Multi-purpose management of the Walloon waterways, from local to global control of the structures

Wallonie mobilité infrastructures SPW

IMDC TRACTEBEL ENGIE

Sumaqua

7th International Meuse Symposium
Nathan Bertouille-Philippe Dierickx
Ludovic Gouverneur
Tim Franken
21 September 2021

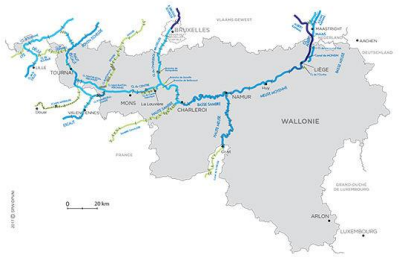
Agenda

1. Introduction, context and goals (Nathan Bertouille-SPW)
2. Optimisation interface presentation (Ludovic Gouverneur-IMDC)
3. Optimisation module presentation (Tim Franken-Sumaqua)

Why a global control of the structures?

Harmonized waterways management

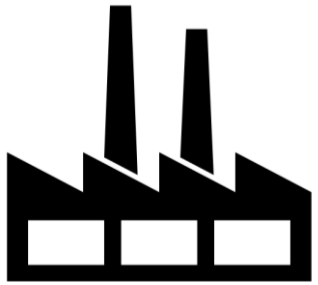
Climate change



Network complexity

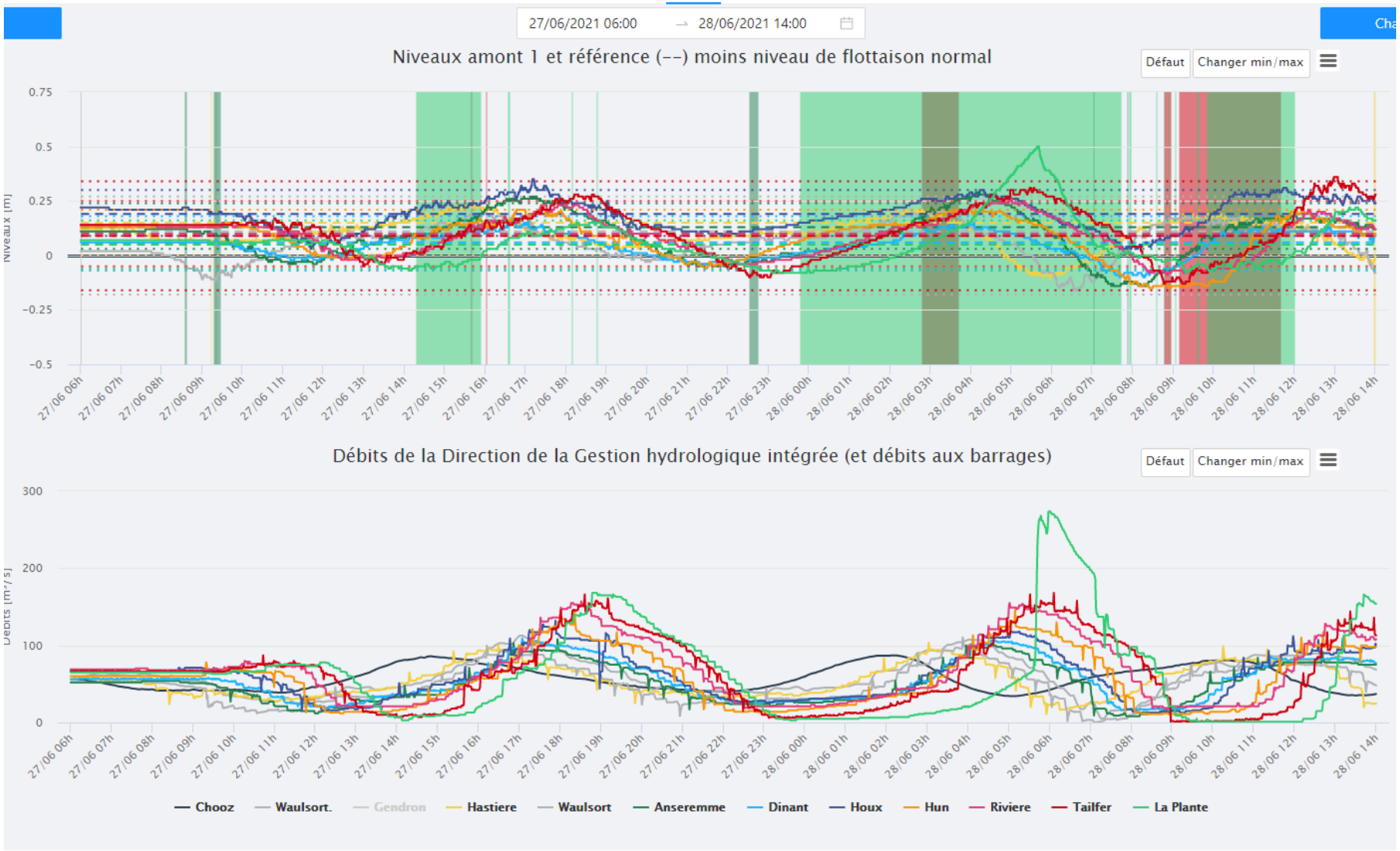
Europe connections

Traffic growth



Industries attractiveness

Why a global control of the structures?



Why a global control of the structures?

Optimisation water management real-time tool

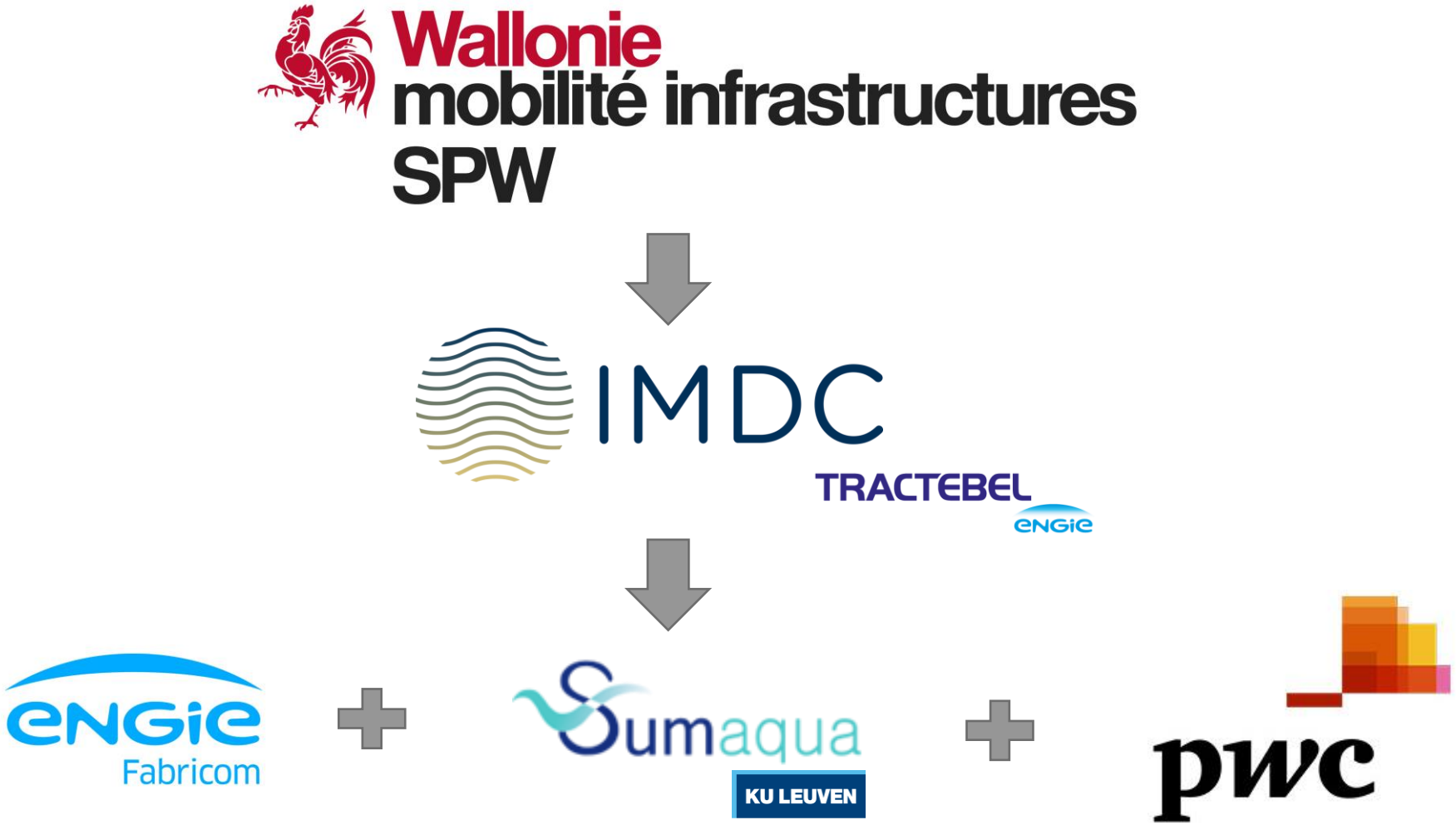
<u>Goal</u>

to guide the permanent worker in choosing the optimal action to be carried out on waterways hydraulic structures

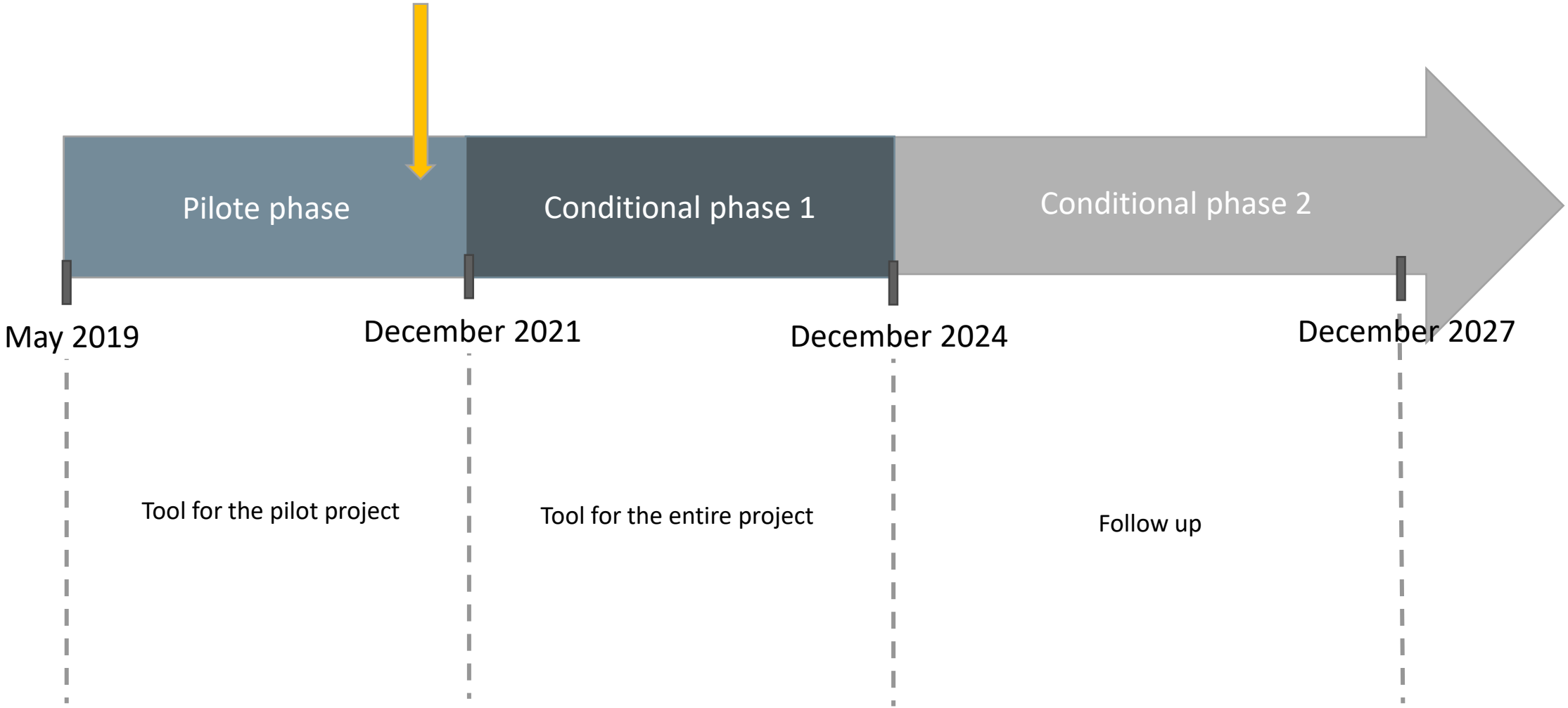
Multi-purpose tool:

