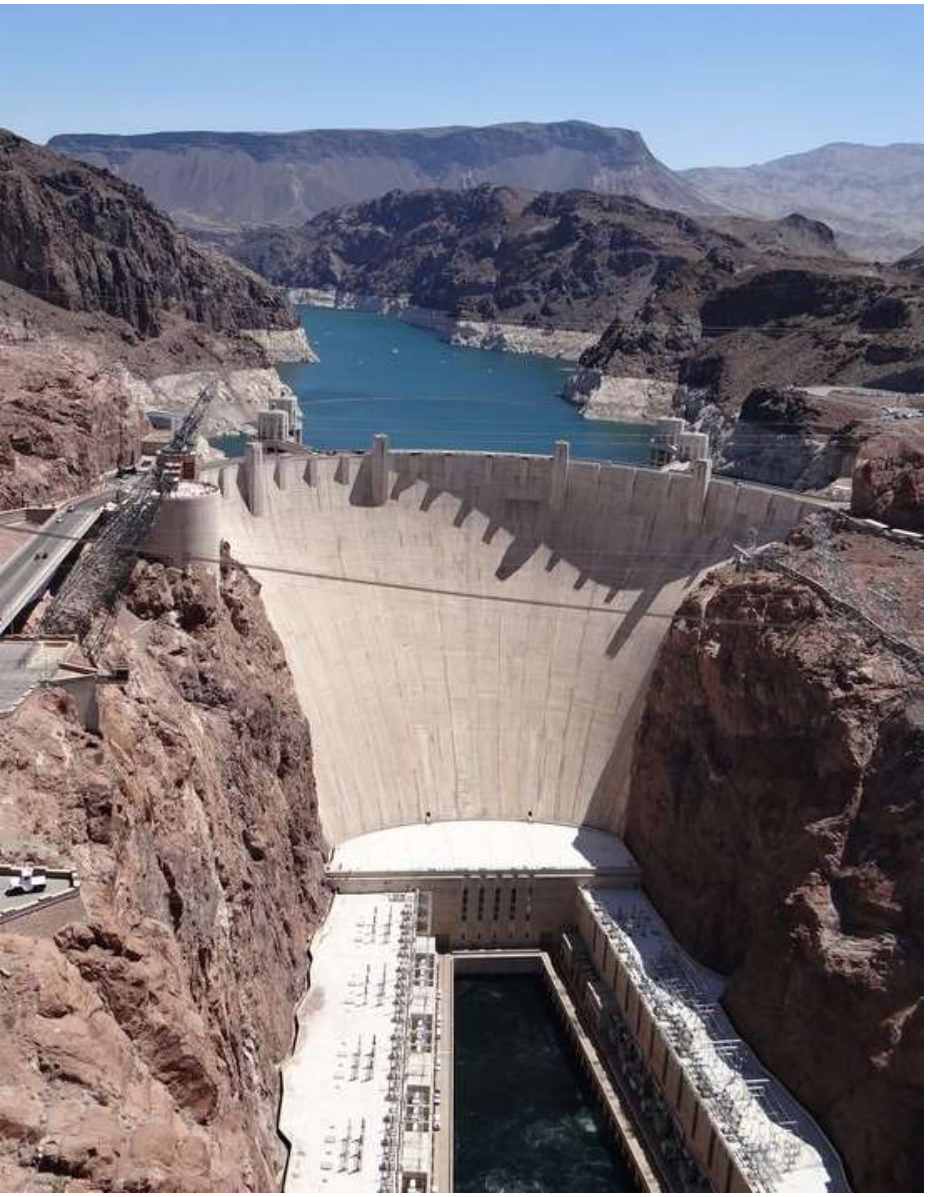
Deltares



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RTC-Tools & Delft-FEWS

Breakout session - Decision Support and Control with Delft-FEWS

Ivo Miltenburg

Klaudia Horvath

2022-11-09

RTC-Tools 2

- RTC-Tools is the Deltares toolbox for control and optimization of environmental systems.
- Delft-FEWS is an open data handling platform, used for the aggregation of (real-time) environmental data flows.
- Together, they provide a platform for the development of decision support systems.

Deltares

History of RTC-Tools

- 2005: Reservoir module for Delft-FEWS.
- 2012: Deltares releases first version of **RTC-Tools source code** to the public. RTC-Tools 1.x connected non-linear hydraulic and reservoir models to the IPOPT optimizer.
  - Promising results, many scientific publications
  - High interest from reservoir operators, but challenging to operationalize, and hard to extend
- 2015: Work starts on new mathematically rigorous foundation.
  - Implementation in Python for more flexibility for the modeler
  - Modelica and automatic differentiation to ensure mathematically correct formulations for the basic equations
  - Focus on optimization alone
- 2016: **RTC-Tools 2.0** released + first pilot projects on new foundation.
  - Focus on optimization and convergence
  - water allocation tool for Rijkswaterstaat using new framework.
  - decision support systems for a number of water boards in The Netherlands.
- 2018: RTC-Tools 2.2
  - 64 bit
  - implementation as Python package (easy debugging within a development environment)
  - Ensemble
- 2019: RTC-Tools 2.3
  - First simulation models: Hume Dam (Australia), Navigation canal system (Germany), Water board Rijnland (Netherlands)
- 2020: RTC-Tools 2.4
  - More focus on Simulation
- **2022: RTC-Tools 2.5**

Users and applications

Operator Scheduler

Consultant

Flow forecaster

Water Authorities

Reservoir operators

Public utilities

Strategic planning

Integrated water resources management

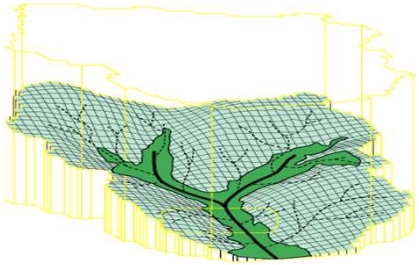
Researcher

Process of Forecasting

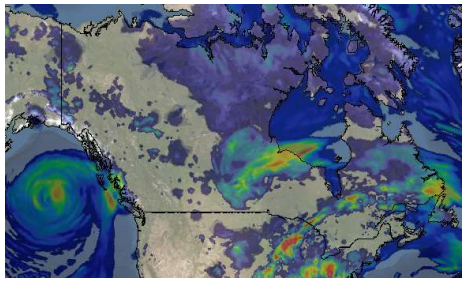
Forecast levels / flows by combining data and models well in advance

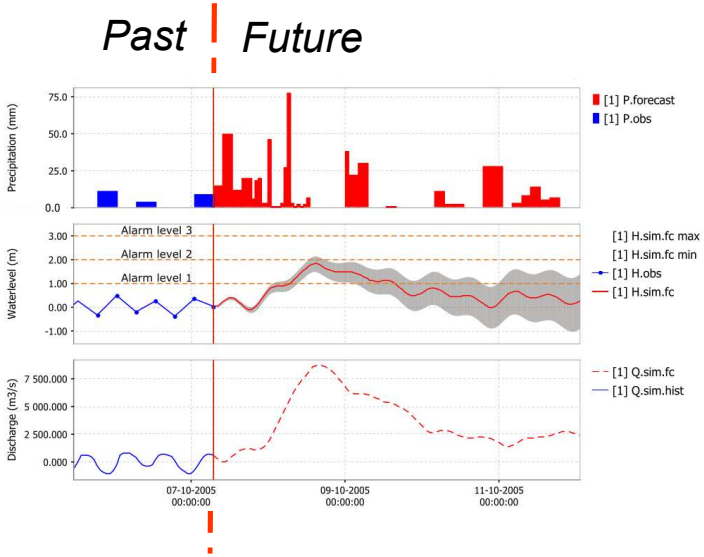
Hydrological and meteorological observations

Models



Meteorological forecasts





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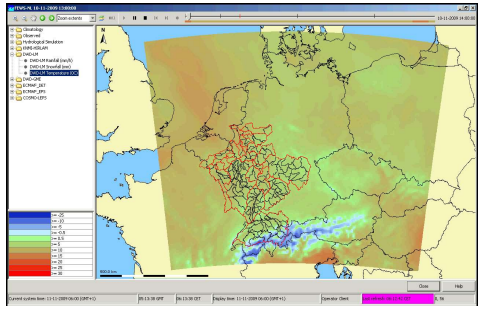
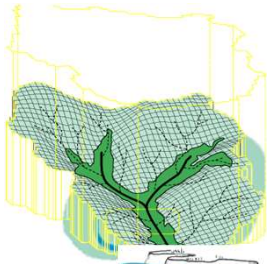
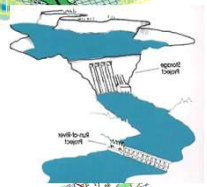
Role of Models in Forecasting Process



Numerical Weather
Prediction models

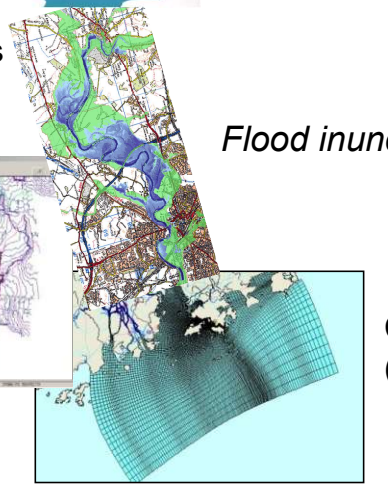


Rainfall-runoff modeling
& snow modeling



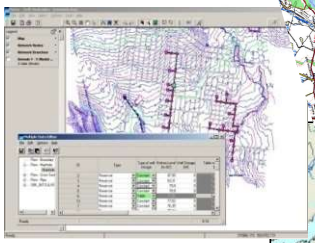
Reservoir Models

Routing models
Hydrodynamic models



Flood inundation models

Urban drainage models



Coastal shelf models
(2D Hydrodynamic)

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Control Examples in operational systems (global)

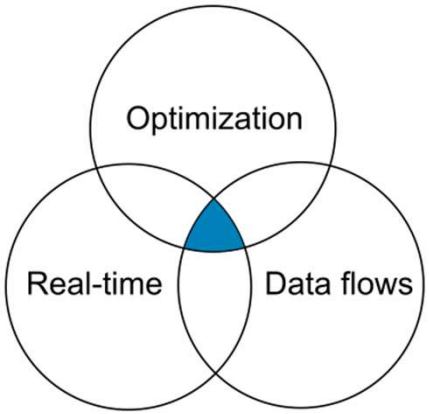
- Some examples/highlights of RTC-Tools applications – Focus on the link with Delft-FEWS
- More complex is not always better – all kinds of flavors are possible
- Food for thought
- Invoke discussion
- Inspiration!

