Hydro-economic modelling

Trade-offs in water quality policy

March 12, 2018, Vincent Linderhof

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Outline

- Introduction
- Part 1
  - Pollution control in the NL
  - Water Framework Directive
- Part 2
  - Economic models with hydrology
  - Hydrological model for cost-effectiveness analysis

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- Pollution control in the Netherlands

Pollution control in the NL

- Since the 1970s environmental law, namely
    - Clean air policy (1976),
    - Water policy (1969), and
    - Nature conservation policy (1967/1998)
- Environmental Impact Assessment (1986)
- Environmental Management Act (1993); integration of policies; forming an integral general environmental licensing procedure.
- EU framework directives (several years)

Source: Environmental Policy in the Netherlands (Schiller, 2009)

Clean air policy

- 1970 Air Pollution Act (APA) forms the legal framework for legislation on air pollution (emissions from point and diffuse sources)
- 1986 Environmental Impact Assessment Act
- 1993 Environmental Management Act (EMA); procedural regulations *integrated* into the EMA-procedure, forming an integral general environmental licensing procedure.
- 1998 EU framework directive Air Quality amending APA and EMA

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Water policy (quality)

- 1969 Surface Water Pollution Act (SWPA); to prevent and to restrict the pollution of surface water by *direct* or *indirect* emissions into the water.
- 1983 Decree Water Quality Standards and Water Quality Monitoring fixing quality standards for drinking water, fishing water, bathing water, amongst others.
- 1986 EIA & 2003 EMA
- 1996 Decree Emission Urban Waste Water due to UWWTD (91/271/EEC)
- 2002 Regional Water Boards

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Nature policy

- 1967/1998 Nature Protection Act
  - the ‘protected natural monuments’,
  - the ‘protected landscapes’,
  - the ‘areas for implementation of international obligations’, and
  - the provision of financial contributions.
- 1979/1991 EU Birds Directive (79/409/EEC) & 1991 Habitat Directive (92/43/EEC)

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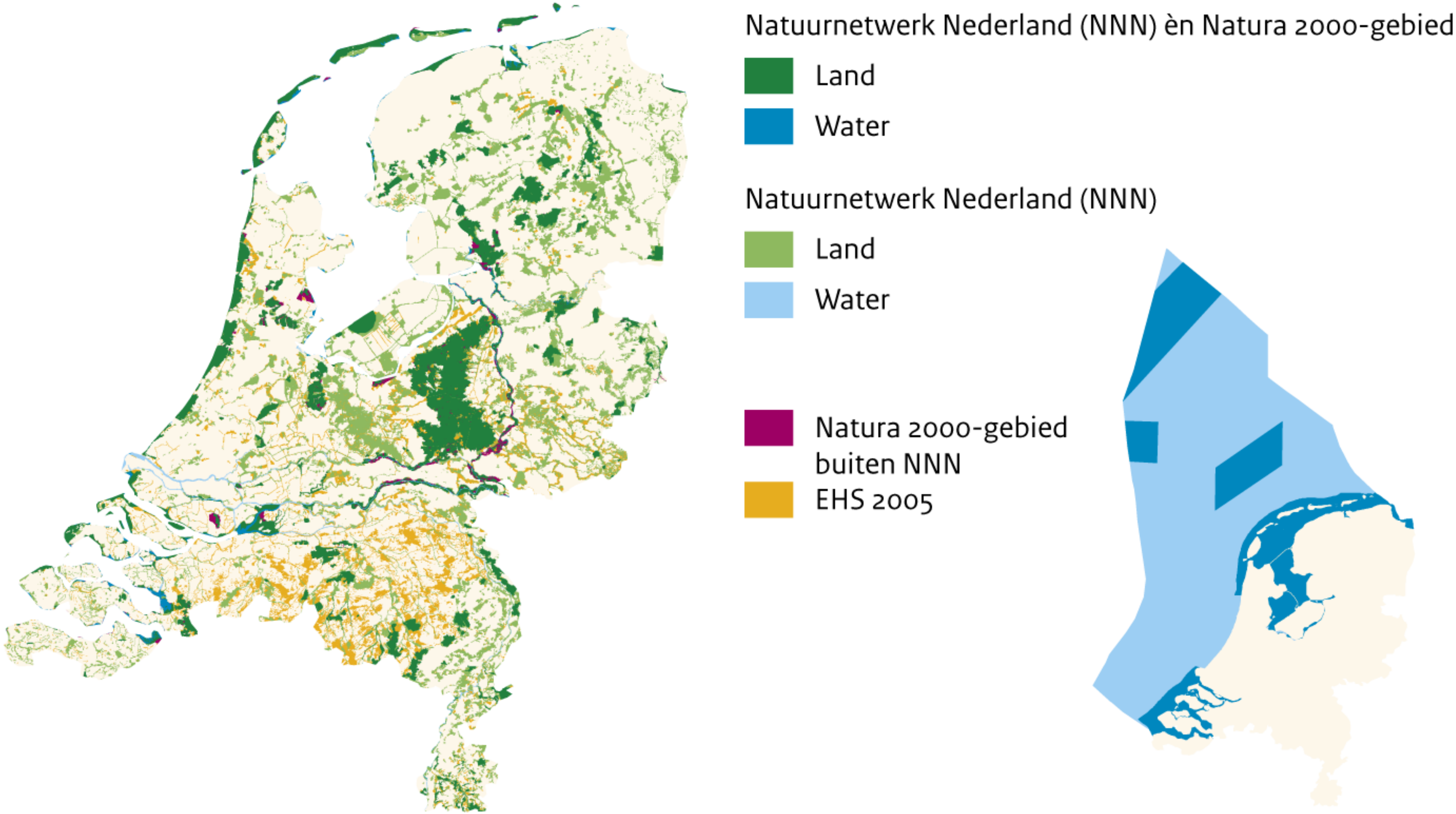
Nature policy

- 1998 Flora and Fauna Act (protection of endangered species)
- 1998 Natura 2000 areas (more than 160 areas in the NL)
    - Nature Management Plan per area
    - Including clean air policy (Program Approach Nitrogen)
    - Including water policy (WFD)
- Policy directed to provinces (2014)
- Nature 2000 areas and provincial nature conservation areas

Natuurnetwerk Nederland en Natura 2000-gebieden, 2015



Bron: IPO 2015 (NNN); EZ (Natura 2000); I&M (rijkswateren);
Nota Ruimte – VROM en LNV (EHS2005);

WUR/aug16
www.clo.nl/nl142502

Pollution control in the NL- summary

- Laws are not rigid, lots of amendments;
  More substances/emissions, sectors, product and production
- Introduction of EU (framework) directives
- Monitoring and reporting
- Changing responsibilities such as
    - Water boards (surface water 2002)
    - Provinces (nature policy 2014)

Pollution control - instruments

- Regulation (monitoring, standards of products, limits)
- Licensing for production/emission
- Permits system (non-tradable and tradable),
- Environmental Impact Assessment
- Subsidies/tax exemptions (promote clean technologies)
- Deposit-refund systems
- Management plans
  (nature areas)

