Case studies on IoT and Big Data

Dr. Ir. Vincent Wolfs
Ir. Kato Schoeters

Agenda

- Introduction

  IoT, Big Data and watermanagement in EU

- Case studies
  1. RainBrain
  2. hAidro
  3. Groundwater indicator
  4. Internet of Thing
  5. iFLUX

- Conclusion

  key insights, take away messages, bottlenecks and challenges

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How can Big Data and IoT support us in tackling water challenges?

imec

Water challenges?

Floods

Rising precipitation amounts lead to more frequent and more extensive flooding from rivers and sewers.

Poor water quality

Reduction in water quality due to an increase in the number of overflows, higher temperatures and longer residence times.

Sea level rise

Due to sea level rise more coastal floods will occur. Sea level rise will also influence the tides along tidal rivers.

Lower water availability

Decreased precipitation and increased evaporation lead to lower flow rates and volumes in groundwater and surface water.

Drought

More frequent and extreme droughts with negative impacts on agriculture and nature.

Biodiversity loss

Rising temperatures are causing changing living conditions and an advance of exotics.

Increasing heat waves

Increase in the number of heat waves and heat wave days with negative impacts on public health and productivity.

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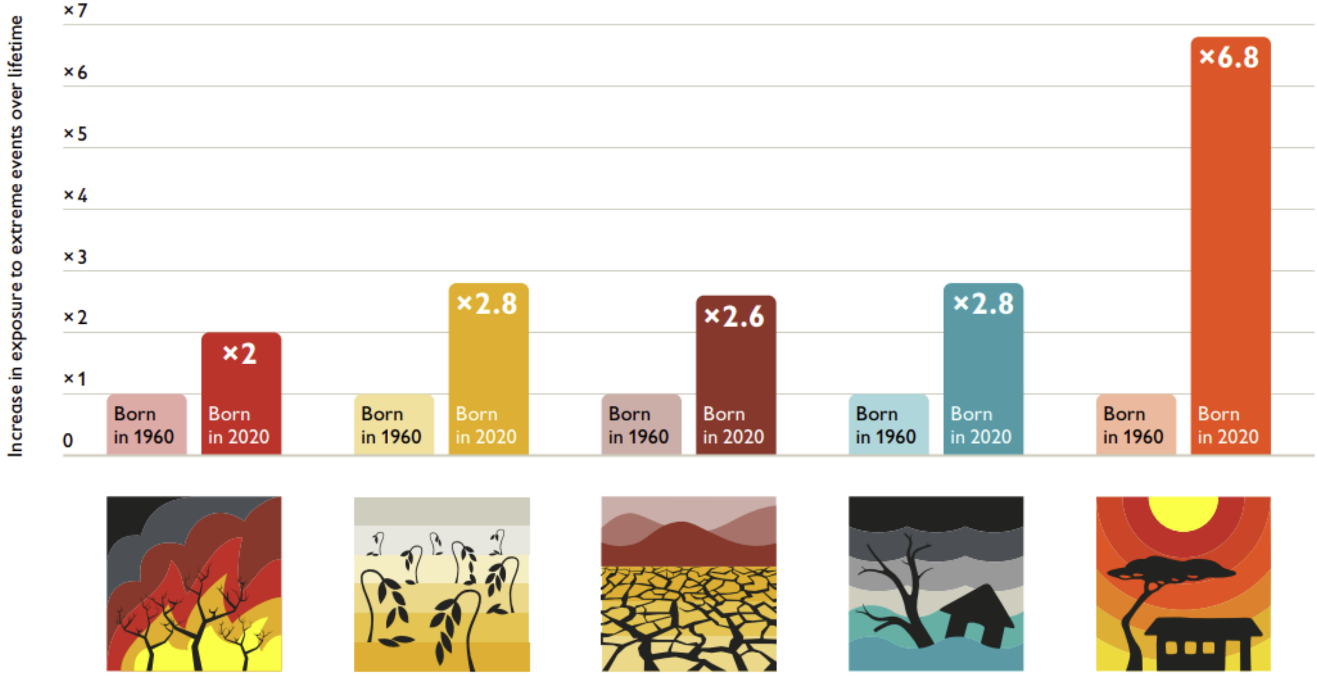
Increase in exposure to extreme events



On average and under Paris Agreement pledges, a child born in 2020 faces **2 times** the risk of **wildfires** than a person born in 1960.

Globally, under Paris Agreement pledges, children born in 2020 face an average **2.8 times** more **crop failures** than their elders.

Under Paris Agreement pledges children born in 2020 will face **2.6 times** more **droughts** on average than people born in 1960.

Globally, under Paris Agreement pledges, children born in 2020 are poised to face **2.8 times** more **river floods**, on average, than those born in 1960.

Under Paris Agreement pledges, children born in 2020 are projected to experience an average of **6.8 times** as many **heatwaves** in their lifetimes than a person born in 1960.

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Use of IoT and Big Data

Internet of Things (IoT):
IoT connects sensors, cameras, drones, radars, satellites, … (=IoT devices)

→ IoT devices are transmitting enormous amount of data

Big Data helps enterprises utilize data that is available around them

→ Big data is the fuel of IoT

Use of IoT and Big Data

TOEKOMSTVERKENNINGEN IN DE DRINKWATERSECTOR (5)

Sensoren steeds belangrijker, ook in watersector

De samenleving raakt in snel tempo 'gesensoriseerd'. In de meeste industriële productieprocessen doen robots en sensoren gezamenlijk het werk dat vroeger door kundige vaklui werd verricht. Sensorisering en robotisering leiden tot een grotere uniformiteit van het product en bieden daardoor de mogelijkheid van verhoging van de standaard. Ook in de watersector zullen sensoren uit een oogpunt van veiligheid, gezondheid en procesoptimalisatie een steeds belangrijker rol gaan spelen, maar dan moeten we ze wel eerst ontwikkelen.

Schema 3.

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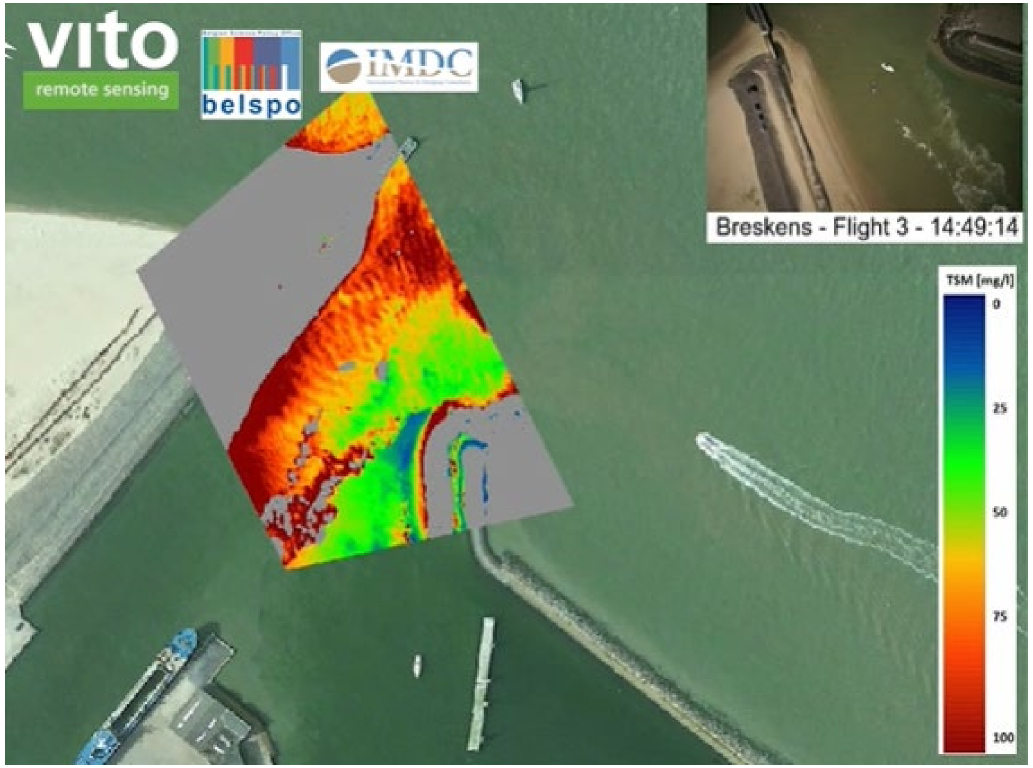
Some examples of digital solutions to water management

1. DroneSED: drones to monitor water quality
2. TerraFlood: mapping and monitoring floods using Sentinel-1 data
3. ‘Curieuzeneuzen’ in the garden
4. …

DroneSED: drones to monitor water quality



Project: 3 year R&D project funded by BELSPO, VITO Remote sensing and IMDC
Where? Belgian coast and Scheldt River

Goal? Gain insights in water quality during dredging works
How? Drone based system to monitor water quality instead of traditional water sampling techniques
Benefit? Possibility to monitor larger areas and measure sediment concentration directly from the drone

TerraFlood: mapping and monitoring floods using Sentinel-1 data

Project: TerraFlood, an initiative by VMM, University of Ghent and Vito
Where?

Goal? Gain insights into spatial and temporal flood occurrence and dynamics
How? Virtual machine application (based on data from the Sentinel-1-satellites)
Benefit? TerraFlood allows to monitor flooding and flood occurrence more accurately.

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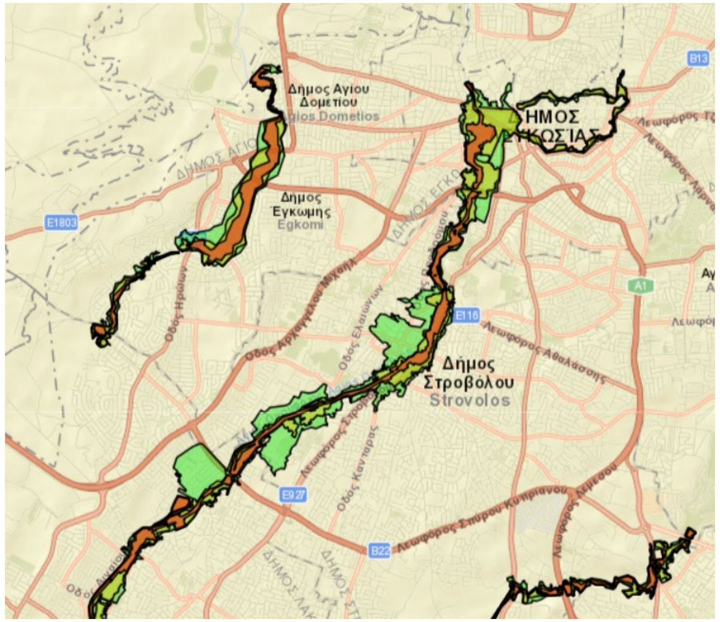
Environmental Risk Management and Information Service – Floods

Project: ERMIS-F, project done by The Cyprus Institute, Sewerage Board of Limassol-Amathus, University of Aegean, North Aegean Water Directorate, Technical University of Crete and Municipality of Chania
Where? Cyprus
Goal? To inform the public about the flood risk hazard in their area
How? GIS web-portal
Benefit? ERMIS-F aims to inform the public in regards to flood risk which can be incorporated into the decision-making tools by each interested target group (government, society, etc)
Source: ERMIS-F



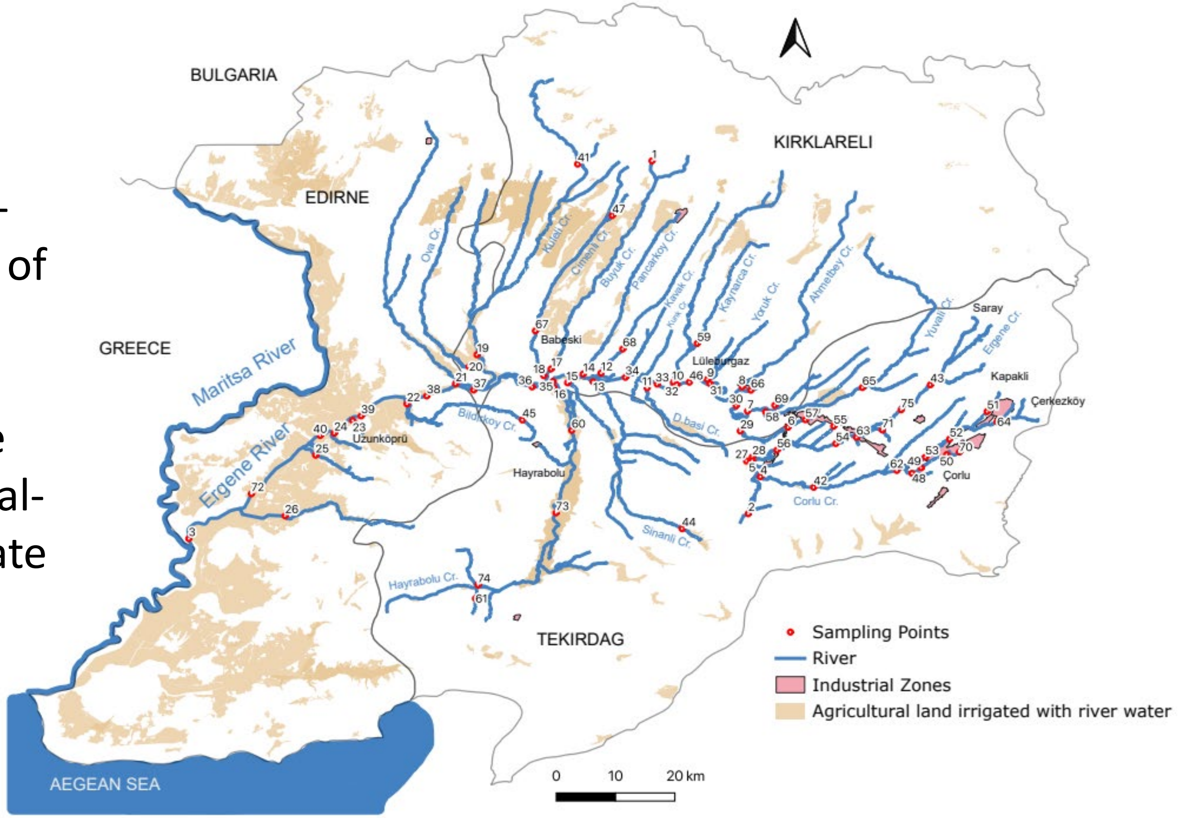
Flood risk map for Cyprus - 20 year return time

Flood risk map for Cyprus - 100 year return time

Flood risk map for Cyprus - 500 year return time

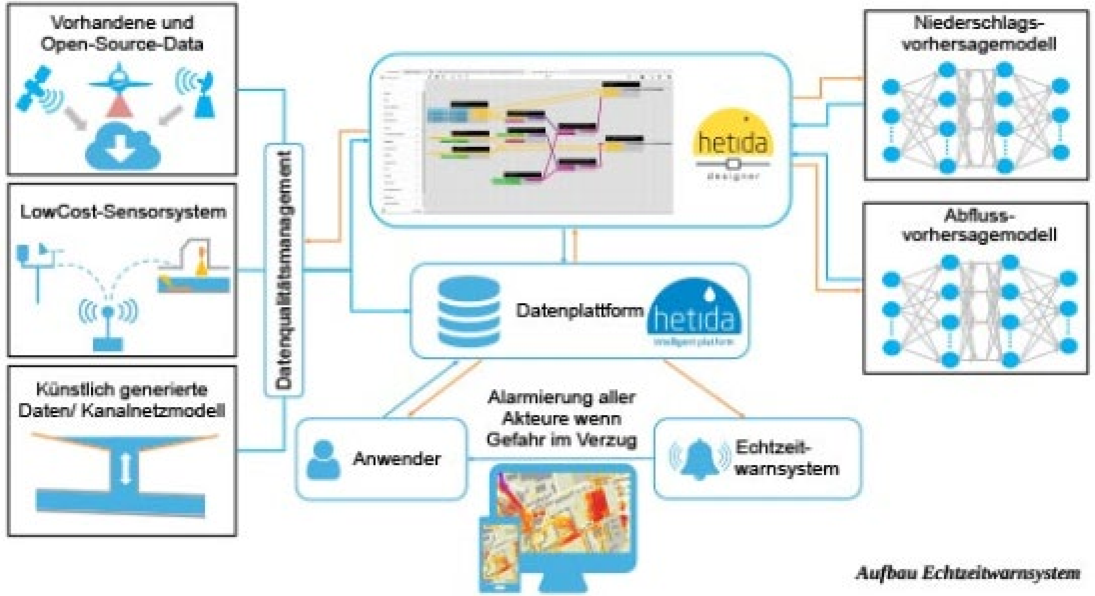
Sustainable Environmental Monitoring via Energy and Information Efficient Multi-Node Placement

