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Bundesministerium für Bildung und Forschung

FlexTreat

Wastewater Reuse for agriculture - Smart Control Concepts

SIWW Water Convention 2022

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Outline

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- Overview FlexTreat Project
- Reuse pilot treatment train
- Smart Control Concepts
- Digital Twin
- Summary and Outlook

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Project objektives & Goals

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Flexible and reliable concepts for sustainable water-reuse in agriculture

Goals

- Development and Demonstration of flexible treatment solutions
- Innovative Process controls (Digital Green Tech)
- Integrated Assessment
  Water quality, Environmental & Health Risk, Resilience, Economic and Environmental Dimension
- Pro-active promotion of the reuse potential (applications)

- „Guideline Risk Management" – based on European Minimum Requirements (EU 2020/741 25. May2020)
- „Guideline Technologies"

FlexTreat: Funded by German Federal Ministry of Education and Research (BMBF) under FKZ 02WV1561A-L

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EU Minimum Requirements for Agricultural Reuse 2020

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(EU 2020/741 25. May2020)

<table>
<tr><th rowspan="2">Reclaimed water quality class</th><th rowspan="2">Indicative technology target</th><th colspan="5">Quality requirements</th></tr>
<tr><th>E. coli (cfu/100 ml)</th><th>BOD_5 (mg/l)</th><th>TSS (mg/l)</th><th>Turbidity (NTU)</th><th>Other</th></tr>
<tr><td>A</td><td>Secondary treatment, filtration, and disinfection</td><td>≤10 or below detection limit</td><td>≤10</td><td>≤10</td><td>≤5</td><td>Legionella spp.: <1,000 cfu/l where there is risk of aerosolization in greenhouses</td></tr>
<tr><td>B</td><td>Secondary treatment, and disinfection</td><td>≤100</td><td rowspan="3">According to Council Directive 91/271/EEC[1] ((Annex I, Table 1)</td><td rowspan="3">According to Directive 91/271/EEC ((Annex I, Table 1)</td><td>-</td><td rowspan="3">Intestinal nematodes (helminth eggs): ≤1 egg/l for irrigation of pastures or forage</td></tr>
<tr><td>C</td><td>Secondary treatment, and disinfection</td><td>≤1,000</td><td>-</td></tr>
<tr><td>D</td><td>Secondary treatment, and disinfection</td><td>≤10,000</td><td>-</td></tr>
</table>

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Drivers for advanced wastewater treatment

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- National:
  - Protection of aquatic ecosystems
  - Removal of chemicals (CEC)
- EU level:
  - Harmonized microbial quality targets for water reuse

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Flexible and reliable concepts for sustainable water-reuse in agriculture

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Investigated Technologies

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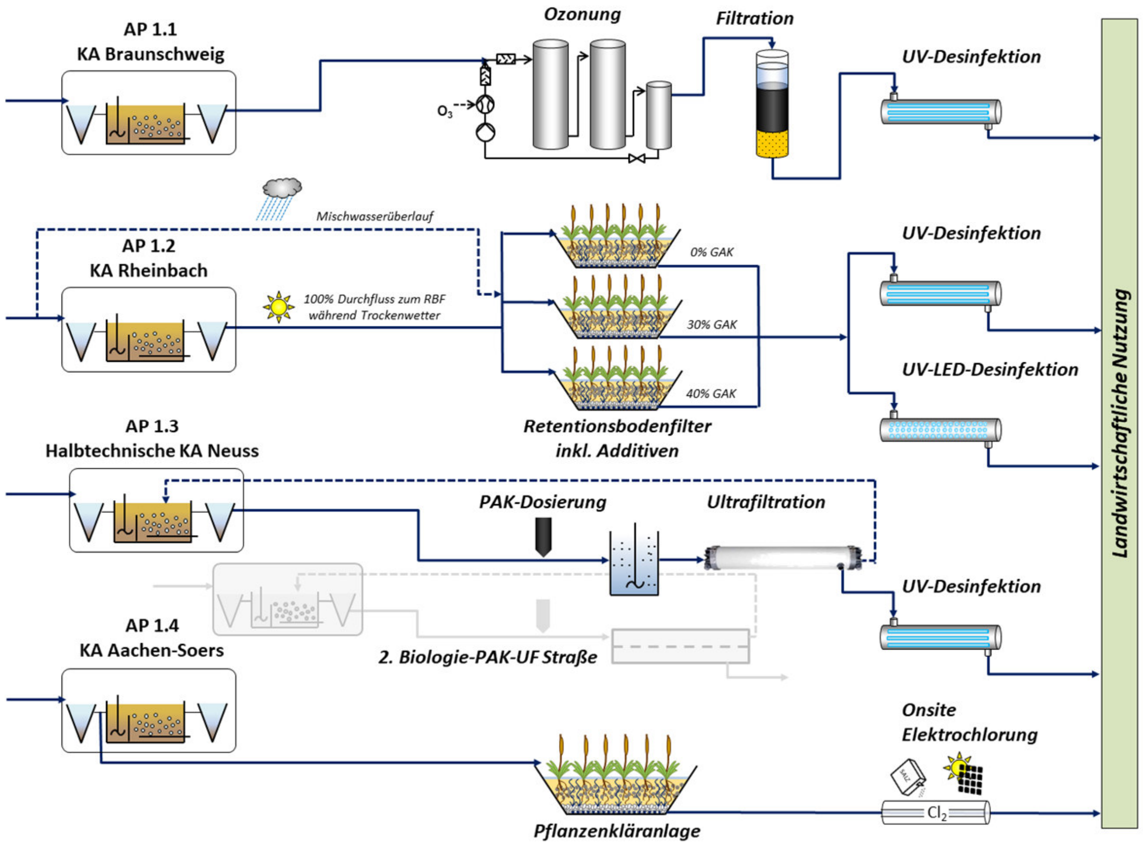

TECH1 Ozone + Biofiltration + UV

TECH2 Retention Soil Filter + UV

TECH3 UV-LED

TECH4 Inline Flocculation + PAC + UF

TECH5 Onsite electro Chlorination

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Tech 1: Scheme pilot plant at WWTP Braunschweig