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- Water Framework Directive

Water Framework Directive

- Water Framework Directive (2000/60/EC)
  - Water quality objectives: good ecological status
  - Time horizon: 2027
  - List of priority substances

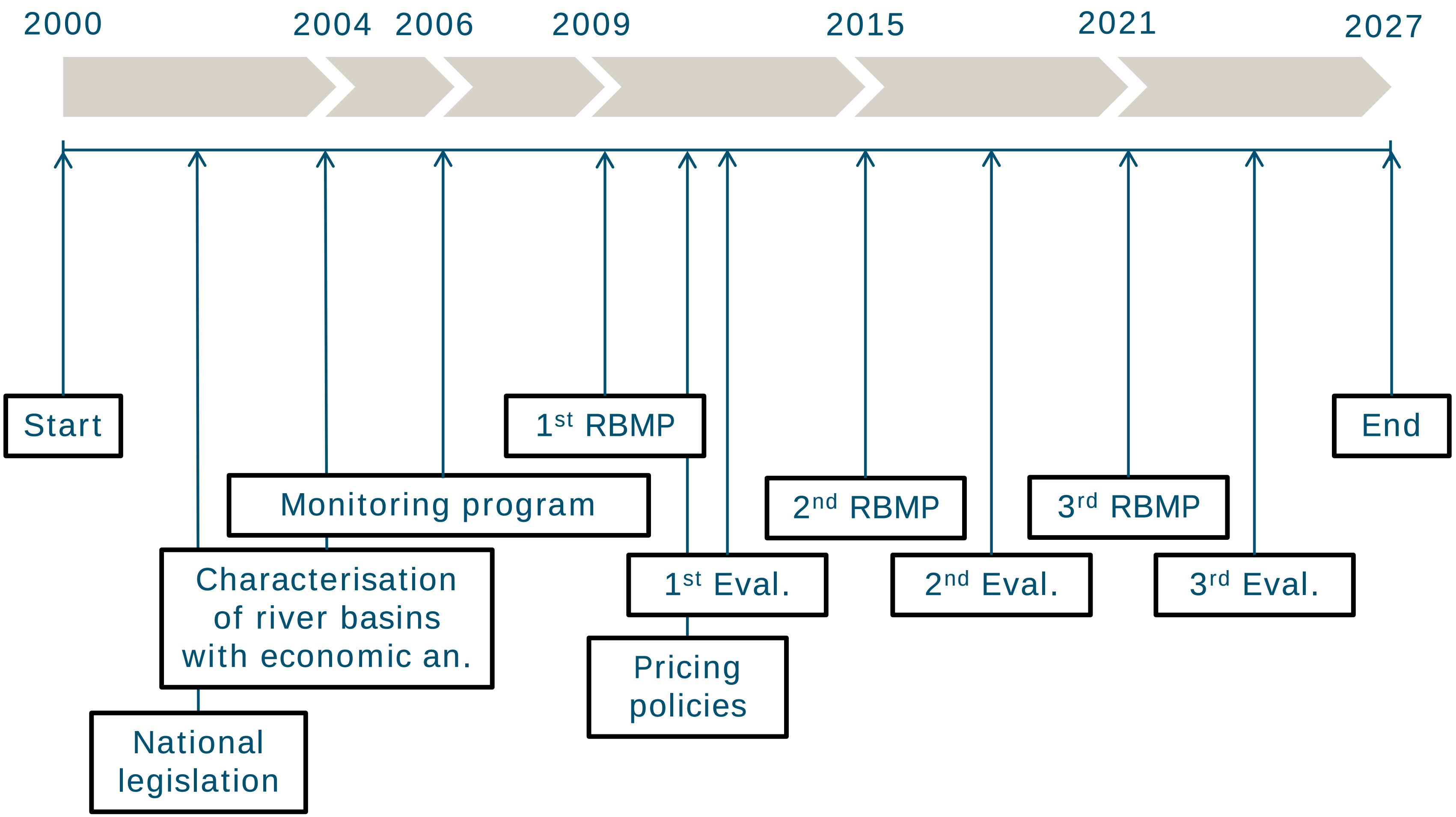
- Economic analyses => impact on the economy