Deltares

RTC-Tools 2 – Delft-FEWS connection

- RTC-Tools has a tight Delft-FEWS connection
- No adapter needed
- Communication through PI-XML format

- Time series, parameters, goals/constraints, etc are prepared in Delft-FEWS
- Modifiers (interactivity)
- Scheduled runs (no interactivity)
- Scenarios
- Visualization (graph/scada/table/text/…)



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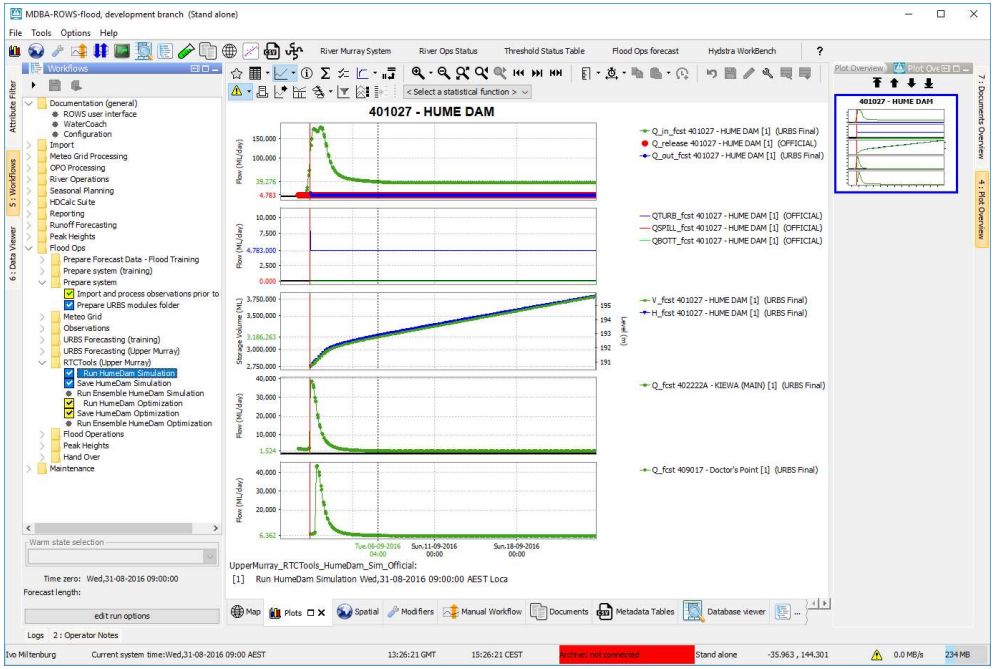
Delft-FEWS interaction – time series/parameters

Takes care of the data exchange with FEWS:

- Forcings
- Structure settings
- Parameters
- Initial conditions (state)



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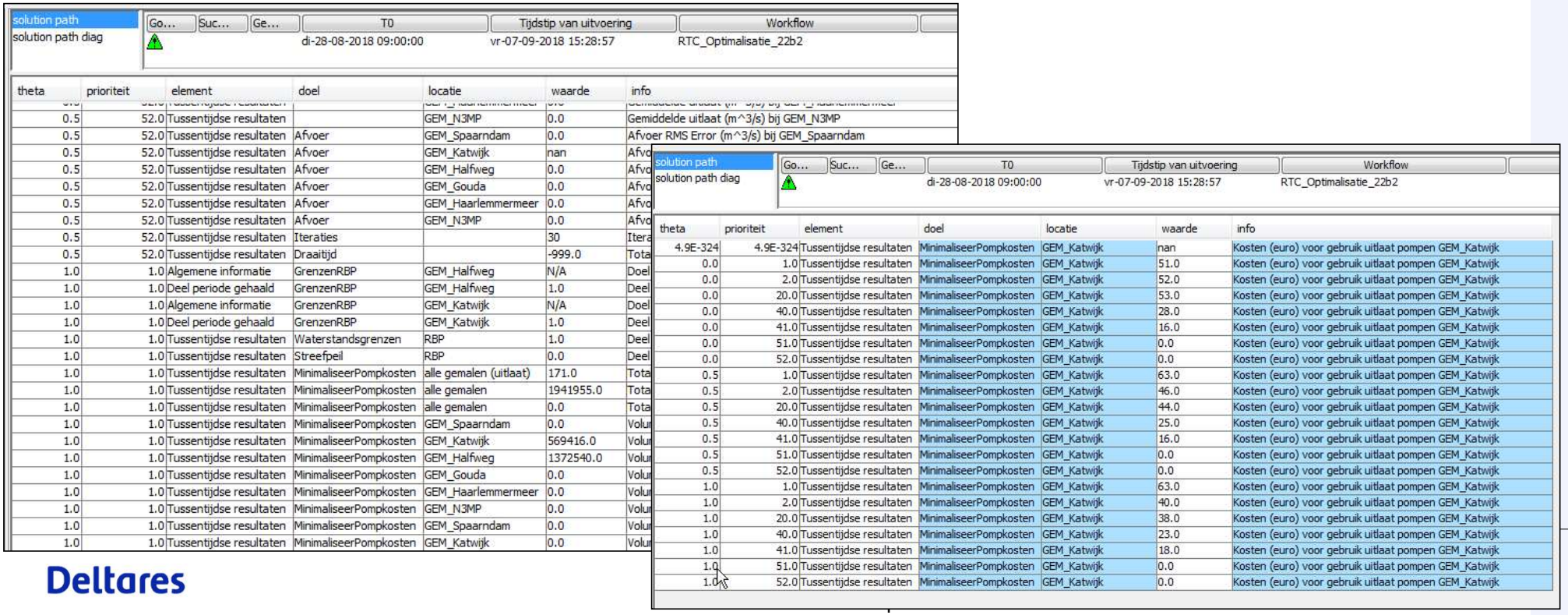
Delft-FEWS interaction - table results

Information Imported as CSV tables
- Filtering / ordering



solution path	Go...	Suc...	Ge...	T0	Tijdstip van uitvoering	Workflow
solution path diag				di-28-08-2018 09:00:00	vr-07-09-2018 15:28:57	RTC_Optimalisatie_22b2

theta	prioriteit	element	doel	locatie	waarde	info
0.5	52.0	Tussentijdse resultaten		GEM_N3MP	0.0	Gemiddelde uitlaat (m^3/s) bij GEM_N3MP
0.5	52.0	Tussentijdse resultaten	Afvoer	GEM_Spaarndam	0.0	Afvoer RMS Error (m^3/s) bij GEM_Spaarndam
0.5	52.0	Tussentijdse resultaten	Afvoer	GEM_Katwijk	nan	Afvo
0.5	52.0	Tussentijdse resultaten	Afvoer	GEM_Halfweg	0.0	Afvo
0.5	52.0	Tussentijdse resultaten	Afvoer	GEM_Gouda	0.0	Afvo
0.5	52.0	Tussentijdse resultaten	Afvoer	GEM_Haarlemmermeer	0.0	Afvo
0.5	52.0	Tussentijdse resultaten	Afvoer	GEM_N3MP	0.0	Afvo
0.5	52.0	Tussentijdse resultaten	Iteraties		30	Itera
0.5	52.0	Tussentijdse resultaten	Draaitijd		-999.0	Tota
1.0	1.0	Algemene informatie	GrenzenRBP	GEM_Halfweg	N/A	Doel
1.0	1.0	Deel periode gehaald	GrenzenRBP	GEM_Halfweg	1.0	Deel
1.0	1.0	Algemene informatie	GrenzenRBP	GEM_Katwijk	N/A	Doel
1.0	1.0	Deel periode gehaald	GrenzenRBP	GEM_Katwijk	1.0	Deel
1.0	1.0	Tussentijdse resultaten	Waterstandsgrenzen	RBP	1.0	Deel
1.0	1.0	Tussentijdse resultaten	Streefpeil	RBP	0.0	Deel
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	alle gemalen (uitlaat)	171.0	Tota
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	alle gemalen	1941955.0	Tota
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	alle gemalen	0.0	Tota
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Spaarndam	0.0	Volu
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	569416.0	Volu
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Halfweg	1372540.0	Volu
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Gouda	0.0	Volu
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Haarlemmermeer	0.0	Volu
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_N3MP	0.0	Volu
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Spaarndam	0.0	Volu
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Volu

solution path	Go...	Suc...	Ge...	T0	Tijdstip van uitvoering	Workflow
solution path diag				di-28-08-2018 09:00:00	vr-07-09-2018 15:28:57	RTC_Optimalisatie_22b2

theta	prioriteit	element	doel	locatie	waarde	info
4.9E-324	4.9E-324	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	nan	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	51.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	2.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	52.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	20.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	53.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	40.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	28.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	41.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	16.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	51.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	52.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	63.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	2.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	46.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	20.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	44.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	40.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	25.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	41.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	16.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	51.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	52.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	63.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	2.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	40.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	20.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	38.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	40.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	23.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	41.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	18.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	51.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	52.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk

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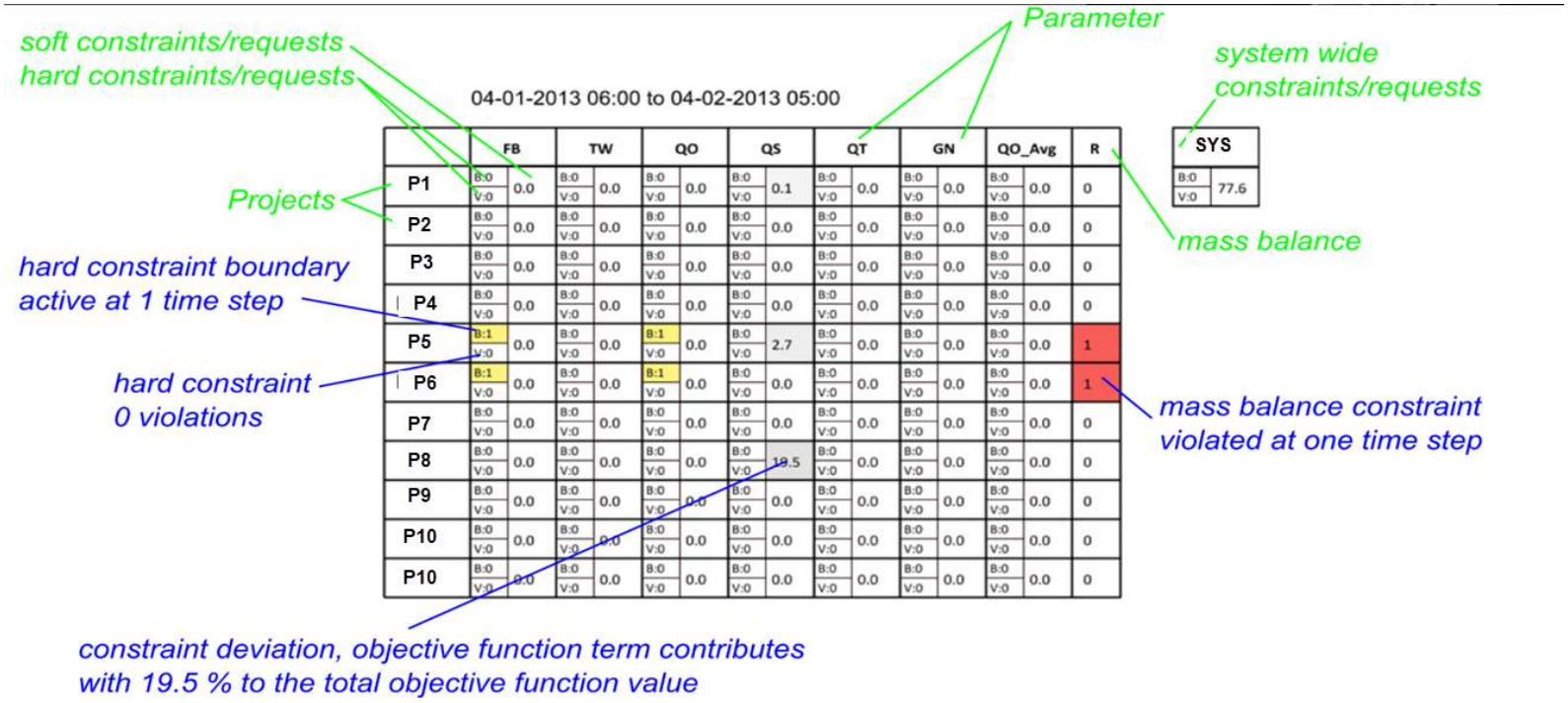
Run information Displayed in FEWS