- Reach and structure security
- Water level for navigation
- Pumps and turbines optimisation
- Ecological minimum flow
- …

PEREX project



PEREX project



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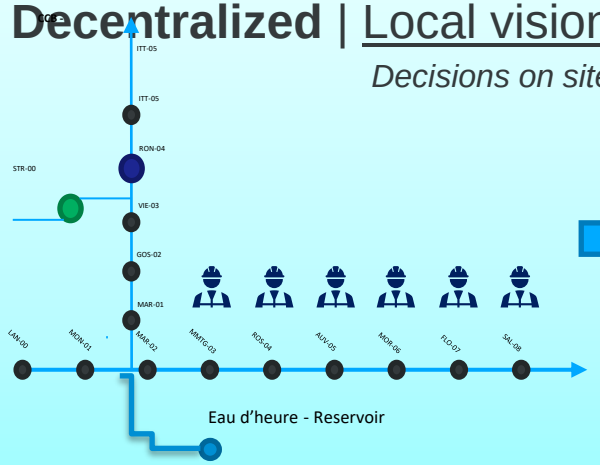
Perex project : overview

now

Decentralized | Local vision

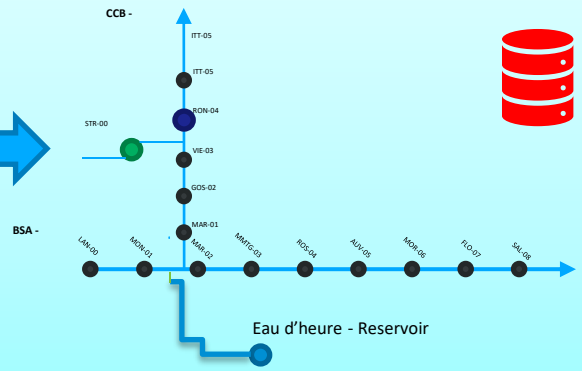
Decisions on site

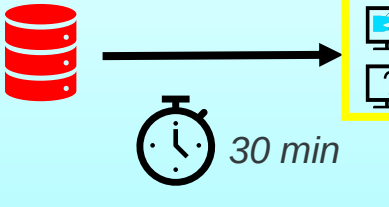


future

Centralized | Global vision |

Decision from the Perex Center, closed loop



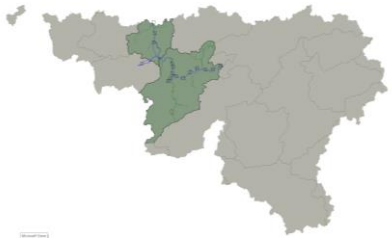


Control strategy

dams,
pumps,
turbines,
reservoirs

Pilot : 1 river + 1 channel

Wallonia : +- 450 km waterways



Detailed model

- HEC-RAS
- Calibration
- Validation

Conceptual model

Optimisation

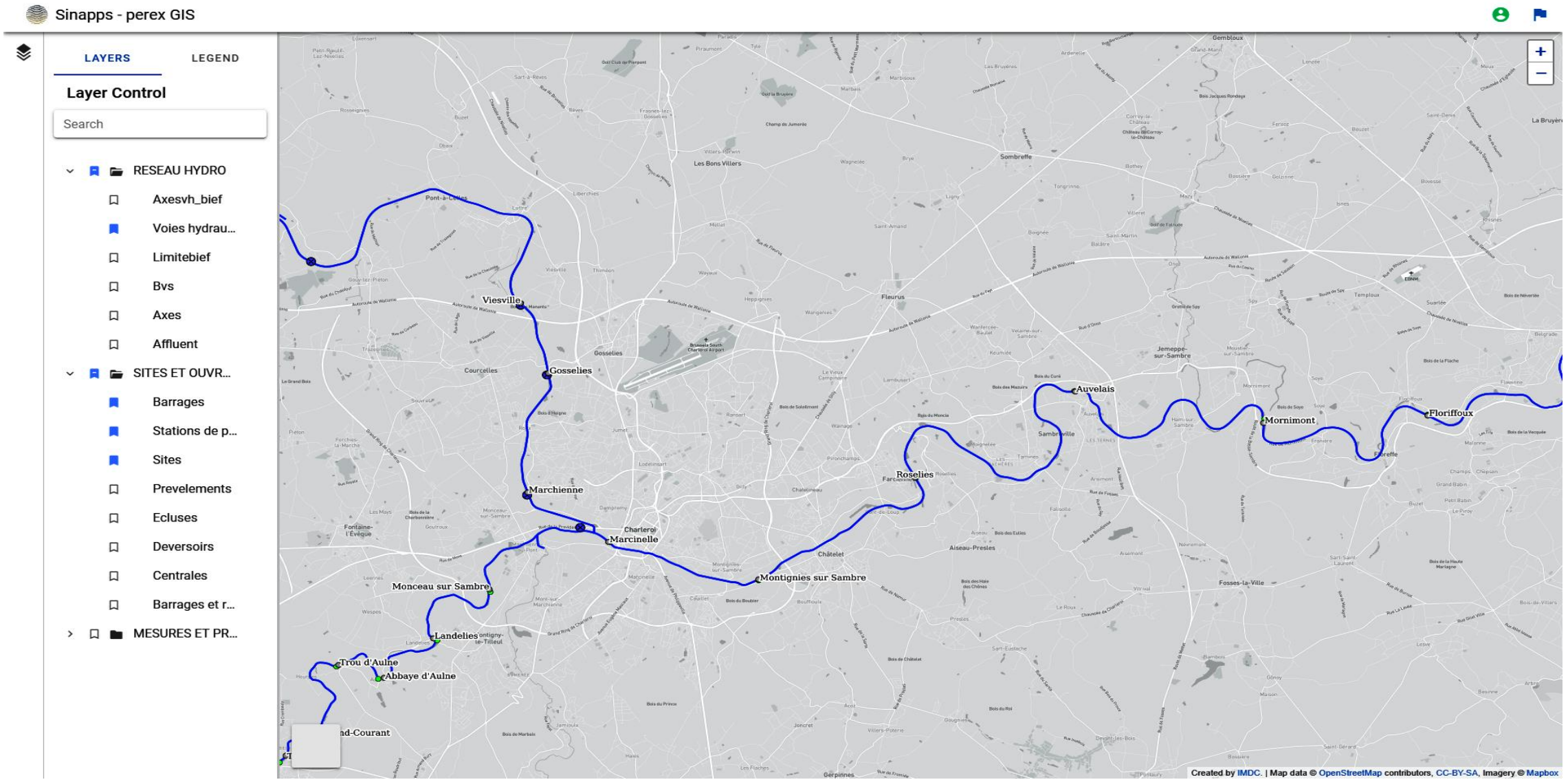
- Security
- Navigability
- Energy
- …

Interface

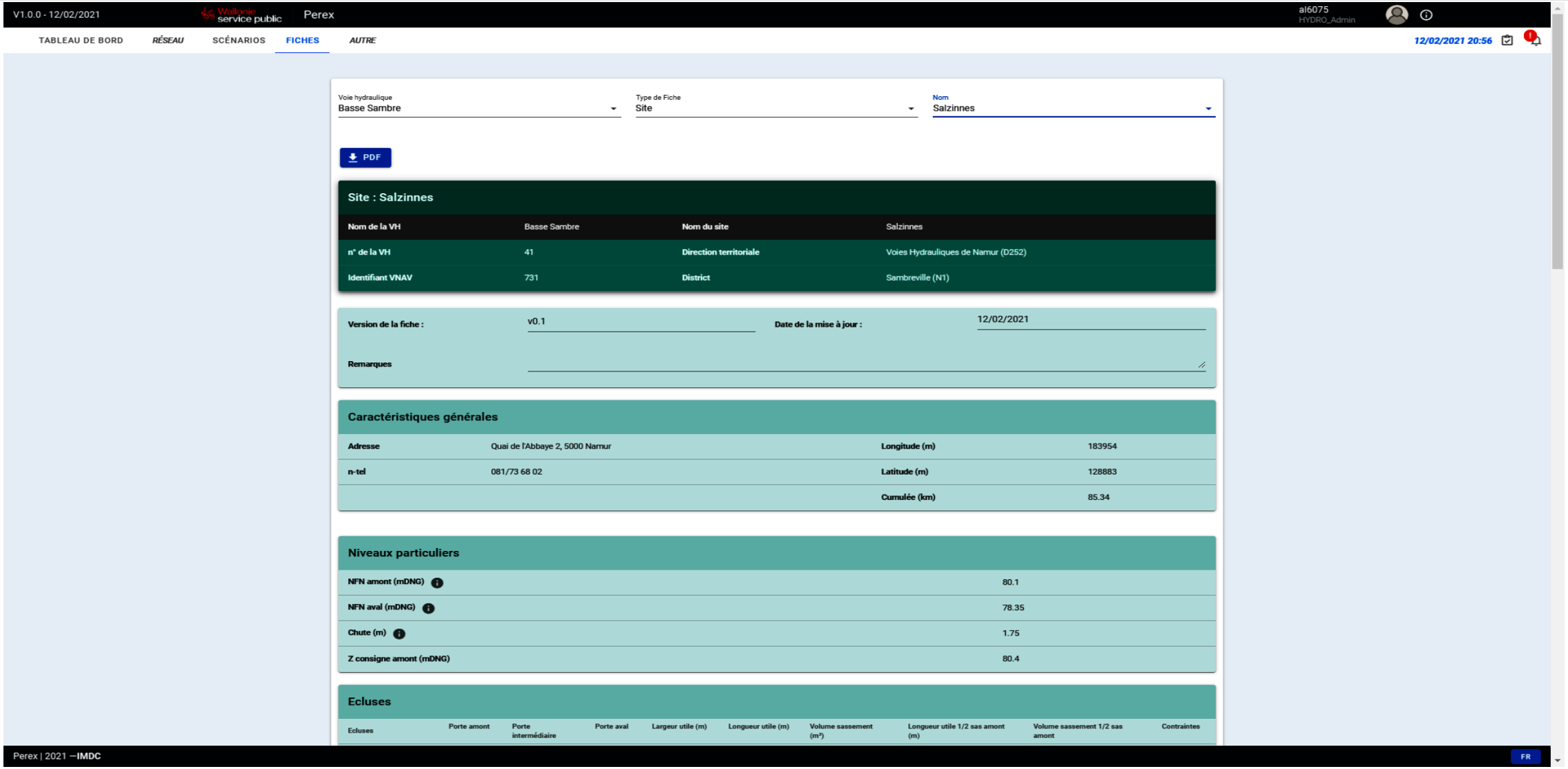
- Metadata search
- Monitoring
- Analysis and control

