Deltares
Enabling Delta Life

Symposium 'Slim Malen: de nieuwe standaard?' Pilot Waterschap Riviereland

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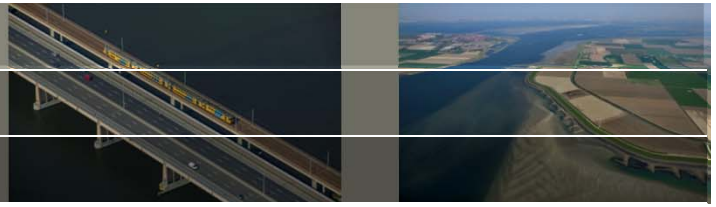
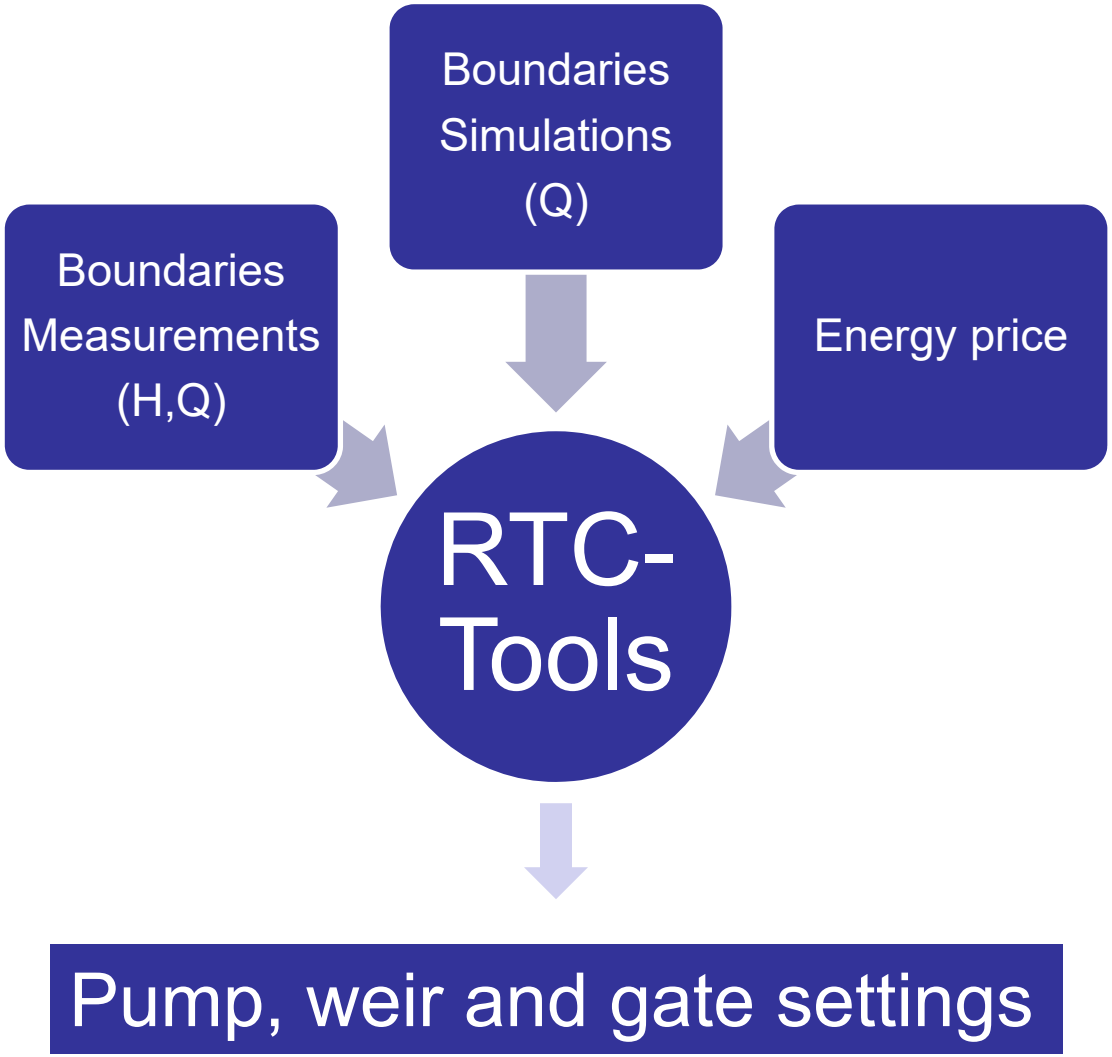
Bart van Esch, Tjerk Vreeken, Teresa Piovesan

08, Maart 2019

Pilots model setup



Year 2013



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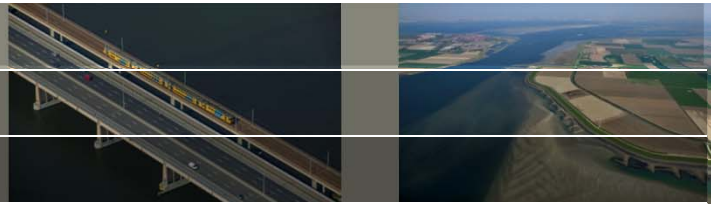
It is all about the process!!



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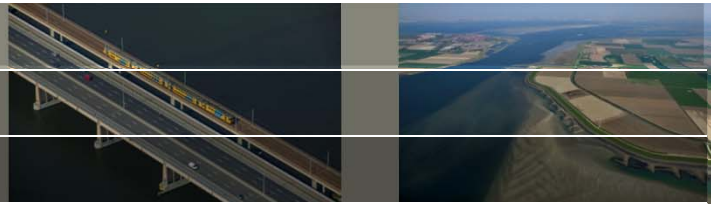
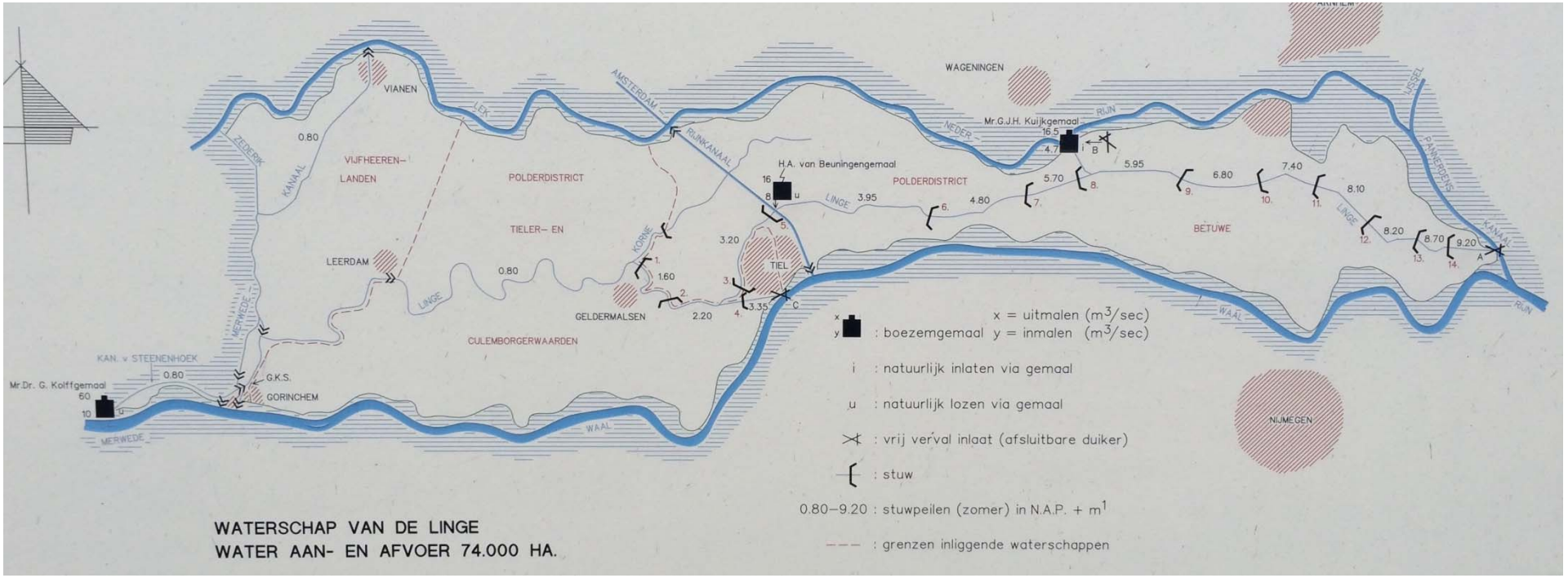
Linge





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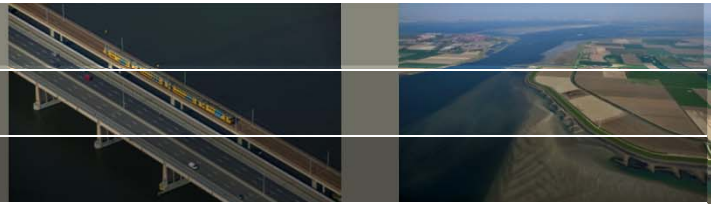
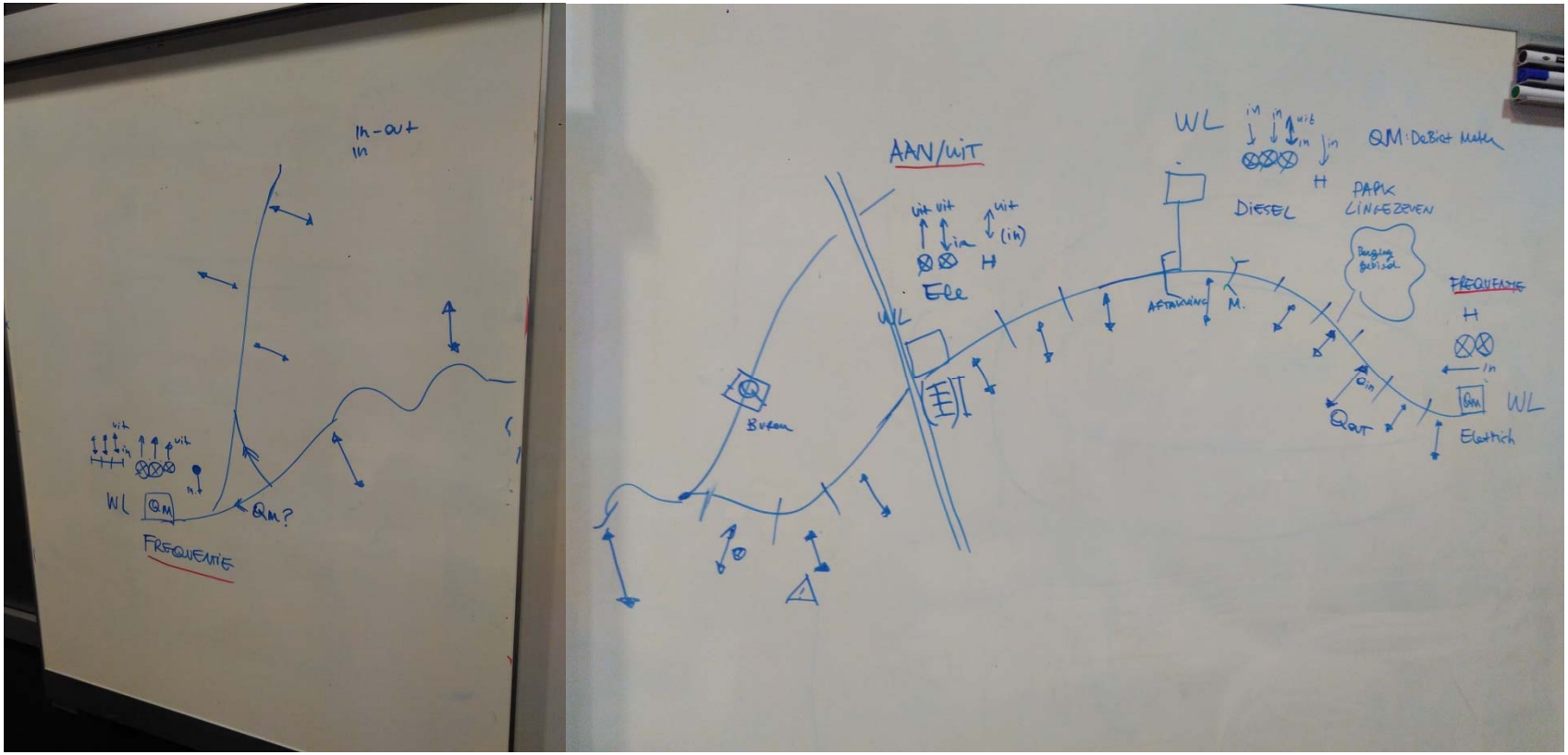
Linge system analysis





