Aigües de Barcelona
La gestió responsable

AMSTERDAM INTERNATIONAL WATER WEEK

Tools and strategy for the optimization of Trihalomethanes levels in a large Water Supply System affected by the effects of Climate Emergency

The case of Barcelona's Metropolitan Area

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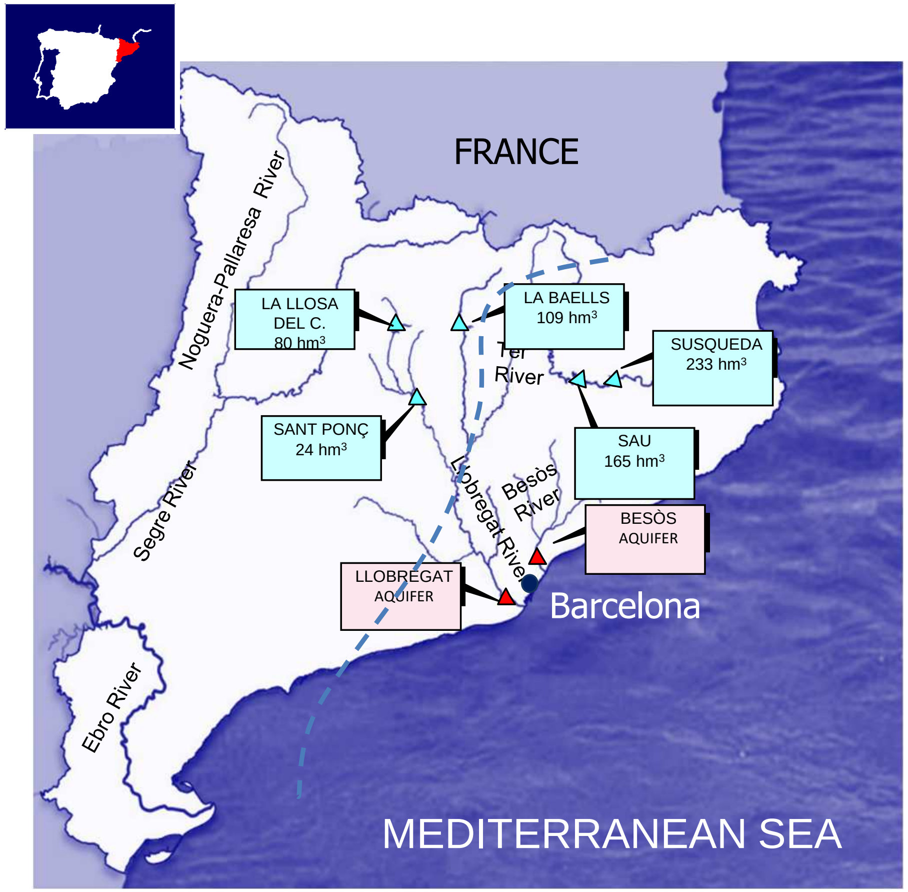
- Introduction: Context and background
- Tools used for the optimization of Trihalomethanes' levels (Barcelona Metropolitan Area)
- *THM Removal Systems* (*TRS*) in *Aigües de Barcelona*
- THM monitoring and prediction
- Conclusions/Summary

Introduction: Context & Background

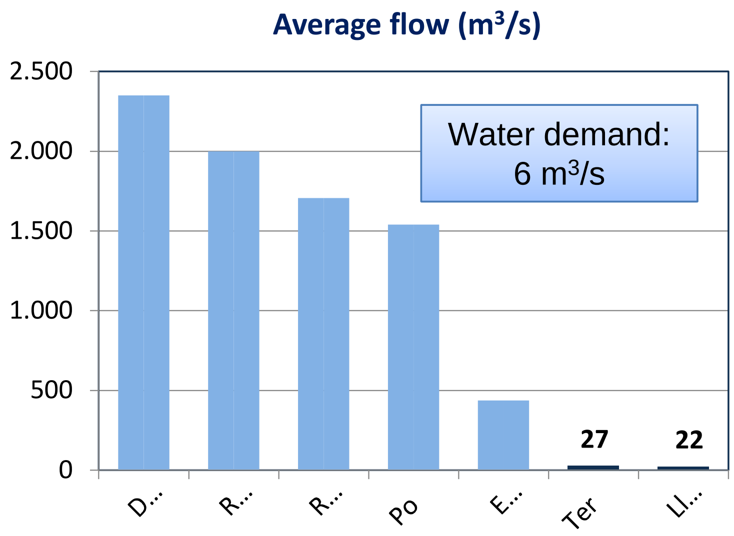
Barcelona’s Metropolitan Area: a very complex reality

Water resources scarcity



Water resources for Barcelona's metropolitan area water supply: Surface water from **Llobregat** and **Ter** rivers (internal basins).

Low flow with **high flow peaks** (Mediterranean climate)



Different water sources

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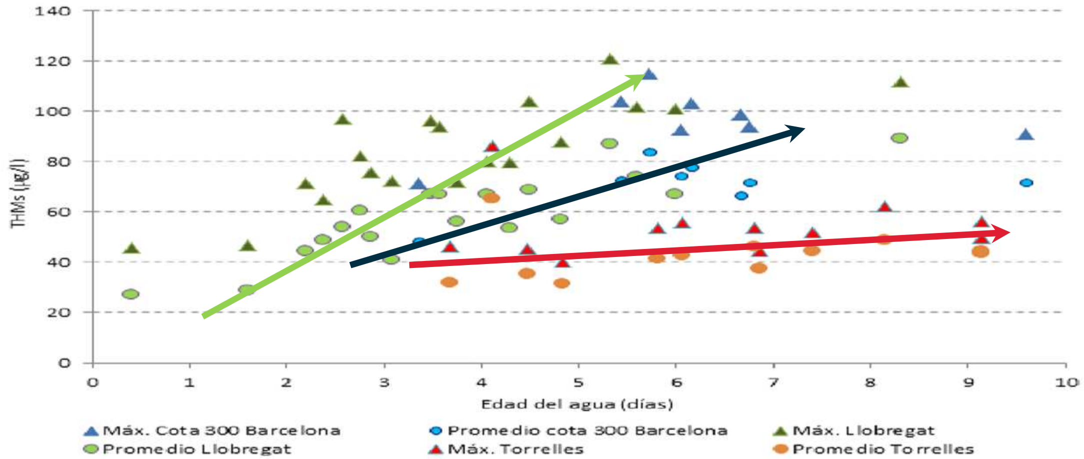
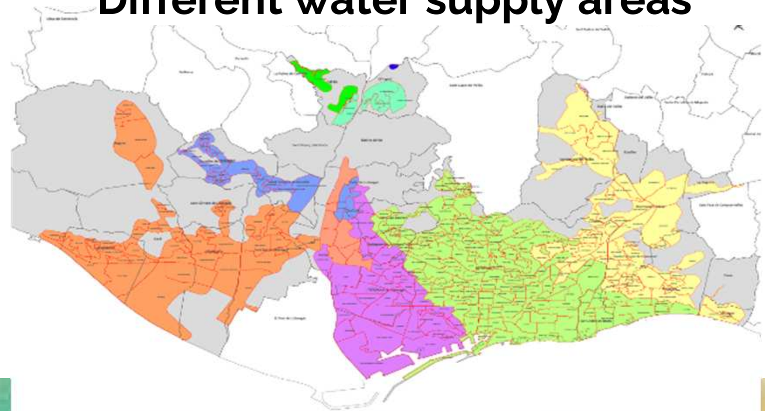
Different water qualities