Web application

Web Application Features : metadata | GIS



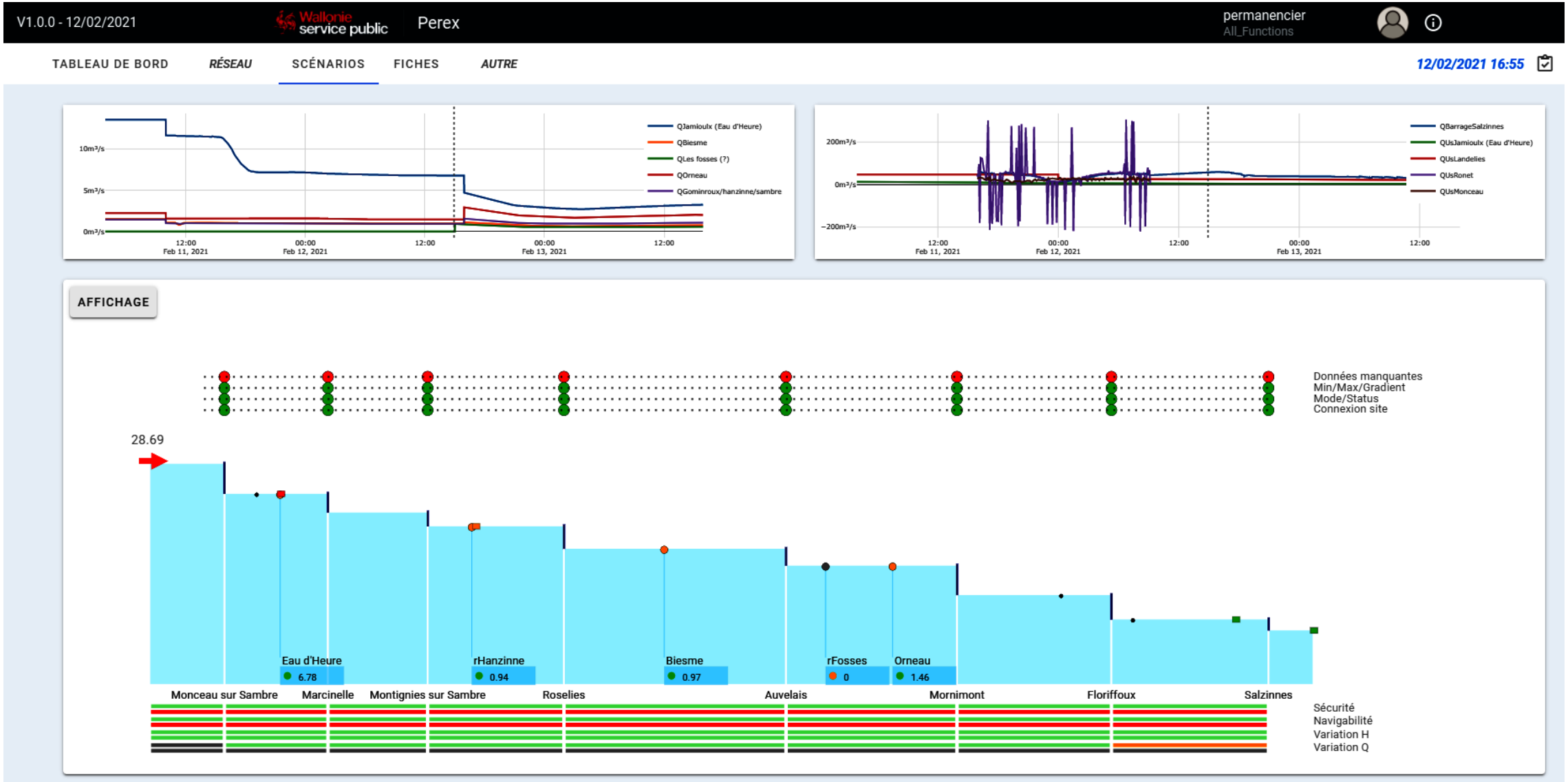
Web Application Features : metadata | FICHES per site



Metadata associated with each site :

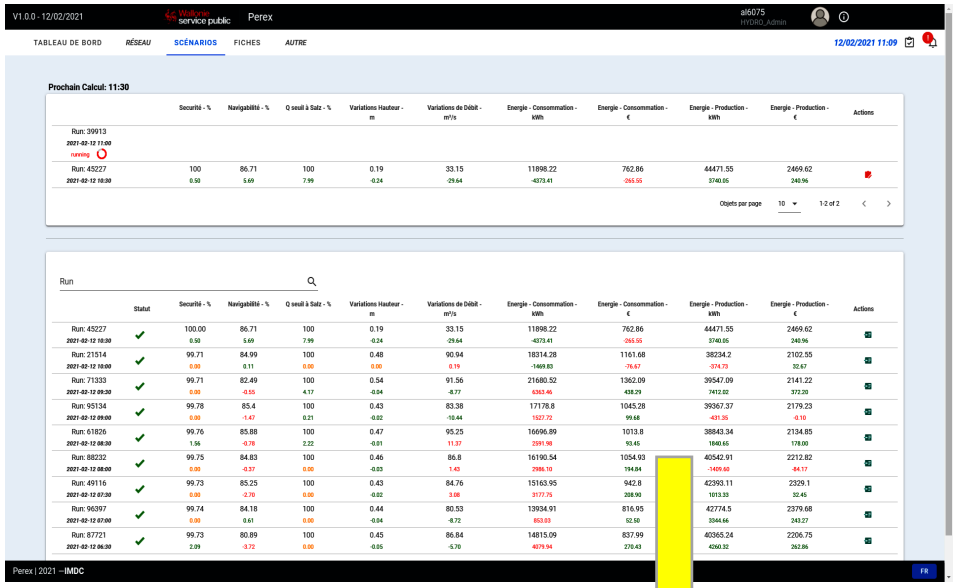
- Equipements (Turbine power, dimension of the dams) and instrumentation (WL, Q) characteristics

Web Application Features : monitoring | PROFIL VIEW per

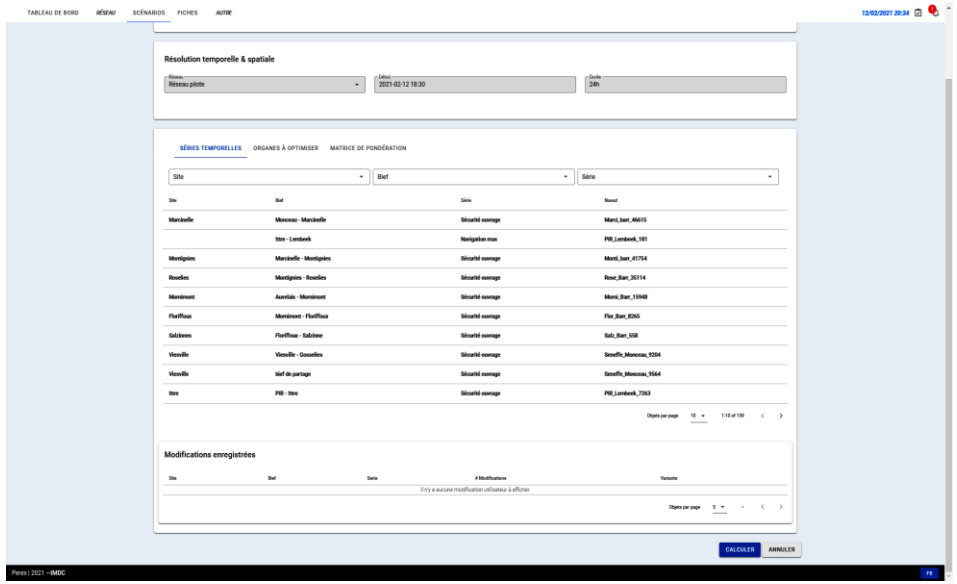


Real-time snapshot of a river/channel : discharges, alarms, indicators

Web Application Features : Analysis and Control



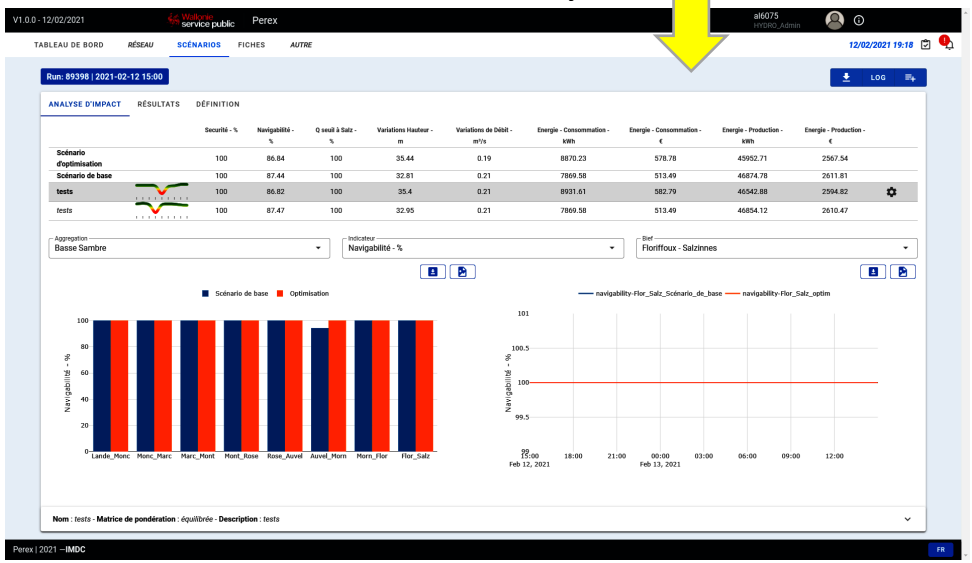
Change operationnal run



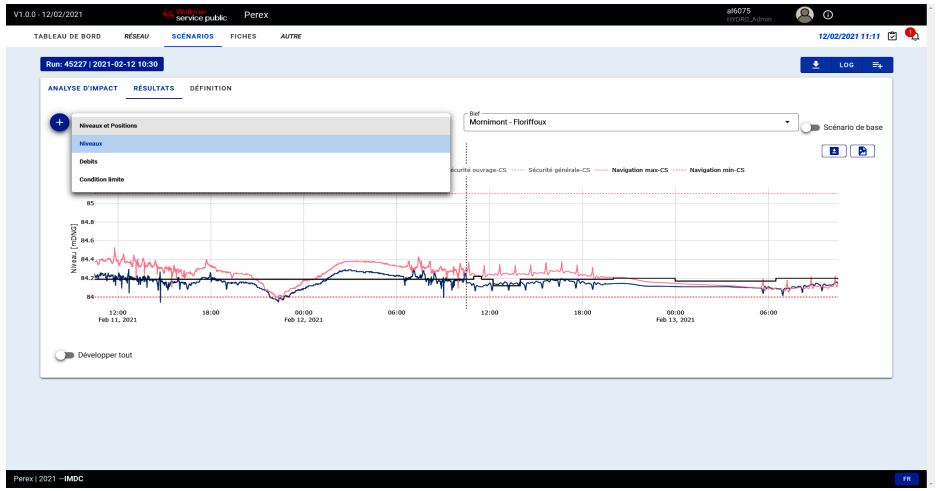
Produce "Variante"