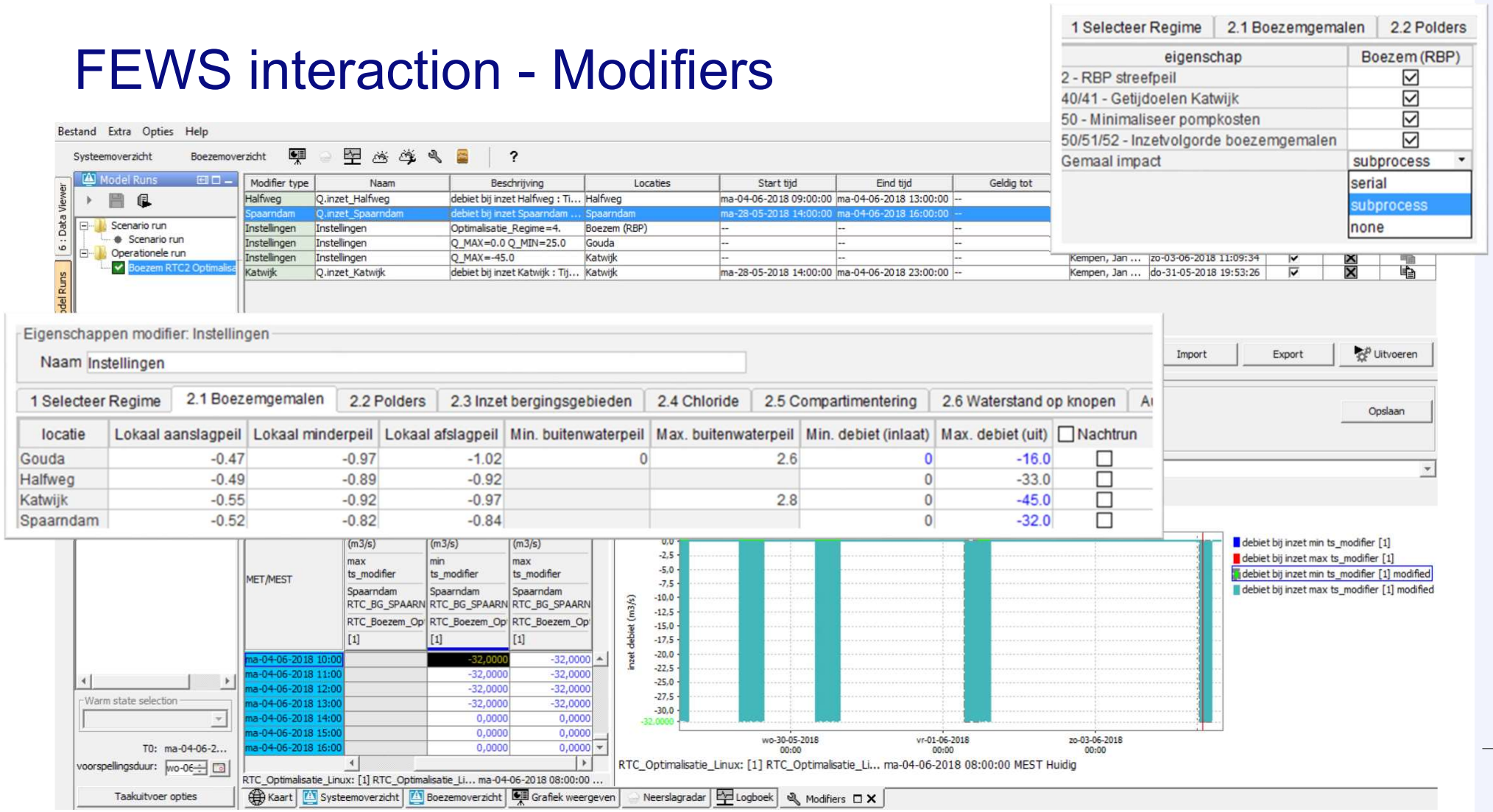
	FB	TW	QO	QS	QT	GN	QO_Avg	R
P1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0
P2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
P3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
P4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
P5	0.0	0.0	0.0	2.7	0.0	0.0	0.0	1
P6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
P7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
P8	0.0	0.0	0.0	19.5	0.0	0.0	0.0	0
P9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
P10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
P10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0

SYS
77.6

Data Imported as Time Series (hourly and aggregated to run length)
and CSV for names of violated constraints and violation magnitudes

Deltares

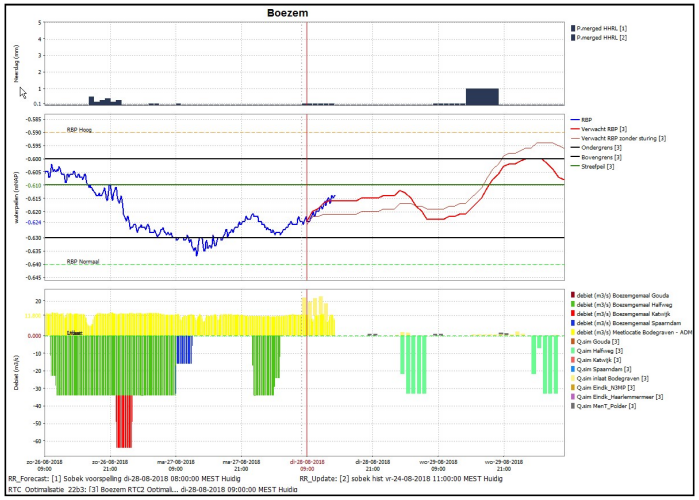
FEWS interaction - Modifiers



Operation Types

Many variations in how the operation forecasts are being used

- Background reference (informative)
- Scenario Tool
- Generation of many (potential) futures to be used by other (statistical) models
- Decision Support
- Direct operations (telemetry)



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Reservoir Operations - Considerations

Scope of optimization/simulation

- Real Time Control
- Short Term Planning
- Long term Planning

Example of (optimization) run types (different set of overall goals/constraints)

- Hydraulic Objectives
- Load Balance
- Max Revenue
- Min/Max Generation
- Pumped Storage

RTC-Tools could assist in maximizing revenue from power sales, while keeping the system compliant with regulations, through multi-objective optimization techniques, under (meteorological uncertainty)

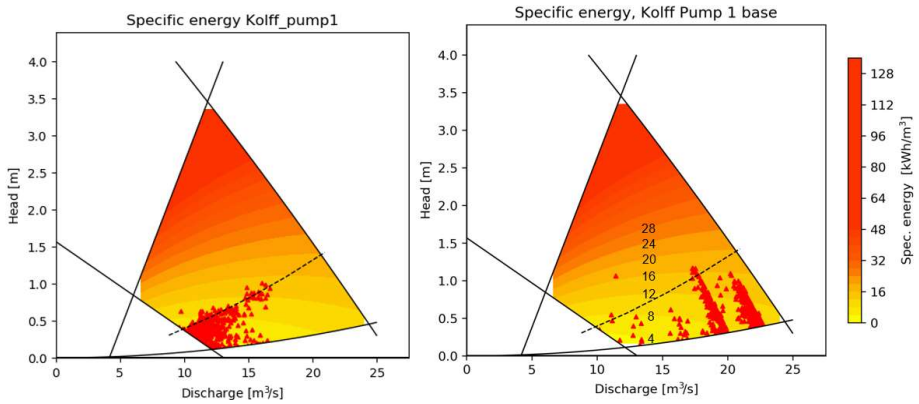
Interest in / Use of Control within Delft-FEWS

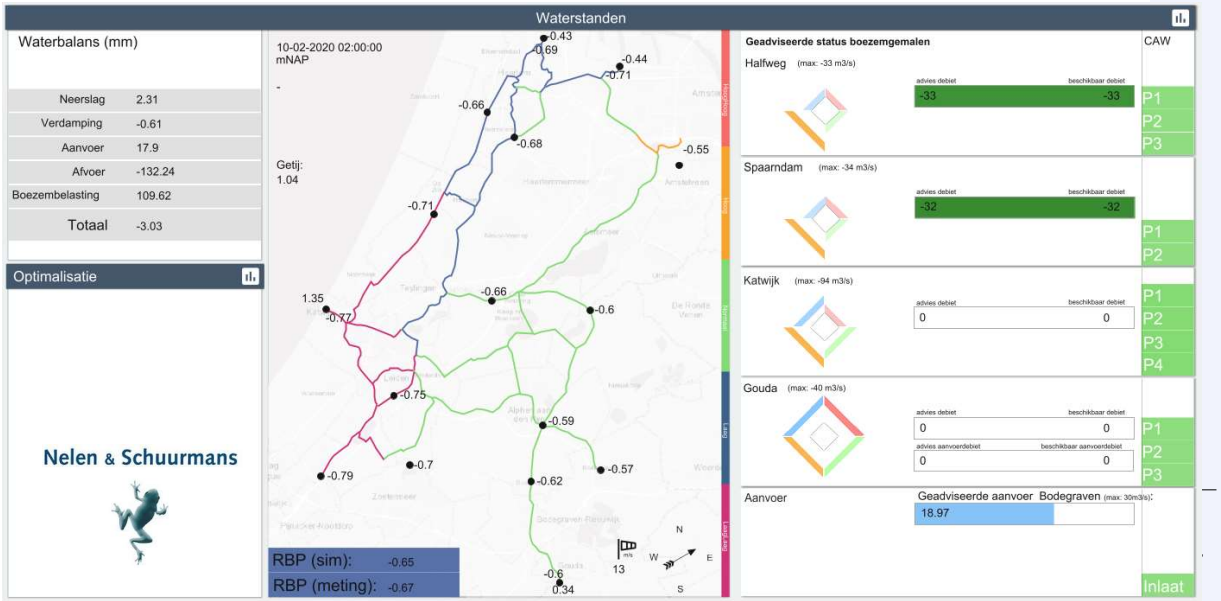
Demonstrations

- Waterboard Rijnland
  - Ring Canal – Pump Station control (optimization)
  - Various Polders

Features:

- Water levels, Water Quality, Energy, Pump costs
- Automatic Regime changes
- Hybrid Model set up (finetune on/off time, energy efficiency of pumps)
- Complete and direct hardware integration (pump control)





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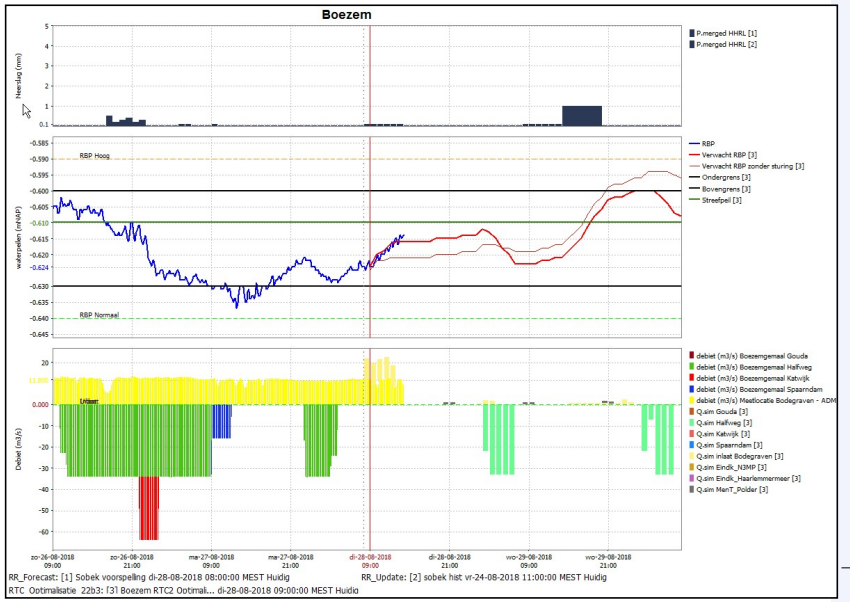
Demo: Rijnland RTC BOSBO 3.0 system

- A decision support and control system for the water board of Rijnland was brought online 2 years ago
- The system provides advice on the dispatch of pumping stations, taking into account the operational objectives of flood control, water quality, and cost savings.
- Advanced Solution Path feedback
- New developments: advice on the use of retention areas (based on Ensembles)
- Future: Also introduce Smart Pumping concepts
  - Pump stage control (energy efficiency/longevity)
  - Goals on pump switching



