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Risk management framework and monitoring solutions supported by soft sensors

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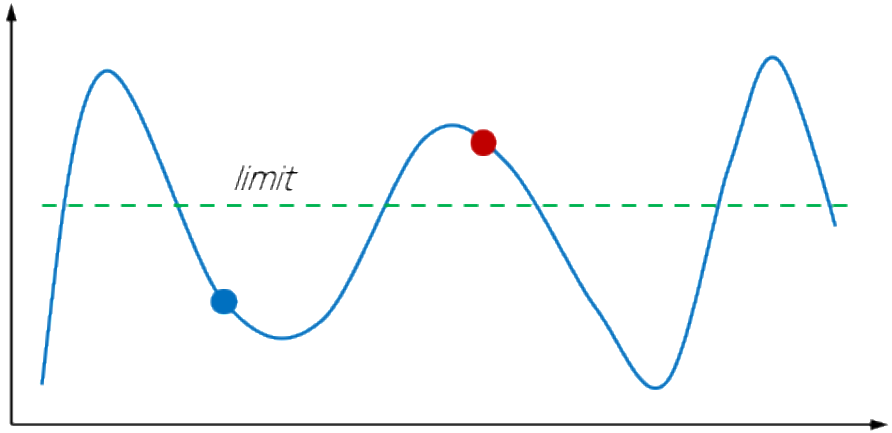
Context

Water quality is defined by:

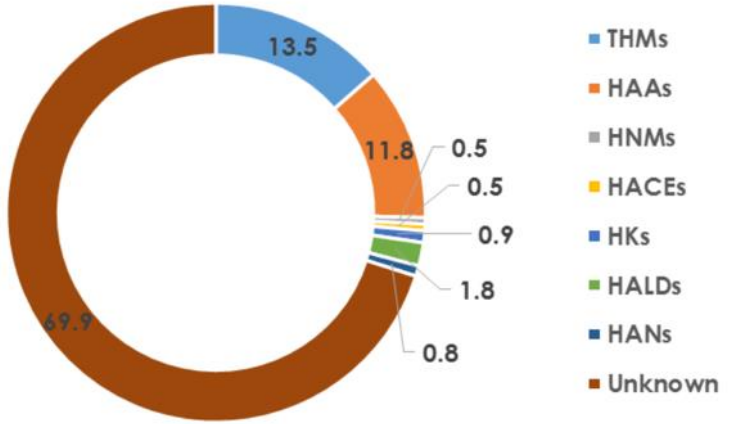
- a multiplicity of parameters (chemical, microbiological)
- affected by relevant variability (source water dynamics, treatments adopted, distribution network characteristics and consumers habits)

Conventional monitoring (concentration-based) using grab samples is not sufficiently protective for consumers and targets only known compounds



https://doi.org/10.1039/D2EW00089J

Disinfection by-products formation



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Our Goal

Development of a **holistic framework integrating source protection, treatment and monitoring** in a **One Health** Approach:

- shift towards risk-based actions instead of concentration-based actions
- exploitation of machine learning to support advanced monitoring able to capture water quality dynamics

World Health Organization

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Risk Assessment: current knowledge

Multiple methodologies and targets:

- pathogenic microorganisms and chemical contaminants
  - time horizon of effects (acute vs chronic)
  - different dose-response models and associated uncertainty
- qualitative and quantitative approaches (deterministic or probabilistic) depending on data availability and objectives
- limited of integration of Chemical Risk Assessment with Effect-Based Monitoring (EBM)
  - unknown compounds, transformation products
  - mixture of chemicals
  - interactions among multiple substances at low concentrations

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Risk Assessment: safeCREW contribution

Our approach:
we harmonized and advanced these aspects through a **decision tree** that supports selecting the **most appropriate level and type of risk assessment** based on the availability and robustness of exposure data

- Three case studies:
  - **Ukraine** (QMRA)
  - **Berlin** (QMRA+QCRA)
  - **Milan** (QMRA+QCRA+EBM)

