

# Deltares



## Simulation with RTC-Tools

### Breakout session Reservoir Management and forecasting

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2020-11-05

# 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.



# 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: First pilot projects on new foundation.
  - water allocation tool for Rijkswaterstaat using new framework.
  - decision support systems for a number of water boards in The Netherlands.
- 2016: **RTC-Tools 2.0** released
  - Focus on optimization and convergence
- 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**
  - Focus on **reservoir simulation**

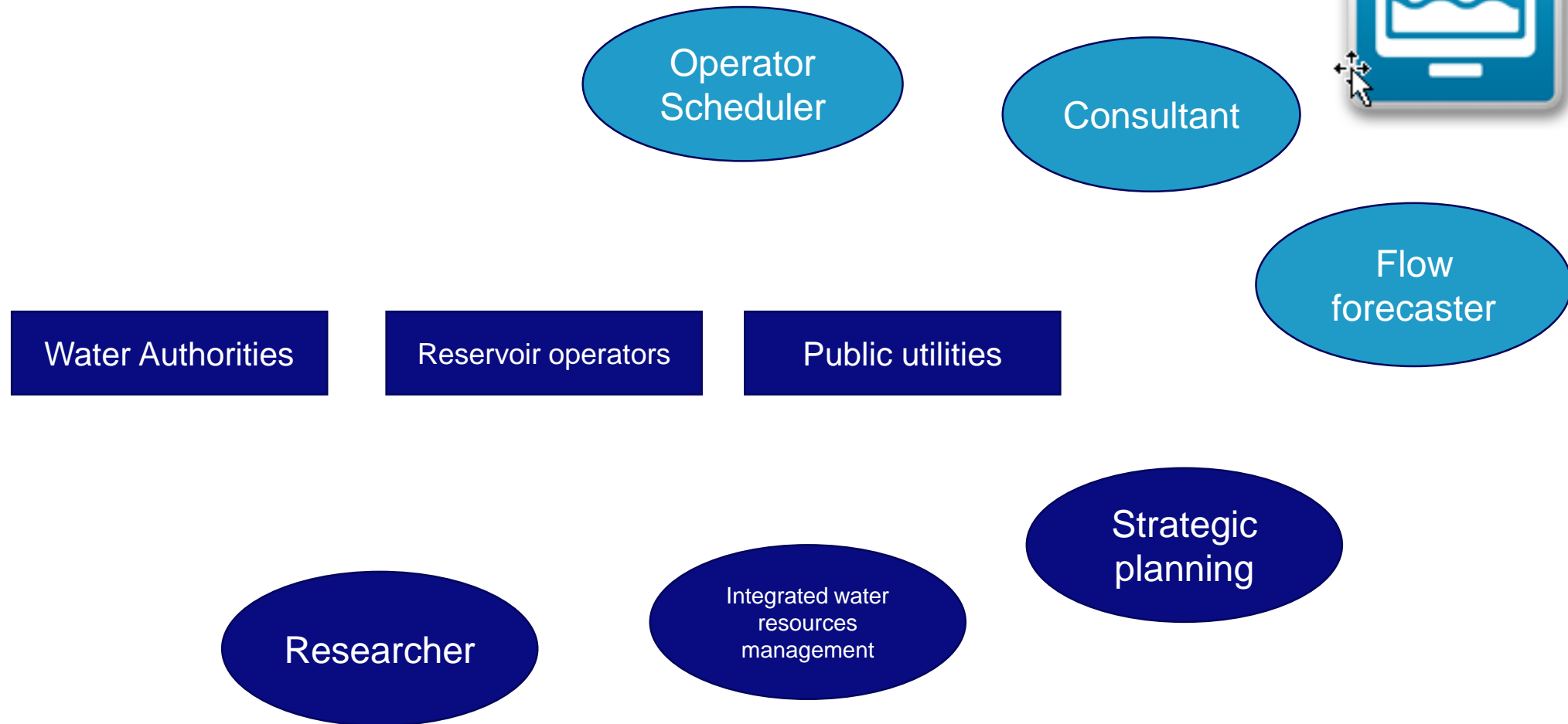


# Use cases for simulation with RTC-Tools

- Reservoir modelling
- Modelling of operational rules (according to obligations)
- Tuning, refinement of optimization result with more details
- Reservoir simulation with exact control rules
- Update mode in forecasting systems
- Calibration, validation of a model that is meant for optimization (during model development)
  - Does the model represent the water system for a known (historic) scenario?
  - Is the model numerically stable?