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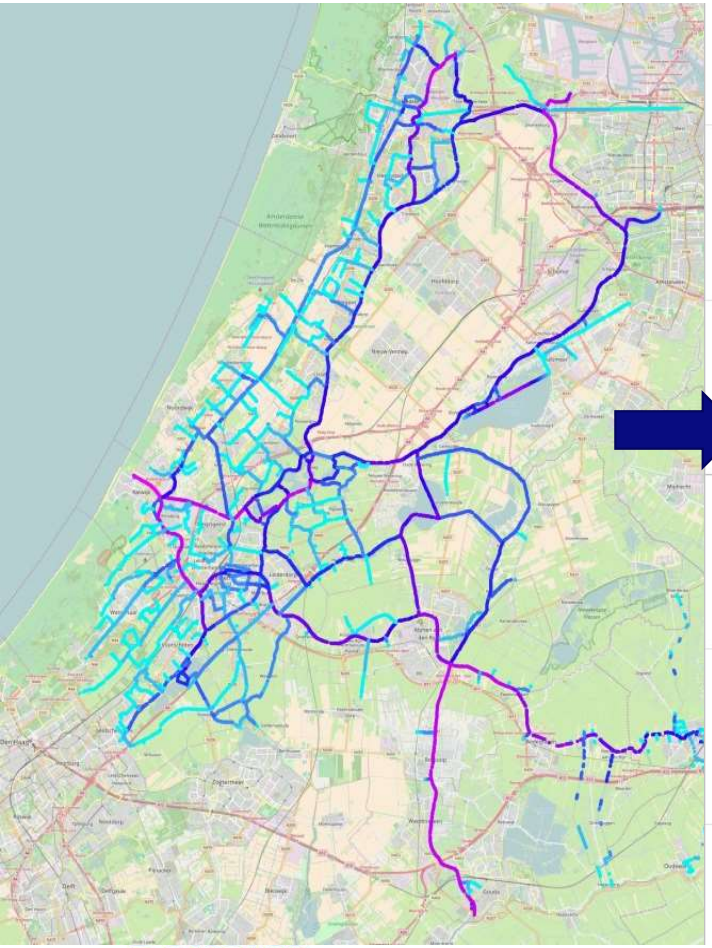
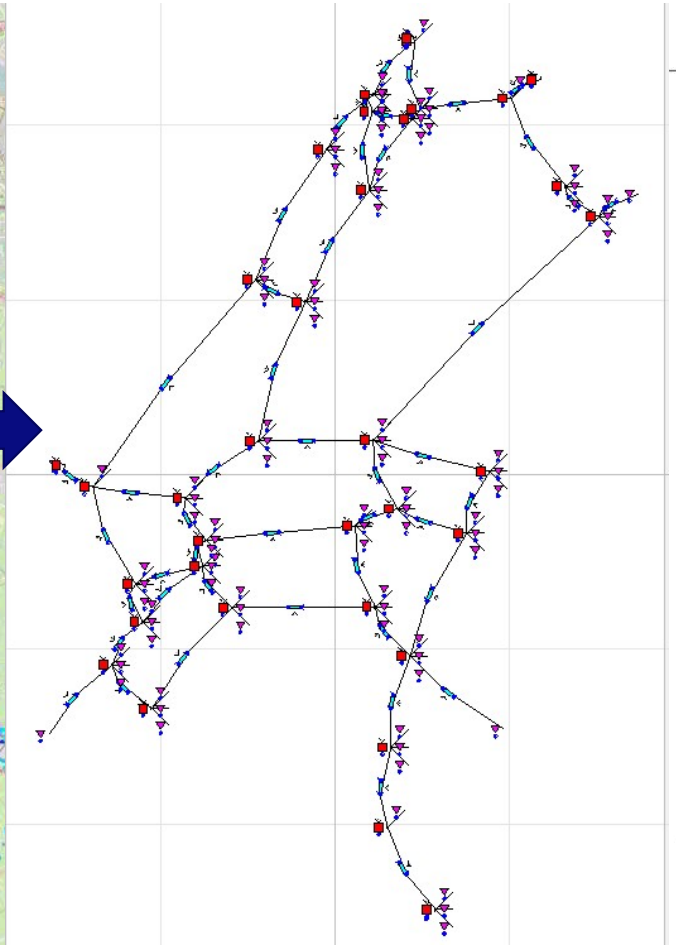
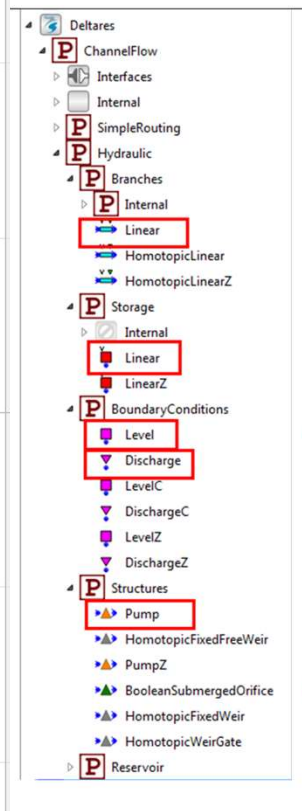
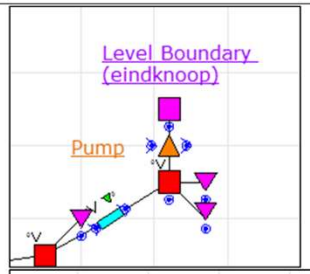
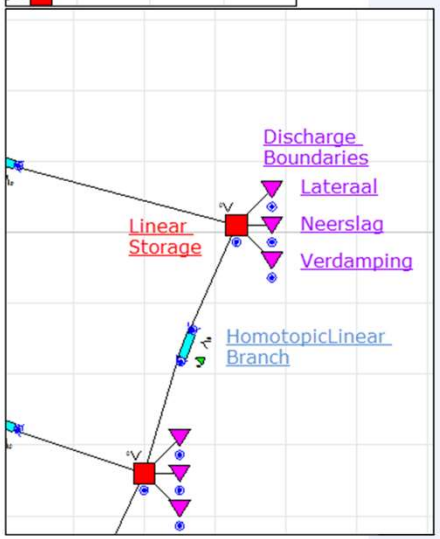
Polder/Ring Canal models: Waterboard Rijnland



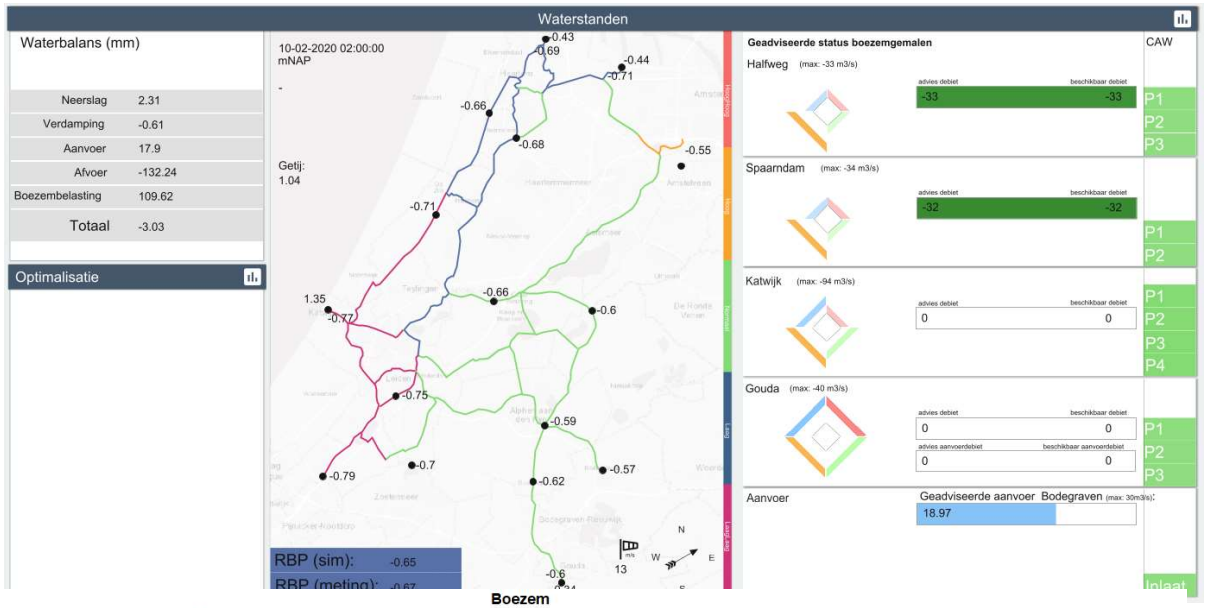


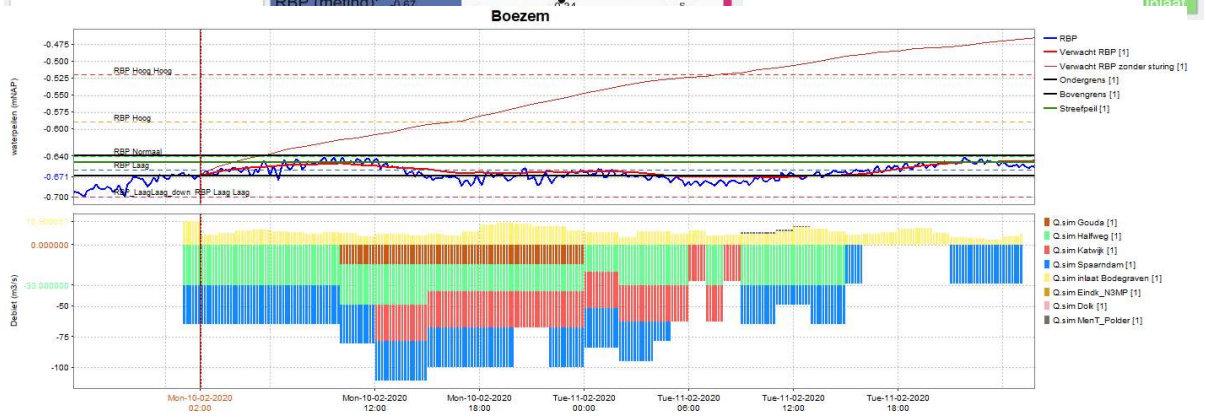






Various RTC-Tools Modifiers in Delft-FEWS





eigenschap	Boezem (RBP)
1 - Binnenwaterstanden bij boezemgemalen	☑
1 - Lokale waterstanden	☑
2 - RBP marges boven/ondergrens	☑
20 - Doorspoelen polderwater vanuit Gouda	☐
20 - Max. chlorideconcentraties	☐
30 - Inzet van noodbergingen	☑
40 - Opgelegde inzet boezemgemalen	☑
Variabele tijdstappen	☐

eigenschap	Boezem (RBP)
2 - RBP streefpeil	☑
40/41 - Getijdoelen Katwijk	☑
50 - Minimaliseer pompkosten	☑
50/51/52 - Inzetvolgorde boezemgemalen	☑
Gemaal impact	subprocess

1 Selecteer Regime | 2.1 Boezemgemalen | 2.2 Polders | 2.3 Inzet bergingsgebieden | 2.4 Chl

eigenschap	Boezem (RBP)
Optimalisatie regime	16. Winterpeil - Nat
Periode	Winter

Deltares

Nelen & Schuurmans

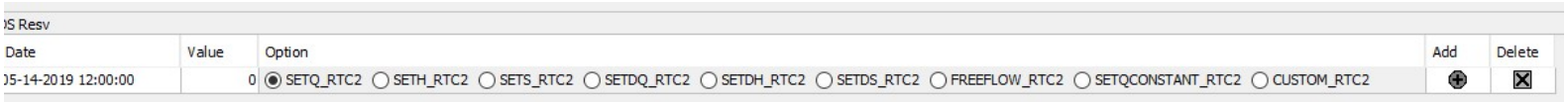
Demonstrations

- National Weather Service (USA)
  - Mud Mountain Dam Simulation

- Features
  - “Replication” of SSARESV model
  - Add Ensemble capabilities
  - Add model interaction
  - Add “special” control logic
  - Increased performance
  - Run on Linux and Windows