26-01-207, Paul Claessens,
Jan vd Braak, Jeroen Wyatt

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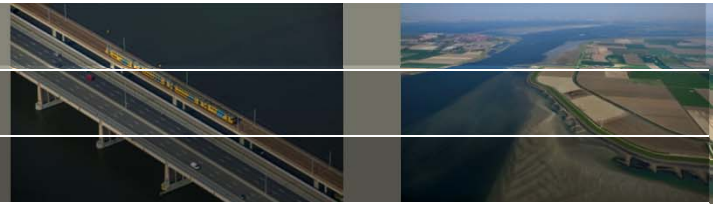
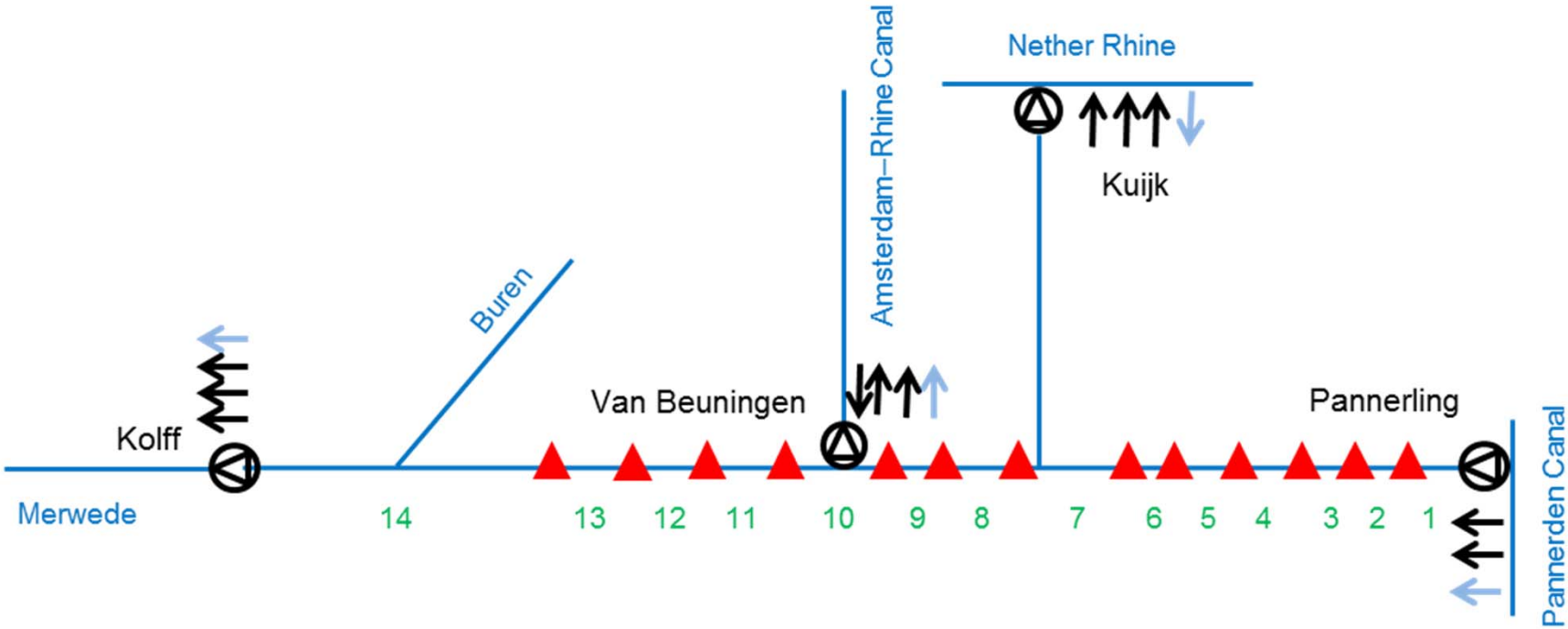
Linge schematics





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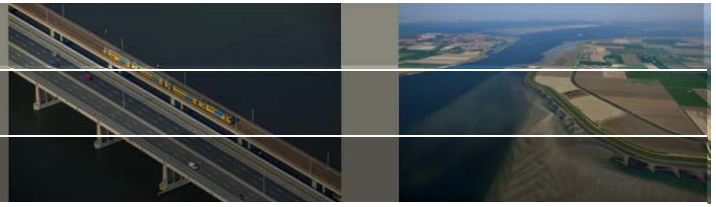
Linge structures schematics



Name	Location (branch)	# and direction of pumps	direction of free flow
Pannerling	1	2 in	In
Kuijk Gemaal	7	3 out	In
van Beuningen Gemaal	10	2 out 1 in	out
Kolffgemaal	14	3 out	out

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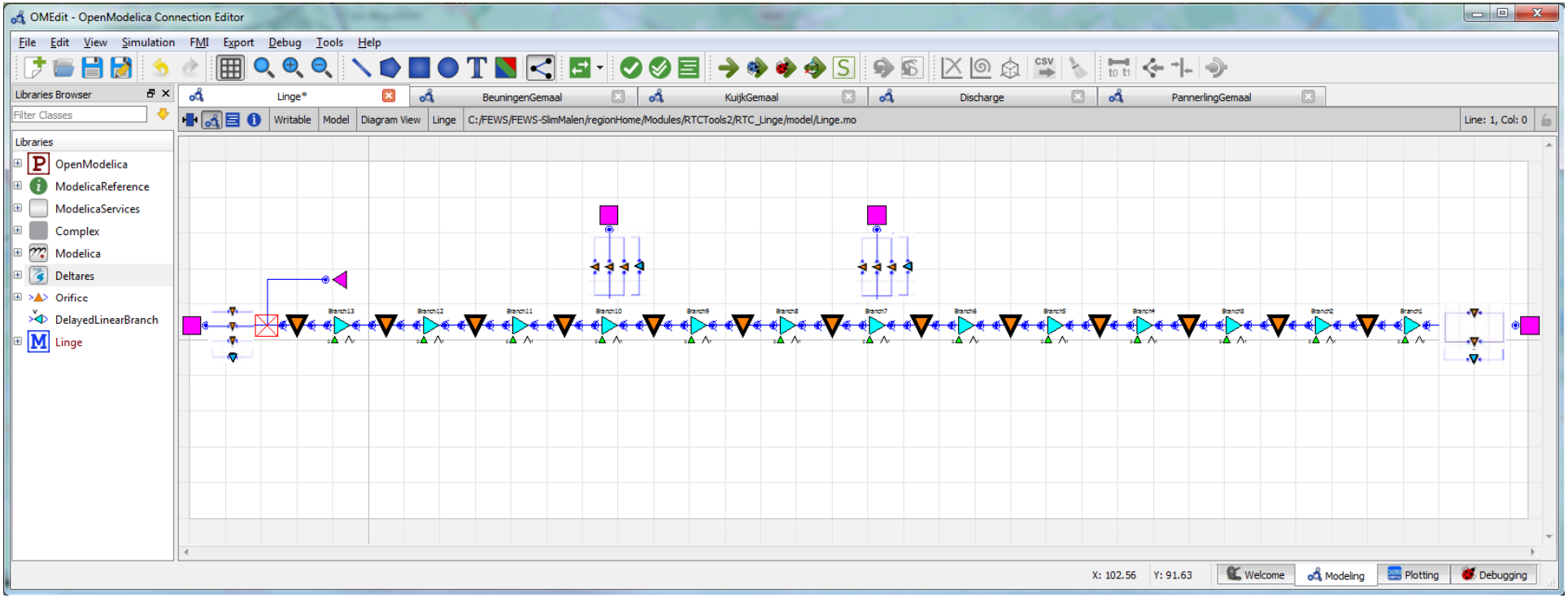
RTC-Tools Linge: system modelling

RTC-Tools



In OpenModelica,
modelling interface of RTC-Tools

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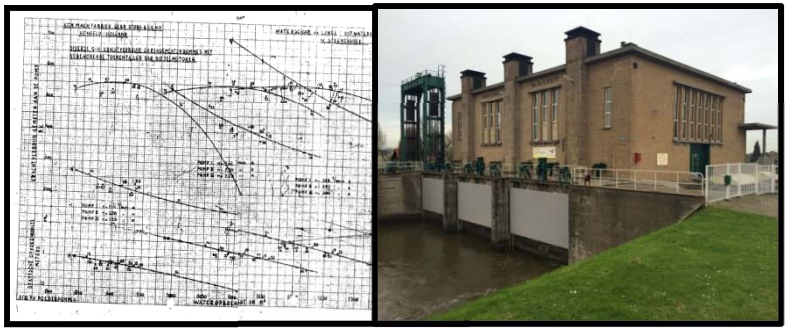
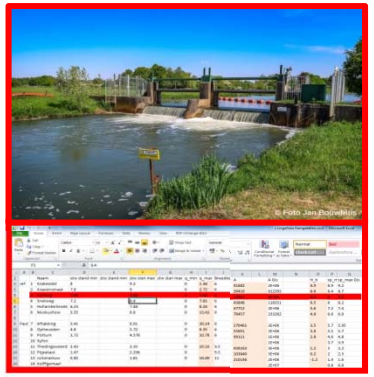
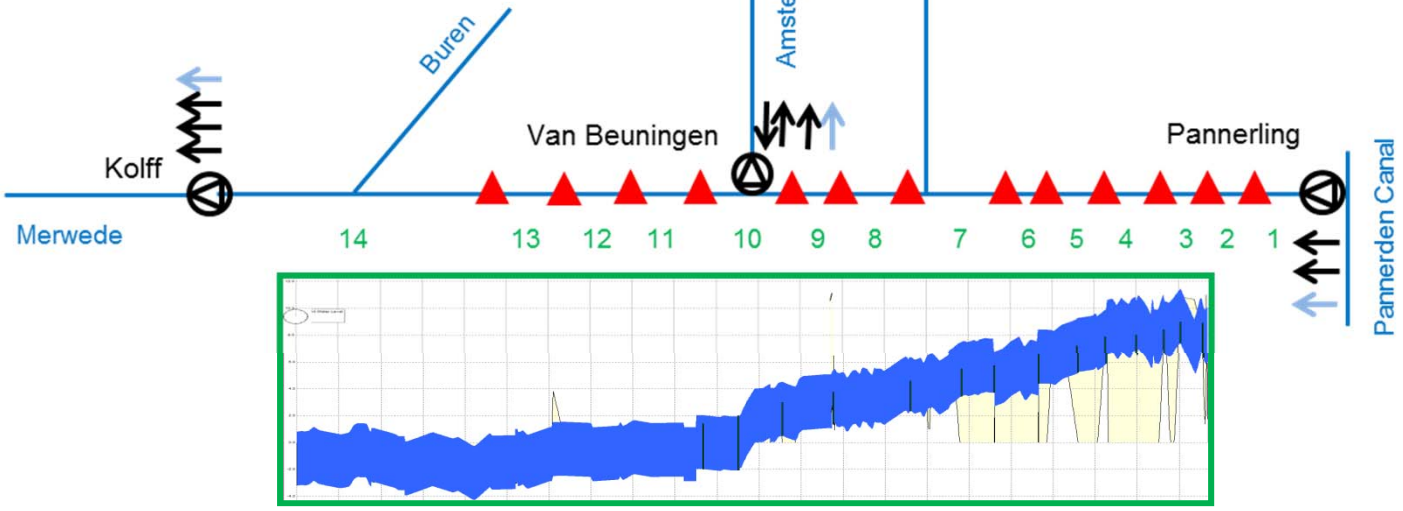
RTC-Tools Linge: system modelling

RTC-Tools

- Relation V/H of the storage elements (panden)
- Weirs and orifices information
- Pump curves in terms of working area







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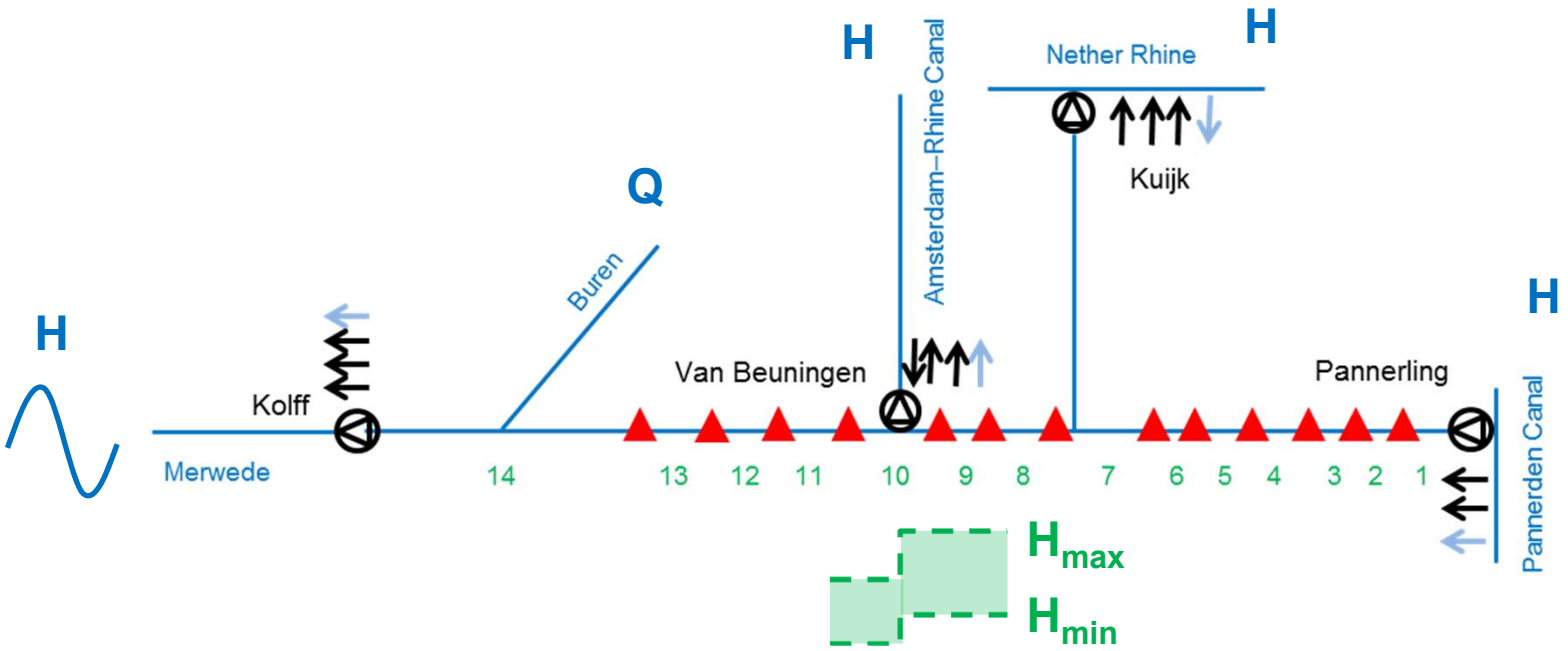
RTC-Tools Linge: Boundaries

Boundaries
Measurements

- Water levels in the outside systems (Merwede, Amsterdam-Rhine canal, Nether Rhine, Pannerden canal)
- Discharges at Buren
- Minimum and maximum water level band (+- 10 cm)