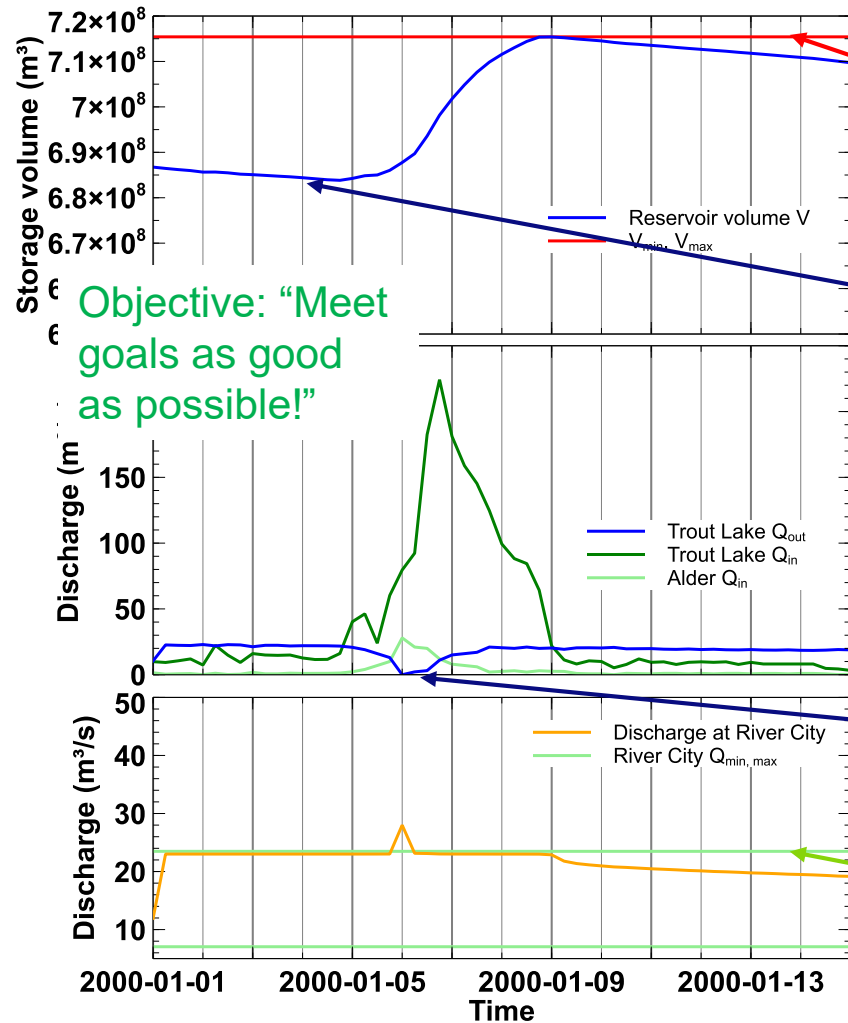
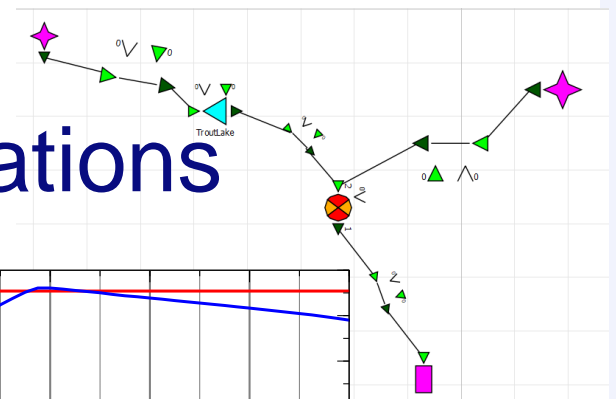
# Users and applications



# 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

# Optimization vs. simulation: reservoir operations



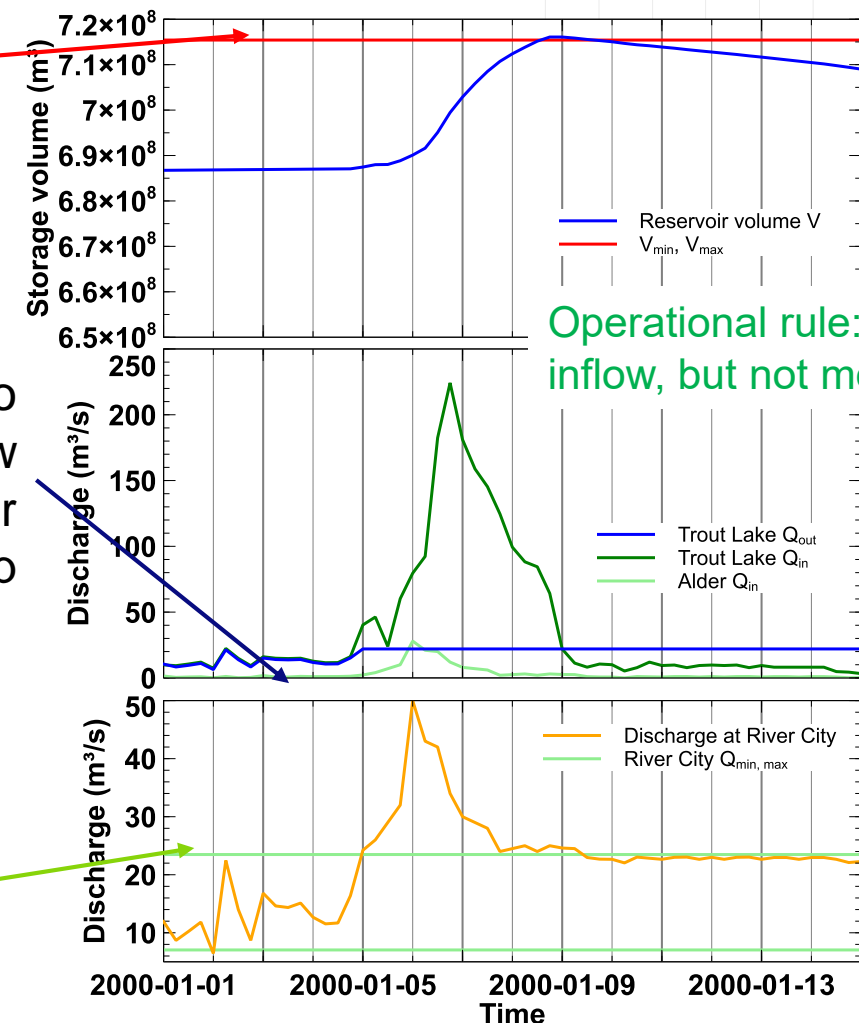
Goal: Max. Volume

Pre-release to catch flood wave

Needs rules to determine outflow  
Easy to track per time step

Reduce outflow to compensate discharge in tributary

Goal: max Q downstream = 23



Operational rule: "Pass inflow, but not more than 23"