Detailed analysis

Indicators, definition of the run



Time serie visualisation Input/output



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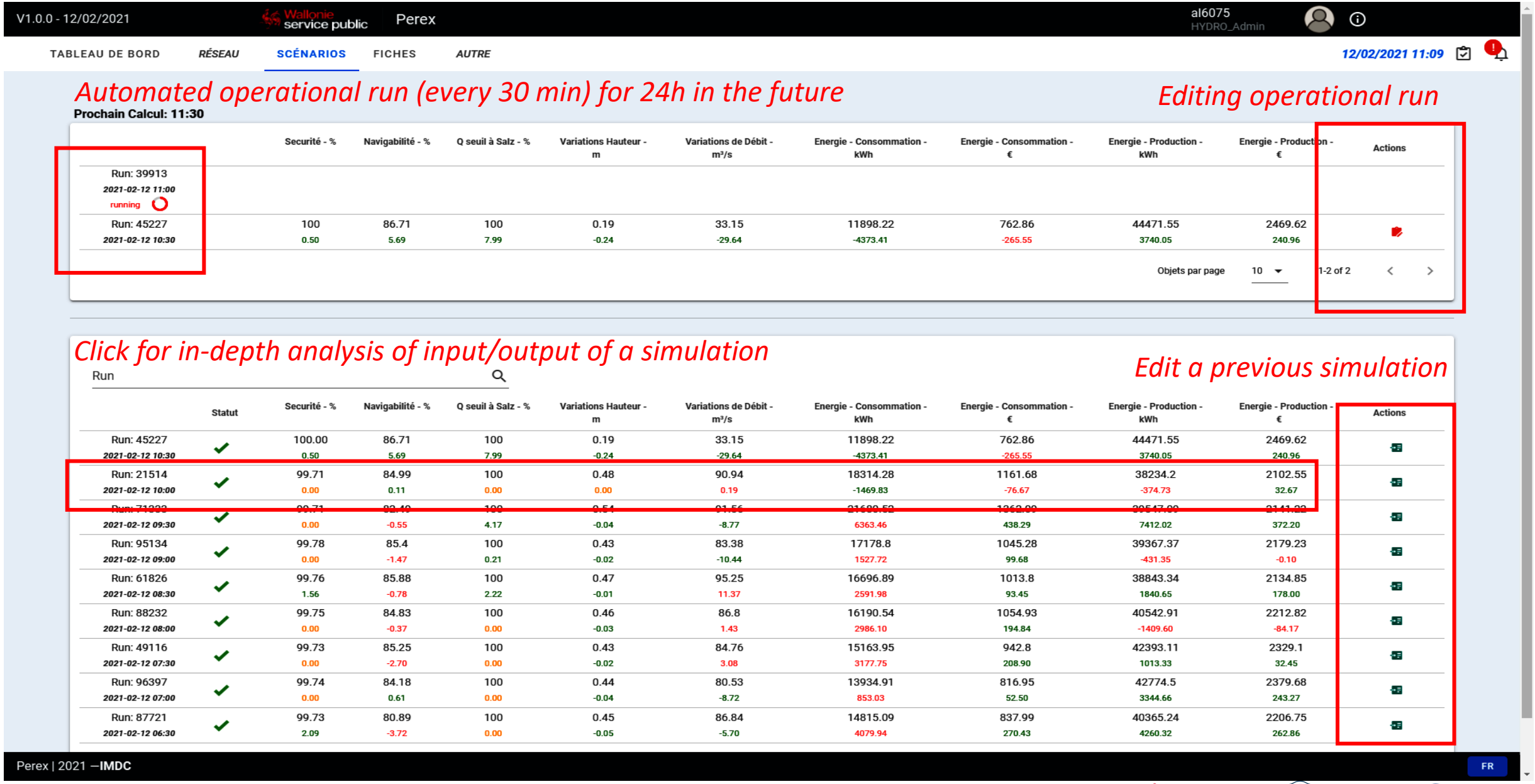
Web Application Features : Optimisation dashboard



	Statut	Securité - %	Navigabilité - %	Q seuil à Salz - %	Variations Hauteur - m	Variations de Débit - m³/s	Energie - Consommation - kWh	Energie - Consommation - €	Energie - Production - kWh	Energie - Production - €	Actions
Run: 39913 2021-02-12 11:00 running											
Run: 45227 2021-02-12 10:30	✔	100 0.50	86.71 5.69	100 7.99	0.19 -0.24	33.15 -29.64	11898.22 -4373.41	762.86 -265.55	44471.55 3740.05	2469.62 240.96	
Run: 21514 2021-02-12 10:00	✔	99.71 0.00	84.99 0.11	100 0.00	0.48 0.00	90.94 0.19	18314.28 -1469.83	1161.68 -76.67	38234.2 -374.73	2102.55 32.67	
[illegible] 2021-02-12 09:30	✔	[illegible] 0.00	[illegible] -0.55	[illegible] 4.17	[illegible] -0.04	[illegible] -8.77	[illegible] 6363.46	[illegible] 438.29	[illegible] 7412.02	[illegible] 372.20	
Run: 95134 2021-02-12 09:00	✔	99.78 0.00	85.4 -1.47	100 0.21	0.43 -0.02	83.38 -10.44	17178.8 1527.72	1045.28 99.68	39367.37 -431.35	2179.23 -0.10	
Run: 61826 2021-02-12 08:30	✔	99.76 1.56	85.88 -0.78	100 2.22	0.47 -0.01	95.25 11.37	16696.89 2591.98	1013.8 93.45	38843.34 1840.65	2134.85 178.00	
Run: 88232 2021-02-12 08:00	✔	99.75 0.00	84.83 -0.37	100 0.00	0.46 -0.03	86.8 1.43	16190.54 2986.10	1054.93 194.84	40542.91 -1409.60	2212.82 -84.17	
Run: 49116 2021-02-12 07:30	✔	99.73 0.00	85.25 -2.70	100 0.00	0.43 -0.02	84.76 3.08	15163.95 3177.75	942.8 208.90	42393.11 1013.33	2329.1 32.45	
Run: 96397 2021-02-12 07:00	✔	99.74 0.00	84.18 0.61	100 0.00	0.44 -0.04	80.53 -8.72	13934.91 853.03	816.95 52.50	42774.5 3344.66	2379.68 243.27	
Run: 87721 2021-02-12 06:30	✔	99.73 2.09	80.89 -3.72	100 0.00	0.45 -0.05	86.84 -5.70	14815.09 4079.94	837.99 270.43	40365.24 4260.32	2206.75 262.86	

Objets par page 10 | 1-2 of 2

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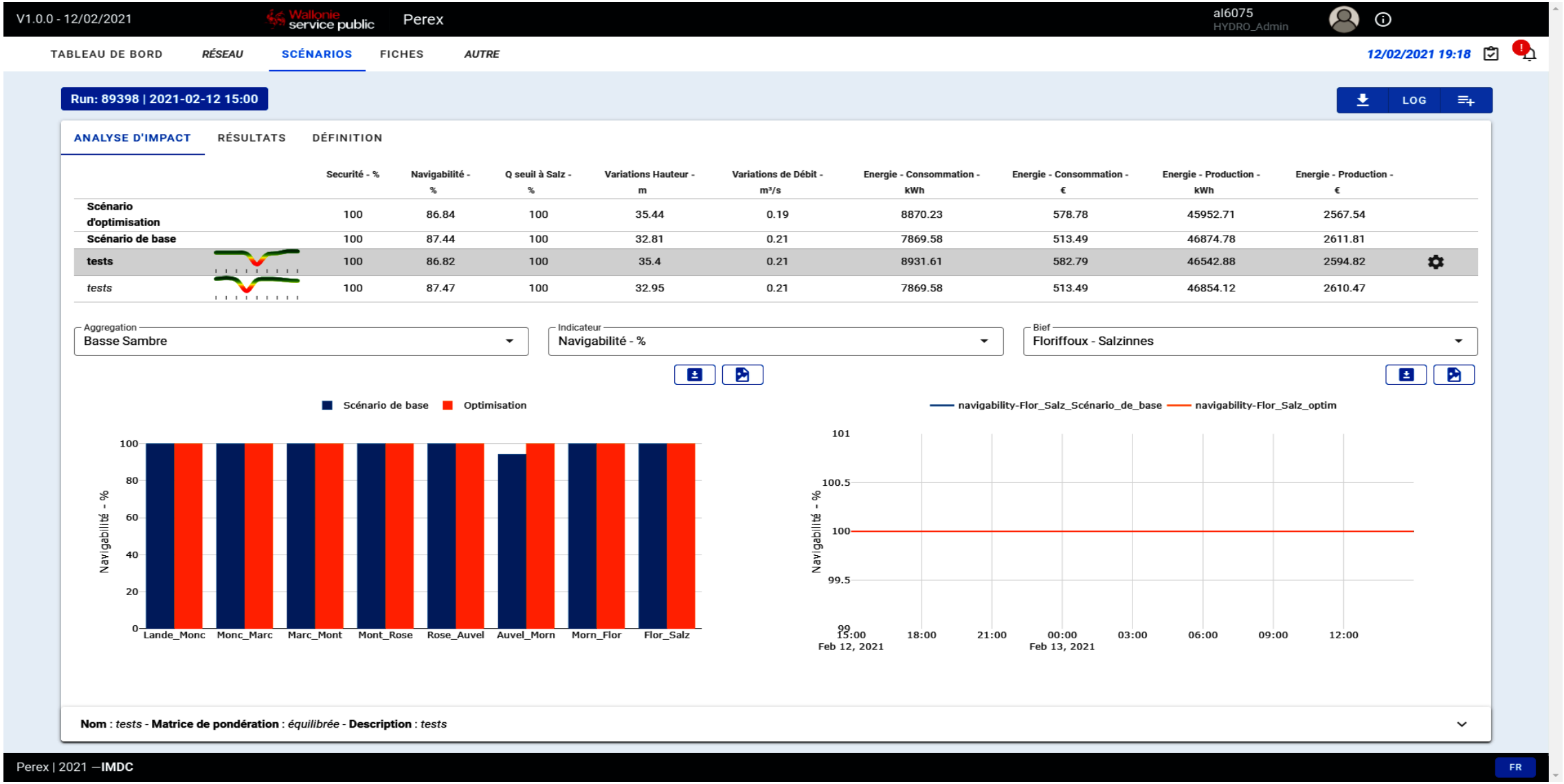
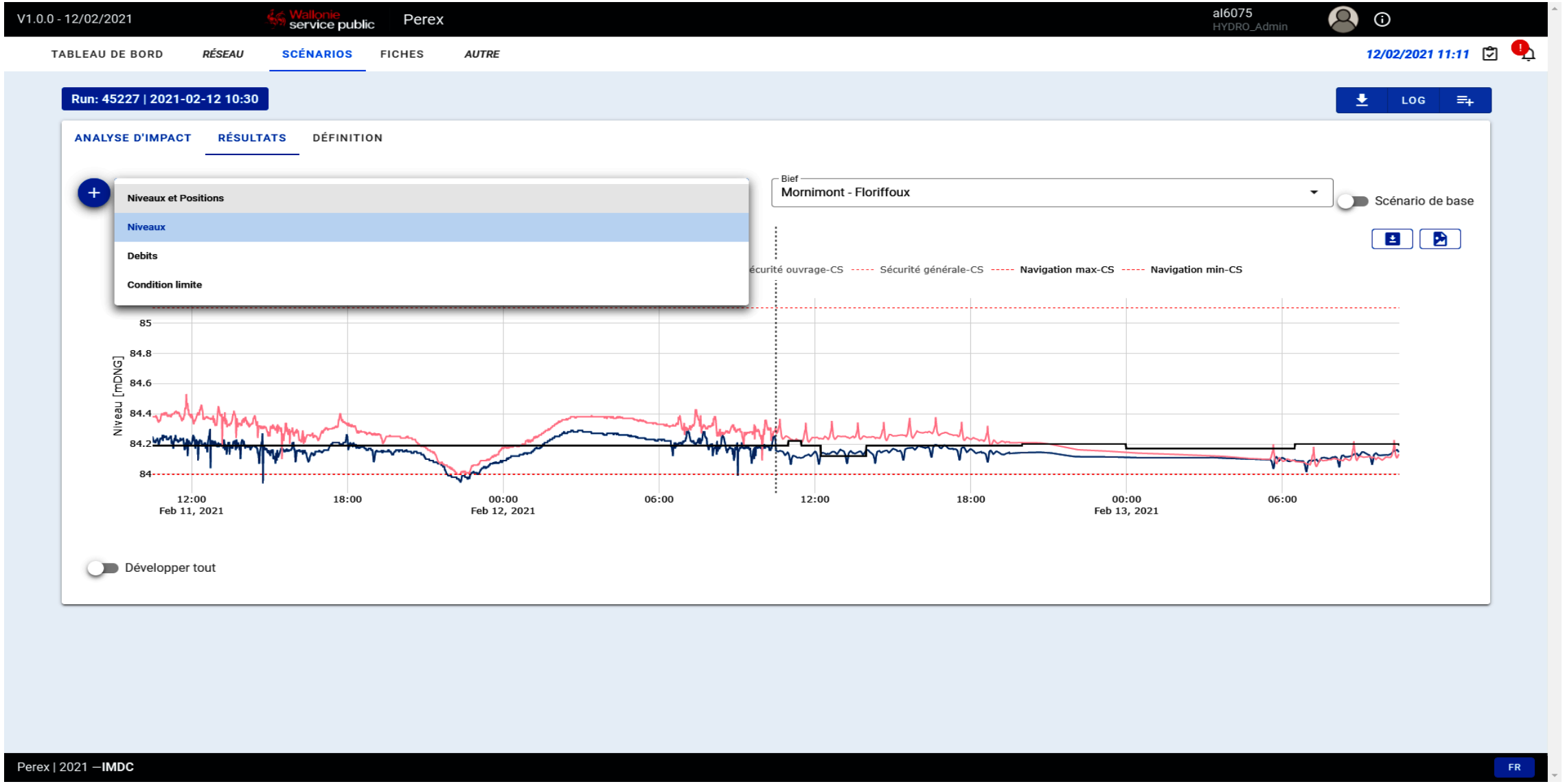
Web Application Features : Impact analysis (indicators)



