

Cost-effective and integrated optimization of the Eindhoven urban wastewater system: from modelling to implementation

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WATERWAYS



PARTNERS4URBANWATER

Langeveld | Lifting | Schilperoort | De Haan



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The Eindhoven system



Complex combined wastewater system

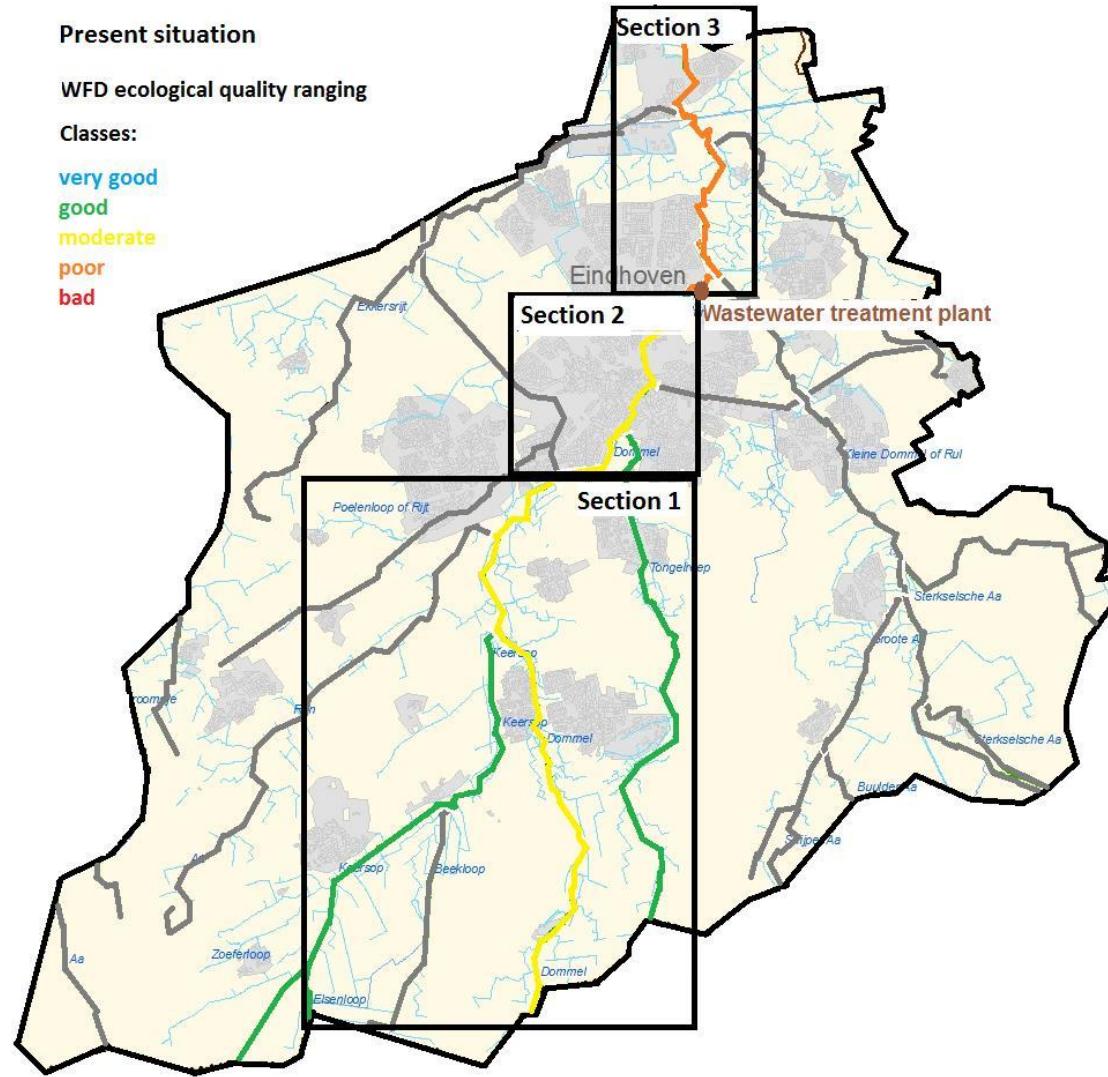
Large area with severe impact on vulnerable surface water

10 municipalities

750,000 PE WRRF

>200 CSOs

The Dommel River: ecological quality



Water Framework Directive (WFD)

Ecology Quality Score
(EQS): closely related to
flora and fauna

EQS scores:
0 (bad) to 1 (excellent)

Chemical and physical
quality are supporting
parameters for EQS



Gomphus vulgatissimus; typical dragonflies for
an “ecological good Dommel” (EQS > 0,6)

