Hydro-economic modelling

Trade-offs in water quality policy

February 15, 2017, Vincent Linderhof

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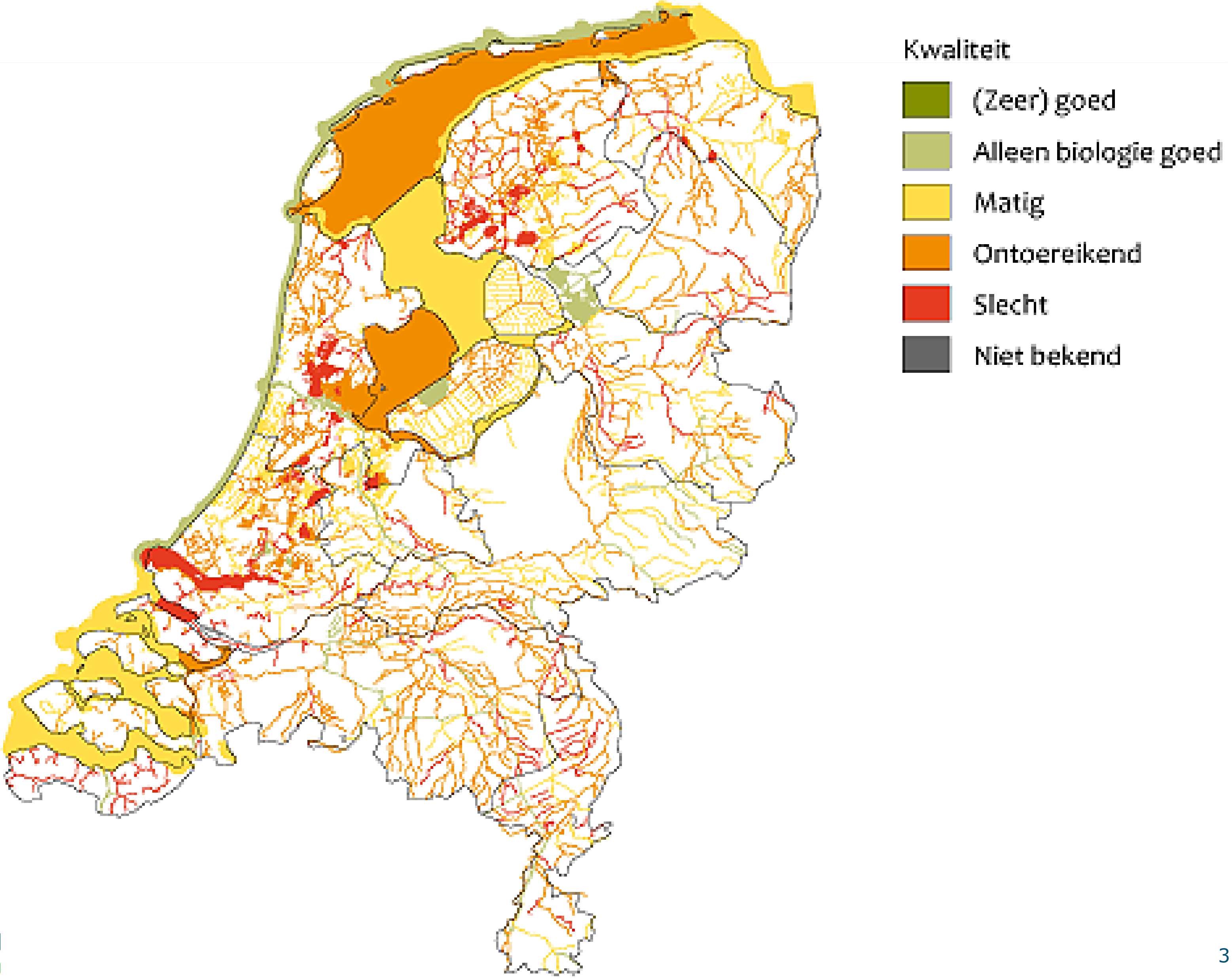
Outline

- Introduction
- Part 1
  - Water Framework Directive
  - Economic models with hydrology
    - Exercise I
- Part 2
  - Trade-off in policy making
  - Hydrological model for cost-effectiveness analysis
    - Exercise II

Status of water quality



Introduction – economy and water

Consumption

Recreation

Production

Water safety

Water for nature

Shipping/transport

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Introduction – economy and water

Production and consumption affect water quality!

Contaminated water

Solutions =>cheapest solution?

Part I

- Water Framework Directive
- Hydro-economic modelling

Water Framework Directive

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

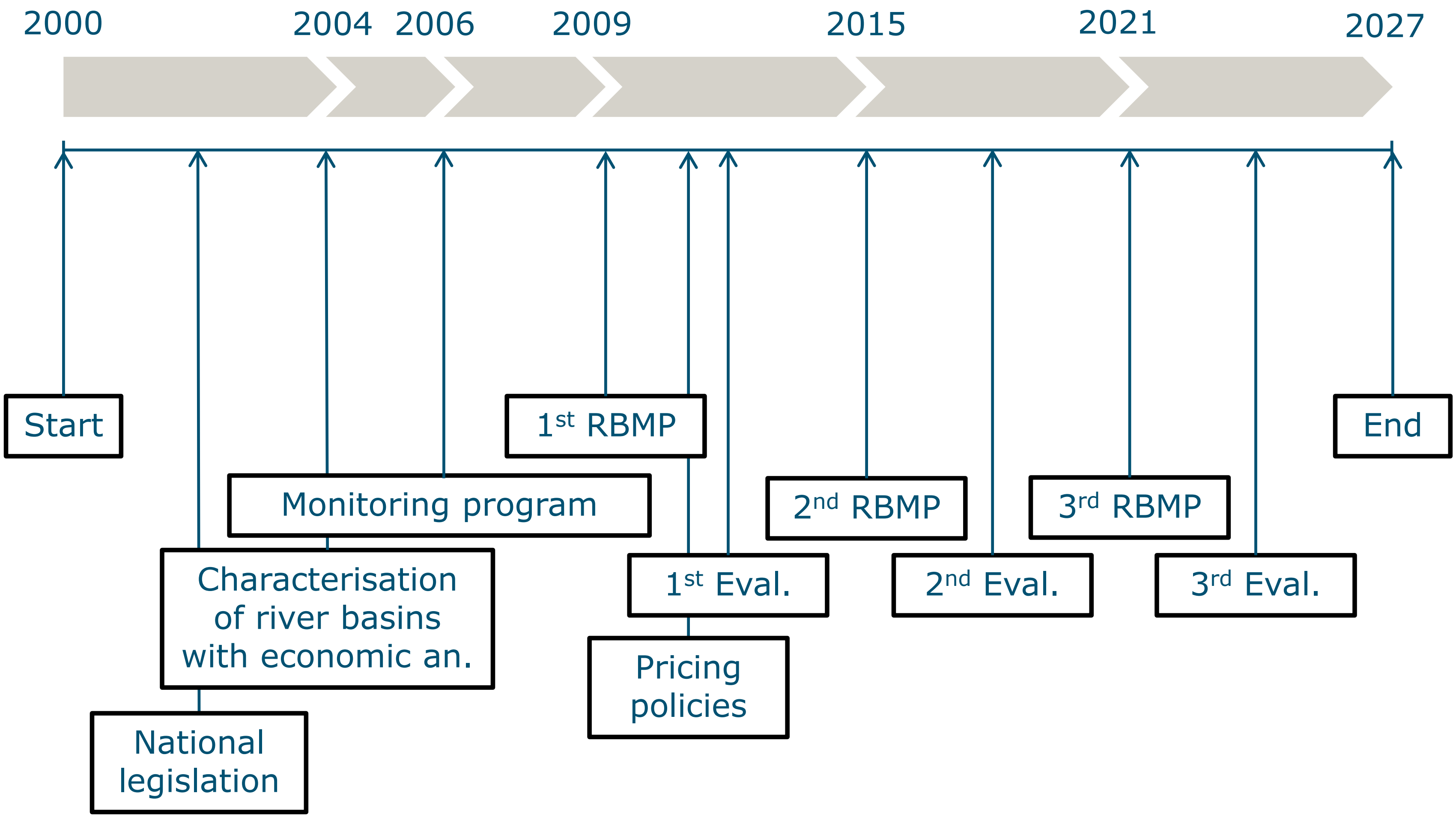
- Economic analyses => impact on the economy