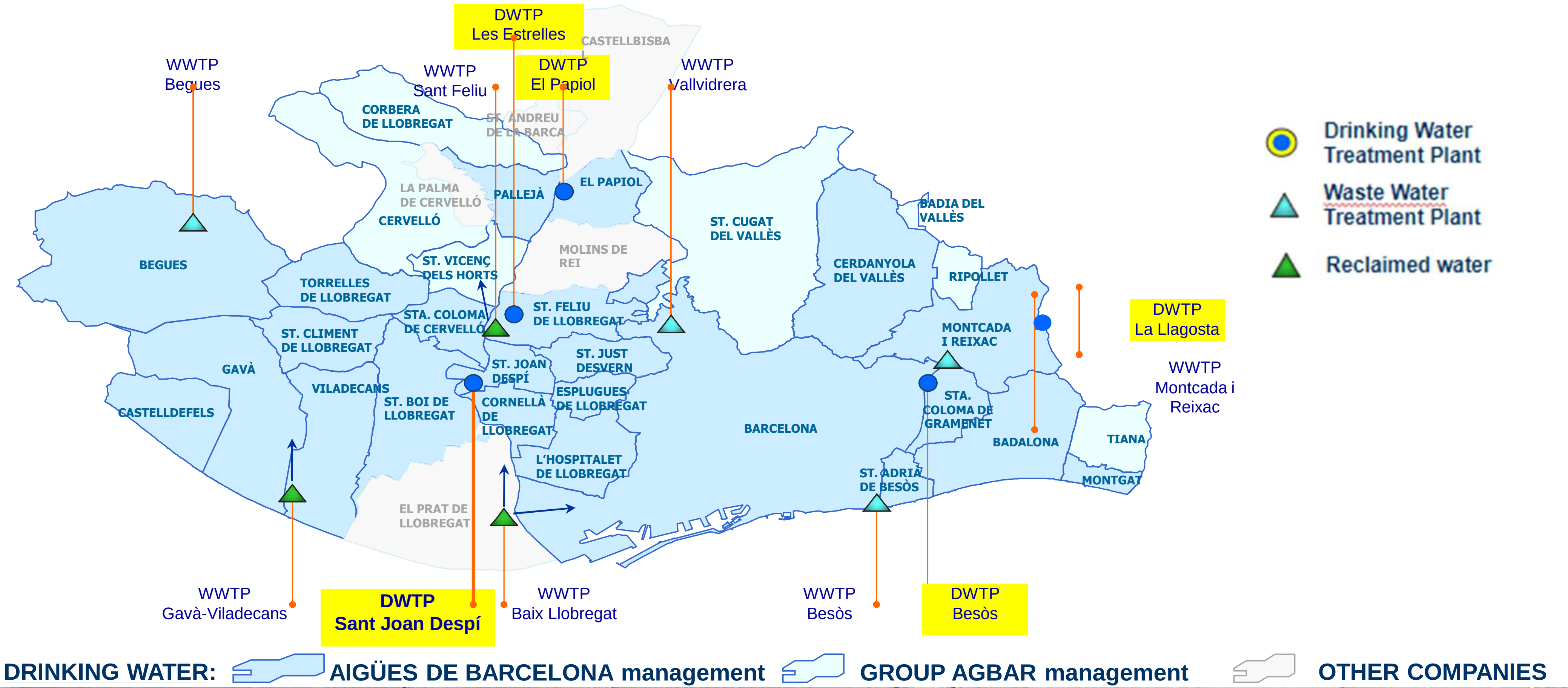
Different distribution of species & THMs evolution



Different water supply areas



Municipalities & Treatment facilities



The Supply System

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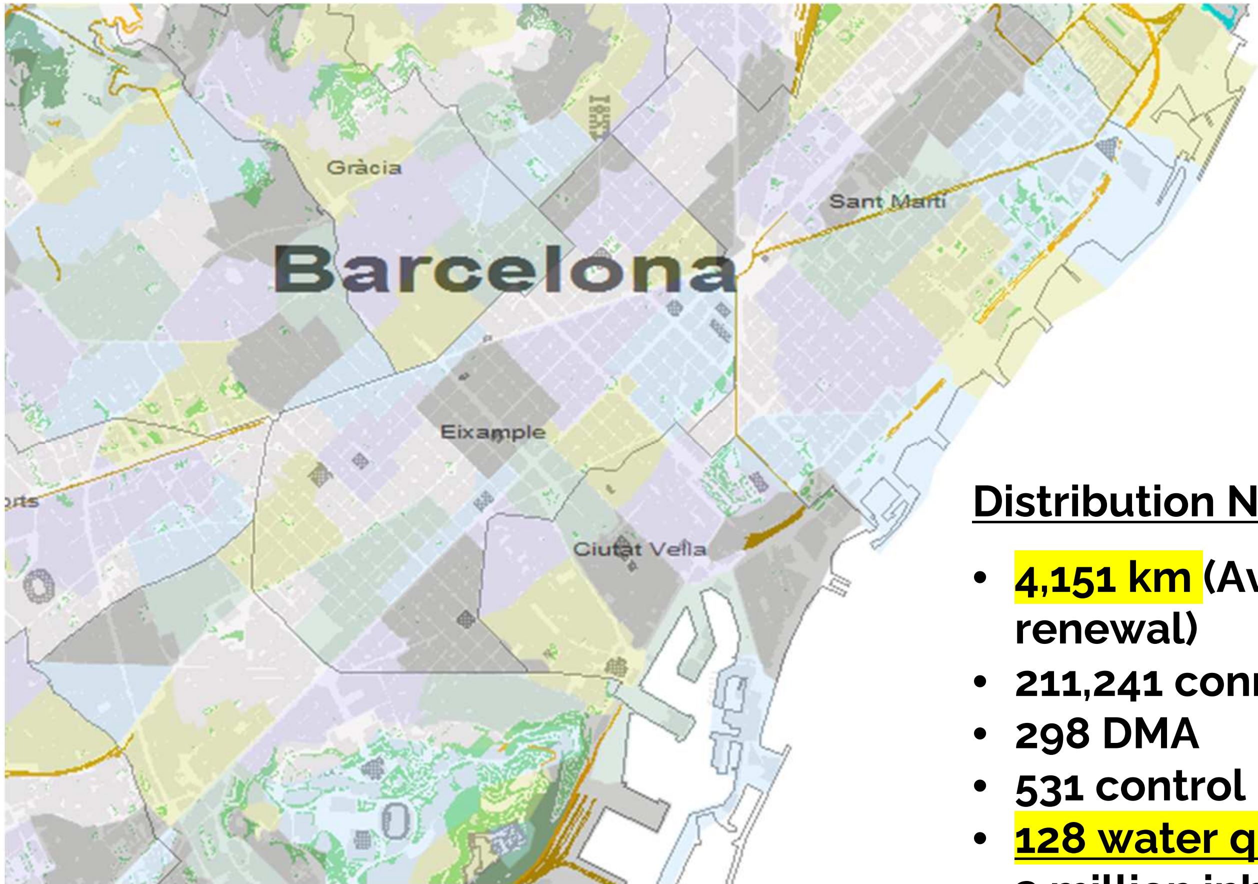

Transport Network:

- 530 km (Average age: 51 years)
- 143 pressure floors
- 227 flowmeters
- 438 pressure transducers
- 65 pumping stations
- 69 water tanks
- 88 water quality online analysers (4 THMs)

Distribution Network:

- 4,151 km (Average age: 33 years, 0,7% annual renewal)
- 211,241 connections
- 298 DMA
- 531 control points (pressure and flow)
- 128 water quality online multiparameter analysers
- 3 million inhabitants, 1,455,172 water meters (1 meter/customer, 73% AMR, average age: 6,6, 86% >=R200)

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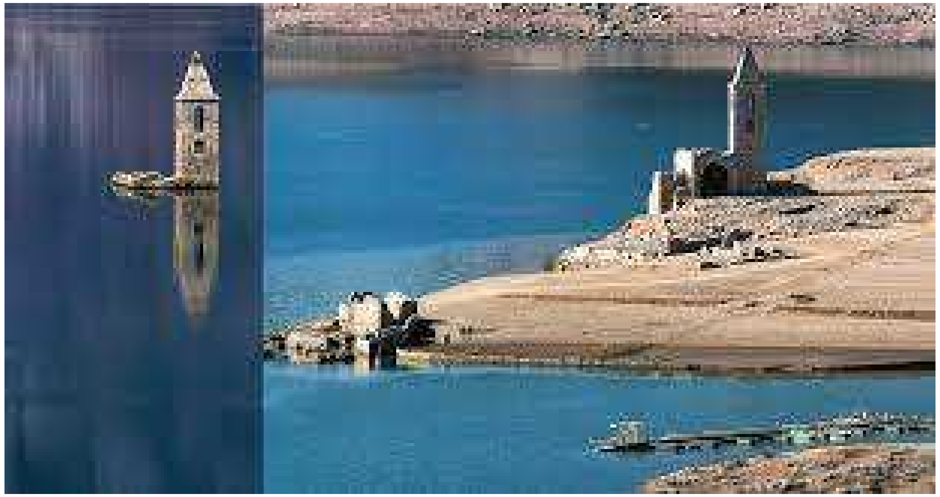
Plus…..

A VERY SEVERE DROUGHT !



Plus….. A VERY SEVERE DROUGHT !