Information for validation of the results

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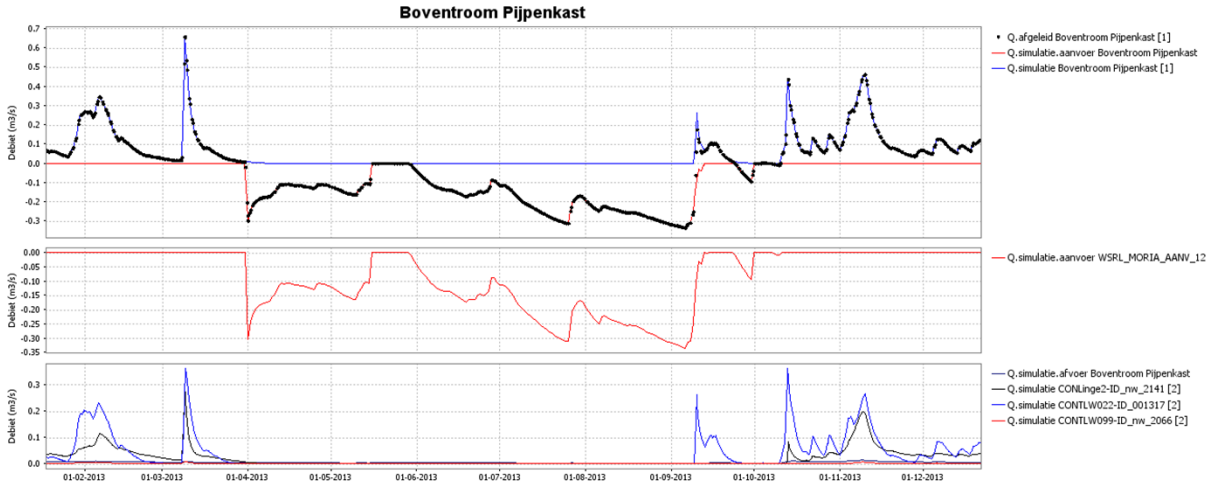
RTC-Tools Linge: Boundaries

Boundaries
Simulations

In and outflows in the different storage elements (panden) for the year 2013

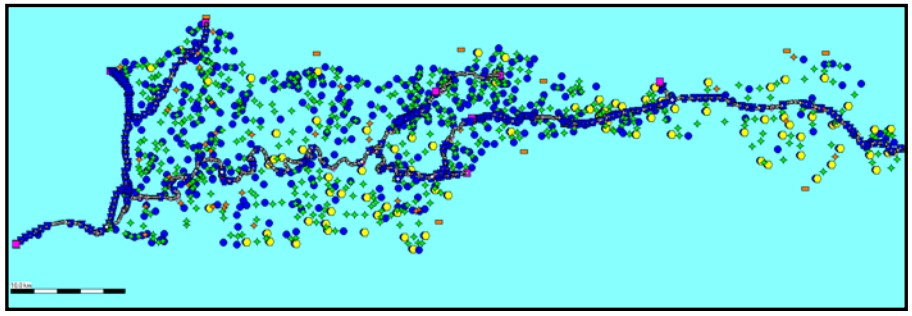


total

outflow

inflow

- Inflows: RR Sobek model calibrated for high flows



- Outflows: (ground) water demands estimates from MORIA

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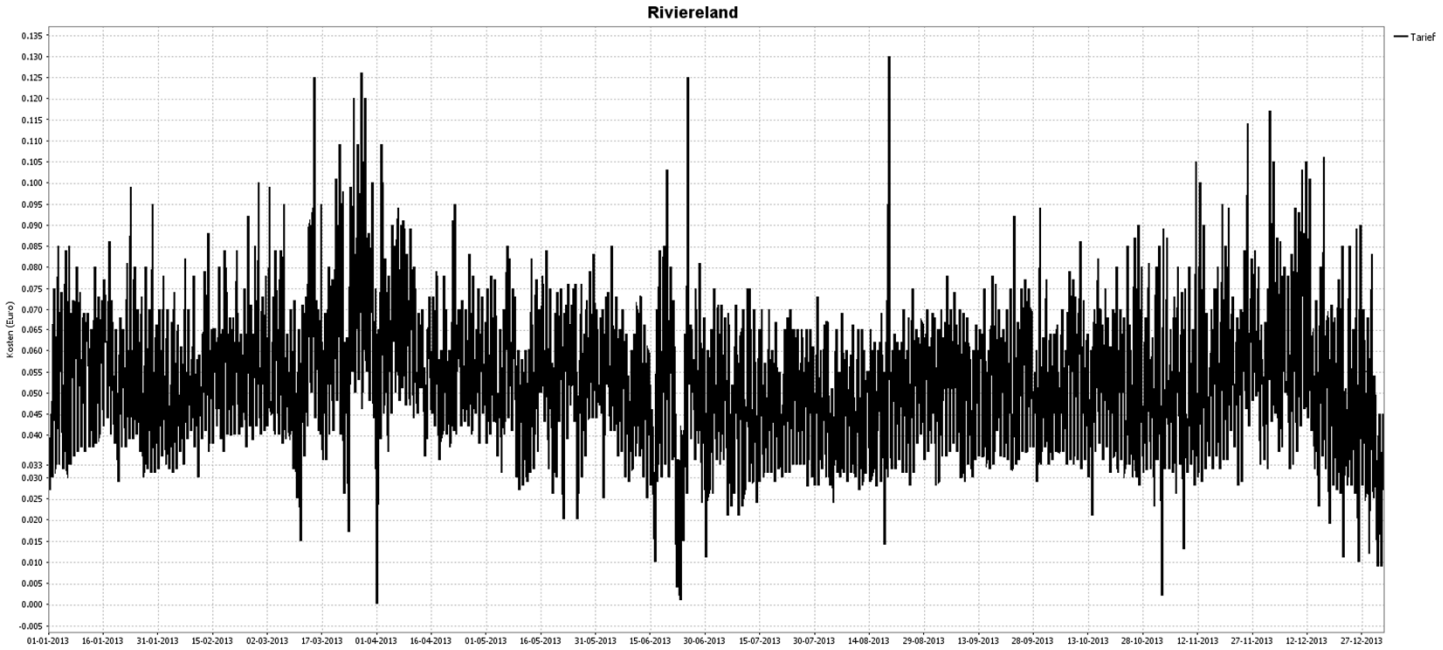
RTC-Tools Linge: energy price

Energy price

APX energy prices for 2013



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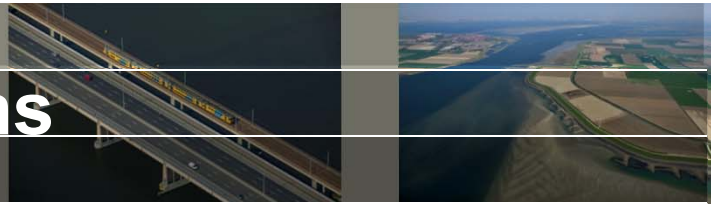
RTC-Tools Linge: Assumptions



- „Perfect forecast”
- Simplified mode

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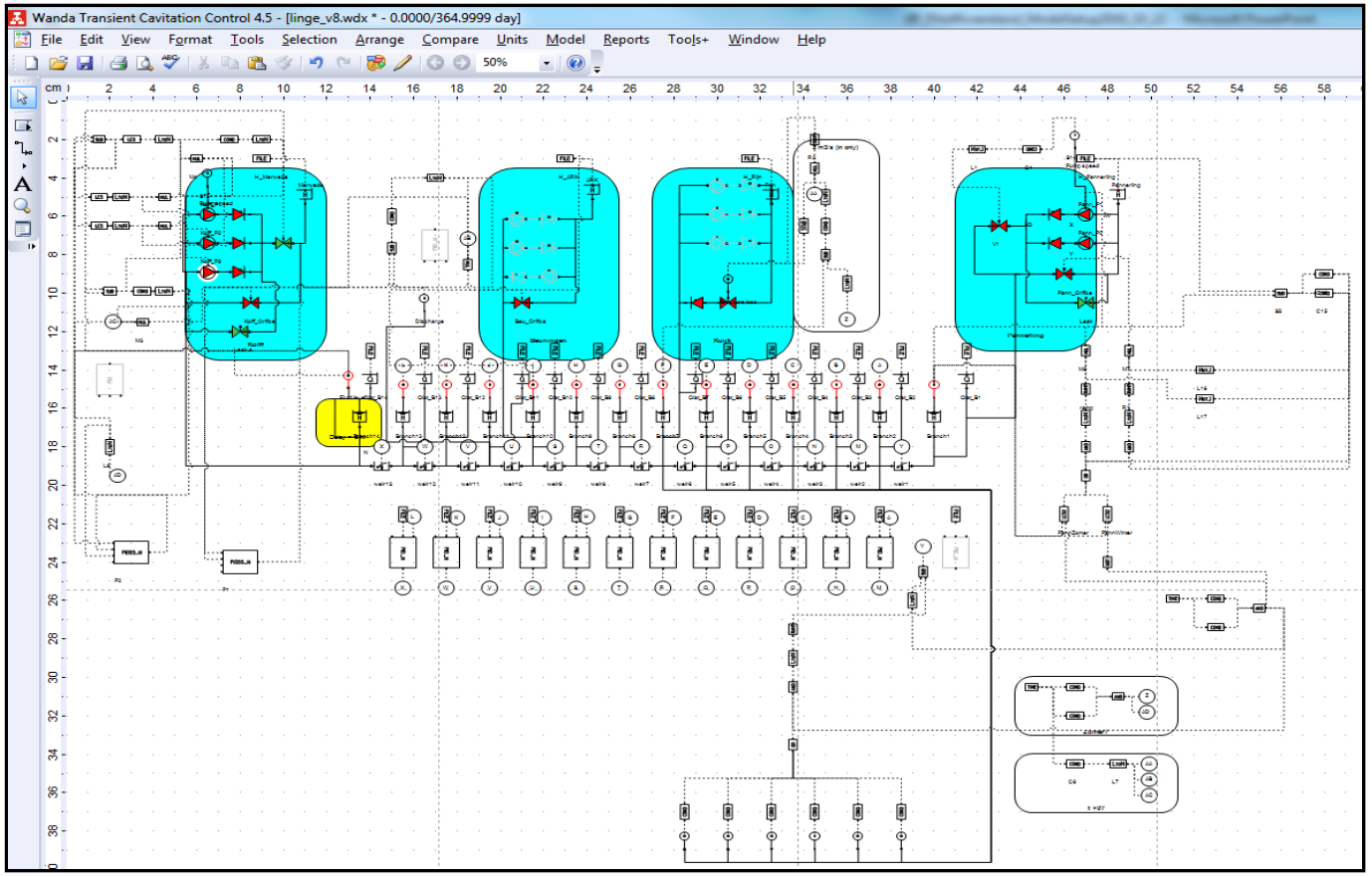
Base model Linge: system modelling



WANDA, features and boundaries identical to RTC-Tools model

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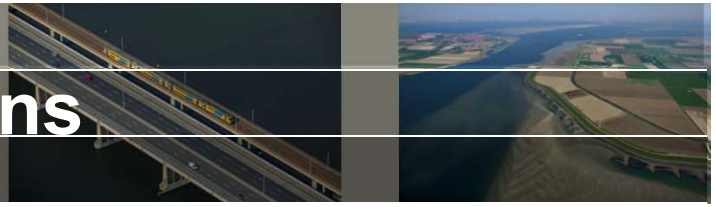
Base model Linge: assumptions



Assumptions for year 2013:

- There are two active pumping stations: Kolff and Pannerling
- Pumps: interval control (turn on if the level is exceeding a thershold and turn off when the level is lower than a threshold)
- weirs: PID controllers
- free flow is preferred if possible
- Control defined on the base of document provided by Rivierenland

- Energy price is not considered in controlling the structures

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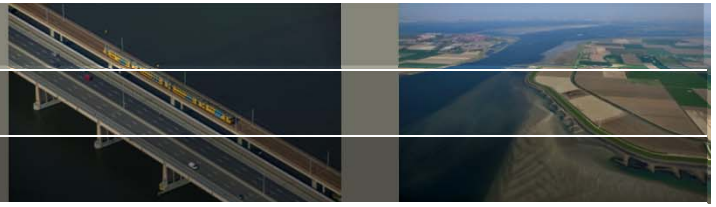
Scenario



- What could have been the best strategy for 2013 for Rivierenland?
- Calculate 2013!
- 12 hour horizon, re-calculated at every 6 hours

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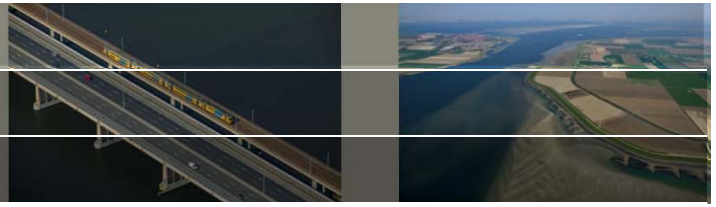
Base scenario validation



	Base	Reality
Kolff pump 1hours (h)	1187	642
Kolff pump 2hours (h)	339	739
Kolff pump 3hours (h)	36	541
Kolff all hours (h)	1526	1922
Kolff cost (kE)	183	195
Kuijk cost (kE)	-	27

The base scenario underestimates the costs about **18%**

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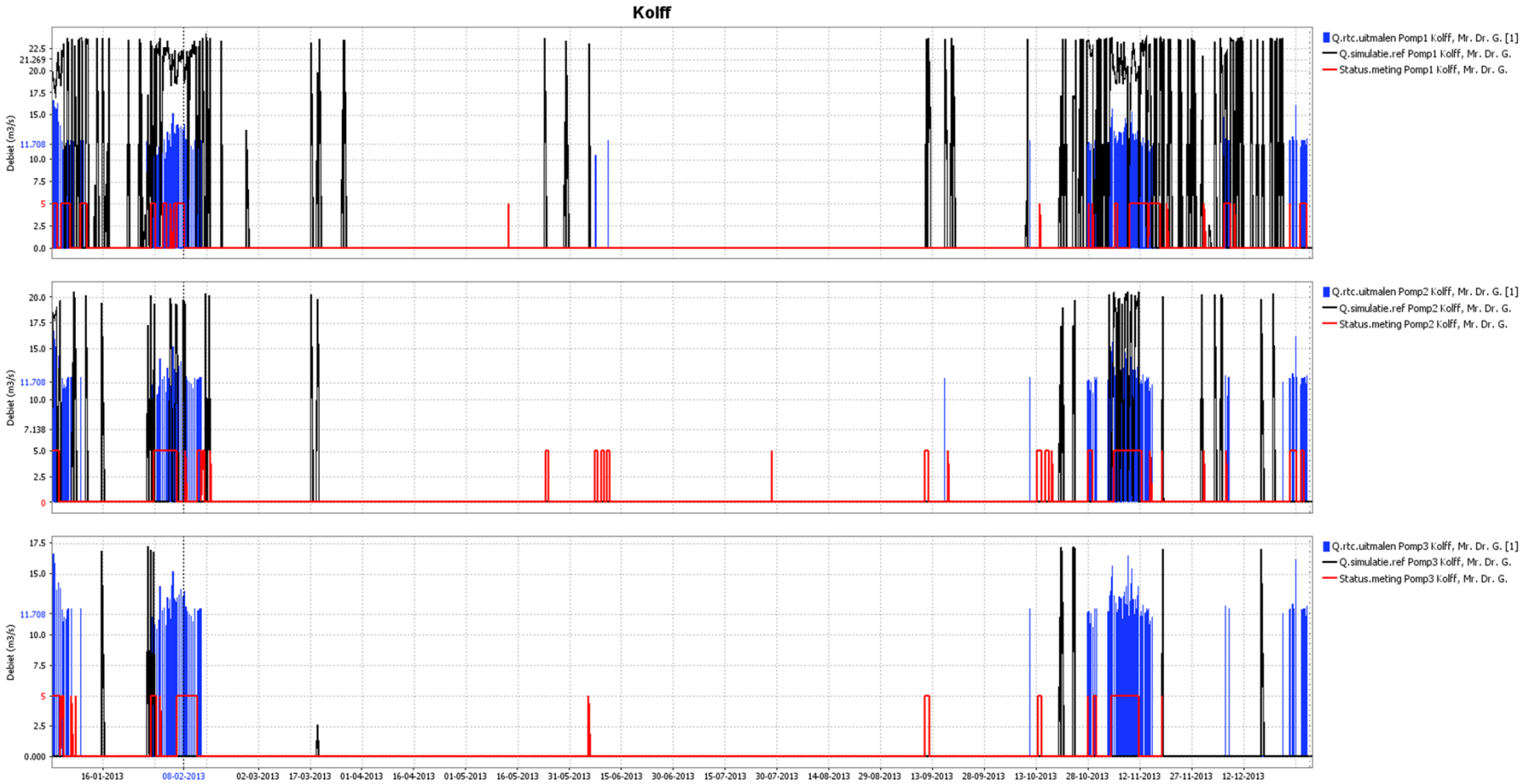
Kolff: red measurement, black: base, blue: rtc