Simulation: looks at one time step only



# Why another simulation software for reservoir modelling?

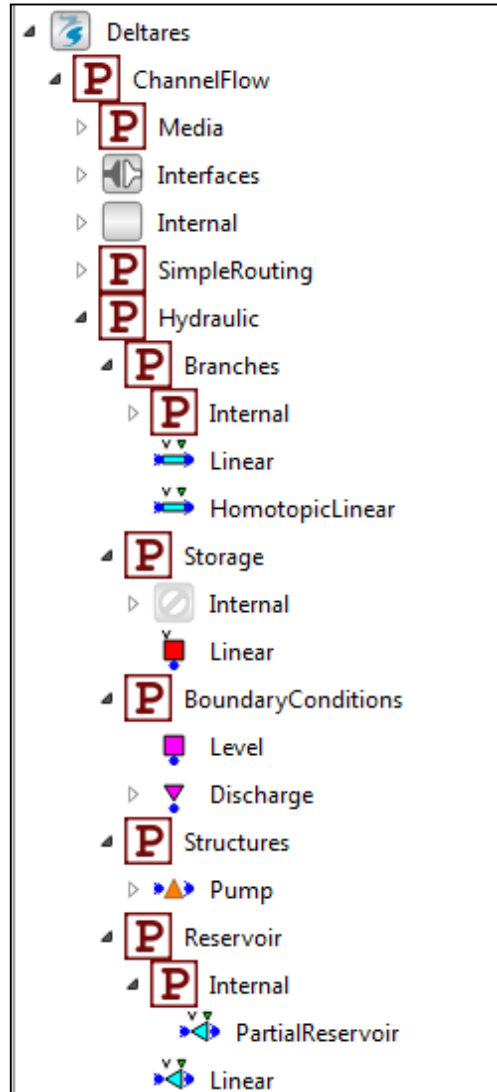
- Delft-FEWS operators wish to change parameters and time series through the FEWS interface.
  - RTC-Tools connects seamlessly to Delft-FEWS (FEWS PI data format)
- Optimization model and simulation model complement each other.
  - More detail in simulation model
  - Forecast-based optimization (ensembles)
  - Two “opinions” for decision support: operational protocol versus forecast-based optimization
- Every reservoir is operated differently.
  - Model legally approved operational protocols
  - Cover different situations (flood, low flow, fish spawning season, ...)
  - 2D-lookup tables for elevation or volume based operations
- Flexible time resolution (seconds, hours, days, months).

# Features of RTC-Tools Sim

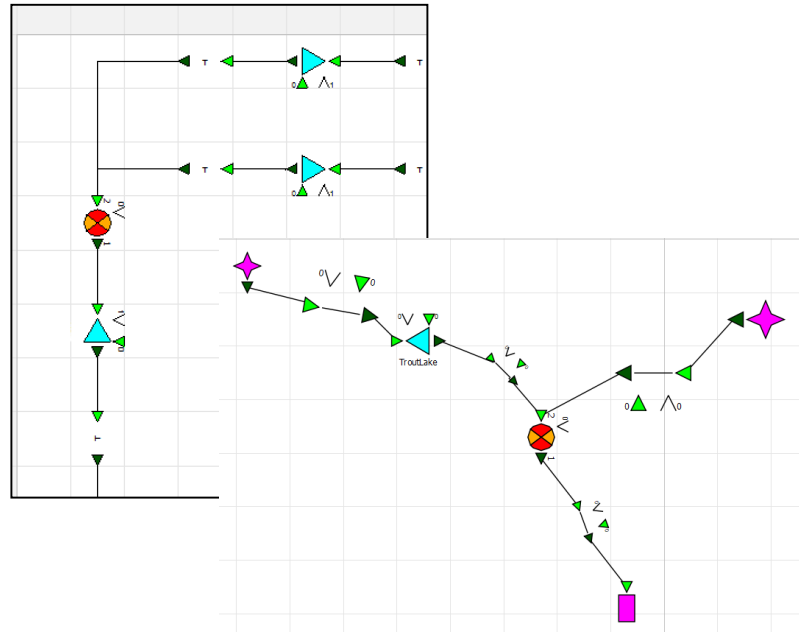
- Seamless integration into Delft-FEWS
- Open Source
- Variable time resolution (timestep and simulation period)
- Endless flexibility in definition of control rules (extendable)
- Large library of model objects
- User community
- Support and Maintenance
- Interfaces
  - FEWS-PI for Delft-FEWS,
  - CSV file format (Excel),
  - BMI (basic modelling interface)