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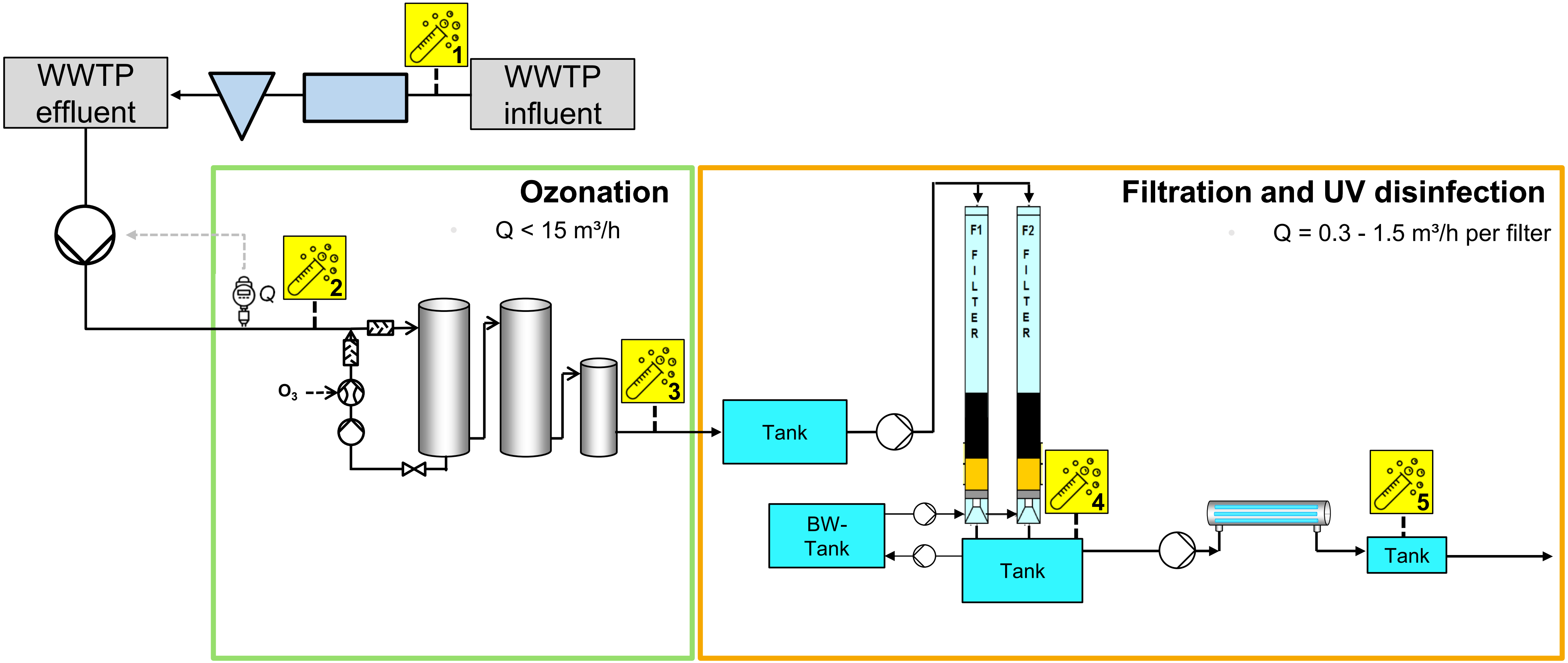

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Quality targets of the advanced treatment train

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Ozonation
- Remove prefined list of chemicals > 80 %
- Compliance on annual average

Filtration
- Remove particles to levels below 1 mg/L
- Compliance based on online turbidity measurement

UV-Disinfection
- Achieve Class A water quality (< 10 E.Coli/100 mL)
- Compliance on weekly sampling (90 % of samples)

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Set up Physical Plant and Digital Twin

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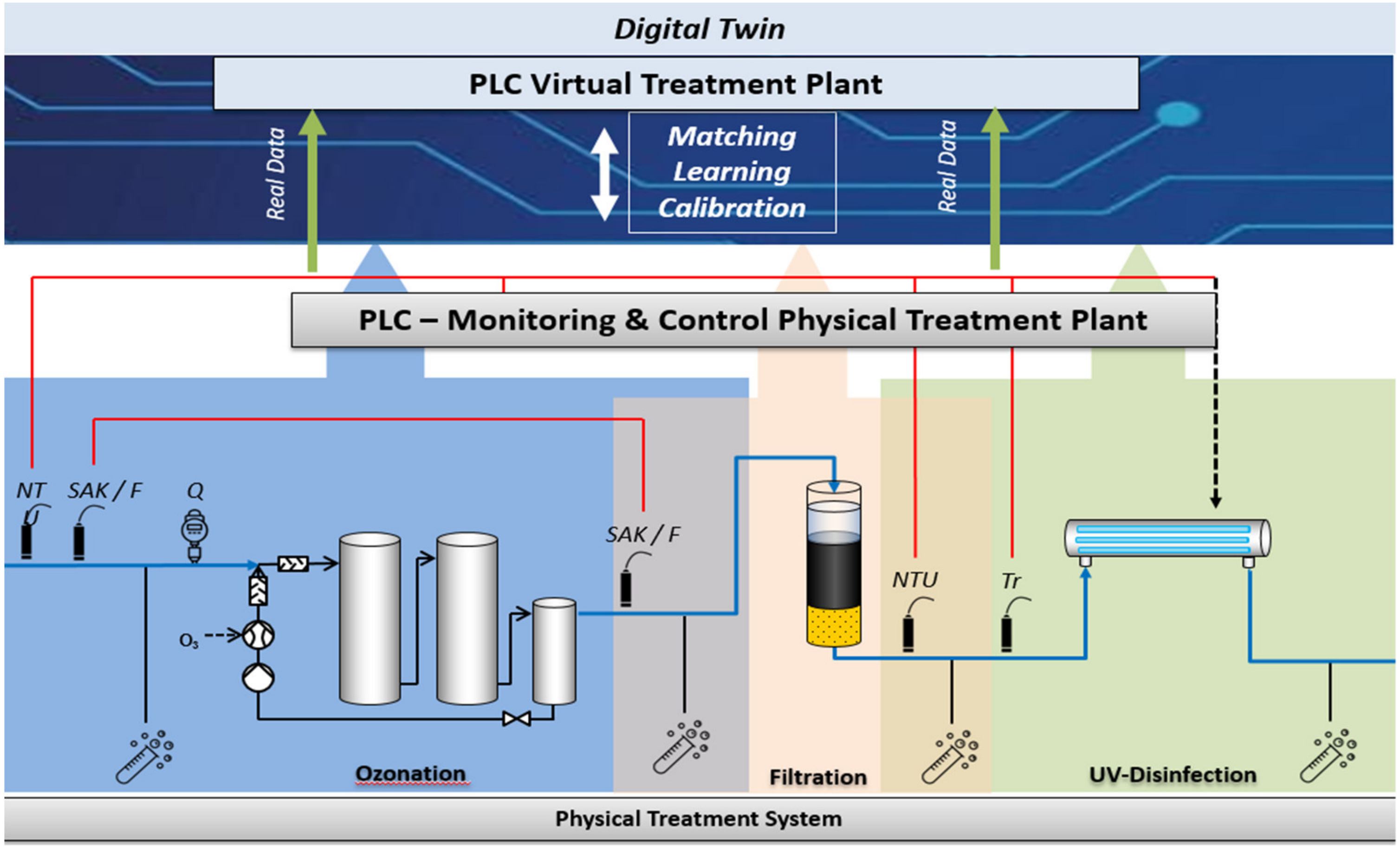