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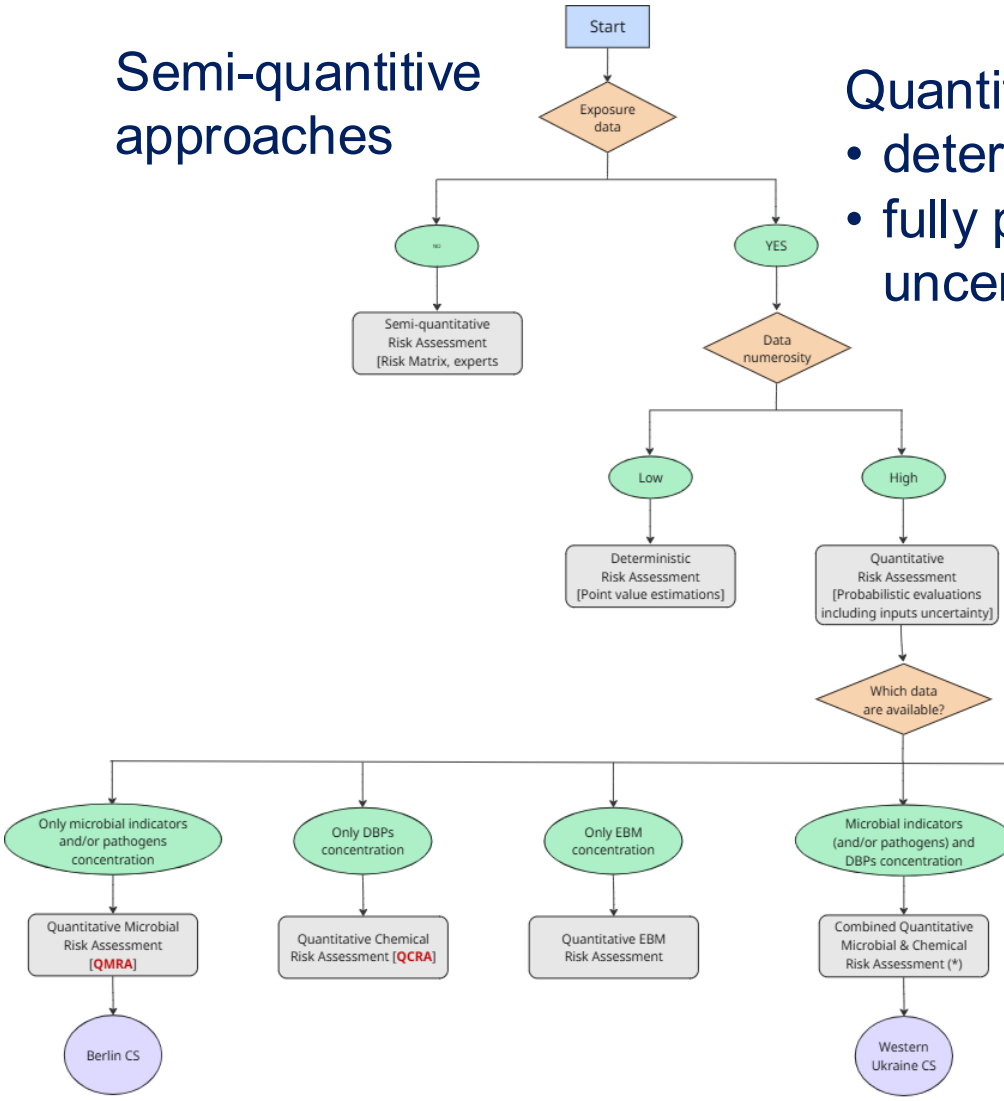
Risk Assessment Decision Tree

Semi-quantitive approaches



Quantitive approaches:

- deterministic (point-value estimate)
- fully probabilistic estimate, incorporating variability and uncertainty in exposure and hazard characterization

estimate confidence for decision-makers

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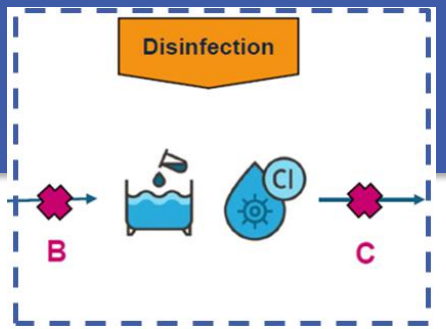
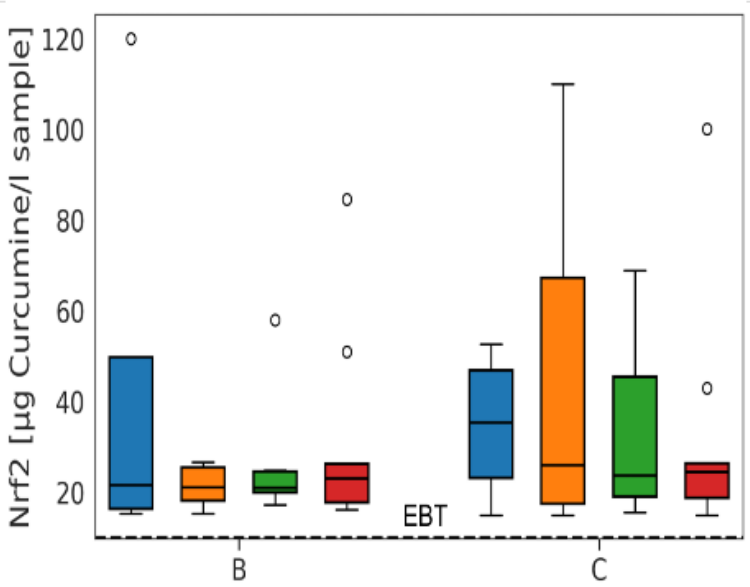
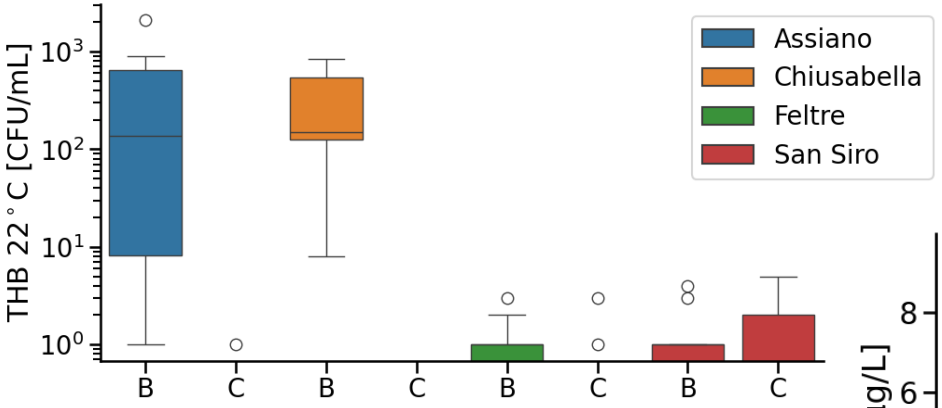
QMRA, QCRA and EBM integration



