Industry requirements from NOM research

Asset Strategy (Water)

V0.6

June 2016

THM health effects

- People can be exposed to THMs in drinking water in a number of ways;
  - *ingestion of drinking water;*
  - *inhalation of indoor air largely due to volatilisation from drinking-water, inhalation; and*
  - *dermal exposure during showering and bathing.*

- USEPA :
  - *Some people who drink water containing total trihalomethanes in excess of the MCL (80µg/L) over many years could experience liver, kidney, or central nervous system problems and increased risk of cancer.*
  - *Long-term exposure to DBPs has been linked to bladder cancer, and possibly colon and rectal cancers. More recent studies have shown that shorter-term exposure to high levels of DBPs may be associated with adverse reproductive and developmental health effects.*
- The International Agency for Research on Cancer (IARC) classified both Chloroform and Bromodichloromethane, two individual THMs, as possibly carcinogenic to humans Group 2B). This category is used where there is inadequate evidence of carcinogenicity in humans and sufficient evidence of carcinogenicity in experimental animals. Bromoform or Chlorodibromomethane were not classified as to their carcinogenicity (Group 3).

THM non-compliance 2015

653no. WSZs

Treated Water TTHM Risk Prioritisation		TTHM (maximum concentration) [µg/L]		
		100 - 200	200 - 300	>300
TTHM (average concentration) [µg/L]	<100	2	2	3
	100 - 150	2	3	4
	>150	3	4	5

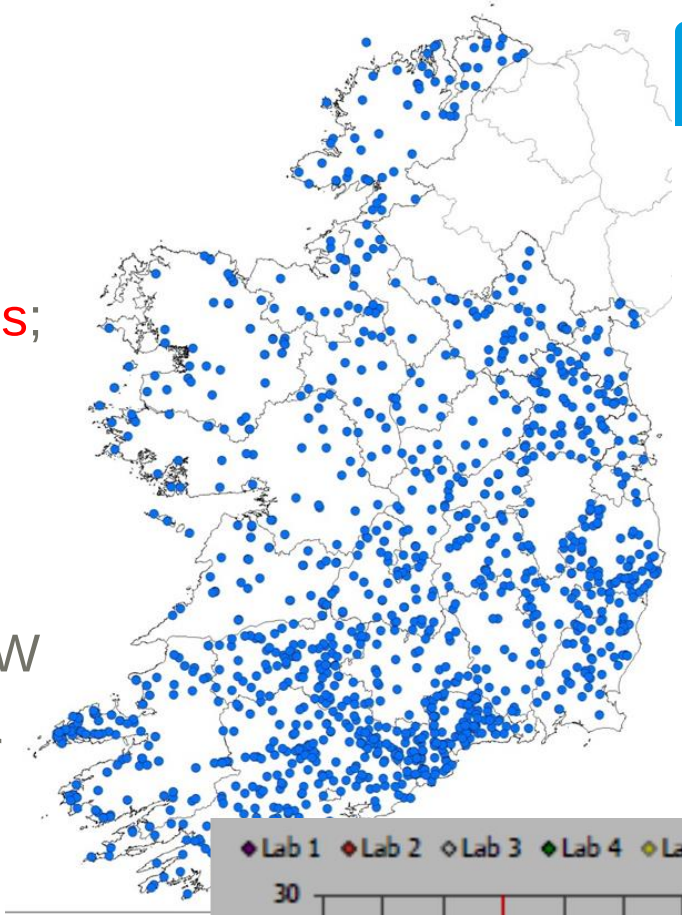
TTHM Risk	No. of WSZs
5	3
4	5
3	7
2	134
Total	149