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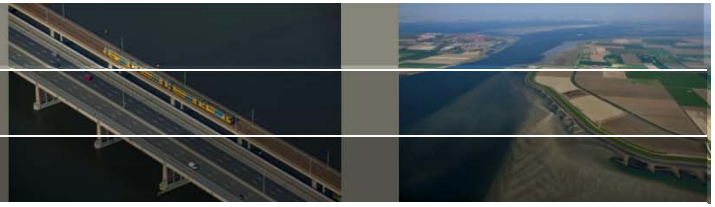
Comparison



	Base	Reality	RTC-Tools
Kolff pump 1hours (h)	1187	642	537
Kolff pump 2hours (h)	339	739	473
Kolff pump 3hours (h)	36	541	419
Kolff all hours (h)	1526	1922	1429
Kolff cost (kE)	183	195	26
Kuijk cost (kE)	-	27	7

The saving by Kolff pumping station is 85%

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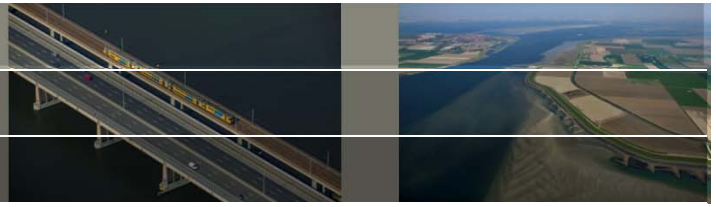
Saving



	Base	Reality	RTC-Tools
Pannerling (kE)	1.8		0.4
Kuijk cost (kE)	-	27	7
Beuningen (kE)	-		2
Kolff cost (kE)	183	195	26
Sum (kE)	**185**		**35**

The saving is **80%**, 150kE / year.

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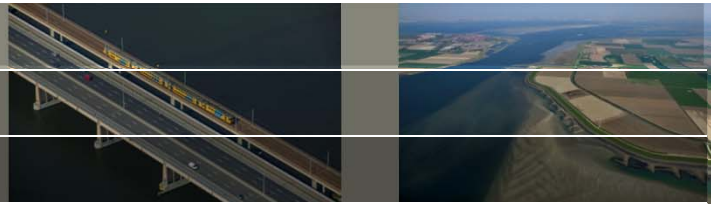
Energy saving



	Base	Reality	RTC-Tools
Pannerling (MWh)	35		11
Kuijk cost (MWh)	-		23
Beuningen (MWh)	-		49
Kolff cost (MWh)	594		83
Sum (MWh)	**629**		**167**

The saving is **73%**, 450MWh / year.

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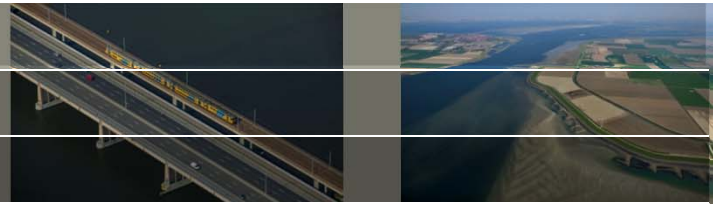
How is that possible???



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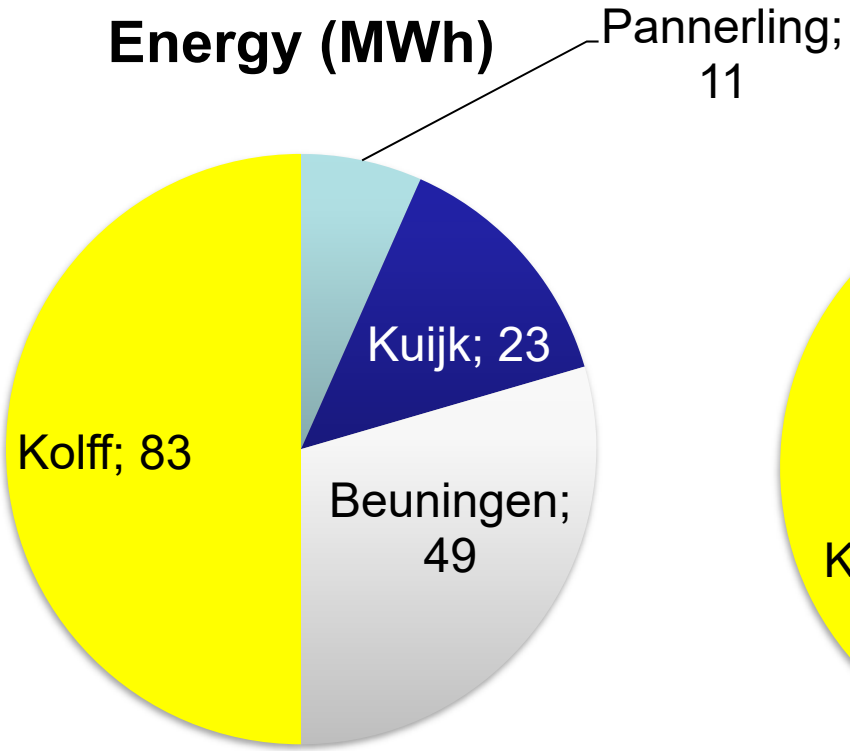
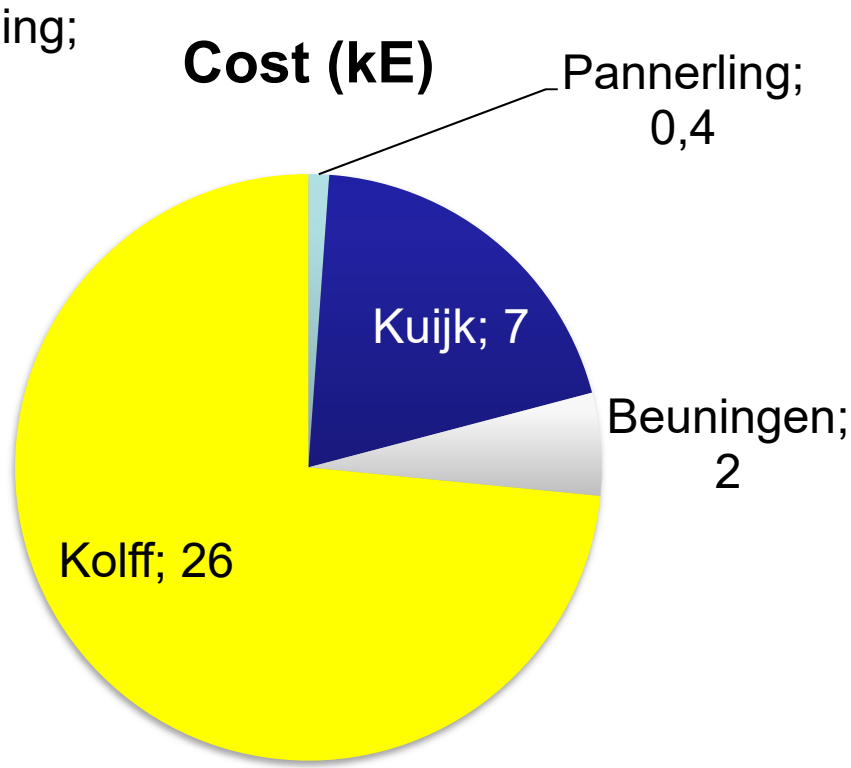
1. Electric pumps are cheaper

167MWh



35kE



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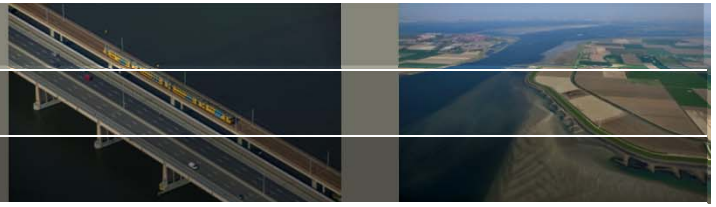
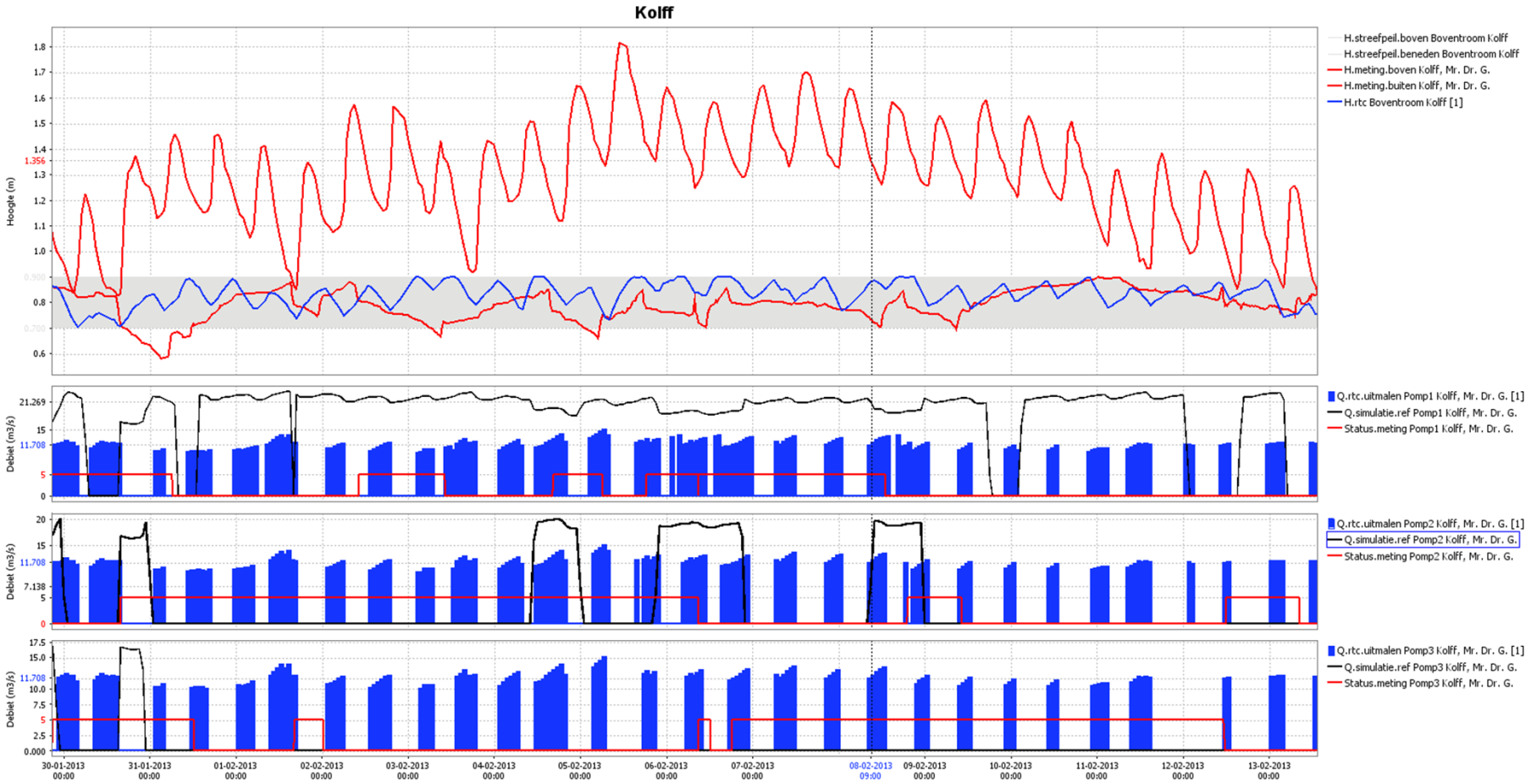
2. Pump at low tide