- Disproportional costs

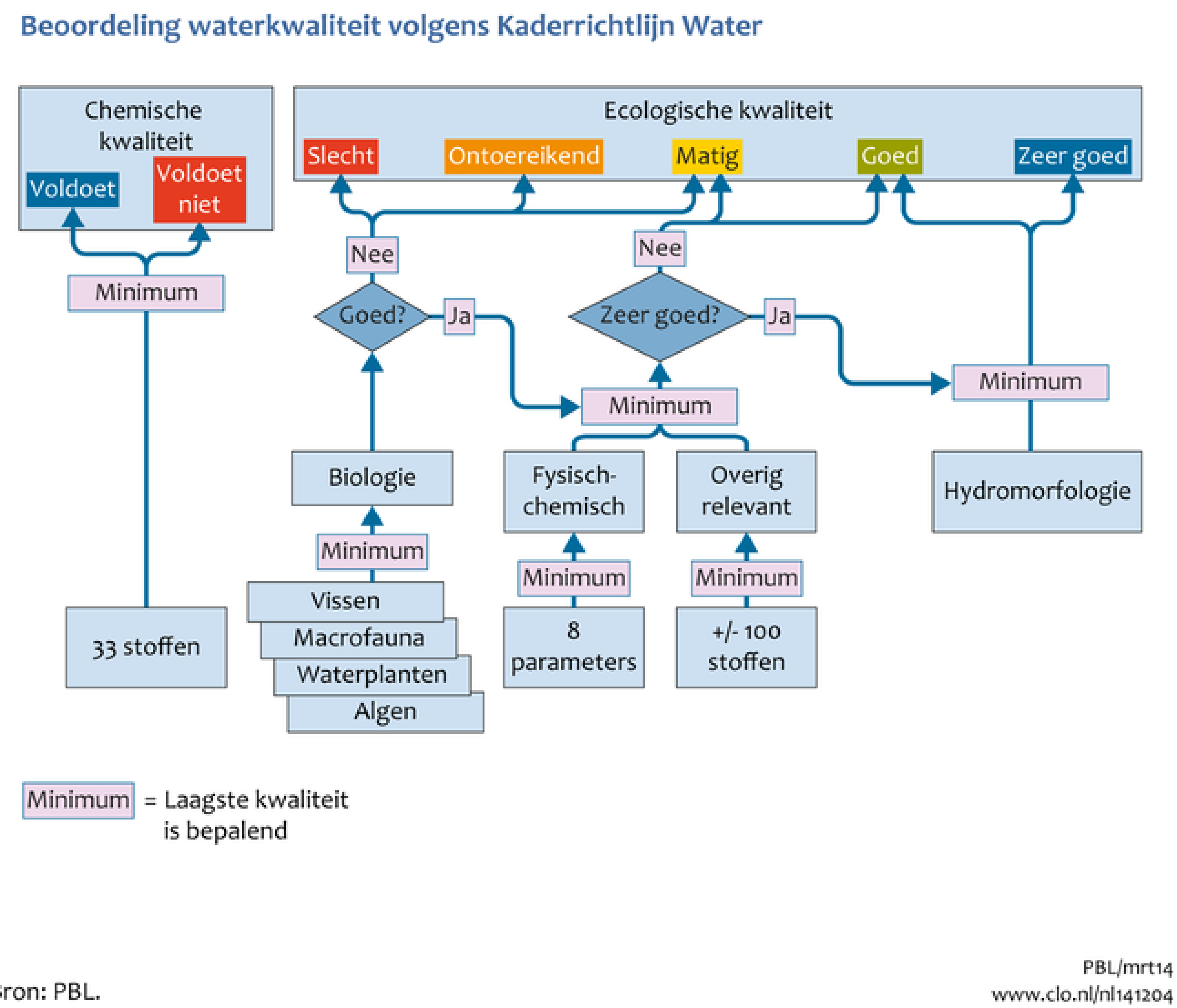
WFD – link with economics

- Article 5: economic analysis of water use
- Article 11&13: program of measures & RBMP
    - Article 5: cost-effectiveness analysis
- Article 9: cost recovery and pricing policies of water services
    - “polluter pays”-principle
    - production and distribution, collection and transport of waste water, waste water treatment, groundwater, water system management

WFD – time line



Assessment of water quality



Measures: fish passages

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Measures: river restoration

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Measures: WWTP improvements

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Measures: manure and natural banks

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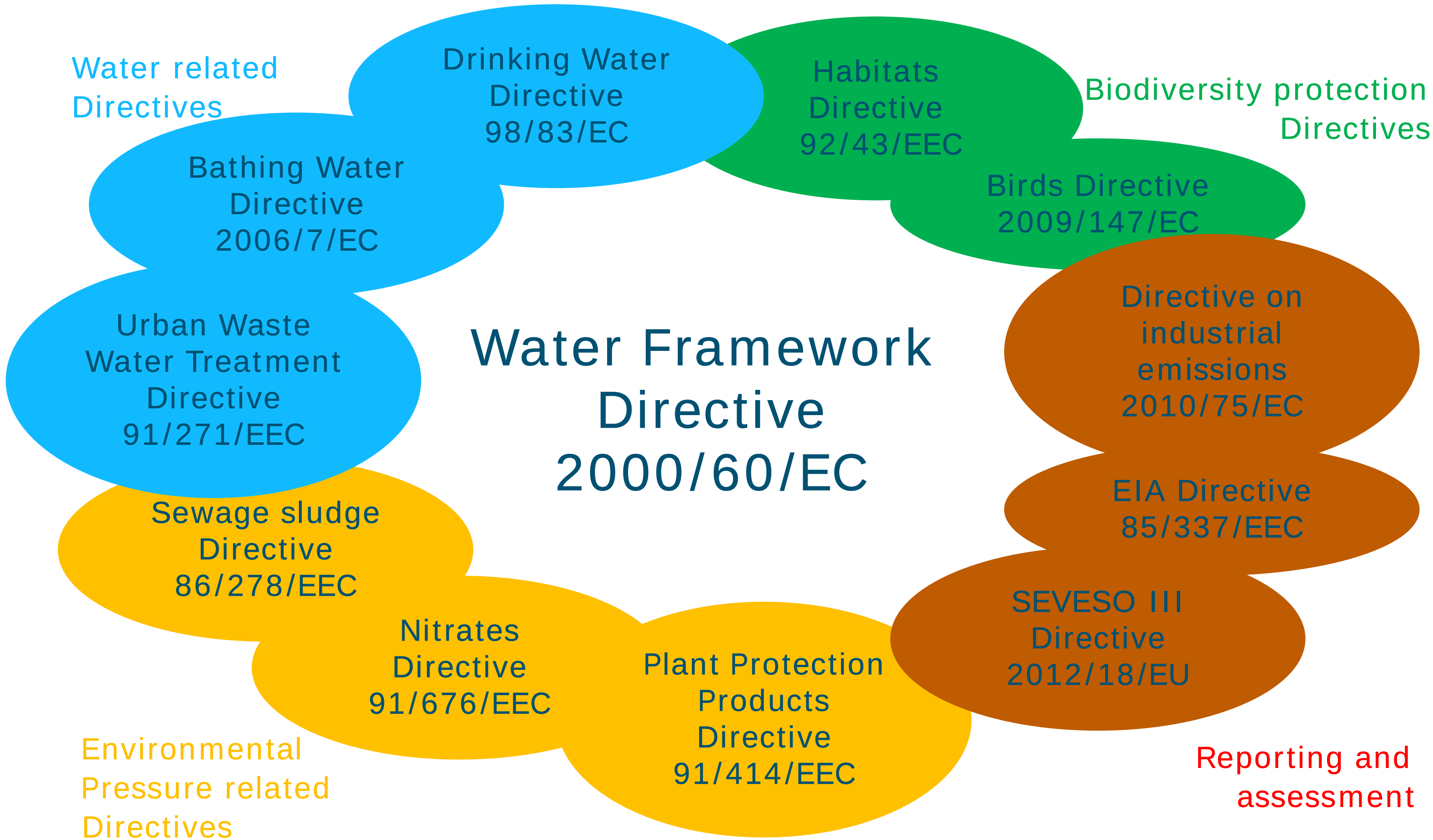
WFD – Link with other directives