Project Sustainable Environmental Monitoring via Energy and Information Efficient Multi-Node Placement, project done by Vienna University of Technology, Vienna, Austria - Istanbul Technical University, Istanbul, Turkiye - University of Vienna, Vienna, Austria
Where? Ergene River, Turkiye (TR)
Goal? A case study for monitoring the water quality of the Ergene River in Turkey. Detailed experiments subject to real-world data show that the proposed method is both accurate and efficient in monitoring a large environment and catching up with dynamic changes.
Source: [IEEE Xplore Full-Text PDF:]



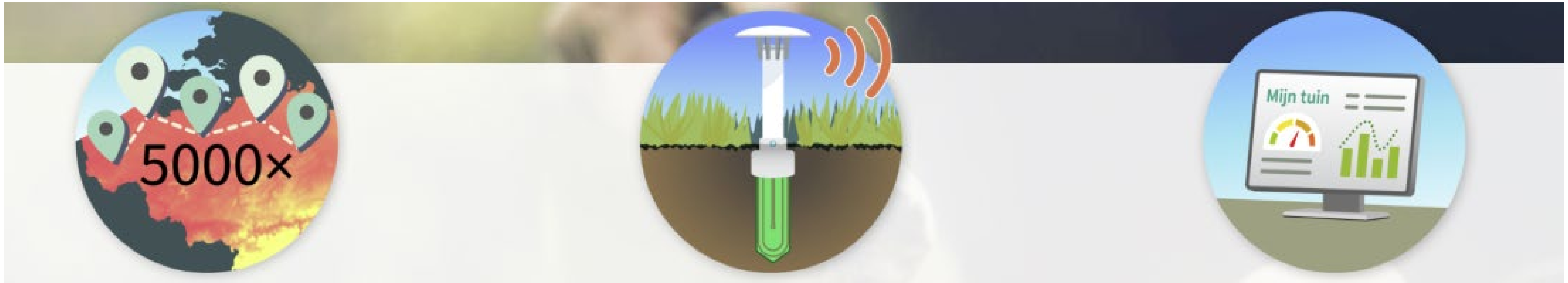
KI-basiertes **Wa**rnsystem vor **S**tarkregen und **u**rbanen **S**turzfluten (**KIWaSuS**)

Project: KIWaSuS, project by Hochschule Ruhr West, Institut für Mess- und Sensortechnik, Gelsenwasser, Abwassergesellschaft Gelsenkirchen mbH, Universität Duisburg-Essen, Neustadt analytics & insights GmbH
Where? Gelsenkirchen
Goal? Increase the advance warning times for flash floods in urban areas, to localise them better and at the same time to provide important information for municipal crisis management in order to better protect affected citizens.
How? Machine learning methods resulting in an intuitive, digital map
Benefit? Prepared alarm and deployment plans for the fire brigade, disaster control and on-call teams of the sewer network operators. In this way, citizens can be warned in time and initiate their own protective measures.
Source: [KIWaSuS – KI-basiertes Warnsystem vor Starkregen und urbanen Sturzfluten]



Aufbau Echtzeitwarnsystem

‘Curieuzeneuzen’ in the garden



“The largest citizen-science study of heat and drought ever”

“Measure the heat and drought in your garden with a smart soil sensor”

“Receive daily updates via a personal dashboard”

CURIEUZE NEUZEN

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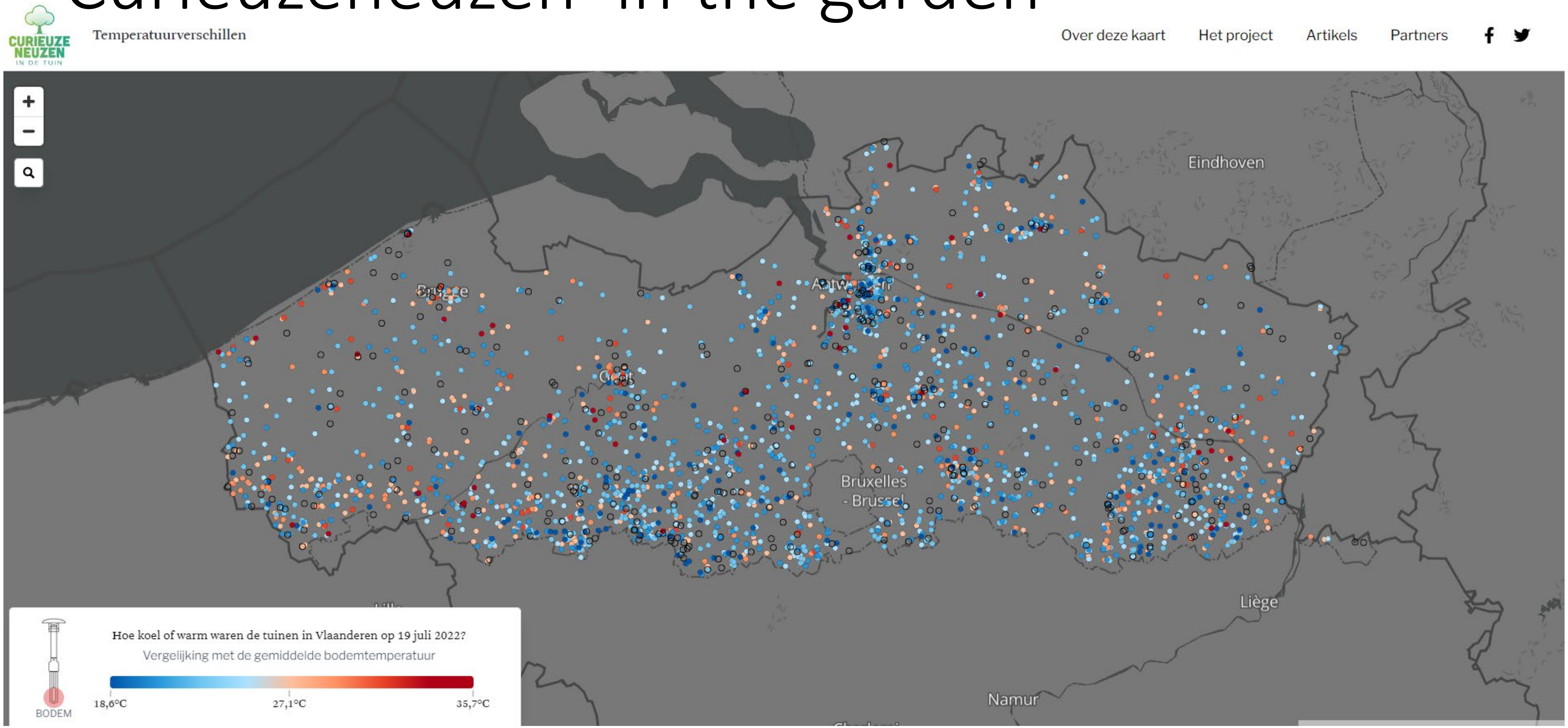
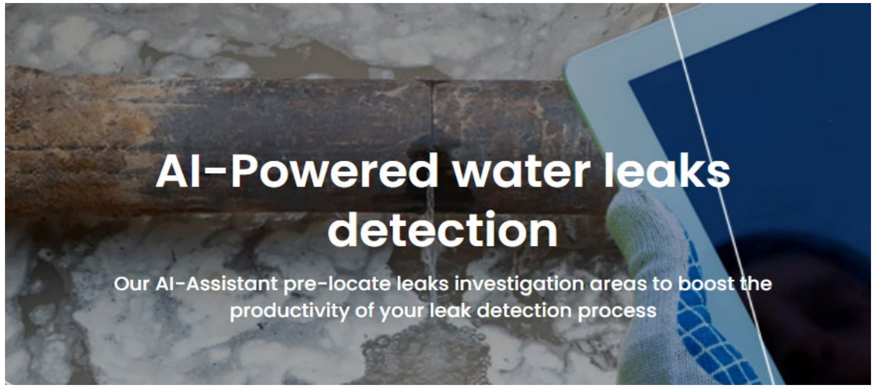
‘Curieuzeneuzen’ in the garden



Others



"A huge amount of remote sensing data is freely and easily available. Copernicus' (Europe's Earth Observation programme) satellites deliver free and open data every day"

Neural net input = digital elevation model (DEM) – neural net output = waterway/ditch detections on top of the DEM

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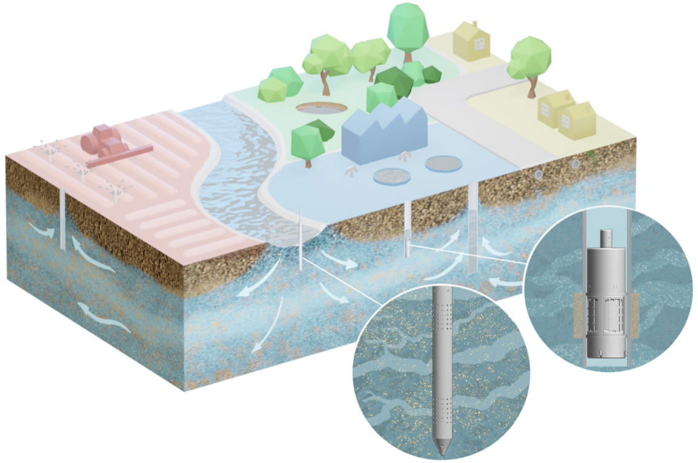
RainBrain
Intelligent real time control using sensor data and simulation models

hAIdro
Low flow predictions in rivers using advanced machine learning models

Groundwater indicator
Groundwater monitoring and forecasts using data-driven models

Case studies

Internet of Water
Netwerk of sensors measuring the water quality in Flanders



iFLUX
How does pollution move in the groundwater?

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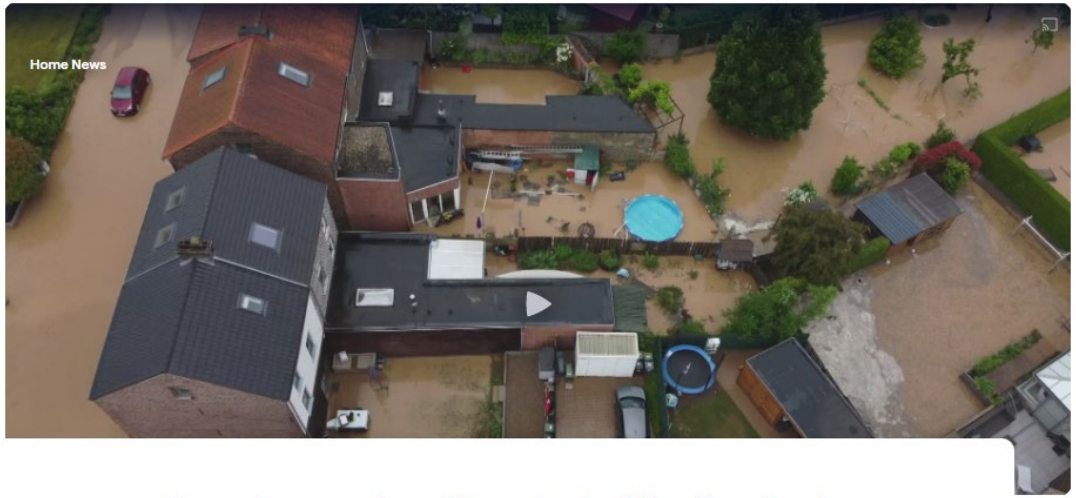
Pluvial floods and droughts happen more often



Drone images show the extent of the flooding in Landen

The clean-up operation is underway in the Flemish Brabant town of Landen following the worst flooding in 20 years. The footage above shows the extent of the flooding.

Mon 06 Jun 13:15

vrt nws flandersnews.be

Flanders eyes private wells as solution for droughts and heavy rainfall

Monday, 2 September 2019

More heavy rain expected in Belgium as code yellow is issued. Credit: Pixabay

The Brussels Times

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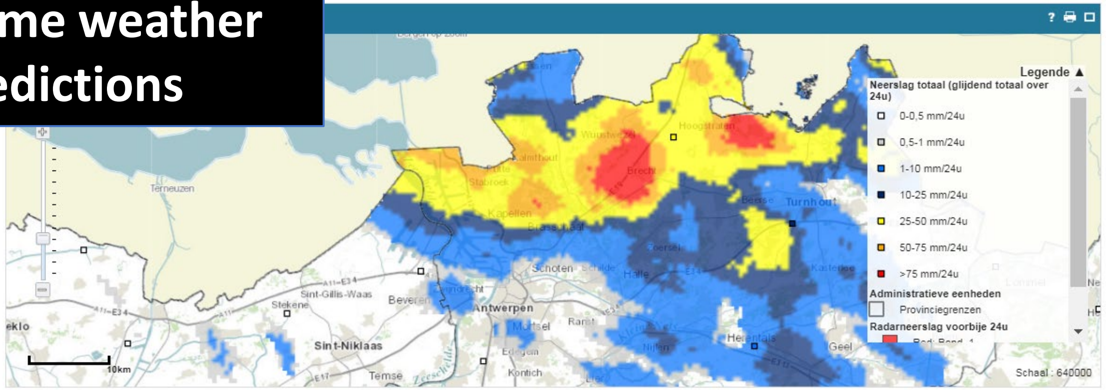
RainBrain: real time forecasting & intelligent control

Real time weather predictions



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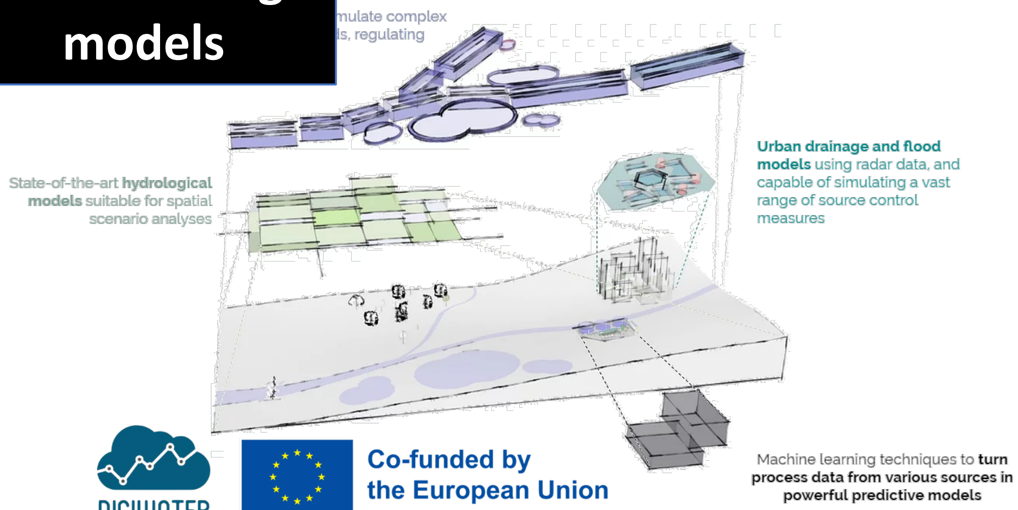
Self-learning models