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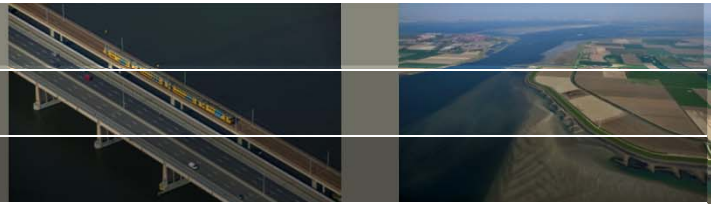
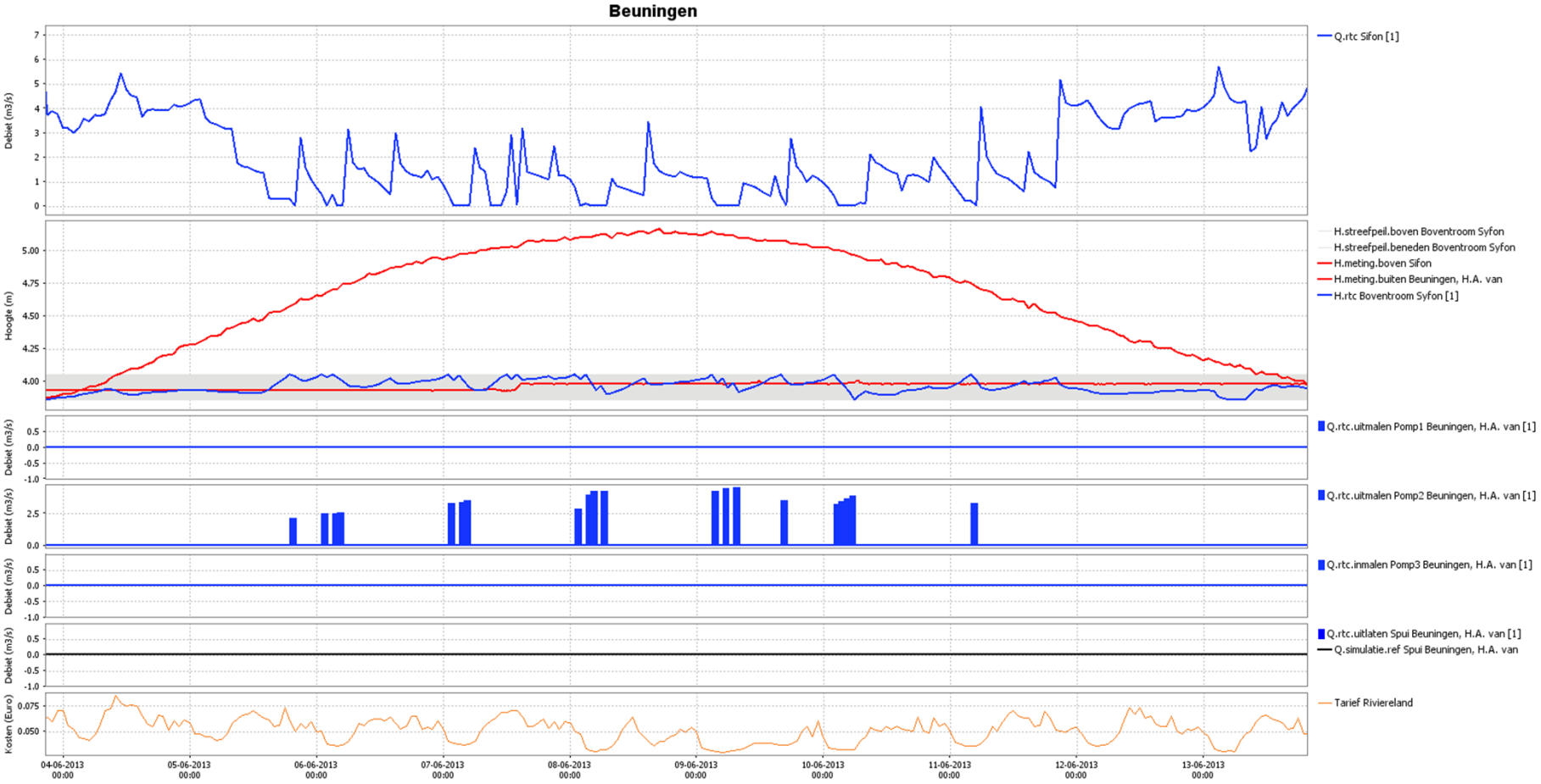
3. Beuningen pumps more





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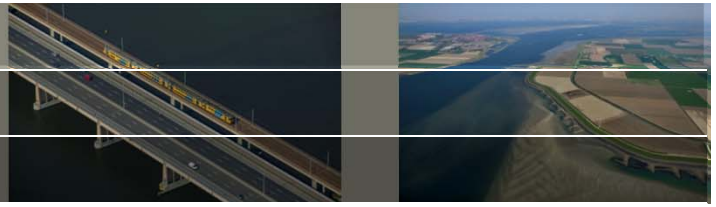

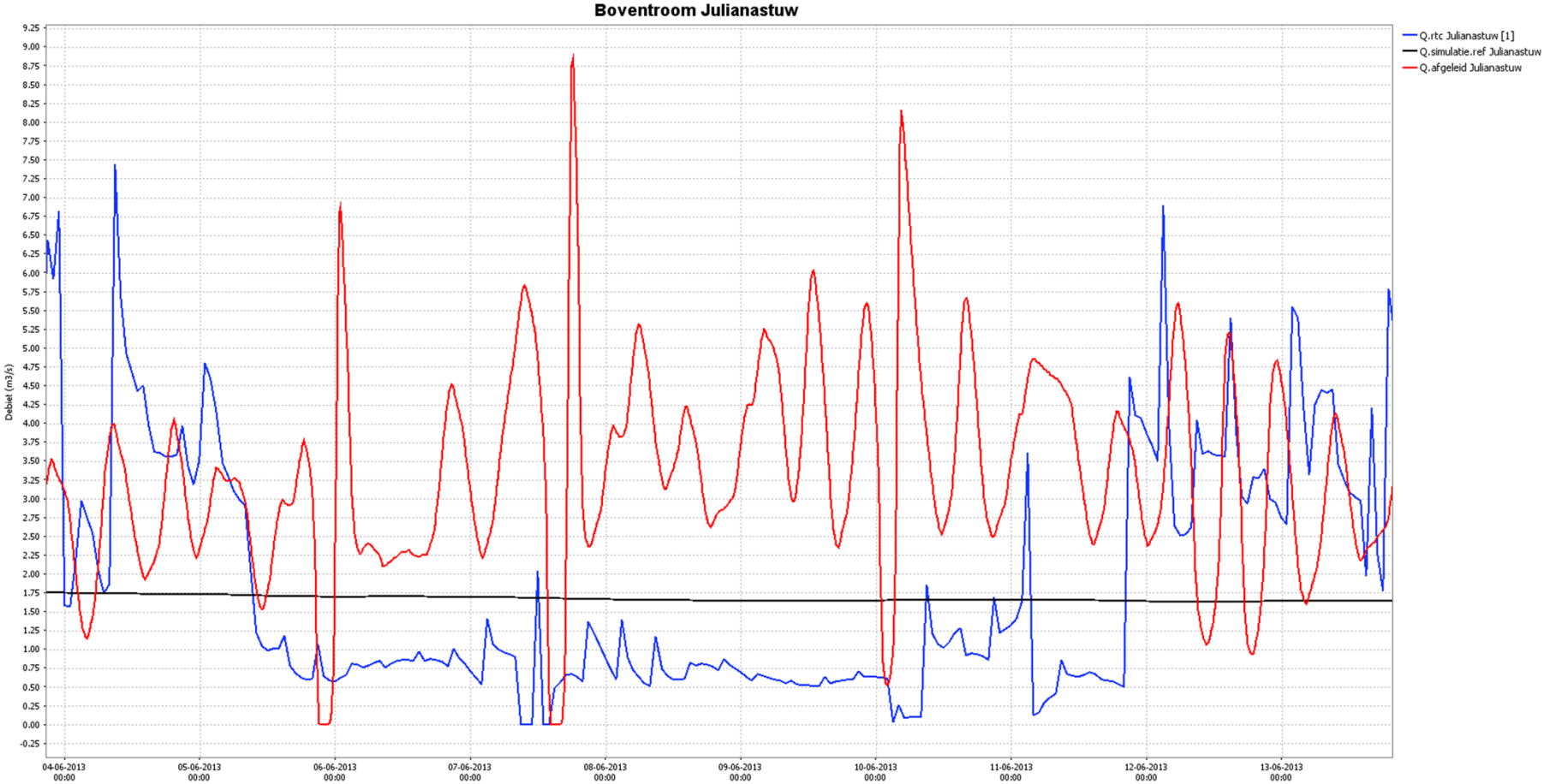

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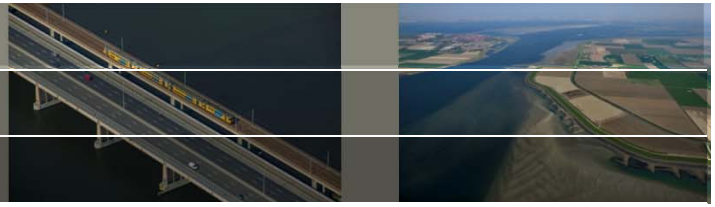