WFD - Basic vs. supplementary measures

Compliance to UWWT Directive

Waste water treatment plant
municipality >2,000 inhabitants
until 2017

Basic measures in WFD

Part of baseline water use

Compliance to WFD Directive

Waste water treatment plant
municipality <2,000 inhabitants
after 2017

Supplementary measures in WFD

Part of cost-effectiveness analysis

Both are part of the River Basin Management Plan

WFD – conclusions

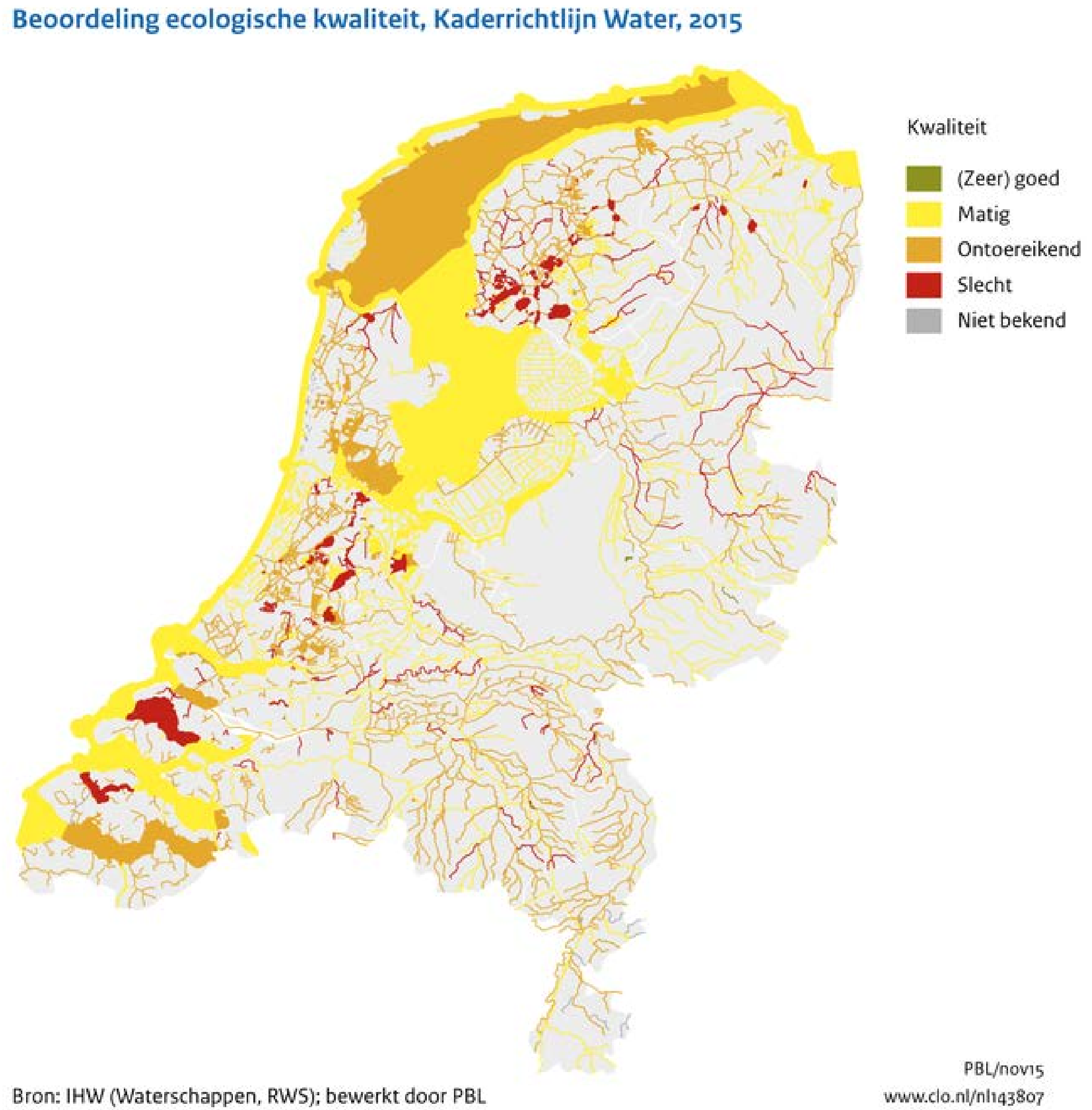
- WFD is the first water-related directive with economic analysis!

- How to relate water quality policy to economics?
- "Living with water" project 2005-2008

Part II

- Hydro-economic modelling
- Cost optimization models

Status of water quality



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Introduction – economy and water

Consumption

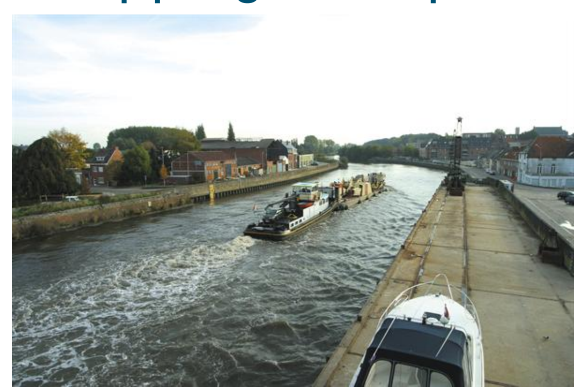
Recreation

Production

Water safety

Water for nature

Shipping/transport



Introduction – economy and water

Production and consumption affect water quality!

Contaminated water

Solutions =>cheapest solution?

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Linking economic and hydrology models

- How can we measure the economic impact of water quality policy?
- Hydro-economic models
    - National economic models (Brouwer et al., 2008; Dellink et al., 2011)
- Cost optimization models
    - Environmental costing model and SWAT Cools et al. 2011) for Nete river basin in Belgium (only N emissions)
    - WFD regiOptimizer (N and P concentrations)

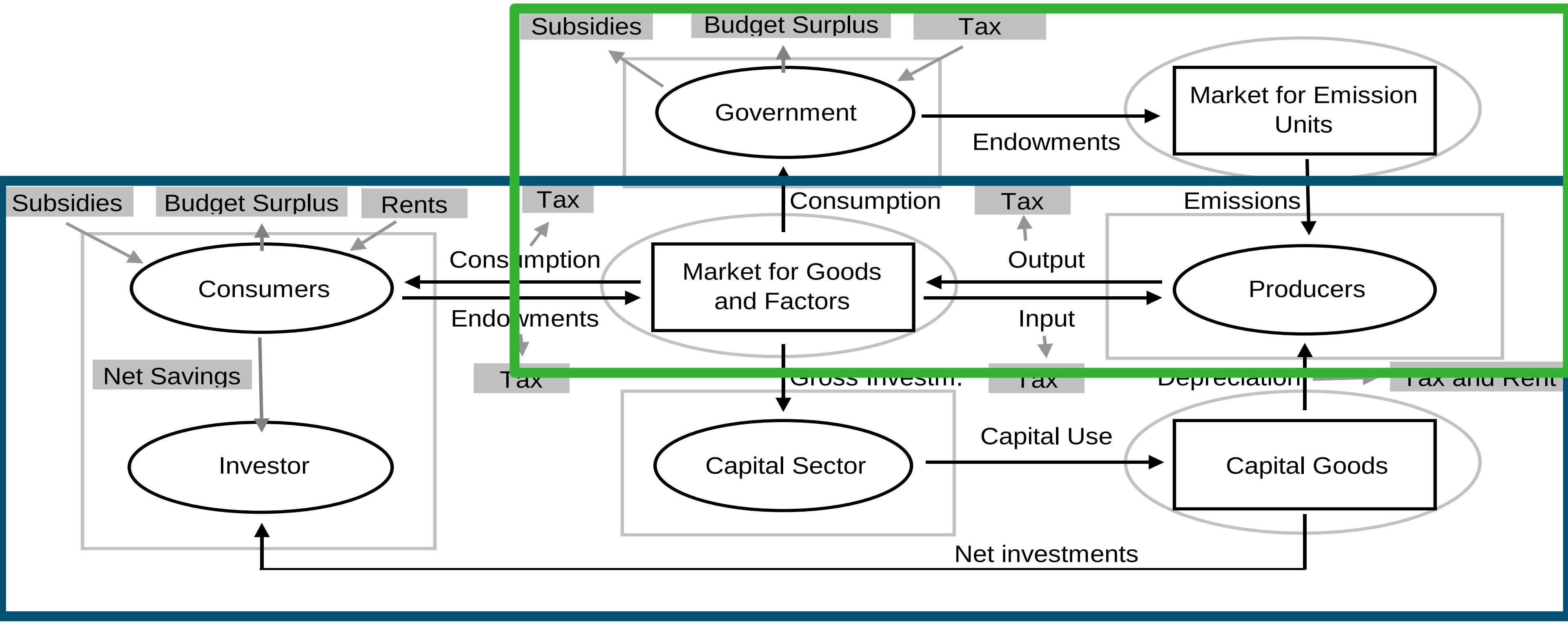
Trade-off methodologies in water policy making

