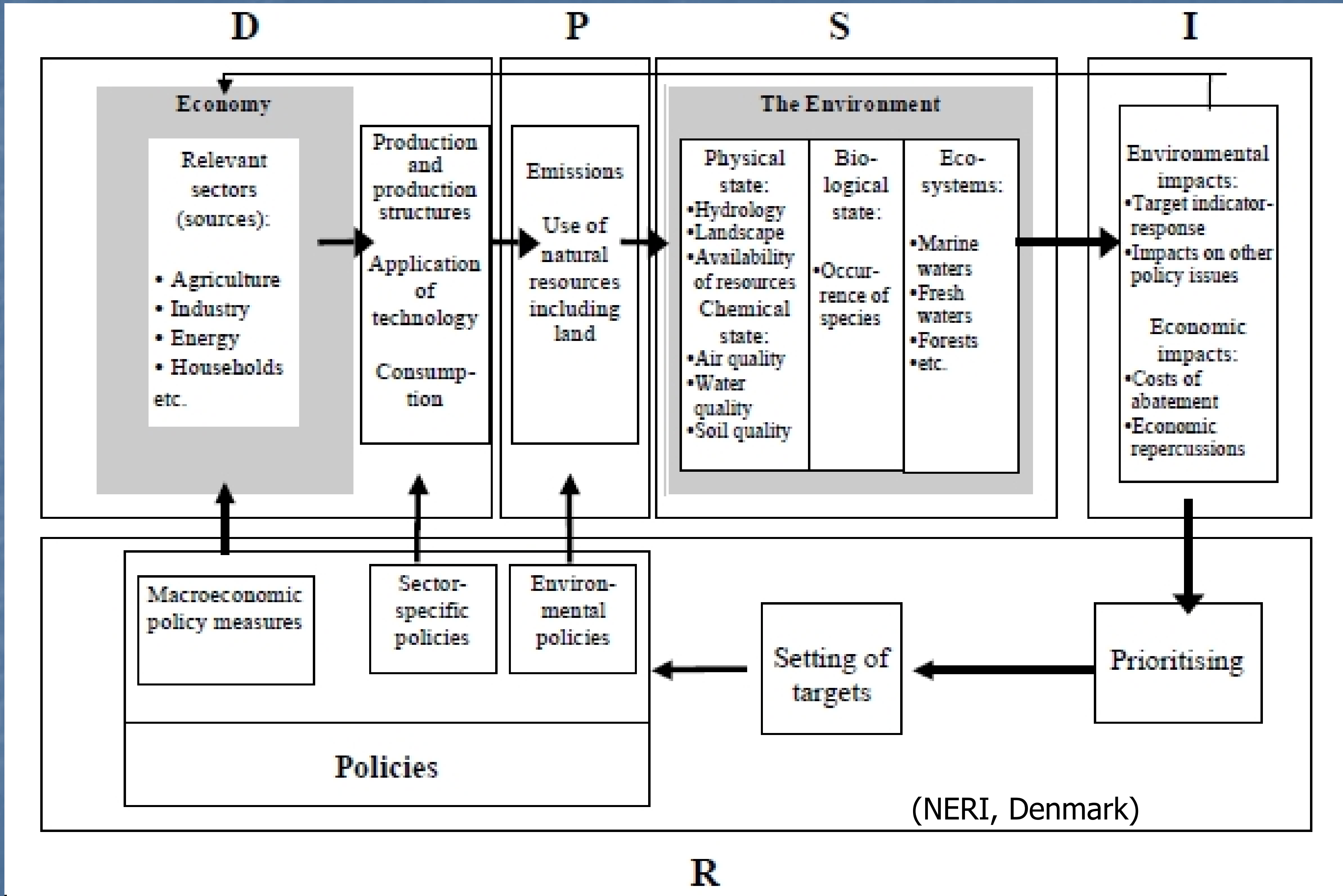


Source: Costantino et al., 2003.