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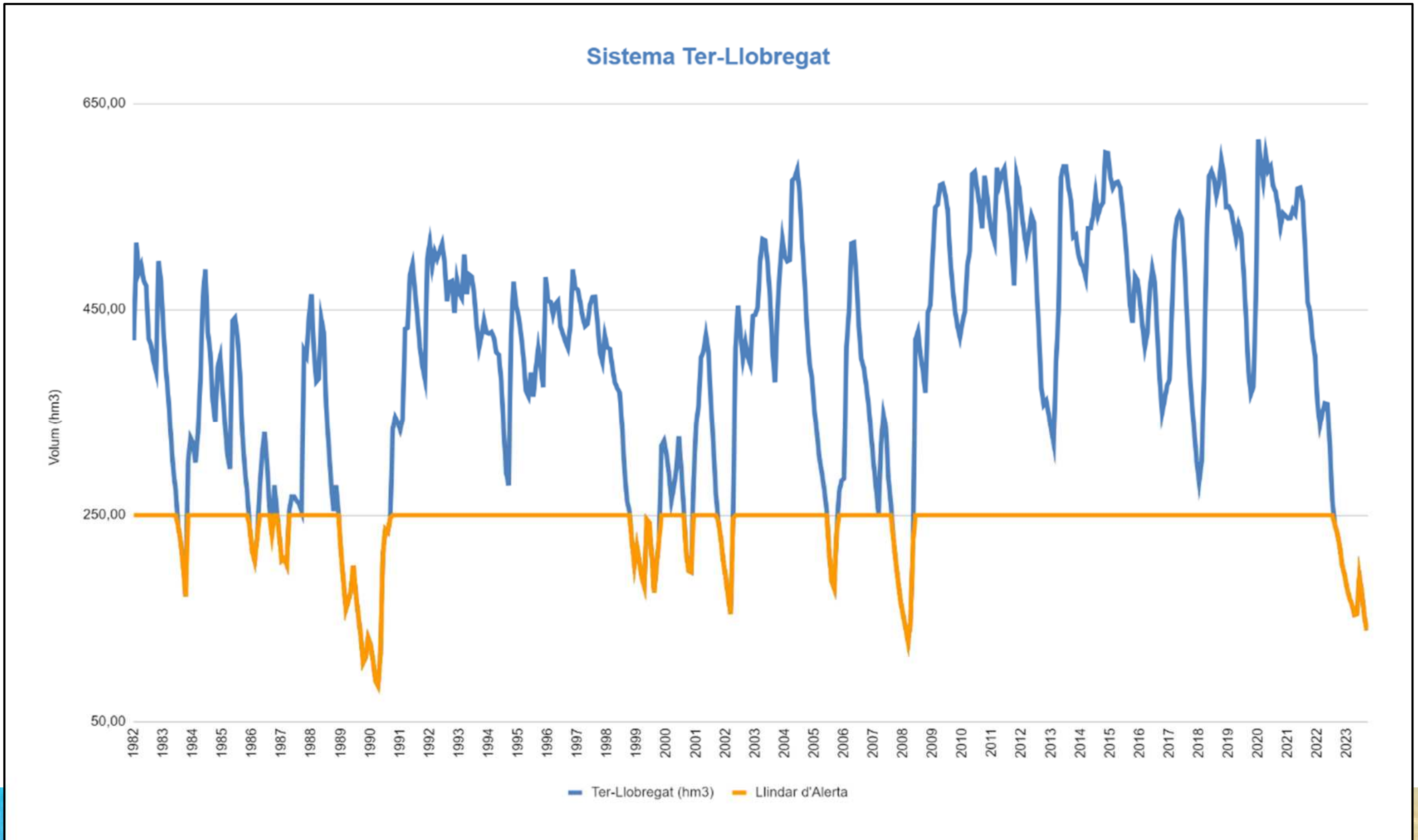
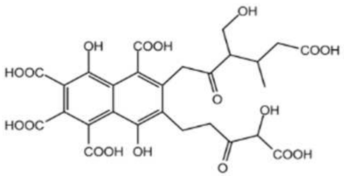
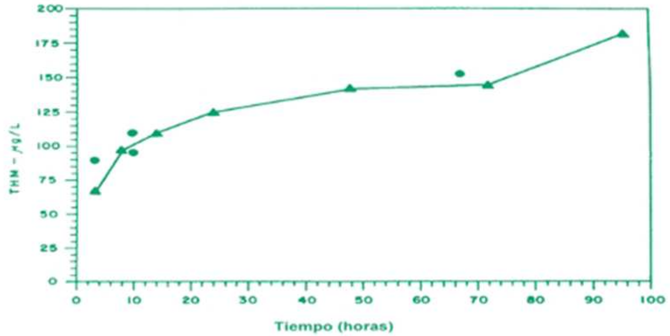
Evolution of the water reserves in reservoirs at Ter-Llobregat system (1982-2023)

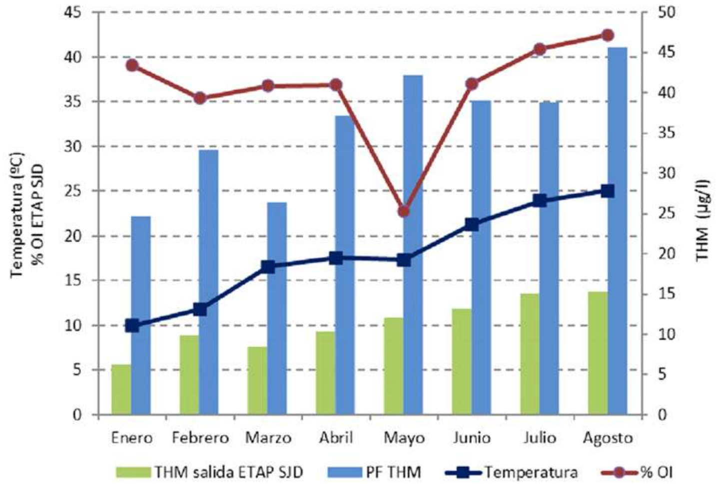


Reminder: most important factors influencing THMs' formation





- **Type and concentration of trihalomethane precursors** (**Organic matter**, Br-, Cl-,…)
- **Temperature**: ↑T ⟶ ↑kinetics of THMs' formation
- **pH**: ↑pH ⟶ ↑THMs
- **Contact time**: ↑Residence time ⟶ ↑THMs
- **Treatment process** at the DWTP and the **disinfection/preoxidation product & dose** used



Climate Emergency effects

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- Type and concentration of trihalomethane **precursors** (**Organic matter**, Br-, Cl-,…): **OM increase**
- **Temperature**: ↑T ⟶ ↑kinetics of THMs' formation
- **pH**: ↑pH ⟶ ↑THMs
- **Contact time**: ↑Residence time ⟶ ↑THMs
- **Treatment process** at the DWTP and the **disinfection/pre-oxidation product & dose** used

- Algae blooms
- Increase of salinity (Br^-)
- etc.

Strategy & tools used for the optimization of Trihalomethanes' levels

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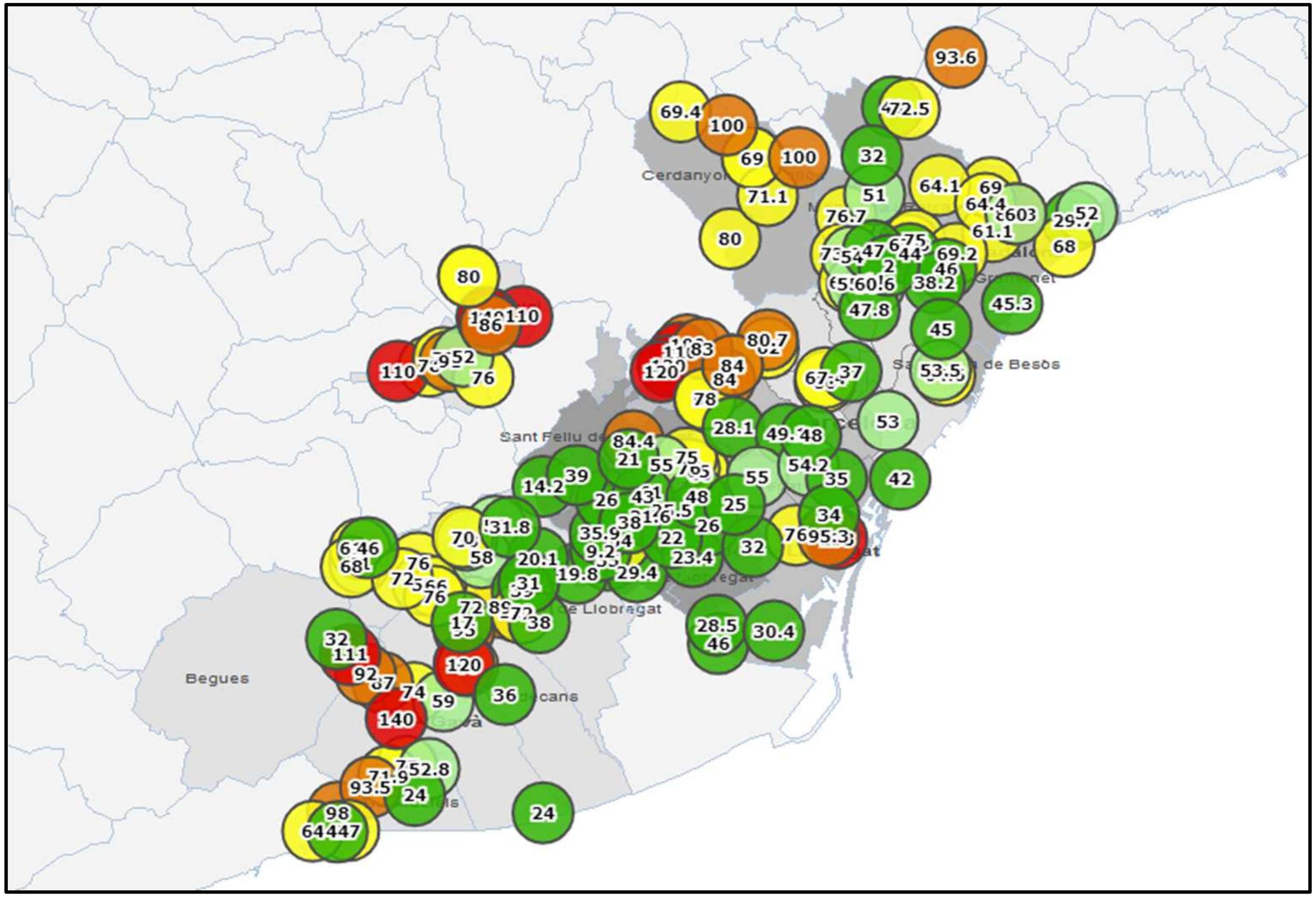
THM levels: the situation we had back in time



