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Enabling Delta Life

Quick Scan Tool for water allocation in the Netherlands

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Overview

Fresh water issues in the Netherlands

The policy process & policy support models

The water allocation model

The Quick Scan Tool application

Using the Quick Scan Tool

Fresh water issues in the Netherlands

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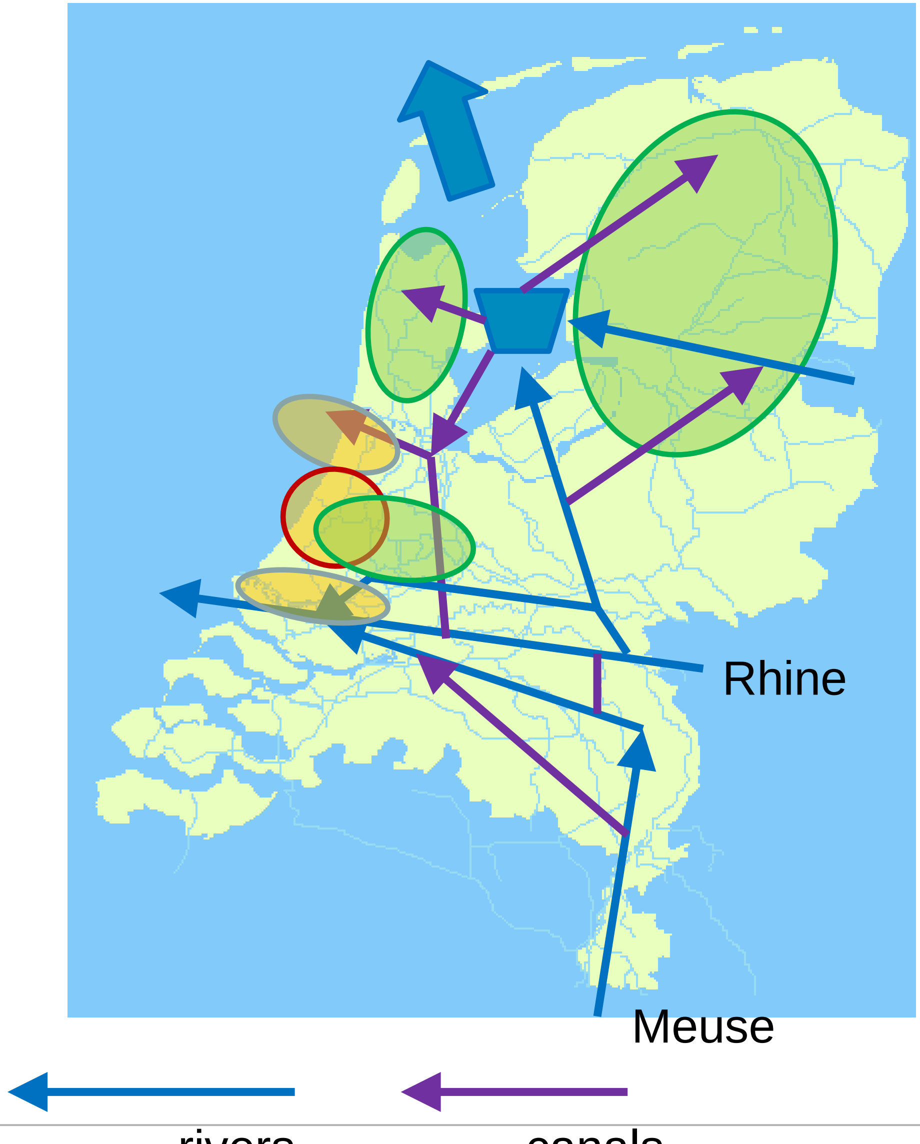
Fresh water supply issues in the Netherlands



Current management issues:

- waterlevel control
- saline intrusion and saline boils

Looking at 2050 and 2085

- warmer climate → increased evapotranspiration
- port developments → increased saline intrusion
- sea level rise → reduced drainage gradients