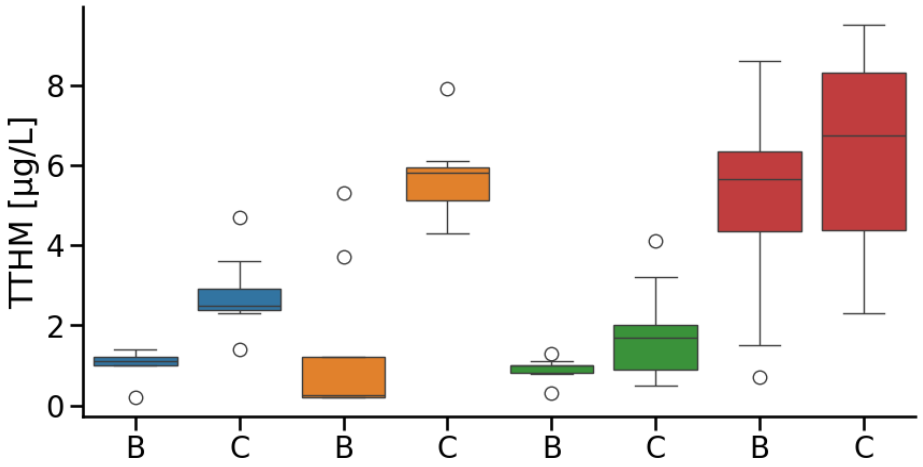
Milan case study (groundwater)

- final chlorination
- microbial monitoring
- THMs (trihalomethanes) monitoring
- toxicity profiling trhough CALUX bioassays





THMs correlated to an activity in the ERa and Nrf2 bioassays



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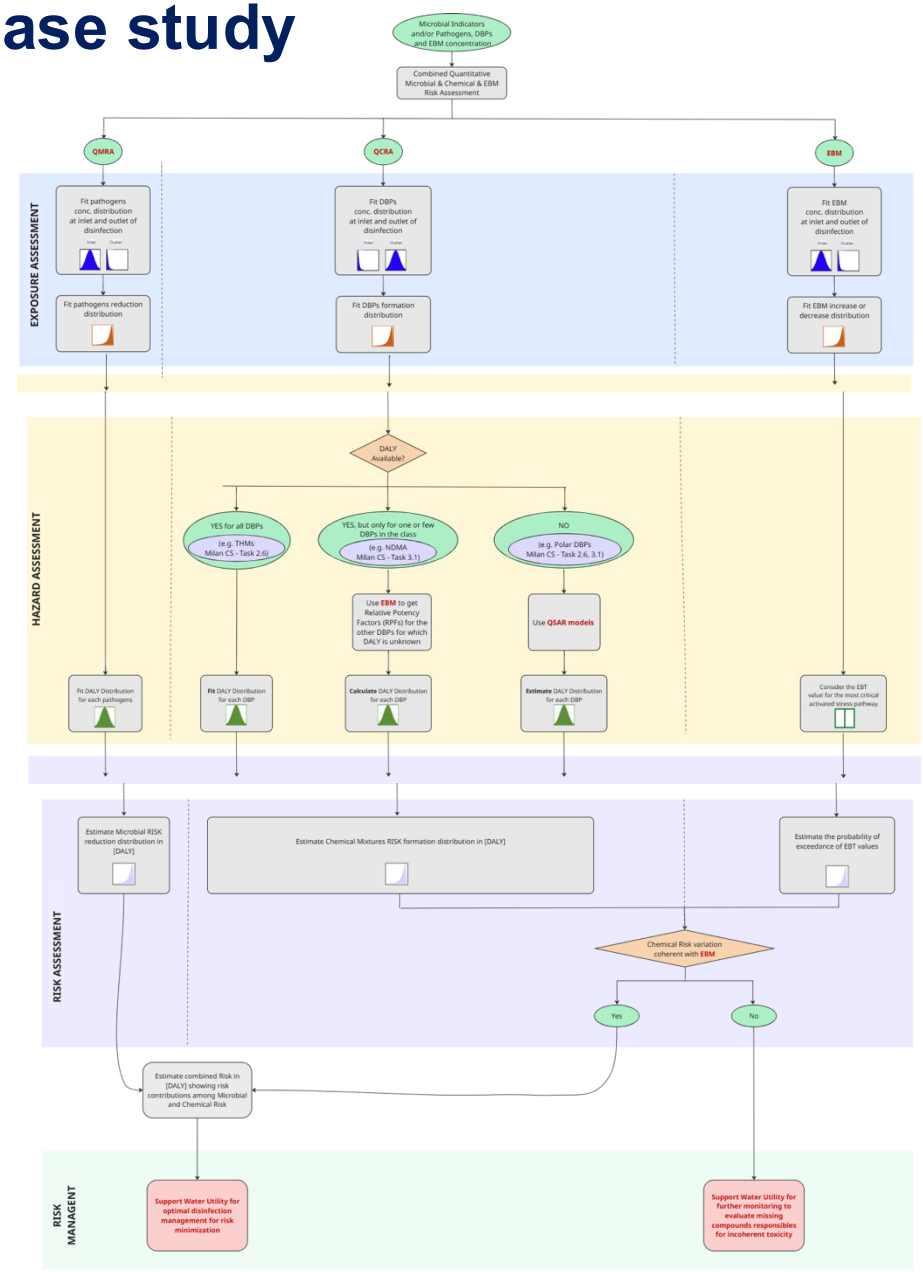
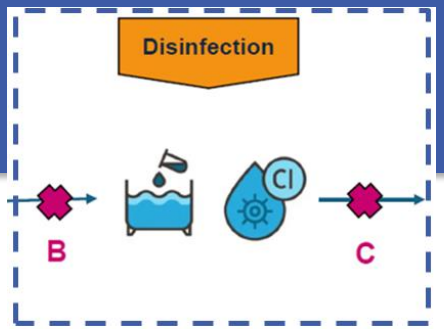
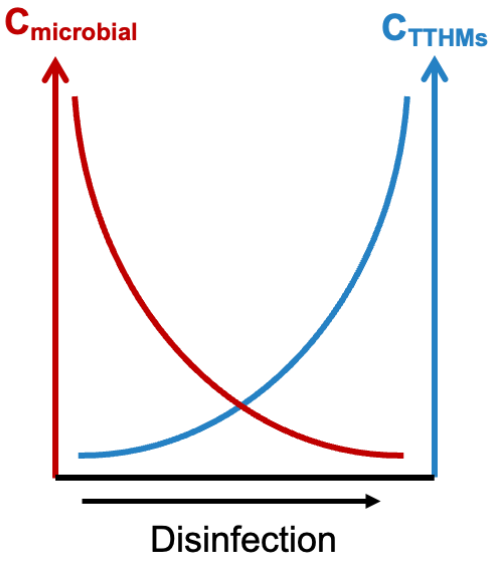
QMRA, QCRA and EBM integration