The Dommel River: ecological quality

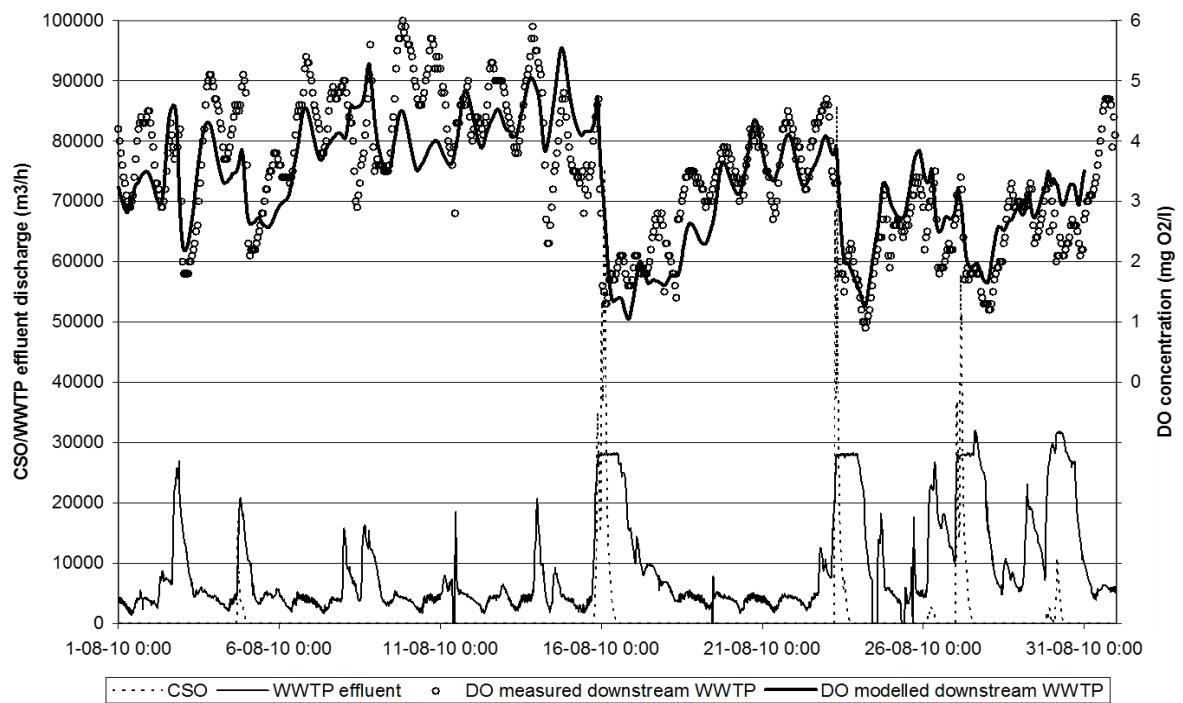
Ecological quality hampered by

1. Chronic effects due to nutrients



2. Acute effects
(peak loading)

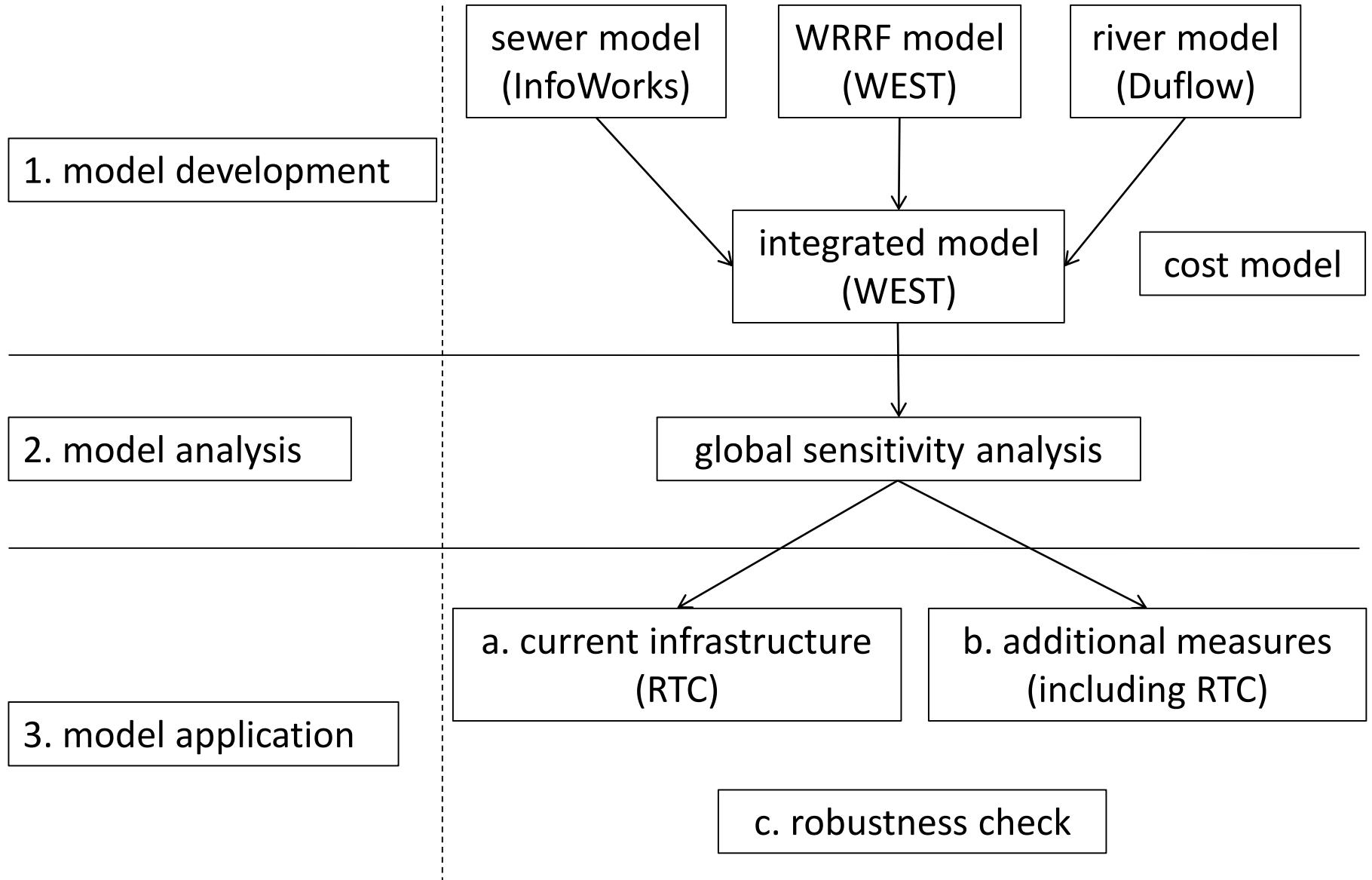
- DO dips
- Toxicity of ammonia peaks



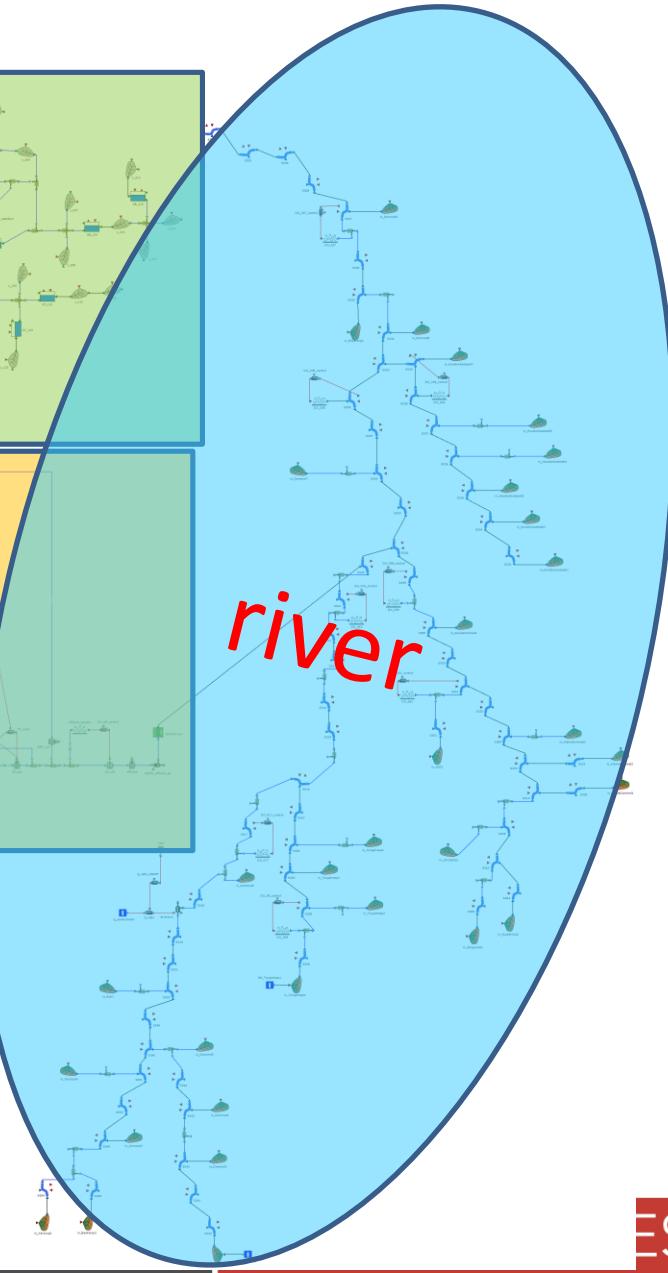
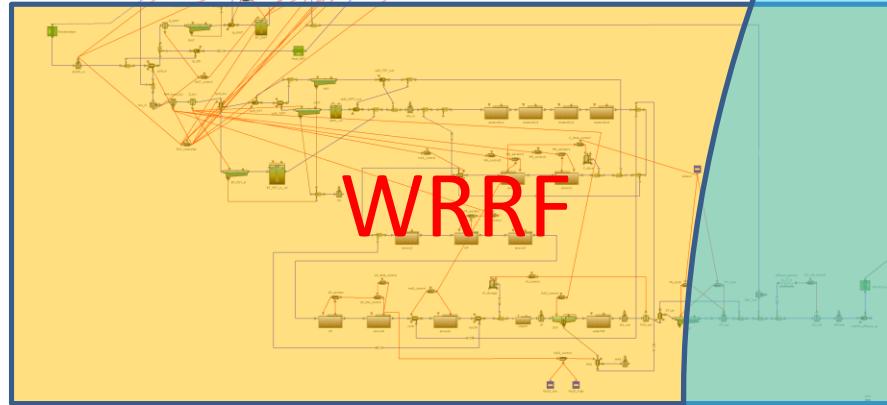
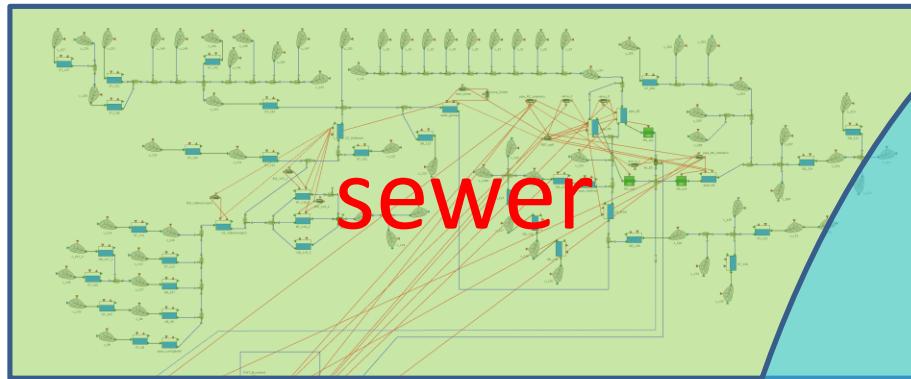
Developing ecological evaluation criteria

- Establish response curves from LIMNO-database for macro-invertebrate species