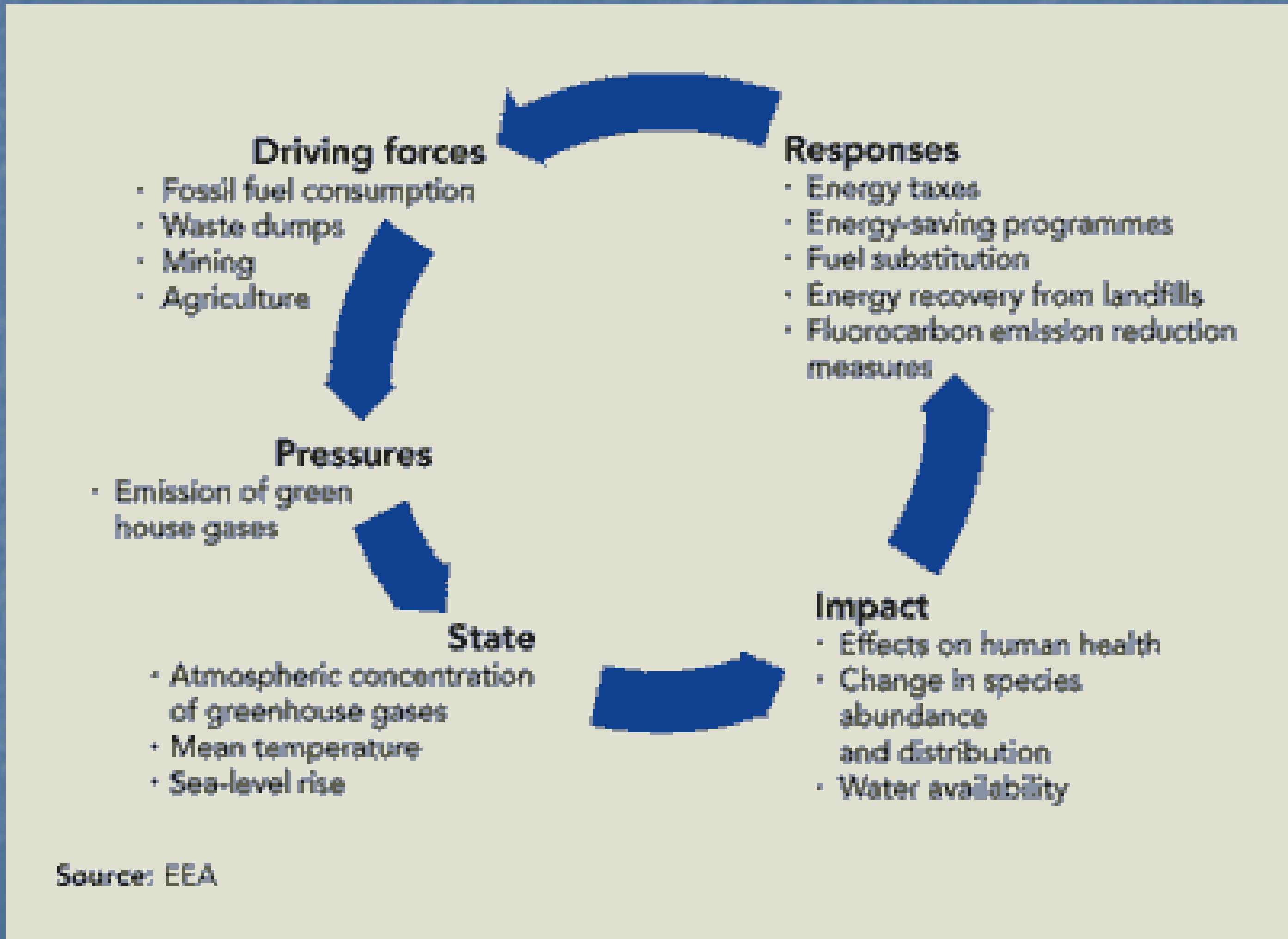
DPSIR Approach



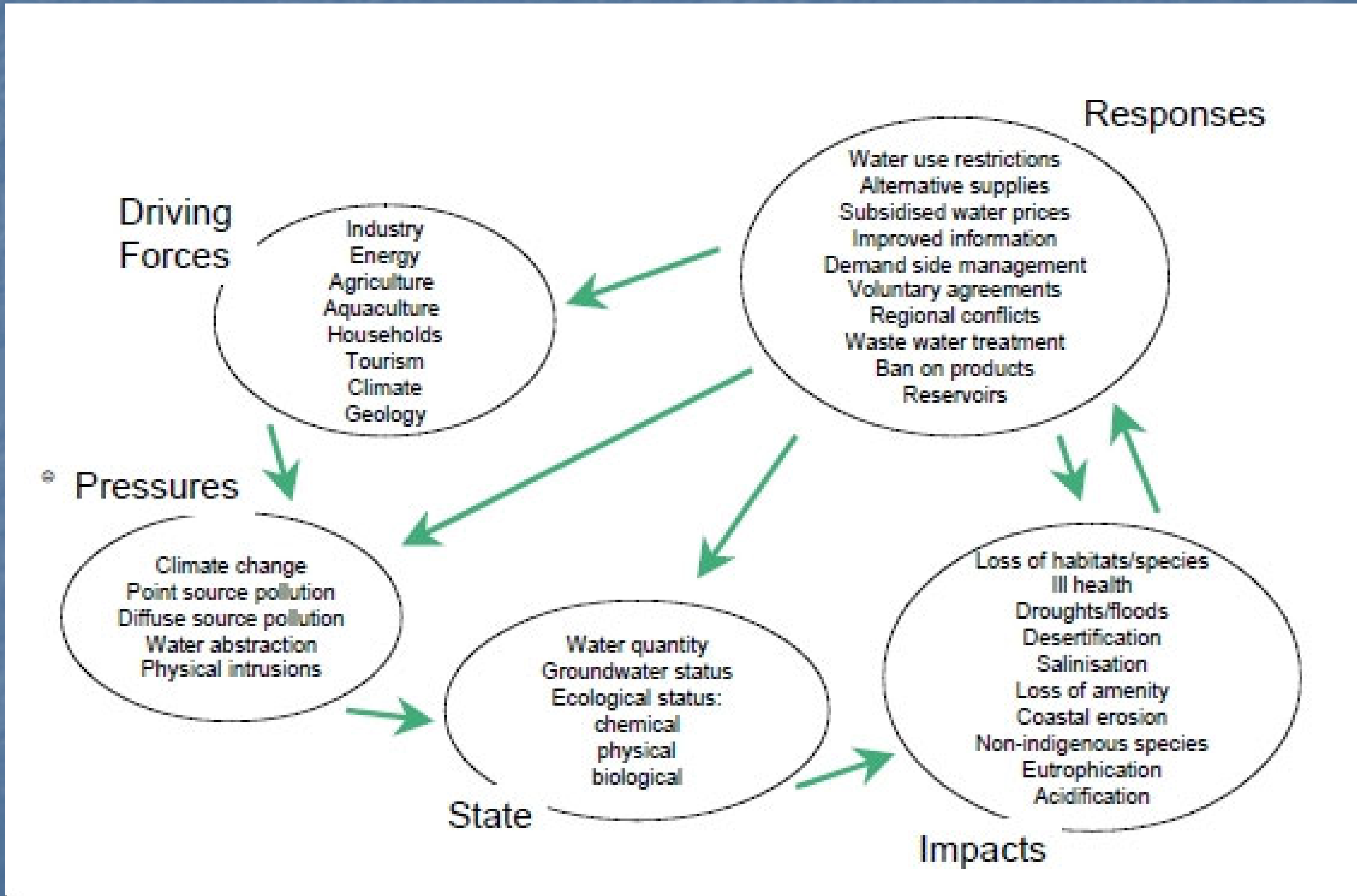
Source: Costantino et al., 2003.


D
P
S
I
Economy
Relevant sectors (sources):
• Agriculture
• Industry
• Energy
• Households
etc.
Production and production structures
Application of technology
Consump-tion
Emissions
Use of natural resources including land
The Environment
Physical state:
•Hydrology
•Landscape
•Availability of resources
Chemical state:
•Air quality
•Water quality
•Soil quality
Bio-logical state:
•Occur-rence of species
Eco-systems:
•Marine waters
•Fresh waters
•Forests
•etc.
Environmental impacts:
•Target indicator-response
•Impacts on other policy issues
Economic impacts:
•Costs of abatement
•Economic repercussions
Macroeconomic policy measures
Sector-specific policies
Environ-mental policies
Setting of targets
Prioritising
Policies
(NERI, Denmark)
R

DPSIR and greenhouse gases

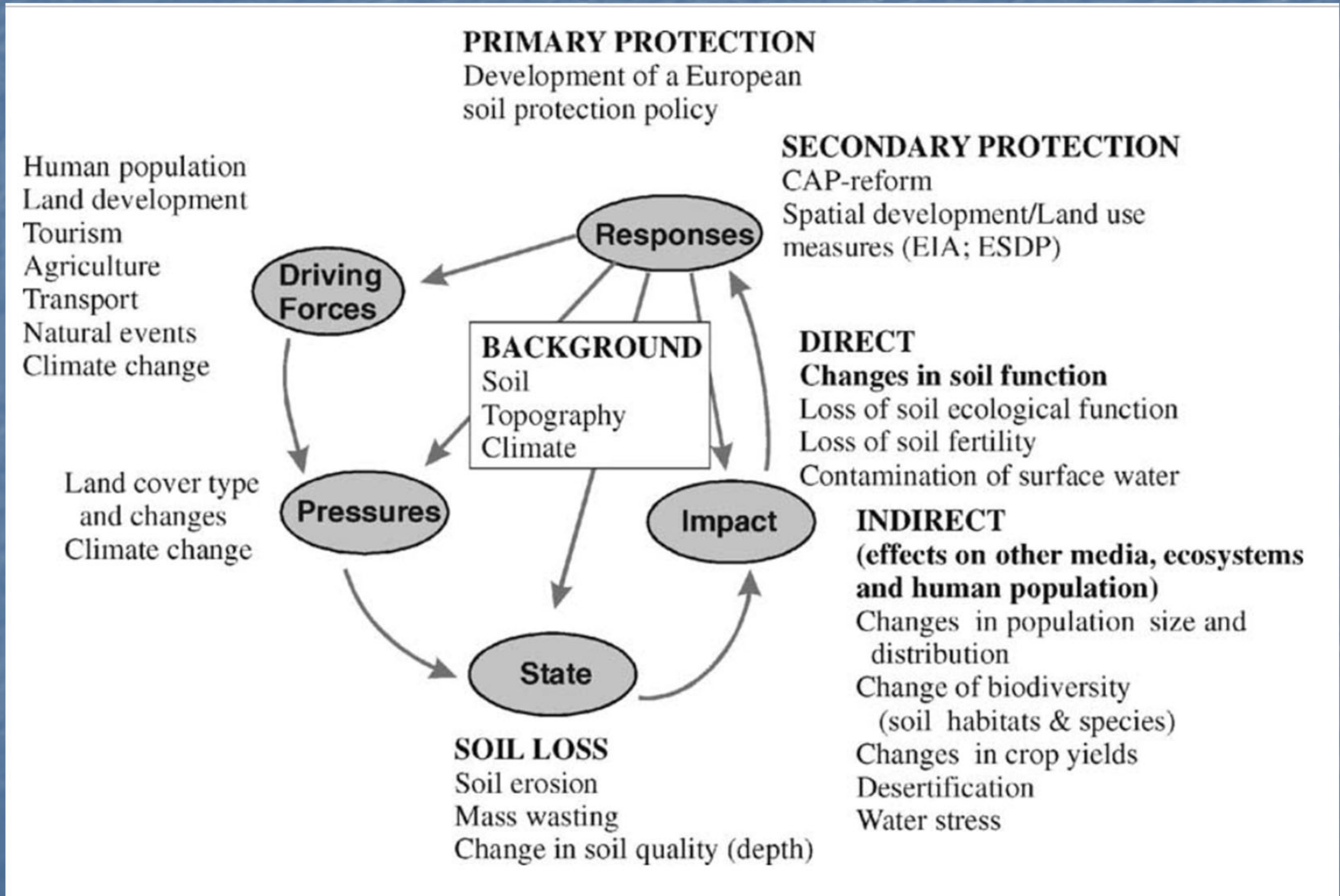


DPSIR in the water sector



DPSIR framework applied to soil erosion

A. Gobin et al. / Environmental Science & Policy 7 (2004)



DPSIR Framework in Forest Management

(Vacik et al., 2006. DOI: 10.1079/9781845931742.0393)(Vacik et al., 2006)