Implementation in Delft-FEWS

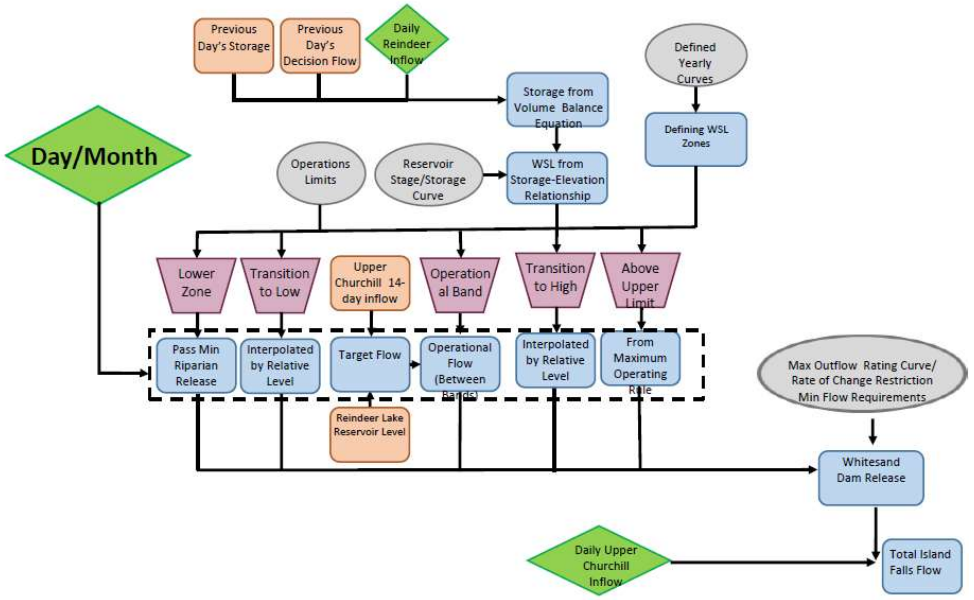
- “SET” control



Demonstrations

- Manitoba Hydro (Canada)
  - Reindeer Lake Simulation

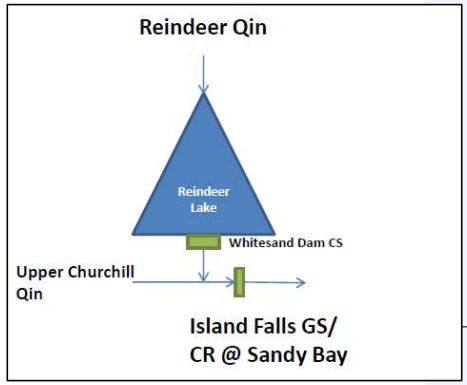
- Features
  - RTC-Tools 2
  - daily timestep
  - Complex control logic
  - Use of CSV lookup tables for easy modification of relations/setting (no operational modification)
- Basic model implementation in Delft-FEWS configuration
  - pre/post processing
  - general adapter
  - modifiers (dynamic model control)
  - set control time steps



CODE	Percentile	Status	14-day back average UPPER CHURCHILL FLOWS [cms]		REINDEER LAKE LEVEL [m ASL]	
			SUMMER	WINTER	summer	winter
1	<10	verydry	150	110	334.8346	334.7845
2	25-Oct	dry	240	160	335.3975	335.3852
3	25-75	normal	396	278	336.2854	336.2719
4	75-95	wet	535	444	336.5121	336.5088
5	95+	verywet	-	-	-	-

Island Falls Target Flow (Whitesand + Upper Churchill)

CODE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
5	720	720	720	720	720	720	720	720	720	720	720	720
4	720	720	720	720	720	720	720	720	720	720	720	720
3	700	700	700	640	640	640	640	640	700	700	700	700
2	640	640	610	500	450	450	450	450	450	460	640	640
1	450	400	350	300	283	283	283	283	300	300	400	450



Demonstrations

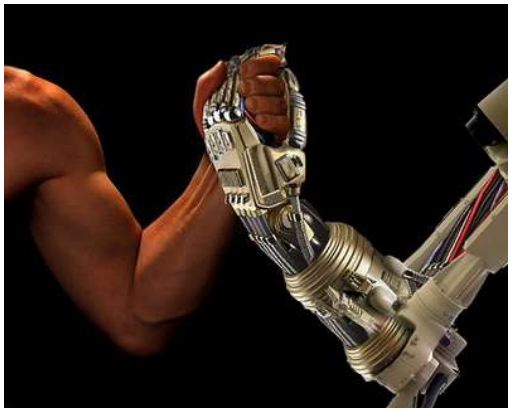
- IWP
- Volkerak Zoommeer

Considerations
Questions

Change Management

Change Management is very important! Some observations:

- Operators/forecasters should be part of the development (and even preperatory) project
- **The model is a tool, should assist the operator to achieve their/the organizations goals better than without the tool. Should be clear that the tool is not 'competition'**
- Do not think of a model as 'coding' the operators brain/knowledge/experience
  - "*This is not what I would have done…")*
  - **In many cases the control strategy from the optimization result would not have been found by an operator – the tool is able to enhance the results in a competing environment**
- Duties shift. Operator gets new responsibilities
  - Changing input for the optimization (scenarios, goals, constraints)
  - In some cases, prescribe (certain) outputs
  - Interpret results
  - *Iterate if necessary…*

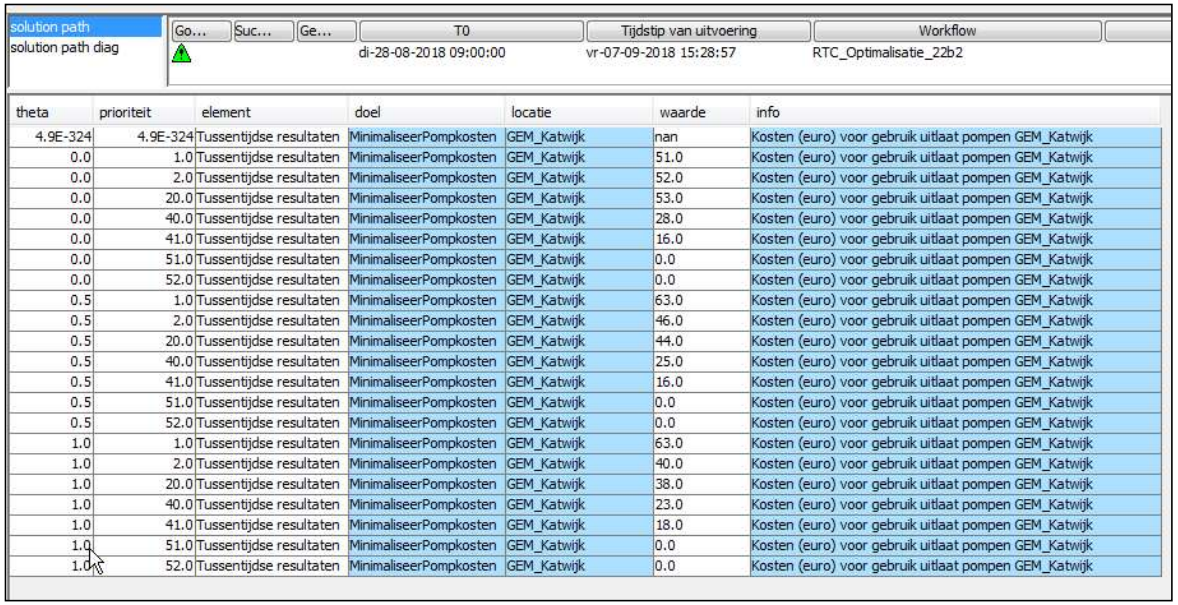


Change Management

Change Management is very important! Some observations:

- Model (Result) Acceptance is KEY.
  - Operators should be able to ‘understand’/’interpret’ the results (Solution Path)
- “Understanding” how a particular optimization result came to be is very difficult, especially for more complex systems.

Table Results in Delft-FEWS
Information Imported as
CSV tables
- Filtering / ordering



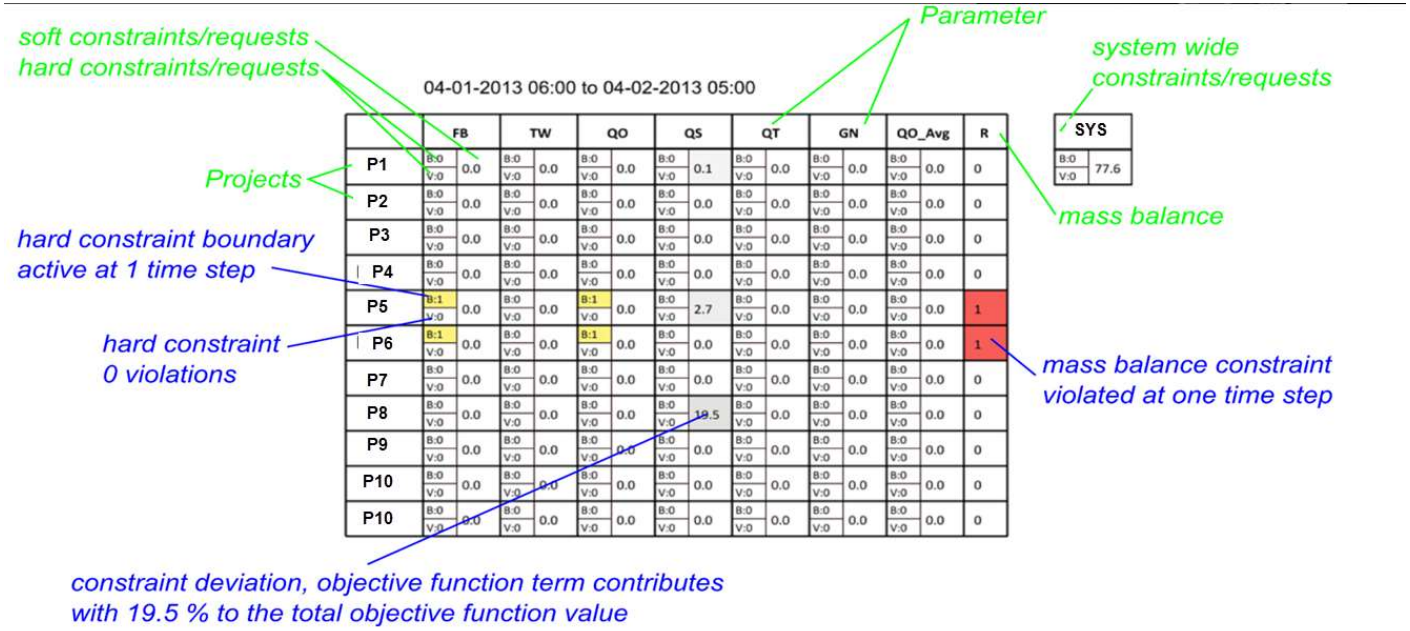
solution path
solution path diag

Go...	Suc...	Ge...	T0	Tijdstip van uitvoering	Workflow
			di-28-08-2018 09:00:00	vr-07-09-2018 15:28:57	RTC_Optimalisatie_22b2

theta	prioriteit	element	doel	locatie	waarde	info
4.9E-324	4.9E-324	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	nan	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	51.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	2.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	52.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	20.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	53.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	40.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	28.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	41.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	16.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	51.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.0	52.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	63.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	2.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	46.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	20.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	44.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	40.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	25.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	41.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	16.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	51.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
0.5	52.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	63.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	2.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	40.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	20.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	38.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	40.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	23.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	41.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	18.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	51.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk
1.0	52.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Kosten (euro) voor gebruik uitlaat pompen GEM_Katwijk

Change Management

- Optimization should be set up to find “an edge” and remove all flexibility at the final optimization step (to remove any randomness)
- Provide information to the modeler on the ‘bottlenecks’ for the results
- What goals (priorities) have most influence on the final results (note – there is not one ‘result’)



	FB	TW	QO	QS	QT	GN	QO_Avg	R
P1	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.1	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	0
P2	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	0
P3	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	0
P4	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	0
P5	B:1 V:0 0.0	B:0 V:0 0.0	B:1 V:0 0.0	B:0 V:0 2.7	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	1
P6	B:1 V:0 0.0	B:0 V:0 0.0	B:1 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	1
P7	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	0
P8	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 19.5	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	0
P9	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	0
P10	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	0
P10	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	B:0 V:0 0.0	0

SYS
B:0 V:0 77.6

Data Imported as Time Series (hourly and aggregated to run length)

CSV for names of violated constraints and violation magnitudes

Community driven development

- Proven technology
- We are happy to work together!