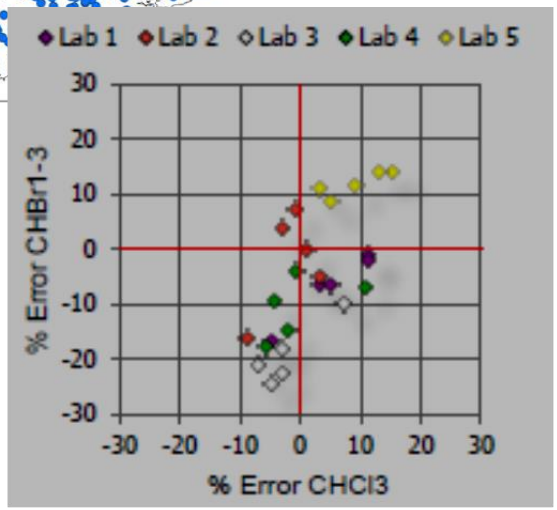
- Existing WTP deficiencies:

1) *No DBP precursor removal process;*
2) *Existing DBP removal and/or disinfection process not optimised;*
3) *Network exceedance after booster chlorination.*

The Challenge

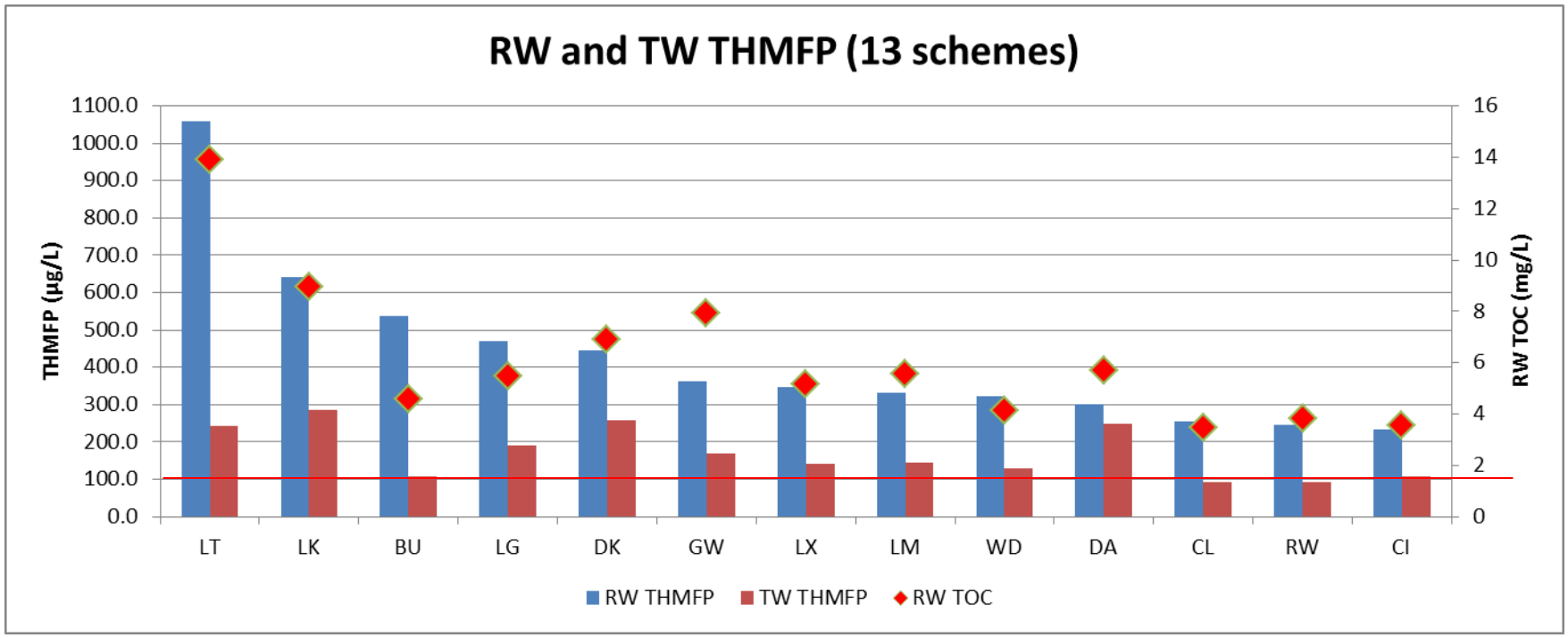
- 860 public WTPs;
- 2,000+ (regulated and emerging) DBPs;
- Limited CAPEX + reducing OPEX;
- Highly variable raw water quality:
- Large no. of WTPs abstracting from SW or GWUDI do not have DBP precursor removal process;
- Incomplete TTHM monitoring;
- Lab THM analysis error;
- Suitable TW THM monitoring surrogate?
- Knowledge management?