Driving force	Climate change
	Groundwater recharge
	Hunting
	Recreation
	Timber production
Pressure	Browsing
	Droughts
	Increasing temperature
	Pests (bark beetles)
	Tourist frequency
	Low timber prices

DPSIR Framework in Forest Management

(Vacik et al., 2006)

Driving force	Climate change
	Groundwater recharge
	Hunting
Pressure	

State	Biodiversity (Shannon–Weaver)
	Growing stock
	Contribution margin II
	Damaged wood by bark beetles
	Employment within the enterprise
	Area with broadleaved regeneration
	Naturalness of tree species composition
	Water percolation quantity
Impact	Ratio biodiversity (Shannon–Weaver)
	Ratio growing stock
	Ratio contribution margin II
	Ratio damaged wood by bark beetles
	Ratio employment within the enterprise
	Ratio broadleaved regeneration area
	Ratio naturalness of tree species composition
	Ratio water percolation quantity

DPSIR Framework in Forest Management

(Vacik et al., 2006)

Driving force	Climate change
	Groundwater recharge
	Hunting
Pressure	
State	Biodiversity (Shannon–Weaver)
	Growing stock
	Contribution margin II
	Damaged wood by bark beetles
	Employment within the enterprise
	Area with broadleaved regeneration
	Naturalness of tree species composition
	Water percolation quantity
Impact	Ratio biodiversity (Shannon–Weaver)
	Ratio growing stock
	Ratio contribution margin II
Response	Introduction of broadleaved measures
	Habitat conservation actions
	Enhancing forest patchiness
	Intensity of silviculture/tending
	Controlled timber harvest
	Training activities for the staff

Examples for drivers (Kristensen, 2004)

https://www.researchgate.net/publication/262559565_Assessing_the_Sustainability_of_Urban_Ecosystems_an_Innovative_Approach/figures?lo=1

- A 'driving force' is a need.
- For an individual drivers are the need for shelter, food and water
  secondary driving forces are the need for mobility, entertainment and culture
- For an industrial sector a driving force could be the need to be profitable and to produce at low costs
- For a nation a driving force could be the need to keep unemployment levels low

Pressures (Kristensen, 2004)

- Driving forces lead to human activities such as transportation or food production, i.e. result in meeting a need. These human activities exert 'pressures' on the environment, as a result of production or consumption processes, which can be divided into three main types:
  - excessive use of environmental resources
  - changes in land use
  - emissions (of chemicals, waste, radiation, noise) to air, water and soil.

Examples of pressures (Kristensen, 2004)

- Use of resources
- Emissions (per driving force for numerous compounds)
- direct emissions to air, water and soil
- indirect emissions to air, water and soil
- Production of waste
- Production of noise
- Radiation
- Vibration
- Hazards (risks)

States (Kristensen, 2004)

- As a result of pressures, the ‘state’ of the environment is affected; that is, the quality of the various environmental compartments (air, water, soil, etc.) in relation to the functions that these compartments fulfill. The ‘state of the environment’ is thus the combination of the physical, chemical and biological conditions.

Examples of states

- Air quality (national, regional, local, urban, etc.) expressed by concentration levels of pollutants
- Water quantity and quality (rivers, lakes, seas, coastal zones, groundwater) expressed by available water in a compartment (e.g. surface water) or in a region and expressed by pollution levels
- Soil quality (national, local, natural areas, agricultural areas) fertility, thickness, infiltration capacity, absorbing capacity,…
- Ecosystems (biodiversity, vegetation, soil organisms, water organisms)
- Humans (health status of people)
- Soil use (land use…)

Examples for states (Kristensen, 2004)

- Population (number, age structure, education levels, political stability)
- Transport (persons, goods; road, water, air, off-road)
- Energy use (energy factors per type of activity, fuel types, technology)
- Power plants (types of plants, age structure, fuel types)
- Industry (types of plants, age structure, resource types)
- Refineries/Mining (types of plant/minings, age structure)
- Agriculture (number of animals, types of crops, stables, fertilisers)
- Landfills (type, age)
- Sewage systems (types)
- Non-industrial sectors
- Land use

Impacts (Kristensen, 2004)

The changes in the physical, chemical or biological state of the environment determine the quality of ecosystems and the welfare of human beings.

In other words changes in the state may have environmental or economic 'impacts' on the functioning of ecosystems, their life supporting abilities, and ultimately on human health and on the economic and social performance of society.

Responses

- A ‘response’ by society or policy makers is the result of an undesired impact and can affect any part of the chain between driving forces and impacts.
- An example of a response related to driving forces is a policy to change mode of transportation, e.g from private (cars) to public (trains), while an example of a response related to pressures is a regulation concerning permissible SO_2 levels in flue gases. Another example is certification of CO_2 emission (trading pollution)

DPSIR summary

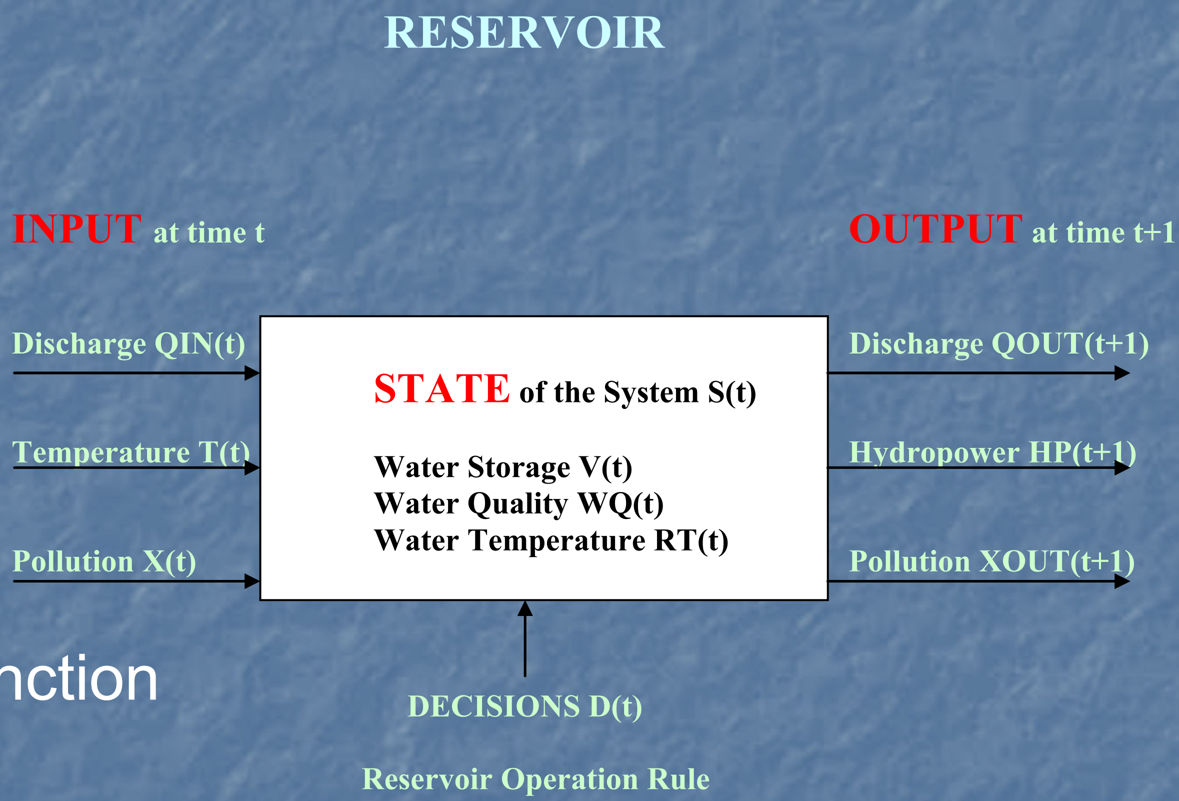
- Provides a logical and flexible framework for assessment and evaluation of impacts
- Often it is applied in a rather descriptive way
- Requires a monitoring system and a date base to quantify the impacts
- Sometimes policies describe rather a general development strategy and then it becomes difficult to measure ist performance

State Space Approach

- More based on numerical models and data
- Assumes that all quantities are measureable
- Assumes that fundamental equations can be applied
  Usually partial differential equations are used
  e.g. Limits of growth, Meadows

State space approach: the 5 elements

- Input
- Output
- State
- Output function
- State transition function



Input

- **Controlled D: Decisions**
  costs allocated for construction, operation and maintenance, (operation rule)

- **partially controlled:**
  reservoir releases (spilling might occur)

- **uncontrolled I:**
  precipitation (streamflows), depending on whether the watershed response is included in the model or not

Output O

- **desirable:**
  water utilization (benefits)

- **undesirable:**
  water deficiencies, floods (losses)

- **neutral:**
  system outflow, seepage, percolation, evaporation etc.