- Development of new features for pilot models
- We use mature components for physical modeling (Modelica) and control modelling (Python)
  → Quick path from idea to feature

Interested in (operational) implementations
- Simulation & Optimization projects
- Better understand needs
- Guide prioritization and developments

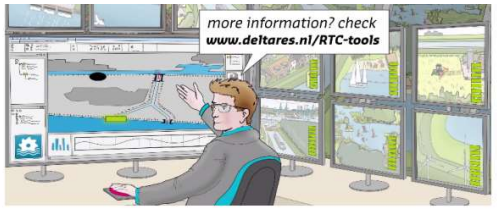
Deltares

Training RTC-Tools

https://softwaredays.deltares.nl/-/rtc-tools-training-2022

- Delft Software Days **online**
- One training with two online sessions:
  - 9 December 2022 (3h - 9:00-12:00 CET)
  - 12 December 2022 (3h - 9:00-12:00 CET)

- Topics:
  - Basics about applying optimization techniques for water systems
  - Within the interactive sessions, the participants learn with the help of a example cases
    - How to make a model schematization of the water system.
    - How to set up an optimization problem by specifying operational goals and physical constraints.
    - How to work with input data and output data and the analysis of model results.
    - How to operate the system with simple feedback control.



About the training

The training is split into two parts. In an introductory lecture, participants will learn the basics about applying optimization techniques for water systems: the mathematical background, the added value of optimization for water system management and different methods for conflict resolution and about methods to handle non-linear equations within the optimization.

Within the interactive sessions, the participants learn with the help of a simple example case of a single reservoir system

- How to make a model schematization of the water system.
- How to set up an optimization problem by specifying operational goals and physical constraints.
- How to work with input data and output data and the analysis of model results.
- How to operate the system with simple feedback control.

Online format

The (1-day equivalent) course will be provided online, making use of both pre-recorded videos as well as online interactive sessions. The videos will cover all the relevant presentations in 10-15 minute focused sections. We'll ask you to watch a play list of these videos in preparation of each interactive session. The interactive sessions will start with a Q&A of the materials from the videos and continue with exercises with an example model.

In preparation of the training, we'll send you all the material and will ask you to install the RTC-Tools on your own machine. While attending the training, it will be essential that you have a sufficiently fast internet connection to support a video call, as well as a headset.

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Inspired? More information?

E-mail RTC-Tools Product Management
Bernhard.Becker@Deltares.nl

Deltares landing page for RTC-Tools 2

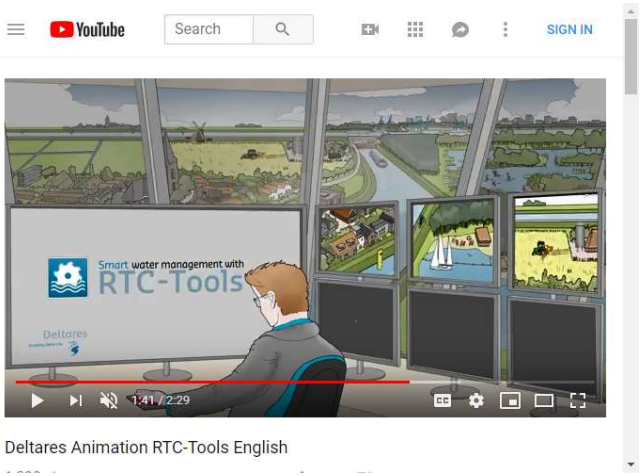
- https://www.deltares.nl/nl/software/rtc-tools-2/
- https://oss.deltares.nl/web/rtc-tools/home

RTC-Tools 2 GIT:

- https://gitlab.com/deltares/rtc-tools

RTC-Tools 2 Documentation

- https://rtc-tools.readthedocs.io/en/latest/



https://youtu.be/GAuQ5ft8vr4

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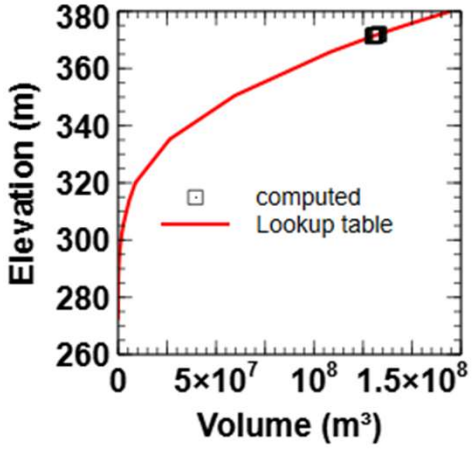
Optimization versus Simulation

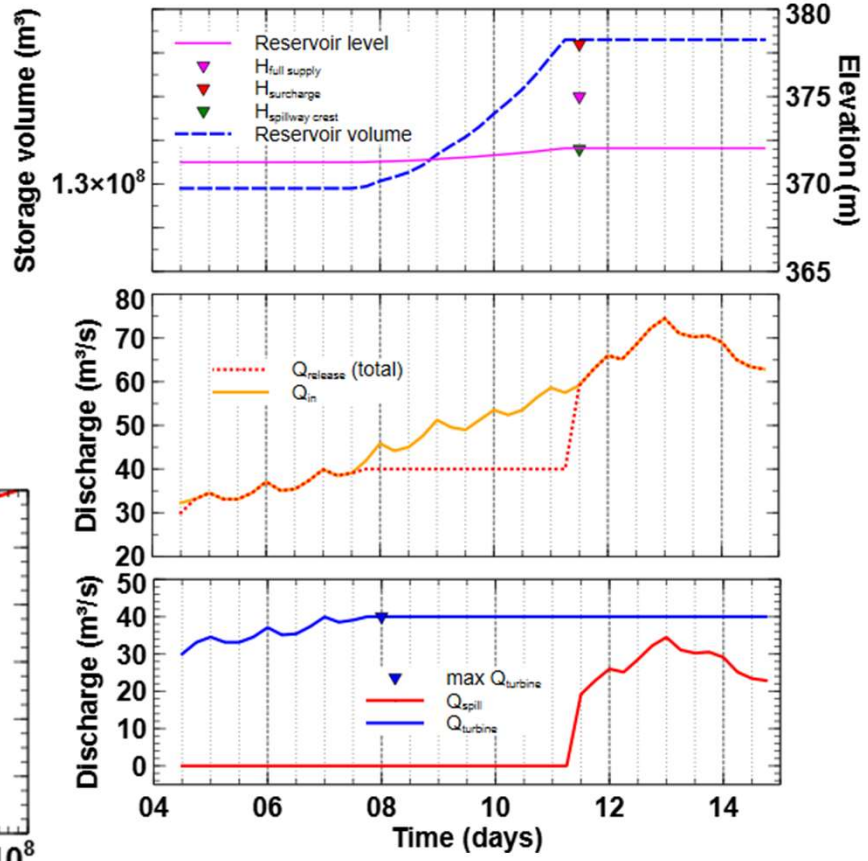
- Simulation: control is defined by the user or with operational protocol
  - If-then-else logic, from time step to time step: how to control
  - External time series for control or derived from control logic (e. g. reservoir release over time)
  - Logic easy to follow, transparent results
  - Move from one time step to another

- Optimization
  - Definition of operational goals instead of rules and conditions: what to achieve?
  - Model determines the control with the help of optimization algorithms for the whole time horizon (control is model output)
  - Anticipation on future events (forecast), but usually requires a bit more interpretation (example: pre-release in case of a flood wave)
  - Optimization for the full time horizon

Modeling reservoir operations/control (I)

- Constant outflow
- User defined reservoir release
- Timeseries from optimization model
- Pass inflow
- If-then-else logic
- Lookup relation for volume – water level





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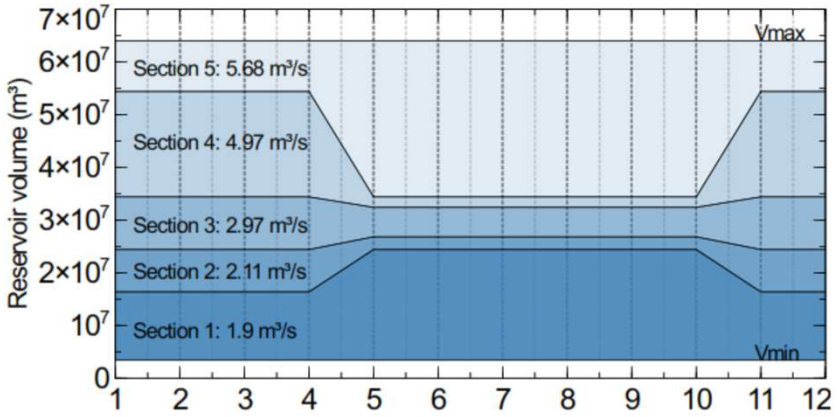
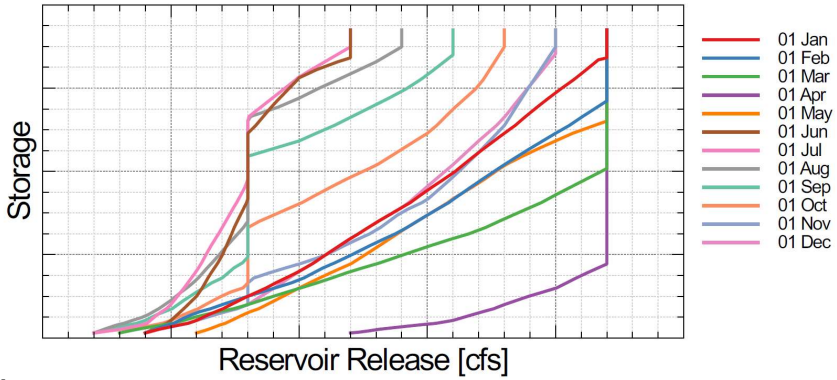
python

Modeling reservoir operations/control (II)

- Operational plan as 2D lookup table
  - Release depends on volume and time in the year
  - Release curve for different months in the year