- Social cost benefit analysis, for WFD (PBL, 2008) or for Marine Strategy (LEI, 2013)
  - Societal costs and benefits
  - Changes in economic behaviour through prices
  - Society (larger scale)
- Cost-effectiveness analysis
  - Cost minimization given environmental targets
  - Maximize environmental pressure reduction given budget
  - Net costs (cost minus benefits)
  - Technical measures

Hydro-economic model (Brouwer et al., 2008)

- Applied General Equilibrium model (static)
- Focus on water-related environmental themes
- Sustainability standards to be met with
  - Abatement technologies (except for dehydration and soil contamination)
  - Emission permits
- Revenues of emission permits are recycled by either tax reduction or lump sum subsidies to households

Hydro-economic model



Source: Gerlagh et al. (2002); Brouwer et al. (2008)

Environmental-economic link

- Tradeable environmental emission permits ("polluter pays principle")

- Measures to invest in (cost-effectiveness curves)

- Trade-off for producers to extend:
  - purchase permits or
  - invest in measures

Economics: bread in economic model

Sectors involved	Production process of bread	Consumer
Government	VAT	Consumer price for bread €2,-
Retail/ whole sale	Supermarket (labour and capital)	
Food industry	Bakery (labour and capital)	
	Water; Wheat flower; Salt	
Agriculture	Farmer (wheat) (labour and capital)	
	Water/ land; Seeds; N & P	

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Hydro-economic model

Table 1 – Social Accounting Matrix (SAM) and Net National Income in the Netherlands in 2000 (in billion euros)

	Primary sector	Secondary sector	Tertiary sector	Capital	Abatement	Trade balance	Net investments	Consumption	Endowments	Sum
Primary sector	18.4	−10.3	−0.9	−0.6	0.0	−4.5	0.0	−2.1	–	0
Secondary sector	−5.5	170.4	−52.5	−59.6	−0.1	0.9	0.0	−53.7	–	0
Tertiary sector	−2.8	−56.9	313.2	−23.1	−0.1	−10.7	0.0	−219.8	–	0
Capital	−3.1	−18.0	−40.1	91.4	0.0	0.0	−30.1	0.0	–	0
Abatement	0.0	−0.1	0.0	0.0	0.2	0.0	0.0	−0.1	–	0
Labour	−1.9	−41.6	−122.7	0.0	0.0	0.0	0.0	0.0	166.2	0
Profits	−4.6	−26.6	−59.4	0.0	0.0	0.0	0.0	0.0	90.6	0
Taxes	−0.5	−17.0	−37.7	−8.1	0.0	0.0	0.0	−20.0	83.3	0
Sum	0	0	0	0	0	−14.3	−30.1	−295.7	340.1	0

Source: Statistics Netherlands.

Table 3 – Emissions in the Netherlands in 2000

	Primary sector	Secondary sector	Tertiary sector	Consumption	Total
Eutrophication (million P-equivalents)	90.4	15.8	11.6	19.6	137.4
Dispersion of toxic substances (billion AETP-equivalents)	0.8	61.7	7.8	17.9	88.3

Source: Brouwer et al. (2008)

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AETP = aquatic eco toxicological potential

Hydro-economic model

- Abatement cost curves

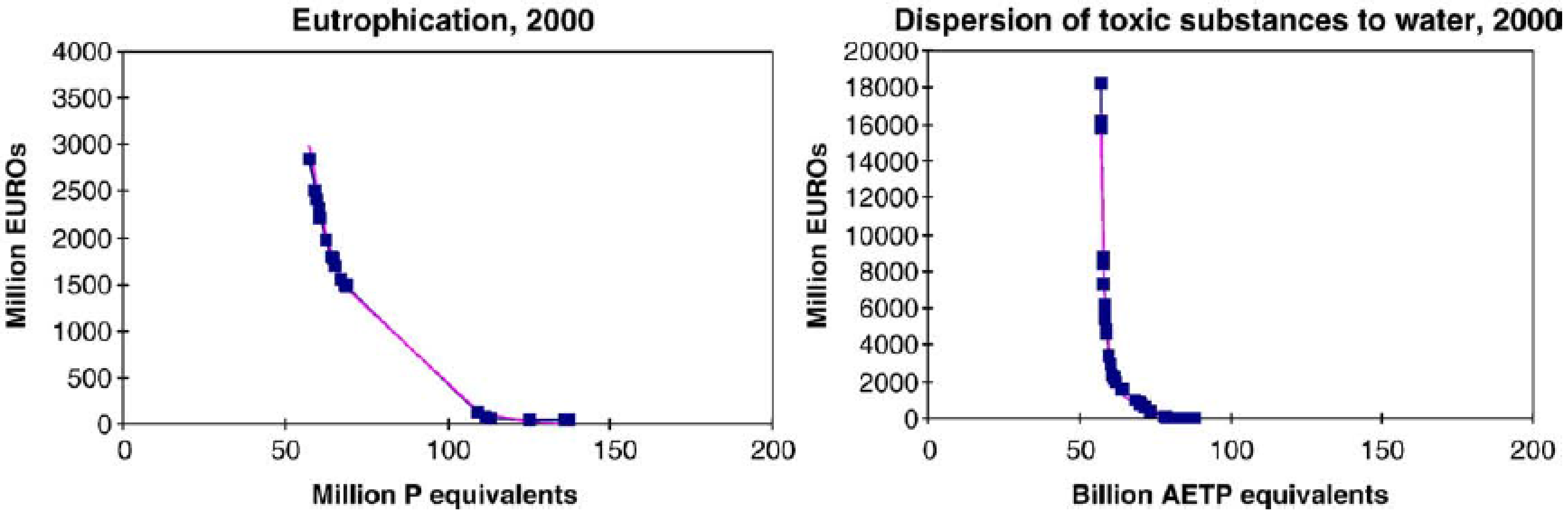
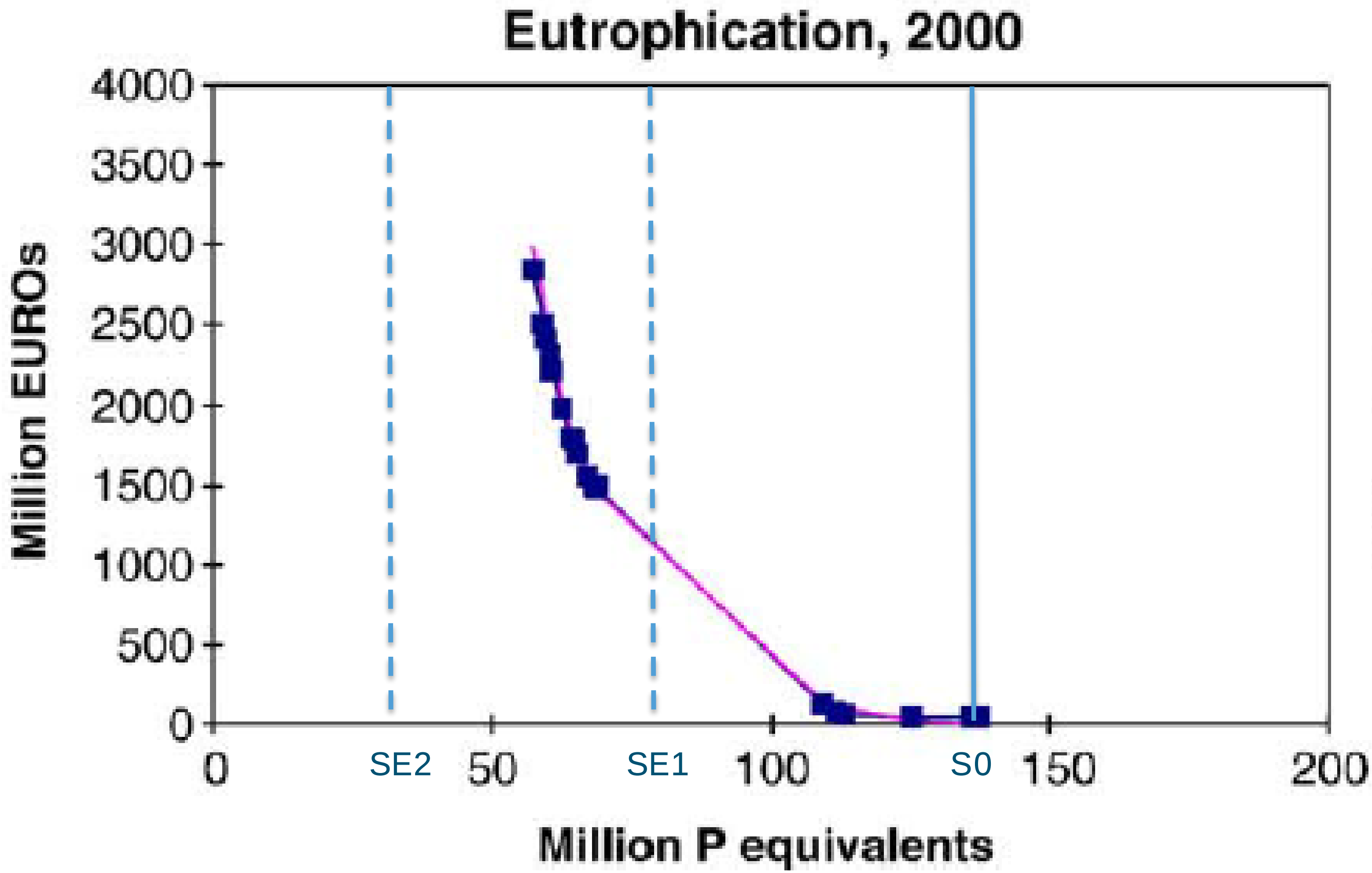