State S

- **Examples:**
  reservoir volumes in timestep t
  soil moisture in timestep t
  vegetation cover in timestep t (winter, summer)

- **System parameters:**
  reservoir capacities, slopes, soils, runoff coefficient, e.g. K and n, parameters of a linear reservoir cascade model for rainfall/runoff modeling or streamflow routing)

Output function F(.)

relates the output O (it is used as a vector) to the state S and the Input I:

O(t)= F(S(t); I(t), D(t))

The Output functions F is only dependent on the previous state S(t) (if a dynamic system is considered) and the input I(t) and D(t)

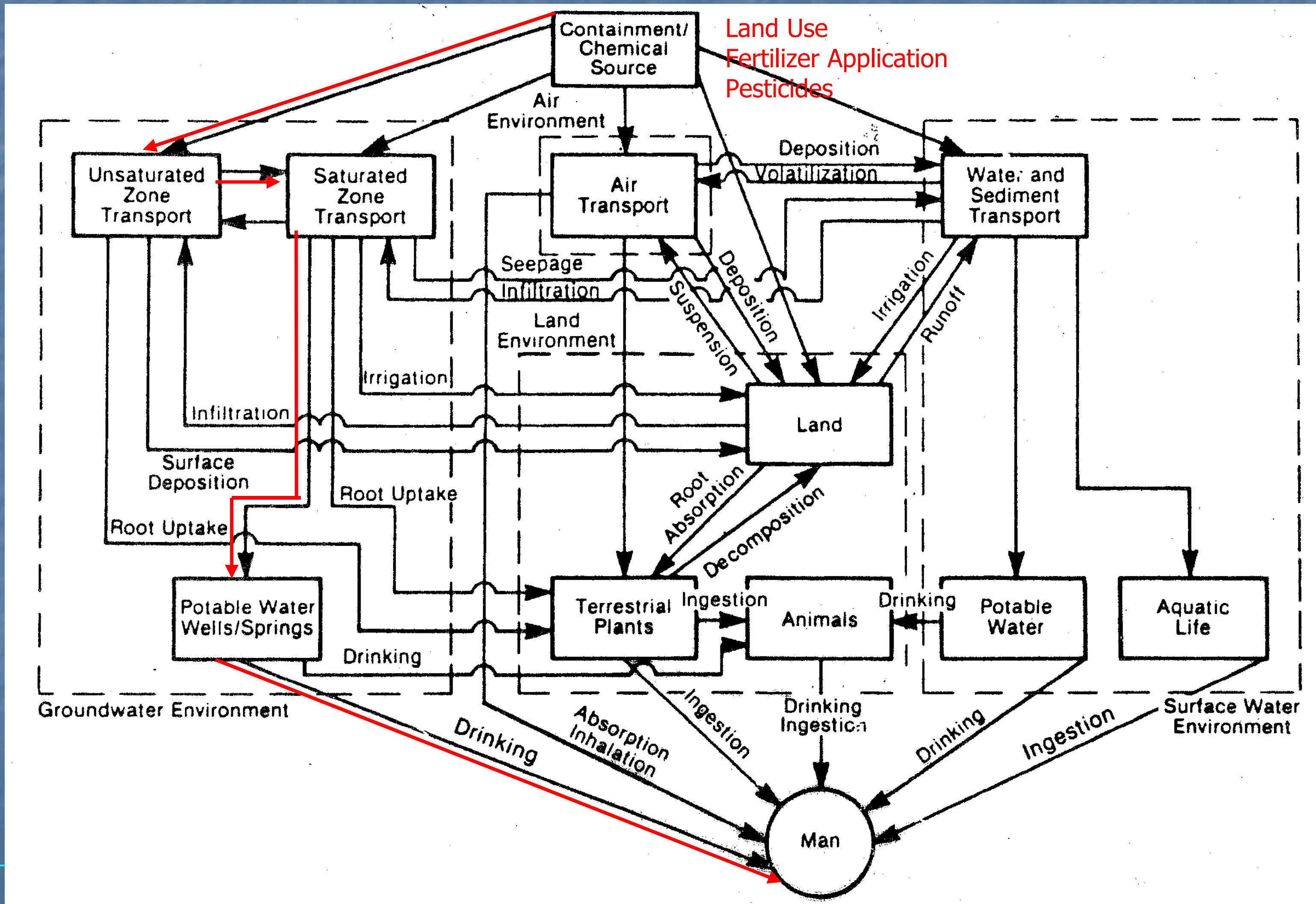
An output variable must not be included !!!!

State transition function G(.)

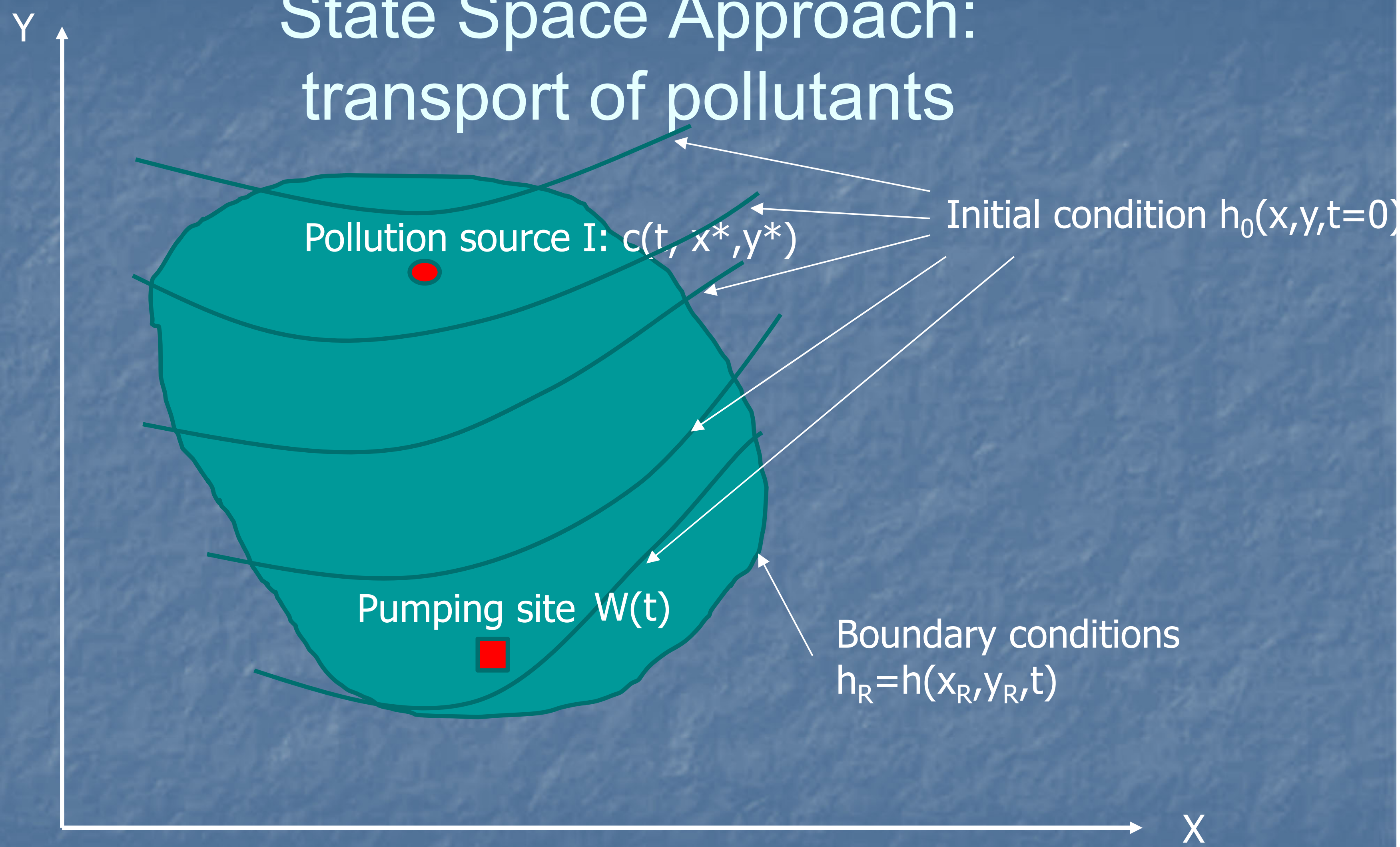
$S(t+\Delta t) = G(S(t); I(t), D(t))$

The state transition function is exclusively dependent on the previous state S(t), the input I(t) and D(t)