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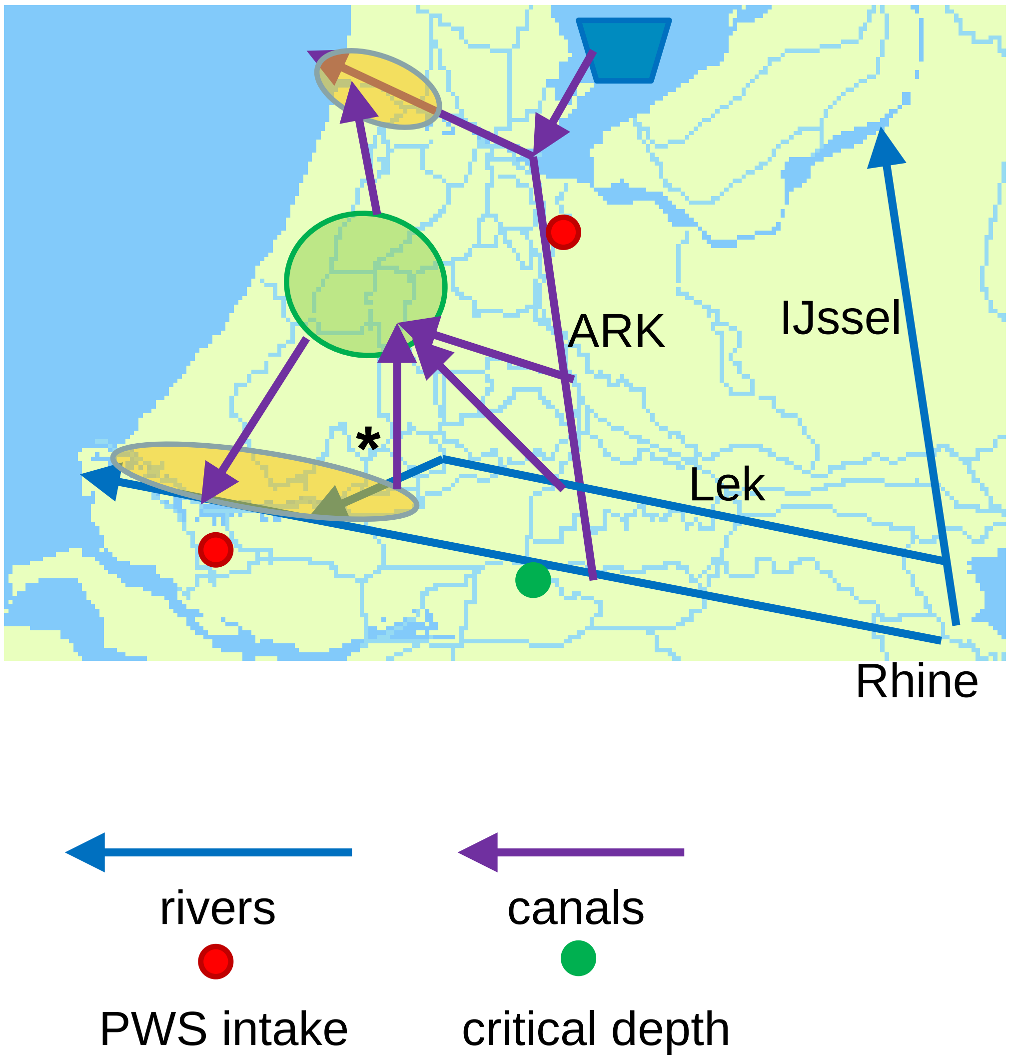
Fresh water supply hotspots



Options:

- Flexible storage level (+10cm)
- Send more water to NW

Impacts

+ less shortage during dry periods
+ combat saline intrusion in NW

- reduced navigation depth Rhine
- higher velocities on ARK shipping canal
- more saline intrusion in SW delta

The Policy Process

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Policy process: Delta Program Fresh Water

Phase 1 ended 2014 with parliament decision

- national focus, possibly large interventions

Phase 2 underway (parliament decision 2021)

- regional focus on hotspots
- process organized by national government with stakeholders including water boards, agricultural sector, drinking water companies, nature & landscape managers
- regions identify interventions (savings, costs, regional impacts)
- national government manages nationwide consequences
- supporting analysis conducted by institutes and consultants
  - reference year: 2015
  - assessment years (2050, 2085)
  - 4 climate/socio-economic change scenario's (WARM, INTENSE)

Policy support models

PAWN: First national model instrument (1980’s);

- surface water allocation, sector models for agriculture, shipping, drinking water, nature

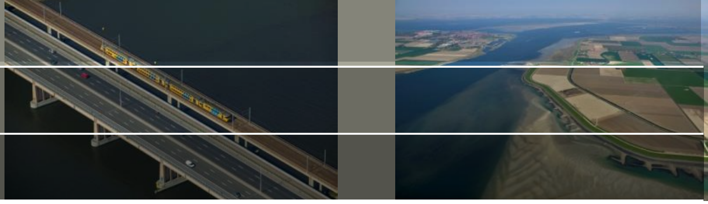
Nowadays:

- National Hydrological Model (coupled surface-groundwater)
- National Hydraulic Model (incl. saline intrusion, temperature)
- National Water Quality model (Water Framework Directive)

Characteristic:

- highly detailed (processes & spatial resolution)
- computation intensive
- useful for detailed evaluation of expected final policy decisions
- not suitable for screening and support of stakeholder processes

Need for a Quick Scan Tool



- For operational support of the National Committee on Water Allocation in periods of drought
  - to be used by Committee members
- For support of the policy process
  - to be used by research institutes and consultants

Purpose:

- Allow screen of intervention options:
  - storage control levels
  - water demand (extractions and flushing)
  - adjustment of capacities (policy only)
- Show regional tradeoffs (water demand, allocation, shortages) preferably extended to sector impacts (agriculture, shipping)

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Quick Scan Tool Requirements

- Accommodate <u>priority based water allocation</u> to support the legally established displacement rules on water requests for extraction, flushing and water level control
- Develop a <u>network model as simple as possible</u> that captures the relevant infrastructure for decisions <u>on the national scale</u>:
  - major intakes and storages
- Use data from the National Hydrological Model
- <u>Show regional tradeoffs</u> (water demand, allocation, shortages) preferably extended to sector impacts (agriculture, shipping)
- Allow easy manipulation of interventions via the GUI
- Provide visual outputs on maps and in graph and table

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The Water Allocation Model

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Choice of modelling concept

Choice amongst different model codes with different concepts:

- Heuristic decision rule approach
- Mathematical programming approach (multi-objective optimization)

Choice made: Mathematical programming

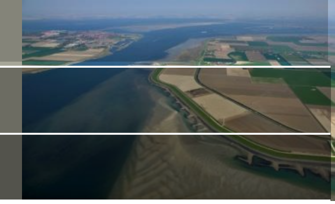
- using Lexicographic Goal Programming
- → transform the multi-objective problem to a sequence of scalar optimization problems
- → solve each problem while retaining the result from the previous priority

Lexicographic Programming approach

The idea of the algorithm is:

1. Minimize f_1 to yield a minimum objective value of ε_1.
2. Minimize f_2 to yield ε_2 subject to the additional constraints
   - $f_1(x) = \varepsilon_1$
3. Minimize f_3 subject to the additional constraints
   - $f_1(x) = \varepsilon_1$
   - $f_2(x) = \varepsilon_2$
4. …