- Translate into concentration thresholds not to be exceeded for given durations and return periods (similar to the Urban Pollution Management Fundamental Intermittent Standards, UPM FIS)
- Create dynamic IUWS model to calculate exceedances (monitoring/modelling from 2010)

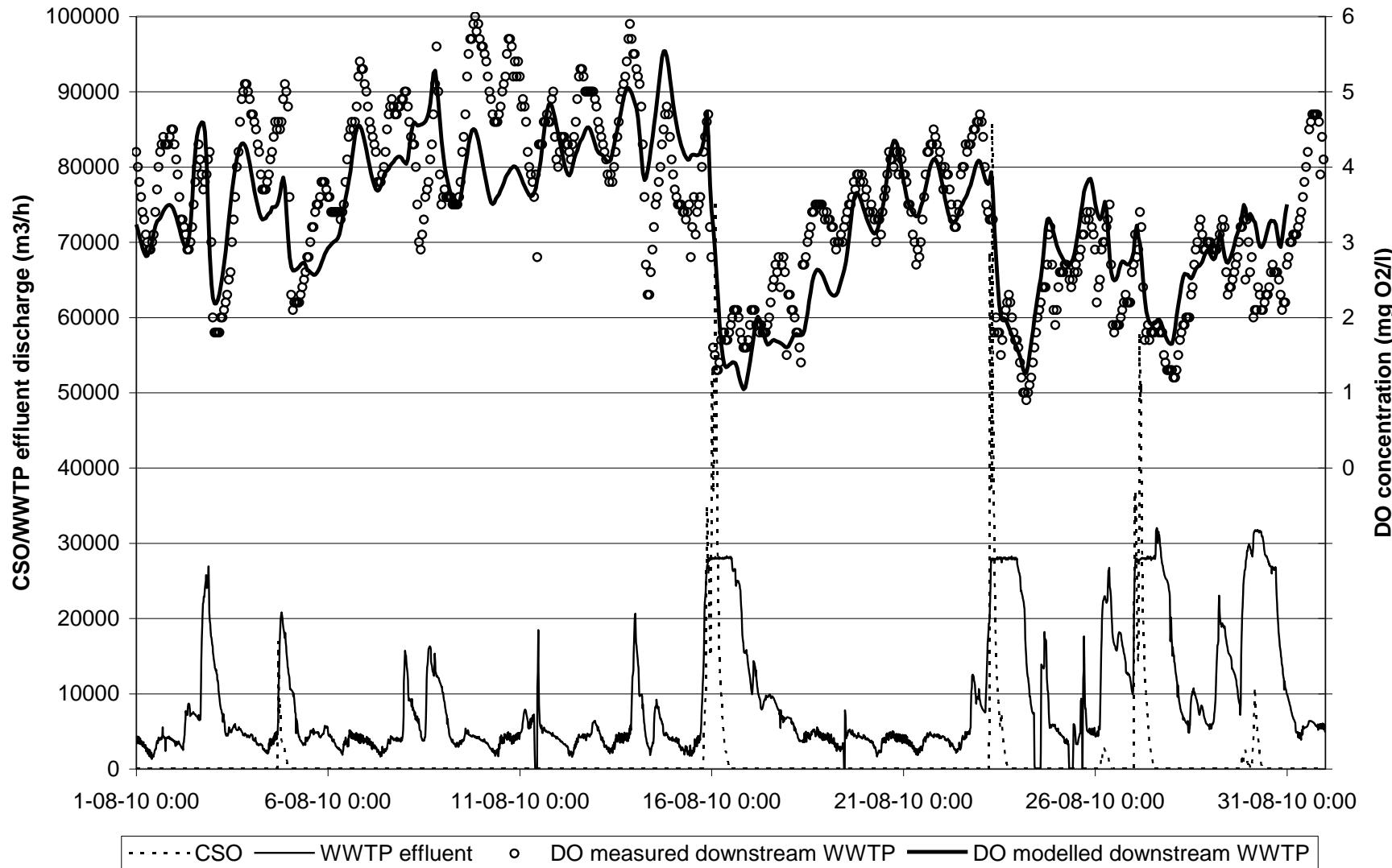
Modeling



DHI WEST® model



Integrated model results: DO at river section DS of WRRF



- One single model:
 - Mass and information flows (impact on receiving water, RTC)
- Speed:
 - Many scenarios
 - Long-term simulation (10y in 3h)
 - Monte Carlo for UA/SA (2000 3w simulations)