- 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



Measures: fish passages

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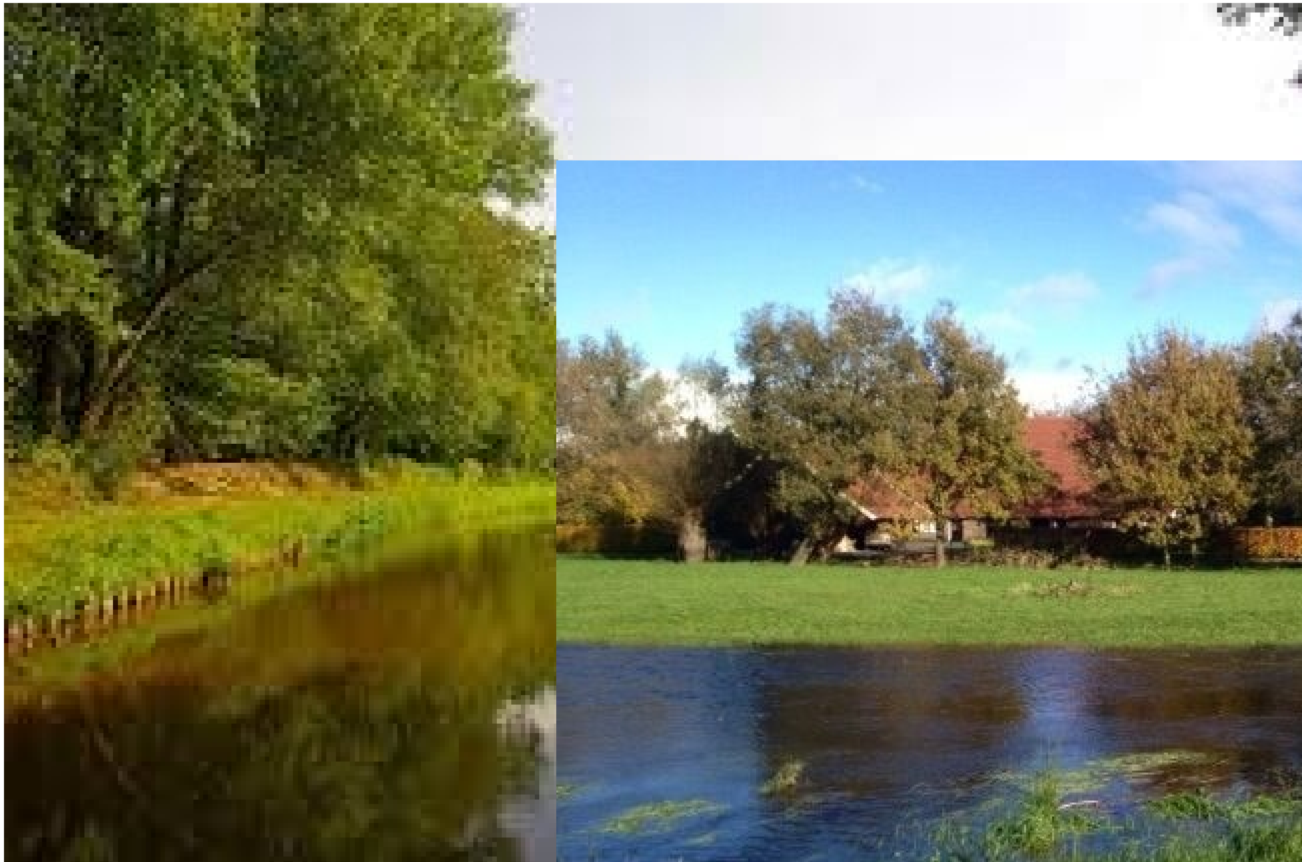
Measures: river restoration



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Measures: WWTP improvements

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Measures: manure and natural banks