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Needs satisfied by Digital Twins

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- Manage & Operate a "new" treatment equipment at the WWTP
- Achieve requested Treatment goals
- Optimize Operation of the Treatment Process
  Energy and chemical consumption in relation to treatment goals
- Understand impacts on treatment process
  varying raw water conditions (inlet treatment process)
  operation of a multi barrier process
- "Virtual Sensor" for information a physical sensor can´t provide (e.g. no surrogate parameter for UV performance)
- Preventive maintenance (information about operational conditions of single components)
- Knowledge Management (Secure operational knowledge, available knowledge for operators)

- Digital Twin as a Virtual Representative of the Treatment Process
  - The physical process is simulated by software
  - Virtual software mirrors the physical plant operation
- Virtual plant
  - simulates in real time process conditions
  - can run "What-If" scenarios
  - used as decision support system
- By using "machine learning" software elements (AI) the virtual plant is self-learning and improves process knowledge over time
- Ultimate goal**:** autonomous operation of treatment via DT

Digital Twin in Practice – Example “Nitrogen Elimination”

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DATA SOURCES

SENSORS
Water quality, flow, other parameters

HISTORICAL DATA
12-36 months of plant operational data

SCADA
Real-time operational data

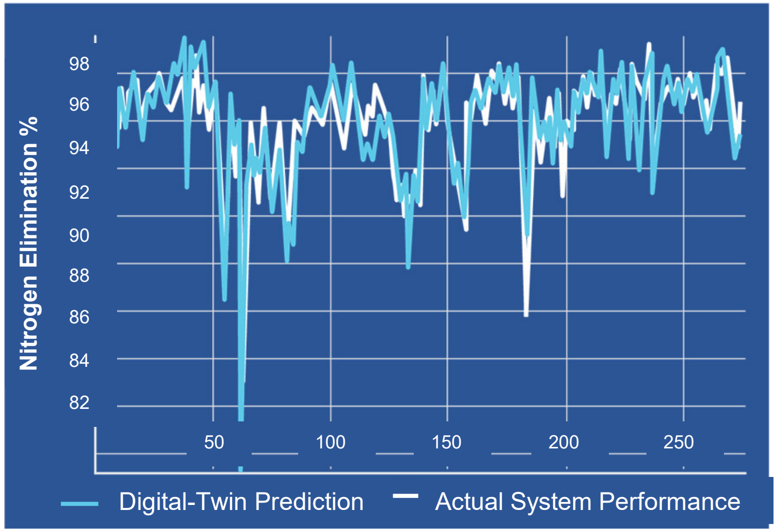
OTHER SOURCES
Lab data, energy consumption measurements, weather forecasts

DECISION INTELLIGENCE

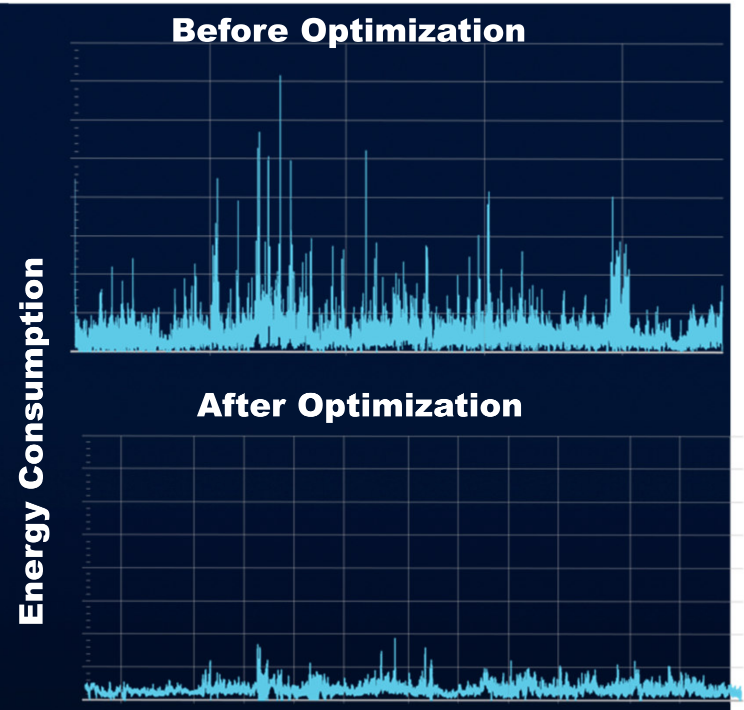
Treatment System Optimization

Digital Twin

Real-time data continuously refines recommendations



SIWW Water Convention 2022



Realized results

30%
reduction in aeration energy usage

1.2M
kWh saved annually

EWE WASSER GmbH

Digital Twin : Development Steps

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- Hard- and Software Architecture
- Available Data Sources
- Modelling Approaches
- Modelling Testing & Validation