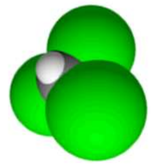
Tools used for the optimization of Trihalomethanes levels
1) Treatment process

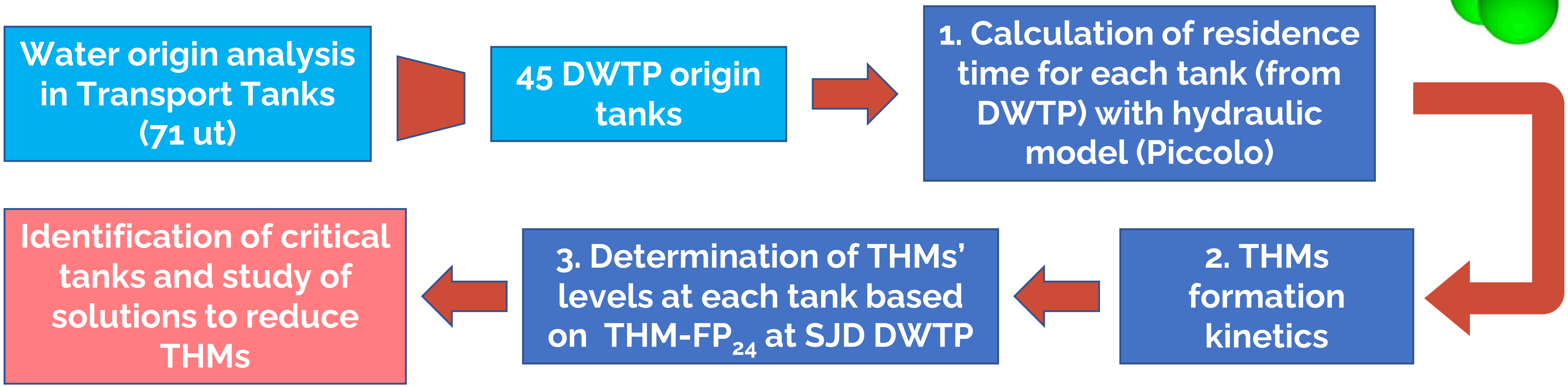
- Mixing of surface water with **groundwater** (lower OM content).
- **OM reduction** through a **Reverse Osmosis** treatment (↑ OPEX)
- Replacement of Cl_2 in the pre-oxidation step by **ClO_2**.
- Improvements in the **GAC regeneration**.
- **Optimization of Cl_2 addition** in the final disinfection.
- Determination of the **THM Formation Potential (THM-FP)** of the water treated at the DWTP and establishment of a maximum setpoint to regulate the operation/treatment. **Online modelling/prediction**.

Tools used for the optimization of Trihalomethanes levels
2) Distribution Network

- Exhaustive **control of the THMs levels** in all the DW Network areas and **verification of the THM-FP prediction**.
- Introduction of water from **other sources** (lower OM & precursors): desalinated water, groundwater, surface water from another river (Ter river).
- **Optimization of residence times** and re-chlorination levels in the network (tanks management).
- Installation of **THM removal systems (*TRS*)** at critical points of the network ('satellite' solution).
- Use of **THM online analyzers** in strategical points of the system, in order to verify the global strategy, monitor water quality and be able to act preventively in case of any potential problem.
- Other operational improvements (tanks out of service, etc.)

Methodology followed to reduce THMs in the water network (I)





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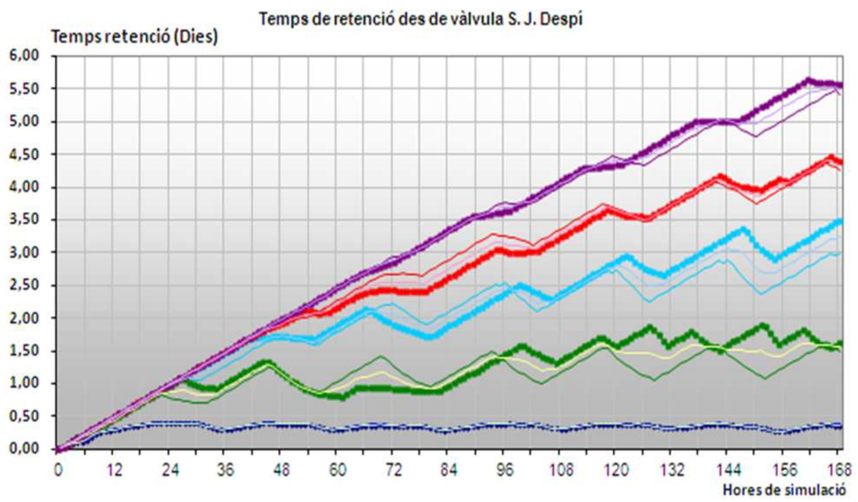
Methodology followed to reduce THMs in the water network (II)

1. Calculation of the residence time for each tank from the DWTP (hydraulic model)

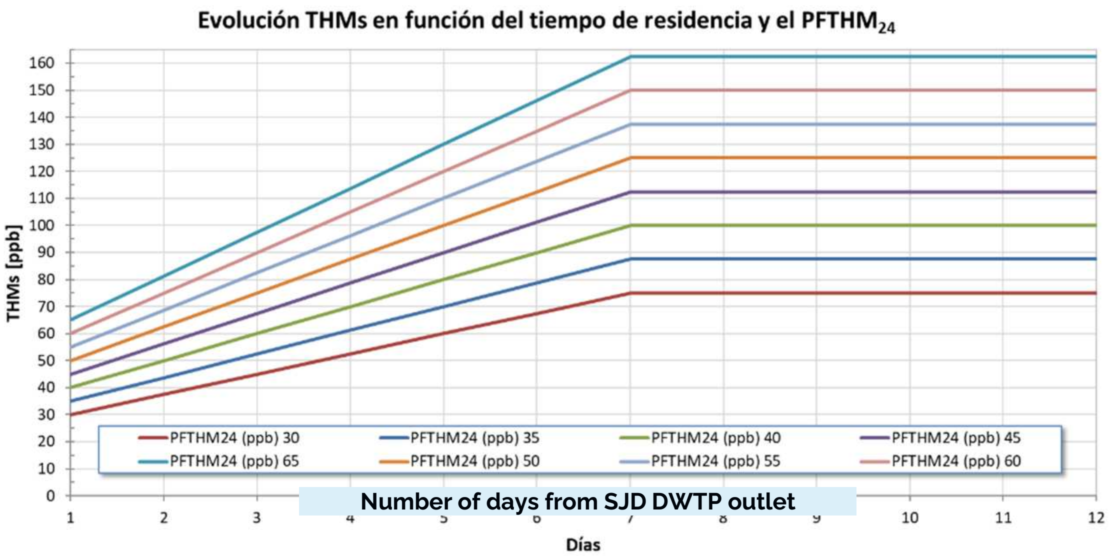


Water residence time (days)	Number of water tanks	water tanks %	Accumulated %
[0-1]	2	4,4%	4,4%
[1-2]	2	4,4%	8,9%
[2-3]	8	17,8%	26,7%
[3-4]	5	11,1%	37,8%
[4-5]	7	15,6%	53,3%
[5-6]	4	8,9%	62,2%
[6-7]	8	17,8%	80,0%
[7-8]	4	8,9%	88,9%
[8-9]	2	4,4%	93,3%
[9-10]	2	4,4%	97,8%
[10-11]	1	2,2%	100,0%
TOTAL	45	100,0%	-

Methodology followed to reduce THMs in the water network (III)

2. THMs formation kinetics

THMs formation f(residence time, $PFTHM_{24}$)