Volume sections



Release curves

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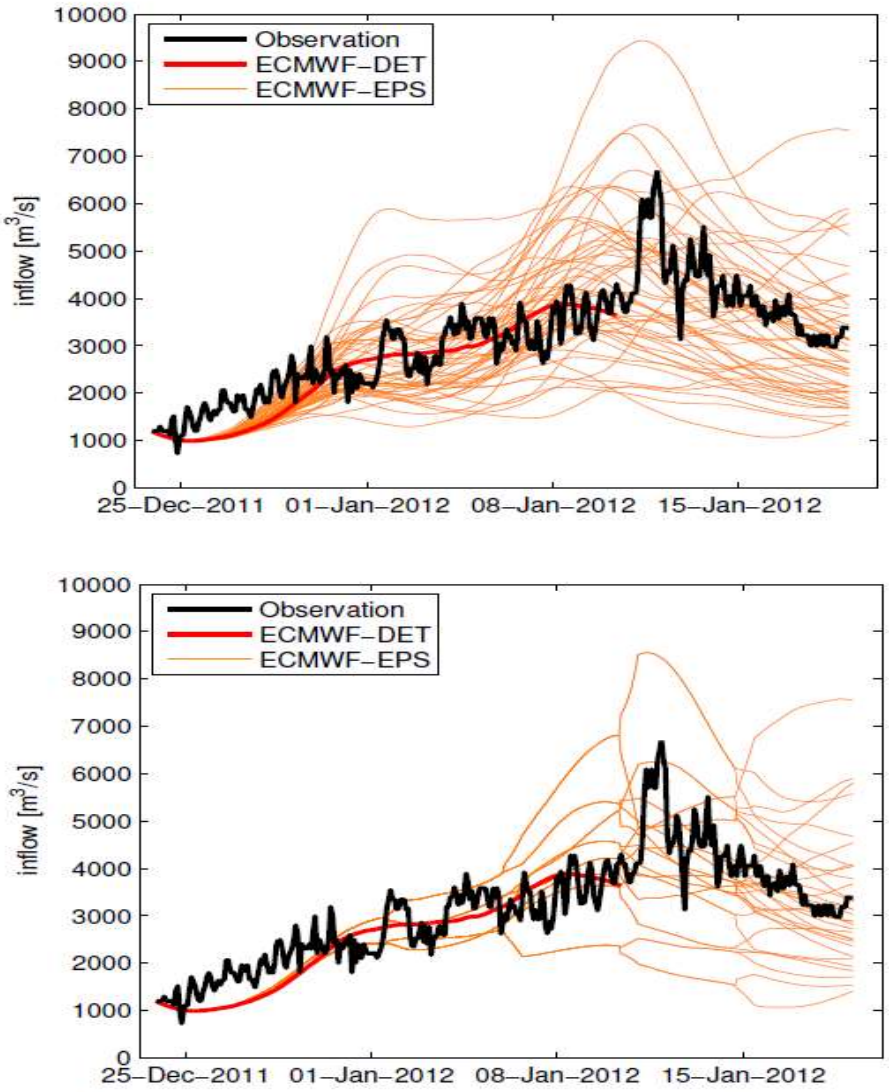
python

Inflow Predictions

- We see all flavors of inflow predictions implemented (together, in combination)
- *Deterministic vs. Probabilistic vs. Stochastic*
- Ensemble forecasts give us some idea about how uncertain the future is.
  - Similarly, ensembles can be used to represent measurement or model
- Ensembles are samples taken from the uncertainty space, allowing computational use with models
- It is important to have estimates of forecast uncertainty, more and more ensemble products are developed and distributed



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Inflow Predictions - (Traditional) Ensemble Runs

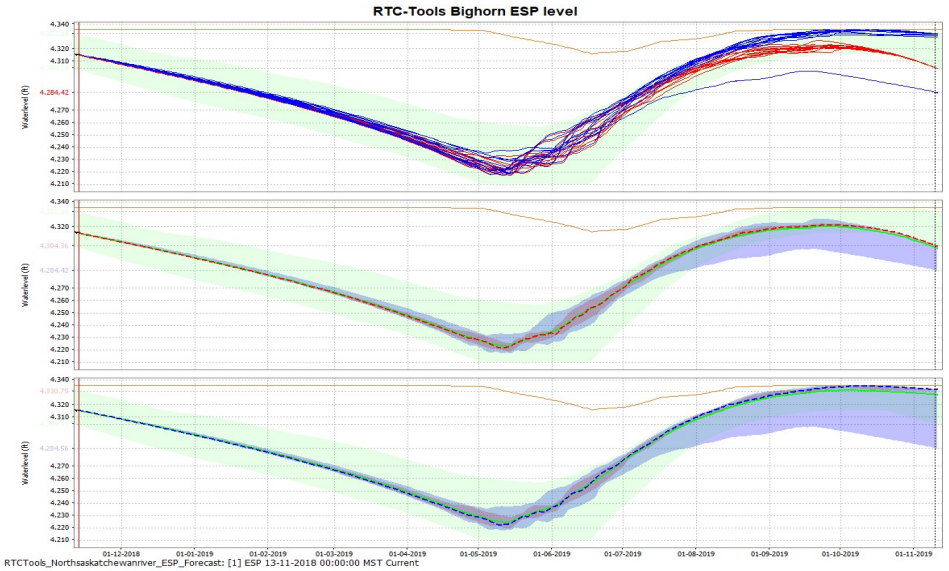
TransAlta (Canada)

Forecasters and traders need insight in operating bandwidth

Solution:

- Optimization with RTC-Tools for different release strategies
  - Minimize Turbine Flows
  - Maximize Turbine Flows
- Pilot project for North Saskatchewan River (2 reservoirs)

- Historical ensemble (30 years)
- Optimization for complete year



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Inflow Predictions - Probabilistic Ensemble Runs

CEMIG (Brazil)

Delft-FEWS - Different hydrological and hydrodynamic models:

HEC-HMS – for the whole brazil

MGB – With data assimilation

SOBEK – including 2D inundation models

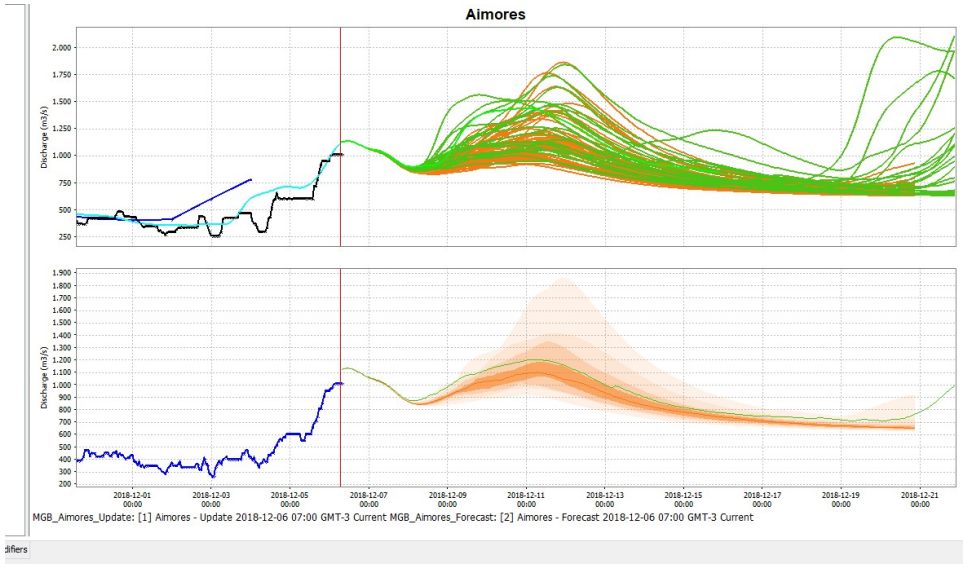
RTC-Tools with Ensemble optimization (probabilistic) for Decision Support

Different metereological forecast

GFS,GEFS, CFS

ECMWF short term and seasonal

CEMIG - Short Term Forecast



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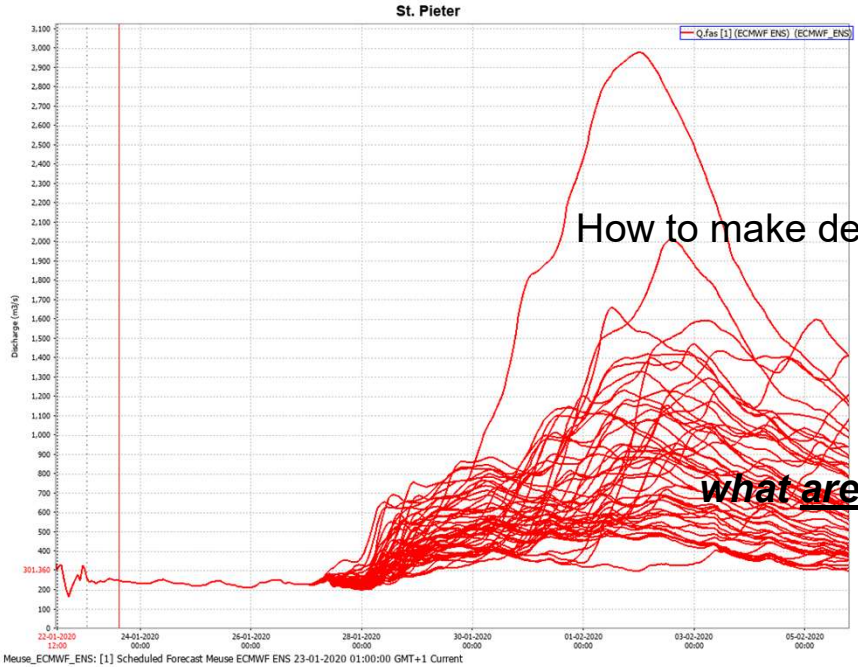
Inflow Predictions - Ensembles

Why apply control on the basis of ensembles?

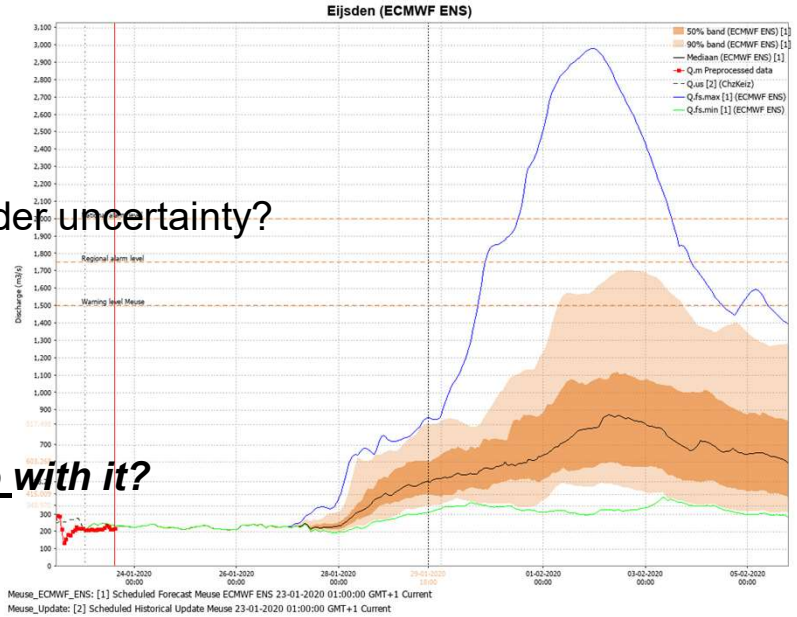
Even if we can infer probabilities from ensemble forecasts….



How to make decisions under uncertainty?

or

what are you to do with it?



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Inflow Predictions - Ensembles

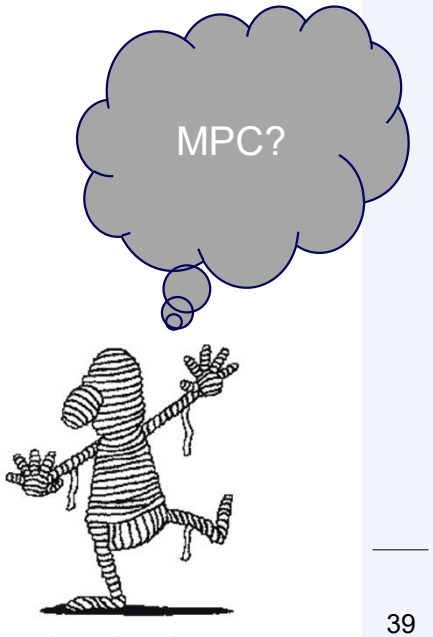
How to apply control on the basis of ensembles?