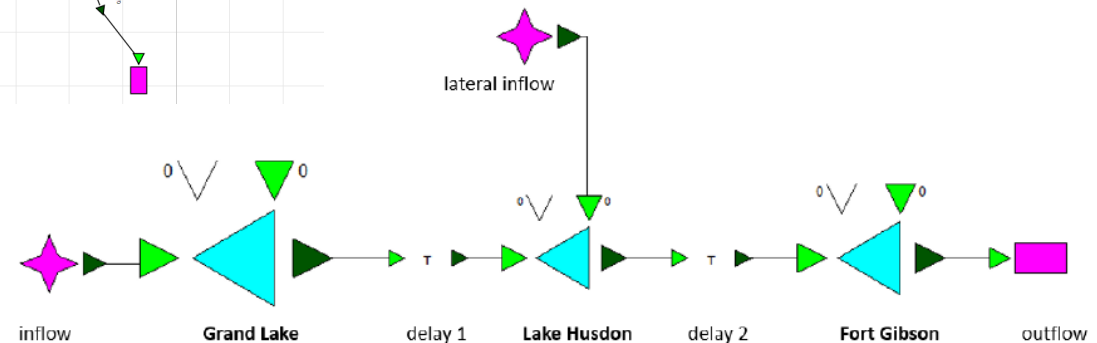
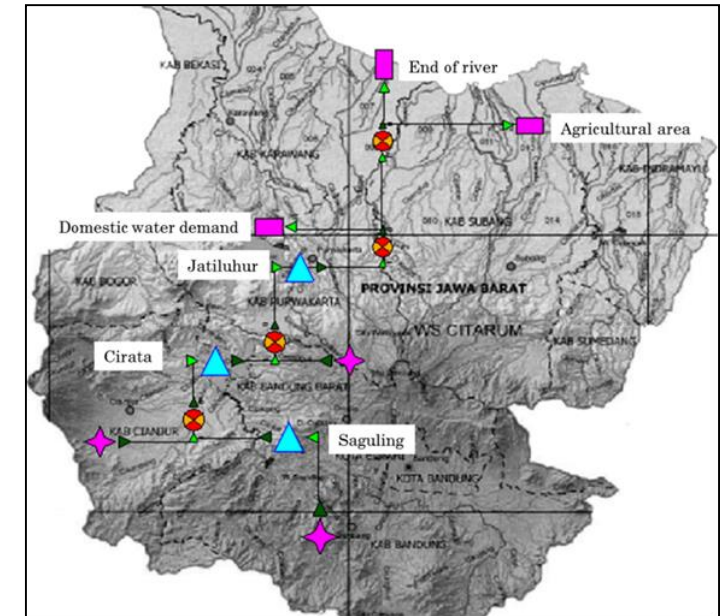
# Modelica schematization – Deltares model library



Reservoir cascade, tributary



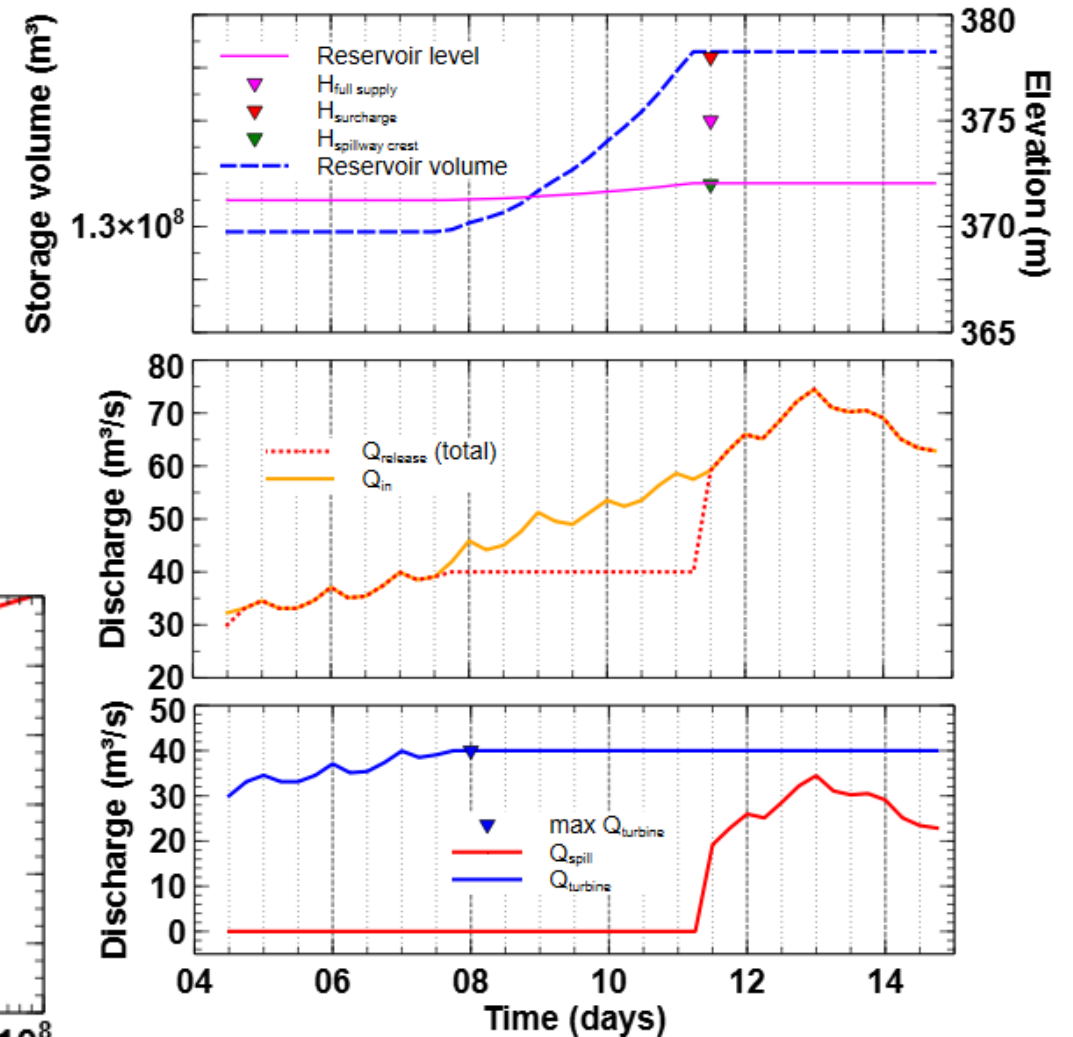
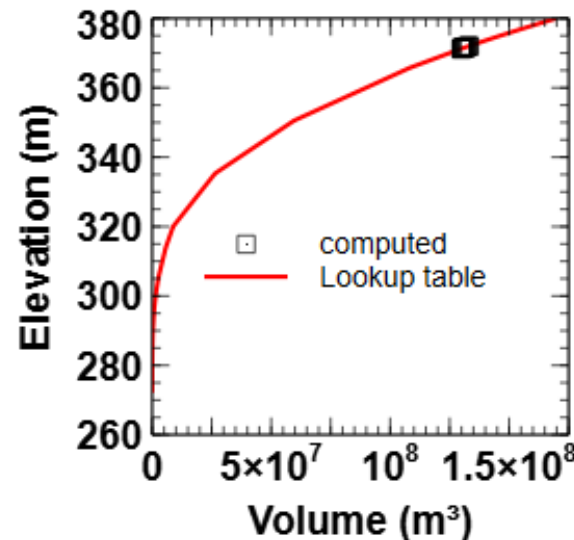
Upper Citarum (Indonesia)