Scenario analysis

- **10-year dynamic** simulations
- Evaluation
 - Ecological framework based on **concentration-duration-frequency** curves for sensitive species (like UPM FIS)
 - Focus on **DO** and **NH₄**
 - Costs (**CAPEX** and **OPEX**)

10-y evaluation framework

Worst river section after
implementation of
baseline upgrades:

- > WRRF hydraulic capacity
- Sewer RTC
- < NH₄ aeration setpoint

										S008 current	S008 baseline					
NH ₄	<i>Duration of the event</i>															
	1 - 5 h	6 - 24 h	> 24 h													
Tolerated frequency per year	12	1.5	0.7	0.3	2	5	4	12.7	67.2	51.6	2	5	3	11.6	70.7	21.5
	4	2	1.2	0.5	4	5	5	14.5	67.3	31.9	4	5	4	15.1	63.4	13.9
	1	2.5	1.5	0.7	5	5	5	17.0	60.7	21.1	5	5	5	17.1	59.0	10.5
	0.2	4.5	3	1.5	5	5	5	9.2	32.3	8.7	5	5	5	2.3	21.0	4.0
DO critical	<i>Duration of the event</i>															
		1 - 5 h	6 - 24 h	> 24 h												
	12	5.5	6	7	1	4	4	9.3	43.8	28.9	1	4	4	7.9	42.0	30.0
	4	4	5.5	6	3	5	5	5.4	41.1	20.7	1	5	4	2.7	36.0	19.1
DO basic	<i>Duration of the event</i>															
		1 - 5 h	6 - 24 h	> 24 h												
	12	3	3.5	4	1	1	1	0.7	5.9	2.6	1	1	1	0.2	1.3	2.0
	4	2.5	3	3.5	1	1	1	0.4	1.8	1.5	1	1	1	0.3	0.9	1.3
	<i>Duration of the event</i>															
		1 - 5 h	6 - 24 h	> 24 h												
	1	2	2.5	3	1	2	2	0.2	1.1	0.9	1	1	1	0.1	0.2	0.7
	0.2	1	1.5	2	1	3	3	0.0	0.4	0.3	1	1	2	0.0	0.0	0.2

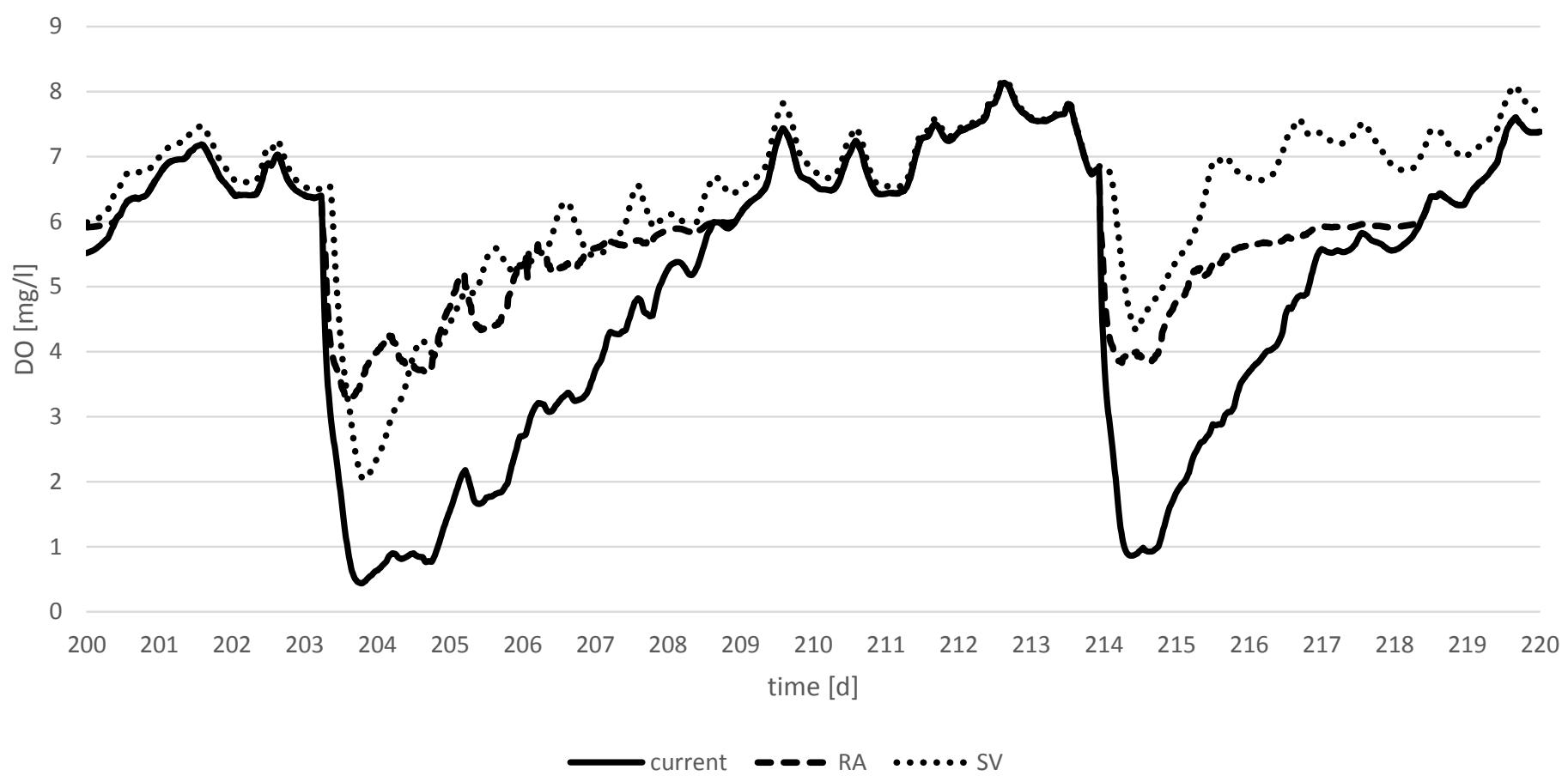
Storage Volume (200k m³)

1	1	1	0.6	2.2	4.5
1	1	1	0.3	1.4	0.8
1	1	1	0.2	0.4	0.4
4	1	2	0.5	0.1	0.2
1	1	1	0.2	0.1	0.4
1	1	1	0.1	0.2	0.3
1	1	1	0.1	0.2	0.2
1	1	1	0.1	0.0	0.1