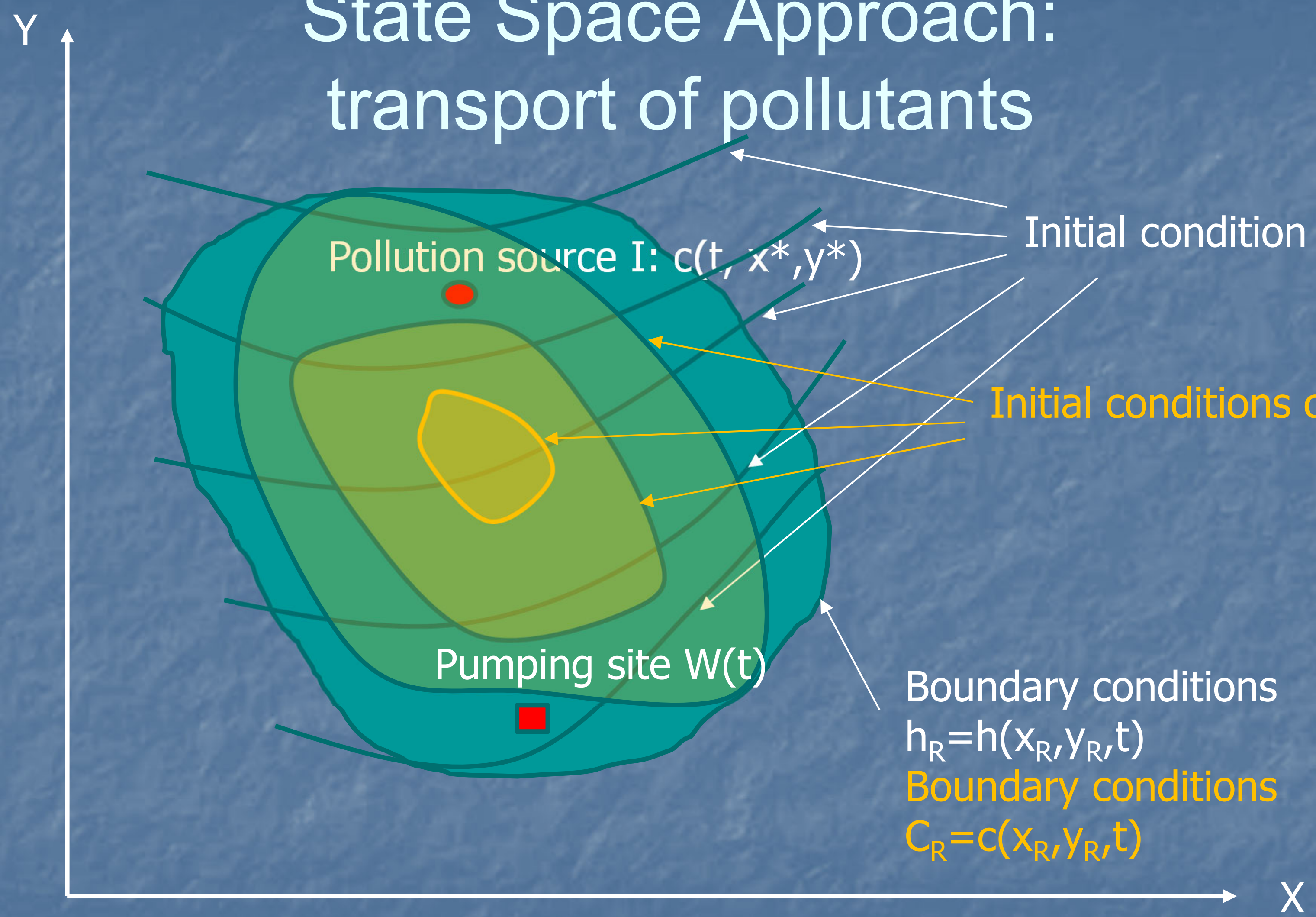
An example:
Land use and impacts on groundwater quality



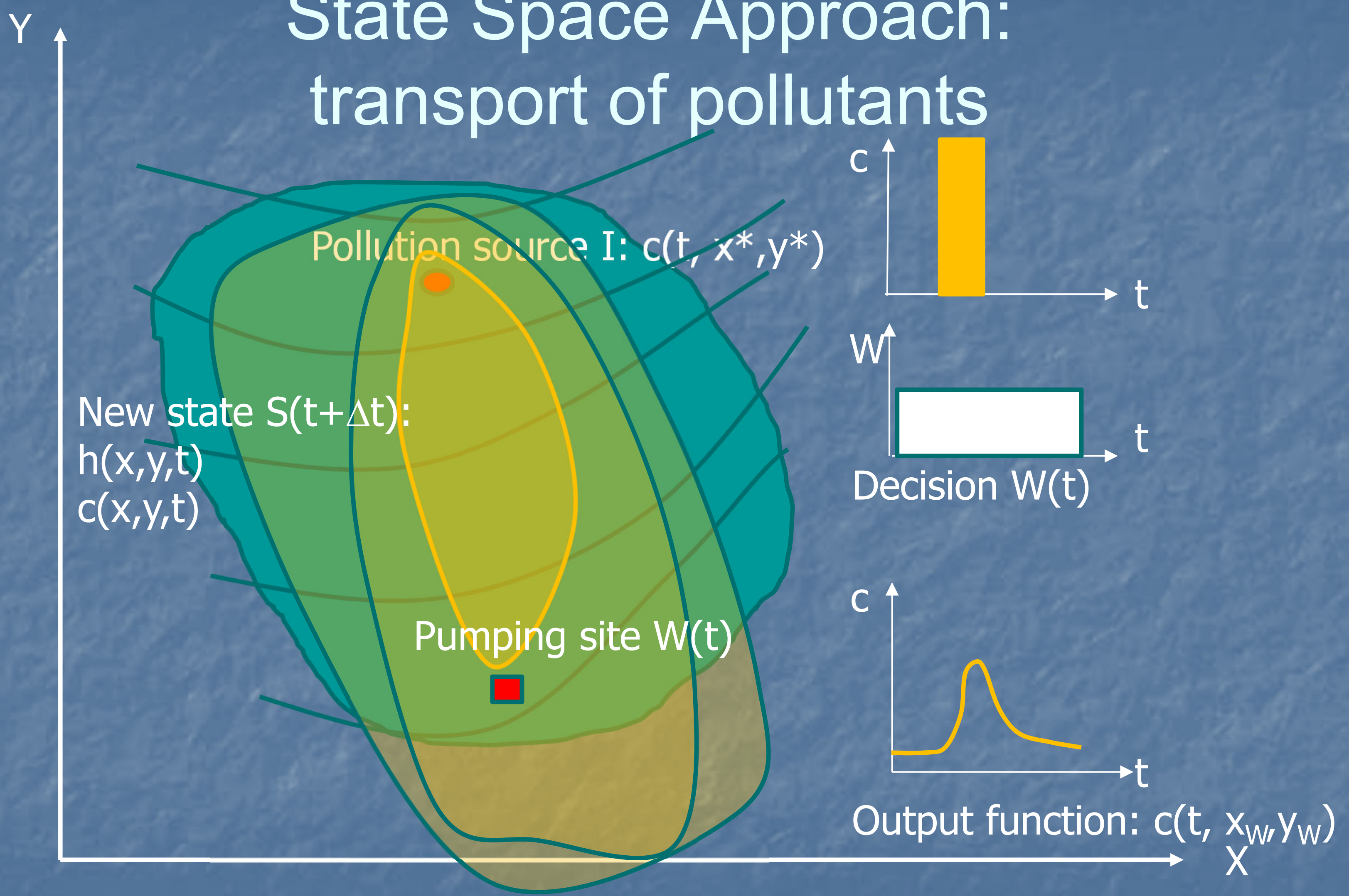
State Space Approach: transport of pollutants