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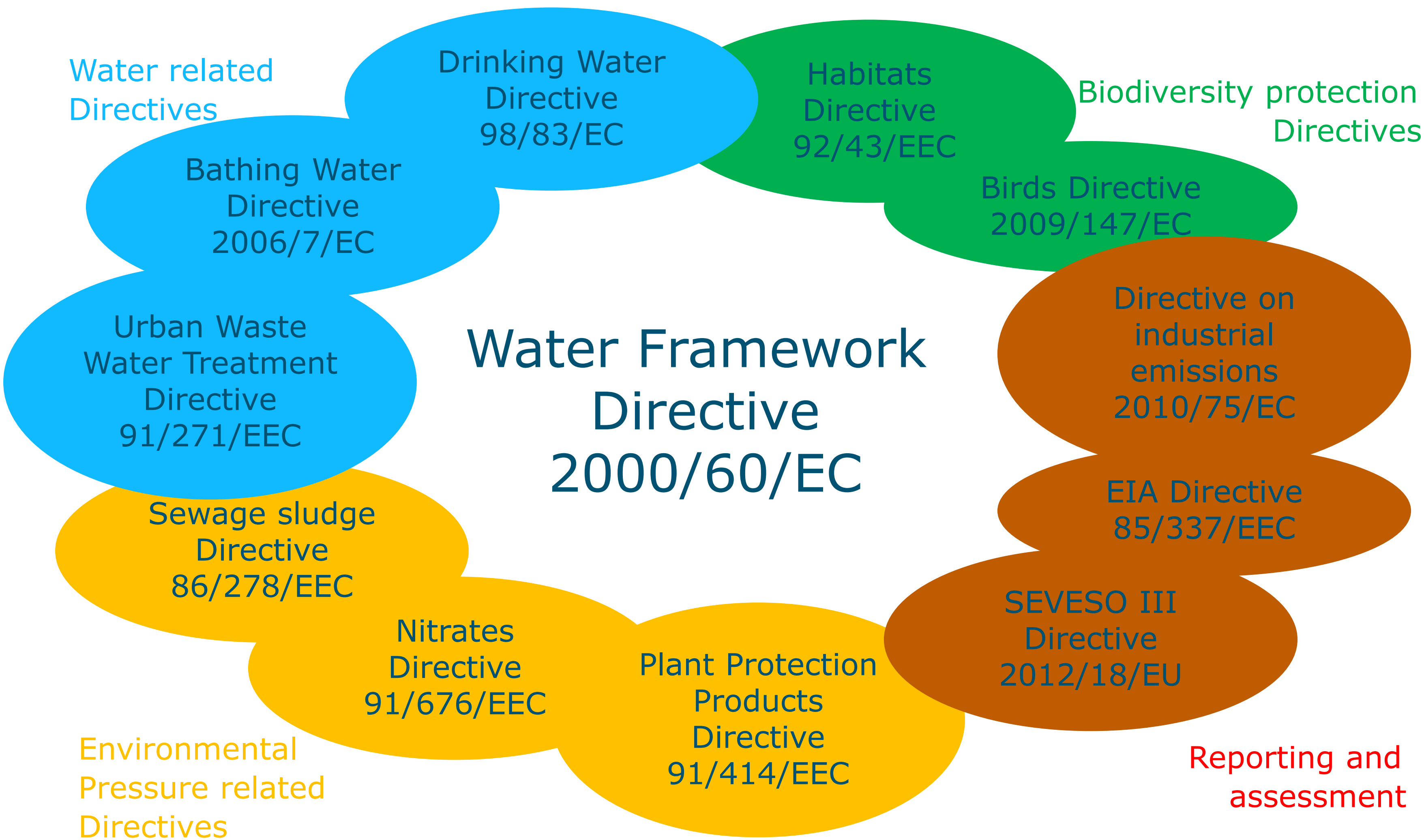
WFD – Link with other directives



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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

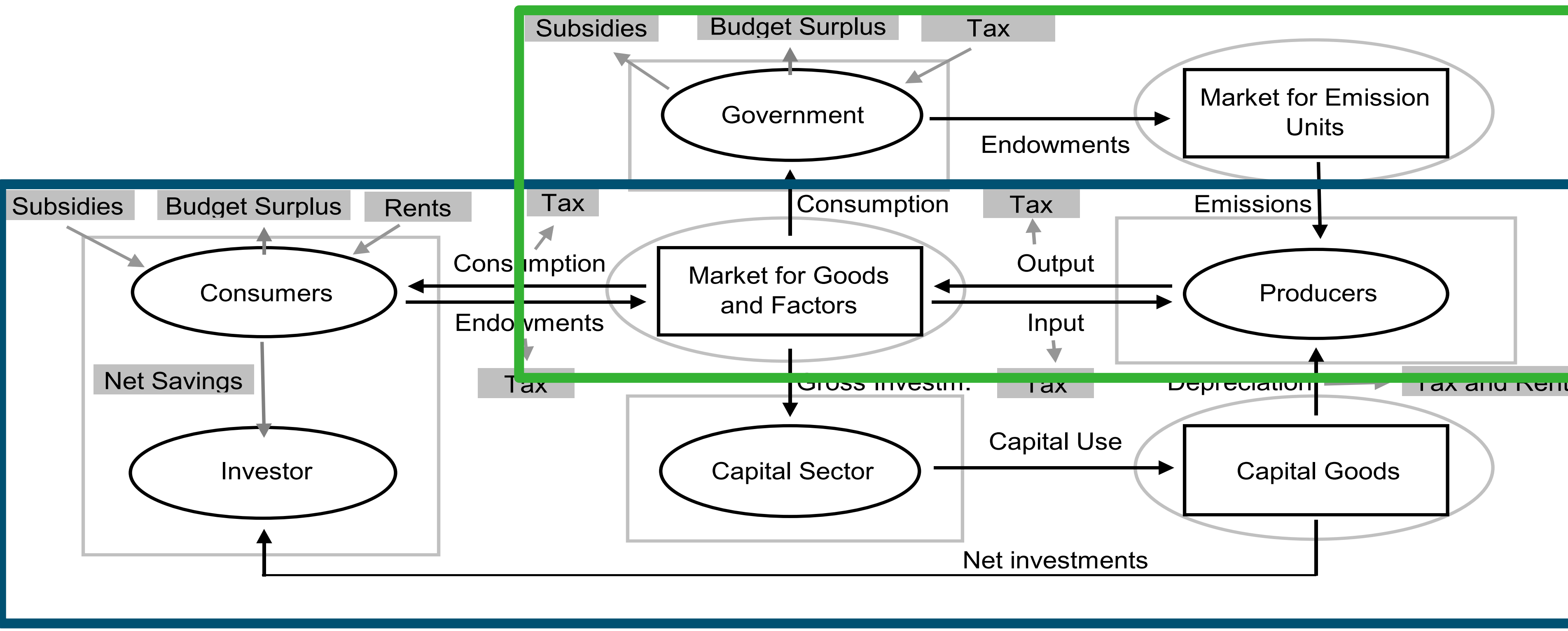
Linking economic and hydrology models

- 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)

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)

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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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

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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Hydro-economic model