Milan case study







disinfection trade-off translated as **DALY** (Disability-Adjusted-Life-Years)

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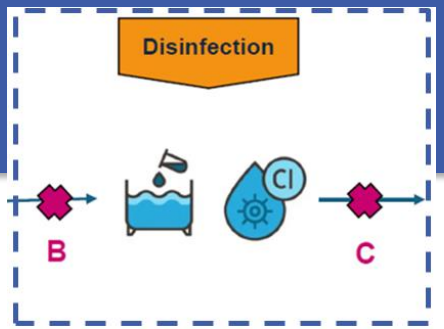
QMRA, QCRA and EBM integration



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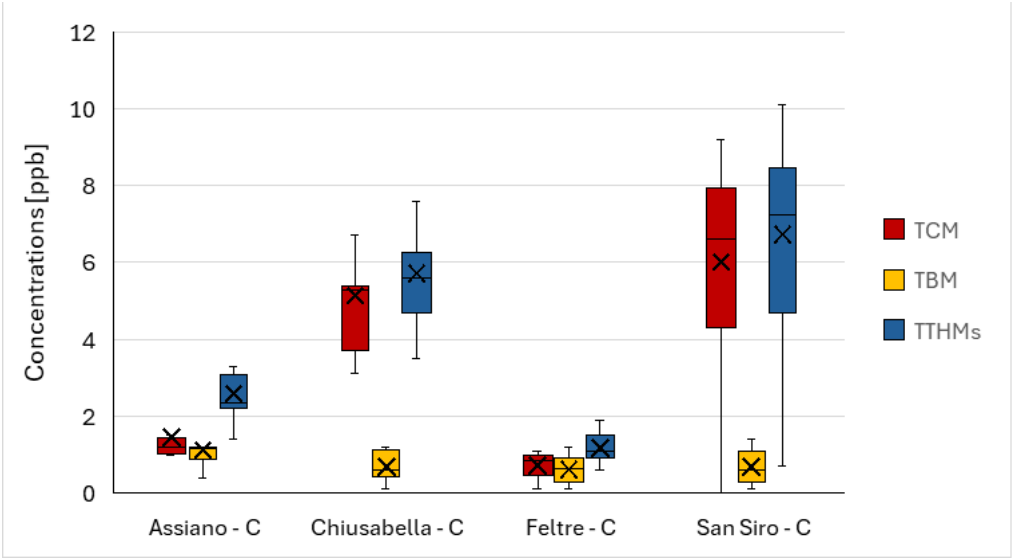