Grand River Dam system (USA)

# Modeling reservoir operations/control (I)

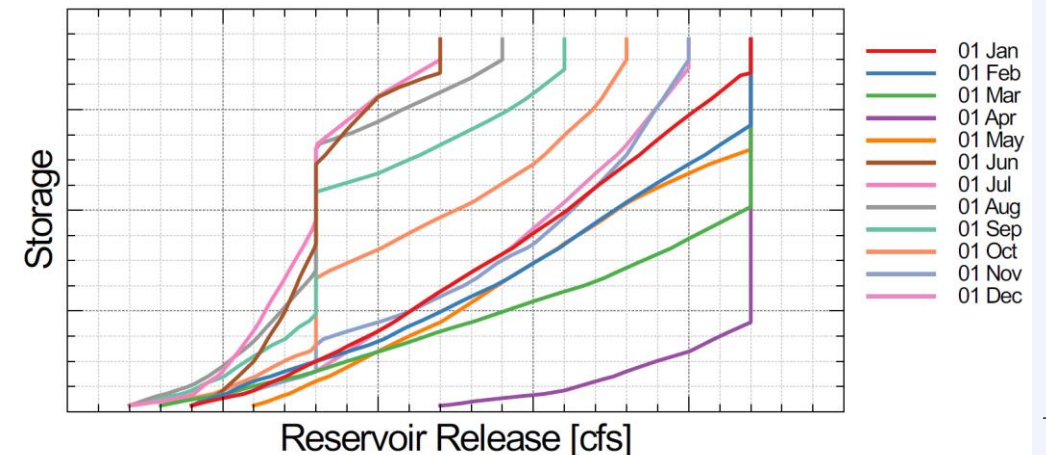
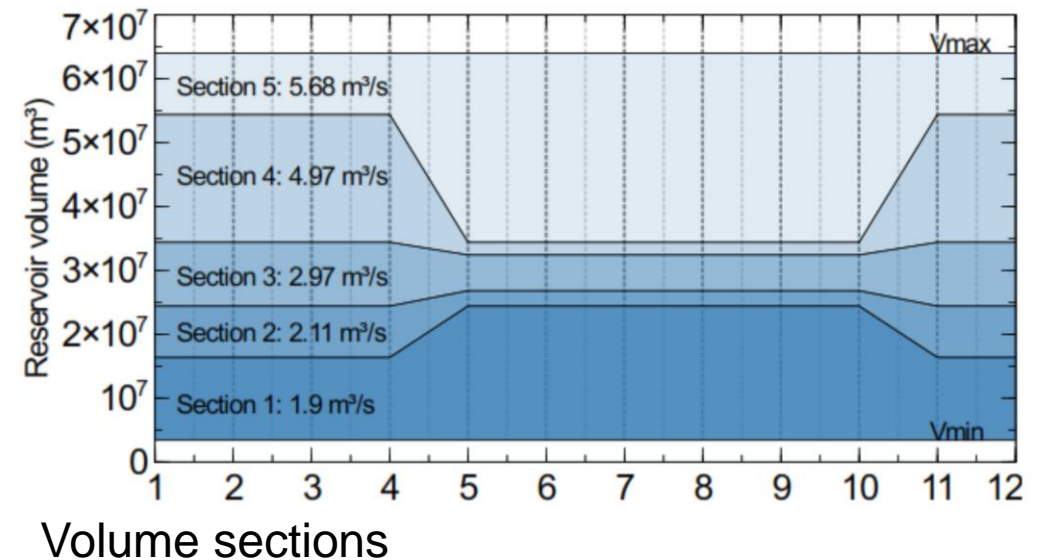
- Constant outflow
- User defined reservoir release
- Timeseries from optimization model
- Pass inflow
- If-then-else logic
- Lookup relation for volume – water level