- Abatement cost curves

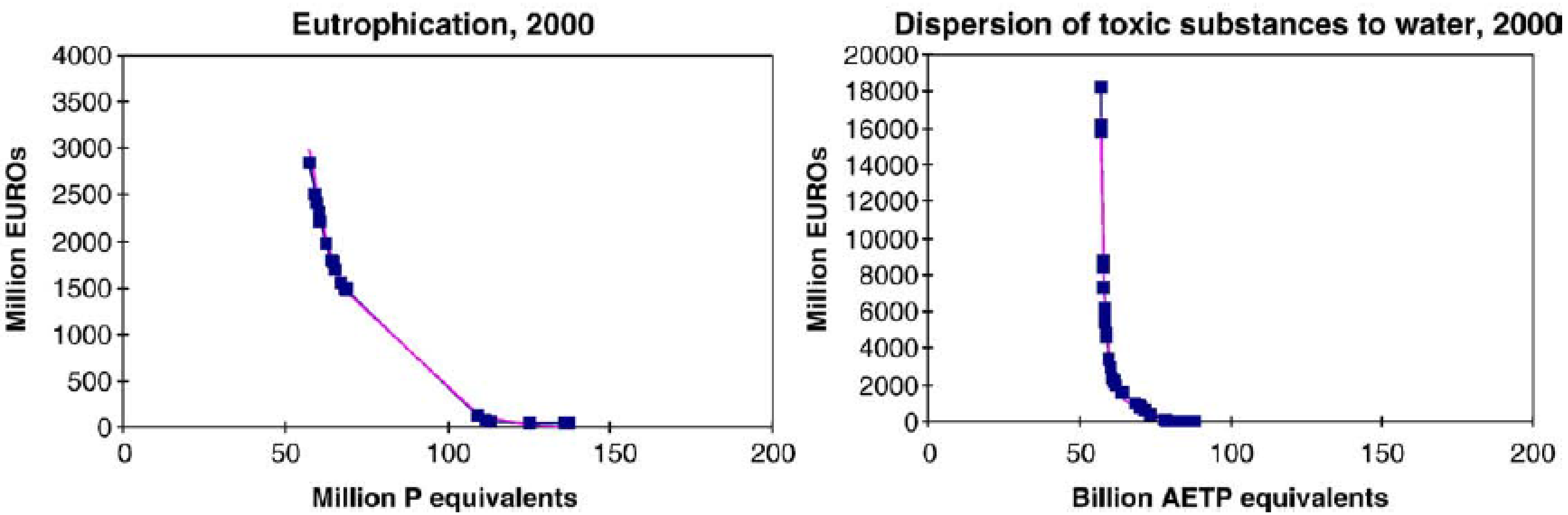

Fig. 2 – Estimated abatement cost curves for eutrophication and the dispersion of toxic substances to water.

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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

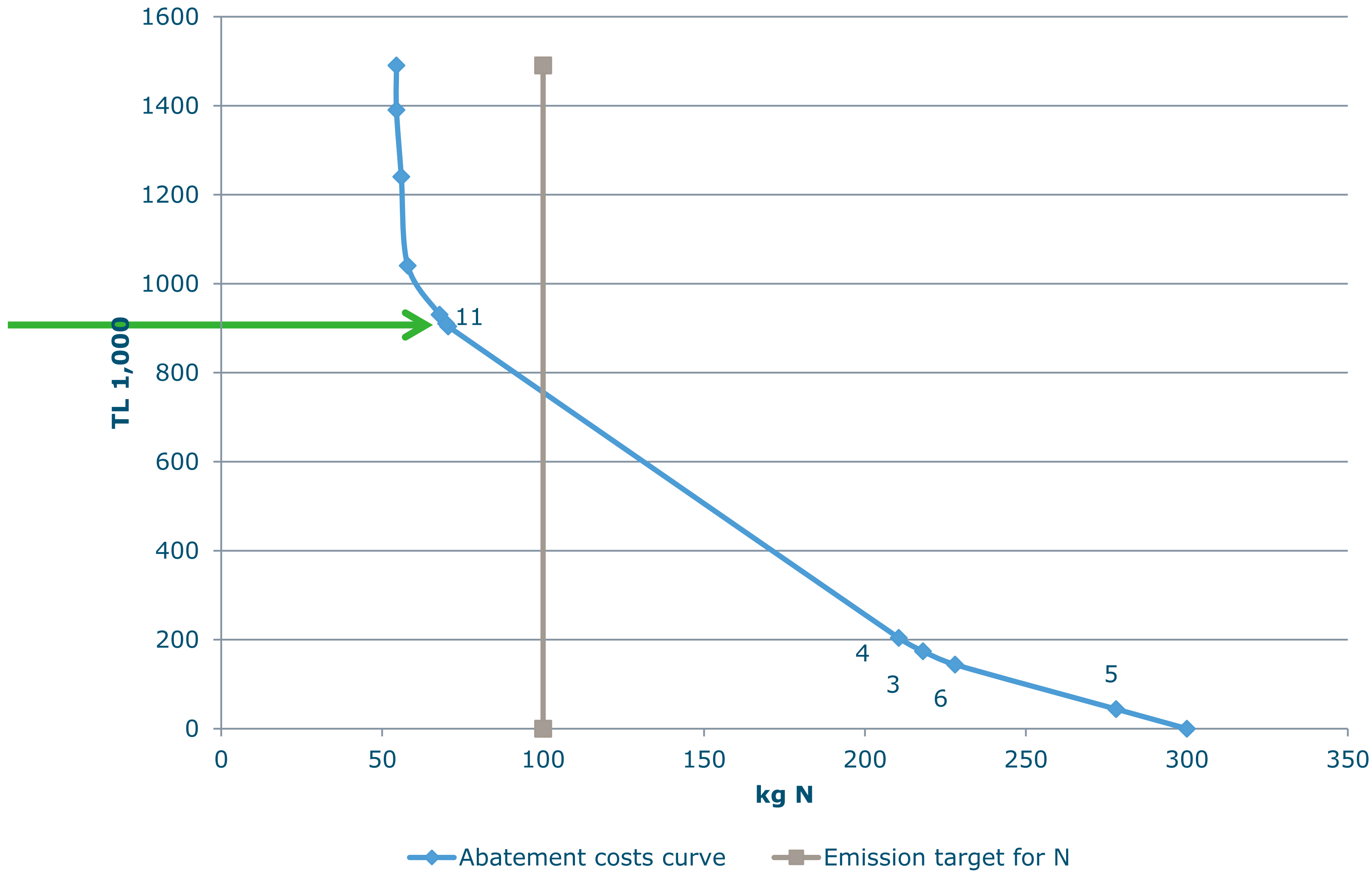
EU water policy:
polluting production
reduced.

Exercise I

- Rank the measures based on cost-effectiveness
- With which set of measures is a reduction of 20.000 kg N realised at minimum costs?
- At what costs?

Exercise I

TL 904.000



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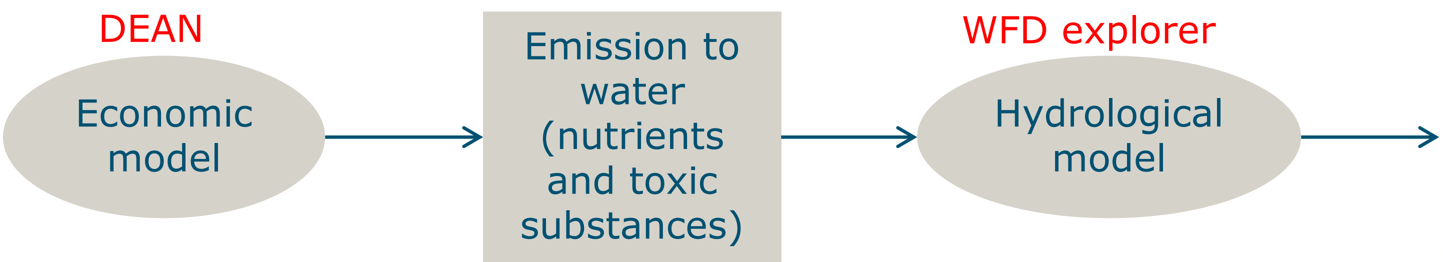
Static vs. dynamic hydro-economic model (Dellink et al., 2011)

- 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



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

Dynamic model - scenarios

Table 1
Policy scenarios and underlying assumptions.