	Securité - %	Navigabilité - %	Q seuil à Salz - %	Variations Hauteur - m	Variations de Débit - m³/s	Energie - Consommation - kWh	Energie - Consommation - €	Energie - Production - kWh	Energie - Production - €
Scénario d'optimisation	100	86.84	100	35.44	0.19	8870.23	578.78	45952.71	2567.54
Scénario de base	100	87.44	100	32.81	0.21	7869.58	513.49	46874.78	2611.81
tests	100	86.82	100	35.4	0.21	8931.61	582.79	46542.88	2594.82
tests	100	87.47	100	32.95	0.21	7869.58	513.49	46854.12	2610.47

Web Application Features : Input/Output analysis



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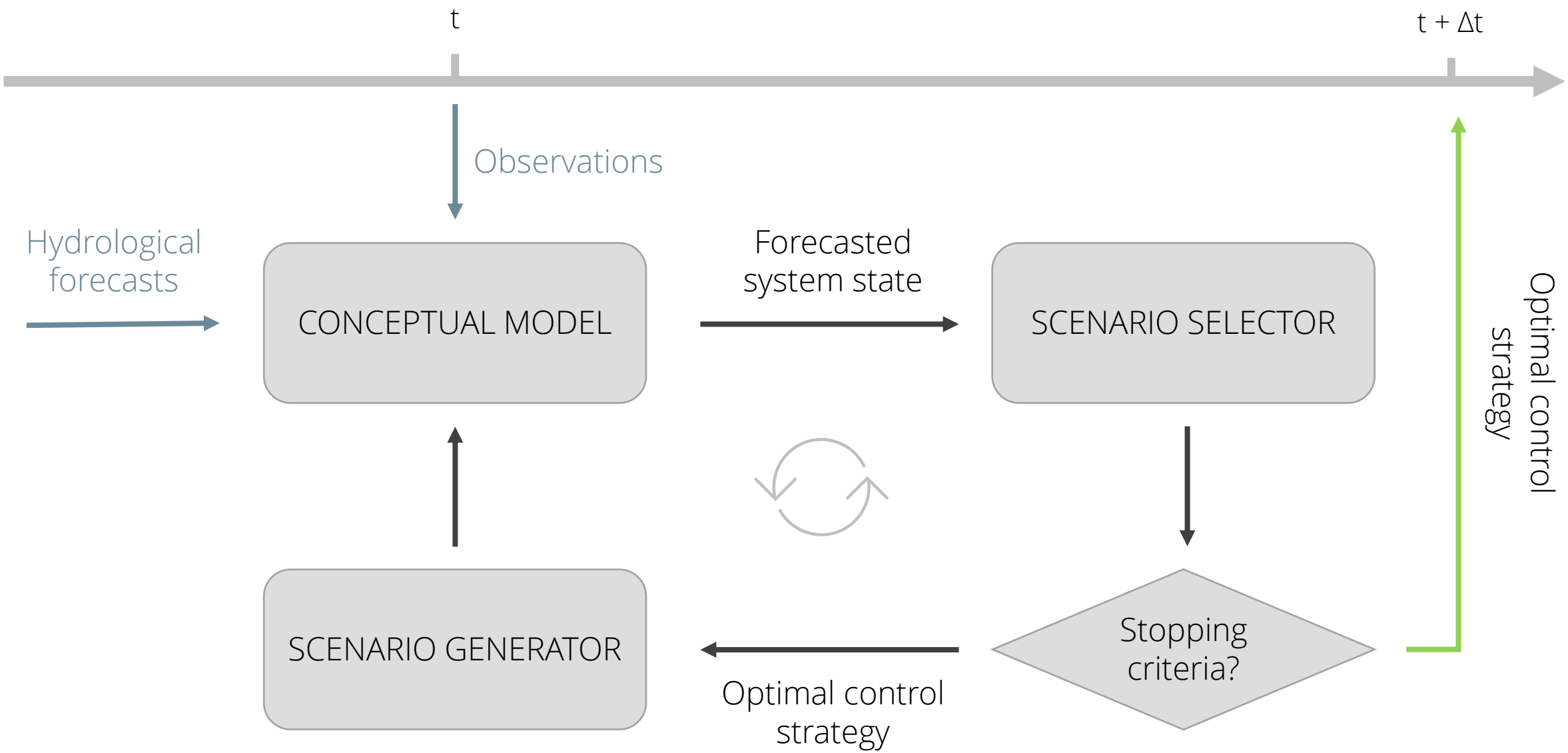
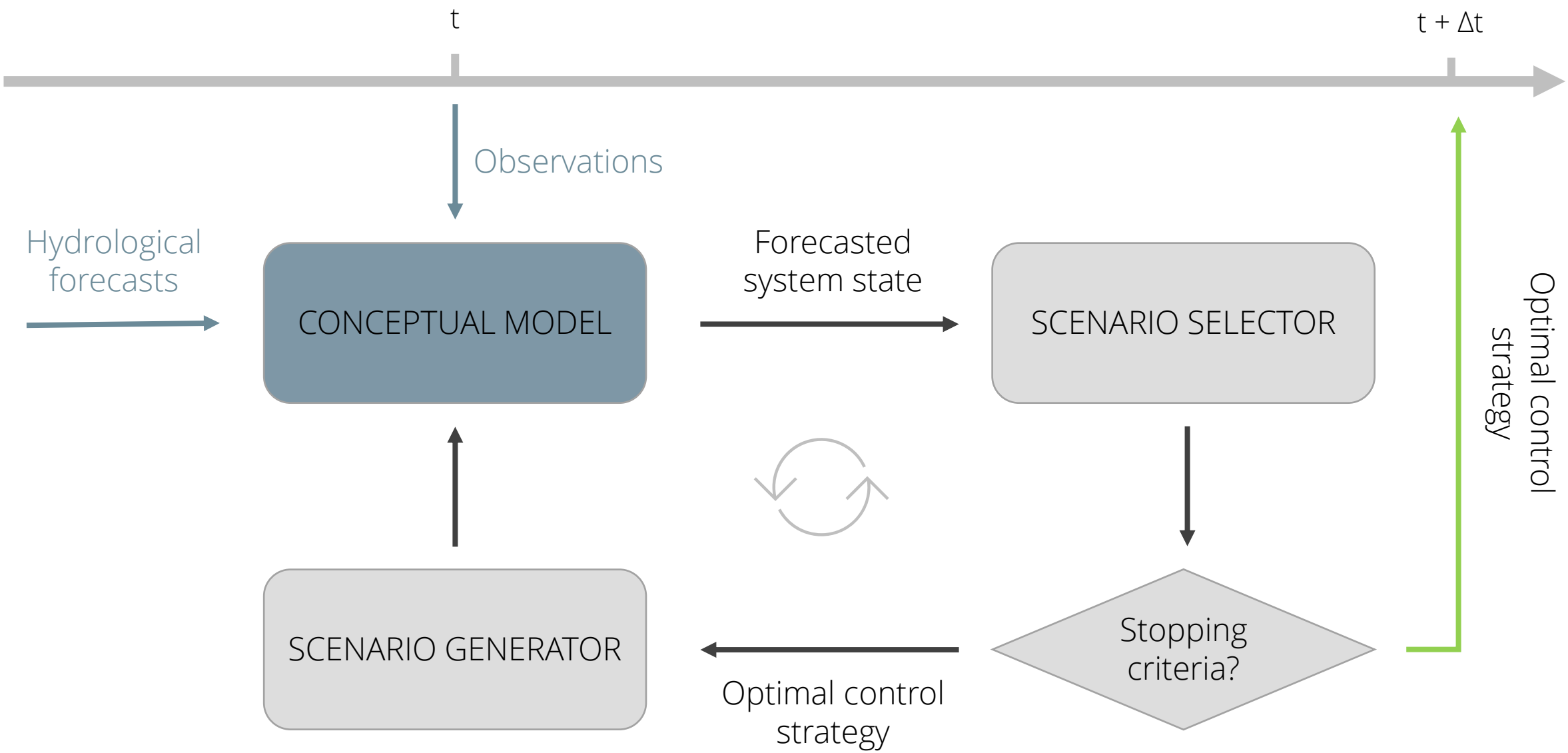