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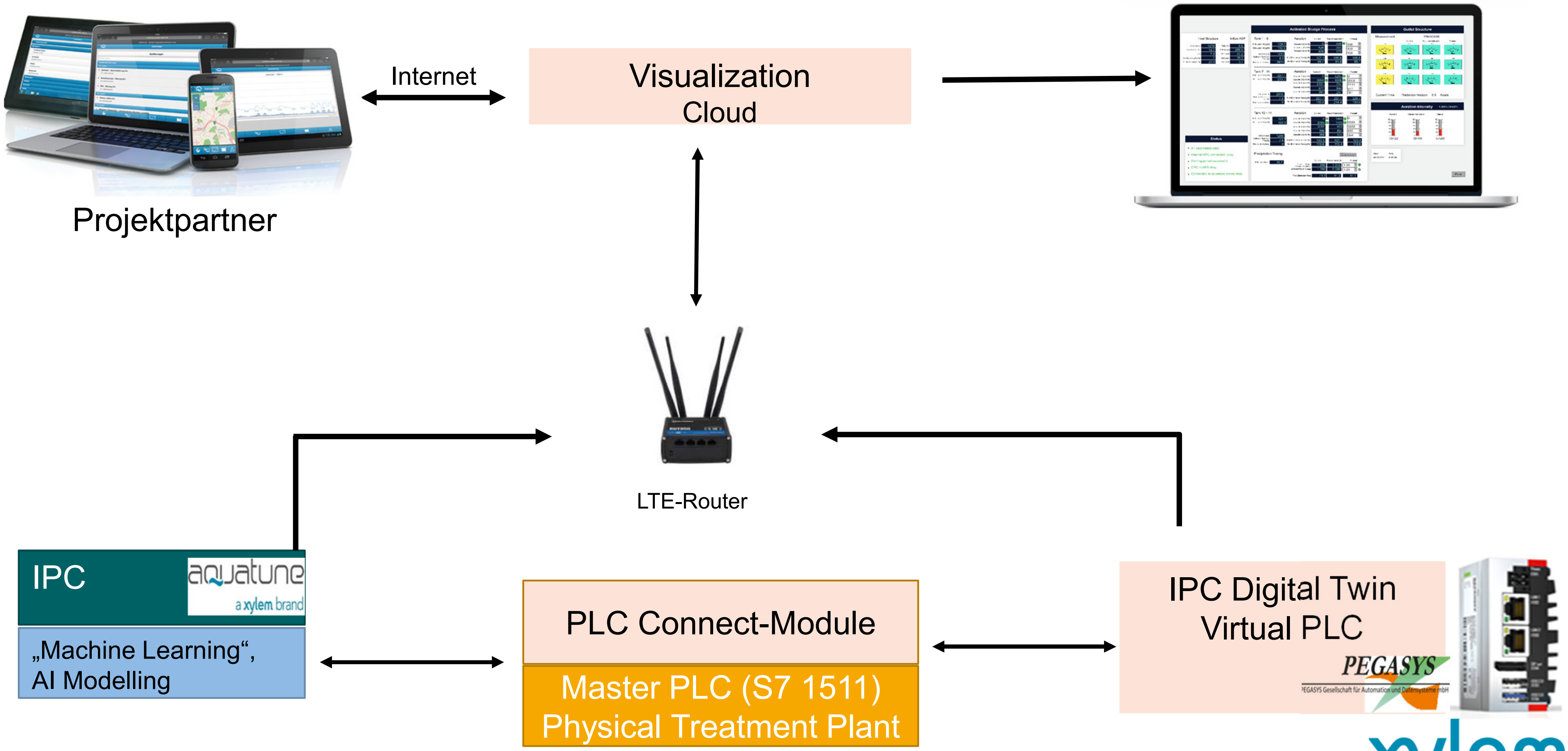
Set up Hard- & Software Architecture



Available Data Sources

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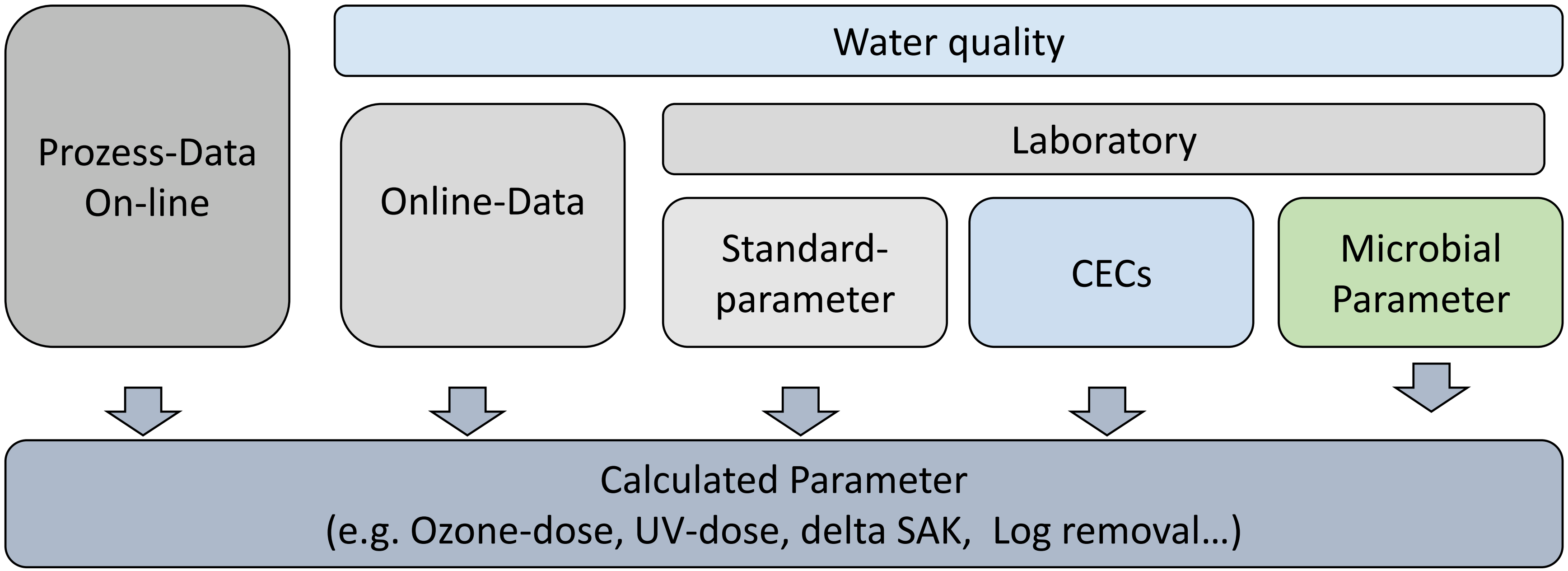