Policy scenario	Domestic emission reduction	Year[a]	Water quality at the border
Baseline policy	0%	2015	Current concentration levels
Lenient unilateral policy	20%	2015	Current concentration levels
Strict unilateral policy	50%	2015	Current concentration levels
Lenient multilateral policy	20%	2015	MPC levels
Strict multilateral policy	50%	2015	MPC levels
Derogated strict policy	50%	2027	Current concentration levels

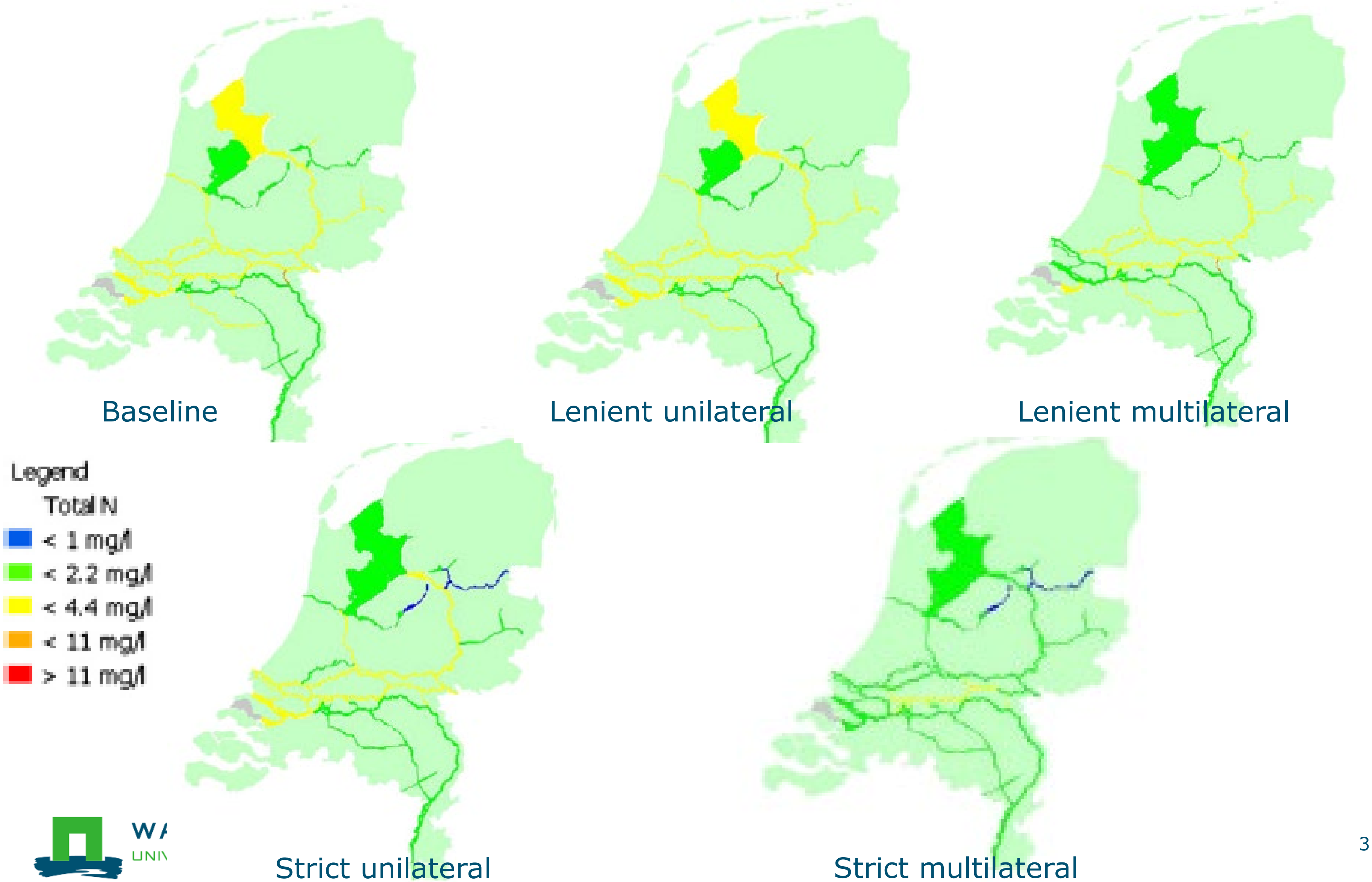
[a] Year by which emissions have to be reduced to the specified level.