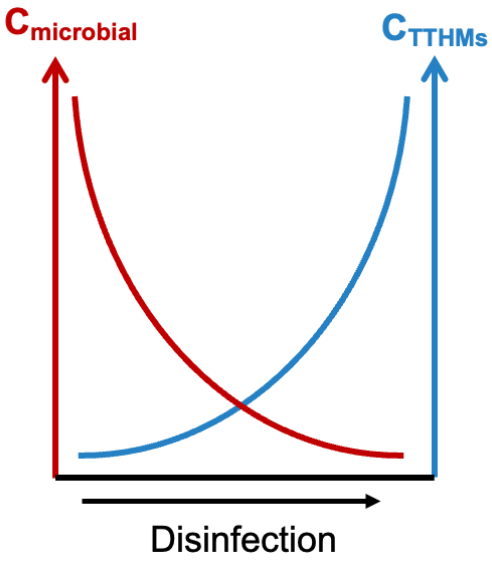
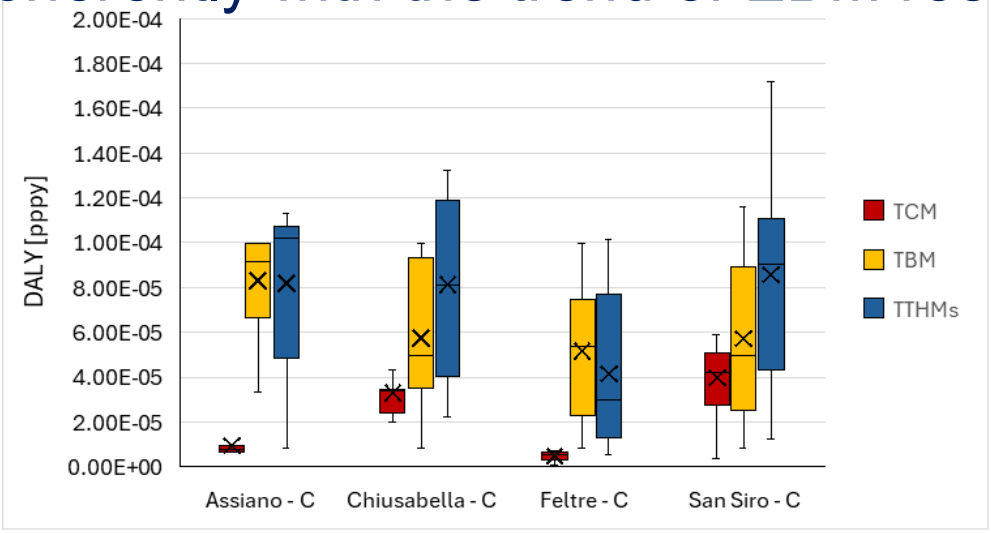




Chemical risk does comparable among DWTPs, coherently with the trend of EBM results



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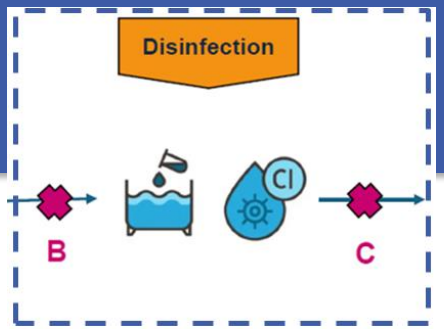

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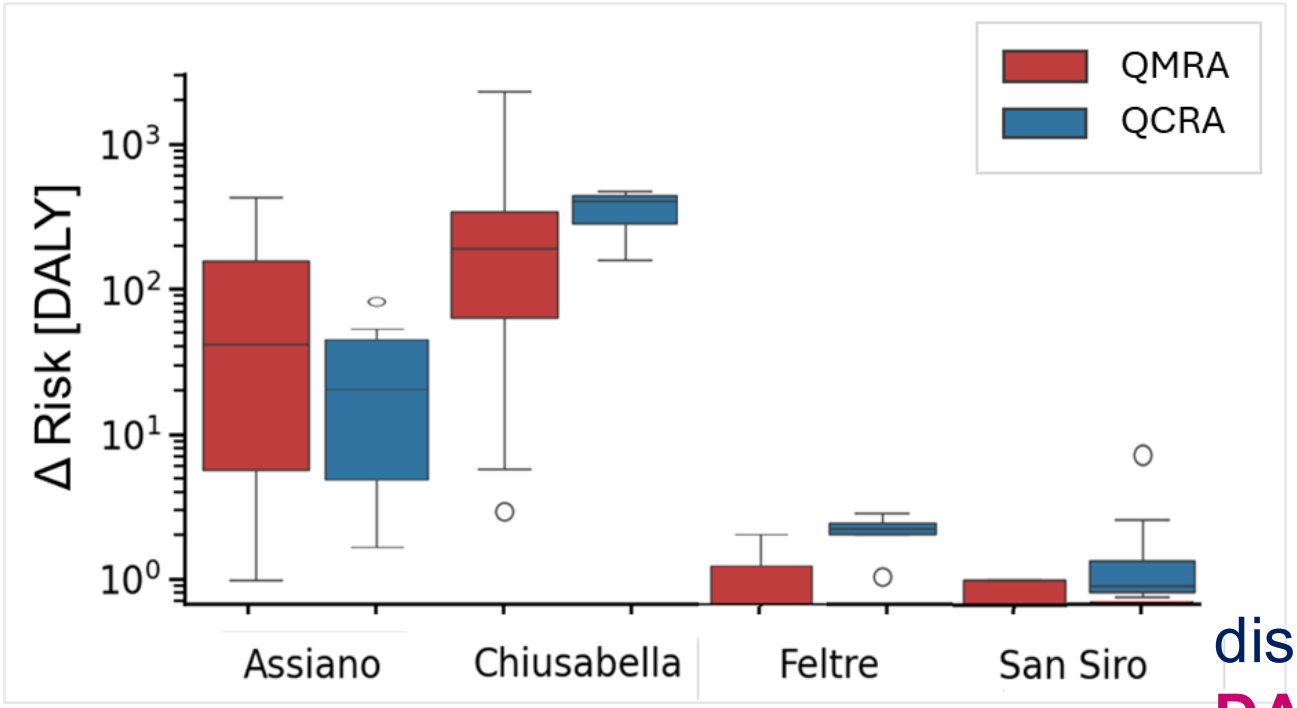