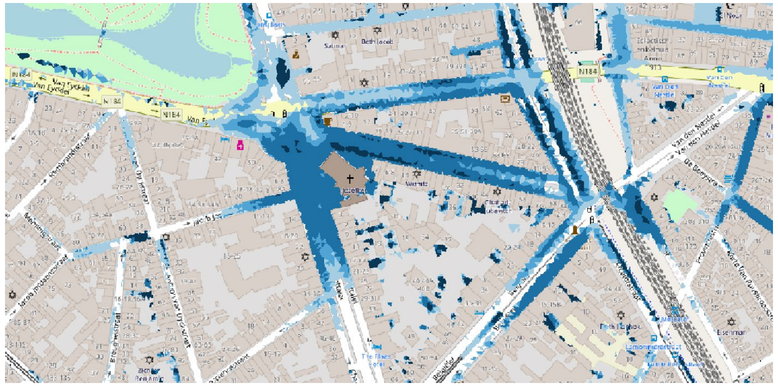


+

Sensors

=

Real time flood predictions & intelligent control



RainBrain

The smart blue-green roof

Healthier green roofs

- RainBrain **monitors and predicts the vegetation's health**
- **Waters vegetation automatically** when needed

The best of IoT and analytics combined

- **Vegetation sensors**, solar panel and LoRaWAN
- Weather data, **machine learning and modeling**
- RainBrain insights and controls through a **mobile app**

Optimized water availability

- RainBrain analyses the current and future water availability
- **Anticipates on extreme weather**: stores water to survive droughts, empties buffers to prevent floods

Developed by

Sumaqua AGILIS GREENBEAT

Piloting in

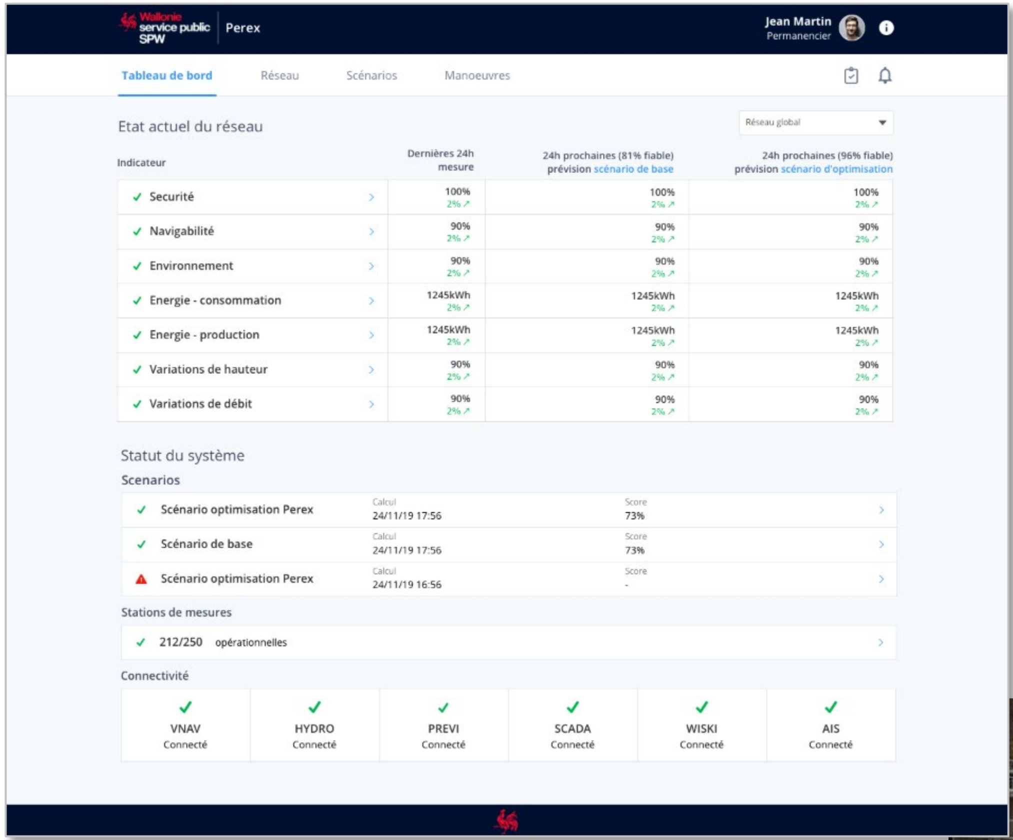
Antwerp (Belgium)
Eindhoven (Netherlands)

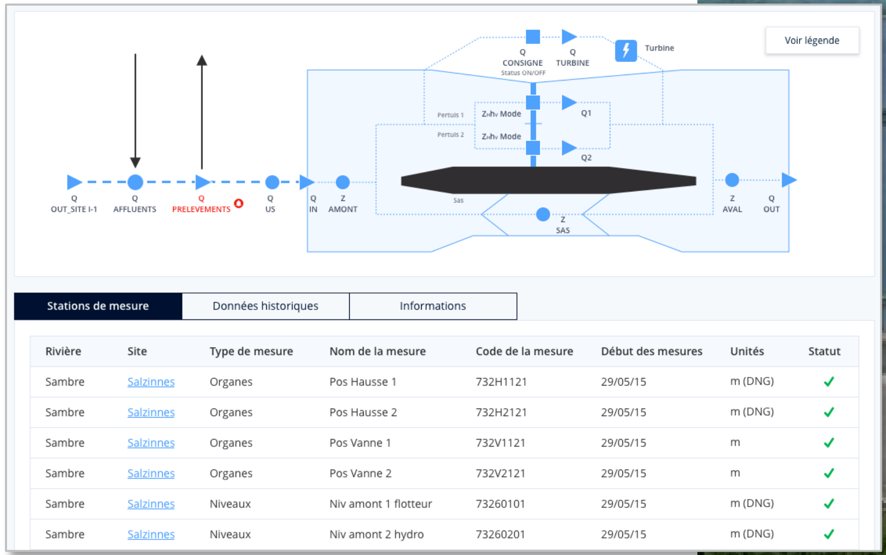
Funded by

SYNCHRONICITY

synchronicity-iot.eu/

Intelligent control of river systems





Wallonie service public SPW

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VLAAMSE MILIEUMAATSCHAPPIJ

Co... the European Union

Challenges faced during the development stage

- **Selection and installation of hardware**: to steer the water system, hydraulic infrastructure is needed (e.g. valve, pumps, …). It was a challenge to select hardware that is reliable, fits in the available space and can be controlled from a remote location.

- **Meteo uncertainties**: the intelligent control system relies on meteo forecasts. Inherently, such forecasts are uncertain and the control algorithm has to take such uncertainties into account to determine the best action.

- **Providing sufficient insight into decision of the intelligent control system**: the intelligent control system makes us of an MPC-RGA algorithm (model predictive control based on a reduced genetic algorithm). Hence, thousands of simulations are constantly performed to determine the best action. It is vital that the user is provided insight into why a decision is made. Thus, it is needed to visualize all objective functions and boundary conditions in a concise yet clear manner to the end user.

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Low flows occur more often, causing major economic and ecological impact

The Albertkanaal (archive picture) is an important link in Belgium's economy.
radio 2

Drought Commission asks to prepare "a cascade of measures" to be taken if water levels drop further

No extra measures are needed for the moment, but a go-ahead has been given to prepare a string of measures for Belgium's main waterways. That's the conclusion after the latest meeting of the so-called Drought Commission that looks into the impact of the present drought in Belgium and decides on possible drinking water restrictions.

Michaël Torfs
Thu 01 Sep 15:14

vrt nws flandersnews.be

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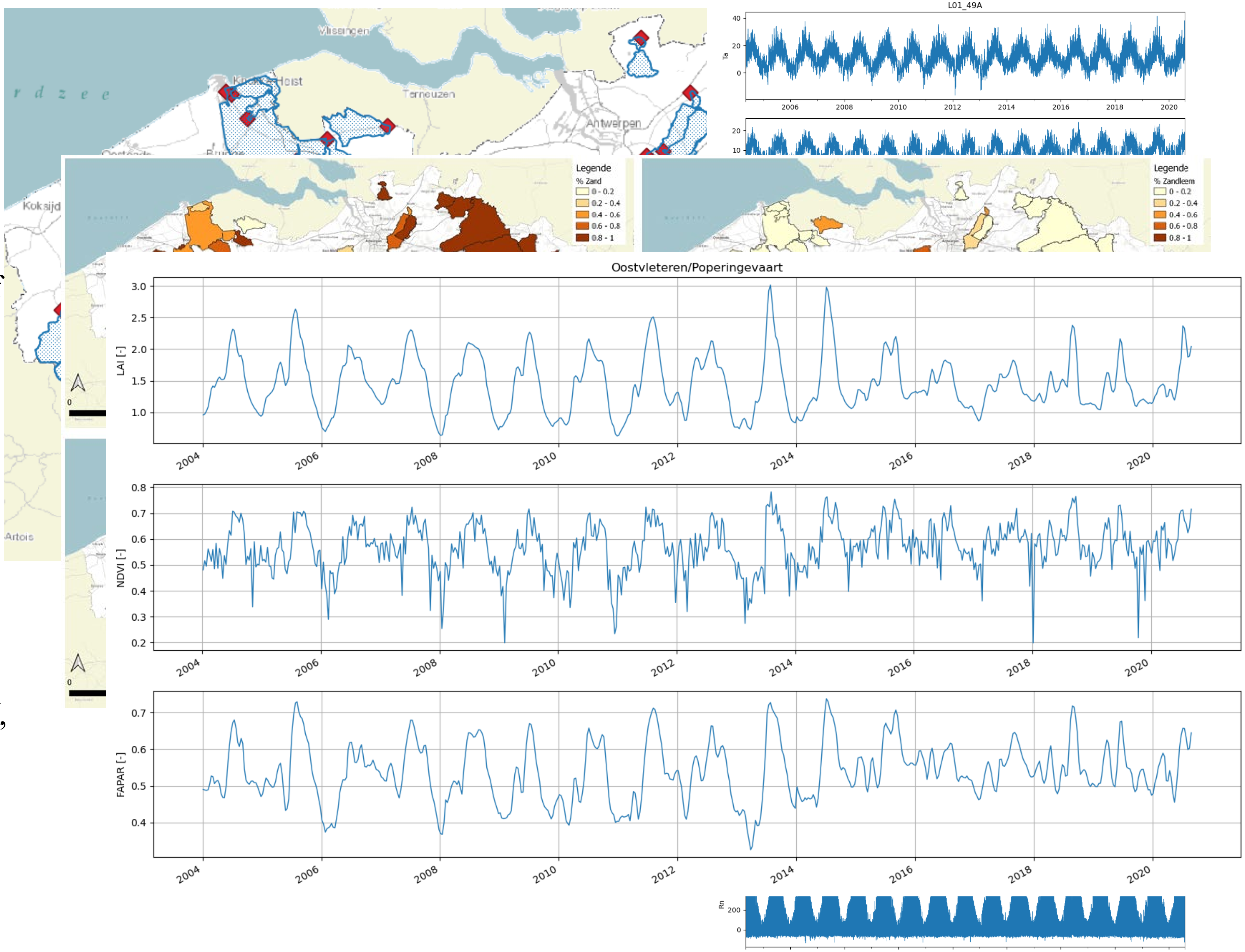
the European Union

Data

<u>Target variable</u>:
Discharge measurements of 100 locations distributed across Flanders

<u>Predictors:</u>

- Meteorological measurements
- Static properties of each catchment
- Effluent from water treatment plants
- Remote sensing data (LAI, NDVI, FAPAR)



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Setup of hAIdro

Large scale datasets

- ✓ Remote sensing
- ✓ GIS databases
- ✓ Climate model data
- ✓ Qualitative info
- ✓ …

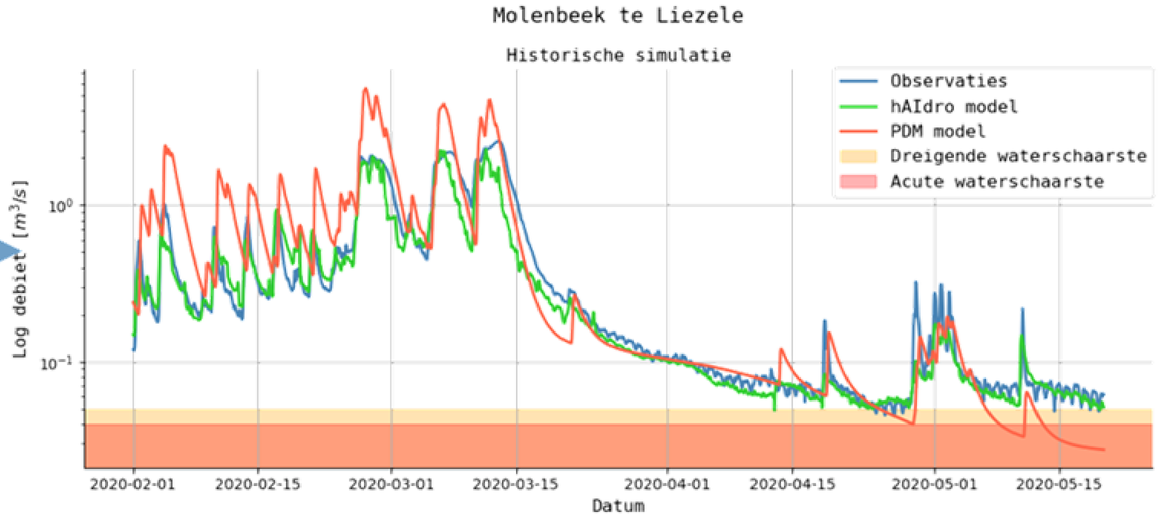
Process based models

hAIdro

Machine learning in a Big Data setting

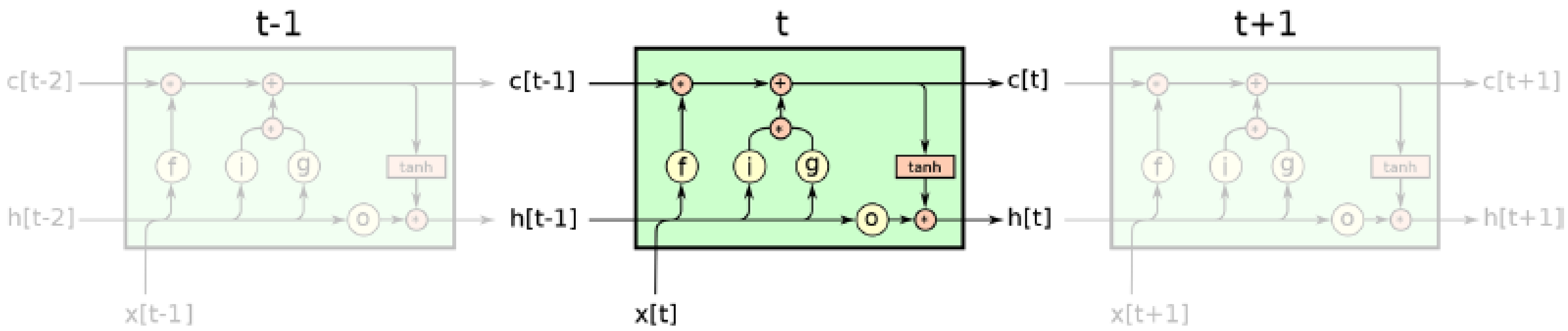
R
Apache Spark
Google Big Query
python
aws