Number of days from SJD DWTP outlet

Llobregat water origin:

$$THM(t)=0{,}25 \cdot PFTHM_{24} \cdot t+0{,}75 \cdot PFTHM_{24}$$

3. Determination of THMs levels at each tank based on $THM\text{-}FP_{24}$ at the DWTP

Escenario 1: Todos reciben agua de ETAP SJD, sin TRS			$PFTHM_{24}$ (ppb)							
			30	35	40	45	50	55	60	65
Depósito	**Origen**	**Edad del agua (días)**	THM max (ppb)							
Mas Guimbau III	Llob, Ter	10,9	75	88	100	113	125	138	150	163
Can Guey IV	Est, Llob	9,1	75	88	100	113	125	138	150	163
Can Güell V	Est, Llob	9,1	75	88	100	113	125	138	150	163
Sta. Amàlia	Llob	8,3	75	88	100	113	125	138	150	163
Can Guey V	Est, Llob	8,1	75	88	100	113	125	138	150	163
Can Güell III	Est, Llob	7,4	75	88	100	113	125	138	150	163
Can Rectoret II	Llob, Ter	7,2	75	88	100	113	125	138	150	163
Viladecans II	Llob	7,2	75	88	100	113	125	138	150	163
Tibidabo Torreó	Llob, Ter	7,1	75	88	100	113	125	138	150	163
Tibidabo Cim	Llob, Ter	6,9	75	87	99	112	124	137	149	161
Mas Guimbau II	Llob, Ter	6,9	75	87	99	112	124	137	149	161
Can Guey III	Est, Llob	6,9	74	86	99	111	123	136	148	160
Can Rectoret I	Llob, Ter	6,8	74	86	98	111	123	135	148	160
Cesalpina III	Est, Llob	6,8	74	86	98	110	123	135	147	159
Cesalpina IV	Est, Llob	6,8	74	86	98	110	123	135	147	159
Begues IV	Llob	6,1	68	80	91	103	114	125	137	148
Can Güell II	Est, Llob	6,1	68	79	91	102	113	125	136	147
Can Guey II	Est, Llob	5,8	66	77	88	99	110	121	132	143
Tres Pins	Llob	5,6	65	75	86	97	108	118	129	140
Bellsoleig	Llob, Ter	5,5	64	74	85	96	106	117	128	138
Vallvidrera	Llob, Ter	5,1	61	71	81	92	102	112	122	132
Sant Climent II	Llob	4,9	59	69	79	89	99	109	119	129
Can Coll	Est, Llob	4,8	59	69	78	88	98	108	118	127
La Sentiu II	Llob	4,6	57	66	76	85	95	104	114	123
Cesalpina II	Est, Llob	4,5	56	65	75	84	93	103	112	121
Montjuïc	**Llob**	**4,3**	**55**	**64**	**73**	**82**	**91**	**100**	**109**	**118**

% OI	**57%**	**50%**	**43%**	**36%**	**29%**	**21%**	**14%**	**7%**
Núm racks	**9**	**8**	**6**	**5**	**4**	**3**	**2**	**1**

Methodology followed to reduce THMs in the water network (IV)

Different measures adopted depending on the tank

Escenario 1: Todos reciben agua de ETAP SJD, sin TRS	PFTHM24 (ppb)							
	30	**35**	**40**	**45**	**50**	**55**	**60**	**65**
Depósito	THM max (ppb)							
Mas Guimbau III			TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter
Can Guey IV			Est	Est	Est	Est	Est	Est
Can Güell V			Est	Est	Est	Est	Est	Est
Sta. Amàlia			Vol	Vol	Vol	Anul	Anul	Anul
Can Guey V			Est	Est	Est	Est	Est	Est
Can Güell III			Est	Est	Est	Est	Est	Est
Can Rectoret II			TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter
Viladecans II			Vol	Vol	Vol	Anul	Anul	Anul
Tibidabo Torreó			TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter
Tibidabo Cim				TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter
Mas Guimbau II				TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter
Can Guey III				Est	Est	Est	Est	Est
Can Rectoret I				TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter	TRS Vall, Ter
Cesalpina III				Est	Est	Est	Est	Est
Cesalpina IV				Est	Est	Est	Est	Est
Begues IV				TRS Beg3	TRS Beg3	TRS Beg3	TRS Beg3	TRS Beg3
Can Güell II				Est	Est	Est	Est	Est
Can Guey II					Est	Est	Est	Est
Tres Pins					TRS	TRS	TRS	TRS

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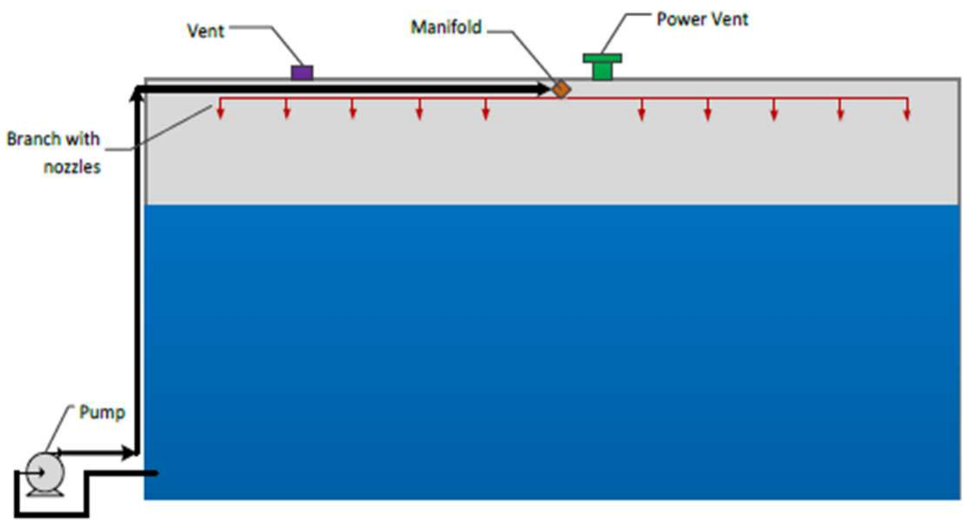
THM Removal Systems (*TRS*) in the Distribution Network

TRS systems in *Aigües de Barcelona*: Configuration



Source: PAX Water Tecnologies

UGSI Solutions (PAX TRS™)

TRS systems in *Aigües de Barcelona*: Configuration

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TRS systems in *Aigües de Barcelona*: Pilot tank (2012)

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- **2 vessels**: 2,000 m³ each one (one blank and the other with *TRS*)

Target: **50% THM removal**

TRS Elements:;

- **Recirculation pump**: 15 l/s, 5.5 kW
- **Vent**: 0.75 kW, (PAX PowerVent), pipe ND400 mm
- **Mixer**: 0.3 kW, PWM400 (PAX Water Technologies)
- **Spray nozzles**: 12 units, ½" diameter, pipe HDPE ND75 and 63 mm
- **Online THM analyser**: THM-100 from *Aqua Metrology Systems*
- **Chlorine-pH analyser**: APMIX-4 from *Severn Trent Services*

TRS systems in *Aigües de Barcelona*: Pilot tank (2012)

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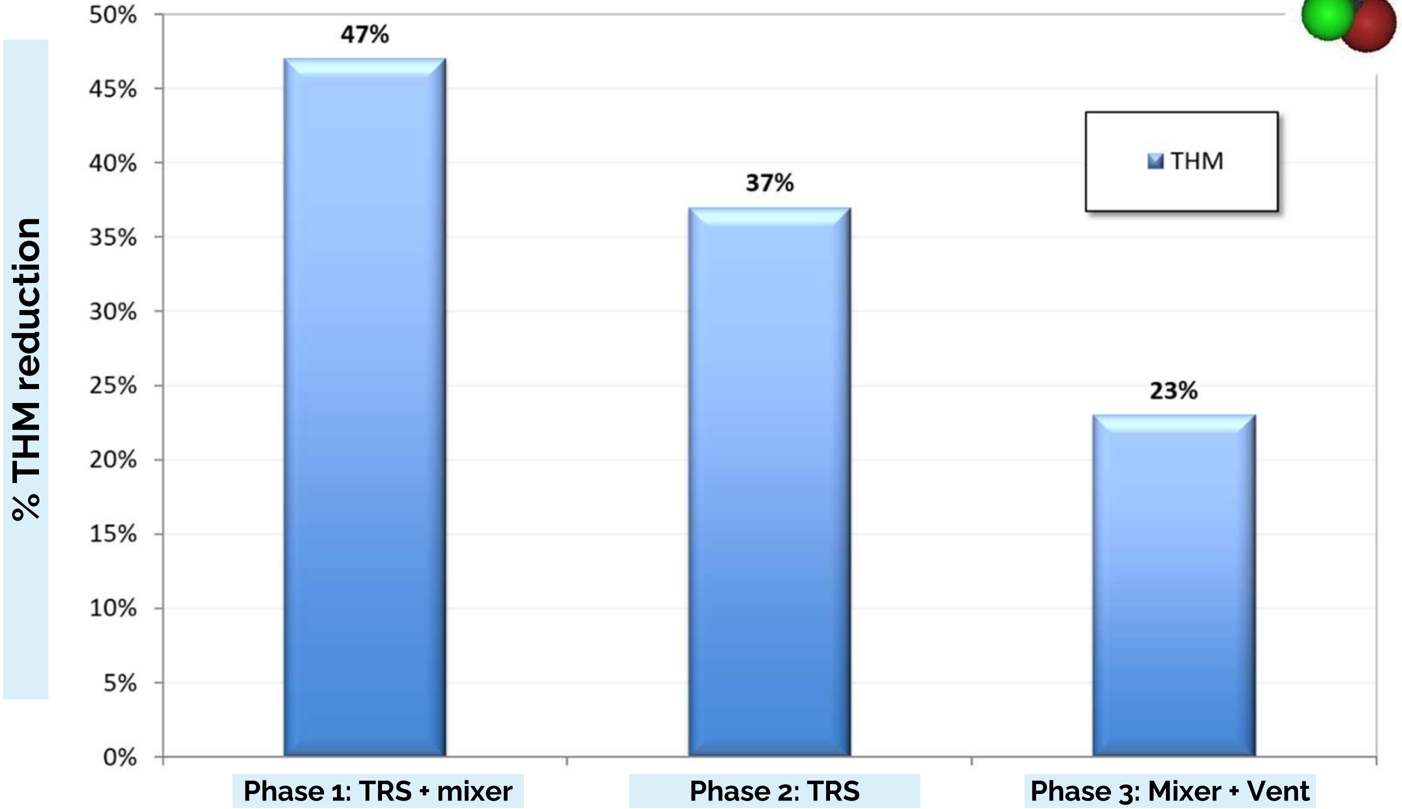
THM outlet reduction between Cell A (with TRS) and Cell B (blank)