Fig. 2 – Estimated abatement cost curves for eutrophication and the dispersion of toxic substances to water.

Hydro-economic model



Hydro-economic model - results

Table 4 – The impact of the different emission reduction scenarios on Net National Income and their total economic cost (in billion euros; price level 2000)

Variant	Variant 1			Variant 2		
Emission reduction scenario	10%	20%	50%	10%	20%	50%
Net National Income	339.3	338.4	329.6	339.4	338.1	308.0
Loss in NNI compared to baseline	0.7	1.6	10.5	0.7	1.9	32.1
Relative change in NNI (%)	−0.2%	−0.5%	−3.1%	−0.2%	−0.6%	−9.4%

Unilateral

Dutch water policy: goods with polluting production more imported.

Multilateral

EU water policy: polluting production reduced.

Static vs. dynamic hydro-economic model (Dellink et al., 2011)

- Not only two situations compared, but also the path from one to another
- The economic model is a forward-looking neo-classical growth model (based on DEAN)
- Linked to hydrological model WFD explorer

DEAN

Economic model → Emission to water (nutrients and toxic substances) → Hydrological model →

WFD explorer

From sector to river basin
NAMWARiB
Brouwer et al. (2005)

Results for phosphates in 2027

Dynamic model – additional features

- Trade off between years (measures/emission rights)
- Growth rates on
  - Economic growth
  - Technological change of abatement
  - Autonomous emission reduction
- Results on water quality at river basin level

Hydro-economic model - conclusions

- National scale
- Links economic model with hydrological model
- Takes into account economic interactions

- Abatement cost curves rather inflexible
  - Not sector specific
  - No regional differences (or diffuse sources)

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Cost optimization model

- Cost optimization on water quality (Linderhof et al. 2010) for the Beerze-Reusel basin (the Netherlands), N and P

- Environmental costing model (Cools et al. 2011) for the Nete basin (Belgium) linked to water flow model, only N

Cost optimization model

- Hydrological model – CEA (Linderhof et al. 2010)
  - Hydrological structure (WFD Explorer)
  - Programmes of measures – cost effectiveness analysis
  - Small scale (part of river basin)
    - Water bodies (part of water system)
    - Catchment Areas