Relevant to build up a „robust“ Data-Set (Source) as Input for the Digital Twin

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Online Sensors

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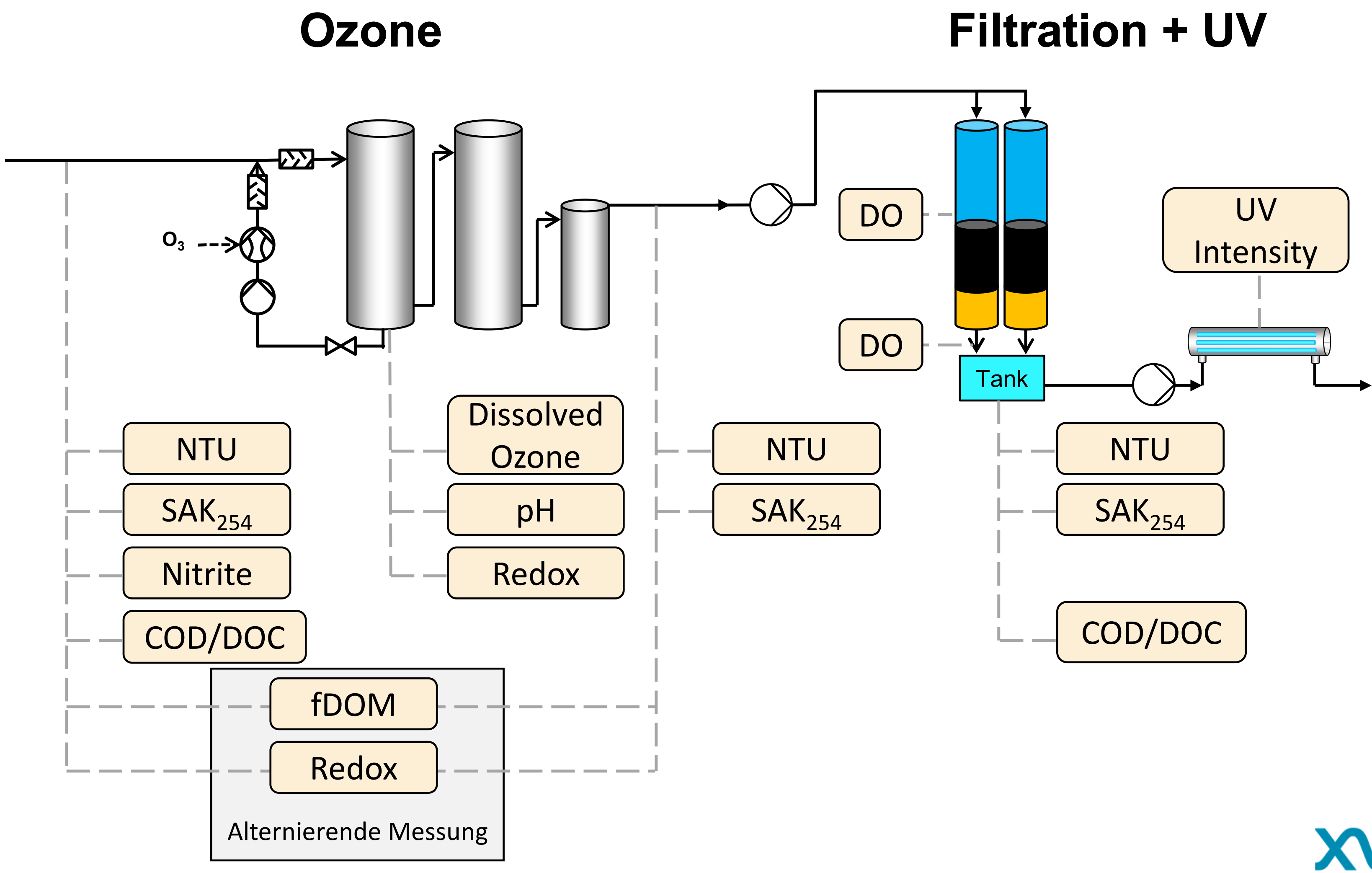

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Modelling approaches Digital Twin

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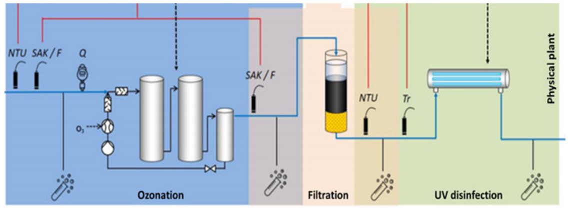
Physical Plant



Deterministic, „First principle“ models

Maschine Learning models, Artifical Neural networks

- Combine models for single treatment steps to describe overall treatment process
- Develop models to represent synergies between treatment steps:
  - Combined Disinfection Performance for Ozonation and UV Disinfection
  - Impact on Filtration performance on UV Disinfection
  - Disinfection Performance with/ without Reduction of CECs
- Develop „Virtual Sensor“ to predict Disinfection Performance