State Space Approach: transport of pollutants



State Space Approach: transport of pollutants



State Space Approach: transport of pollutants

Input: Pollution Source I: c(t, x*,y*)
State: Groundwater level at time t h(t,x,y)
flow velocity v at time t v(x,y,t) (v_x (t), v_y(t))
pollution level c at time t c(x,y,t)
Output: pollution level c at x_w,y_w c(x_w,y_w,t)
Decision: Water abstraction at x_w,y_w in time interval (t, t+ΔT) = W(t)

State transition function S(t+Δt)=F(S(t), I(t); W(t))
Output function O(t+Δt)= G(S(t), I(t); W(t))

To solve the problem initial conditions are needed:

$h_0(x,y)= h(x,y,t=0)$

$c_0(x,y)=c(x,y,t=0)$

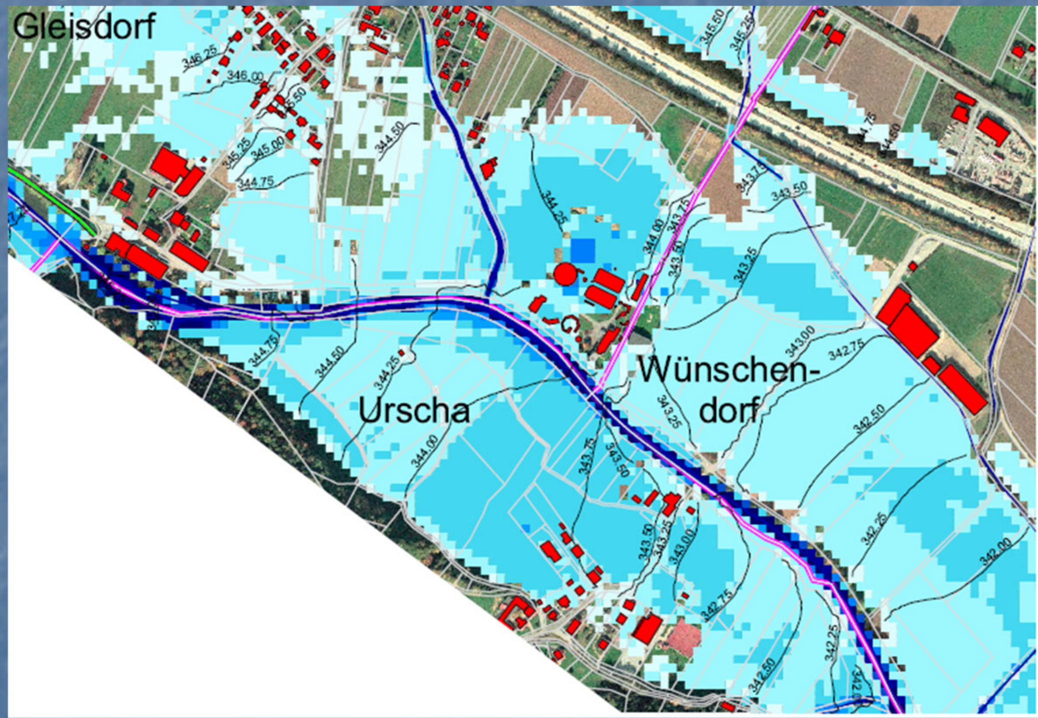
and boundary conditions are needed:

$h_R(t)= h(x_R,y_R,t)$

$c_R(t)=c(x_R,y_R,t)$

State space approach flooding

Input: rainfall somewhere upstream generates a flood $Q_{in}(t)$

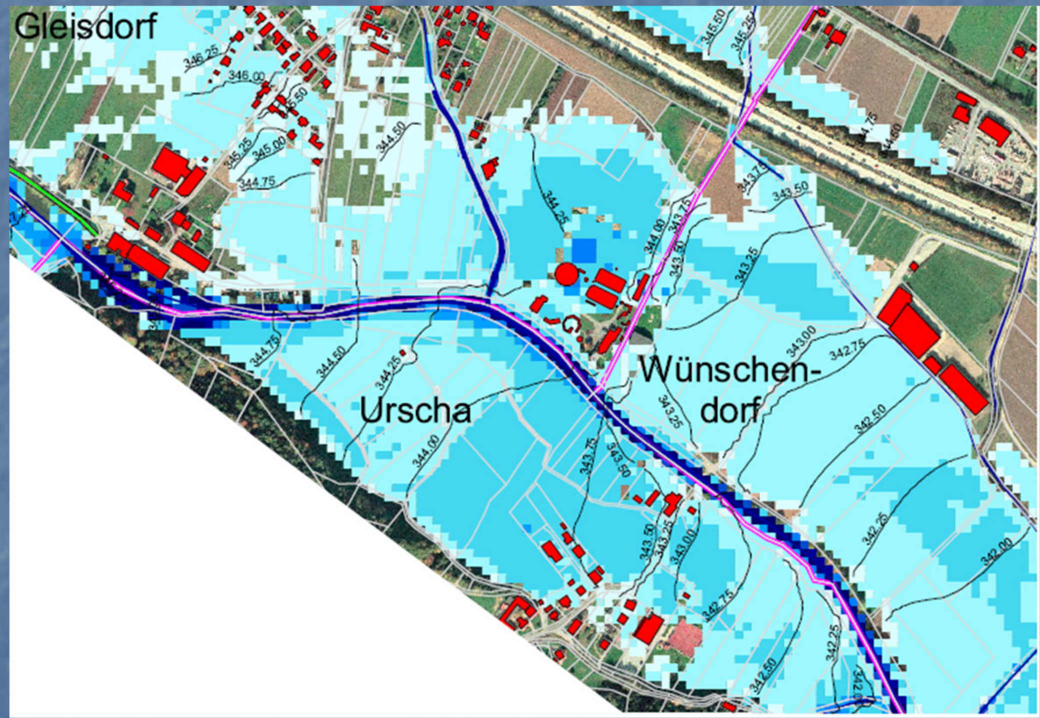


Lower boundary :

State space approach flooding

Input: rainfall somewhere upstream generates a flood $Q_{in}(t)$

State: water table $h(x,y,t)$
derived: h_{inund} (x,y,t)
$v(x,y,t)$, v_x and v_y



Lower boundary :