TRS: Vent+spray nozzles+recirculation

TRS systems in Aigües de Barcelona: final deployment

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Water Tank	Installation year	Volume (m^3)	Configuration
Begues II	2015	3,000	Mixer + vent
Begues III	2014	3,000	Mixer + vent
Sant Climent II	2015	1,000	Mixer + vent
Castelldefels (Cell A)	2012	2,000	Mixer + vent + spray nozzles
Tres Pins (Cell C)	2014	3,000	Mixer + vent + spray nozzles
Vallvidrera	2014	3,000	Mixer + vent + spray nozzles + online THM analyzer

TRS systems in *Aigües de Barcelona*: Costs

- Installation (Materials and assembly)
  - Depends on water tank volume, accessibility to water tank, % THM to remove, additional civil works, electric power extension, etc.
  - Complete *TRS* (vent + spray nozzles network + recirculation pump) with mixer, 3,000 m^3 water tank: **200 k€**
  - Mixer and vent: **85 k€**
  - Online THM analyser: **60 k€** (requires air conditioning and air filtering system)

- Operation
  - **12 €/day** Mixer + vent
  - **33 €/day** complete TRS
  - **0.039 €/m^3**, 39% lower than advanced treatment (Reverse Osmosis)

TRS systems in *Aigües de Barcelona*: Maintenance

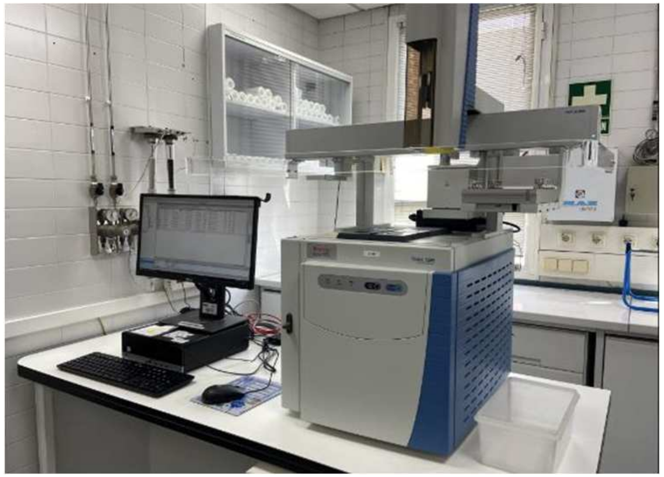
- If good selection of equipment, low frequency and maintenance costs.
- Filter cleaning (depending on environmental conditions: dust, humidity, vegetation)
- Visual inspection of equipment and common electromechanical preventive/predictive maintenance operations.

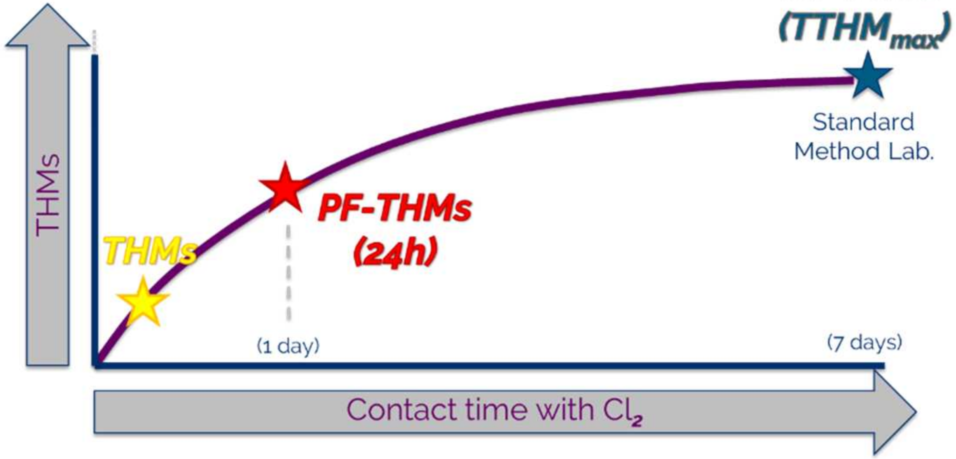



THM Monitoring and prediction

Manual THM monitoring (Lab.)

Trihalomethanes (P&T-GC/MS) (every 12h)





Trihalomethanes'
Formation Potential
THM-PF 24h (every 12h)

Limit THM-PF = 45-50 ug/l

⭐ THM Online Analyser

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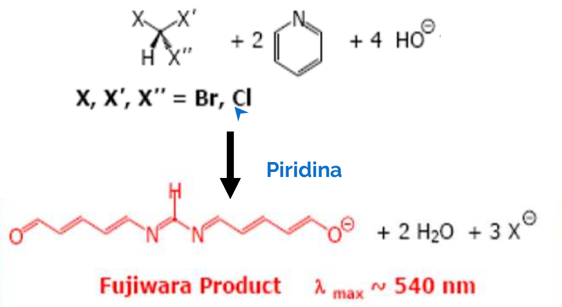
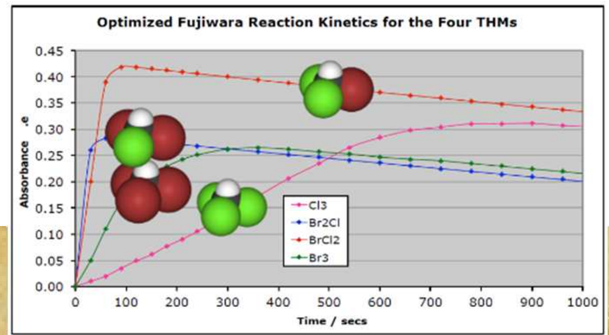
THM-100 from *Aqua Metrology Systems Limited*

Main features:

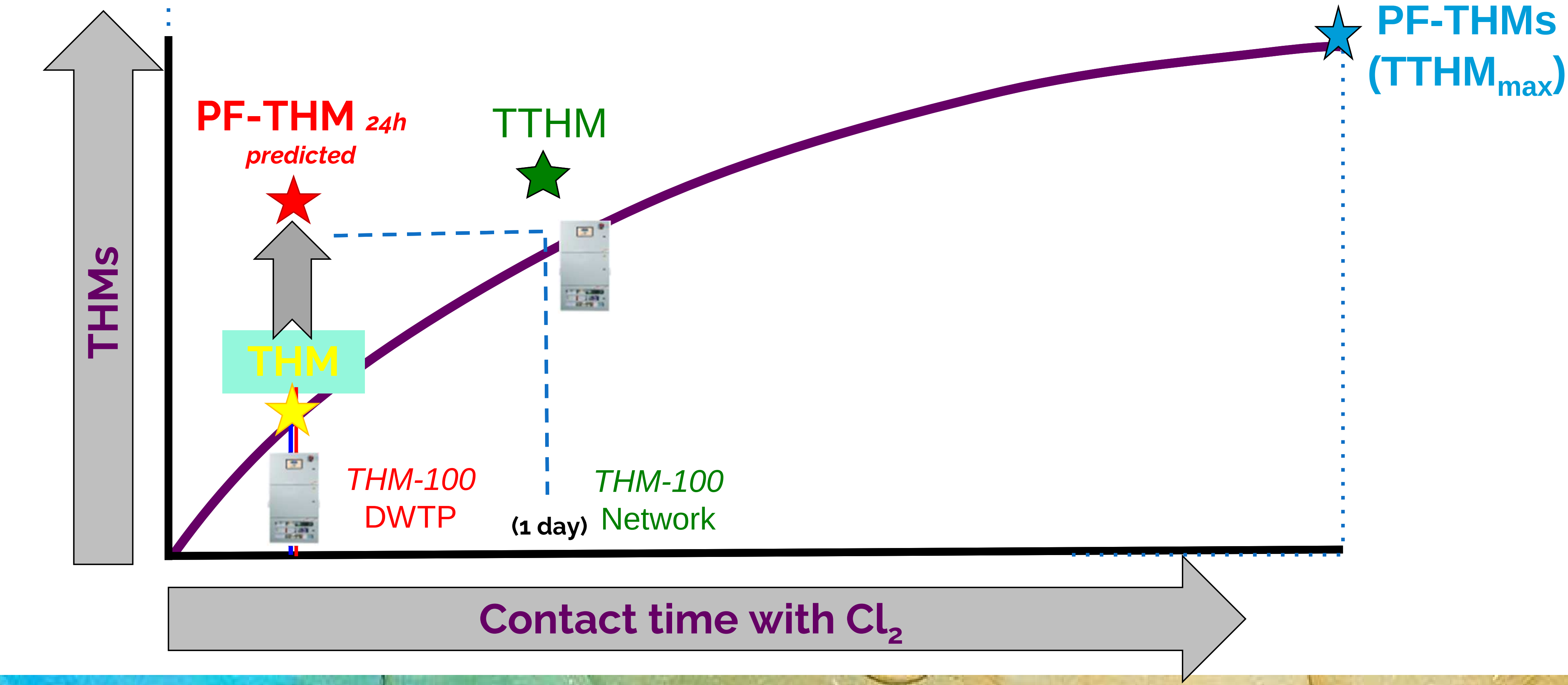
- Measurement of Chloroform, Bromoform & $CHBrCl_2$+$CHBr_2Cl$
- Total THM sum calculation
- On-line automated sampling, programmed to sample every 4 hours.
- Auto-calibration
- Telemetric transmission of data (cloud via cellular + 4-20mA SCADA)
- Installation requirements: connection to water network, drain, Internet service, air compressor, air conditioning.