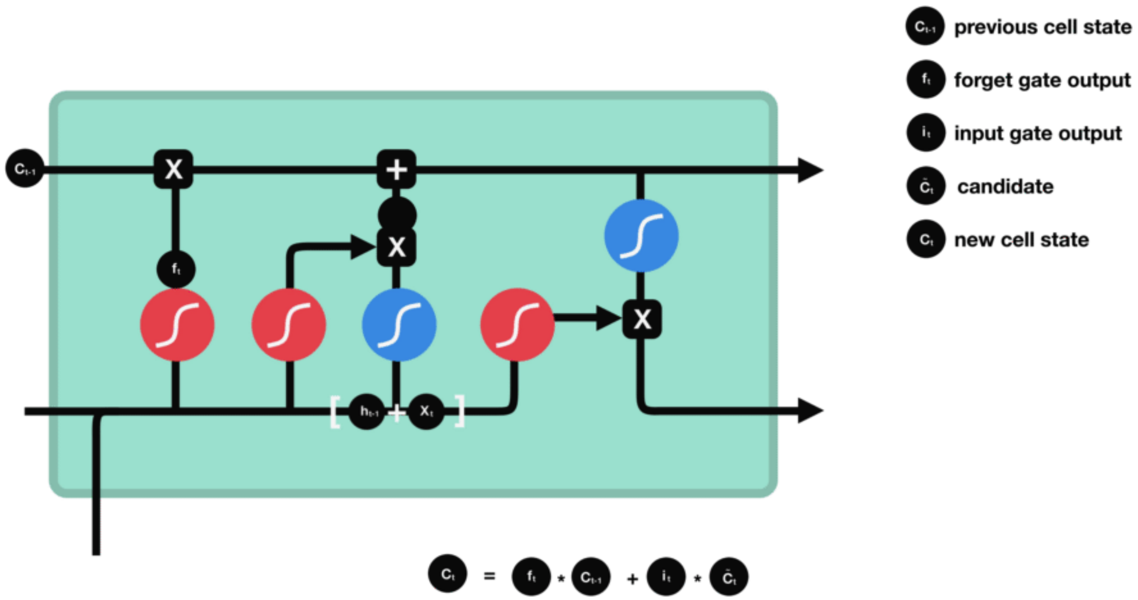
Low flow forecasts, up to 30 days ahead

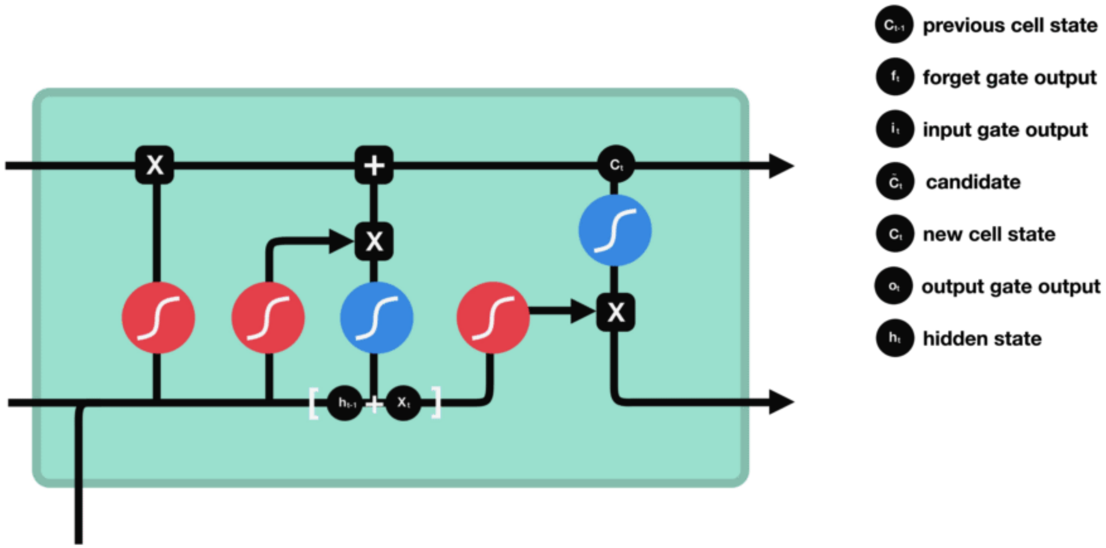


Model structure: LSTM

8 million datapoints used for training







hAIdro

Contact

Variabele

Categorie

Voorspelling

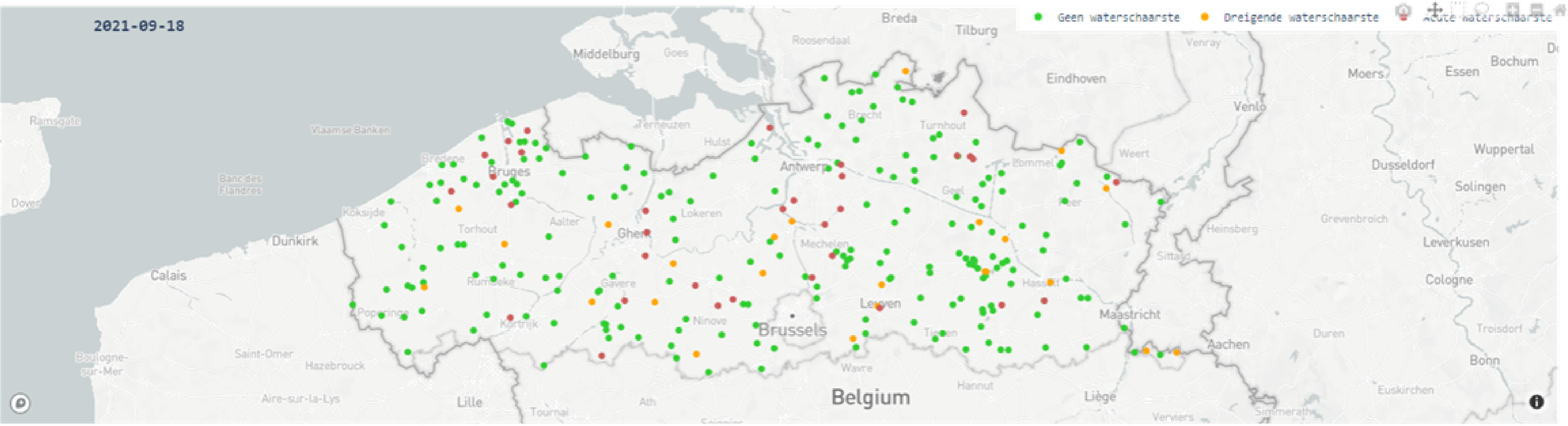
20210918T00

Station type

× Q × ungauged × H

Aantal dagen vooruit

0d 5d 15d 29d



Station

Select...

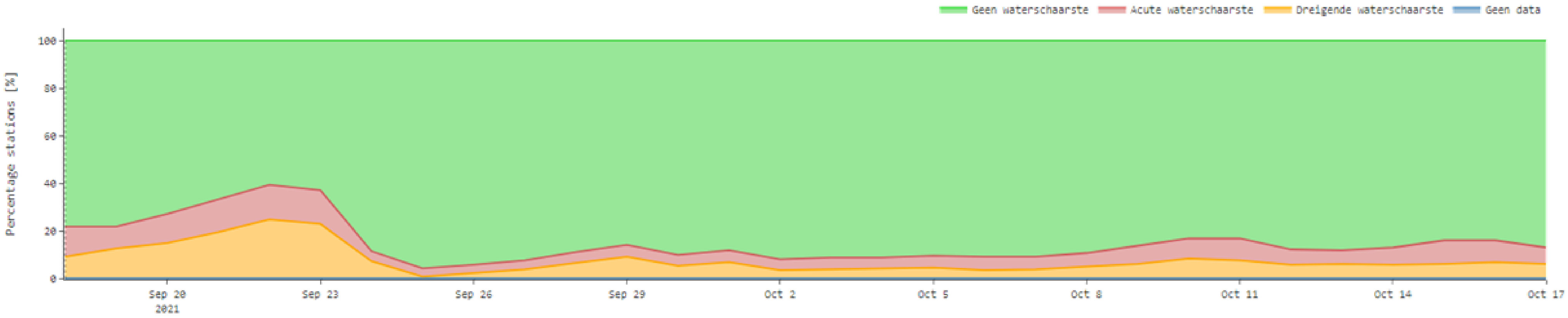
Frequentie

Dagelijks

Log schaal

Toon neerslag

Categorie



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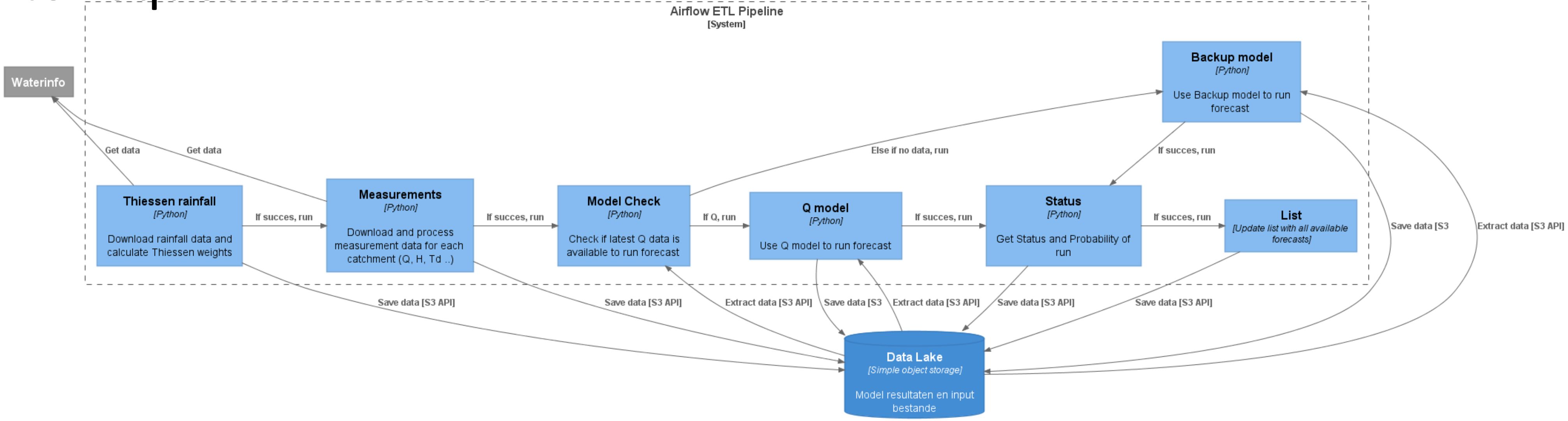
- Cloud based forecasting system to put models in production
- Low flows are forecasted 2x/day in 266 stations up to 30 days ahead
- Ensemble forecasts from ECMWF (50 members)
- API to request all results



Challenges faced during the development stage

- This is a novel machine learning approach based on a LSTM model. While applications of LSTM models are being found increasingly in (very) recent scientific literature, its application is still novel and encounters several challenges. The overall main challenge was to provide sufficiently accurate results with this LSTM model. Hereto, different model structures were tested, for which each a calibration was performed. To assess the extrapolation behaviour, a k-fold cross validation was performed.

- Another major challenge was the selection of appropriate input variables. Different input selection methods were tested to identify the most relevant input variables.

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Groundwater levels drop, causing limited water availability and huge ecological impacts

rob voss foto

Groundwater levels down dramatically, rivers and streams gradually dying up.

The ongoing drought has seen groundwater levels in Flanders fall dramatically. Groundwater levels in our region are already "low to very low" at 79% of the measuring points used. Meanwhile, water levels in rivers and streams have also fallen noticeably. Historically low average flow rates are being recorded at 18% measuring points along our waterways. That's according to new figures from the Flemish Environment Agency (VMM). While nature and agriculture (and now also shipping) are encountering ever greater difficulties as a result of the drought, there is no threat to drinking water supplies for the time being.

Fri 05 Aug 14:49

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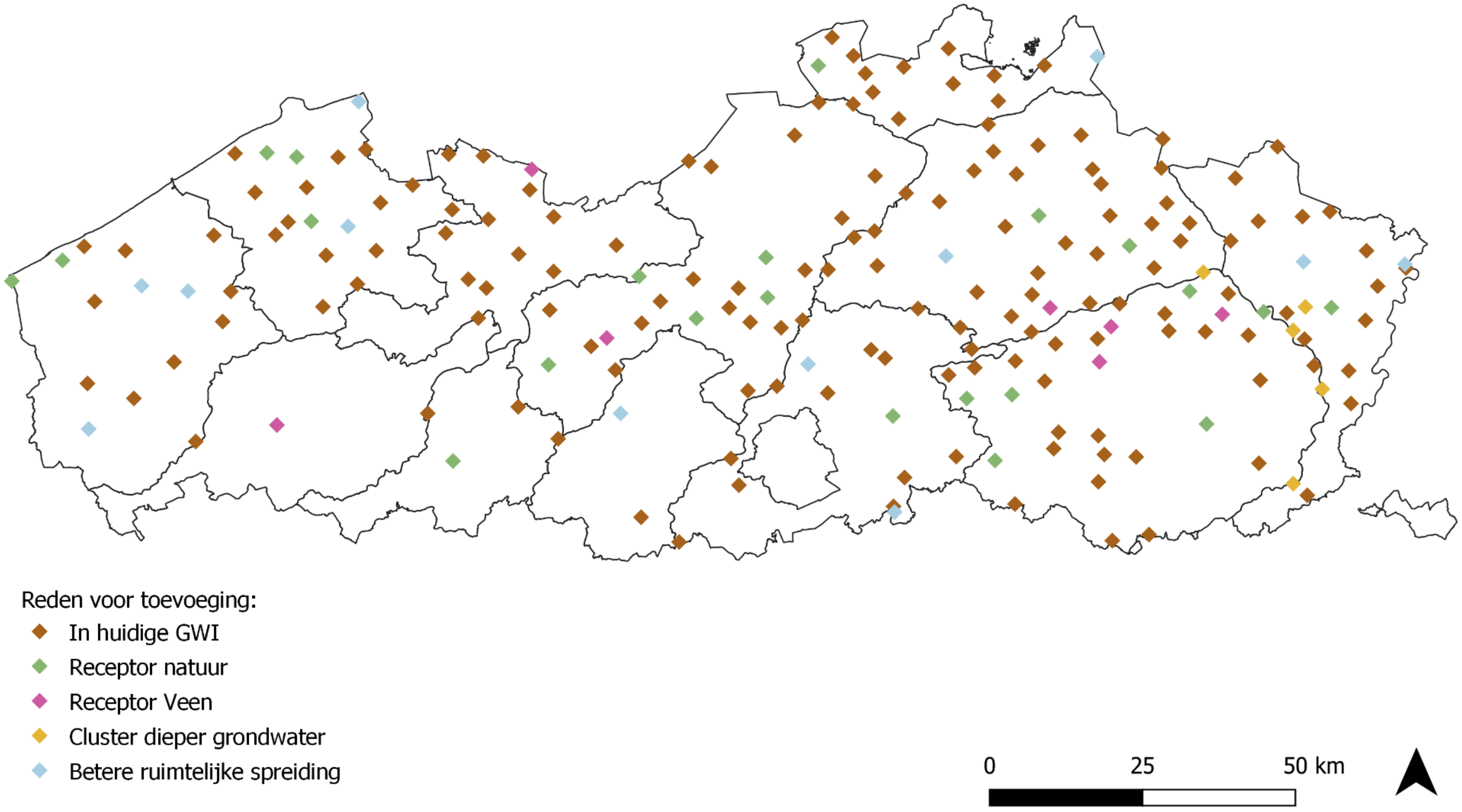
vrt nws flandersnews.be