Formulation of goals

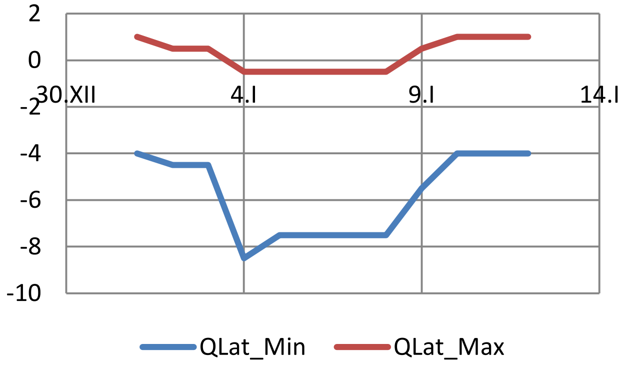



E.g. in our case the ordered list of goals

1. Stay within capacity ranges $H_{min} \leq H \leq H_{max}$
   $Q_{min} \leq Q_{instream} \leq Q_{max}$
2. preserve minimal target levels: $H \geq H_{target\ min}$
3. provide drinking water: $Q_{extract} \geq Q_{req.pws}$
4. preserve medium levels: $H \geq H_{medium}$
5. provide regional demands $Q_{extract} \geq Q_{req.pws} + Q_{req.region}$
6. preserve medium high levels: $H \geq H_{mediumhigh}$
7. provide water for flushing: $Q_{instream} \geq Q_{req.flushing}$
8. preserve target lake levels $H \leq H_{target\ max}$
9. minimize flows on inlets and outlets

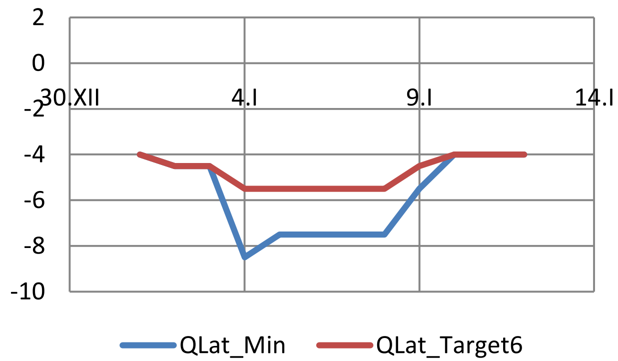
Formulation of goals

Lateral (priority 1)

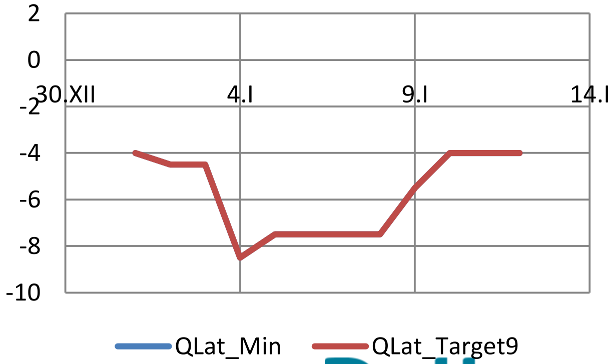


Squeezing the solution space of Lateral fluxes (extractions)

Lateral (priority 6)



Lateral (priority 9)



QLat_Max	= Natural Contribution
QLat_Target6	= QLat_Max + Utilities Request
QLat_Target9	= QLat_Target6 + Rural Request
QLat_Min	= QLat_Target9

Note: extractions are negative

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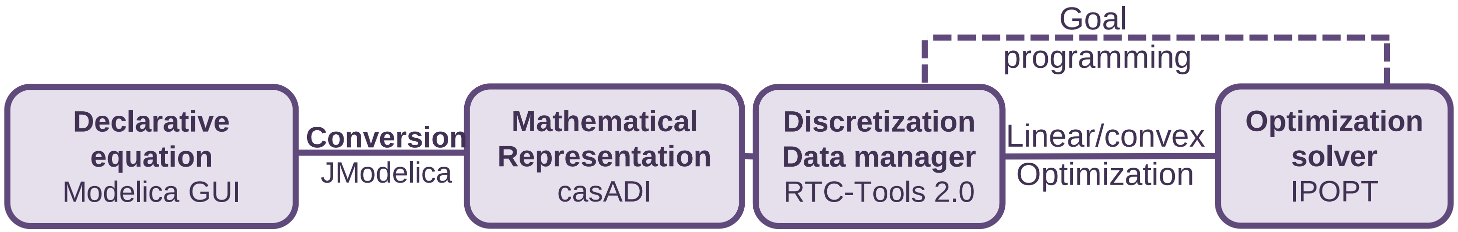
The model engine: RTC-Tools 2

RTC-Tools 2.0 is a open source toolbox for control and optimization of environmental systems.

- Mathematical framework designed for stable operation in environments that require consistent results
  - Convex optimization under uncertainty
  - Multi-objective optimization
    - > weighted programming
    - > lexicographic goal programming
- Interdisciplinary, object-oriented model formulation using Modelica
- Flexibility in control formulation using python scripting
- Integration capability with among others Delft-FEWS