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Beerze-Reusel

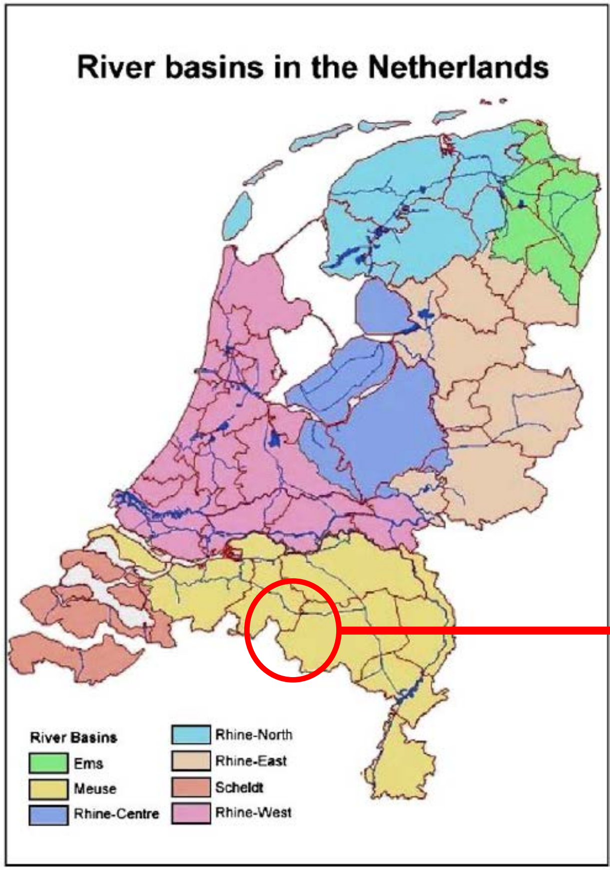
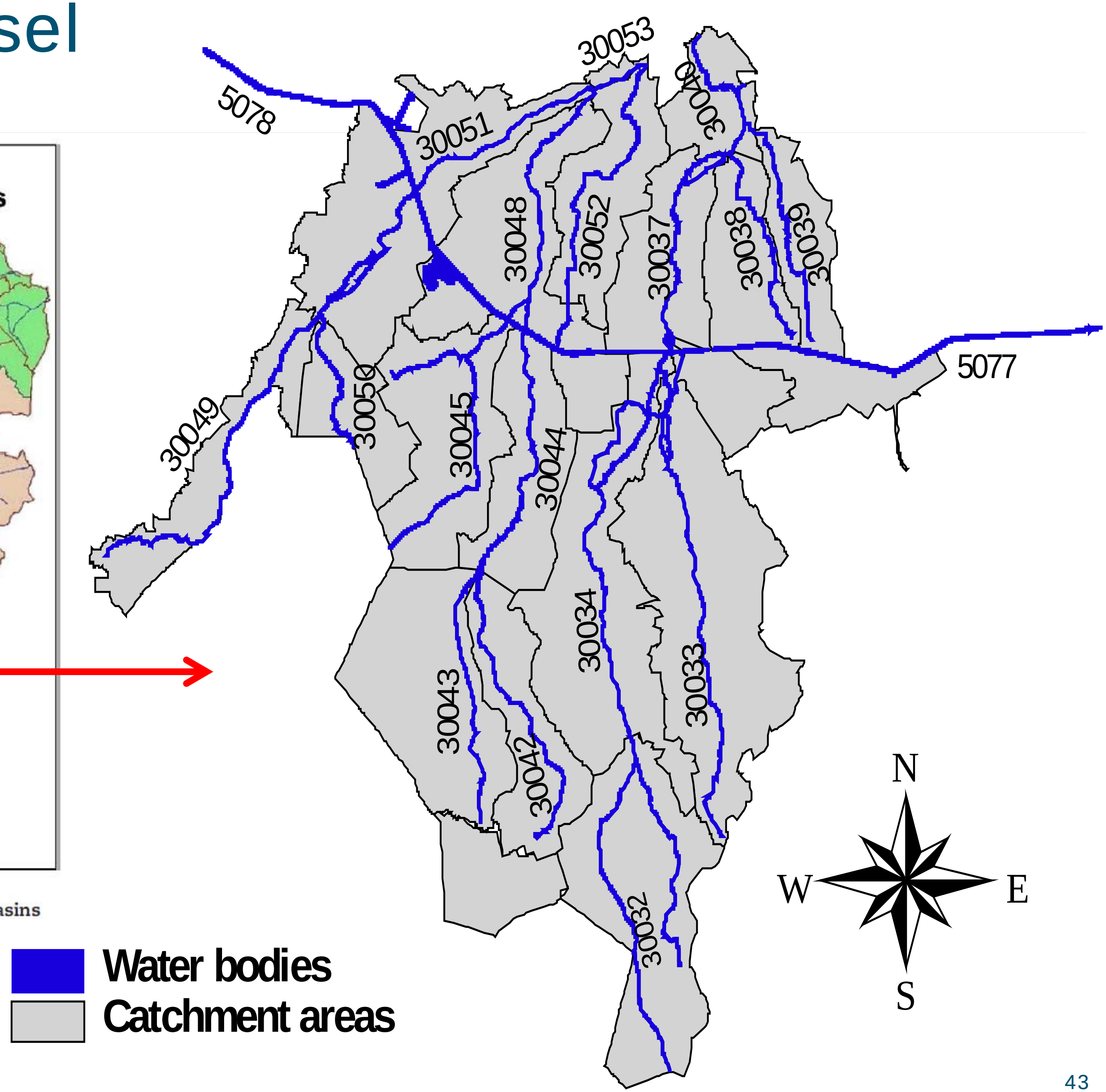


Fig. 5 – The Netherlands split up in the seven river basins distinguished in the WFD.