Inventorizing datapoints ground water



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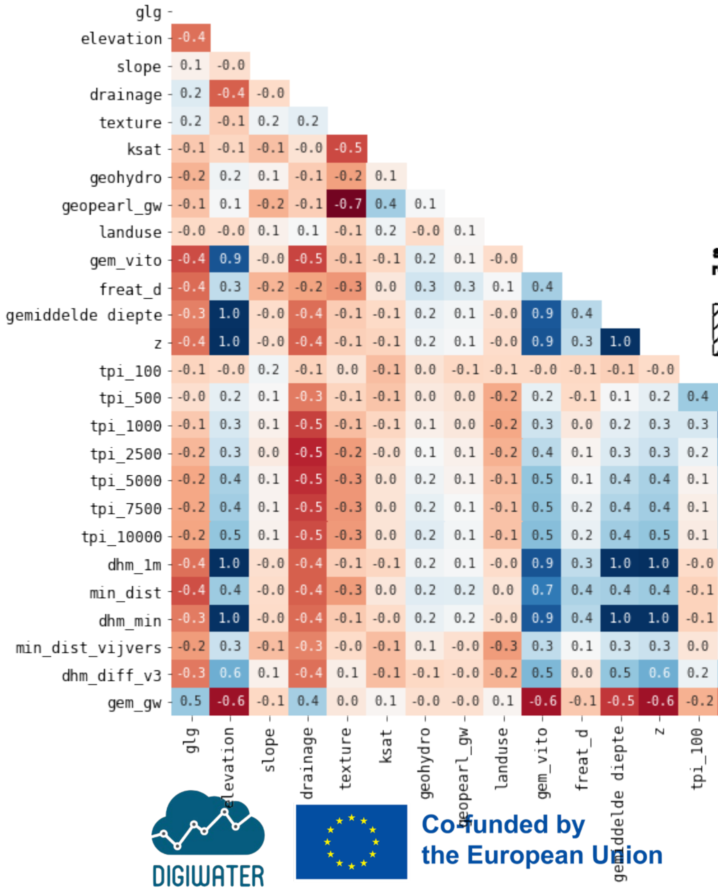
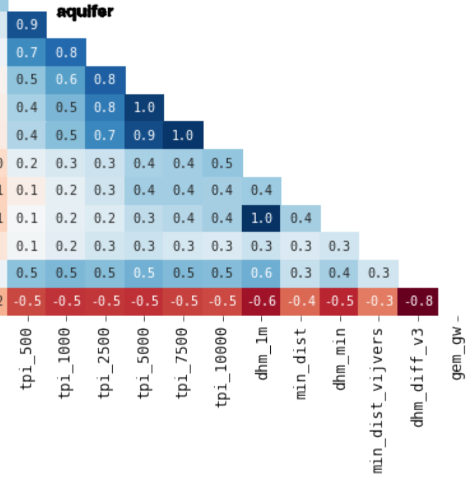
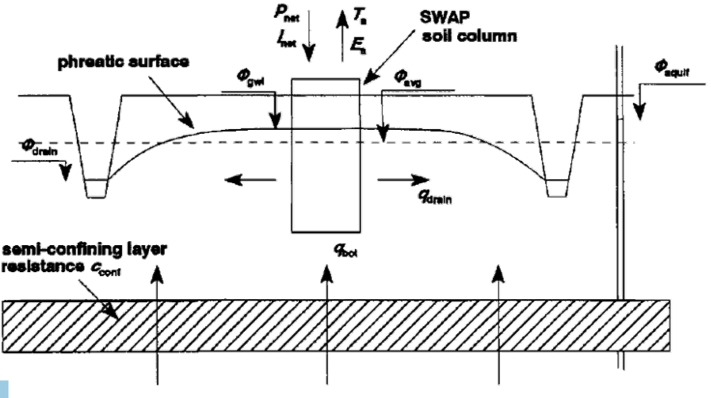
Which model is best to simulate groundwater levels?

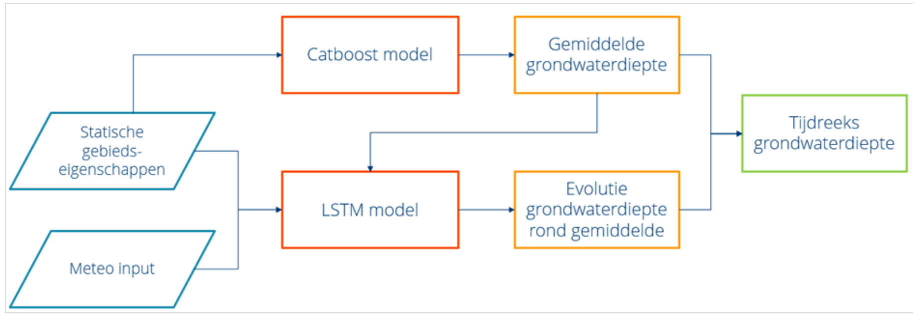
SWAP

(= detailed soil moisture and groundwater model)

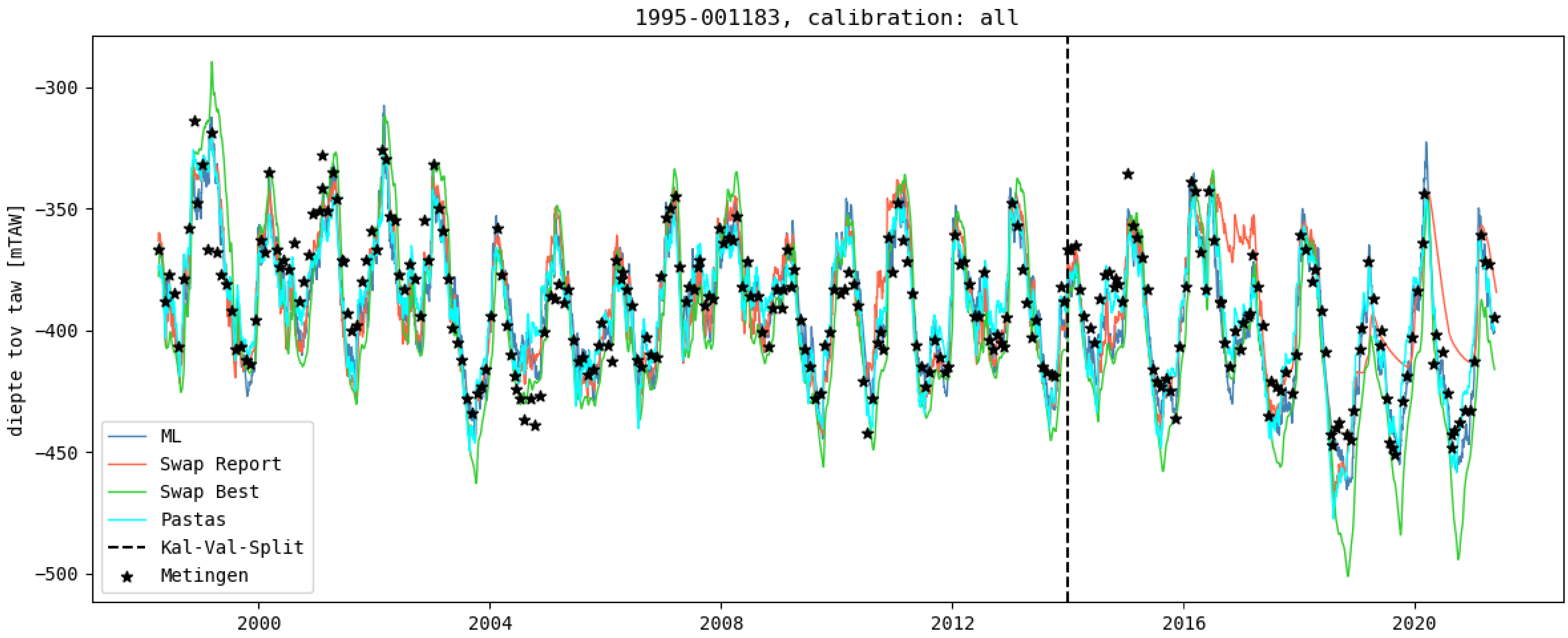


Machine learning models

(= combination of Catboost and LSTM)



Groundwater simulation results



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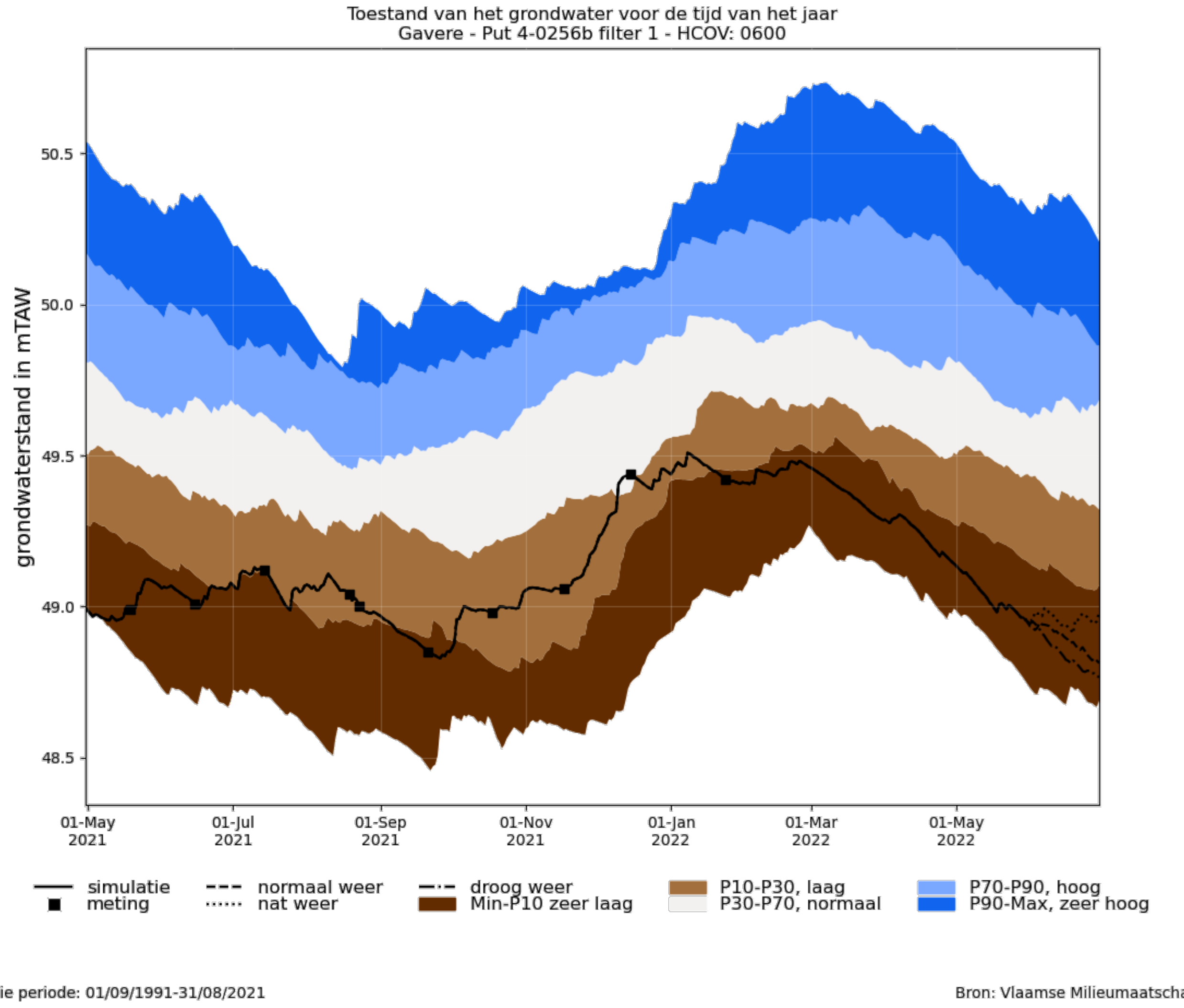
Example result: groundwater status



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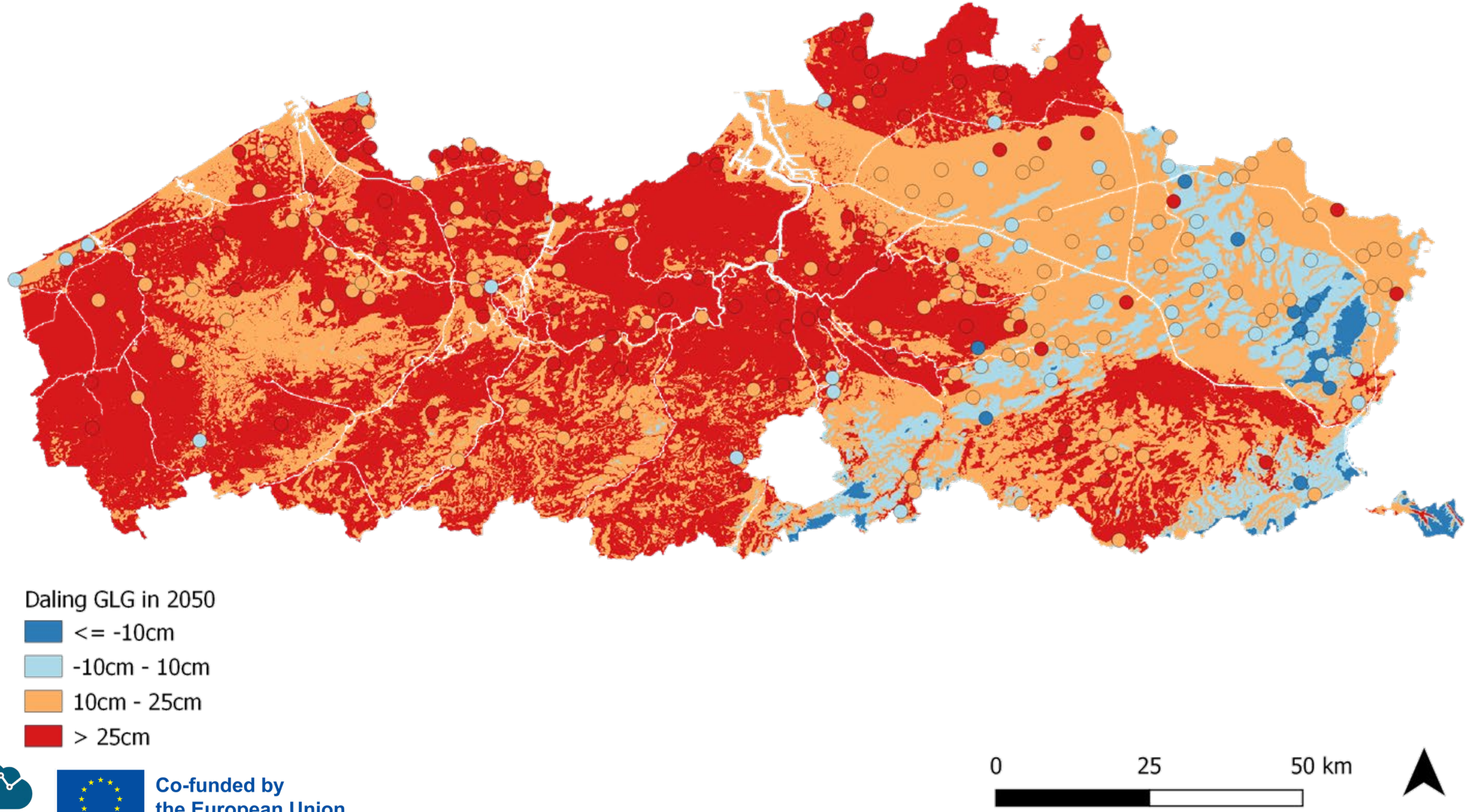
Changes in groundwater levels under future climate (2050)



Challenges faced during the development stage

- As with the hAIdro model, it was a challenge to select the correct input variables. For instance, rainfall series with different time lags (and moving average windows) can be selected. Hereto, we tested different input selection methods.
- Another challenge was to visualize the results of the groundwater indicator in a manner that is easily interpretable by a wide audience of both expert and non-expert users. The results of the groundwater model are published in popular press (e.g. newspapers), and hence had to be very clear and easily interpretable.