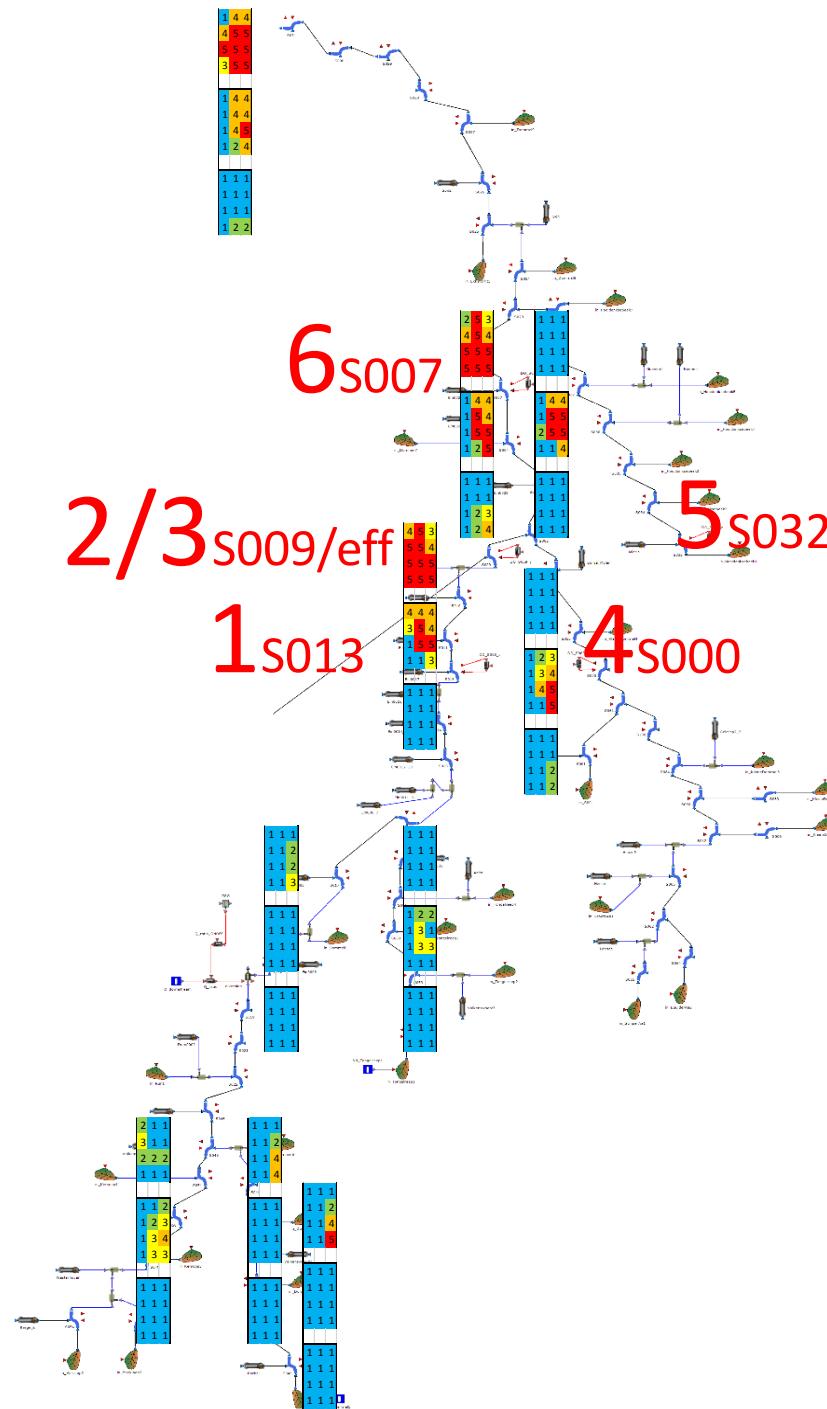
River Aeration

1	1	1	0.3	3.4	6.8
1	1	1	0.1	1.3	3.0
1	1	1	0.0	0.8	0.8
1	1	1	0.0	0.0	0.0
1	1	1	0.0	0.2	0.2
1	1	1	0.0	0.0	0.1
1	1	1	0.0	0.0	0.0
1	1	1	0.0	0.0	0.0

River Aeration vs. Storage Volume

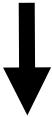


DO: in-stream aeration



Before

WRRF



DO crit.

	S013	S011	S010	S009	S002	S003	S004	S007	S008
1 1 1	0.3 1.8 5.1	1 1 1 1	0.7 1.7 6.0	1 1 1 1 1.0 2.9 6.3 4 4 4	25.8 38.0 25.3 3 4 4	17.3 37.5 27.1 2 4 4	12.9 41.5 27.8 2 4 4	11.0 41.4 29.0 1 4 4	8.6 42.6 29.6 1 4 4
1 1 1	0.0 0.7 1.8	1 1 1 1	0.1 1.0 2.1	1 1 1 1 0.0 1.4 2.3 3 5 4	6.7 29.9 12.4 2 5 4	3.5 25.3 13.6 1 5 4	3.1 28.3 16.0 1 5 4	2.4 28.5 17.5 1 5 4	3.0 32.5 18.5 1 5 4
1 2 3	0.1 1.0 1.5	1 1 1 3	0.1 0.8 1.8	1 1 1 3 0.6 0.8 2.0 1 5 5	0.5 13.4 8.9 1 5 5	0.2 8.7 8.1 1 5 5	0.1 10.6 9.2 1 5 5	0.3 11.0 10.5 1 5 5	0.3 10.7 11.7 1 5 5
1 1 3	0.0 0.1 0.3	1 2 3	0.0 0.2 0.4	1 3 4 0.1 0.4 0.6 1 1 3	0.0 0.1 0.3 1 1 3	0.0 0.0 0.3 1 2 4	0.0 0.2 0.5 2 1 4	0.2 0.1 0.7 1 2 5	0.1 0.2 1.1 1 2 5
1 1 1	0.1 0.5 0.5	1 1 1	0.1 0.8 0.8	1 1 1 0.6 1.1 1.1 1 1 1	0.5 1.3 1.4 1 1 1	0.2 1.2 0.9 1 1 1	0.1 1.1 1.4 1 1 1	0.3 1.3 1.7 1 1 1	0.3 1.1 1.9 1 1 1
1 1 1	0.0 0.3 0.3	1 1 1	0.0 0.5 0.6	1 1 1 0.0 0.4 0.7 1 1 1	0.3 0.5 0.8 1 1 1	0.0 0.3 0.5 1 1 1	0.0 0.7 0.8 1 1 1	0.2 0.7 1.1 1 1 1	0.3 0.8 1.4 1 1 1
1 1 1	0.0 0.2 0.3	1 1 1	0.1 0.4 0.4	1 1 1 0.0 0.4 0.6 1 1 1	0.1 0.2 0.3 1 1 1	0.0 0.3 0.3 1 1 1	0.0 0.3 0.5 1 1 1	0.0 0.2 0.7 1 1 2	0.1 0.5 1.1 1 2 3
1 1 2	0.0 0.0 0.2	1 1 2	0.0 0.1 0.2	1 2 3 0.1 0.2 0.3 1 1 1	0.0 0.0 0.1 1 1 1	0.0 0.0 0.0 1 1 1	0.0 0.0 0.1 1 1 3	0.0 0.1 0.3 1 1 3	0.0 0.1 0.4 1 2 4

DO bas.