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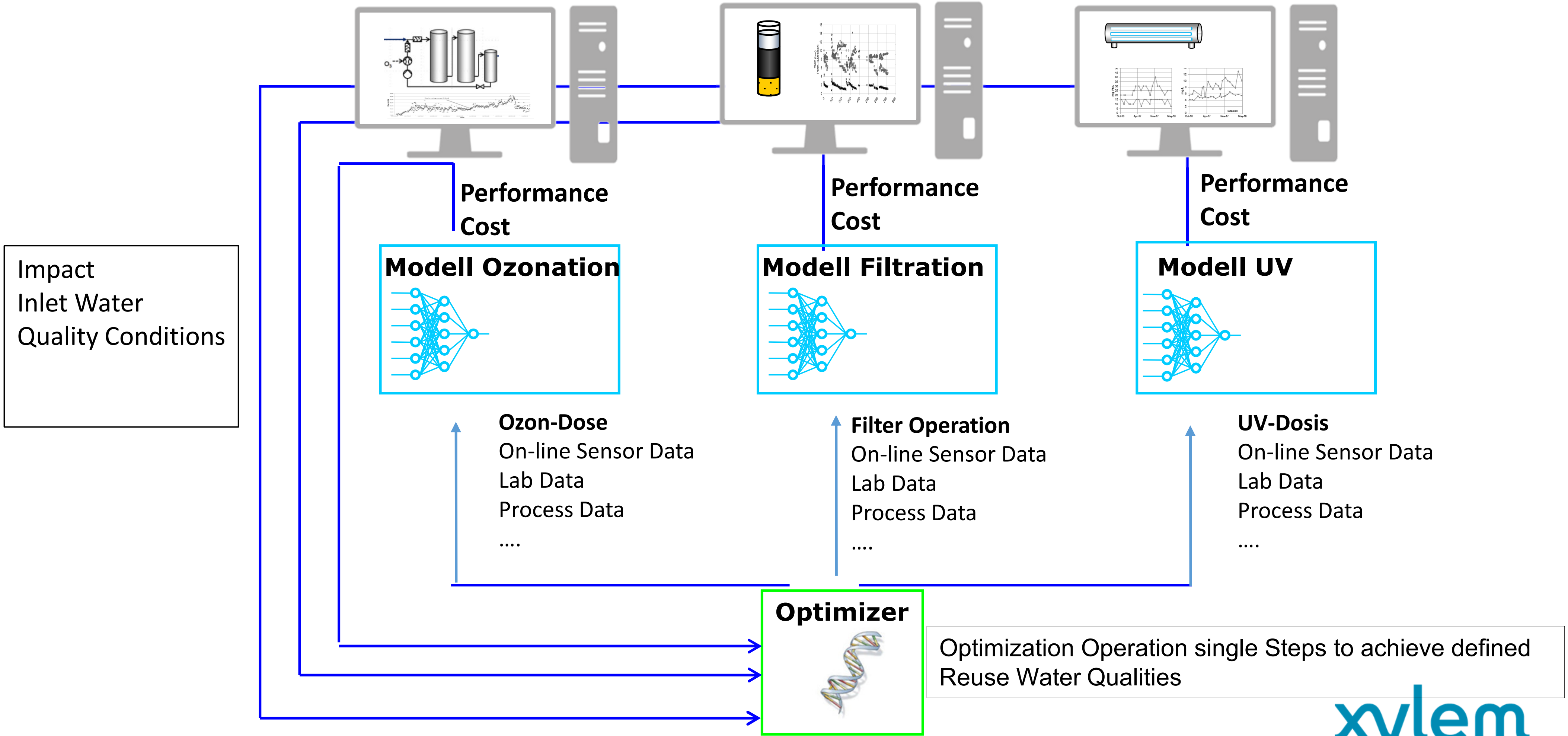
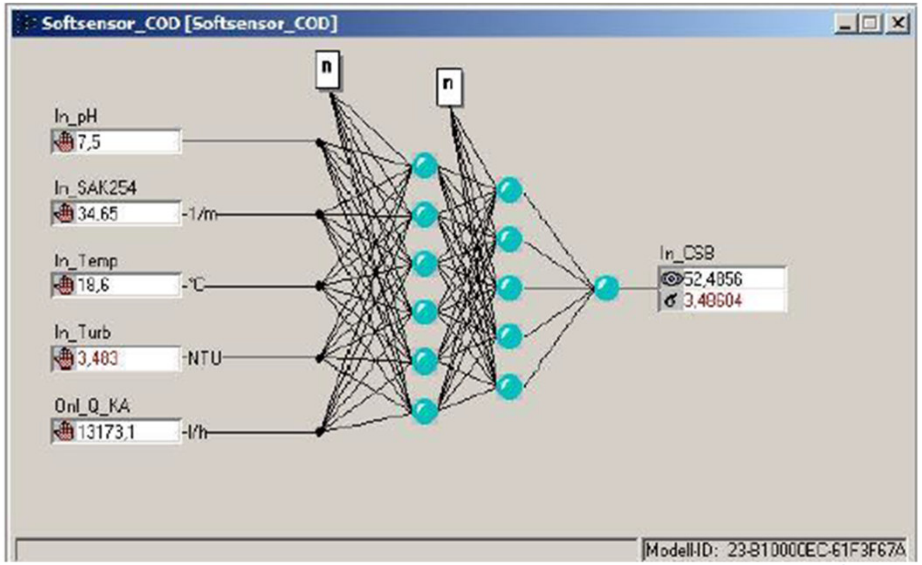
AI Model and Optimization Strategy



First results Artificial Neural Networks

1		Time	In_E	In_Coag	In_BA_Ozonung	In_Temp	In_pH	In_Turb	In_Oxy	In_SAK254	In_DOC	In_CSB	In_CSBgel	In_NO2	In_Pges	In_orthoP	In_AFS	In_Fe
2	Time	1,00	0,52	-0,35	0,87	0,21	0,70	-0,64	0,53	-0,18	-0,06	-0,34	-0,06	-0,04	-0,21	0,24	-0,24	-0,44
3	In_E	0,52	1,00	-0,25	0,57	-0,26	0,32	-0,41	0,27	-0,04	0,08	-0,08	0,10	0,09	-0,14	-0,10	-0,09	-0,17
4	In_Coag	-0,35	-0,25	1,00	-0,20	-0,02	-0,33	0,21	-0,17	0,36	0,30	0,43	0,41	0,17	0,13	-0,01	0,04	0,04
5	In_BA_Ozonung	0,87	0,57	-0,20	1,00	0,21	0,71	-0,61	0,51	-0,11	0,00	-0,22	0,06	-0,08	-0,15	0,22	-0,14	-0,39
6	In_Temp	0,21	-0,26	-0,02	0,21	1,00	0,52	-0,08	0,45	0,09	0,10	-0,31	-0,08	-0,40	-0,20	0,36	-0,44	-0,17
7	In_pH	0,70	0,32	-0,33	0,71	0,52	1,00	-0,52	0,59	-0,10	-0,06	-0,39	-0,15	-0,23	-0,25	0,15	-0,33	-0,36
8	In_Turb	-0,64	-0,41	0,21	-0,61	-0,08	-0,52	1,00	-0,60	0,18	-0,04	0,44	0,11	0,26	0,46	-0,14	0,52	0,58
9	In_Oxy	0,53	0,27	-0,17	0,51	0,45	0,59	-0,60	1,00	-0,08	0,12	-0,46	-0,31	-0,40	-0,50	0,09	-0,55	-0,52
0	In_SAK254	-0,18	-0,04	0,36	-0,11	0,09	-0,10	0,18	-0,08	1,00	0,73	0,69	0,64	0,08	0,13	-0,09	0,07	-0,03
1	In_DOC	-0,06	0,08	0,30	0,00	0,10	-0,06	-0,04	0,12	0,73	1,00	0,52	0,43	0,06	-0,09	0,03	-0,18	-0,27
2	In_CSB	-0,34	-0,08	0,43	-0,22	-0,31	-0,39	0,44	-0,46	0,69	0,52	1,00	0,72	0,38	0,45	-0,10	0,49	0,33
3	In_CSBgel	-0,06	0,10	0,41	0,06	-0,08	-0,15	0,11	-0,31	0,64	0,43	0,72	1,00	0,20	0,19	0,15	0,11	0,01
4	In_NO2	-0,04	0,09	0,17	-0,08	-0,40	-0,23	0,26	-0,40	0,08	0,06	0,38	0,20	1,00	0,36	0,05	0,28	0,14
5	In_Pges	-0,21	-0,14	0,13	-0,15	-0,20	-0,25	0,46	-0,50	0,13	-0,09	0,45	0,19	0,36	1,00	0,34	0,74	0,76