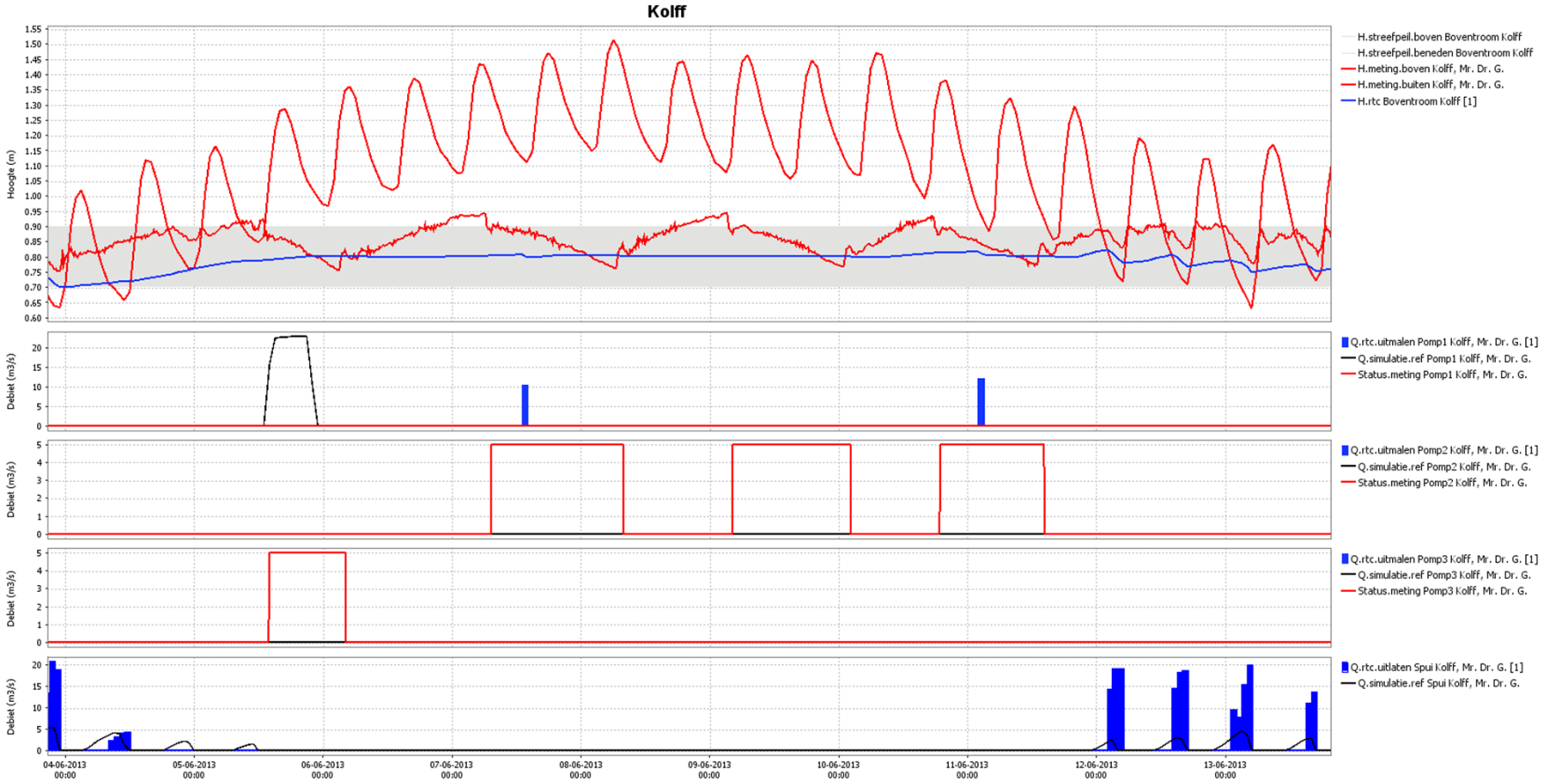

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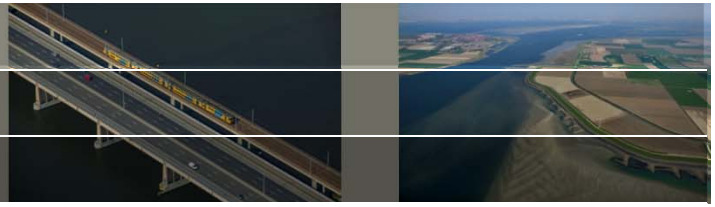
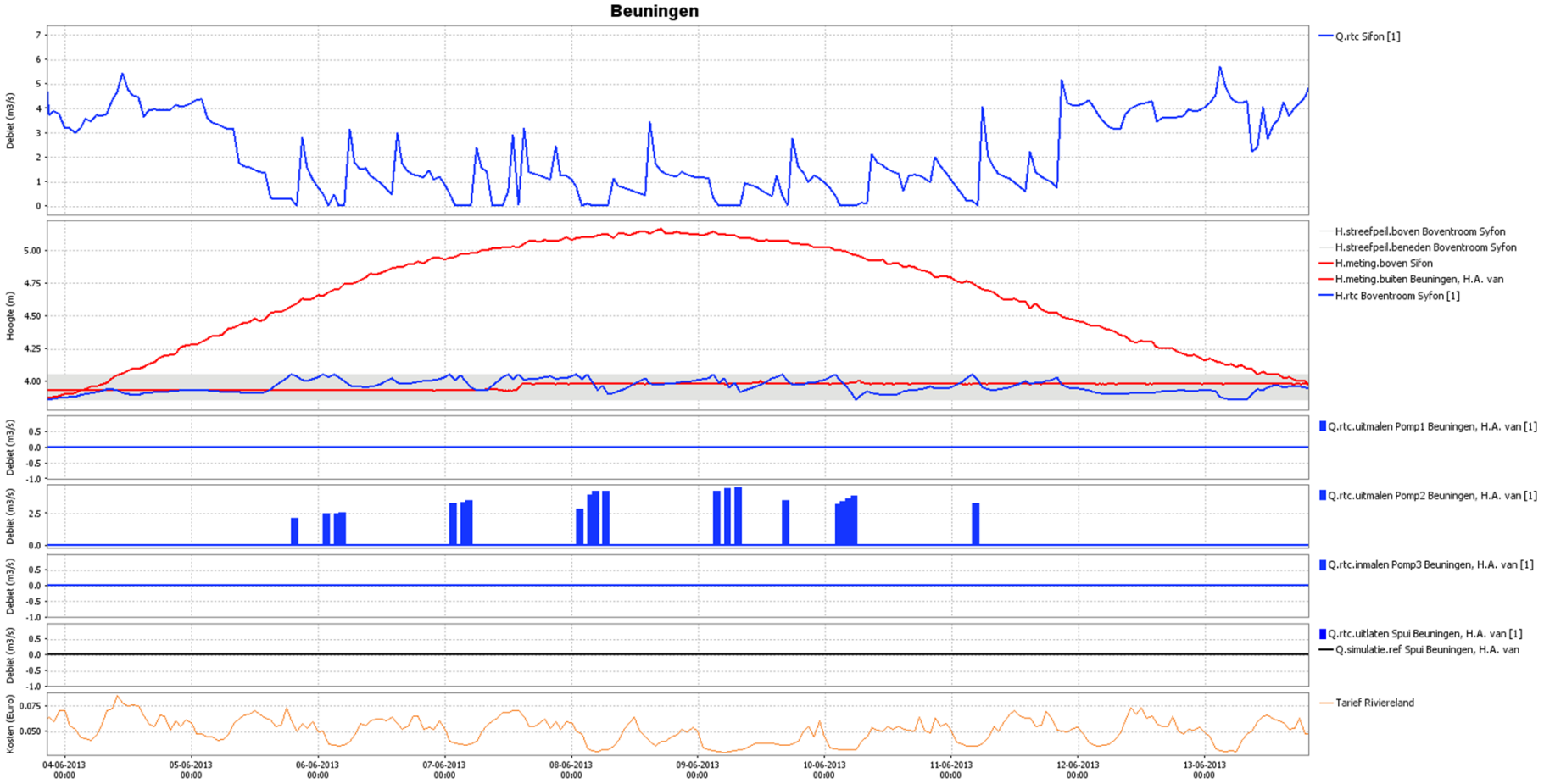
4. Pumping at low price





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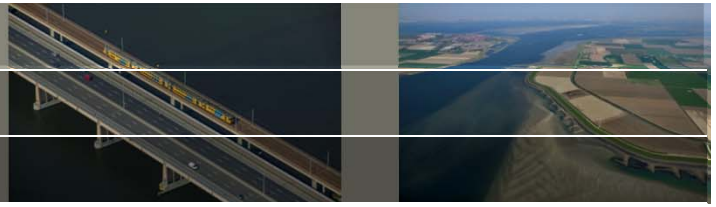
5. Pumping efficiently



	Base	RTC-Tools	Reality
Kolff all hours (h)	1526	1429	1922
Kolff cost (kE)	183	26	195
Kolff energy(MWh)	594	83	-

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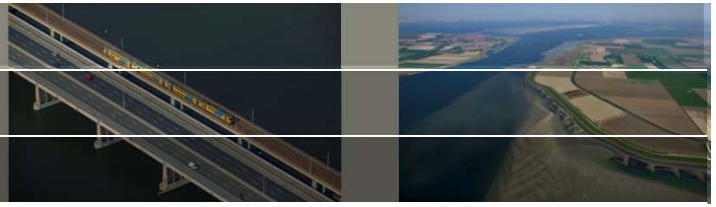
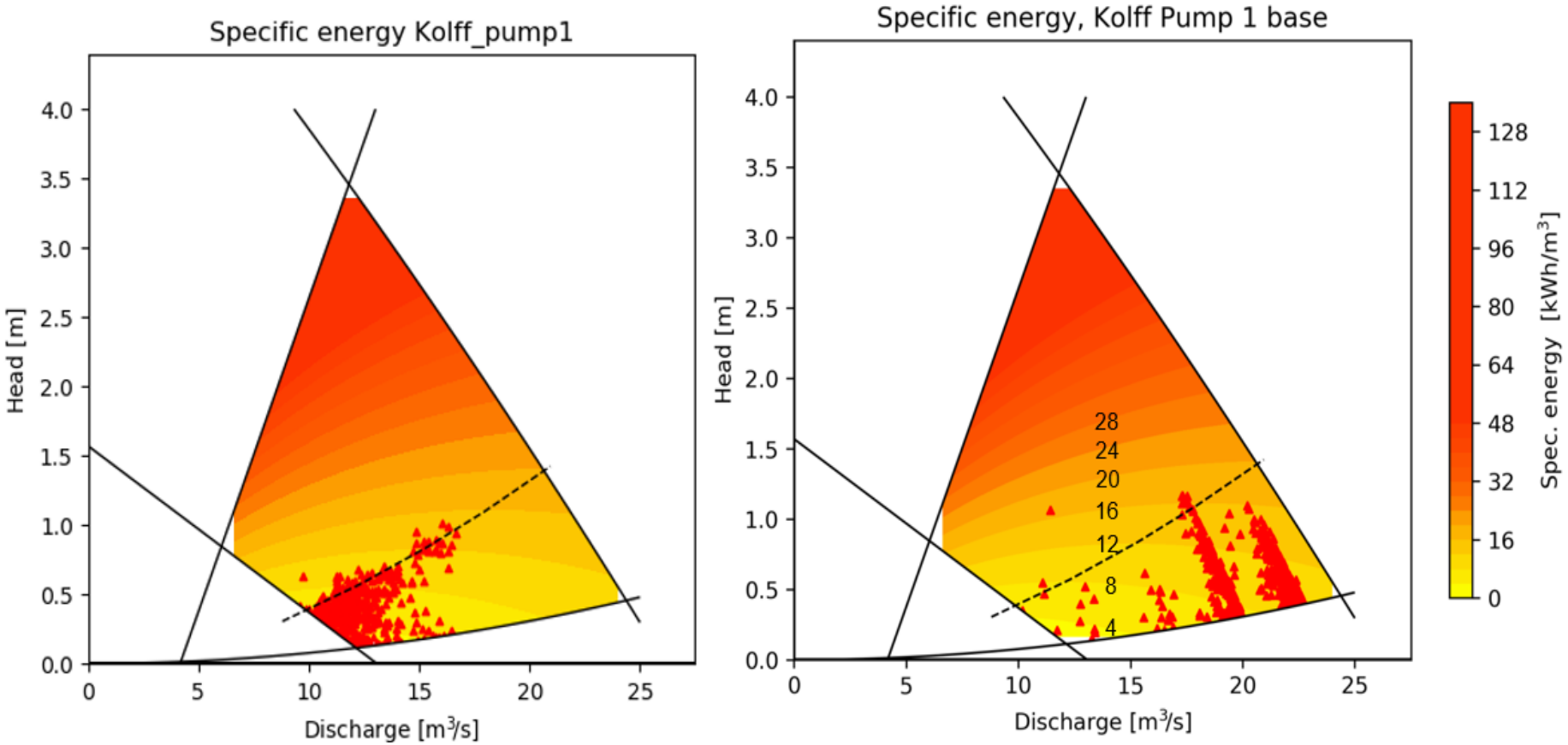
5. Pumping efficiently





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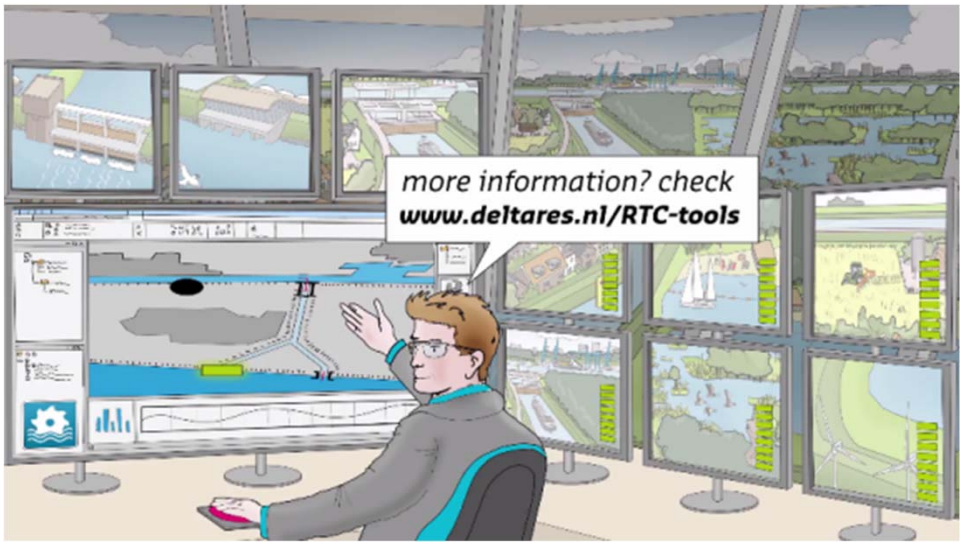
What can we do with RTC-Tools model now?

Scenario studies

- Optimization integral system
- More flexible water levels
- Different pumps
- Optimal efficency of pumps
- Optimal costs or energy use
- Switch pumping/free flow
- Optimize rainy / dry periods



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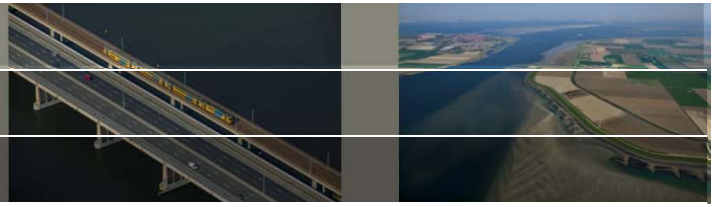
Summary



80% saving of costs

1. More electric
2. Pumping at low tide
3. Beuningen pumps more
4. Pumping at low price
5. Pumping at higher efficiency
6. Anticipating and buffering

www.slimmalen.nl

jan.talsma@deltares.nl

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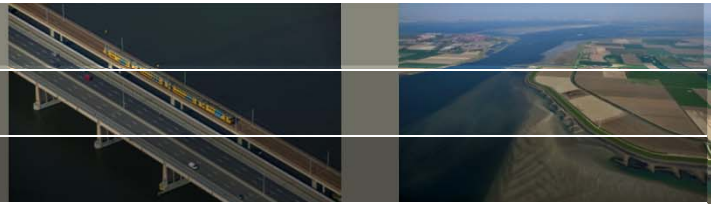
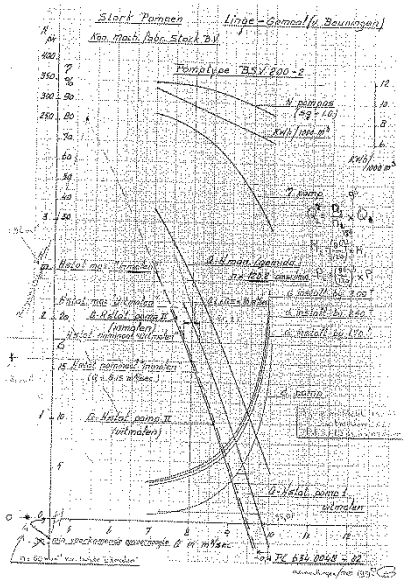
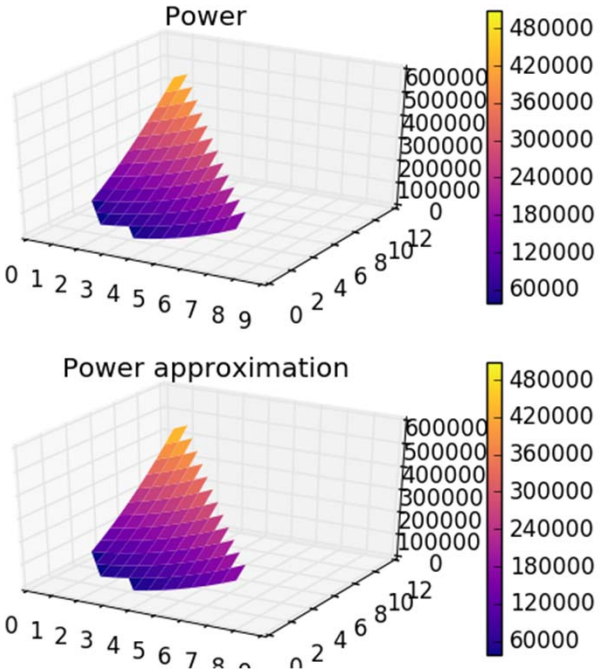
(convex) Pump modelling







https://www.crompton.co.in/centrifugal-monoset-pumps/

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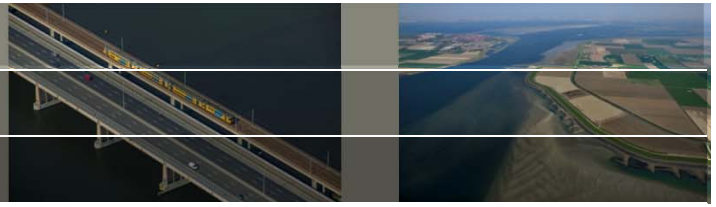
Convex pump modelling



$$\begin{aligned} \underset{Q}{\text{minimize}} \quad & \sum_{t_d=0}^{t_{dn}} \delta P_{app}(Q(t_d), H(t_d))\Delta t \\ \text{subject to} \quad & f_i(Q,H)\delta \leq 0,\ i = 1,\ldots,m \\ & \delta = sgn(Q) \\ & \delta \in \{0,1\} \text{ and } \delta \in \mathbb{Z}, \\ & f(Q(t_d)) \leq 0. \end{aligned}$$

$$\begin{aligned} \underset{Q}{\text{minimize}} \quad & \sum_{t_d=0}^{t_{dn}} P_{help}(t_d)\Delta t \\ \text{subject to} \quad & f_i(Q,H) - (1-\delta)H_{\text{offset},i} \leq 0,\ i = 1,\ldots,m, \\ & P_{app}(Q,H) - M(1-\delta) \leq P_{help}(t_d), \\ & m\delta - P_{help}(t_d) \leq 0, \quad P_{help}(t_d) - M\delta \leq 0, \\ & Q - \delta Q_{max} \leq 0, \quad 0 \leq Q, \\ & \delta \in [0,1] \text{ and } \delta \in \mathbb{Z}, \quad f(Q(t_d)) \leq 0. \end{aligned}$$