Dynamic model – economic results

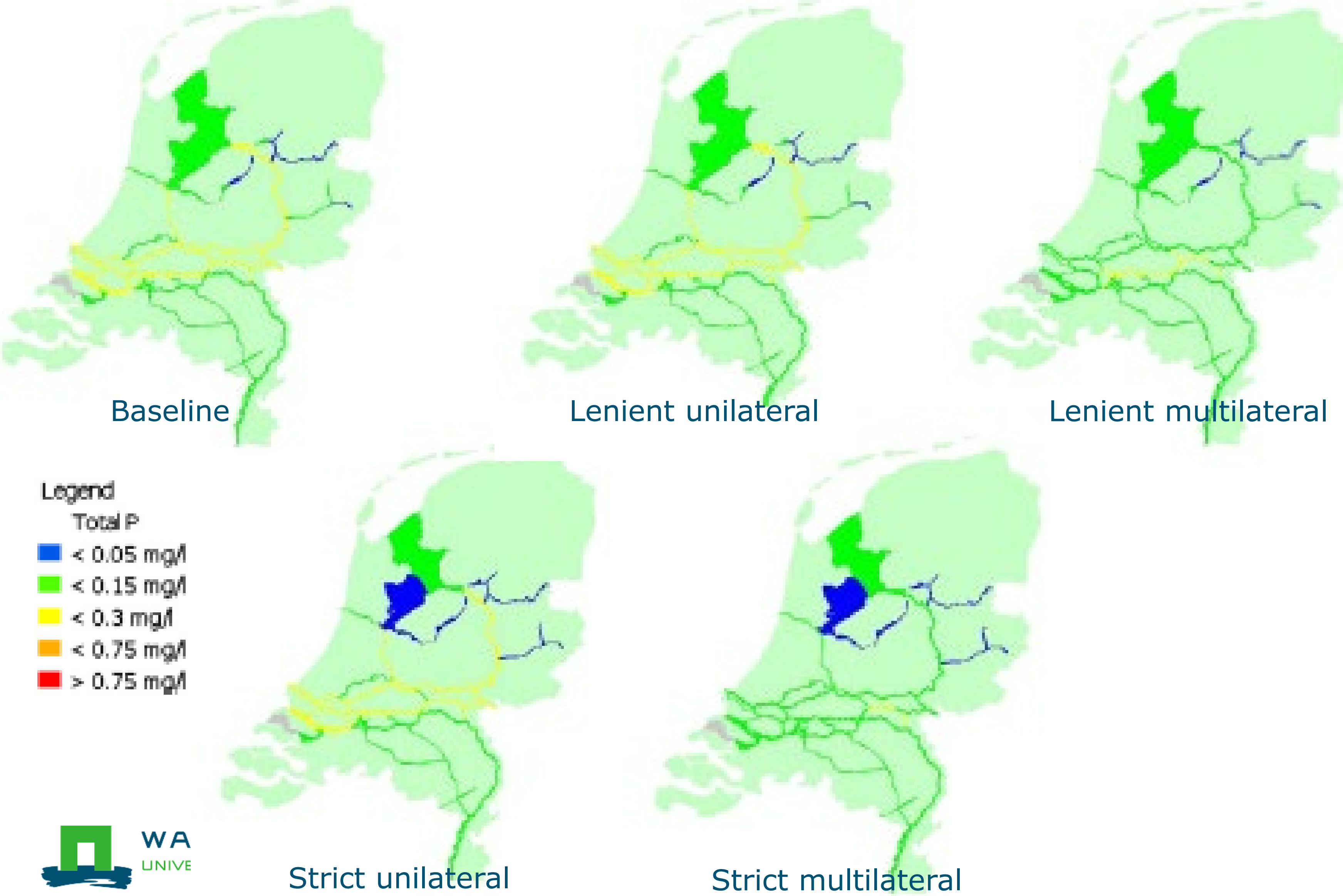
Table 2
Main model results for the different policy scenarios.

Key indicators	Lenient policy				Strict policy			
	2010	2015	2020	2030	2010	2015	2020	2030
Macroeconomic results (%-change compared to baseline projection)								
Gross Domestic Product	−0.03	−0.03	−0.03	−0.04	−0.19	−0.75	−0.77	−0.80
Net National Income	−0.03	−0.03	−0.03	−0.04	−0.02	−0.76	−0.78	−0.82
Total private household consumption	−0.02	−0.02	−0.02	−0.03	0.25	−0.14	−0.16	−0.19
Total production	−0.04	−0.04	−0.04	−0.04	−0.19	−1.44	−1.46	−1.49
Capital investment	−0.02	−0.03	−0.03	−0.03	−1.03	−0.68	−0.70	0.73
Sectoral results (%-change compared to baseline projection)								
Private household consumption Agriculture	−0.11	−0.12	−0.12	−0.12	−0.01	−3.00	−3.01	−3.02
Private household consumption Industry	−0.03	−0.03	−0.04	−0.04	0.13	−0.83	−0.84	−0.86
Private household consumption Services	−0.01	−0.01	−0.01	−0.01	0.22	0.21	0.19	0.16
Production Agriculture	−1.36	−1.47	−1.47	−1.47	−1.97	−33.25	−33.22	−33.18
Production Industry	−0.08	−0.09	−0.09	−0.10	−0.53	−4.08	−4.10	−4.13
Production Services	0.04	0.04	0.04	0.04	0.05	1.36	1.34	1.31
Production Abatement services	24.92	27.99	27.98	27.97	38.13	93.71	93.67	93.60
Environmental results (%-change compared to baseline projection)								
Emission of nutrients (N, P)	0.00	0.00	0.00	0.00	−13.65	−36.40	−36.40	−36.40
Emission of metals (Cd, Cu, Ni, Zn)	−3.56	−9.49	−9.49	−9.49	−16.29	−43.43	−43.43	−43.43
Prices (baseline index = 1.00, constant 2000 prices)								
Wage rate index	1.00	1.00	1.00	1.00	1.00	1.01	1.01	1.01
Exchange rate index	1.00	1.00	1.00	1.00	1.00	1.02	1.02	1.02
Price index of abatement services	0.95	0.93	0.90	0.86	0.95	0.92	0.90	0.86
Price index nutrients permits	1.55	1.71	1.89	2.30	1.26	1.56	1.56	1.56
Price index metals permits	1.54	2.09	2.31	2.82	1.85	175.09	174.67	173.99

Dynamic model – results for N in 2015



Dynamic model – results for P in 2015



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)

Part II

- Trade offs in policy
- Hydrological model – cost-effectiveness analyses

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

Hydrological model – CEA (Linderhof et al. 2010)

- Hydrological structure (WFD Explorer)

- Programmes of measures – cost effectiveness analysis

- Small scale (part of river basin)
- Low level
  - Water bodies (part of water system)
  - Catchment areas