RTC-Tools 2 software components

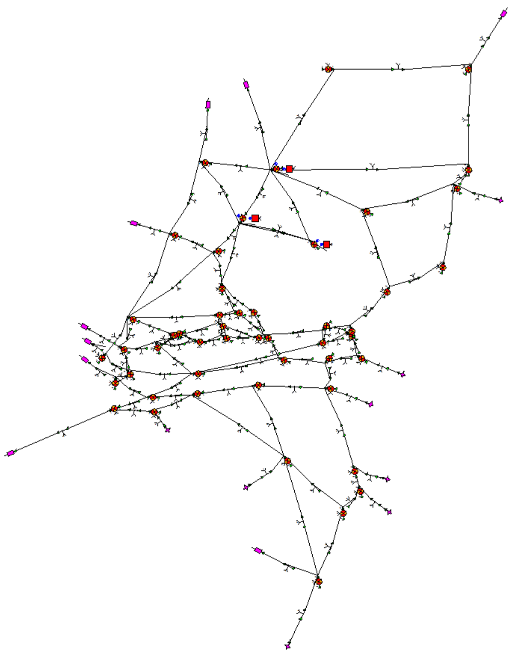


*der (A*H)=Q*

$$\frac{d(A*H)}{dt} = Q$$

$$\frac{(AH)_{a+t} - (AH)_a}{t} = Q_{a+t} - Q_a$$

Model schematization



RTC-Tools manages:
- conversion with CasADi
- discretization
- data handling
- calling solver

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Quick Scan Tool/RTC-Tools python snippets

Each goal and input data are connected to a variable
Each variable represents a state of a network element

Processing an input file

```
elif "QLat" in max_value_id:
    g.append(MaximumForcingGoal(self.get_timeseries(
        max_value_id), state_id, priority, function_range))
elif "QOut" in min_value_id:
    g.append(MinimumDischargeGoal(
        self.get_timeseries(min_value_id), state_id, priority, function_range))
elif "QOut" in max_value_id:
    g.append(MaximumDischargeGoal(
        self.get_timeseries(max_value_id), state_id, priority, function_range))
elif "HMin" in min_value_id and "HMax" in max_value_id:
    g.append(LevelRangeGoal(self.get_timeseries(min_value_id),
                            self.get_timeseries(max_value_id), state_id, priority, function_range))
elif "QOut.Q" in state_id:
    g.append(MinimizeDischargeGoal(state_id, priority, (0,1),1))
```

Assigning goals to RTC-Tools

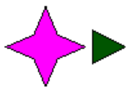
```
class MaximumForcingGoal(Goal):

    def __init__(self, QForc_max, QForc_state, priority, function_range, function_nominal=1):
        self.target_max = QForc_max
        self.state = QForc_state
        self.priority = priority
        self.function_range = function_range
        self.function_nominal = function_nominal
    def function(self, optimization_problem, ensemble_member):
        return optimization_problem.state(self.state)

    # The penalty variable is taken to the order'th power.
    order = 1
```

Some network elements in Modelica

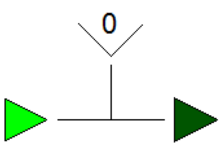
Inflow



```
within Deltares.ChannelFlow.SimpleRouting.BoundaryConditions;

block Inflow
  extends Deltares.ChannelFlow.Internal.QSO;
  // Inputs
  input Modelica.SIunits.VolumeFlowRate Q;
equation
  QOut.Q = Q;
end Inflow;
```

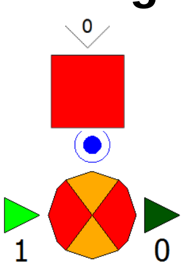
Branch




```
within Deltares.ChannelFlow.SimpleRouting.Branches;

block Steady
  extends Deltares.ChannelFlow.Internal.QSISO;
  extends Deltares.ChannelFlow.Internal.QForcing;
  extends Deltares.ChannelFlow.Internal.QLateral;
equation
  QOut.Q = QIn.Q + sum(QForcing) + sum(QLateral.Q);
end Steady;
```

Storage




```
within Deltares.ChannelFlow.Hydraulic.Storage;

model Linear "Storage with linear level-storage relation"
  extends Internal.PartialStorage(HQ.H(min = H_b));
  // Surface area
  parameter Modelica.SIunits.Area A;
  // Bed level
  parameter Modelica.SIunits.Position H_b;
equation
  V = A * (HQ.H - H_b);
end Linear;
```

The Quick Scan Tool application

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Development process

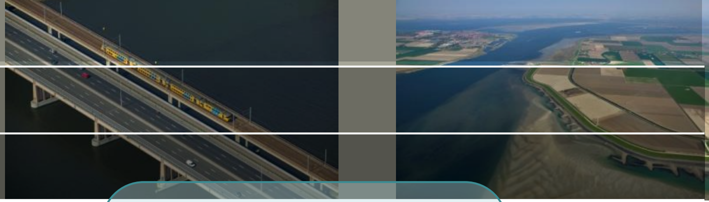
- Joint requirements analysis with members National Committee on Water Allocation
- Joint model schematization design sessions with key expert of the Committee
- Joint design to implement intervention options in the model
- Validation by experts of institutes

First prototype;