# 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



Release curves



# FEWS interaction - Modifiers

Bestand Extra Opties Help

Systeemoverzicht Boezemoverzicht

Model Runs

Scenario run  
Scenario run  
Operationele run  
Boezem RTC2 Optimalisatie

Modifier type	Naam	Beschrijving	Locaties	Start tijd	Eind tijd	Geldig tot
Halfweg	Q.inzet_Halfweg	debiet bij inzet Halfweg : Tij...	Halfweg	ma-04-06-2018 09:00:00	ma-04-06-2018 13:00:00	--
Spaarndam	Q.inzet_Spaarndam	debiet bij inzet Spaarndam ...	Spaarndam	ma-28-05-2018 14:00:00	ma-04-06-2018 16:00:00	--
Instellingen	Instellingen	Optimalisatie_Regime=4.	Boezem (RBP)	--	--	--
Instellingen	Instellingen	Q_MAX=0.0 Q_MIN=25.0	Gouda	--	--	--
Instellingen	Instellingen	Q_MAX=-45.0	Katwijk	--	--	--
Katwijk	Q.inzet_Katwijk	debiet bij inzet Katwijk : Tij...	Katwijk	ma-28-05-2018 14:00:00	ma-04-06-2018 23:00:00	--

1 Selecteer Regime

2.1 Boezemgemalen

2.2 Polders

eigenschap

Boezem (RBP)

2 - RBP streefpeil

40/41 - Getijdoelen Katwijk

50 - Minimaliseer pompkosten

50/51/52 - Inzetvolgorde boezemgemalen

Gemaal impact

subprocess

serial

subprocess

none

Eigenschappen modifier: Instellingen

Naam Instellingen

1 Selecteer Regime

2.1 Boezemgemalen

2.2 Polders

2.3 Inzet bergingsgebieden

2.4 Chloride

2.5 Compartimentering

2.6 Waterstand op knopen

Al

locatie	Lokaal aanslagpeil	Lokaal minderpeil	Lokaal afslagpeil	Min. buitenwaterpeil	Max. buitenwaterpeil	Min. debiet (inlaat)	Max. debiet (uit)	Nachtrun
Gouda	-0.47	-0.97	-1.02	0	2.6	0	-16.0	<input type="checkbox"/>
Halfweg	-0.49	-0.89	-0.92			0	-33.0	<input type="checkbox"/>
Katwijk	-0.55	-0.92	-0.97		2.8	0	-45.0	<input type="checkbox"/>
Spaarndam	-0.52	-0.82	-0.84			0	-32.0	<input type="checkbox"/>

Warm state selection

T0: ma-04-06-2...

voorspellingsduur: wo-06-2018

Taakuitvoer opties

MET/MEST

(m3/s)

max ts\_modifier

min ts\_modifier

max ts\_modifier

Spaarndam

RTC\_BG\_SPAARN

RTC\_BG\_SPAARN

RTC\_BG\_SPAARN

RTC\_Boezem\_Op

RTC\_Boezem\_Op

RTC\_Boezem\_Op

[1]

[1]

[1]

ma-04-06-2018 10:00

ma-04-06-2018 11:00

ma-04-06-2018 12:00

ma-04-06-2018 13:00

ma-04-06-2018 14:00

ma-04-06-2018 15:00

ma-04-06-2018 16:00

-32,0000

-32,0000

-32,0000

-32,0000

0,0000

0,0000

0,0000

inzet debiet (m3/s)

wo-30-05-2018 00:00

vr-01-06-2018 00:00

zo-03-06-2018 00:00

RTC\_Optimalisatie\_Linux: [1] RTC\_Optimalisatie\_Li... ma-04-06-2018 08:00:00 MEST Huidig

debiet bij inzet min ts\_modifier [1]

debiet bij inzet max ts\_modifier [1]

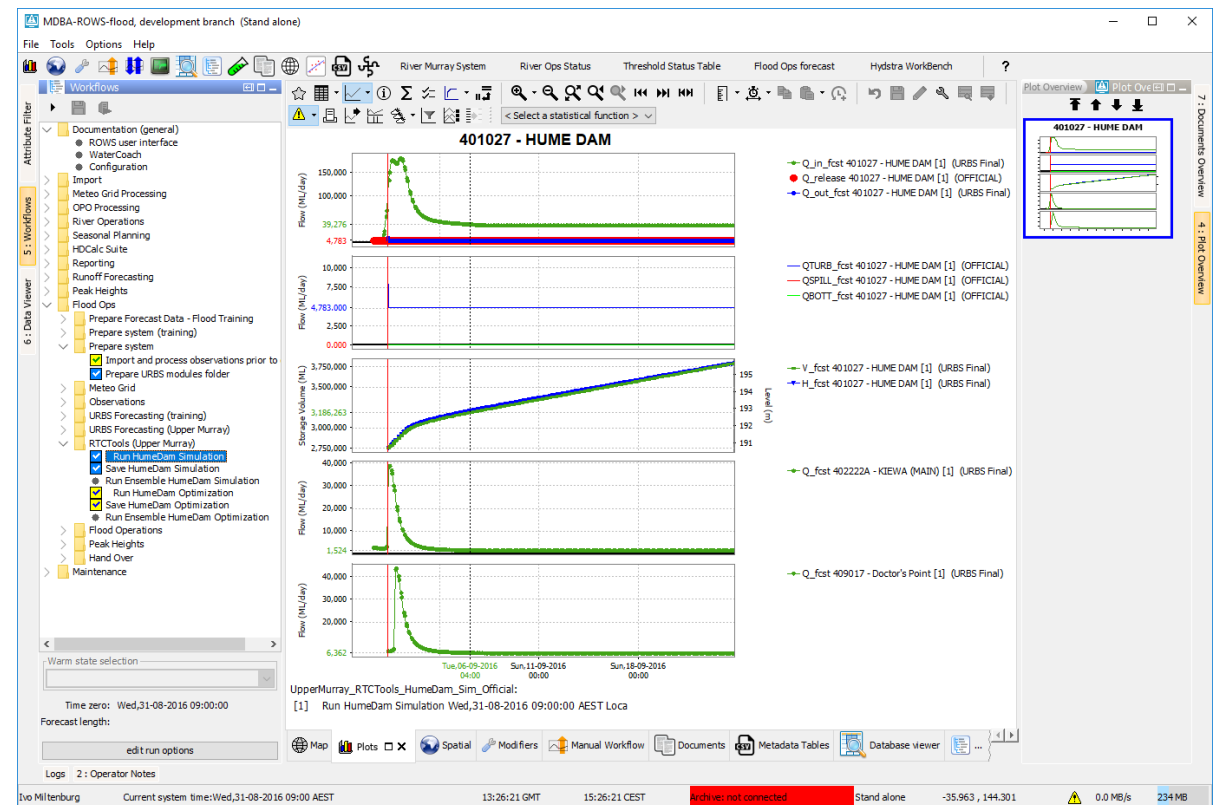
debiet bij inzet min ts\_modifier [1] modified