DO crit.

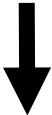
	S023	S024	S025	S026	S027	S028	S029	S030	S031
1 4 4	8.1 41.2 29.7	1 4 4	7.0 37.4 30.5	1 4 4	6.6 31.7 28.9	1 4 4	6.3 30.1 31.3	1 4 4	4.4 26.7 31.2
1 5 4	1.9 30.1 18.6	1 5 4	2.8 25.9 17.7	1 5 4	1.0 21.9 15.6	1 4 4	0.4 18.7 12.2	1 4 4	0.5 15.1 10.8
1 5 5	0.3 10.1 11.7	1 5 5	0.3 8.3 11.1	1 5 5	0.1 7.4 8.4	1 4 5	0.1 4.9 7.9	1 4 5	0.2 3.1 6.9
1 2 5	0.1 0.2 1.3	1 3 5	0.0 0.3 1.1	1 2 4	0.0 0.2 0.9	1 3 4	0.0 0.3 0.7	1 2 4	0.0 0.2 0.6
1 1 1	0.3 1.4 2.0	1 1 1	0.3 1.3 1.8	1 1 1	0.1 0.6 1.7	1 1 1	0.1 0.8 1.6	1 1 1	0.2 0.9 1.6
1 1 1	0.1 0.7 1.5	1 1 1	0.2 0.6 1.4	1 1 1	0.3 0.7 1.3	1 1 1	0.2 1.0 1.3	1 1 1	0.1 0.8 1.0
1 2 3	0.1 1.0 1.3	1 1 2	0.0 0.8 1.1	1 1 2	0.3 0.4 0.9	1 1 1	0.3 0.4 0.7	1 1 1	0.1 0.5 0.6
2 1 4	0.2 0.1 0.5	1 1 3	0.0 0.1 0.4	1 1 3	0.1 0.1 0.3	1 1 2	0.0 0.1 0.2	1 1 2	0.0 0.2 0.2

DO bas.

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After

WRRF



	S013	S011	S010	S009	S002	S003	S004	S007	S008	
DO crit.	1 1 1	0.0 0.2 5.1	1 1 1	0.7 1.0 5.9	1 1 1 1.1 2.0 6.3	1 1 3 0.0 0.3 17.1	1 1 4 0.1 0.9 25.7	1 1 4 0.4 5.2 28.2	1 3 4 0.9 14.5 28.4	1 1 4 0.0 0.0 29.0
	1 1 1	0.0 0.0 0.2	1 1 1	0.0 1.1 1.8	1 1 1 0.0 0.9 2.3	1 1 1 0.0 0.0 0.1	1 1 1 0.0 0.1 0.5	1 1 1 0.0 0.2 1.7	1 1 1 0.0 1.7 3.2	1 1 1 0.0 0.0 0.0
	1 1 1	0.0 0.0 0.0	1 1 1	0.0 0.1 0.8	1 1 3 0.1 0.5 1.6	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.1	1 1 2 0.0 0.0 0.4	1 1 1 0.0 0.2 1.0	1 1 1 0.0 0.0 0.1
	1 1 1	0.0 0.0 0.0	1 1 1	0.0 0.0 0.0	1 1 1 0.0 0.0 0.1	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0
DO bas.	1 1 1	0.0 0.0 0.0	1 1 1	0.0 0.0 0.1	1 1 1 0.1 0.1 0.2	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0
	1 1 1	0.0 0.0 0.0	1 1 1	0.0 0.0 0.1	1 1 1 0.0 0.1 0.2	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0
	1 1 1	0.0 0.0 0.0	1 1 1	0.0 0.0 0.0	1 1 1 0.0 0.1 0.1	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0
	1 1 1	0.0 0.0 0.0	1 1 1	0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0



	S023	S024	S025	S026	S027	S028	S029	S030	S031	
DO crit.	1 1 4	0.2 0.8 33.7	1 1 4 0.1 0.9 29.9	1 1 3 0.2 1.0 17.4	1 1 3 0.6 1.8 14.6	1 1 2 0.6 1.7 10.4	1 1 2 0.5 1.9 10.3	1 1 2 0.7 2.0 12.3	1 1 3 0.3 2.5 18.5	1 1 4 0.2 3.1 25.1
	1 1 1	0.0 0.2 0.7	1 1 1 0.0 0.3 0.7	1 1 1 0.0 0.3 0.7	1 1 1 0.0 0.7 0.7	1 1 1 0.0 0.6 0.7	1 1 1 0.0 0.8 0.7	1 1 1 0.0 0.7 0.8	1 1 1 0.0 1.2 1.3	1 1 1 0.0 1.1 1.3
	1 1 1	0.0 0.0 0.2	1 1 1 0.0 0.1 0.2	1 1 1 0.0 0.1 0.2	1 1 1 0.0 0.0 0.2	1 1 1 0.0 0.0 0.2	1 1 1 0.0 0.0 0.2	1 1 1 0.0 0.1 0.5	1 1 1 0.0 0.2 0.6	1 1 1 0.0 0.2 0.7
	1 1 1	0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0
DO bas.	1 1 1	0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.1	1 1 1 0.0 0.0 0.1	1 1 1 0.0 0.0 0.1	1 1 1 0.0 0.0 0.1	1 1 1 0.0 0.0 0.1	1 1 1 0.0 0.0 0.1
	1 1 1	0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0
	1 1 1	0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0
	1 1 1	0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0	1 1 1 0.0 0.0 0.0



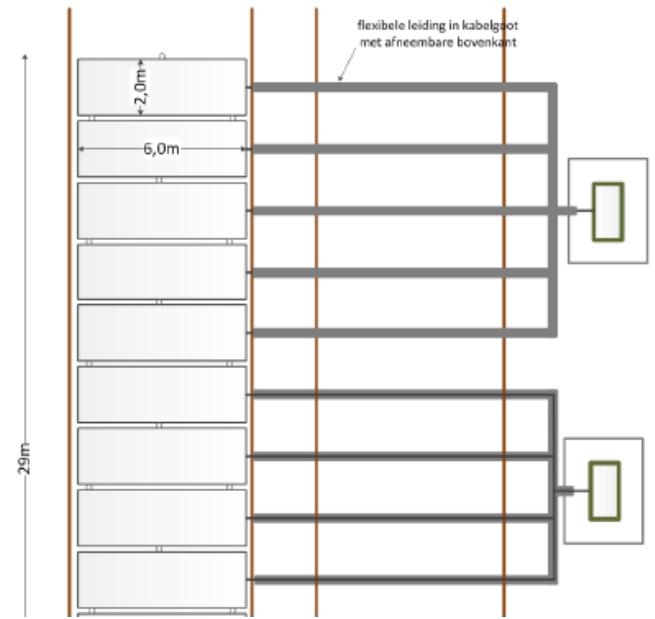
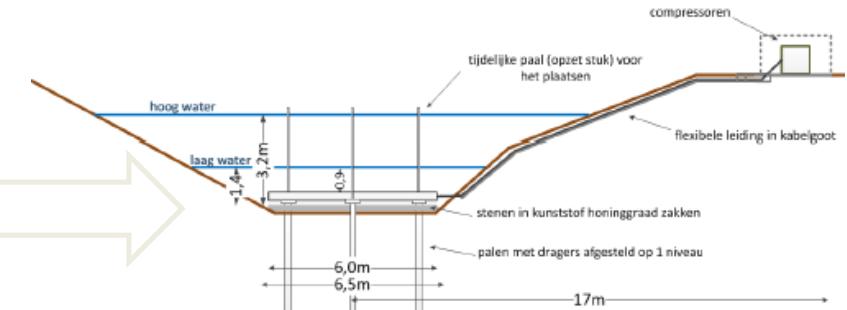
River aeration