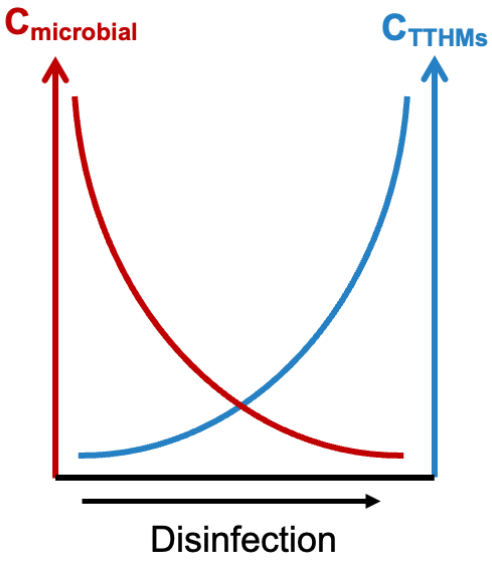

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Risk-informed decision-making for the optimization of disinfection performance

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Challenges for water quality monitoring

Need to feed risk-informed actions through reliable water quality data, but:

- high-frequency monitoring could be a complex task (e.g. DBPs)
- plant and distribution network monitoring could be a complex scenario:
  - climate variability
  - aging infrastructure
  - water quality dynamics

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Water quality monitoring: the safeCREW solution

Possible directions:

- transition from reactive to proactive
- design early-monitoring systems

through **virtual (soft) sensing**, i.e. the use of information hidden in low-informative online sensors to predict the value of high-informative parameters

- Define an overall pipeline to guide the design of soft-sensors in new scenarios
- Application of the soft-sensor paradigm to three case studies

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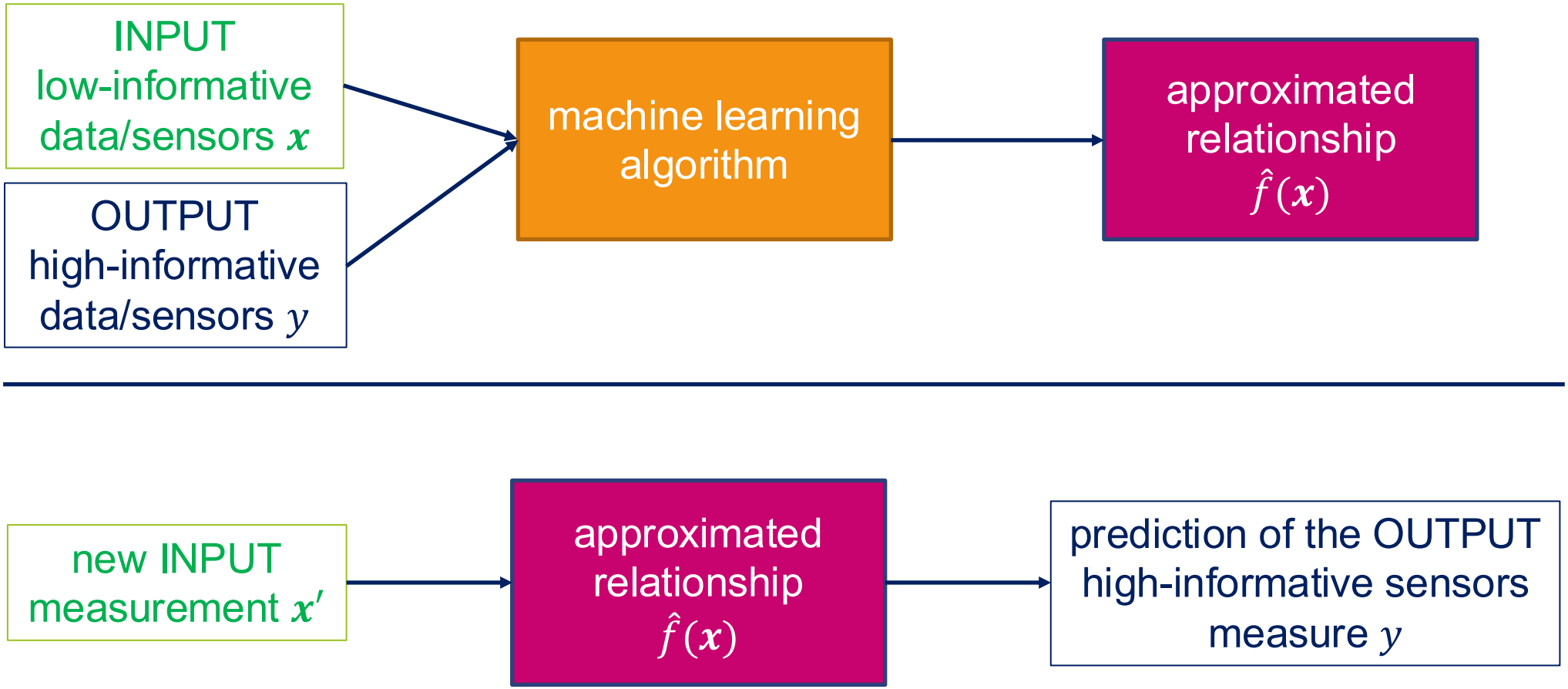
Soft-Sensors: Overall Idea