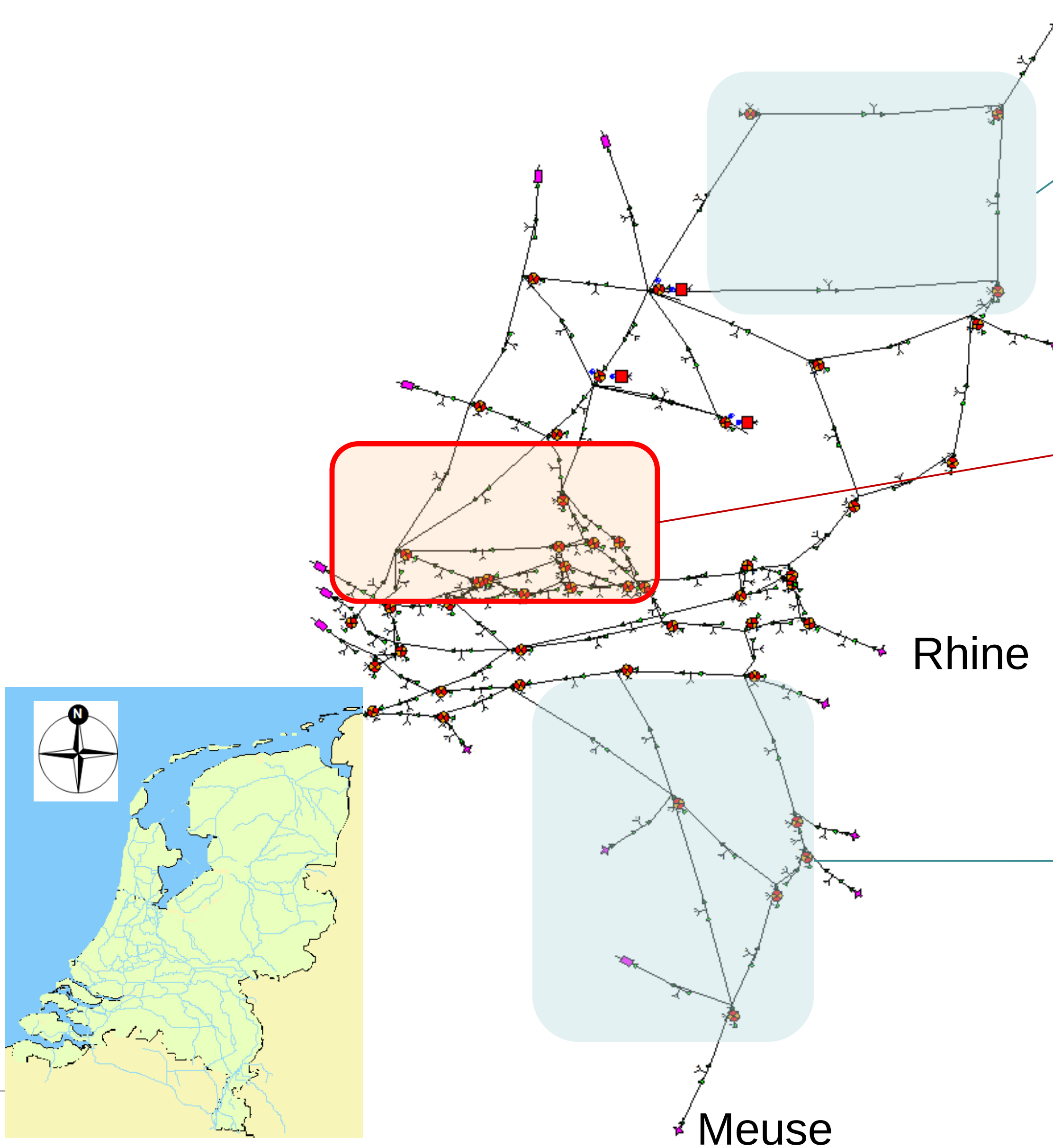
- Excel: dashboard, data handling, pre/postprocessing
- RTC-Tools: water allocation model

Final application:

- Delft-FEWS: GUI, data handling, pre/postprocessing
- RTC-Tools: water allocation model