debiet bij inzet max ts\_modifier [1] modified

# FEWS interaction – time series

Takes care of the data exchange with FEWS:

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



# FEWS interaction - table results

Information Imported as CSV tables  
- Filtering / ordering

<div> <div>solution path</div> <div>Go... Suc... Ge...</div> <div>T0</div> <div>Tijdstip van uitvoering</div> <div>Workflow</div> </div> <div> <div>solution path diag</div> <div> <div>di-28-08-2018 09:00:00</div> <div>vr-07-09-2018 15:28:57</div> <div>RTC_Optimalisatie_22b2</div> </div> </div>						
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	Afvoer RMS Error (m^3/s) bij GEM_Katwijk
0.5	52.0	Tussentijdse resultaten	Afvoer	GEM_Halfweg	0.0	Afvoer RMS Error (m^3/s) bij GEM_Halfweg
0.5	52.0	Tussentijdse resultaten	Afvoer	GEM_Gouda	0.0	Afvoer RMS Error (m^3/s) bij GEM_Gouda
0.5	52.0	Tussentijdse resultaten	Afvoer	GEM_Haarlemmermeer	0.0	Afvoer RMS Error (m^3/s) bij GEM_Haarlemmermeer
0.5	52.0	Tussentijdse resultaten	Afvoer	GEM_N3MP	0.0	Afvoer RMS Error (m^3/s) bij GEM_N3MP
0.5	52.0	Tussentijdse resultaten	Iteraties		30	Iteraties
0.5	52.0	Tussentijdse resultaten	Draaitijd		-999.0	Totaal draaitijd (s)
1.0	1.0	Algemene informatie	GrenzenRBP	GEM_Halfweg	N/A	Doelwaarde
1.0	1.0	Deel periode gehaald	GrenzenRBP	GEM_Halfweg	1.0	Deelwaarde
1.0	1.0	Algemene informatie	GrenzenRBP	GEM_Katwijk	N/A	Doelwaarde
1.0	1.0	Deel periode gehaald	GrenzenRBP	GEM_Katwijk	1.0	Deelwaarde
1.0	1.0	Tussentijdse resultaten	Waterstandsgrenzen	RBP	1.0	Deelwaarde
1.0	1.0	Tussentijdse resultaten	Streefpeil	RBP	0.0	Deelwaarde
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	alle gemalen (uitlaat)	171.0	Totaal
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	alle gemalen	1941955.0	Totaal
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	alle gemalen	0.0	Totaal
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Spaarndam	0.0	Volume
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	569416.0	Volume
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Halfweg	1372540.0	Volume
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Gouda	0.0	Volume
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Haarlemmermeer	0.0	Volume
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_N3MP	0.0	Volume
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Spaarndam	0.0	Volume
1.0	1.0	Tussentijdse resultaten	MinimaliseerPompkosten	GEM_Katwijk	0.0	Volume

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

# Support and Maintenance

- Free and Open Source
- Deltares license agreement for operational use (similar to Delft-FEWS license agreement)
- Continuity in Support and Maintenance:
  - Support with own models and installation
  - New releases
  - Inclusion of model in test bench at Deltares
- User meetings
- Community driven development
- Training

# 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






# Training RTC-Tools

- Delft Software Days online
- One training with two online sessions:
  - 24 November
  - 1 December 2020
- Topics:
  - Reservoir optimization and simulation with RTC-Tools
  - Interaction with Delft-FEWS
- <https://softwaredays.deltares.nl/2020/>



## Online RTC-Tools Training

**Tuesday, 24 November 2020**

Location, Room	M5 Teams
Date	24 November 2020
Time	15:00 - 18:00 CET / CEST (Delft time, UTC+2)
Type of event	 Course
Registry fee	€ 565 excluding 21% VAT
Chair	Bernhard Becker

## Description

RTC (Real-Time Control) Tools is an open-source toolbox for control and optimization of water systems like reservoir cascades, canal systems or river systems. RTC-Tools can support operational decisions on a short-term scale (1-2 weeks on time resolution in minutes or hours), mid-term scale (weeks to months) or long-term scale or strategic planning (years).

### RTC-Tools

- Resolves conflicting objectives, such as the management of a reservoir system towards flood protection, water supply and hydropower production.
- Finds the optimal operational scheme for the water system under given hydrological conditions.
- Can incorporate ensemble forecasts in order to deal with uncertainty and generate robust solutions. Model runs can be carried out for each ensemble member individually, but RTC-Tools can also find an optimal operational scheme for the whole ensemble.
- Supports system analysis for strategic planning of catchment-wide water usage and water allocation, e. g. for climate change studies.
- Can be used for optimization simulations.
- Integrates seamlessly into Delft-FEWS

### 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 multiple online interactive sessions (2 x 3 hours on consecutive days). 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.