- Measure (in real time) x and generate the corresponding prediction $\hat{y}$
- Define the output we are willing to provide: prediction, alert

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Soft-Sensor for network monitoring

Milan case study

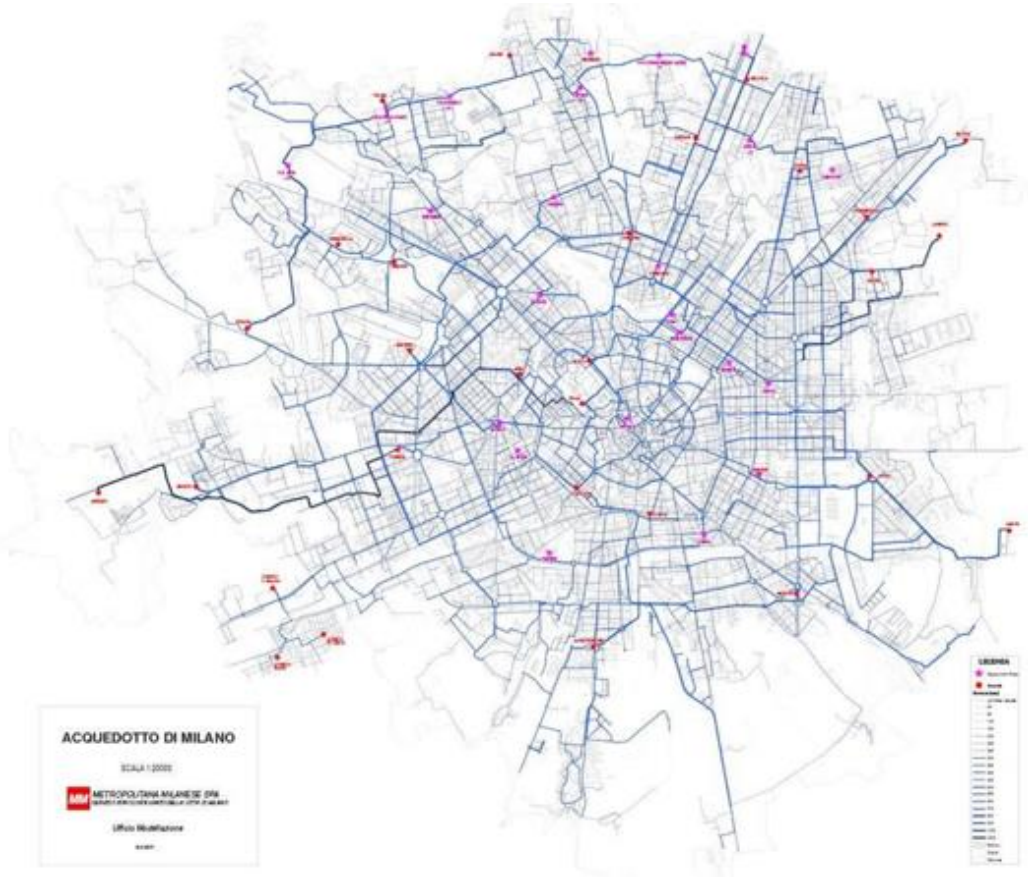
- Selection of 9 supply points
- January-December 2024

INPUT (~35000 samples per supply point)

- Color
- Temperature
- pH
- Conductivity
- Nitrate
- Free Chlorine
- TOC

OUTPUT (~20 samples per supply point)

- TTHMs



- Heterogeneity among different supply points: grouping of data according to similarity
- Different models for each group