5 US-EPA accredited labs
Sample water spiked at TTHM 79.5µg/L (60% $CHCl_3$)

RW and TW THMFP



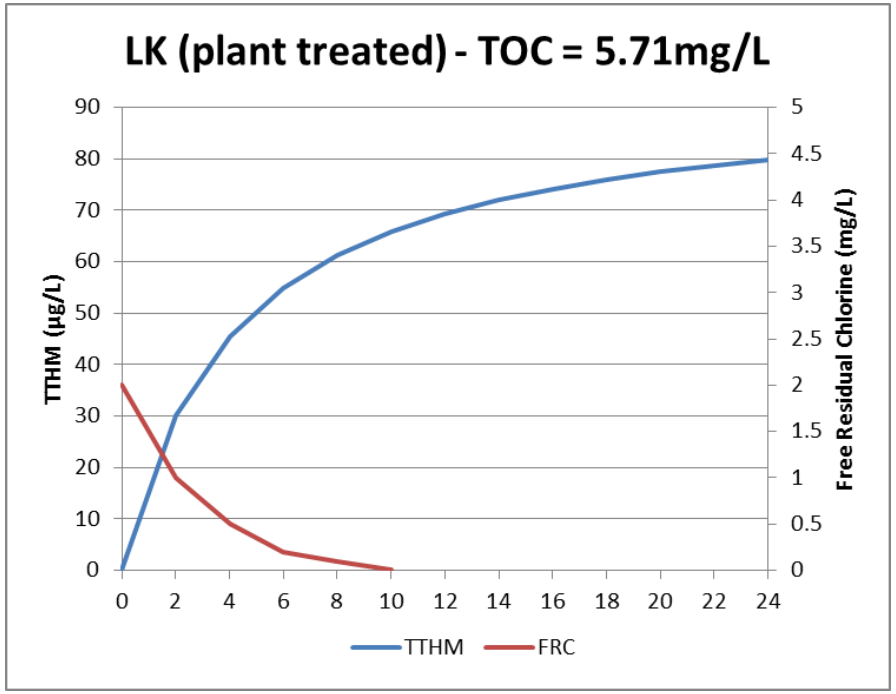
THMFP test – 7 days, 25°C, pH adjusted to 7.0, applied chlorine dose = 3 x TOC

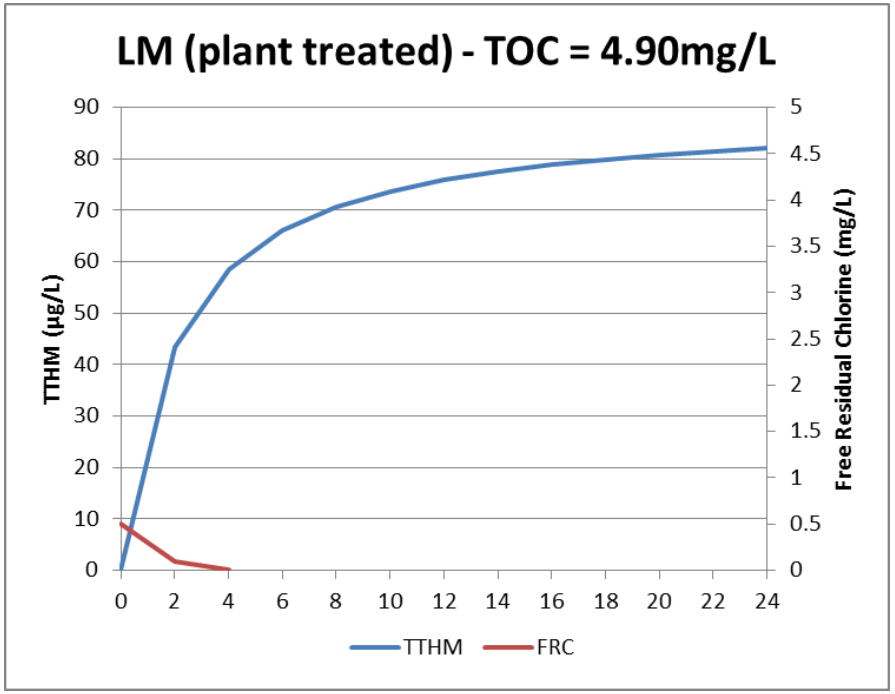
- Chloroform – between 87% to 98% of total THM;
- Correlation coefficient RW THMFP vs RW TOC = 0.738 and TW THMFP vs TW TOC = 0.649 – THMFP and TOC not a strong correlation;
- TW THMFP on 11no. WTPs exceeds parametric limit.