Water resources research Journal (submitted end of August)
Convex modeling of pumps in order to optimize their energy use
Klaudia Horváth, Bart van Esch, Tjerk Vreeken, Ivo Pothof, Jorn Baayen

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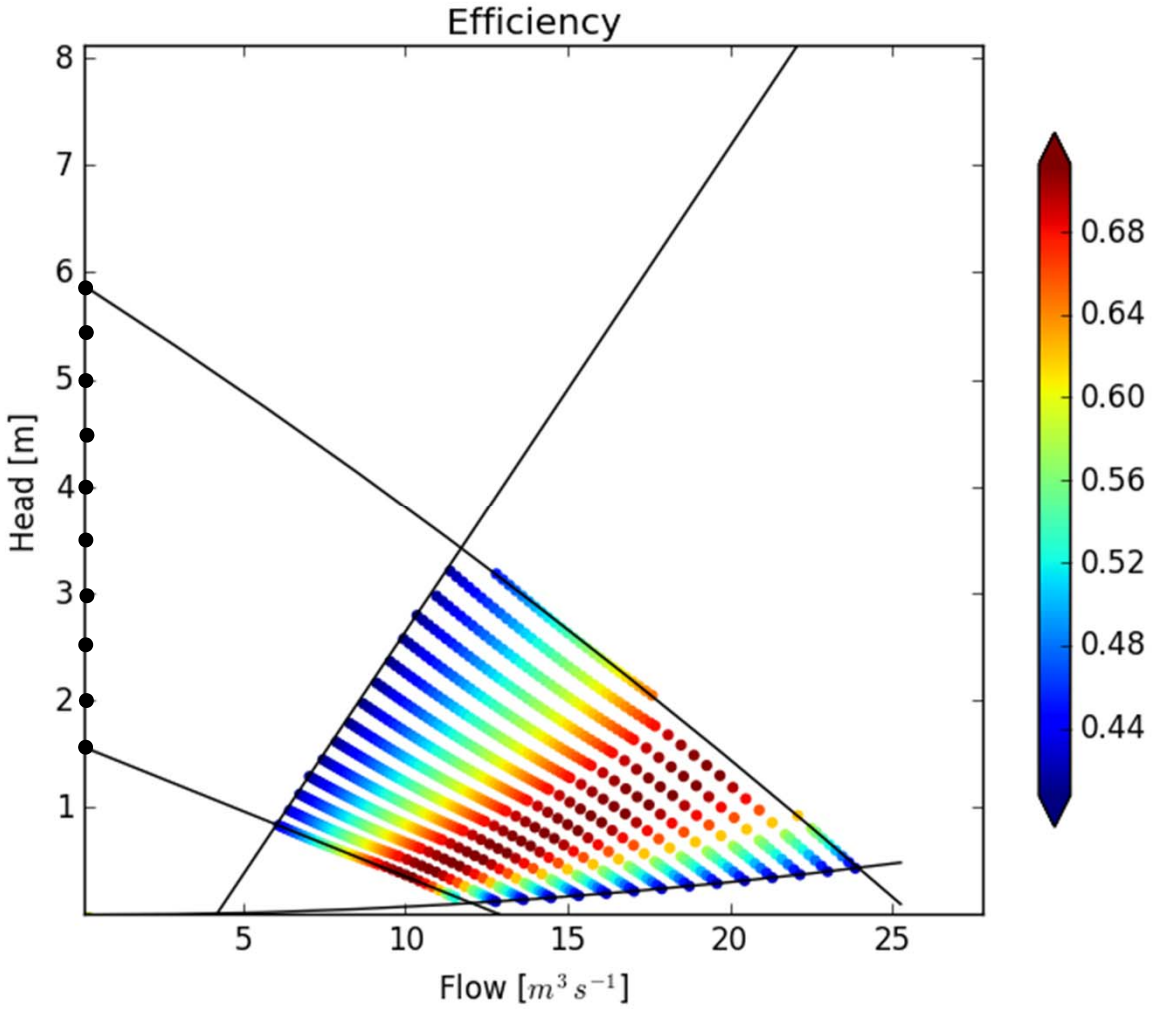
Pump modelling: working area



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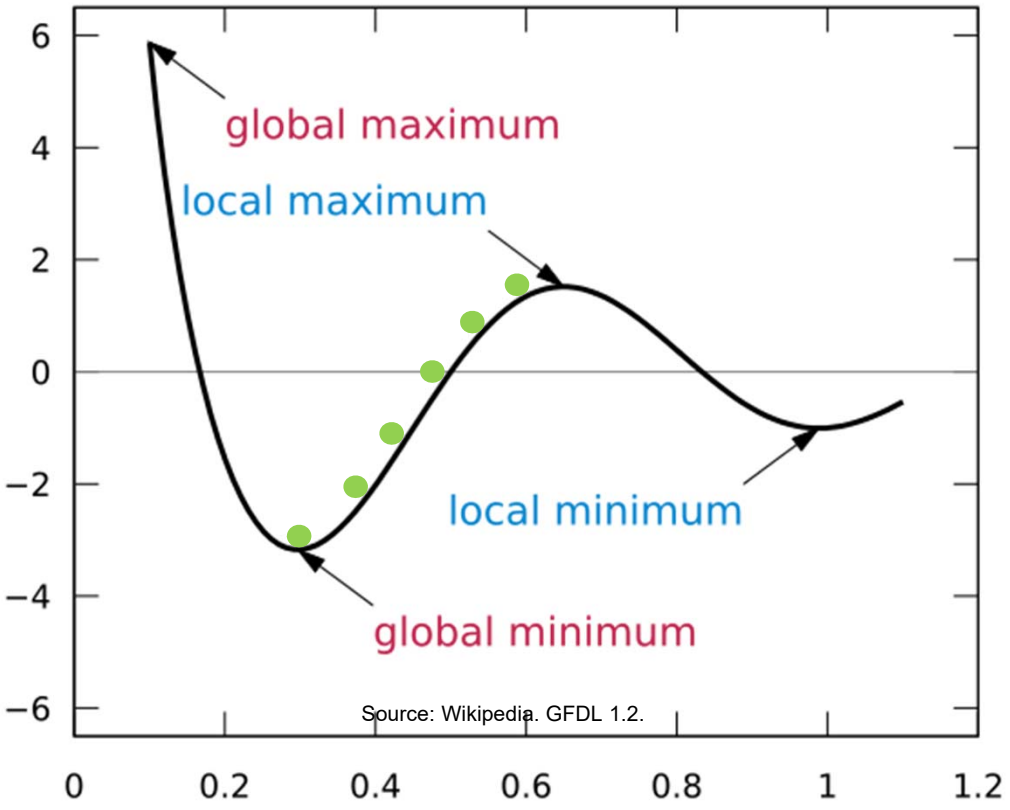
Local and global optima



Source: Wikipedia. GFDL 1.2.

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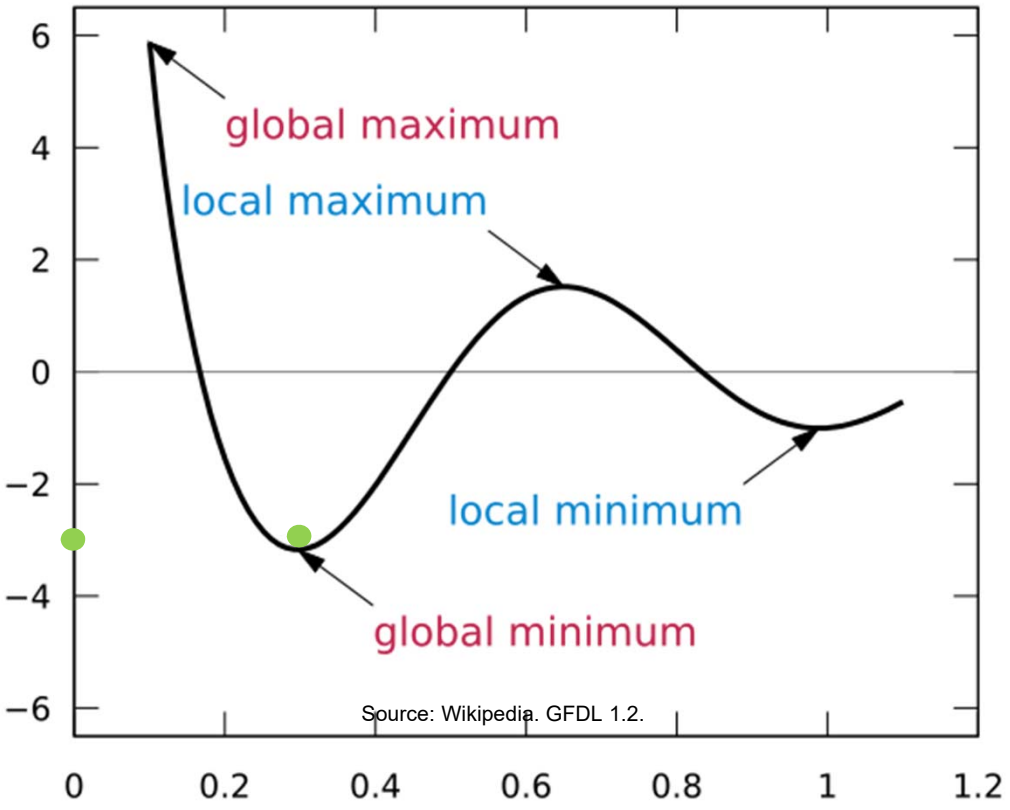
Local and global optima



Source: Wikipedia. GFDL 1.2.

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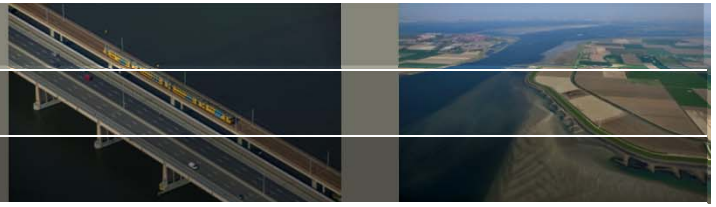
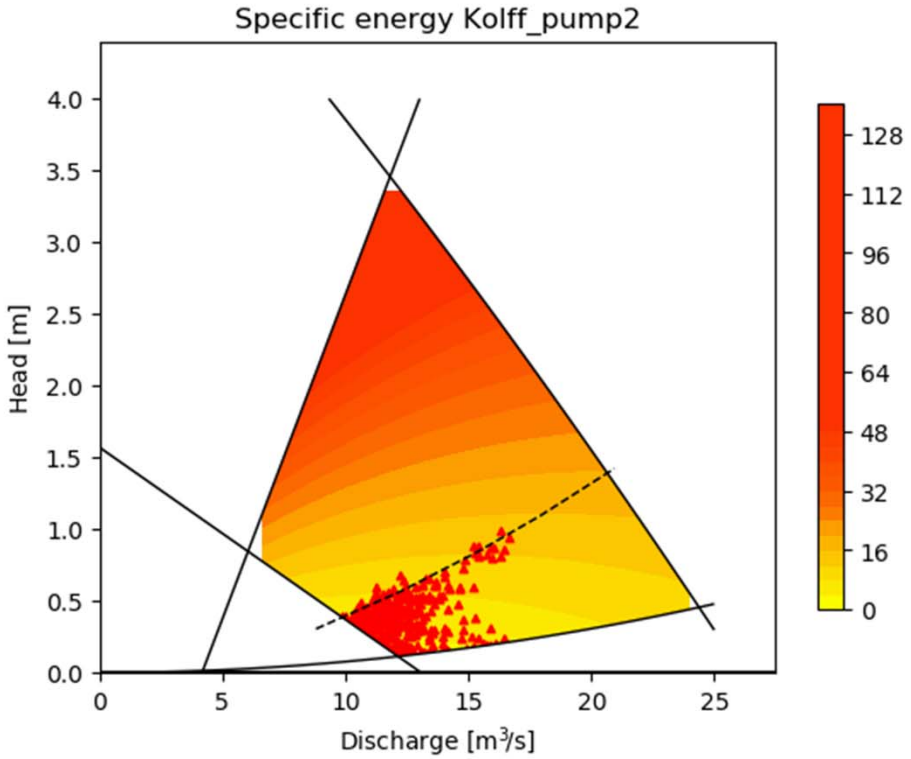
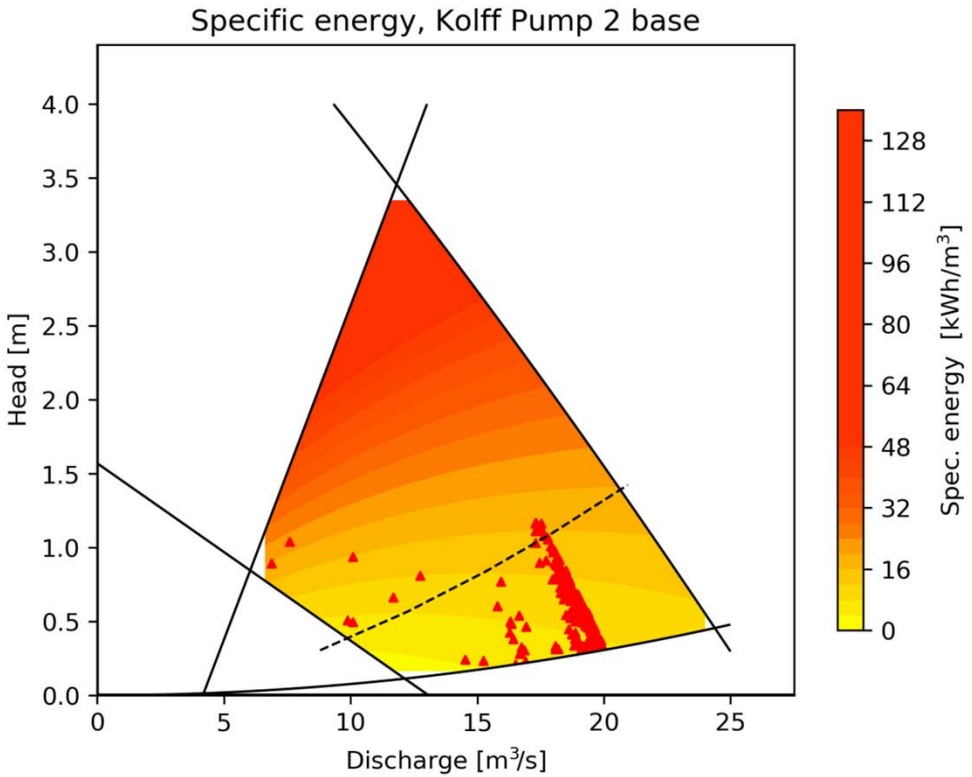
5. Pumping efficiently