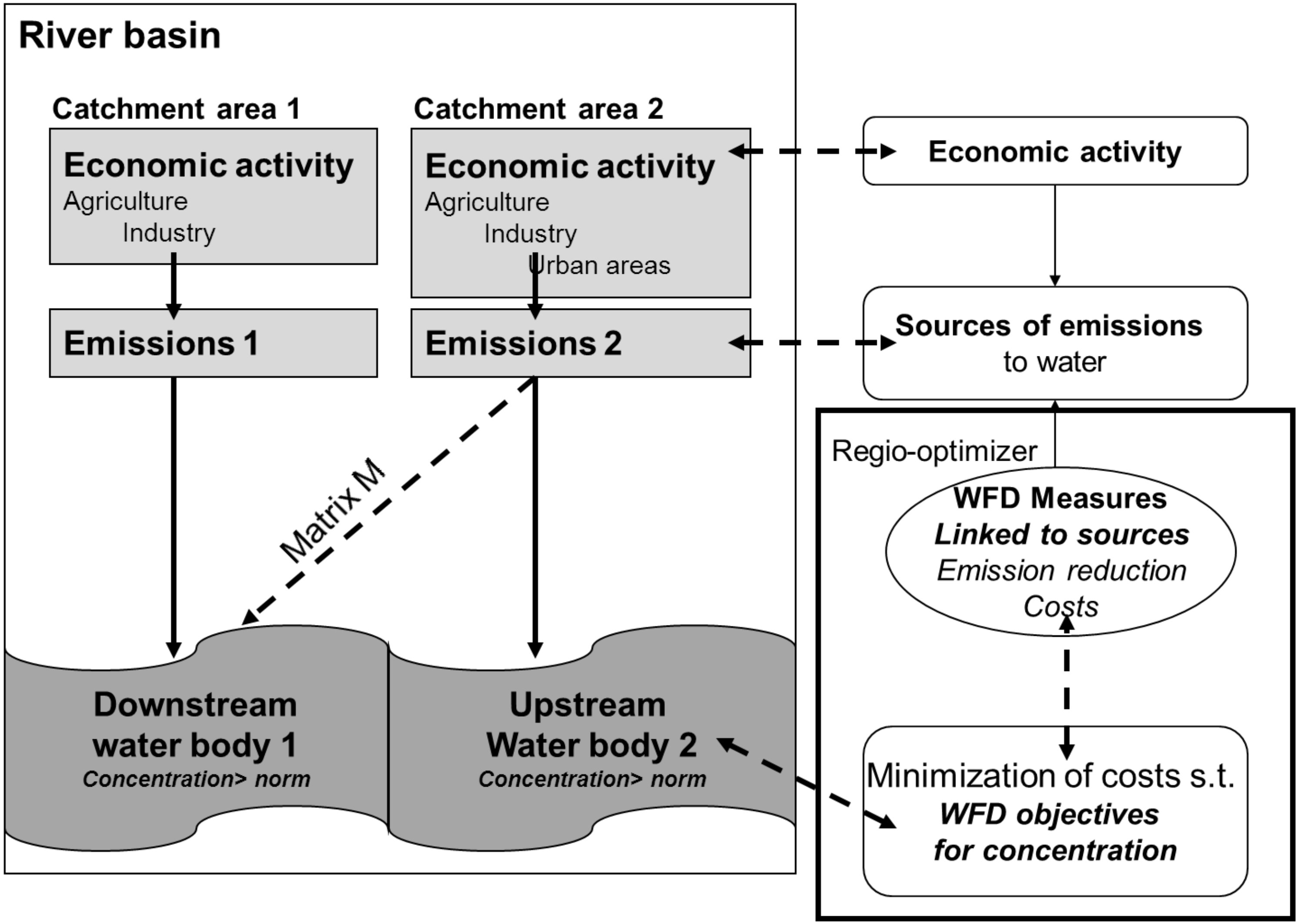


Hydrological model - CEA

- Cost minimization of program of measures
- Subject to water quality targets (concentration)

- Measures
  - Related to one or more substances (N and P)
  - Measures linked to water bodies (WWTP) or catchment areas (agriculture)

Scheme


River basin
Catchment area 1
Catchment area 2
Economic activity
Agriculture
Industry
Economic activity
Agriculture
Industry
Urban areas
Emissions 1
Emissions 2
Economic activity
Sources of emissions
to water
Matrix M
Regio-optimizer
WFD Measures
Linked to sources
Emission reduction
Costs
Downstream
water body 1
Concentration> norm
Upstream
Water body 2
Concentration> norm
Minimization of costs s.t.
WFD objectives
for concentration

Model

Minimize $\sum_{j \in J} \sum_{k \in K} X_{jk} C_{jk}$ (1)

Subject to

Emission levels: $E_{ks} = E_{ks}^{0} \left(\prod_{j \in J} 1 - \varepsilon_{jks} X_{jk} \right)$ (2)

Sum of emissions: $E_{is} = \sum_{k \in K} E_{ks} Y_{ik}$ for k and s (3)

Changes in water quality: $Q_{is} = Q_{is}^{0} \left[1 - \sum_{i' \in I} M_{ii's} \left(\frac{E_{i's}^{0} - E_{i's}}{E_{i's}^{0}} \right) \right]$ (4)

Water concentration target: $Q_{is} \leq \tau_{is}$ (5)

$0 \leq X_{jk} \leq 1$ (6)

i is water body/catchment area, *j is* measure; *k* is emission source, *s* is substance. *X* is implementation degree, *E* is Emissions, *Q* is Concentration, *C* is costs, *M* is transport matrix, and τ is target of concentration

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Relative reduction

- Measure 1: 20% emission reduction
- Measure 2: 50% emission reduction
- Suppose emissions are 100 units
- Measure 1 reduces 20%=> 20 units removed and 80 units left
- Measure 2 reduces 50%=> 40 units removed and 40 units left
- Total reduction is then: 60 units or 60% (100x.2+80x.5)

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Transport matrix for N

		Water bodies for water quality measurement									
		5077	5078	30032	30033	30034	30037	30038	30039	30040	30042
Water Bodies with point sources	30032			63		32	16			9	
	30034					32	16			9	
	30037		60				32			9	
	30039								76	9	
Catchment areas	300032			37		19	9			5	
	300033				100		6			4	
	300034					17	9			5	
	300035	50									
	300036	50									
	300037						12			7	
	300038							100		4	
	300039								24	3	
	300040									35	
	300042										100
	300045										
	300046		20								
	300047		20								
	Total	100	100	100	100	100	100	100	100	100	100

Up-downstream water bodies

Direct link catchment-water body

Characterisation of Beerze-Reusel

Table 1 Different nutrient emission sources in the river basin

	Number of sources	Emissions (kg per day)		Share of emissions (%)	
		N	P	N	P
Total	112	1,606.7	119.1	100.0	100.0
Agriculture	21	114.2	9.0	7.1	7.5
Construction	21	6.0	0.8	0.4	0.7
Industry	1	6.7	1.7	0.4	1.4
WWTP	4	579.8	59.5	36.1	49.9
Sewage system	21	32.3	33	2.0	2.8
Shipping	17	1.7	0.3	0.1	0.2
Atmospheric deposition	21	128.6	0.0	8.0	0.0
Inflowing water from Belgium/other River basins	5	407.4	11.4	25.4	9.5
Inflowing water	1	330.0	33.3	20.5	27.9

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Program of measures

Type of measure	Emission reduction capacity (%)	Number of measures
Agriculture and atmospheric deposition (catchments)		
Manure free corridor	5	21
Buffer strips (crop free corridors) special crops	5	21
Crop free corridors with paths open for public	10	21
Buffer strips (crop free corridors) grassland	8	21
Buffer strip (crop free corridors) arable land	8	21
Helofytefilters with reed	5	21
Natural banks (5 meters wide)	5	21
Subtotal Agriculture		147
Upgrade of WWTP (four WWTP)		
Fourth stage of WWTP	90	4
Helofytefilters with reed (additional stage) *	5-8	4
Additional N-filters*	56-90	3
Additional chemicals to remove P emissions*	20-55	3
Additional P filters*	14-89	3
Subtotal WWTP		17
Sewer improvements (catchments)		
Separate sewage system for rain water	80	21
Sewer improvement: decoupling of stormwater overflow	50	21
Reconstruct stormwater overflow facilities	75	21
Sewer improvement: larger storage settling tanks	50	21
Sewer improvement: increasing the flowing of rain water	50	21
Subtotal Sewer		105
Total number of measures		269

Results

- Policy 25% reduction of concentrations in river basin
- Inflow of N and P from Belgium remains constant.

- 25% reduction of N is almost as expensive as reducing N and P by 25%

	Costs	Additional costs Difference in costs with RED25%	Total costs of RED25%
	€ mln	€ mln	€ mln
RED25%N	53.6	0.4	54.0
RED25%P	10.2	43.8	54.0

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Results

- Policy 25% reduction of concentrations in river basin
- Inflow of N and P from Belgium is reduced.
- 25% reduction of N is almost as expensive as reducing N and P by 25%
    - Multilateral=> € 4 mln vs. unilateral=> € 54 mln

	Costs	Additional costs Difference in costs with RED25%+	Total costs of RED25%+
	€ mln	€ mln	€ mln
RED25%N+	3.2	0.4	3.6
RED25%P+	2.9	0.7	3.6

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Conclusions

- Water relates to many economic activities.
- Policy decisions more and more based on (economic) trade-offs!
- Hydrological models do not take into account economic changes due to interventions in the water system.
- Hydro-economic models can take into account economic aspects such as
  - Feed backs between economic sectors
  - Price changes (polluter pays principle)
  - Minimum cost for society of policies

If you want to convince a politician, you have to talk in euros!

End

Thank you for your attention!

More information:

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