TOC ≠ THMFP (reactivity of NOM)

Chua, 1996

THM formation and chlorine decay



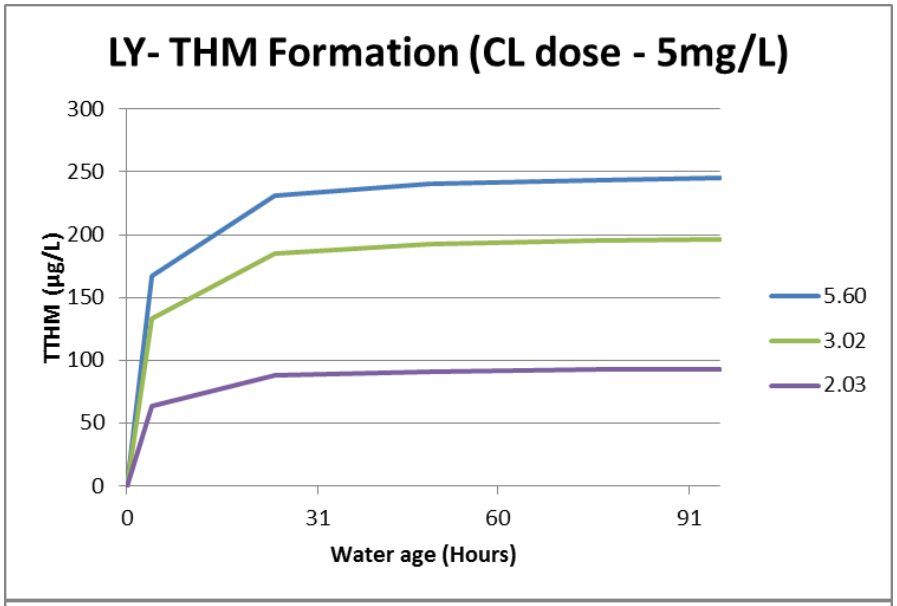


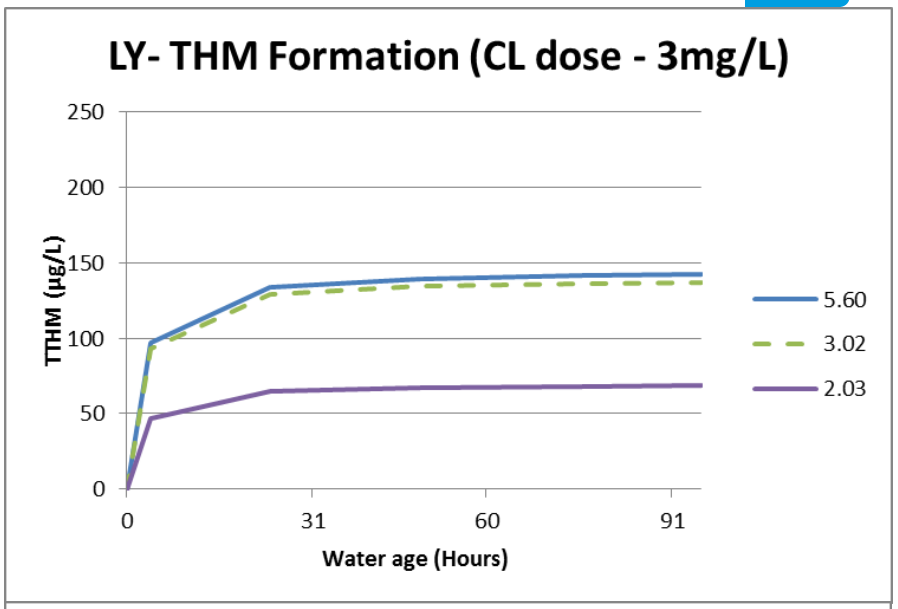
- THM formation curves show initial rapid growth 0 to 8hrs, slow growth after 10hrs;
- Chlorine decay curves show initial rapid rate of chlorine consumption 0 to 2hrs; and
- THM formation continues after RFC = 0 (*intermediate chlorinated organic compounds are formed which undergo breakdown at a low reaction rate to form THMs*)