t
t + Δt
Observations
Hydrological forecasts
CONCEPTUAL MODEL
Forecasted system state
SCENARIO SELECTOR
Optimal control strategy
SCENARIO GENERATOR
Stopping criteria?
Optimal control strategy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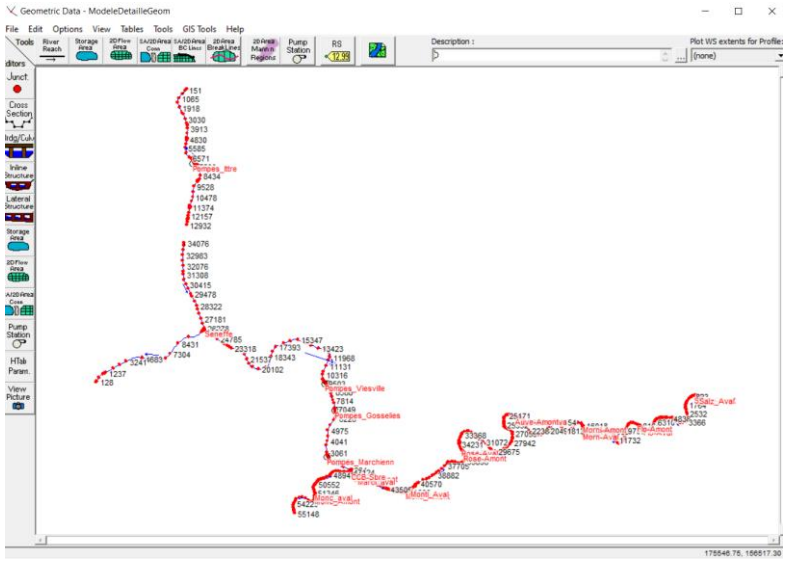
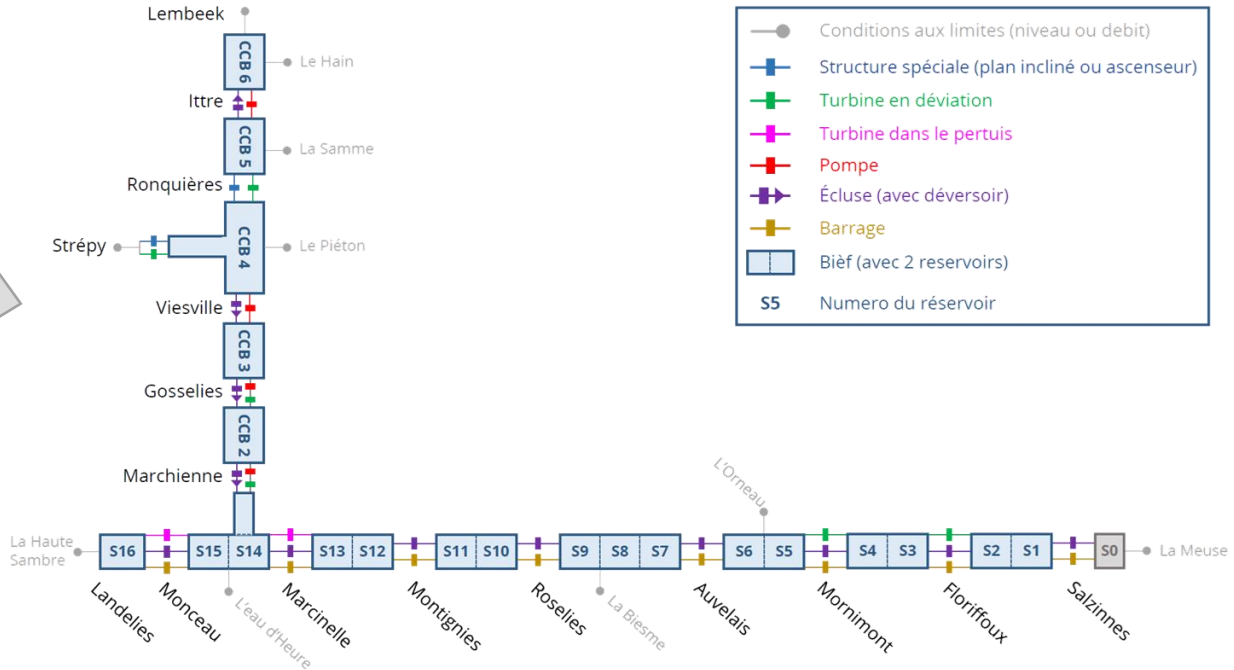
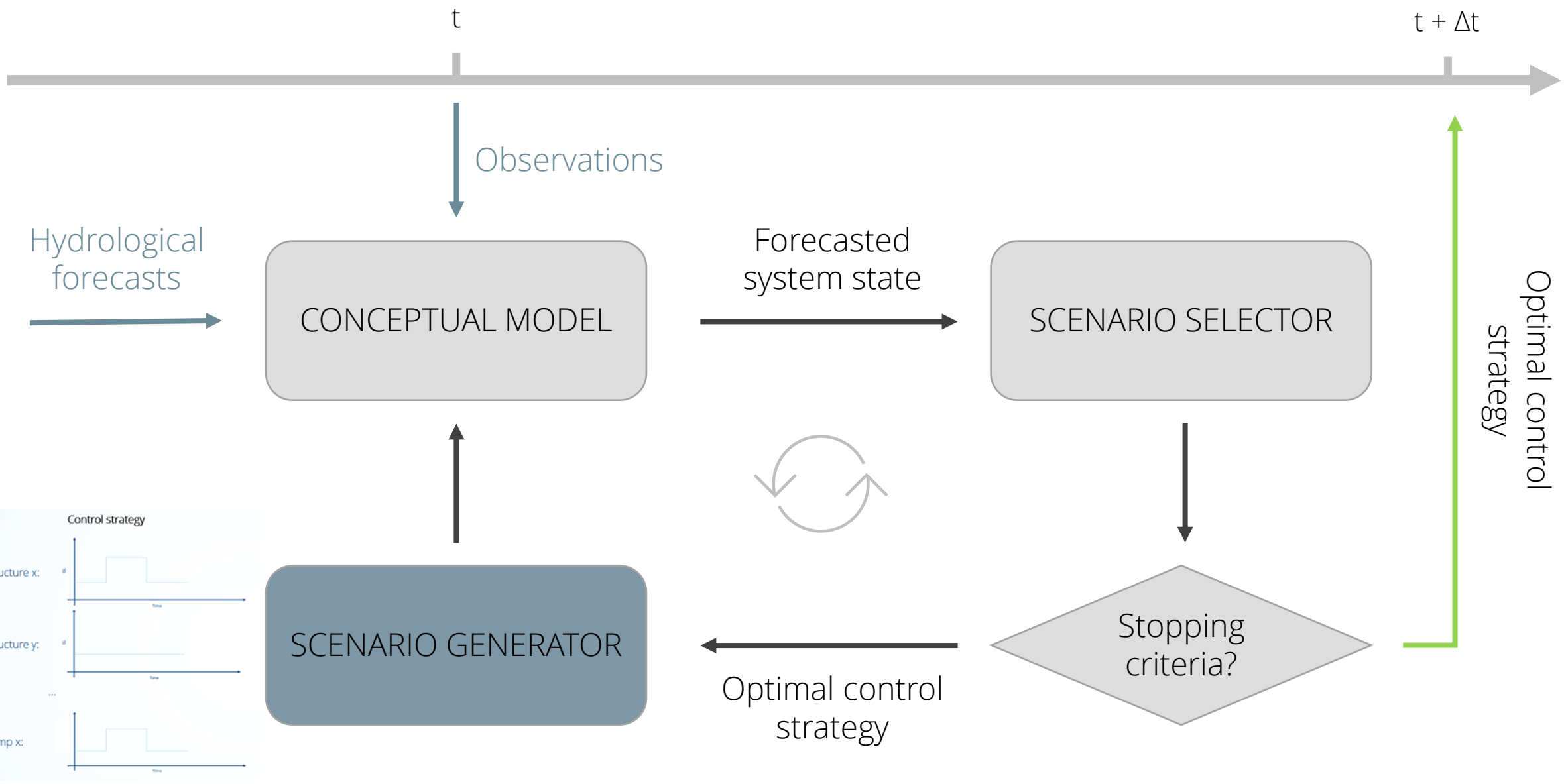