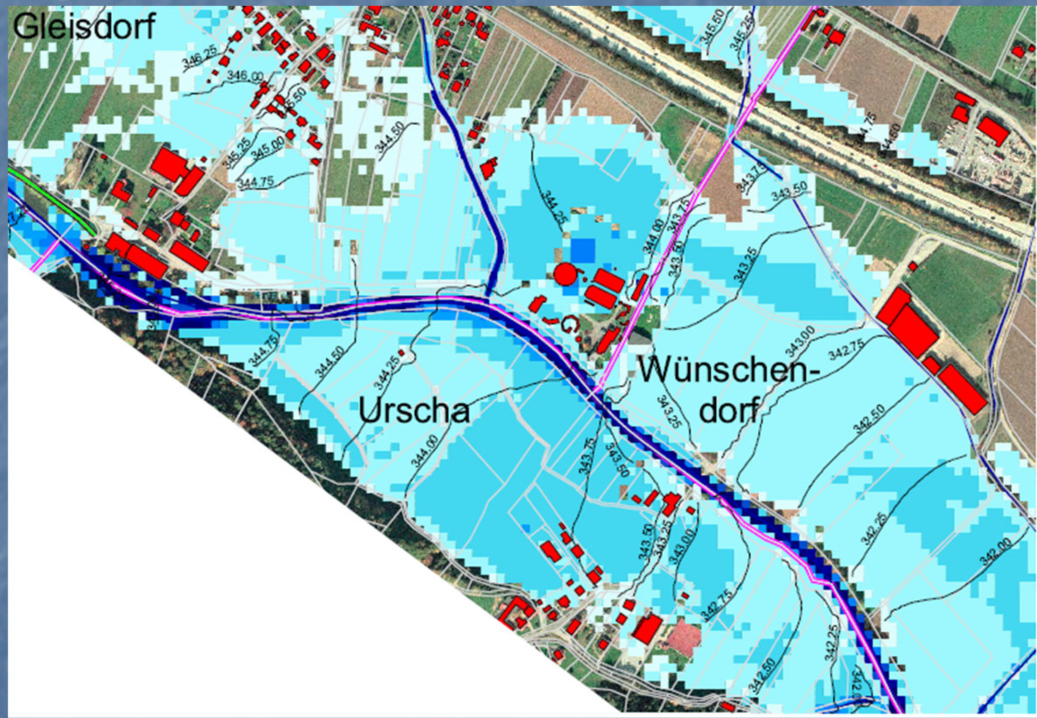
State space approach flooding

Input: rainfall somewhere upstream generates a flood $Q_{in}(t)$

State: water table h(x,y,t)
derived: h_{inund} (x,y,t)
v(x,y,t), v_x and v_y

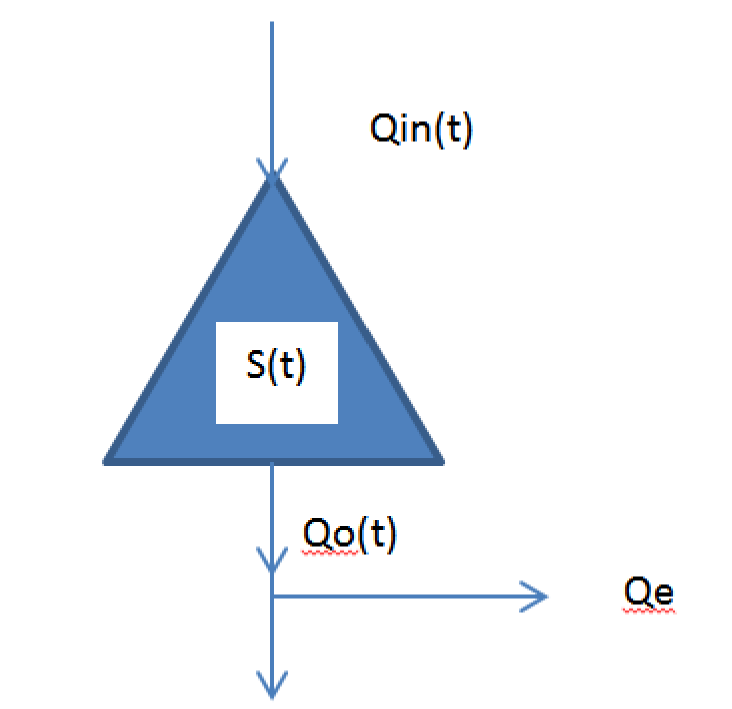
Output: exposed objects or value at risk

Lower boundary :



Example: Reservoir Operation Rule

- A reservoir serves flood protection and irrigation

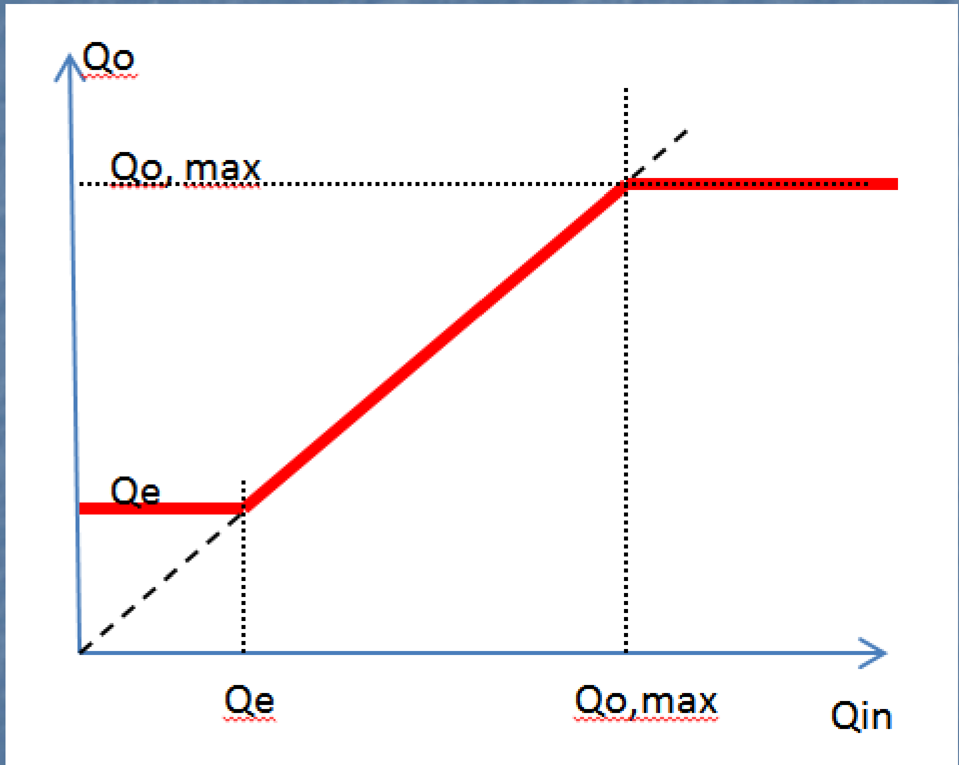


Given: Smax, Smin and Qin(t) and S(t=0)

Define the operation rule that:

Qo(t) < Qo,max	flood protection
Qo(t) > Qe	irrigation

Reservoir Operation Rule (Decision)



This rule is defined by
Qo(t)=Min{Max[Qin(t), Qe], Qo,max}
can be kept as long as
Smin<S(t)<Smax

Otherwise:

when S(t)>Smax then Qo(t)=Qin(t)
when S(t)<Smin then Qo(t)=Qin(t)

Formulation of the State Transition Function

- Starting with $Qo(t)=Min\{Max[Qin(t), Qe], Qo,max\}$

  the water balance equation can be formulated

  $S'(t+\Delta t) = S(t)+[Qin(t)-Qo(t)] \cdot \Delta t = S(t)+ [Qin(t)-Min\{Max[Qin(t), Qe], Qo,max\}] \cdot \Delta t$

- It must be ensured that $Smin<S(t+ \Delta t)<Smax)$ and the

  the state transition function can be formulated

  $S(t+ \Delta t)=Min\{Max[S'(t+ \Delta t), Smin],Smax\} = G[S(t), I(t)]$

Formulation of the Output Function

- $Qo(t) \cdot \Delta t = S(t) - S(t+\Delta t) + Qin\ (t) \cdot \Delta t = F\{S(t), G[S(t), I(t)]\}$

Goals and objectives

Objectives indicate the directions of state change of a system desired by the decision maker(s).

There are three possible ways to improve an objective:

maximizing it,
minimizing it or
maintaining it at a given (status quo) position.

Examples

Examples of objectives are optimization of economic payoff, environmental quality, water supply, mitigation of natural and man-made hazards.

Criteria

criteria are based on standards, rules or tests on which judgements or decisions can be based.

One or several criteria may characterise an objective.