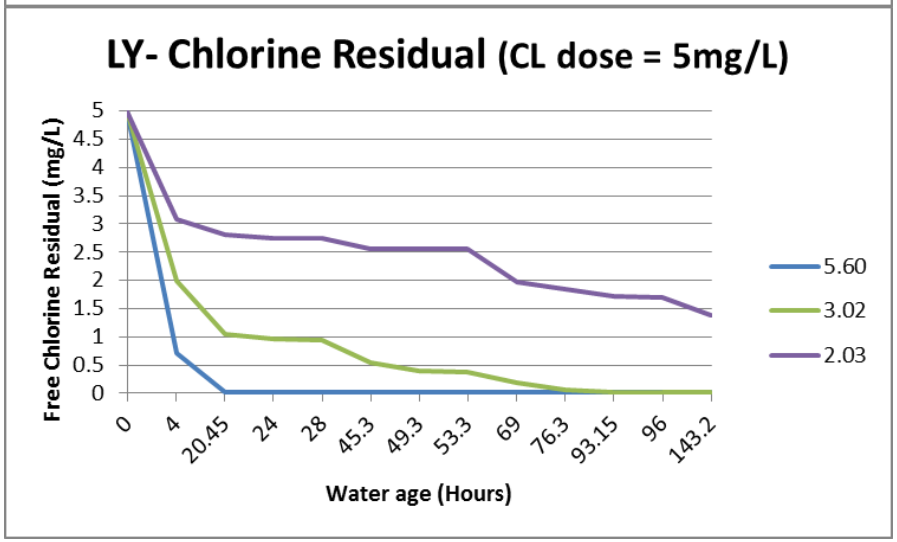
TOC ≠ THMFP (reactivity of NOM)