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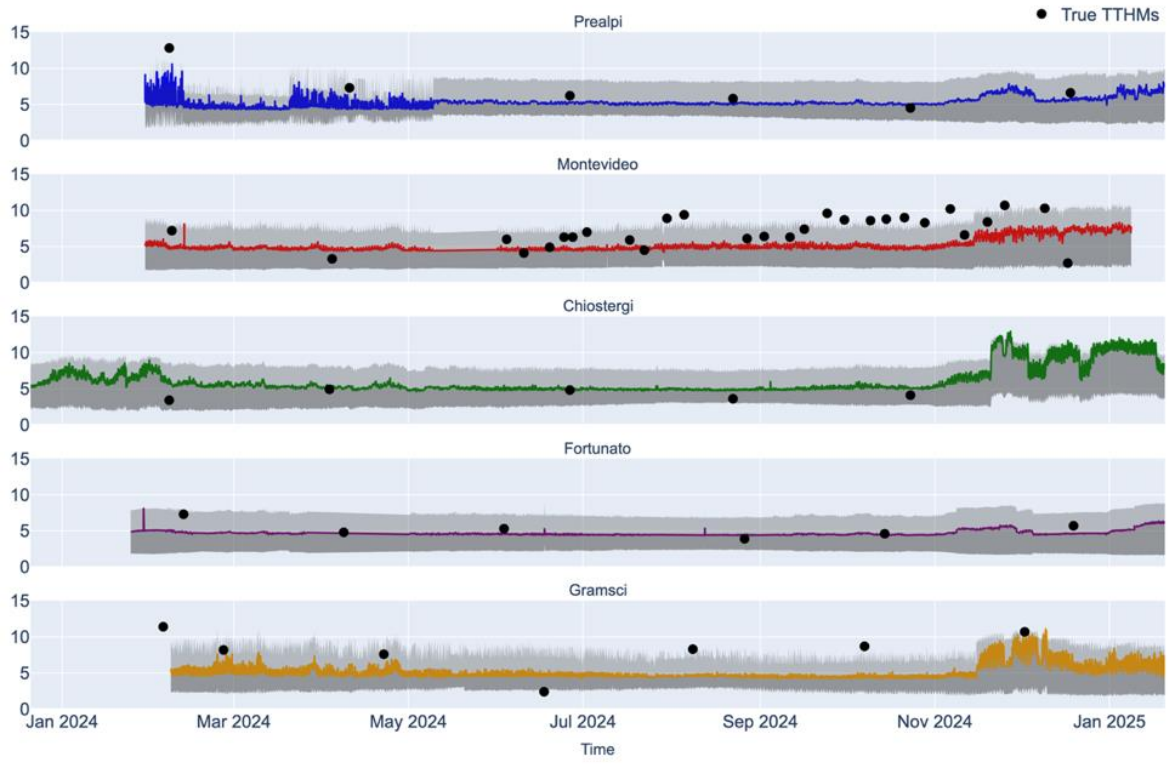
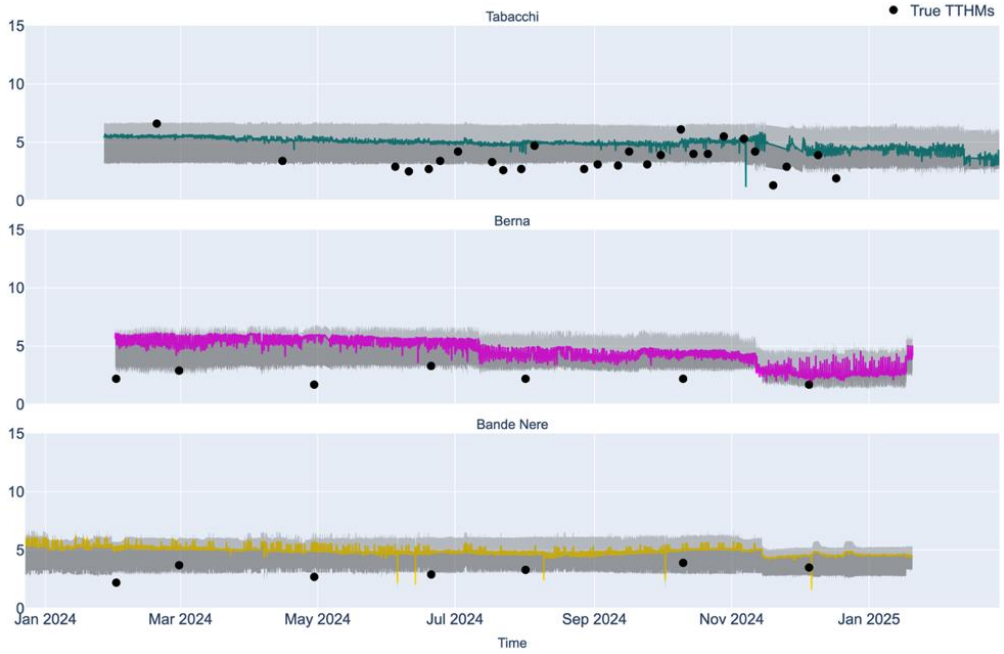
Soft-Sensor for network monitoring

Milan case study

- Good results even if local specificity and seasonality can affect accuracy in some supply points





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In conclusions

We provided tools for a comprehensive public health protection strategy, enabling quantitative evaluation of trade-offs:

- Flexible and scalable risk assessment framework to support decision-makers in managing drinking water supply systems
- EBM as complementary insight supporting chemical risk interpretation when toxicological data are incomplete
- Advances in monitoring tools to feed engineered- and risk-informed management of drinking water supply systems

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