The network schematization



large simplification of main water system

minimal simplification of main water system

large simplification of main water system

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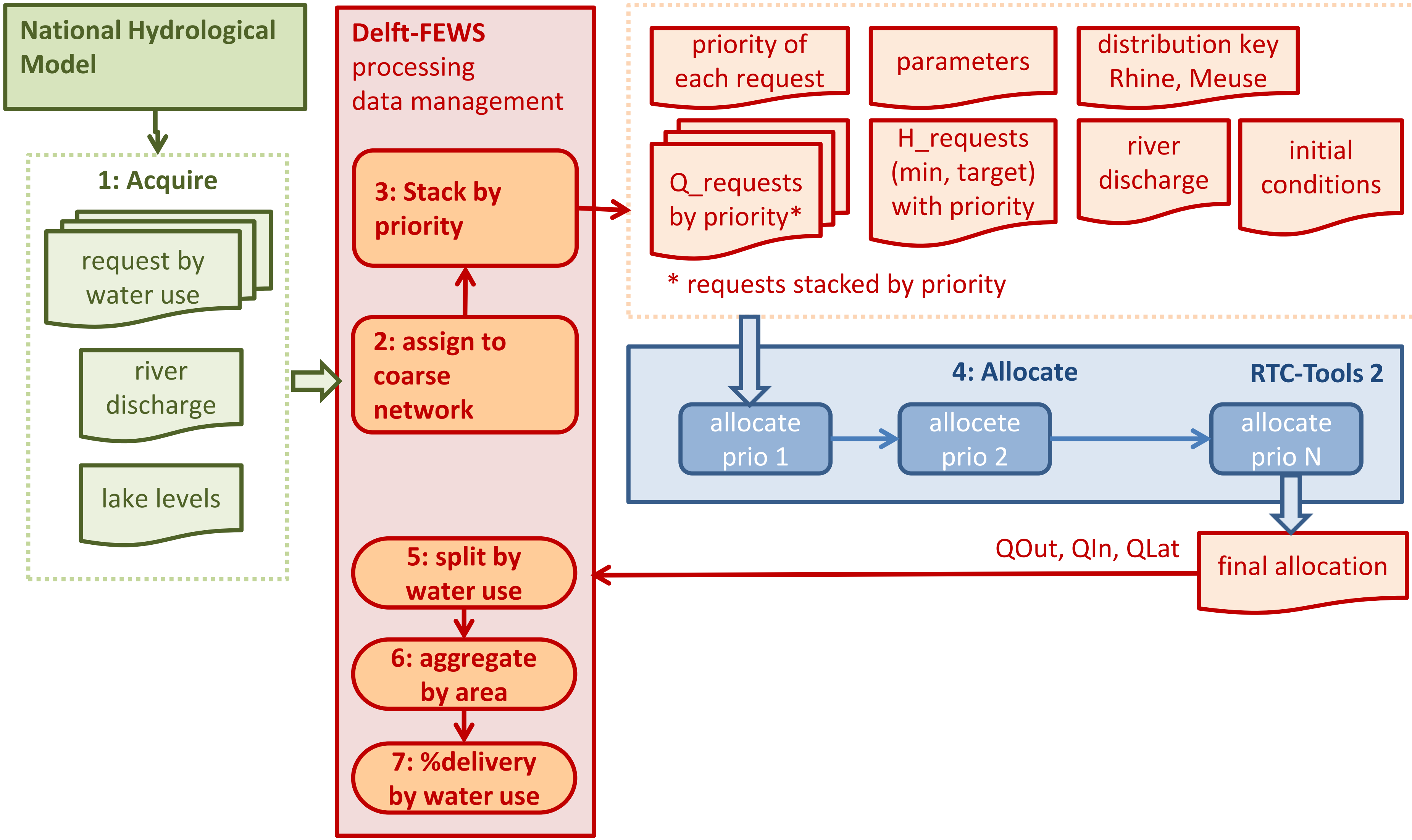
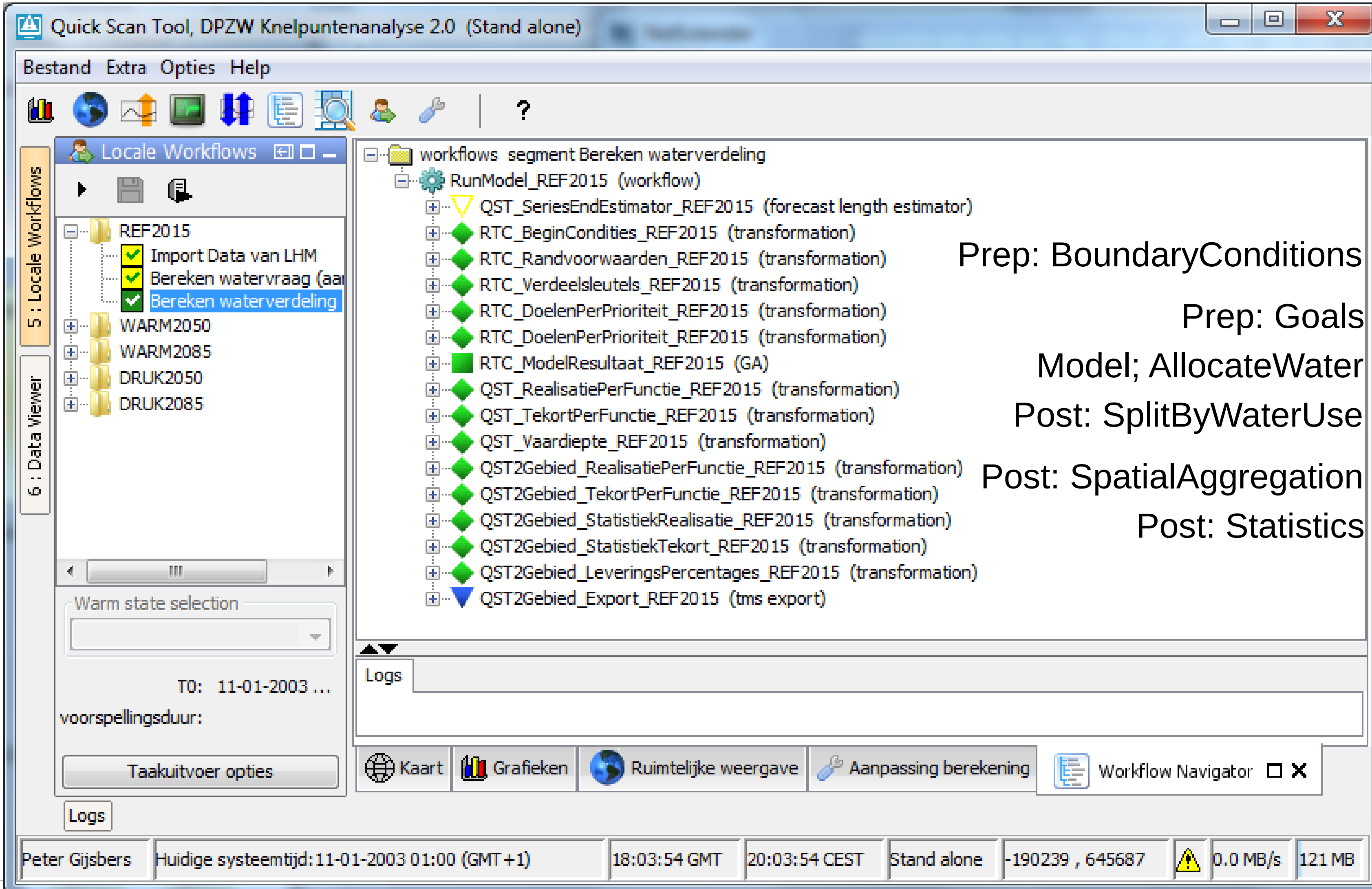
Quick Scan Tool data and workflow