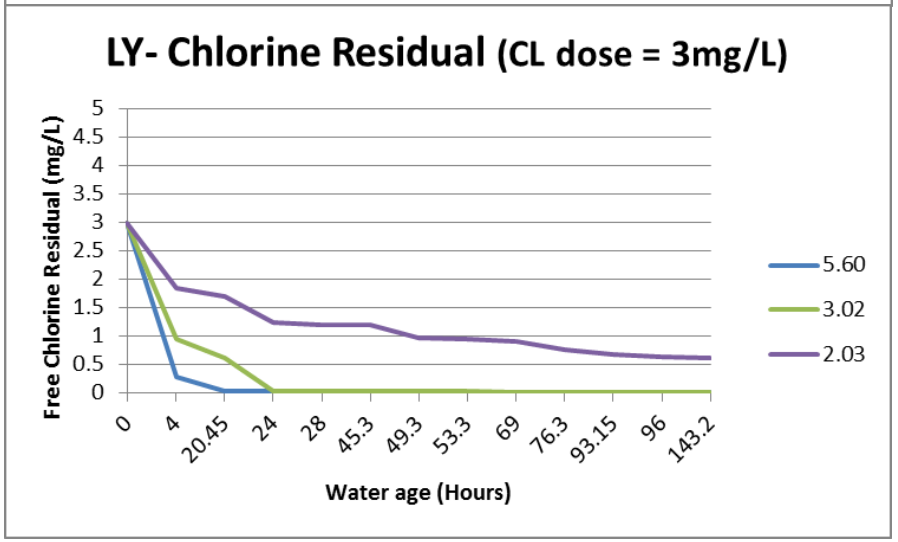
Chua, 1996

THM formation and chlorine decay









Kerr, 2011

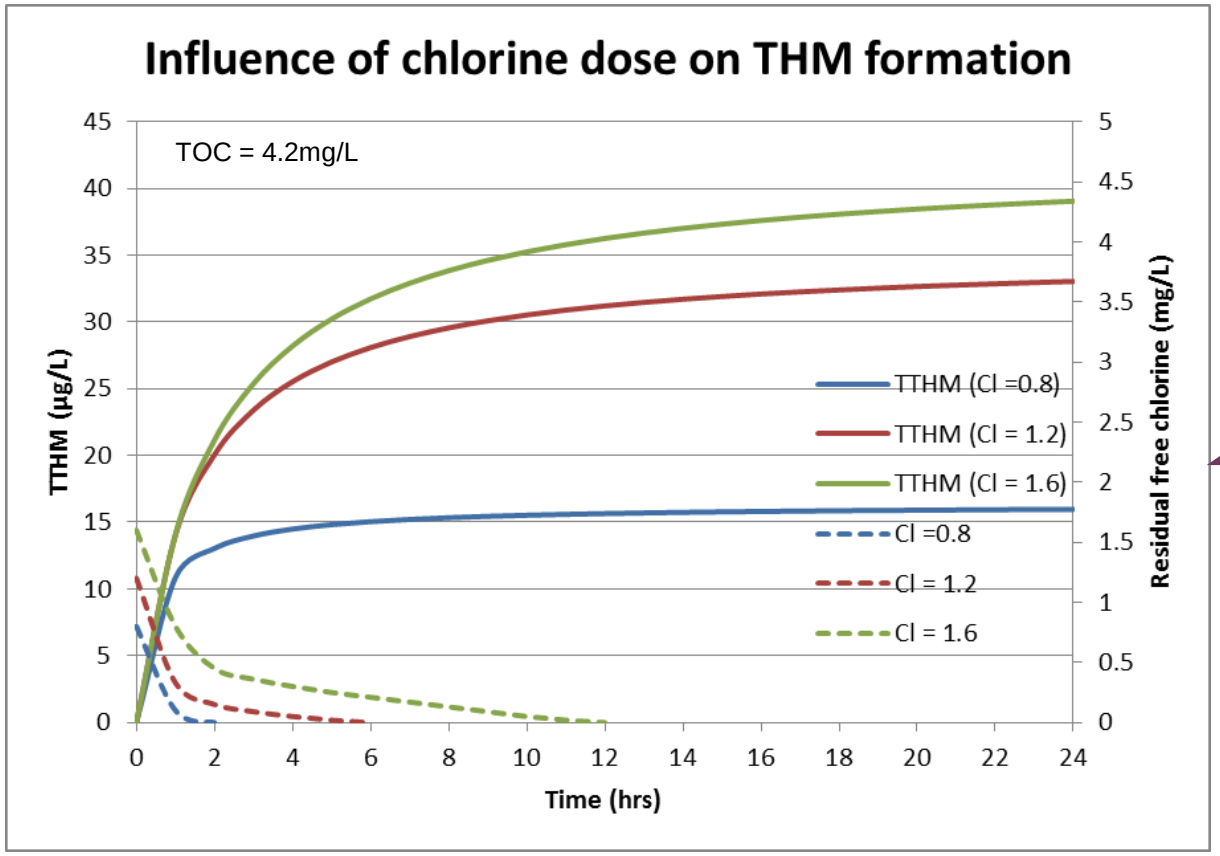
Blend - L.Keel 53% + L.Salt 9% + L.Greenan 38%