10 to 20 times more cost efficient than CSO storage

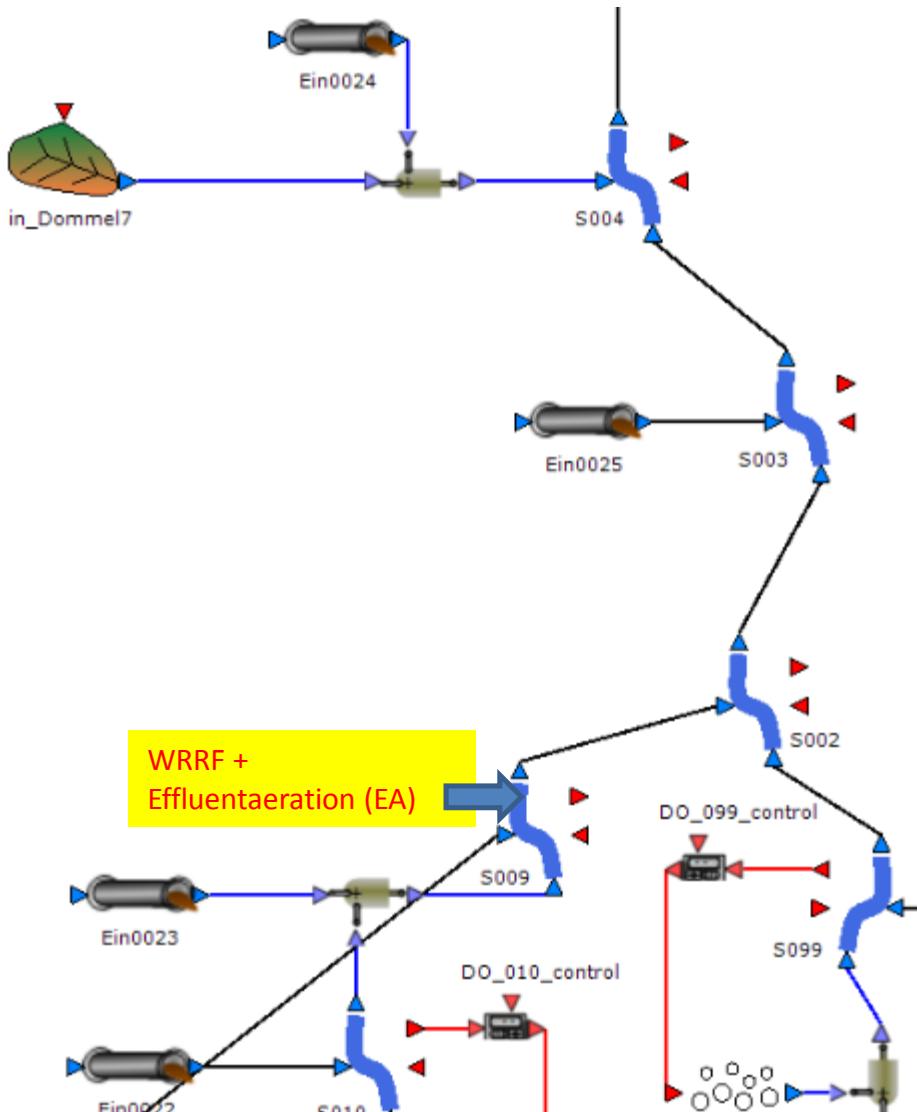


Plan for 1st DEMO
(120 kgO₂/hr)

Pilot research
(25 kgO₂/hr)



Working with the integrated model: determining capacity effluent aeration



NB

DO critical	Duration of the event			5009	5002	5003	5004															
	1 - 5 h	6 - 24 h	> 24 h																			
Tolerated	12	5,5	6	7	4,3 5,5 4 1	39,0 21,1 44,2 18,9	69,9 21,1 11,3 17,9	37,6 5,4 4,5 5,5	4,4 4,5 4,4 3,5	26,5 9,2 38,5 15,0	46,2 9,2 19,8 11,8	31,2 3,5 3,5 2,5	16,7 5,5 4,4 5,5	46,3 6,2 38,9 16,3	30,8 21,5 14,7 14,7	2,4 2,5 4,7 1,5	4,4 4,7 37,0 0,7	12,4 4,7 37,0 16,3	45,3 23,1 17,1 17,1			
frequency per year																						
	0,2	1,5	2	3	1 1 1	0,0 0,0 0,1	0,0 0,0 0,1	0,0 0,0 0,1	1 1 1	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0

NB_DOd_EA360_SOD5

DO critical	Duration of the event			5009	5002	5003	5004													
	1 - 5 h	6 - 24 h	> 24 h																	
Tolerated	12	5,5	6	7	1,1 1 1 1 1	1,0 0,0 1,0 2,4 0,0	3,3 0,0 1,0 2,4 0,0	26,6 1,6 15,2 26,8 3,4	1,6 1,6 15,2 26,8 3,4	3,0 0,1 6,8 7,8 0,1	20,6 6,8 11,5 11,5 0,0	28,9 7,8 23,3 27,7 0,0	1,3 1,4 4,4 4,4 0,0	3,2 0,4 11,5 11,5 0,0	23,3 11,5 27,7 27,7 0,0					
frequency per year																				
	0,2	1,5	2	3	1 1 1	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	1 1 1	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0

NB_DOd_EA200_SOD4

DO critical	Duration of the event			5009	5002	5003	5004												
	1 - 5 h	6 - 24 h	> 24 h																
Tolerated	12	5,5	6	7	1,1 1 1 1 1	1,0 0,0 1,9 2,3 0,0	3,1 1,1 1,1 1,1 0,0	19,6 1,5 10,2 23,7 3,4	1,2 1,2 1,2 1,2 0,2	2,0 0,2 1,2 2,2 0,2	16,3 4,1 3,6 8,0 0,0	27,6 3,6 21,7 21,7 0,0	1,3 1,3 3,4 2,5 0,0	2,5 0,0 5,2 28,5 0,0	21,7 11,5 28,5 28,5 0,0				
frequency per year																			
	0,2	1,5	2	3	1 1 1	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	1 1 1	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0