Beerze-Reusel

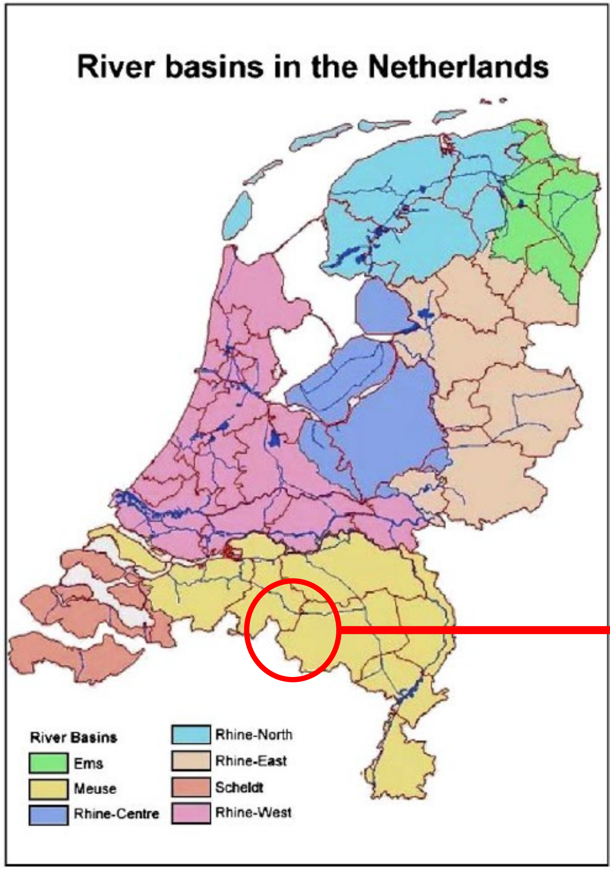
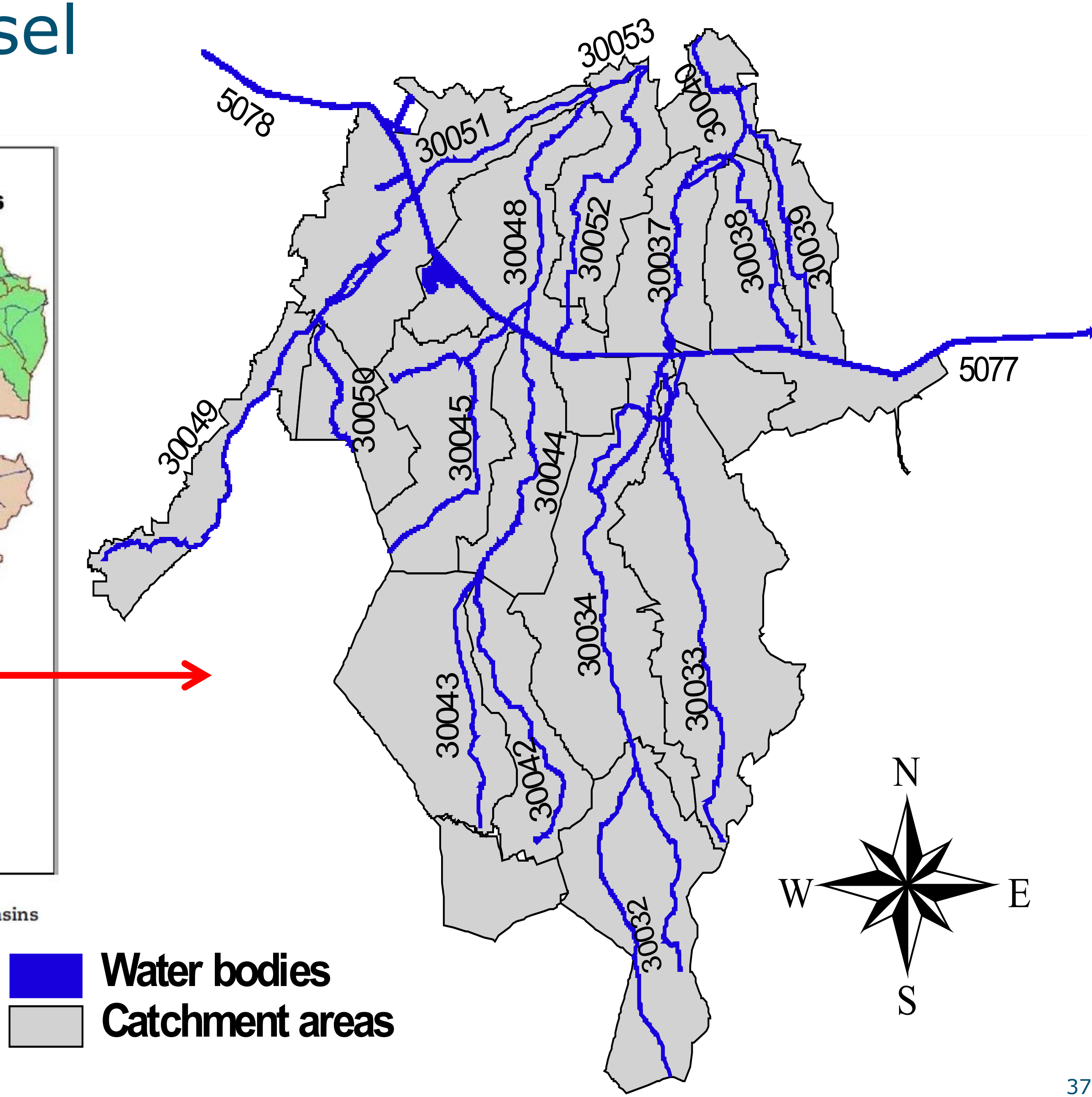


Fig. 5 – The Netherlands split up in the seven river basins distinguished in the WFD.



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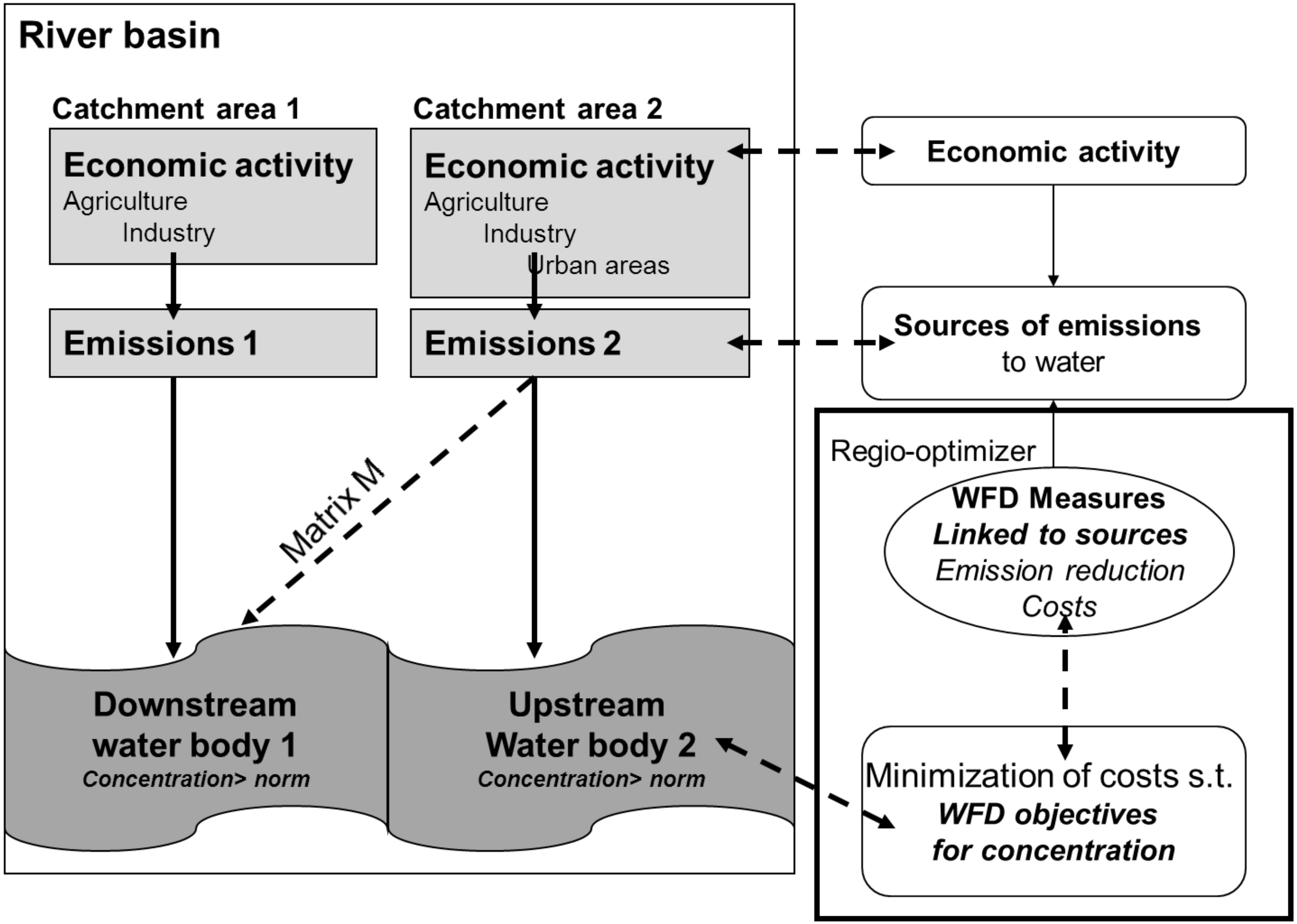
Hydrological model - CEA