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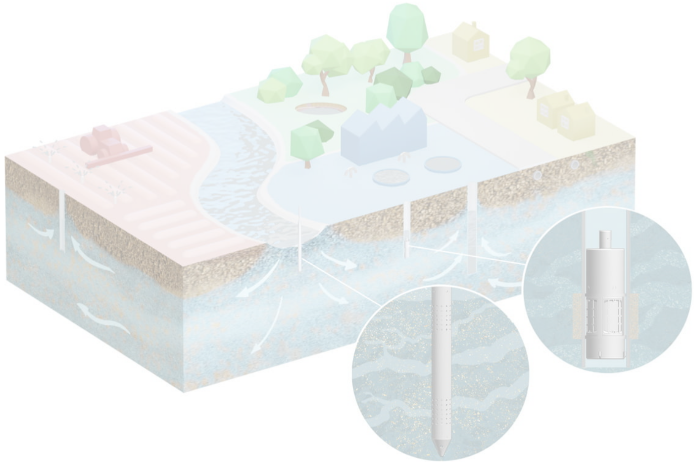
Case studies

Internet of Water
Netwerk of sensors measuring the water quality in Flanders



iFLUX
How does pollution move in the groundwater?

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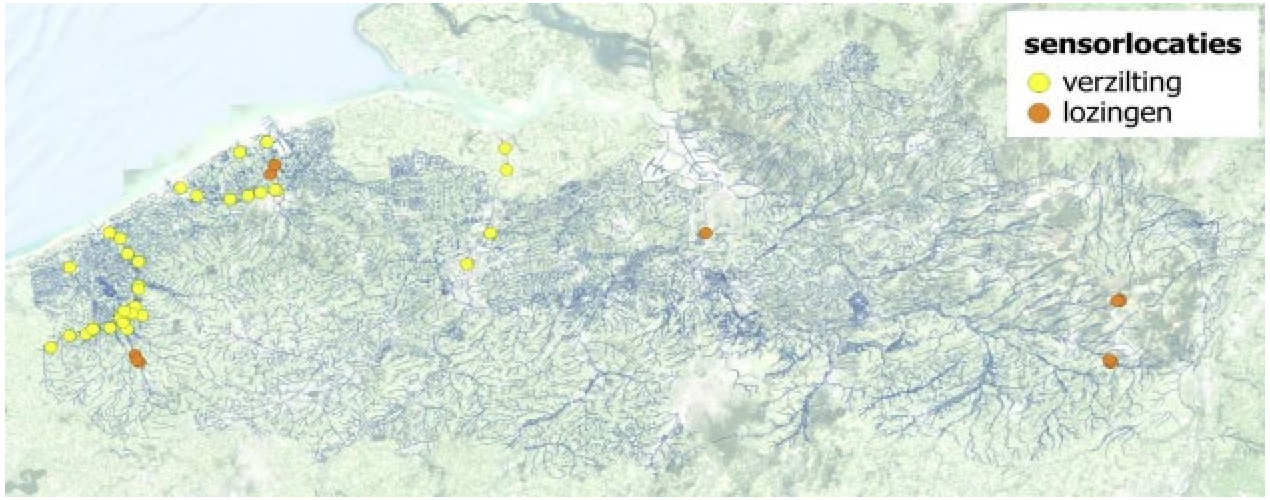
Internet of Water Flanders

Internet of Water Flanders

1) Real-time monitoring of discharges into the surface water

- Impact of domestic and industrial wastewater
- Overflows and incidents



2) Mapping real-time salinization

- On the coast and in the polders
- In port areas and canals

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Internet of Water Flanders

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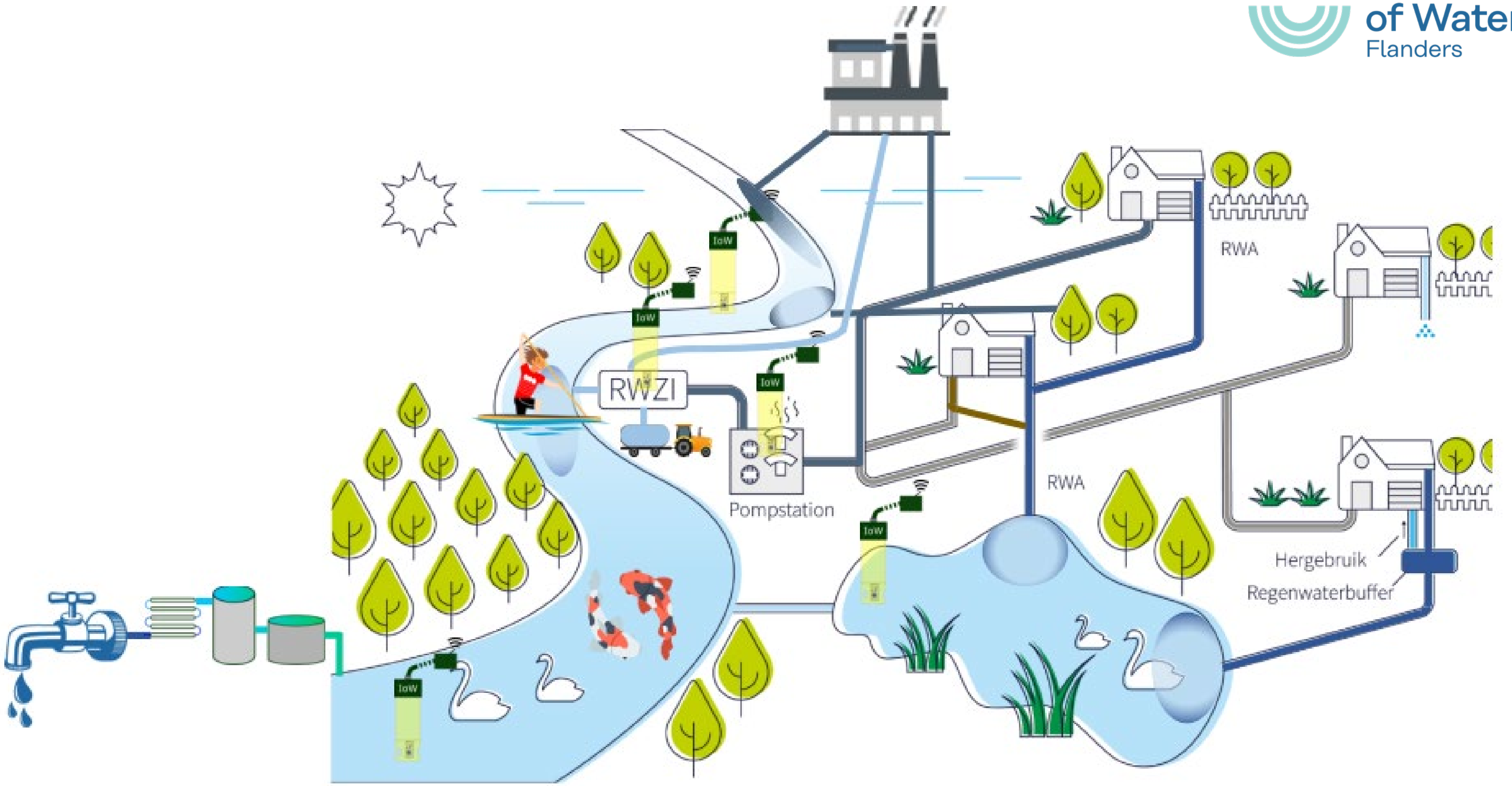
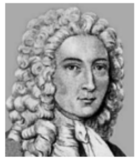
Overflows



Overflows

- h: easy & reliable
- Q: difficult/impossible
- h → Q (formule Poleni)



OVERSTORTEN
Debietformule van Poleni

$$Q_{CSO}(t) = \frac{2}{3} \cdot C_D \cdot B \cdot \sqrt{2gH^3(t)}$$

Measurement quantity

Measurement quality

- Very labour-intensive
- Sampling
- Continiuous measurement

Modelling quantity

- Waterlevels
- Discharges (Poleni)
- Detail vs. conceptual model

Modelling quality

- Large uncertainties wash-off & sedimenttransport
- Alternatives (e.g. CSO generator)

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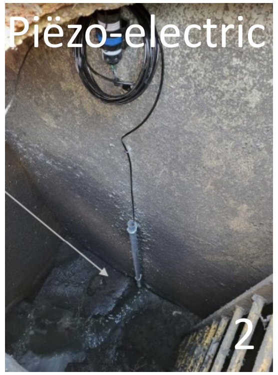
Water quantity

→ waterlevels

→ discharges

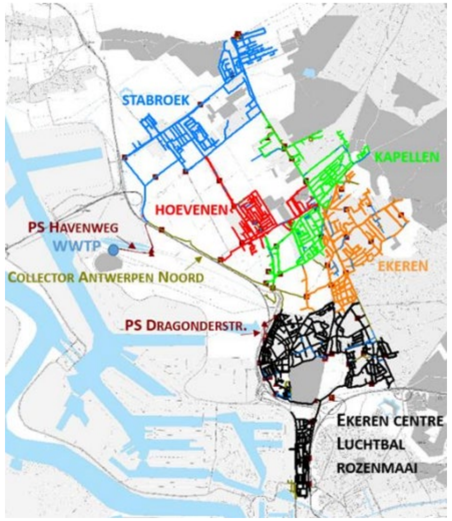
Measurement

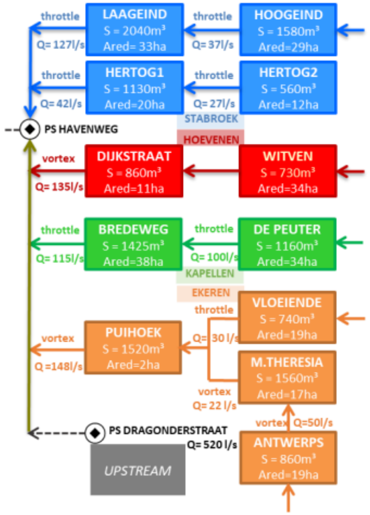
1) Distance: time reflected wave
2) Distance: pressure on membrane
3) Velocity: frequency shift (Doppler)



Modelling

1) Hydrodynamic
2) Conceptual model





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Water quality

Measurement

1) Continuous measurement pollutants: expensive and labour intensive
2) Continuous measurement proxy's: cheaper, but no unambiguously conversion
3) Discontinuous measurement pollutants: cheaper but labour intensive

Modelling

1) Dissolved fraction (NH4, TP, …): conservative mass transport
2) Attached fraction (BZV, CZV, …): much uncertainty in wash-off and sediment transport

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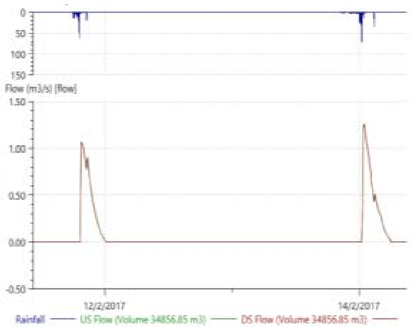
COCKLE

DEBIET

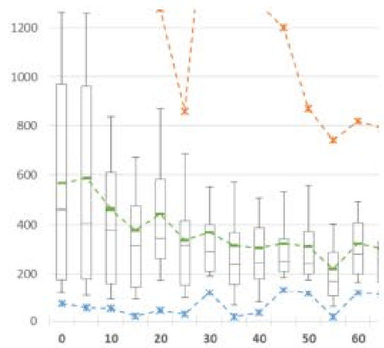
Gemodelleerd
(hydrodynamisch)
of
Gemeten
(geconverteerd
waterpeil)



CSV

CONCENTRATIE

Stochastische
databank
metingen



COCKLE

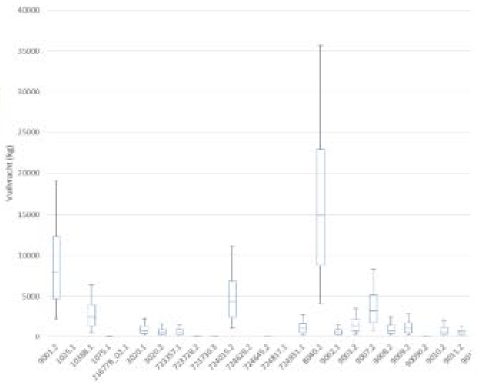
Calculator of Overflow
Concentration-Known
Load Emissions

python

XLSX

RAPPORTAGE

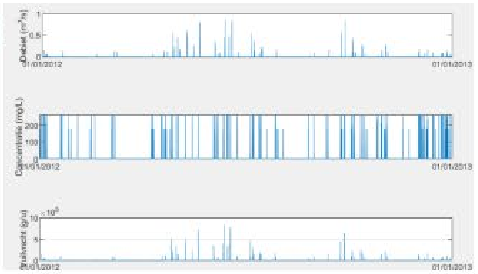
(Vracht)
Emissie
statistiek



CSV

GEDETAILLEERDE TIJDREEKSEN

Momentane
impact



COCKLE

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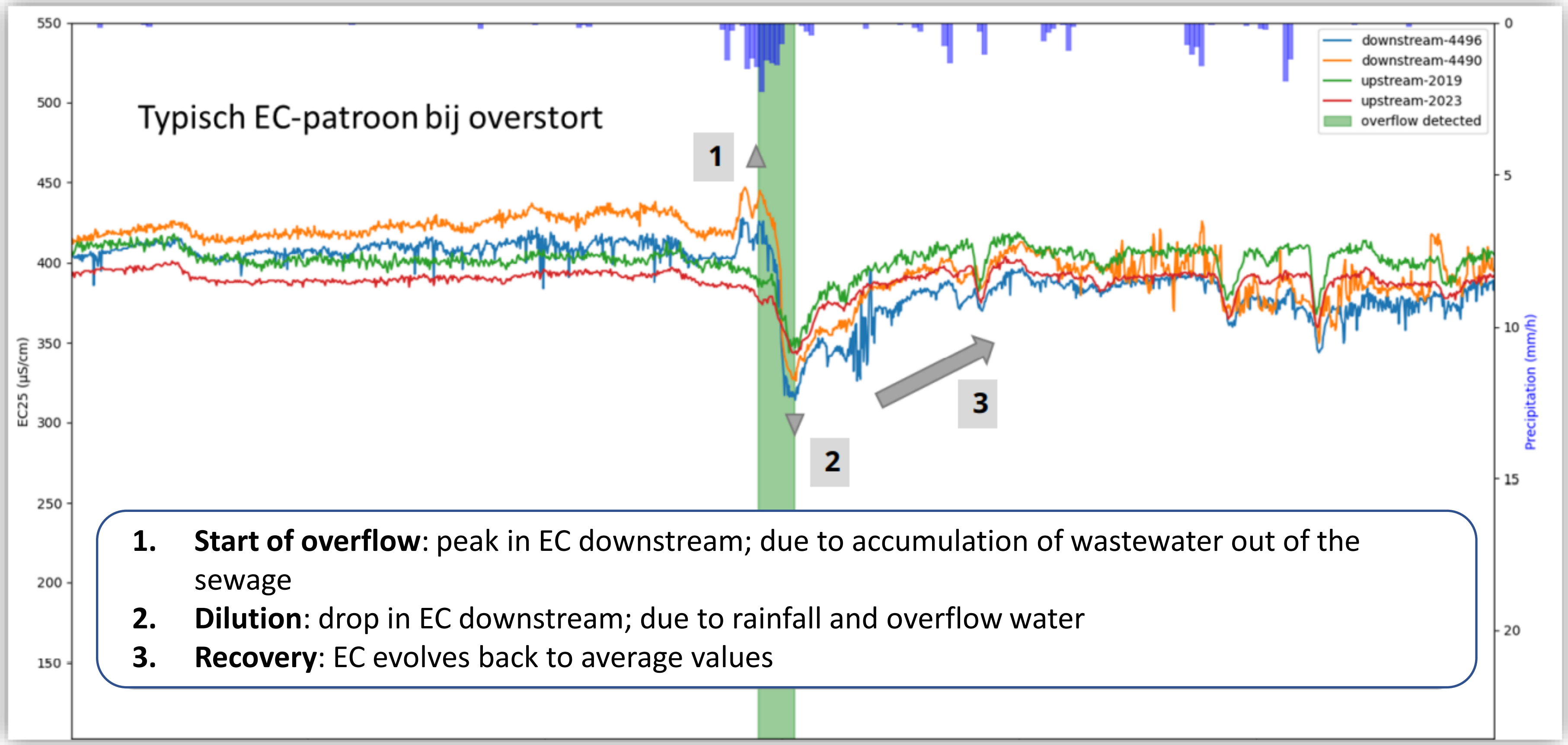
Typical EC-pattern overflow