CONCEPTUAL MODEL

- Conceptual model starts from HEC-RAS model
- Simplified representation of the system
- Intelligent **mix of data-driven and physical based** model concepts:
  - Conservation of mass
  - Equations of the structures
- Very **performant**:
  - Up to 20.000x speed increase
  - 0.004 s / day of simulation
- Written in C++
- **Data assimilation** integrated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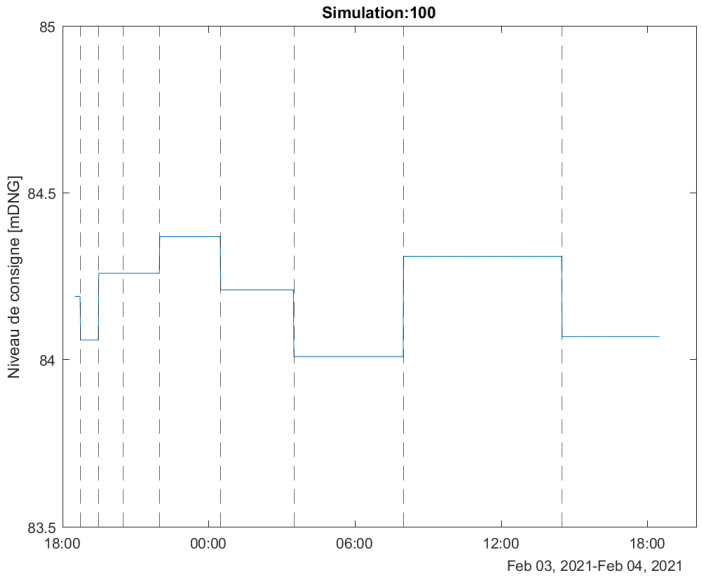
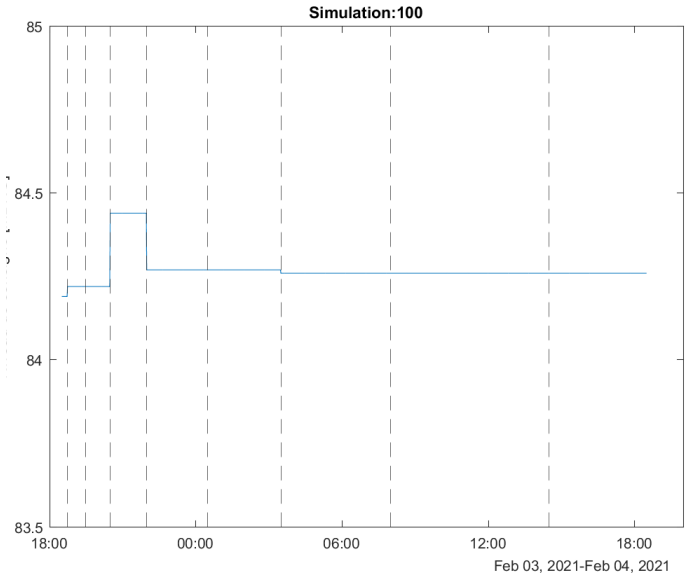
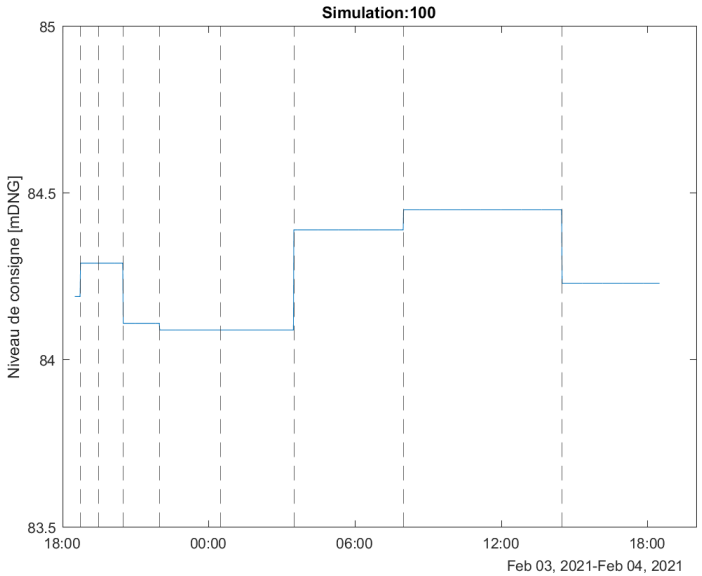
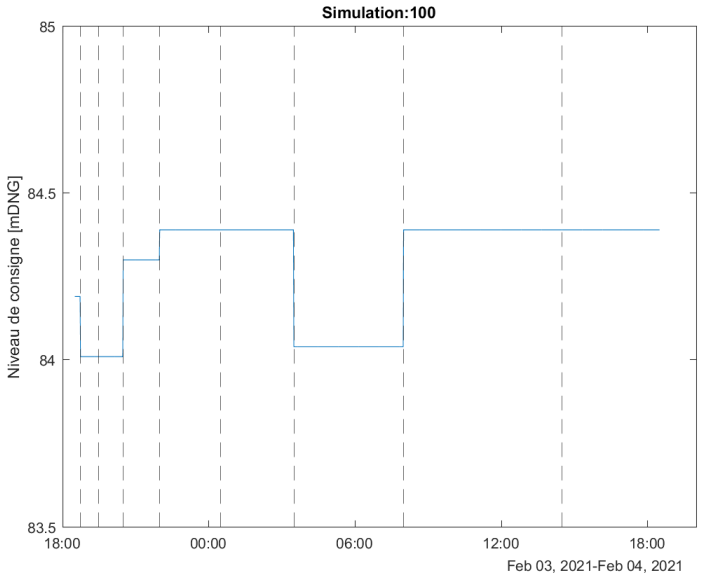
Control strategy
Structure x:
Structure y:
Pump x:
SCENARIO GENERATOR
Optimal control strategy
Stopping criteria?









SCENARIO GENERATOR

- Parallel Reduced Genetic Algorithm
- Generates **many potential control strategies** within defined limitations:
  - ✓ Can we optimize the structure?
  - ✓ How much / fast can it move?
  - ✓ …
- New strategies generated as:
  - ✓ **Mutations** of existing strategies
  - ✓ New (pseudo-) **random** strategies
  - ✓ **Cross-overs** between optimized strategies
- **Robust** solution for operational tool
- Pilot project contains 19 manipulated variables

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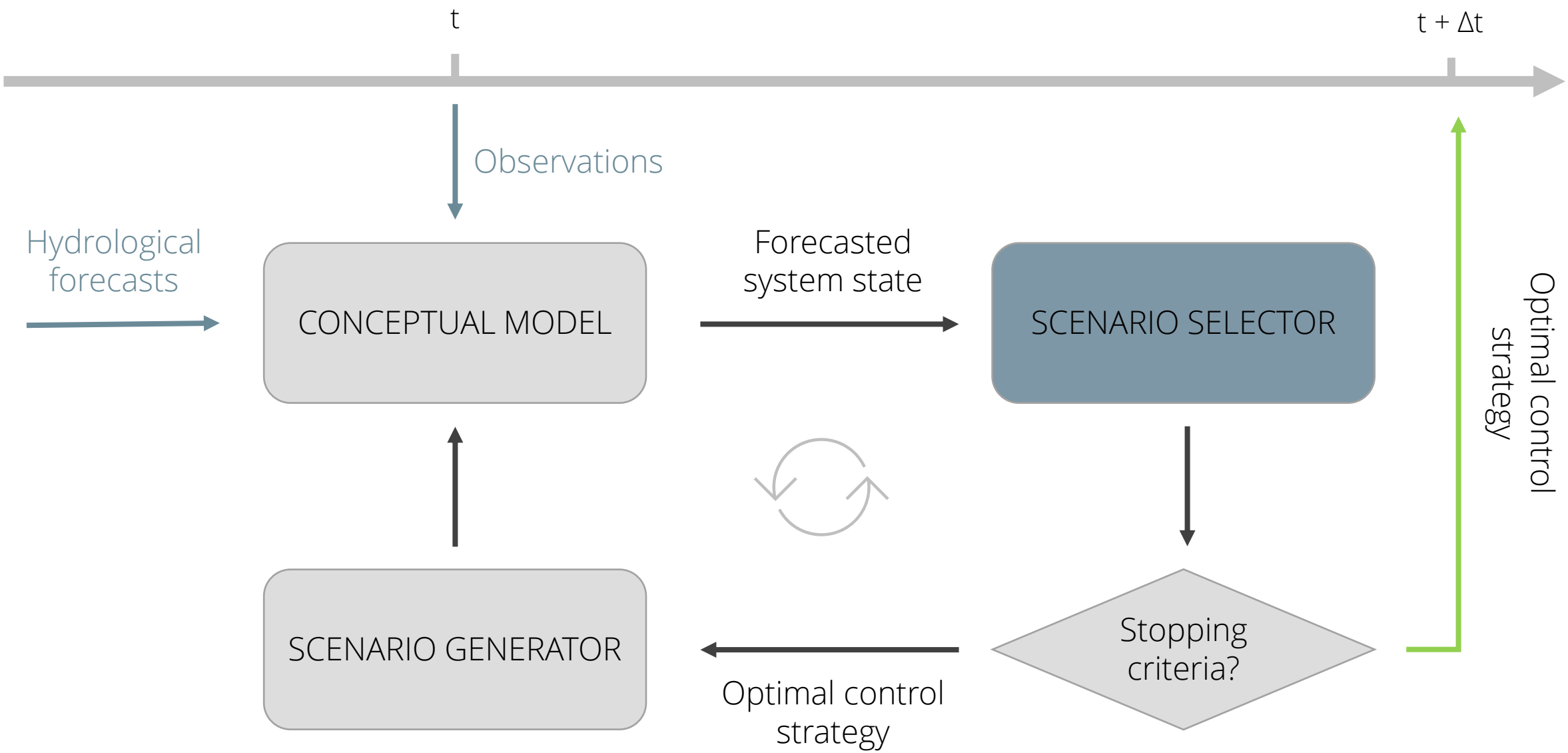
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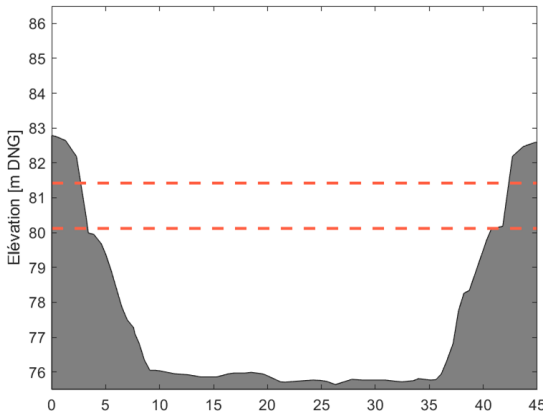
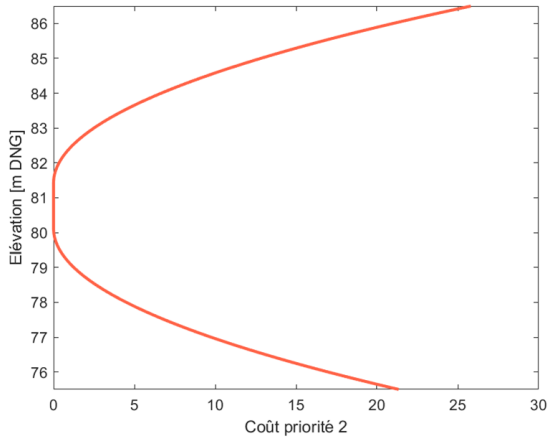
Priority	Objective
1	Safety at the structures
2	General safety
3	Navigation
4	Discharge and water level variations, Ecological discharges, Economic costs and benefits





$$O_{prior4} = \sum_{i=1}^{n_{MV}} \left(\sum_{j=1}^{N_{ctrl}} c_{i,movepen} (u_{i,j} - u_{i,j-1})^2 \right)$$
$$+ \sum_{i=1}^{nbief} \left(\sum_{j=1}^{N_{pred}} c_{i,q,min} * \left(\min (q_{i,j} - q_{i,min}, 0)^2 \right) + c_{i,\Delta h} * \max \left(var(\overleftrightarrow{h_i}) \right) + c_{i,\Delta q} \right.$$
$$\left. * \max \left(var(\overleftrightarrow{q_i}) \right) \right) + \sum_{i=1}^{npomp} \left(\sum_{j=1}^{N_{pred}} c_{i,p} * \left(dh_{i,j} * cr_{ip} * q_{i,j} \right) \right)$$
$$+ \sum_{i=1}^{nturb} \left(\sum_{j=1}^{N_{pred}} -c_{i,t} * \left(dh_{i,j} * cr_{it} * q_{i,j} \right) \right) + \sum_{i=1}^{nbief} c_{i,v} \left(60 * \sum_{j=1}^{N_{pred}} q_{i,j} - q_{i,T} \right)^2$$

SCENARIO SELECTOR

- Chooses the best potential control strategy
- **Transparent** with different priorities and objective functions
- Soft constraints are used within the objective function to **penalize the exceedance of a threshold**
- **Flexible** system with weight matrix to shift the importance within a priority depending on the situation
- Objective functions incorporate the model results of 87 variables along the pilot project