Options

- Simulate all possible measures for all forecast ensemble members
  - Pro: straightforward
  - Con: computation time, lot of information and no advise for the end user

- Simulate one measure for all forecast ensemble members
  - Pro: useful scenario analysis if one knows what kind of measure it to be taken
  - Con: limited help on what measure to take, and no final advise for the end user

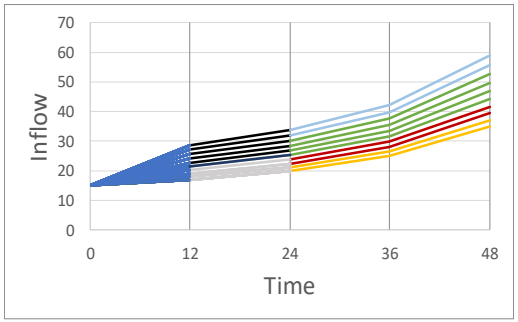
- Let computer determine what is the best measure, given the ensemble forecast(s)
  - Pro: transparent evaluation of objectives, with advise for end user
  - Con: Difficult? Computation time?

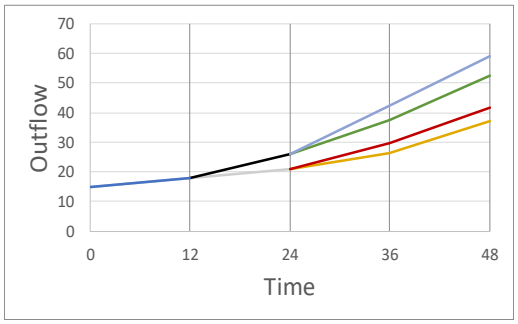


www.animaatjes.nl

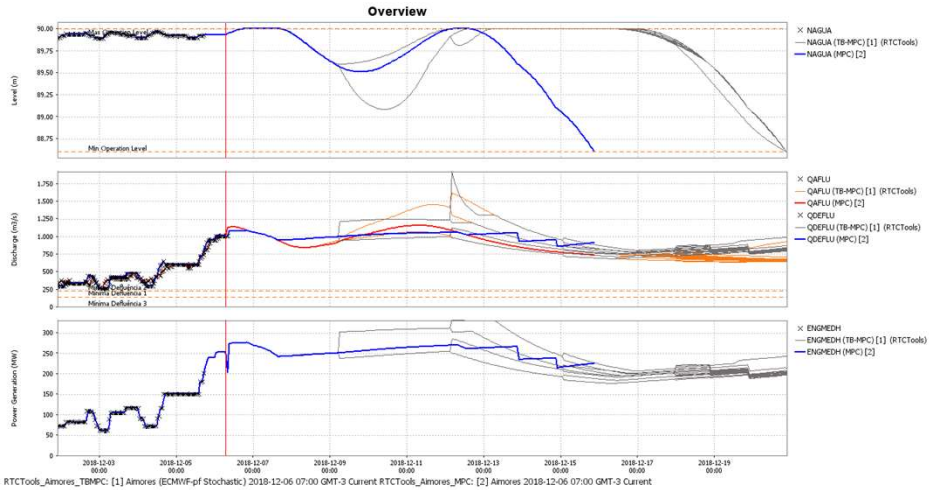
Stochastic Optimization

- Tree Based MPC (Raso et al., 2014)
- Split ensembles at control points in clusters or bundles
- Compute optimal control per bundle (branch)





Salto Grande (Uruguay/Argentina)
RTC-Tools uses deterministic and multi-stage stochastic optimization to integrate the different management objectives and constraints to receive an optimum release strategy over forecast horizons of up to 15 days



Type of operating rules

Simulation vs Optimization

- Both methodologies are widely (and effectively) used in decision making processes
- Simulation = Making decisions timestep per timestep (typically if-then basis).
- Optimization = Finding the optimal strategy, while satisfying all constraints
- RTC-Tools 2 uses the internal model for optimization and simulation, so is able to simulate. Current developments for RTC Simulation.

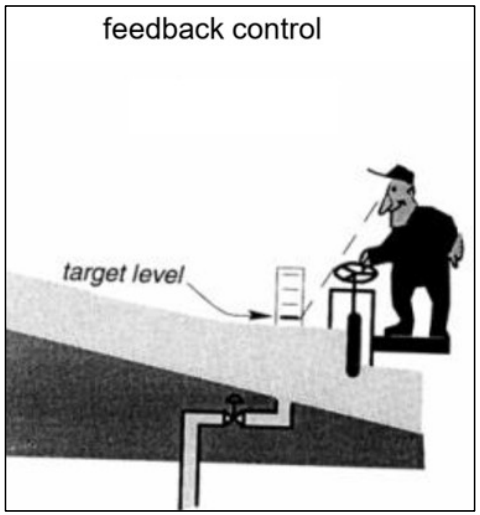
Objectives of control/Operating Rules

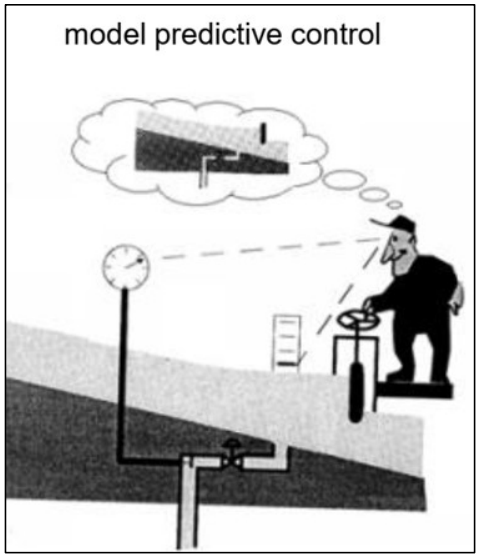
Classical optimization in water systems
(**model predictive control**)

- Maximum power production (hydropower)
- Operational objectives of flood control (upstream and downstream)

With RTC-Tools we can also support optimizing for:

- Load balance (meat load request)
- Forecast uncertainty (ensembles)
- Ensemble trees
- Flexibility on the energy market
- Impact based forecasting





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Objectives of control

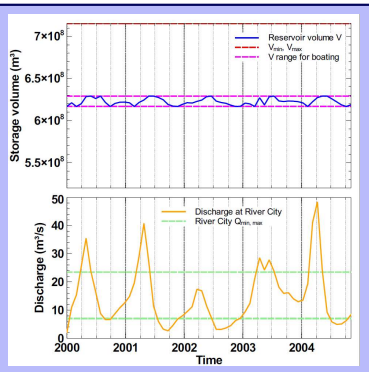
Model Predictive Control with **Goal Programming** allows for multiple goals/constraints at various priorities, resulting in an optimal control strategy

Applications include:

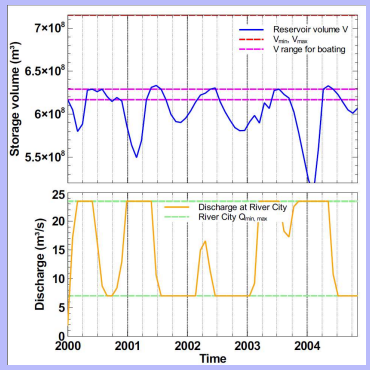
- Water levels/volumes (most)
- Min/max flow requirements (most)
- Water quality (salinity) – Rijnland (Netherlands)
- Sedimentation goals – J-POWER (Japan)
- Maximum Hydropower production
- Load balance
- …

Deltares

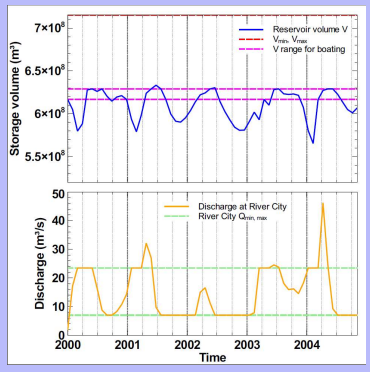
1. Reservoir volume range has priority over discharge, volume range goal is fully met, discharge goal as good as possible under the given conditions (including high priority goal).



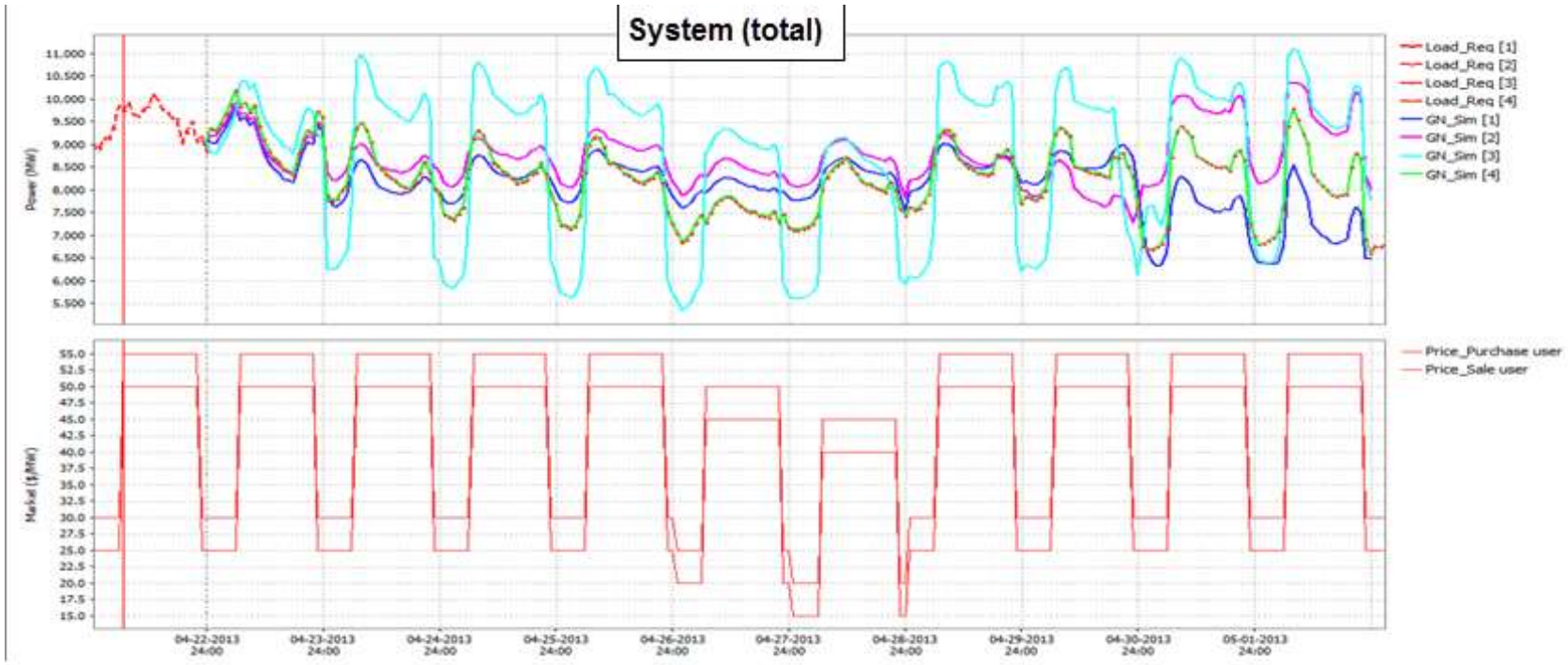
2. Discharge has priority over reservoir volume, discharge goal is fully met, volume range not.



3. Compromised solution, both conflicting goals are not fully met, but both are jointly met in a balanced way.



Hydropower Control



4 different runtypes: Min Generation, Max Generation, Max Revenue, Load balance

Deltares