Identification of societal preferences

- A very difficult step
  it should be based on governmental declarations, development plans, international and national standards

Impact table

- The impact table quantifies the measurable impacts of each alternatives on all the criteria

alternatives	A1	A2	A3	Aj	An
criteria C1					
C2					
C3					
Ci				Cij	
Cm					

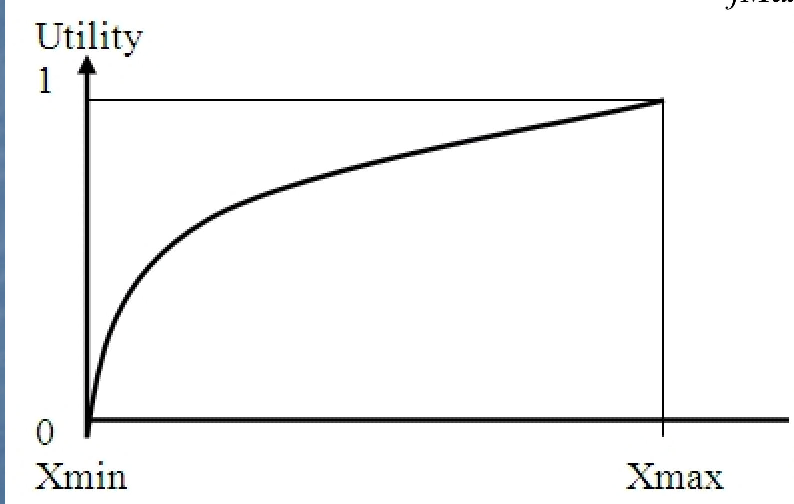
Efficiency or pay-off table

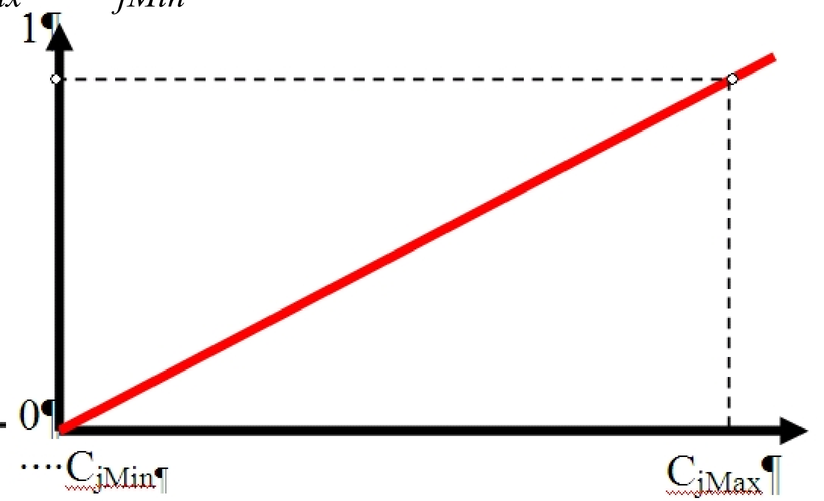
- The impact table is transformed into the efficiency table by scaling all physical outputs onto a scale (0-1)
  - Linear scaling
  - Nonlinear scaling
  - Scaling a physical unit onto a ordinal scale

Scaling

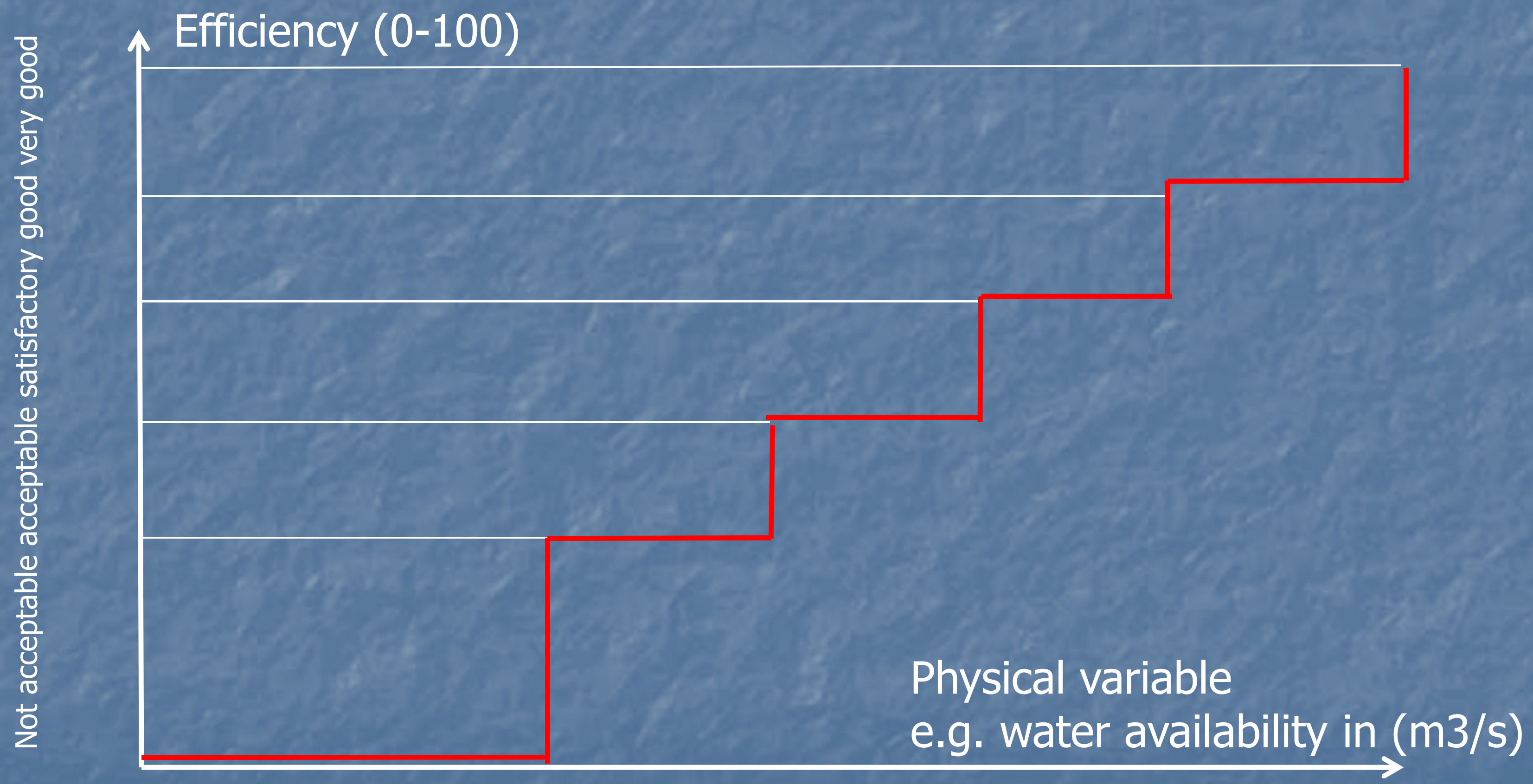
- The physical outcomes have to be transferred into appreciation values (often the efficiency in reaching an objective is used)

$$a_{i,j} = \frac{c_{i,j} - c_{jMin}}{c_{jMax} - c_{jMin}}$$





Scaling


Not acceptable acceptable satisfactory good very good
Efficiency (0-100)
Physical variable
e.g. water availability in (m3/s)

Ranking of alternatives

- In the efficiency table all elements are scaled within 0-1
- Now outcomes with respect to different criteria have to be compared
- This requires preferences of each partner and trade-offs

Different approaches

- outranking techniques (for discrete alternatives only)
- distance-based techniques and
- value- or utility-based techniques.

Sensitivity analysis

- Several sources of uncertainties are inherent to the whole process

  deficits and errors in the data base
  randomness in natural processes
  uncertainties in models
  imprecision in knowledge of societal preferences
  external interventions

- Therefore a sensitivity analysis is obligatory

Sensitivity and uncertainty

- To consider the various sources of uncertainty different approaches are possible
- Change the physical outcomes by +/- 10 % and analyse the impacts on ranking
- Describe the inputs by a pdf and estimate the pdf of the outputs (by simulation)
- Chnage the preferences and anaylse the consequences for ranking

Summary and Conclusions

- A framework for linking loads with responses has been formulated
- (Plan impact matrix, efficiency matrix, Dose Response functions…)
- Identification of main elements in this process

Summary

- DPSIR a logical framework to analyse complex and not well structured problems
- State Space Approach: a physically based framework rather applicable for well defined problems
- The evaluation of impacts is always related to societal preferences and thus the qualitative evaluation may change, even when the impact level is the same