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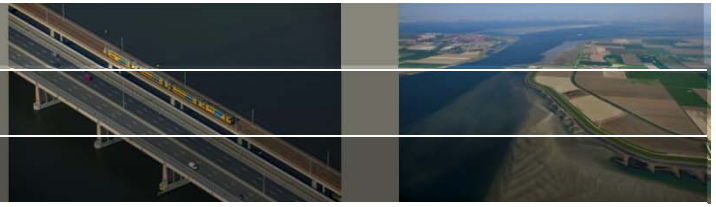
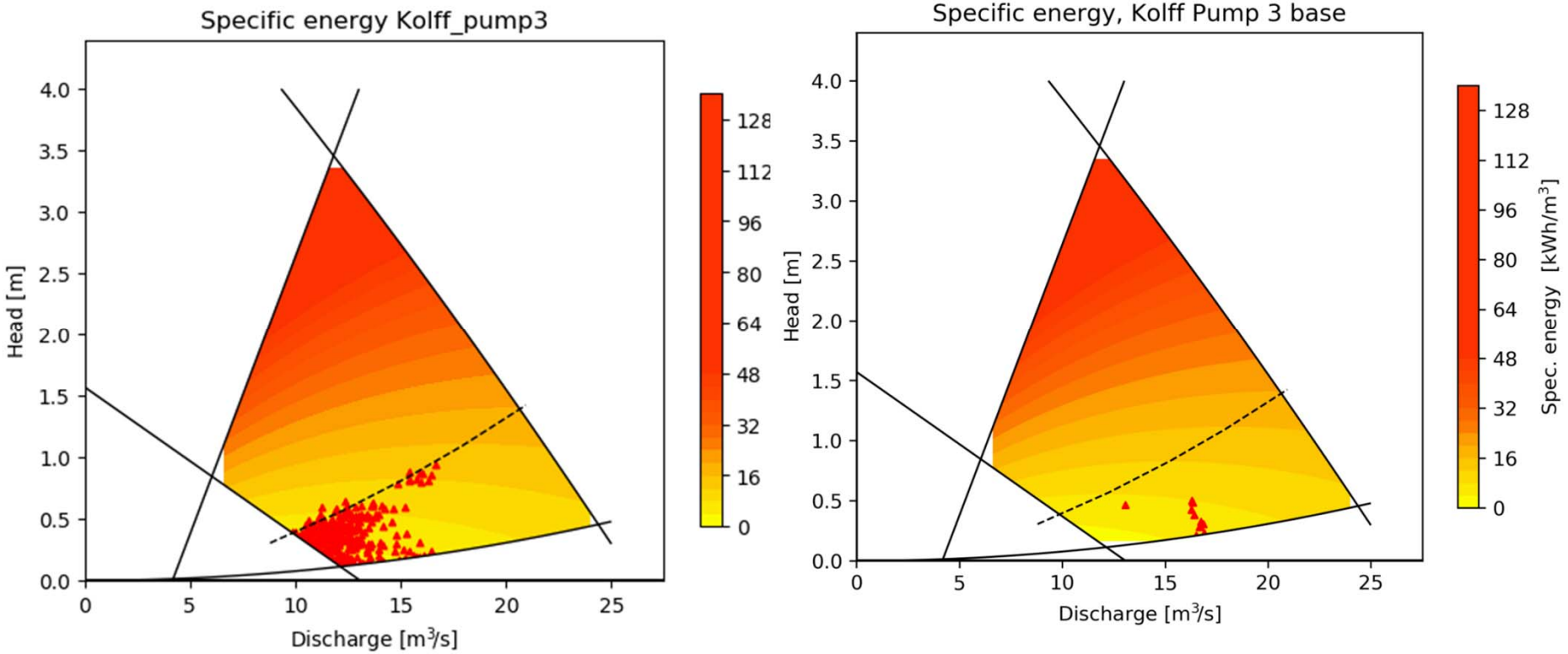
5. Pumping efficiently





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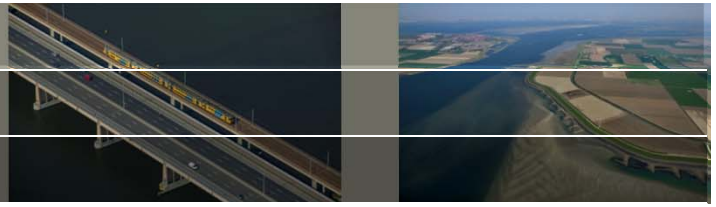
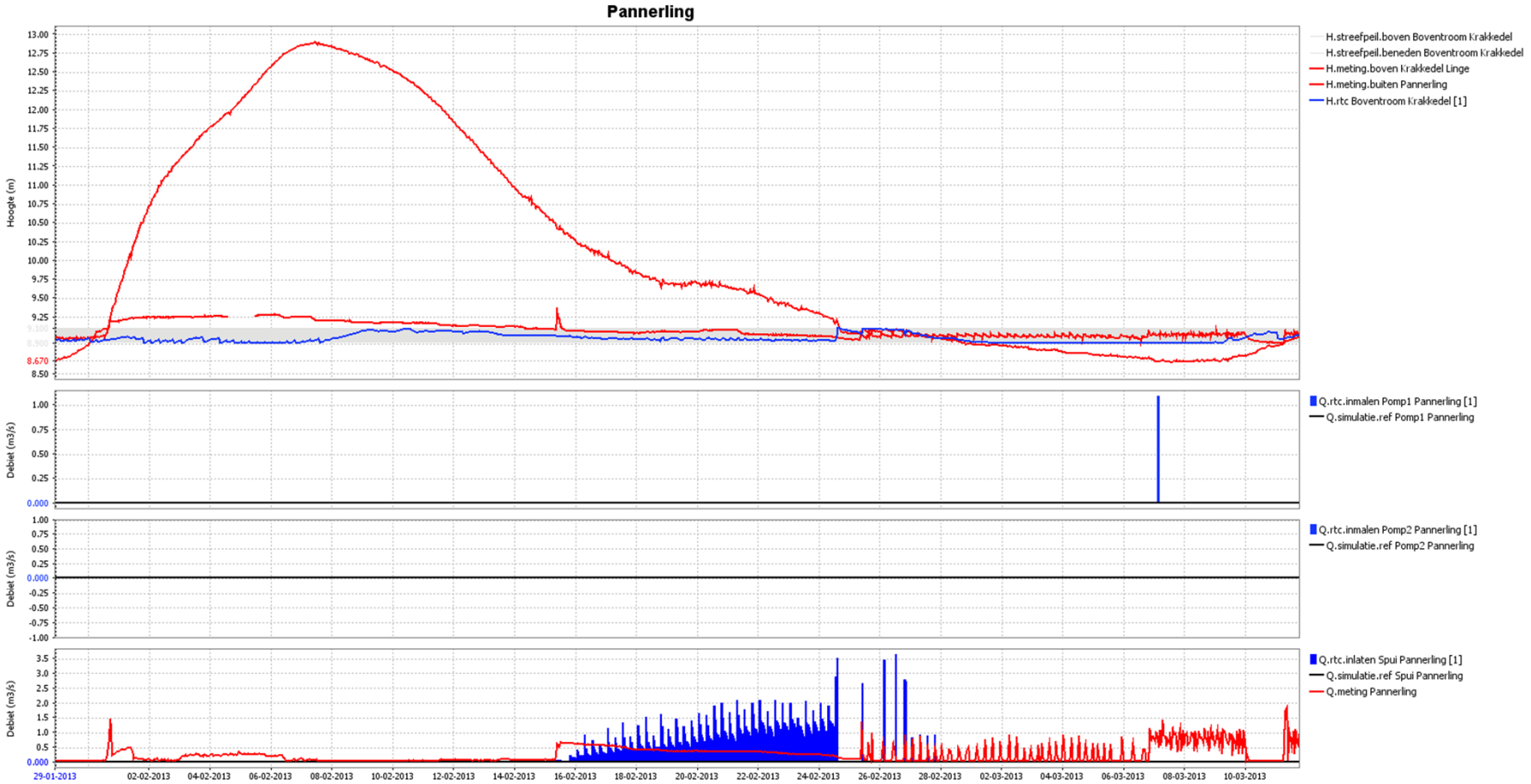
6. Buffering and anticipating





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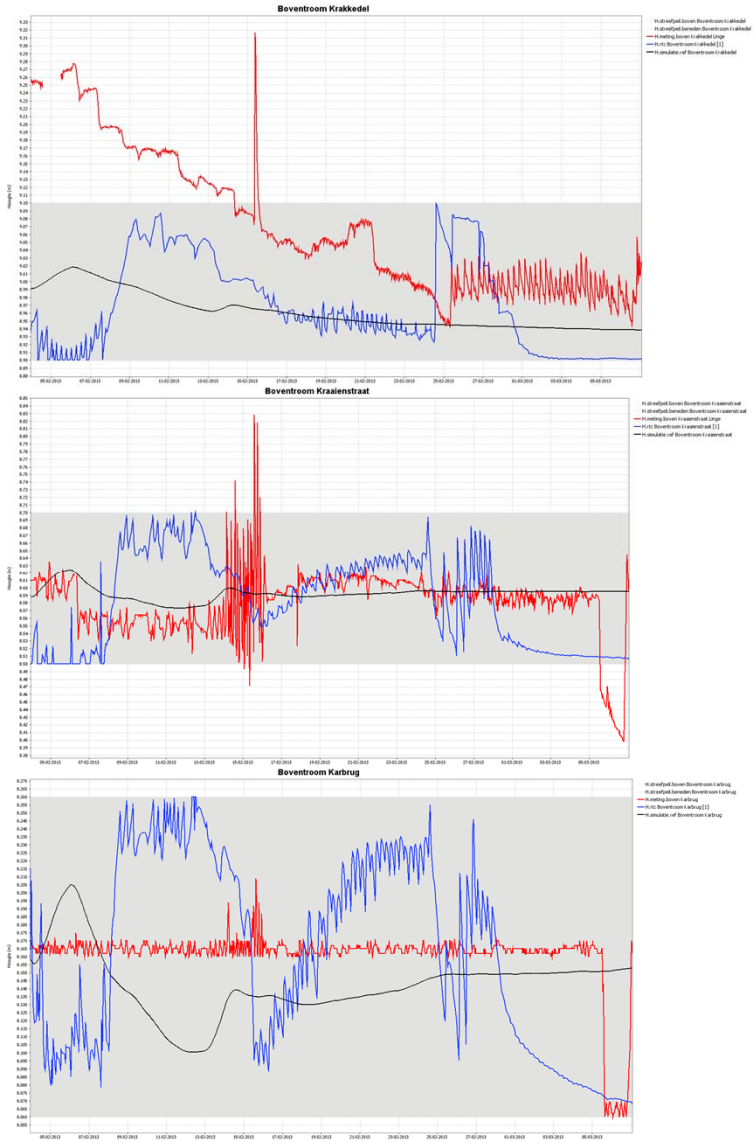
6. Buffering and anticipating

Pool 1

Pool 2

Pool 3



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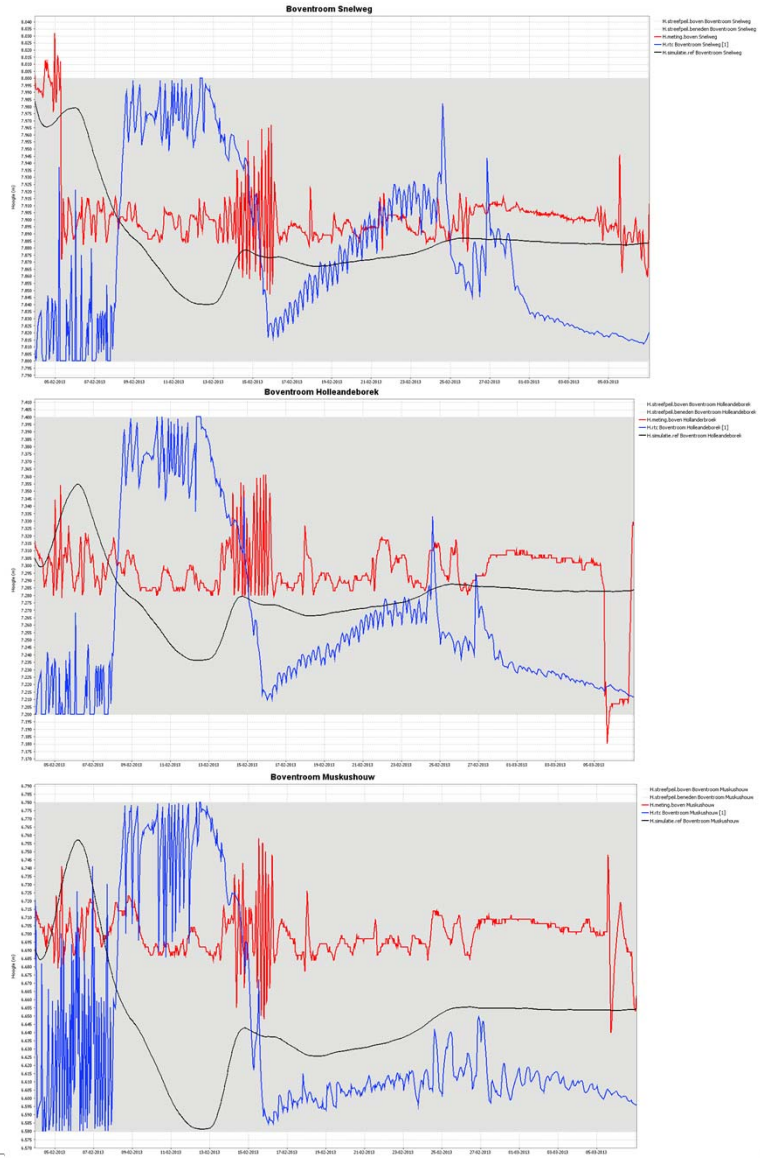
6. Buffering and anticipating

Pool 4

Pool 5

Pool 6



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