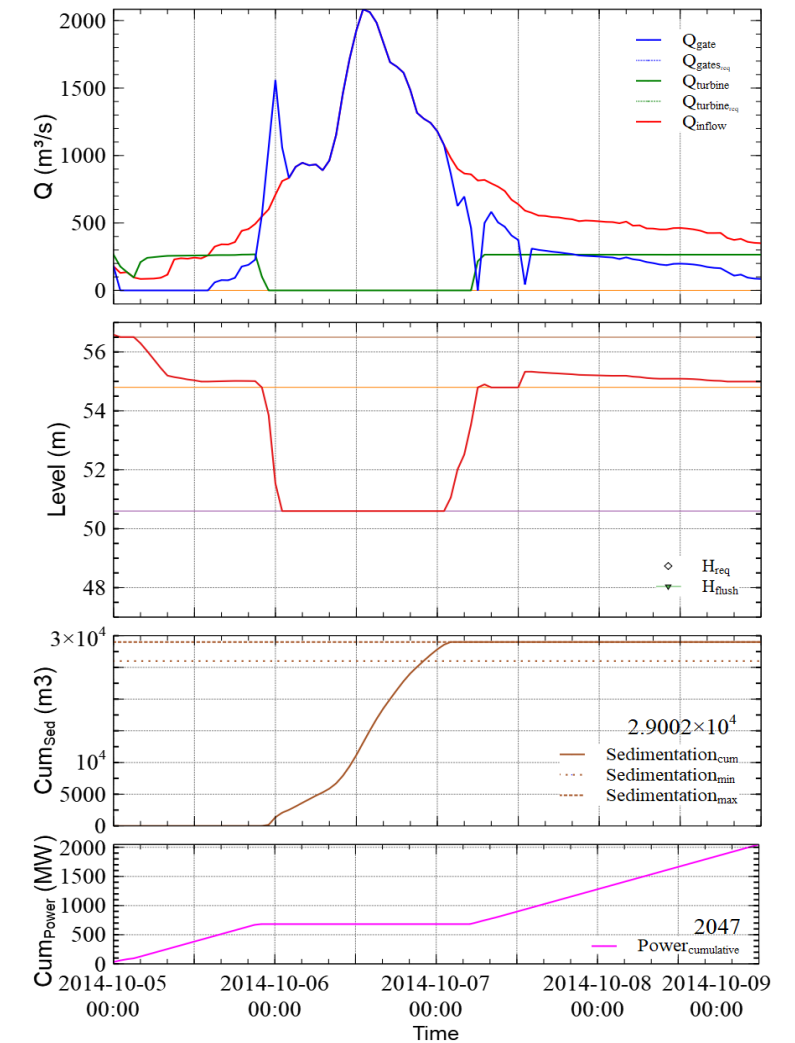
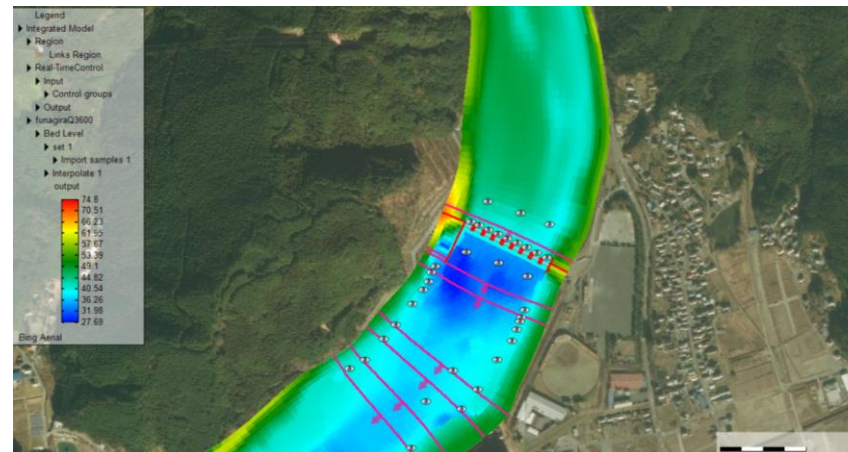
In preparation of the training, we'll send you all the material and will ask you to install the RTC-Tools on your own machine. While attending the training, it will be essential that you have a sufficiently fast internet connection to support a video call, as well as a headset.

### Online Course dates

Session 1: Tuesday, 24 November 2020, 15:00 – 18:00 CET (Delft time)  
Session 2: Tuesday, 1 December 2020, 15:00 – 18:00

# Breakout Session November 9

- Breakout session at the 3<sup>rd</sup> International Delft-FEWS User Day (November 9)
  - ***Meet your colleagues from Reservoir Management and environmental impacts***
- Topics:
  - Sedimentation Management
  - Dam Stability
  - Water quality
  - ...



# Inspired? More information?

E-mail RTC-Tools Product Management

[Ivo.Miltenburg@Deltares.nl](mailto:Ivo.Miltenburg@Deltares.nl) / [Bernhard.Becker@Deltares.nl](mailto:Bernhard.Becker@Deltares.nl)

Deltares landing page for RTC-Tools 2

- <https://www.deltares.nl/nl/software/rtc-tools-2/>

RTC-Tools 2 GIT:

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

RTC-Tools 2 Documentation

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

**Deltares**