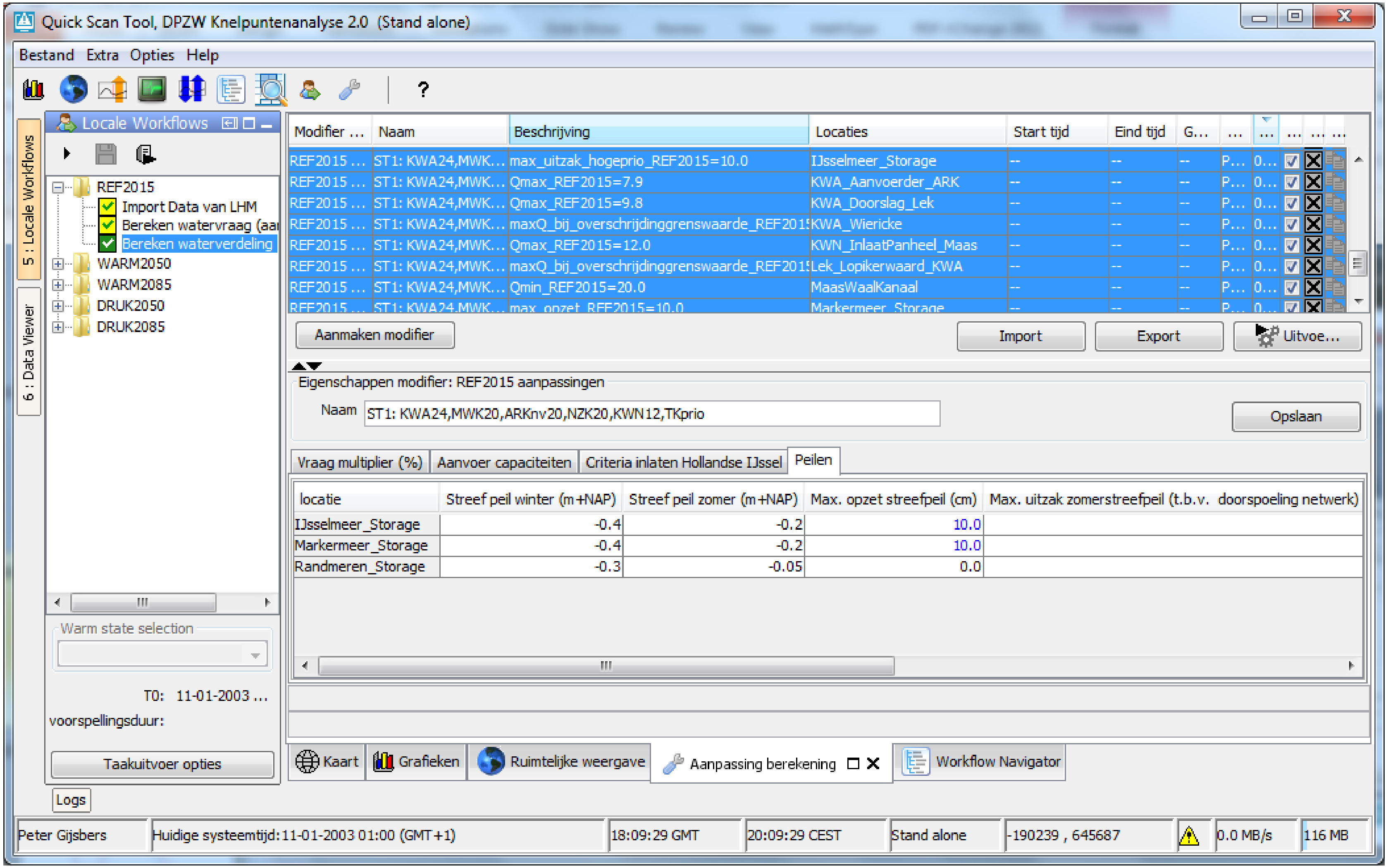


Legend: software application | file | process | end-result

Quick Scan Tool workflow navigator



Quick Scan Tool intervention options



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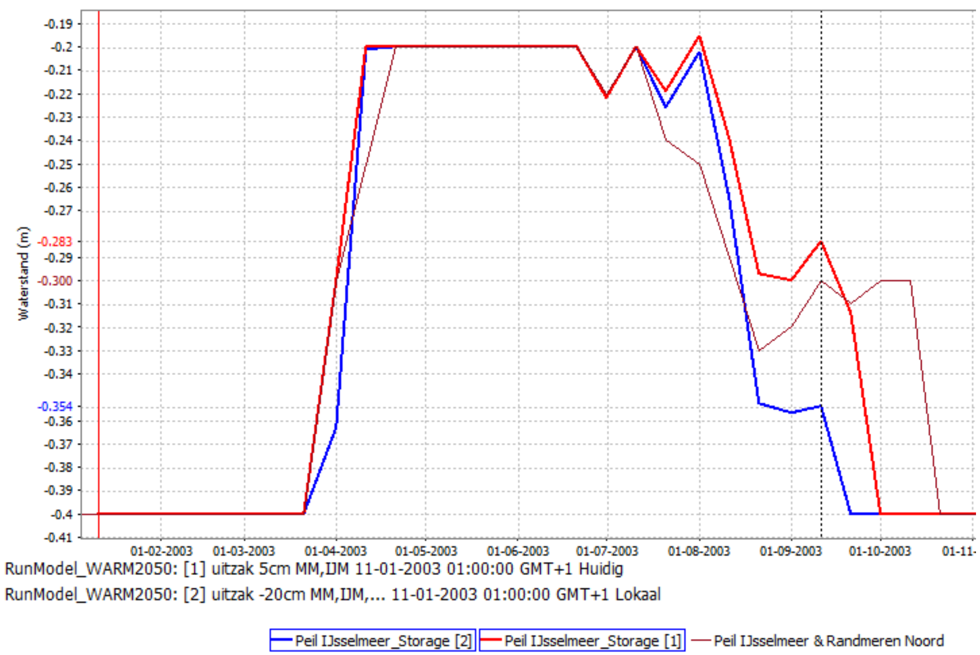
Using the Quick Scan Tool

Validation results vs. Nat. Hydrological Model

Purpose:

- prevent surprise outcomes when an intervention is chosen for evaluation in National Hydrological Model (NHM)
- → observation of similar behavior/system responses between NHM and Quick Scan Tool



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Validation results vs. Nat. Hydrological Model

Reference year 2015 **(**hydrological series: 1980-2006)
snapshot at August 8, 2003
Variable: Realization of water extraction for rural areas

NHM run

QST run

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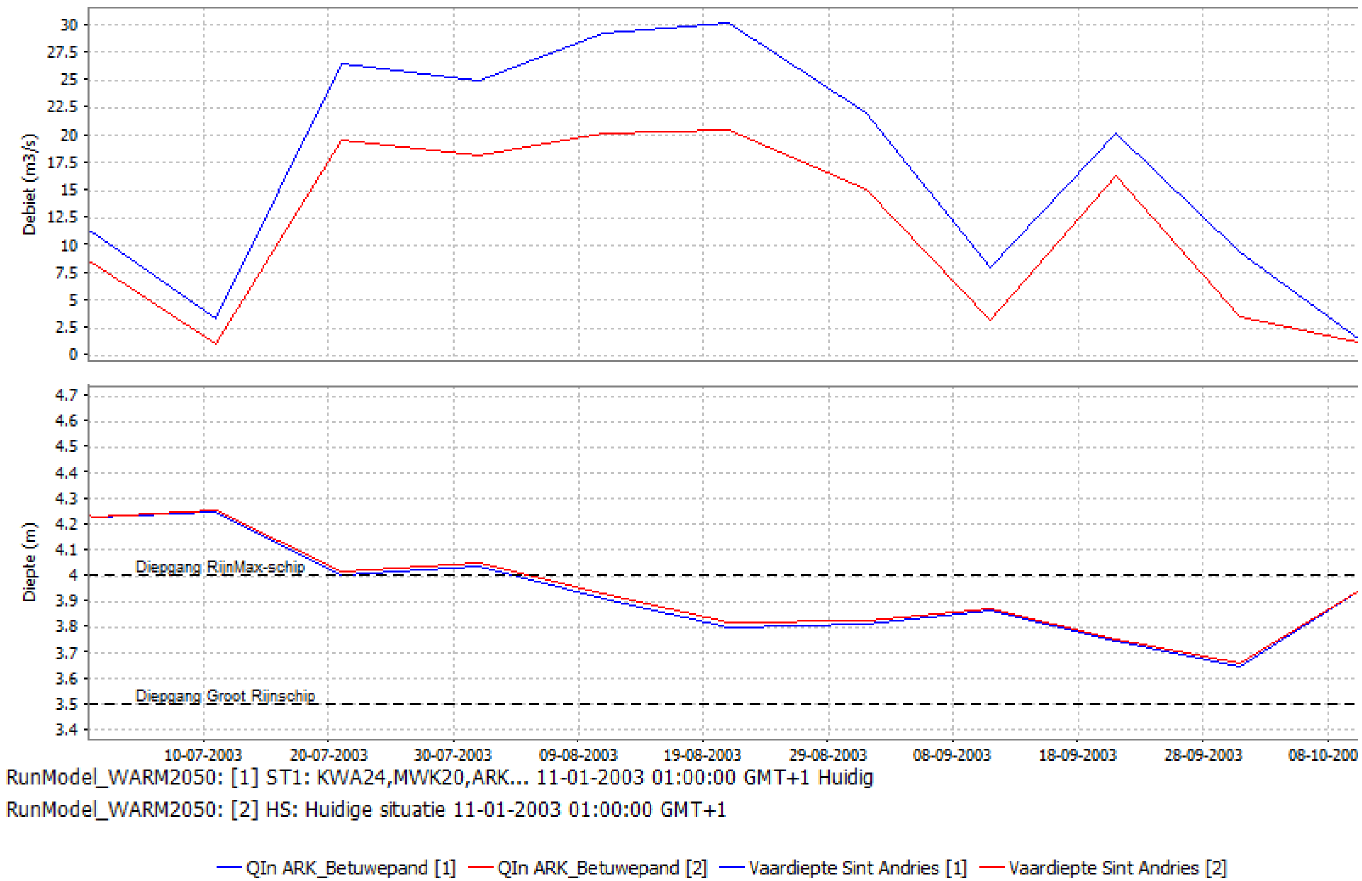
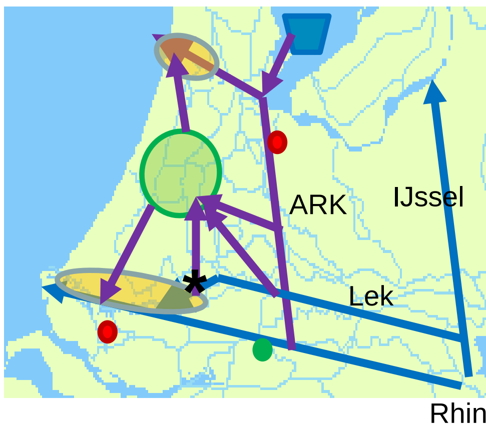
Prel. analysis: Stress test WARM2050 scenario

(top) More water going North for flushing purposes and water supply
(bottom) Hardly any impact on navigation depth at most critical river location





current situation

WARM scenario in 2050

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Conclusions

Conclusions


- The validation study shows that the Quick Scan Tool can:
  - support priority based water allocation
  - provides useful answers to assist the policy process with regional trade-offs while screening of intervention options

- The software frameworks made development more a configuration and composition task than a programming task, requiring relative limited development time was limited
  - RTC-Tools software framework provides an easy entry point for development of mathematical programming based water allocation model without much programming/scripting
  - Delft-FEWS provides an useful framework for decision support system development providing good insight in data streams of the application