TOC = 5.60mg/l – no treatment

TOC = 3.02mg/l – L.Keel CFC+RGF

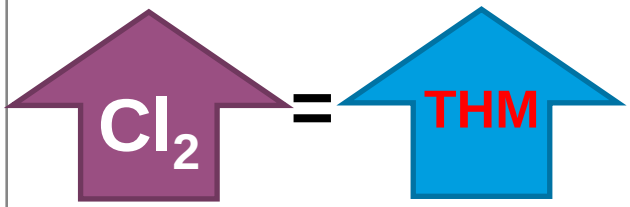
TOC = 2.03mg/l – (L.Keel + L.Greenan) CFC+RGF

Influence of chlorine dose on THM formation



Conclusions:

- THM formation is a function of chlorine dose

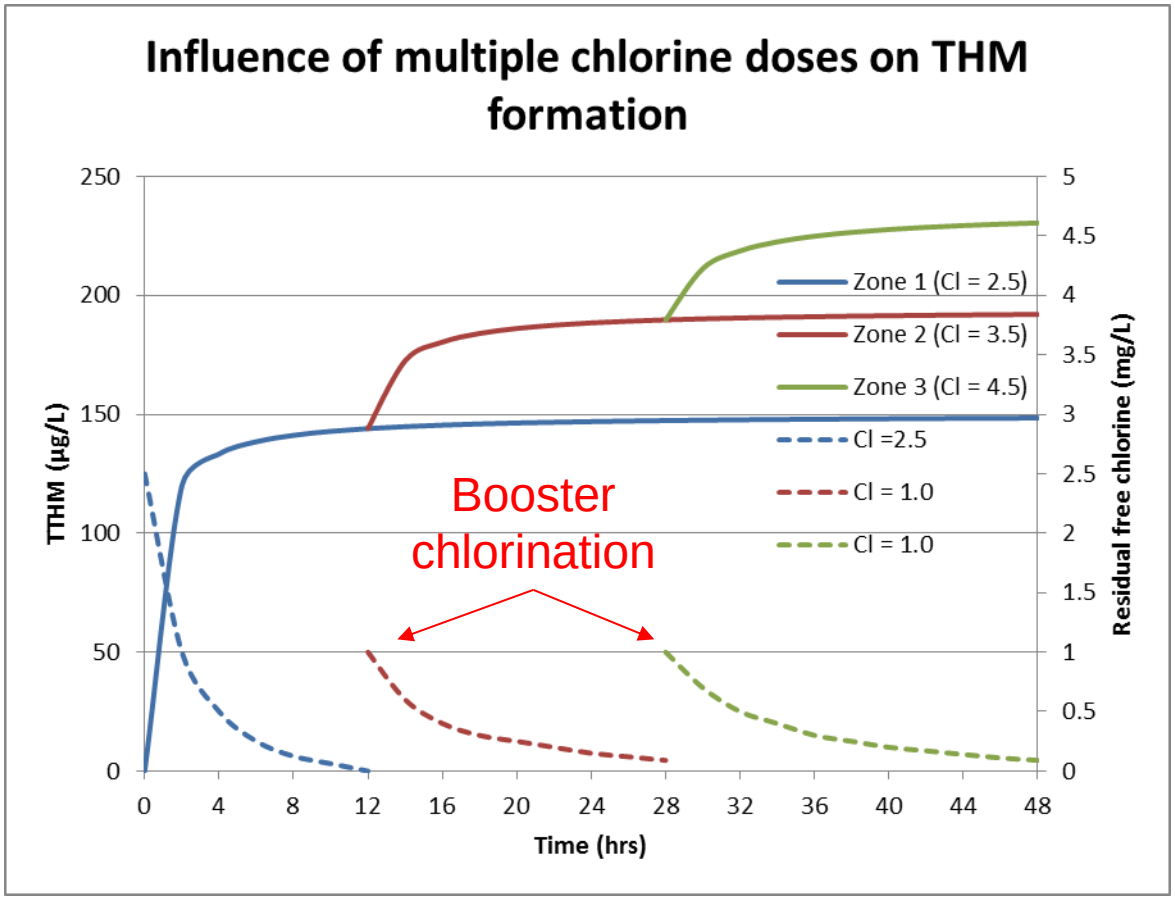


- THM formation in distribution system is chlorine limited

- Optimising chlorine dose is essential for management of THM formation in distribution networks