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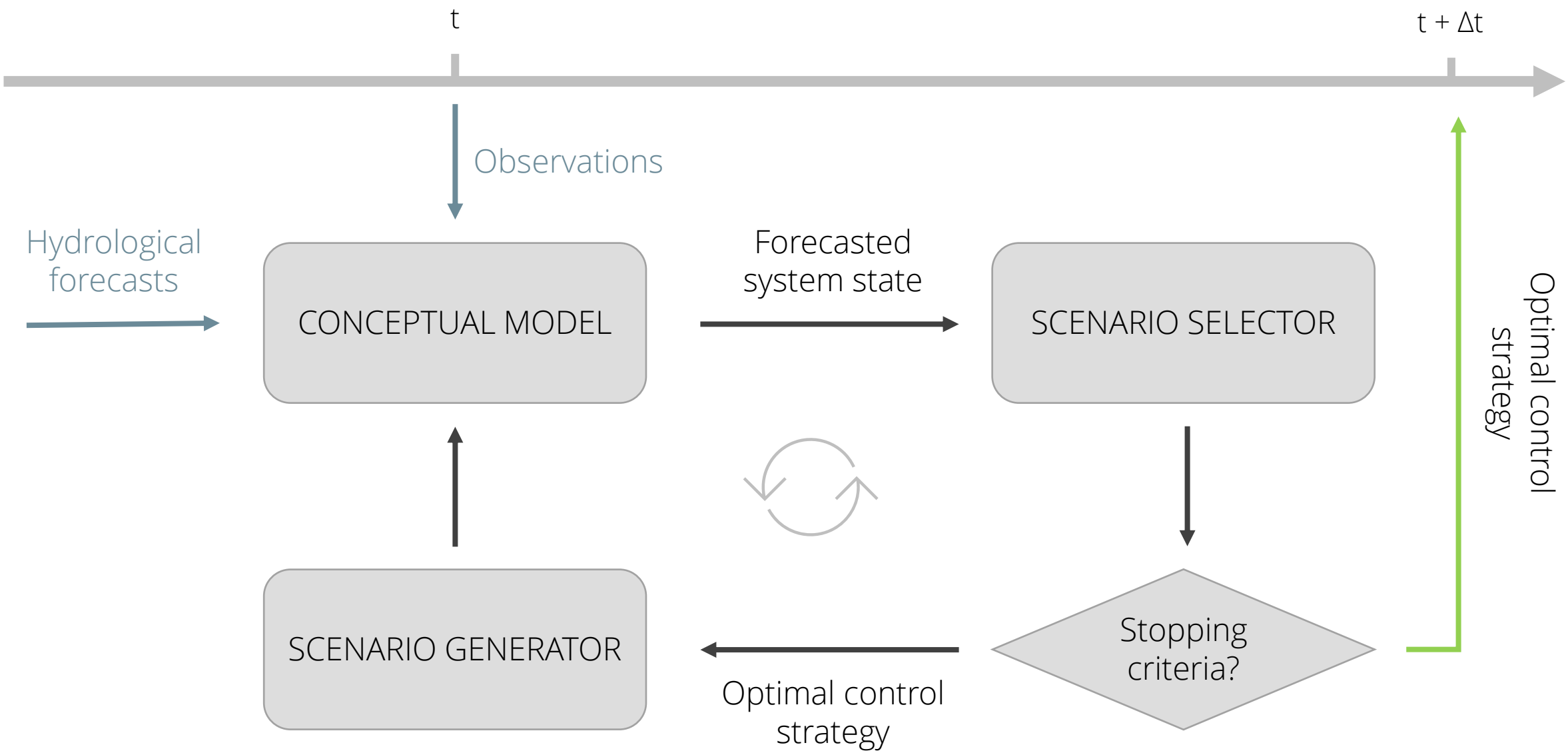
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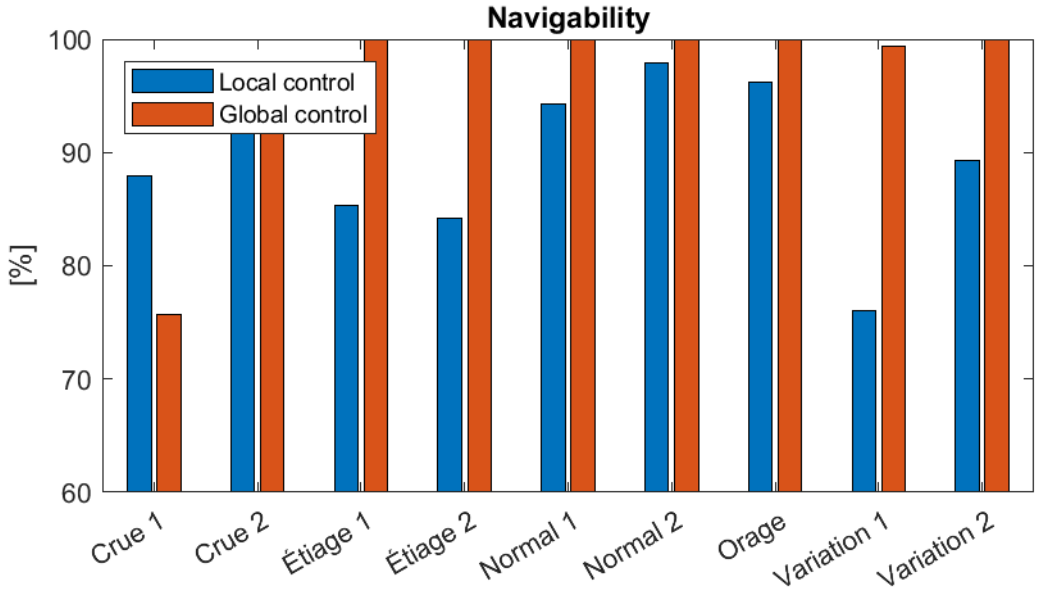
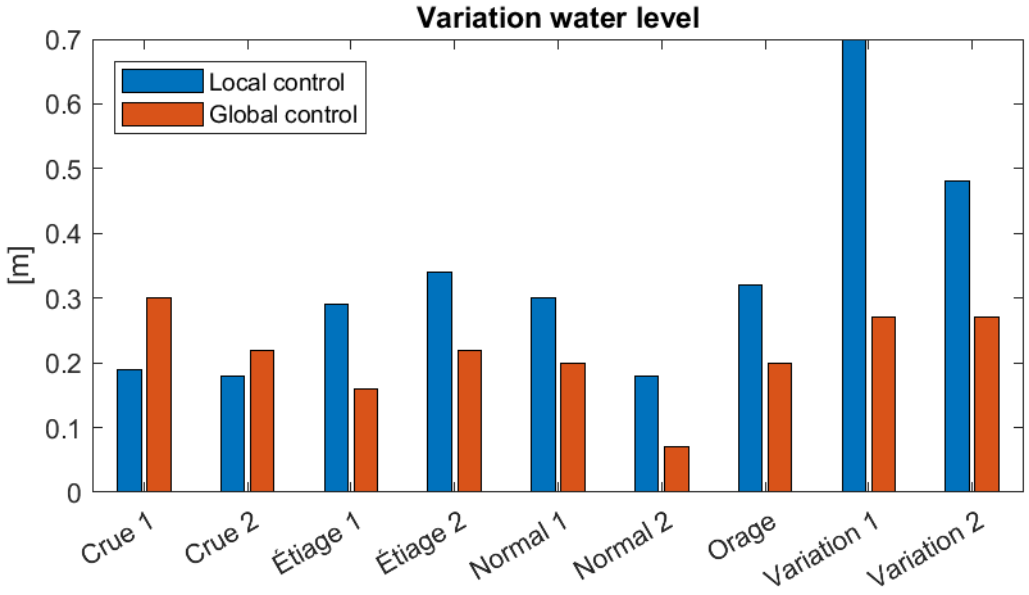
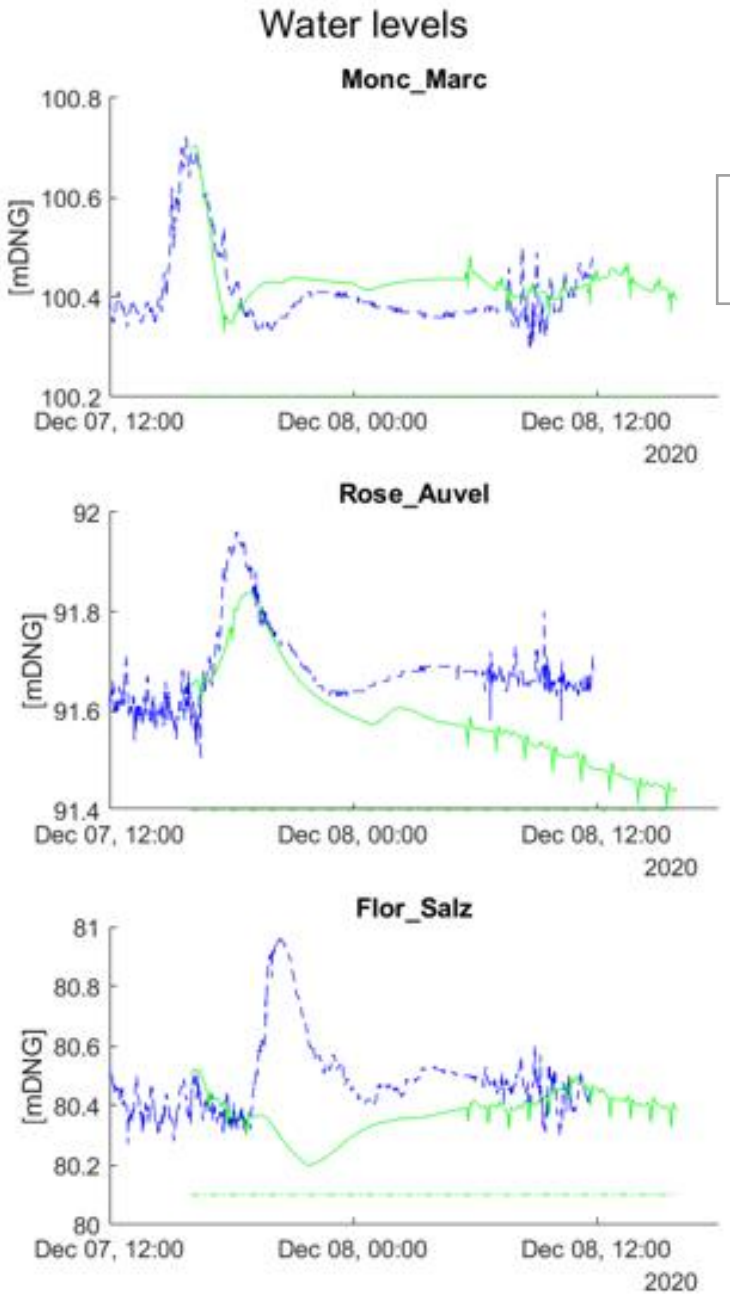




Results

- Optimization **reduces the cost of the objective functions** resulting in better indicator values for a variety of historical events
- **Stable performance** across the events
- Improvements in the pro-active and re-active water management

Upstream



Measurements

Optimization results

Downstream

Results

- Optimization **reduces the cost of the objective functions** resulting in better indicator values for a variety of historical events
- **Stable performance** across the events
- Improvements in the pro-active and re-active water management

Next steps

- Research to improve the current solution:
  - ✓ Analysis of the operational optimizations over the past months revealed that the data assimilation module could be improved
  - ✓ Further investigate the effect of the (uncertain) hydrological forecasts on the optimization results
- Testing the current solution:
  - ✓ Link between the optimization tool and the terrain will soon be realized
  - ✓ “Real Life” tests to assess the performance of the optimization in operational setting

Thank you for your attention

Contact:

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ludovic.gouverneur@imdc.be
tim.franken@sumaqua.be