Fujiwara Reaction:



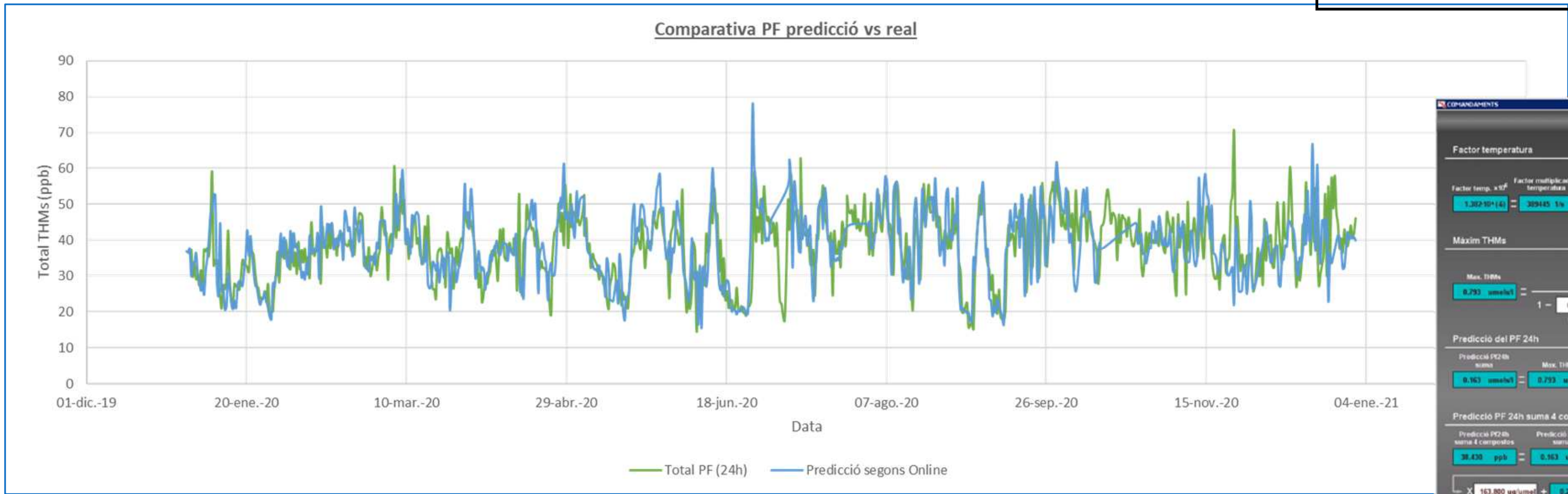


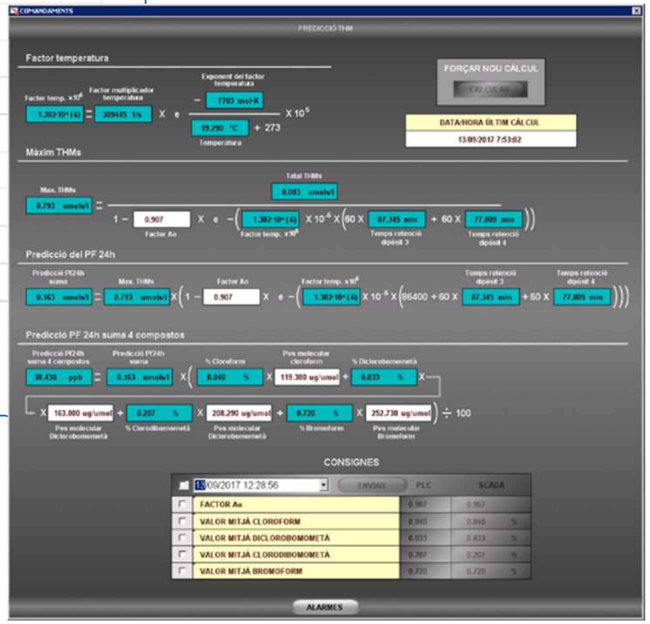
THM-FP (24h) prediction



THM-FP (24h) online prediction (modelling)

$$[THM](t) = [THM]_{max}\left(1 - A_0 e^{-k''t}\right)$$





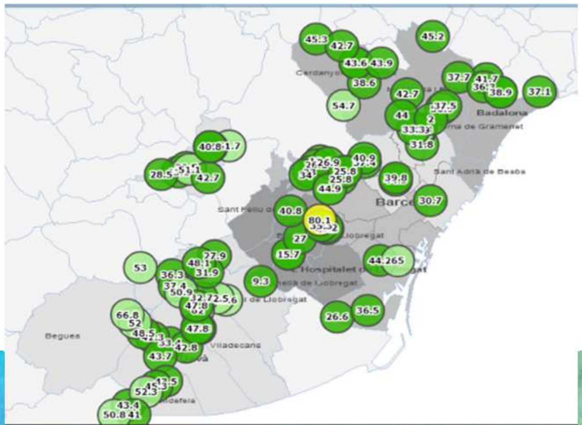
Entry data of the model:

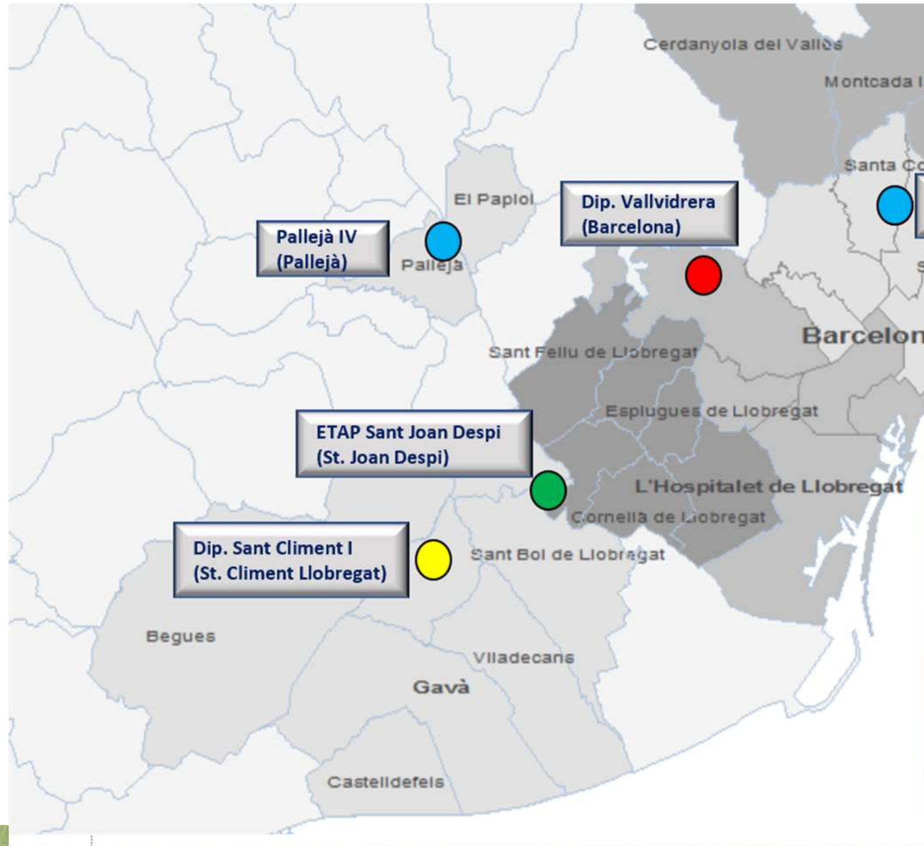
- THM-FP
- THM online results
- Residence time DWTP
- Temperature

The Online Analyzers

Criteria for the location of instruments:

- Water supplied by the administration (main entries to the system)
- Continuous monitoring of the water treated at the Sant Joan Despí DWTP: THM & THM-FP
- Tanks with high residence times (control of the efficiency of the *TRS* systems installed)
- Potentially critical points, located 1,5 day from DWTP (validation of the FP strategy)





Conclusions / Summary

Conclusions

- The management of trihalomethanes (THM) in distribution systems can become very complex, especially when raw water quality is poor and the distribution network extensive, with high retention times of the water till the supply points.
- This management becomes even more difficult when the systems suffer from **water scarcity** in their sources, as the quality is also deteriorated, a problem that has increased in many countries a result of the **climate emergency**.
- THM levels are a **non-conservative magnitude**, as concentrations increase over time from the outlets of the Drinking Water Treatment Plants (DWTPs) or delivery points; thus, even when the values at the DWTP outlets and/or at the reception points are consistent, problems may arise, especially at the most extreme points of the distribution networks, if the water management strategy THMs is not adequate or it's not optimized for these difficult contexts.
- To ensure that THMs values are obtained that not only comply with the requirements of current legislation at all supply points but are also optimized, it is necessary to design a **comprehensive and preventive strategy** throughout the whole supply system, jointly considering the actions carried out at the **treatment plants** and in the **distribution network.**

Strategy summary

- **Optimization of treatment process** (OM removal, disinfectants used and dosing).
- **Optimization of residence times** and re-chlorination levels in the network (tanks' management).
- Determination of the **THM Formation Potential** of the water treated at the DWTP and establishment of a **maximum setpoint** to regulate the operation/treatment.
- **Online modelling/prediction of THM-FP at DWTP** (and in the whole water network, under development).
- Installation of **THM removal systems (*TRS*)** at critical points of the network.
- Use of **THM online analysers** in strategical points of the system, in order to verify the global strategy, monitor water quality and be able to act preventively in case of any potential problem.

And it works !

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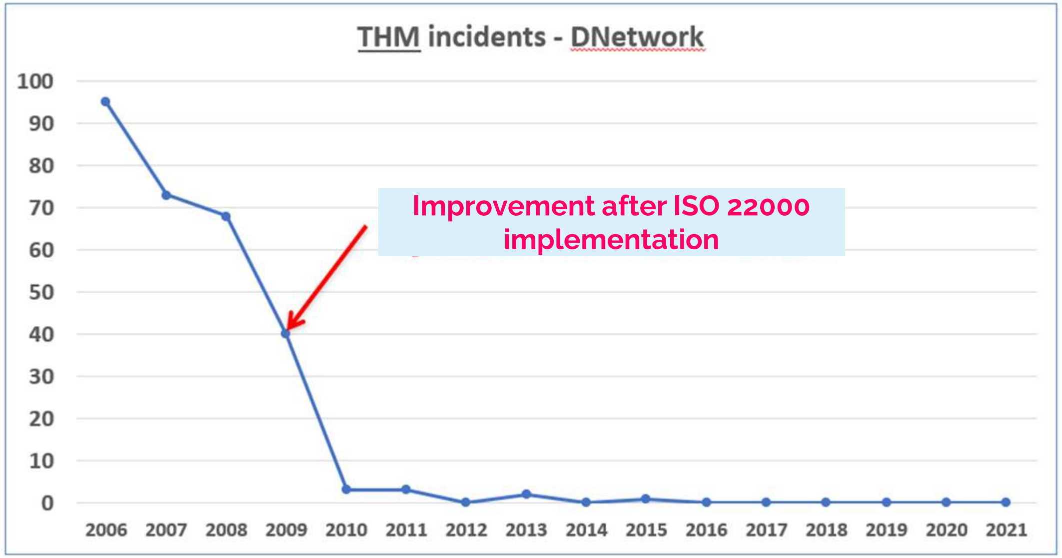
TRIHALOMETHANES	Quality Incidents (values > 100 µg/l)		Average Values (µg/l)		
	Before ISO 22000 (2008)	After ISO 22000 (2019)	Before ISO 22000 (2008)	After ISO 22000 (2019)	Reduction (%)
DWTP	68	0	96,9	13,5	**86**
Distribution Network	116	0	96,0	44,8	**53**

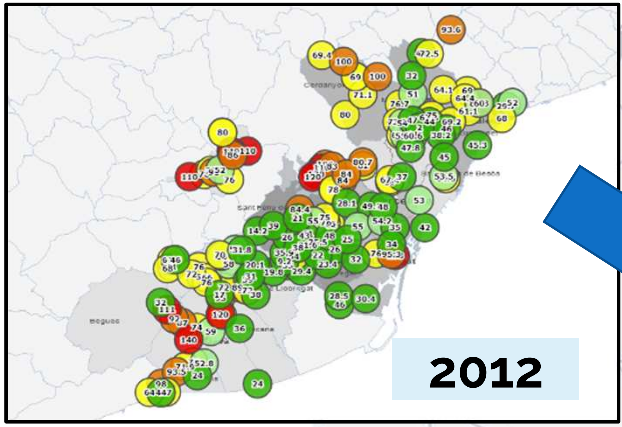
REGULATORY NONCOMPLIANCES (Directives *98/93/CE* & *(UE) 2020/1784*)

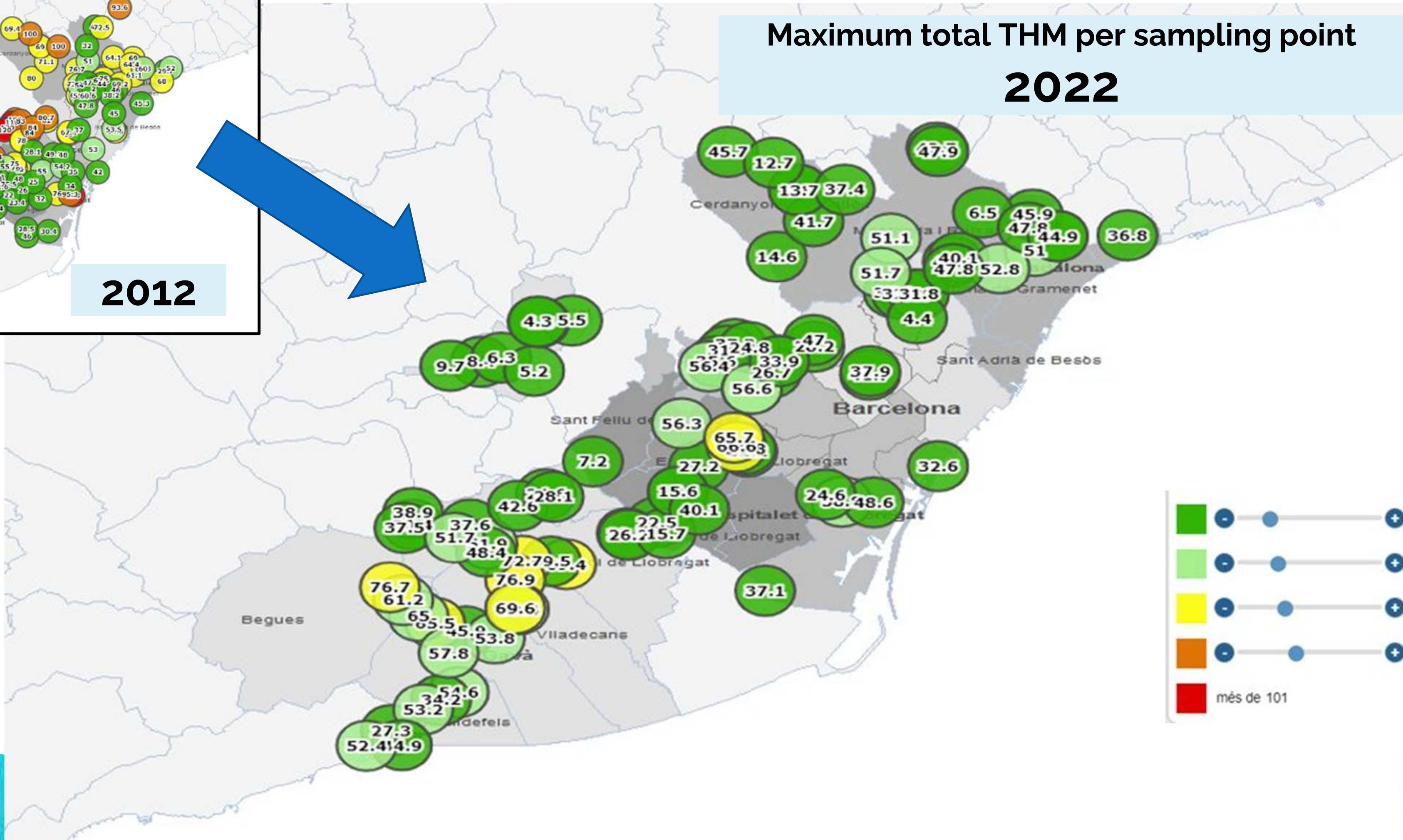
Parameter	Before ISO 22000 (2008)	After ISO 22000 (2020)
Trihalomethanes	24	0

THMs quality incidents



The current situation





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