Overflow detection based on:

- CUSUM algorithm (cumulative control chart): detection of 'change'
- Detection 'lift' and 'drop' in EC measurements
- Rainfall threshold

Detection overflowevents

Applications:

- Frequency of overflowevents with impact
- Duration of impact of overflow
- Size of impact of overflows

Importance:

- Many overflows are not measured
- Overflows become more important with increasing degree of purification
- Measurement impact in the waterway vs. Registration overflow
- Prioritisement based on impact on waterway

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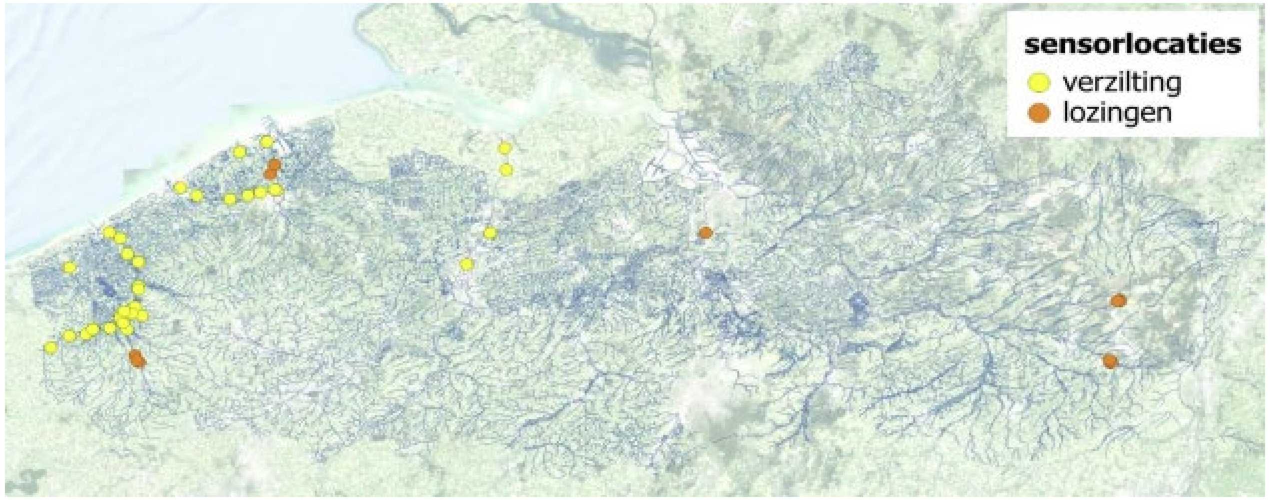

1) Real-time monitoring of discharges into the surface water

- Impact of domestic and industrial wastewater
- Overflows and incidents

2) Mapping real-time salinization

- On the coast and in the polders
- In port areas and canals

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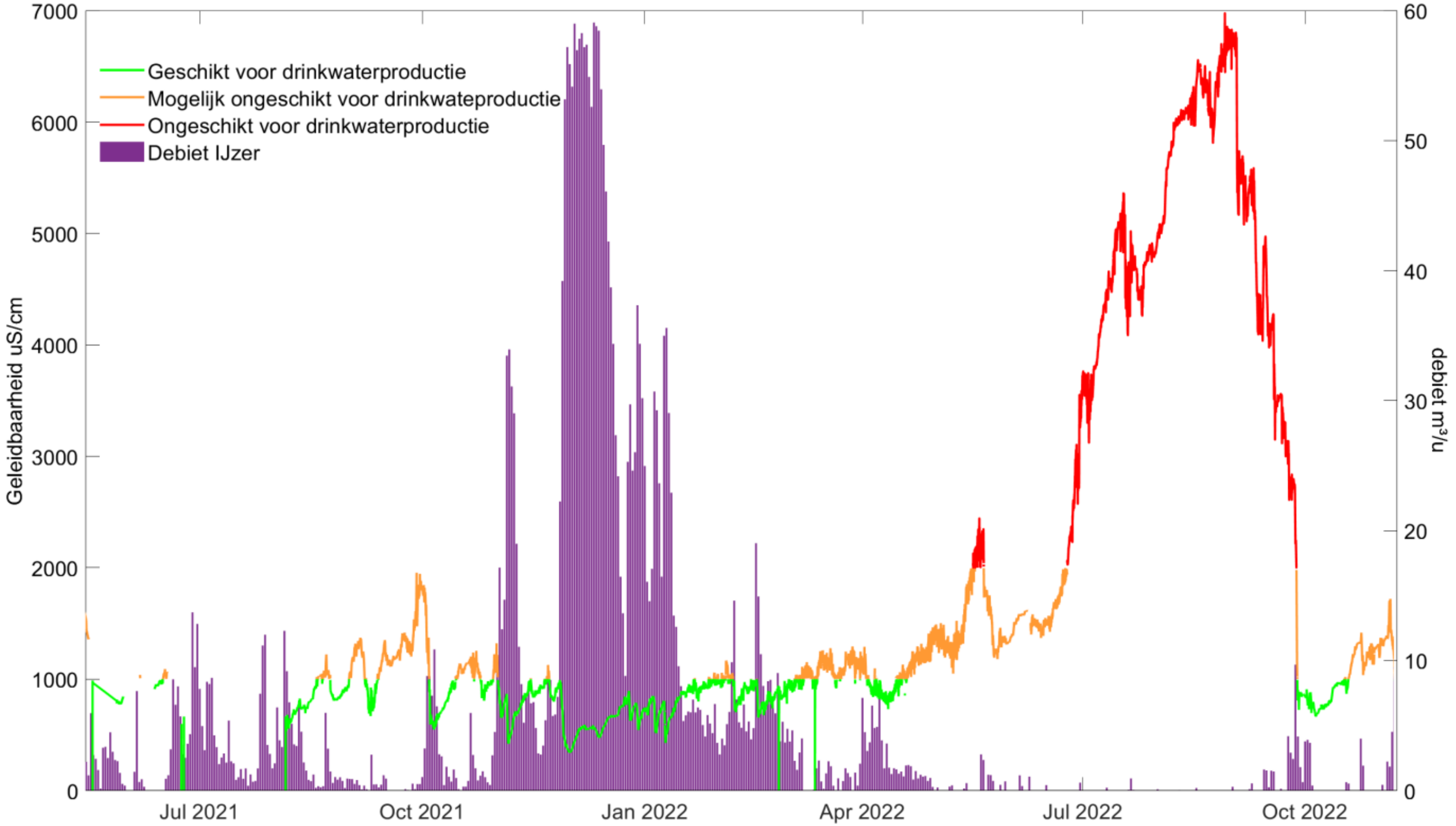
Salinization



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Salinity as a dryness indicator

- Insufficient flow to wash away penetrating ‘salt tongues’
- Low water levels can lead to upward seepage of saline groundwater
- Low rainfall results in less dilution of industrial effluents
- Salinization affects capture by industry, agriculture and drinking water production

→ **Salinization is a good proxy indicator for the cumulative effect of drought**

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Salinization indicator

How do we convert sensory conductivity data to easily interpret information and indicators for salinization?

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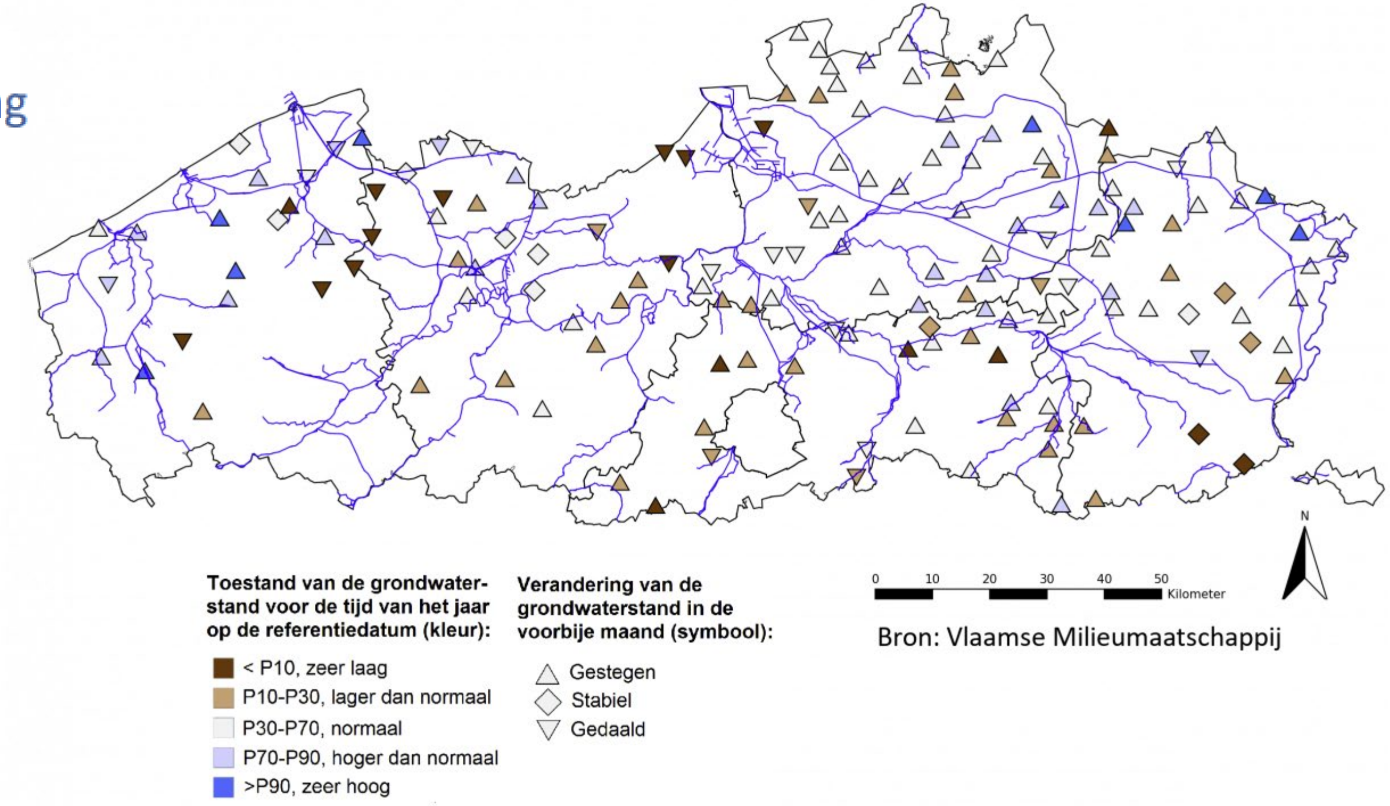
Salinization indicator

cfr. groundwater level indicator

Situation 5/02/2023

- $\frac{GW_{t-1\,maand} - GW_t}{p90 - p10} * 100 < -5\ \%$: stijging
- $\frac{GW_{t-1\,maand} - GW_t}{p90 - p10} * 100 > 5\ \%$: daling
- Ander geval: stabiel



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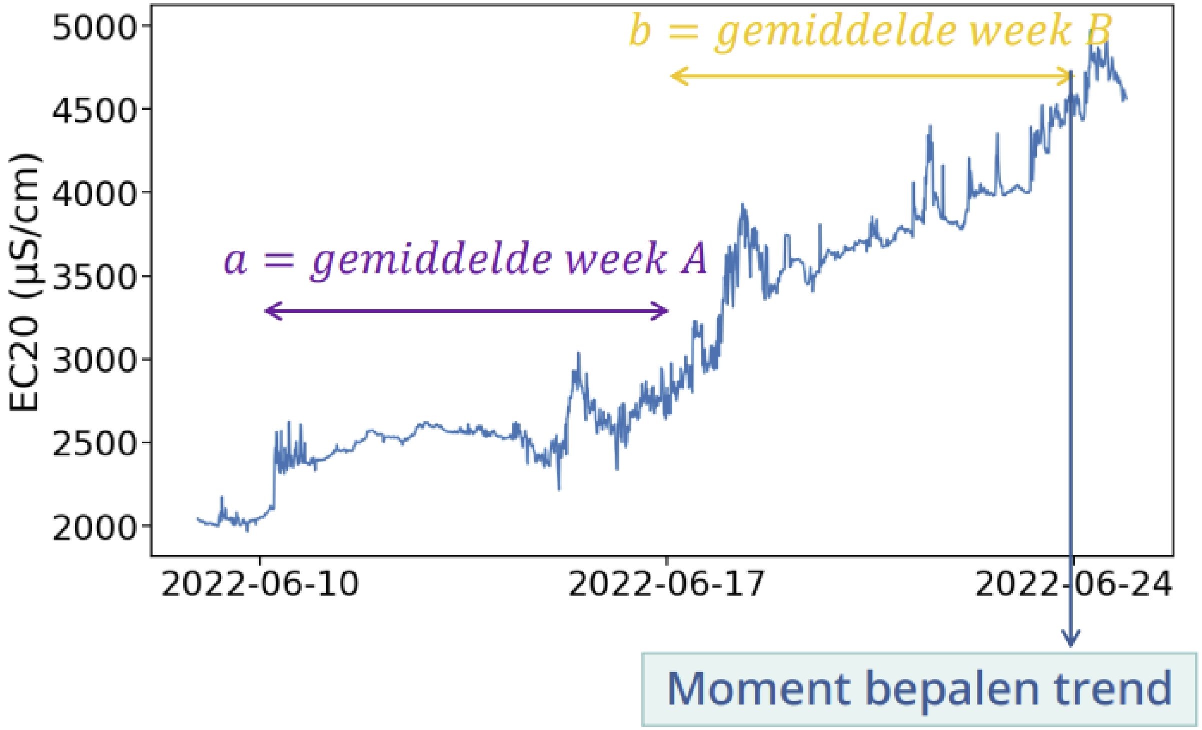
Salinization indicator

Surface water ‘faster’ system than groundwater → measuring with weeks instead of months



$$trend = \frac{b - a}{p90 - p10} * 100$$

↓

- *trend > 5%* → *stijging*
- *-5% < trend < 5%* → *stabiel*
- *trend < -5%* → *daling*