	Eff_Coag	Eff_BA_Ozonung	Eff_pH	Eff_Oxy	Eff_SAK254	Eff_DOC	Eff_orthoP	Eff_Bromat	DMF_BV	DMF_Coag	DMF_V_Filter	DMF_BA_Ozonung	DMF_pH	DMF_Turb	DMF_Oxy	DMF_SAK254	DMF_DOC	DMF_CSB	DMF_CSBgel	DMF_Pges
Time	-0,35	0,87	0,63	-0,17	0,16	-0,19	0,27	-0,65	1,00	-0,35	0,22	0,92	0,67	-0,10	0,29	-0,48	-0,35	-0,34	-0,35	0,30
In_E	-0,27	0,55	-0,03	0,06	-0,16	0,25	0,03	0,23	0,51	-0,25	0,12	0,59	0,45	-0,01	0,69	-0,78	-0,23	-0,40	-0,33	0,19
In_Coag	1,00	-0,21	-0,24	0,10	0,27	0,30	-0,04	0,05	-0,35	1,00	0,14	-0,20	-0,38	-0,26	-0,24	0,18	0,06	0,11	0,27	-0,81
In_BA_Ozonung	-0,21	1,00	0,72	-0,21	0,17	-0,14	0,25	-0,65	0,91	-0,20	0,33	1,00	0,69	-0,22	0,27	-0,51	-0,30	-0,31	-0,28	0,16
In_Temp	-0,01	0,23	0,56	-0,26	-0,16	-0,19	0,30	-0,35	0,21	-0,02	0,47	0,21	0,46	-0,19	-0,15	0,24	0,08	0,06	-0,01	0,06
In_pH	-0,33	0,71	0,76	-0,24	-0,11	-0,27	0,01	-0,40	0,70	-0,33	0,47	0,71	0,83	-0,14	0,25	-0,27	-0,19	-0,20	-0,19	0,32
In_Turb	0,21	-0,61	-0,65	-0,09	0,09	0,18	-0,08	0,29	-0,63	0,21	-0,24	-0,61	-0,56	0,41	-0,47	0,48	0,32	0,42	0,33	-0,11
In_Oxy	-0,17	0,51	0,55	-0,01	-0,22	-0,26	0,01	-0,35	0,52	-0,17	0,41	0,51	0,51	-0,35	0,26	-0,24	-0,19	-0,16	-0,19	0,10
In_SAK254	0,36	-0,12	-0,05	-0,08	0,71	0,74	-0,12	0,04	-0,18	0,36	0,12	-0,11	-0,02	-0,15	-0,17	0,53	0,67	0,65	0,71	-0,27
In_DOC	0,30	0,01	0,16	-0,11	0,45	0,79	0,04	-0,10	-0,08	0,30	0,24	0,01	0,03	-0,24	-0,12	0,30	0,69	0,45	0,44	-0,21
In_CSB	0,43	-0,24	-0,36	-0,17	0,63	0,63	-0,07	0,12	-0,35	0,43	-0,14	-0,22	-0,34	0,05	-0,29	0,43	0,60	0,69	0,77	-0,28
In_CSBgel	0,41	0,02	-0,04	-0,22	0,53	0,44	0,19	0,10	-0,07	0,41	-0,06	0,06	0,00	-0,07	-0,06	0,18	0,33	0,55	0,66	-0,24
In_NO2	0,16	-0,11	-0,32	-0,12	0,36	0,20	0,04	-0,15	-0,06	0,17	-0,08	-0,02	-0,32	0,14	-0,44	0,14	0,18	0,19	0,12	-0,06
In_Pges	0,13	-0,16	-0,47	-0,08	0,40	0,21	0,43	0,07	-0,20	0,13	-0,20	-0,15	-0,28	0,23	-0,35	0,23	0,14	0,26	0,25	0,06



Example Softsensor COD:

1:1 Correlation CSB und SAK-254 shows a Correlation factor of 0.69 (38 Data-Sets).

Using 5 Input Parameter (pH, T, NTU, Flow and SAK-254) results in a Correlation factor of 0.95. (38 Data-Sets).

First results Artificial Neural Networks

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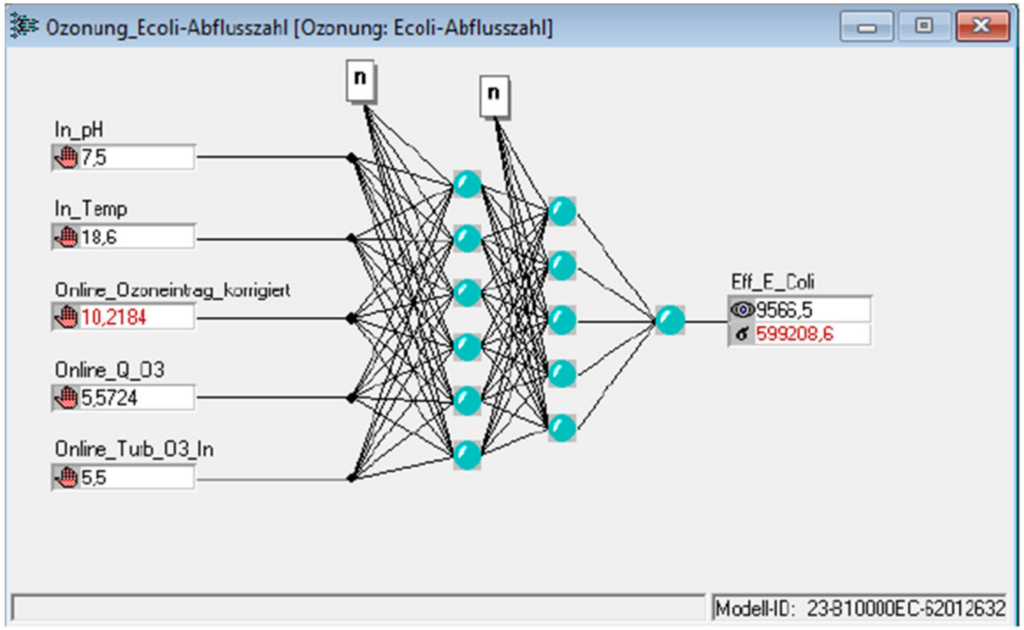