NB_DOd_EA200_SOD5

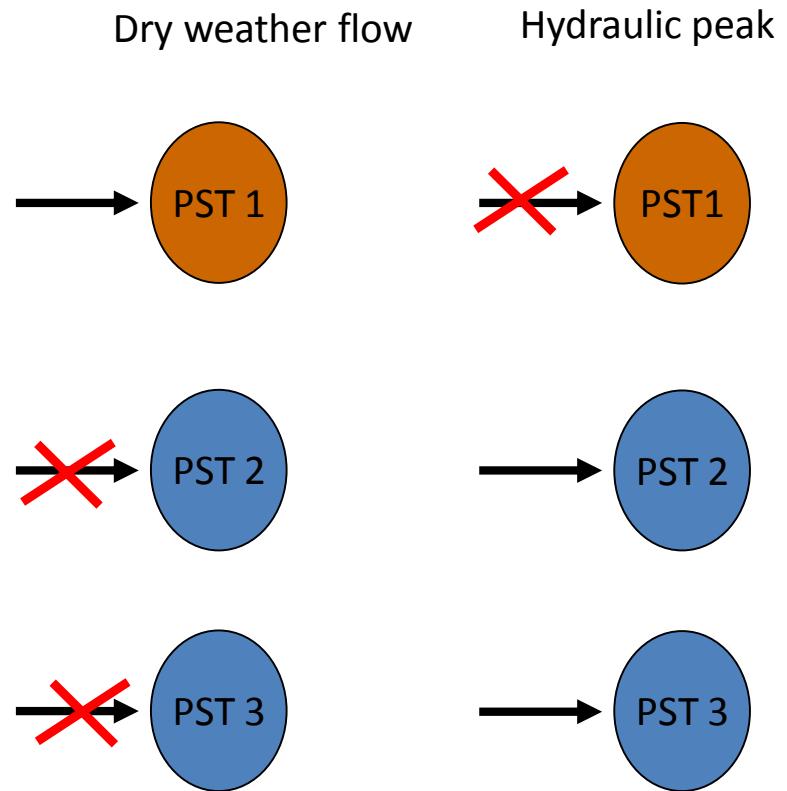
DO critical	Duration of the event			5009	5002	5003	5004												
	1 - 5 h	6 - 24 h	> 24 h																
Tolerated	12	5,5	6	7	1,1 1 1 1 1	2,1 0,0 2,1 2,4 0,0	6,1 1,1 1,1 2,4 0,0	27,0 1,3 17,8 26,7 3,4	3,4 2,2 3,4 4,8 3,4	4,3 0,2 21,9 28,7 0,0	21,9 8,0 28,7 8,4 0,0	28,7 8,4 5,4 23,8 27,9	1,4 1,4 4,4 2,0 0,0	2,5 0,2 12,9 11,4 0,0	21,7 11,4 27,9 27,9 0,0				
frequency per year																			
	0,2	1,5	2	3	1 1 1	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	1 1 1	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0

NB_DOd_EA150_SOD5

DO critical	Duration of the event			5009	5002	5003	5004												
	1 - 5 h	6 - 24 h	> 24 h																
Tolerated	12	5,5	6	7	1,2 1 2,1 1 1	7,2 0,0 4,1 3,0 0,0	12,0 6,9 6,9 5,6 0,0	27,0 6,9 6,9 26,7 3,4	3,4 2,2 3,4 4,8 3,4	4,7 0,2 11,1 9,3 0,0	26,2 8,0 11,1 28,9 0,0	28,9 8,4 9,3 12,1 0,0	1,4 1,4 4,4 0,5 0,0	6,1 0,5 15,7 12,1 0,0	27,8 12,1 27,8 27,8 0,0				
frequency per year																			
	0,2	1,5	2	3	1 1 1	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	1 1 1	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	0,0 0,0 0,0	

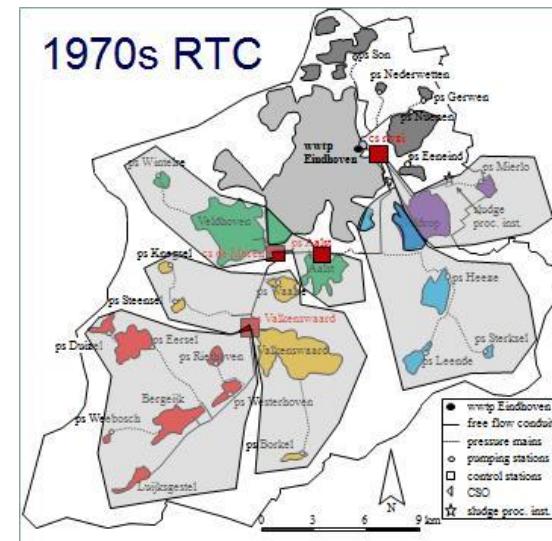
Smart Buffers to reduce first flush

Other way of using the existing infra-structure



Outcome – ‘Smart measures’

- Operational control: best use of existing infrastructure
 - Sewer-South
 - WRRF
- Requiring investments
 - Surface water aeration
 - Effluent aeration
 - Several adjustments on WRRF
- Stepwise implementation: ‘adaptive strategy’



Status and Perspectives

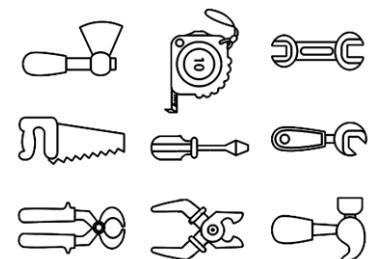
- Integrated sewer RTC implemented in 2015
- First pilot aeration installation soon in the river near the WRRF effluent
- ‘Smart Buffers’ under implementation
- Effluent aeration in design phase
- As NH_4 limits might be introduced, measures to lower the NH_4 effluent (CEPT, MR aeration) are still relevant and will be further tested

Conclusions

- Integrated (sewer + WRRF + river) model built for dynamic 10-y evaluation of river water quality
- Sewer RTC and other measures in sewer and WRRF reduce the DO issue but are not sufficient
- Remaining DO issue could be effectively solved by installing in-stream aeration at 4-6 locations, as more conventional measures (e.g. storage) are not effective nor efficient
- Some measures were tested to reduce peaks in case of NH_4 limits, PST 'Smart Buffers' now being implemented
- Significant savings compared to initial budget (now app. 40M EUR → app. 75% saving)

Conclusions

- Evaluation criteria change faster than service life of infrastructure (sewer 80 years, WRRF 20-30 years), adaptive planning is required
- Fast dynamic models to simulate river water quality are required to simulate 10-y time series for evaluation of measures
- The integrated model is a very strong tool to find the most cost efficient measures



Check WEFTEC proceedings for info

- Similar project in Odense (DK) with VCS Denmark and CH2M
- Combined system, storm system, 3 WRRFs, 80 km of streams
- Used for planning and for discussions with the Regulator