Salinization indicator

Status conductivity, general thresholds

Status	**Conductivity as indicator for salinization**
Normale	Median measuring points conductivity < 2.000µS/cm
Waking phase: dry	Median measuring points conductivity > 2.000µS/cm
Alarm phase: very dry	Median measuring points conductivity > 4.000µS/cm
Crisis: extremely dry	Median measuring points conductivity > 8.000µS/cm

Status conductivity, Thresholds depending on measuring point

Status	**Conductivity as indicator for salinization**
Normale	Conductivity <75th percentile
Drought condition 1	Conductivity >75th percentile
Drought condition 2	Conductivity >95th percentile

Trendindication: situation ameliorating or deteriorating

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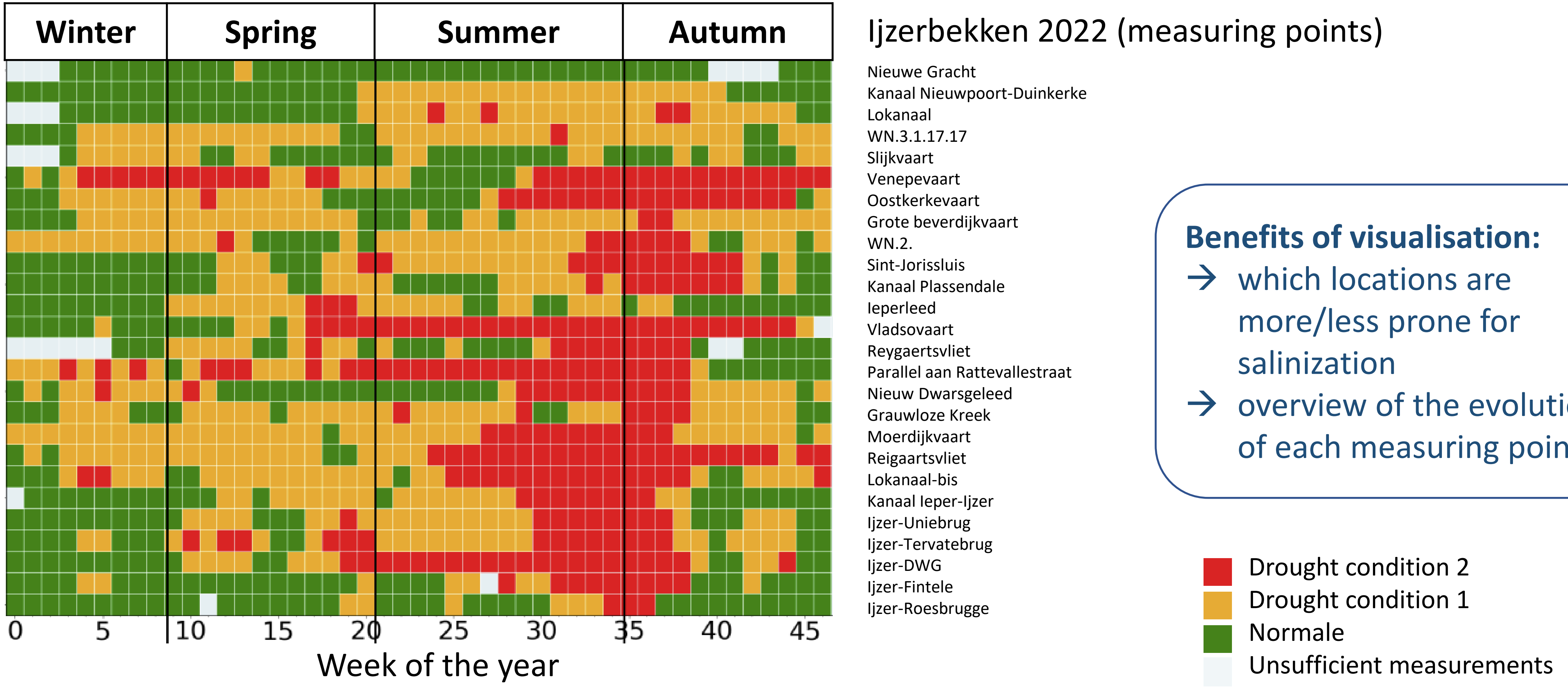
Visualisation of salinization indicator

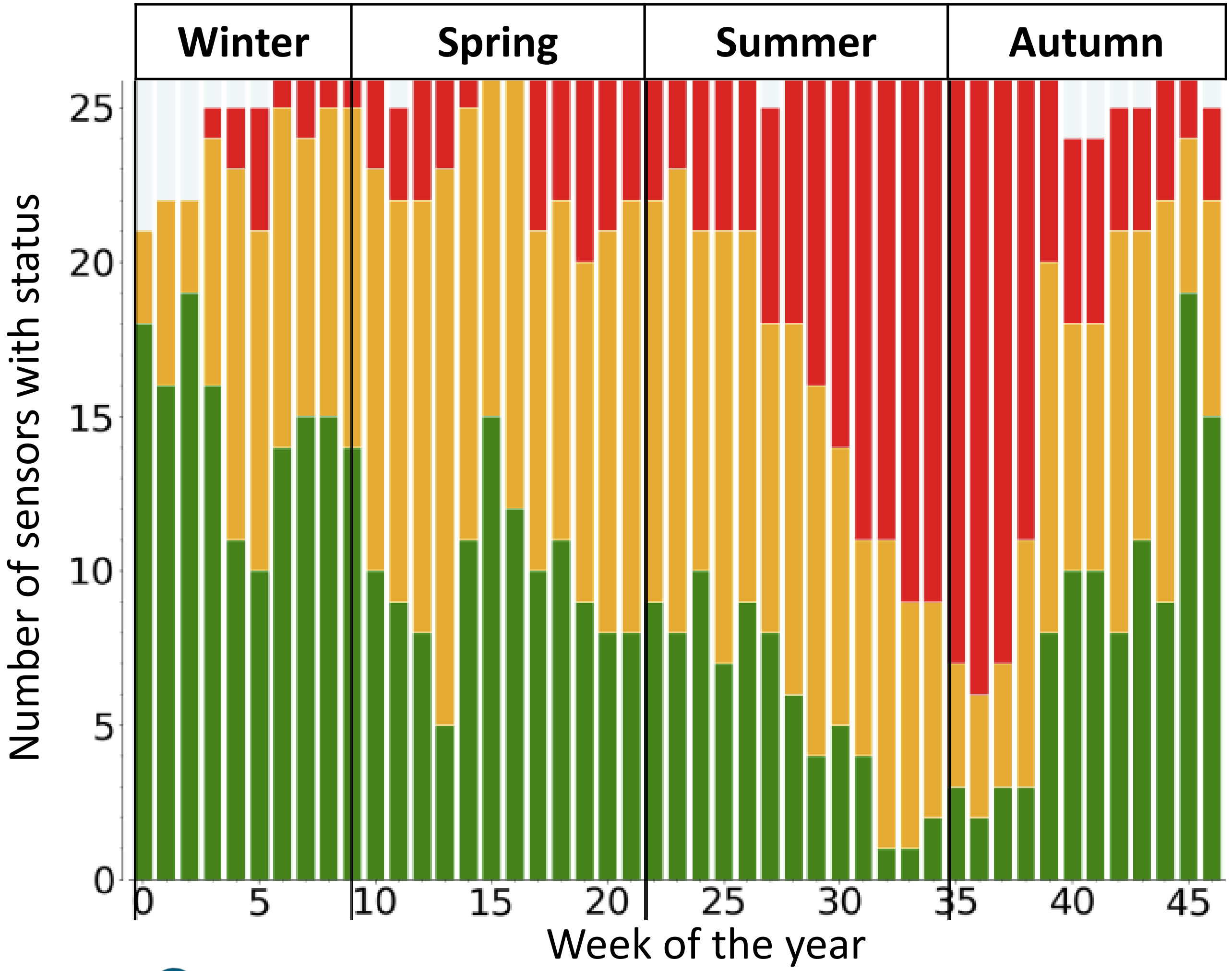


Benefits of visualisation:

→ which locations are more/less prone for salinization

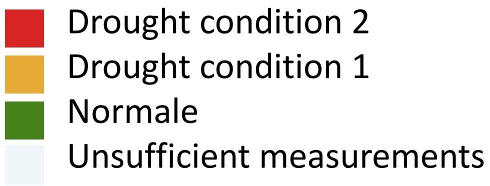
→ overview of the evolution of each measuring point

Visualisation of salinization indicator



Ijzerbekken 2022 (measuring points)

Benefits of visualisation:
→ Evolution of the year
→ Absolute numbers per status



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Visualisation of salinization indicator

increasing

stable

decreasing

Drought condition 2
Drought condition 1
Normale
Unsufficient measurements

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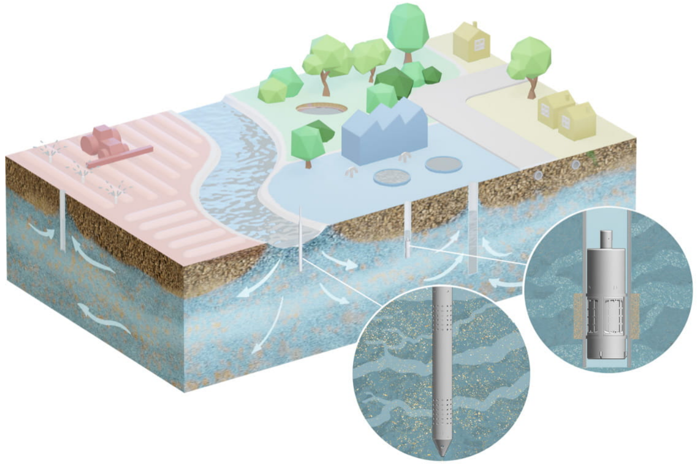
Case studies

Internet of Water

Netwerk of sensors measuring the water quality in Flanders



iFLUX

How does pollution move in the groundwater?

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iFLUX is a spin-off company of the University of Antwerp and
VITO and has a unique state of the art technology on
groundwater.

Challenges?

SITE REMEDIATION

- ✓Determine spreading risk
- ✓Optimize remedial design
- ✓Shorten after-care monitoring

AGRICULTURE

- ✓Ensure water supply
- ✓Monitor nitrate run-off
- ✓Manage water drainage and irrigation

LAND RESTORATION

- ✓Guide nature conservation
- ✓Manage drought risks
- ✓Screen diffuse pollution
- ✓Control salt water intrusion

WATER INFRASTRUCTURE

- ✓Circular groundwater use
- ✓Determine infiltration capacity
- ✓Monitor environmental impact
- ✓Smart dewatering systems

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Some case studies

Agenda

- Introduction
  IoT, Big Data and watermanagement in EU

- Case studies
  1. RainBrain
  2. hAidro
  3. Groundwater indicator
  4. Internet of Thing
  5. iFLUX
  6. …

- Conclusion
  key insights, take away messages, bottlenecks, challenges, …

Conclusion

- Key insights
- Take away messages
- Bottlenecks
- Challenges

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Key insights

1. Technology is improving → more and more opportunities
   - New sensors (e.g. nitrate sensors, flow/flux sensors, low-power gauges, …)
   - Advanced data analytics (AI, machine learning, deep learning, …)

2. Many projects are running→ lessons learned

Take away messages

✓**Upscale** projects to larger area, different areas, different sectors, …

✓**Open data**: make results and measurements accessible

✓**Visualisation** of results for better understanding

✓**Participation**: involve the relevant partners and actors from the field

✓**Reduction of costs** on the longterm (by avoiding damage)

Determine a well-defined strategy:

→start from an existing problem, what is your goal?

→no ‘ad hoc’ solutions, think bigger

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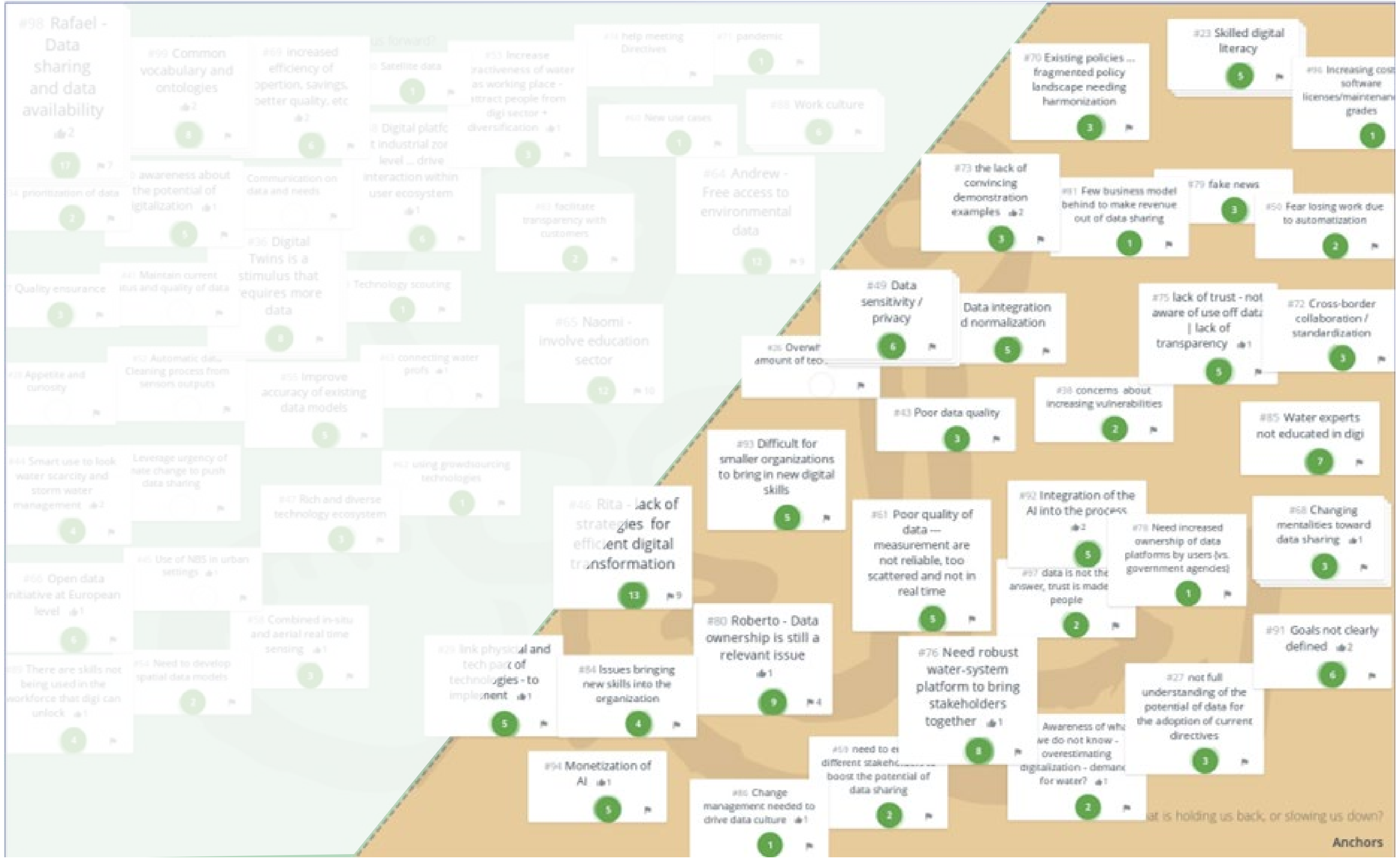
Bottlenecks

- Data sharing and data availability
- Lack of strategies for efficient digital transformation
- Data ownership



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Challenges

Cybersecurity

Climate change → more extreme events
Impossible to 'manage' all natural or man-made disruptions/disasters

Resources: funding, time, people, …

Holistic approach (environmental, social, cultural, health, economic, …)

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