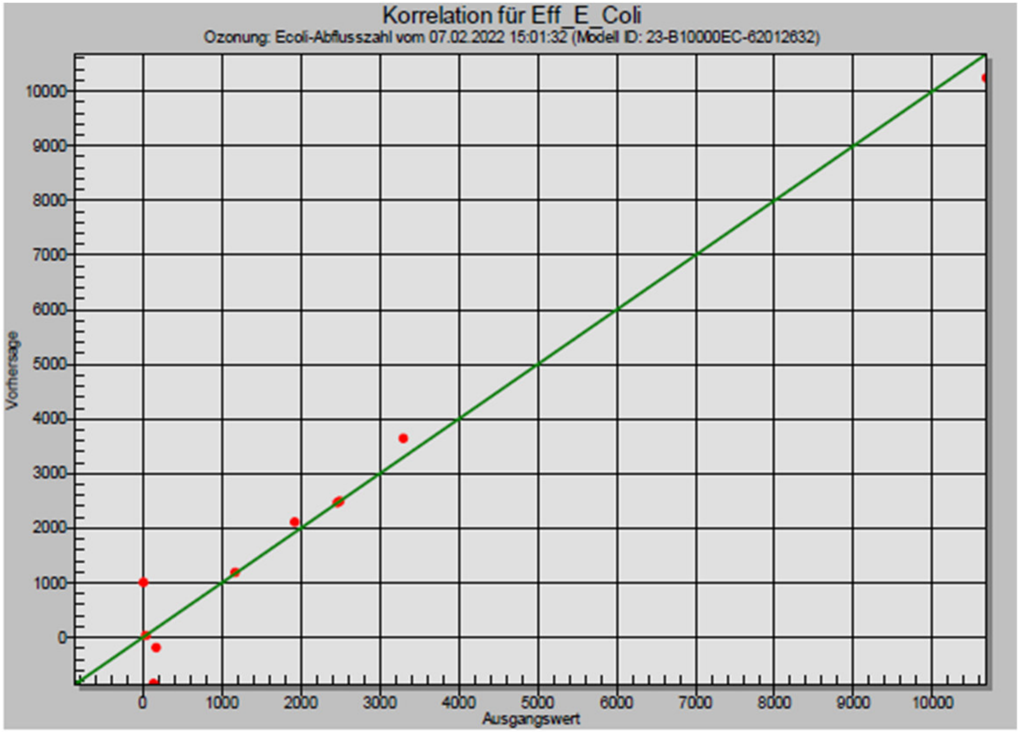

Input-Parameter:
pH, T,
Ozone-dose (Nitrite compensated),
Flow,
NTU

Output-Parameter:
E-Coli

Data-Sets: 10
Performance: 98,6%

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Summary & Outlook

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The development of the Digital Twin will be based on deterministic (first principle) models and data driven machine learning models (Artificial Networks). Models for the single treatment steps will be combined to describe the overall treatment process.

- Expected outcomes are understand synergies between treatment steps:
- Combined Disinfection Performance for Ozonation and UV Disinfection
- Impact on Filtration performance on UV Disinfection
- Disinfection Performance with/ without Reduction of CECs
- Development of a „Virtual Sensor“ to predict Disinfection Performance.

Project Start: March 2021

- M 1-6 — Installation & Start up Physical Plant
- M 6-12 — Implement Hardware and Software for Digital Twin
- M 12-18 — Digital Twin implemented and tested
- M 18-24 — Digital Twin Validation I
- M 24-30 — Digital Twin Validation II

Project End: Feb 2024

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Acknowledgments

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Projektträger Karlsruhe
Karlsruher Institut für Technologie

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Employees 17,000

Countries ~150

Continents 7

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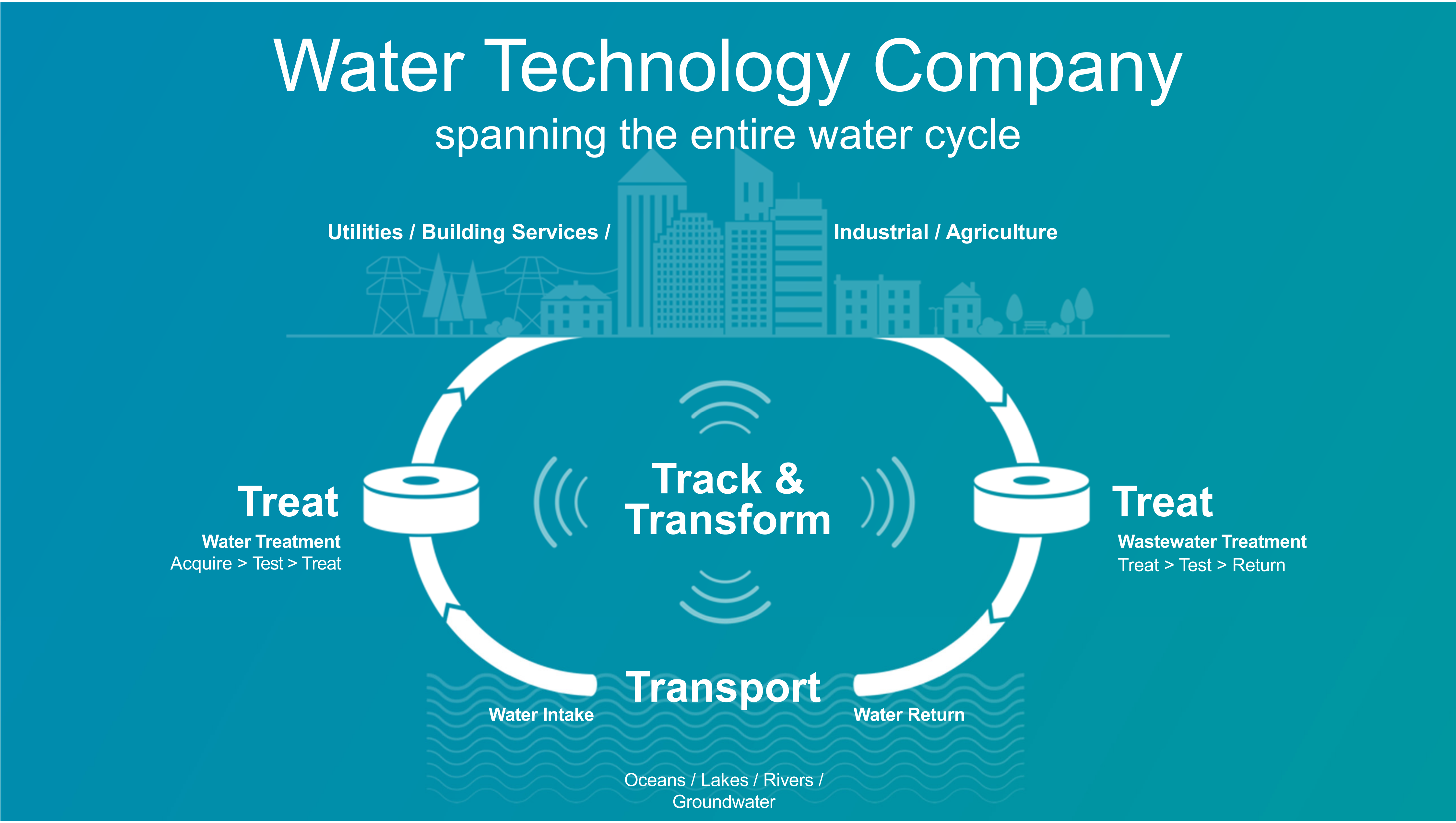
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