- 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



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Exercise II

- Is the presented set of measures the most cost-effective one to achieve two objectives:
  - Reduction of nitrogen (N) by 75.000 kg and
  - Reduction of pesticides by 1.500 kg?

- What can you tell about the cost-effectiveness of measures in the table?

Exercise II

- No, it isn't

	Costs	Emission reduction		Cost-effectiveness		Cumulative		
Measure	*cost per year*	*Nutrient*	*Pesticides*	*Nutrient*	*Pesticides*	*Sum nutrients*	*Sum pesticides*	*Sum costs*
	TL 1,000	*1,000 kg*	*1,000 kg*	*TL/kg N*	*TL/kg N*	*1,000 kg*	*1,000 kg*	*TL 1,000*
Train farmers on improved	30	7.5	0.3	4	100	7.5	0.3	30
Enforce laws by inspectors (water, fertiliser, pesticides)	20	2.0	0.2	10	100	9.5	0.5	50
Improve chain management of	100	0.0	1.0		100			
Training (knowledge) of staff at industrial WWTP	100	50.0	0.0	2		59.5	0.5	150
Reuse of treated wastewater in	44	22.0	0.0	2				
Enforce use of advanced treatment facilities In Zones	30	10.0	0.0	3		69.5	0.5	180
Buffer strips along waterways	110	11.0	1.0	10	110	80.5	1.5	290
Limit fertilizer & pesticide use sensitive & protected areas	200	20.0	1.0	10	200			

Model

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

Subject to

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

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

Changes in water quality: $Q_{is} = Q^0_{is} \left[1 - \sum_{i' \in I} M_{ii's} \left(\frac{E^0_{i's} - E_{i's}}{E^0_{i's}} \right) \right]$ (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 25%=> 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)

Transport matrix for N

		5077	5078	30032	30033	30034	30037	30038	30039	30040	30042
		Water bodies for water quality measurement									
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) N	Emissions (kg per day) P	Share of emissions (%) N	Share of emissions (%) 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

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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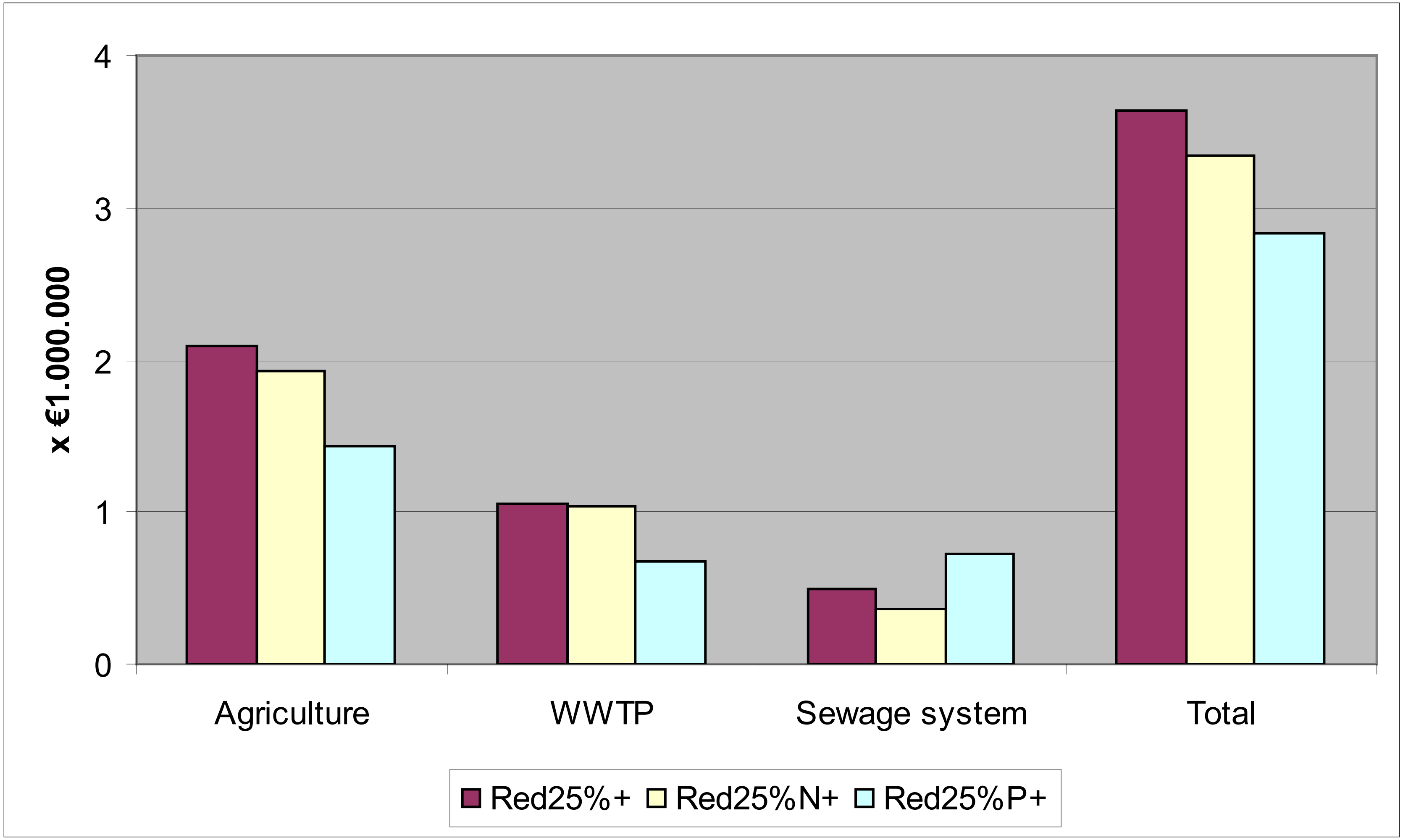
Results


4
3
2
1
0
x €1.000.000
Agriculture
WWTP
Sewage system
Total
Red25%+
Red25%N+
Red25%P+

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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