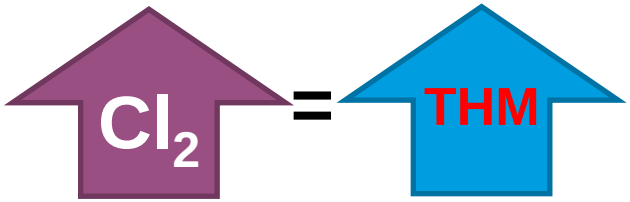
Chua, 1996

Influence of multiple chlorine doses on THM formation



Conclusions:

- THM formation increases after each chlorine dose (booster chlorination)



- Optimising chlorine dose is essential for management of THM formation in distribution networks

RH, 2012

THM precursor process removal efficacy

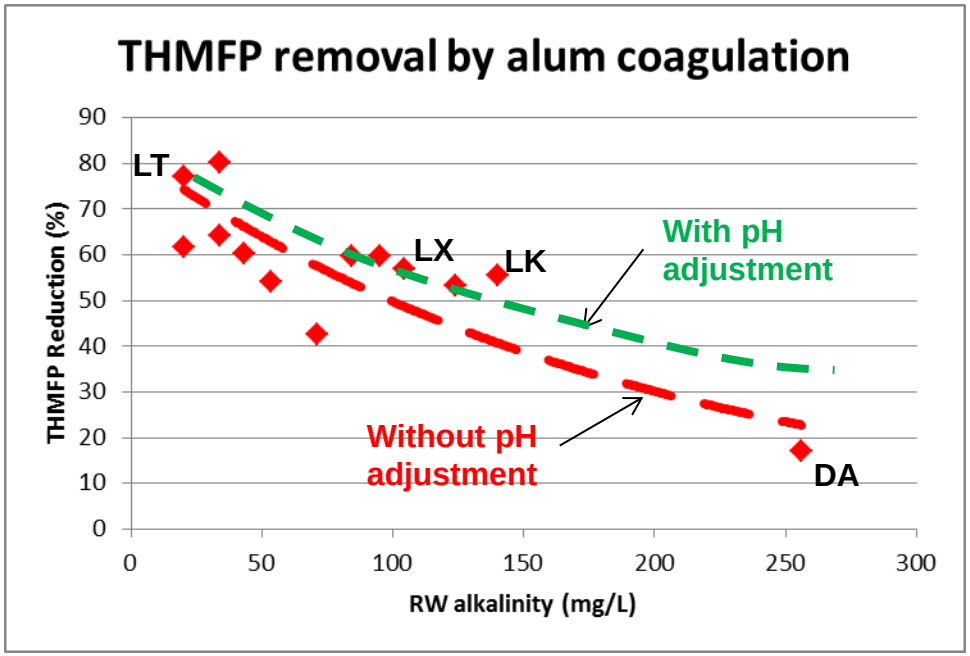
	Colour reduction (%)	UVA reduction (%)	TOC removal (%)	THMFP reduction (%)	Conclusions
Alum coagulation (no pH adjustment)	61 – 83*	32 – 80*	17 – 56*	27 – 68*	Optimising coagulation pH can improve precursor removal, reduces required coagulant dose and chlorine demand.
Alum coagulation (with pH adjustment)	61 – 89*	56 – 80*	35 – 61*	48 – 68*	
Ozonation (1mgO_3/mgTOC)	77 – 93 (84)	44 – 65 (56)	2 – 11 (8)	24 – 36 (29)	High O_3 dose required.
SSF	10 – 35 (21)	3 – 23 (13)	13 – 35 (21)	15 – 22	
GAC (< ±2 months)	64	64	72	72	Excellent medium for reducing precursors.
GAC (> ±2 months)	23	14	23	29	Performance declines rapidly when adsorption capacity is exhausted.
UF membranes	20 – 80*	20 – 80*	20 – 80*	20 – 80*	

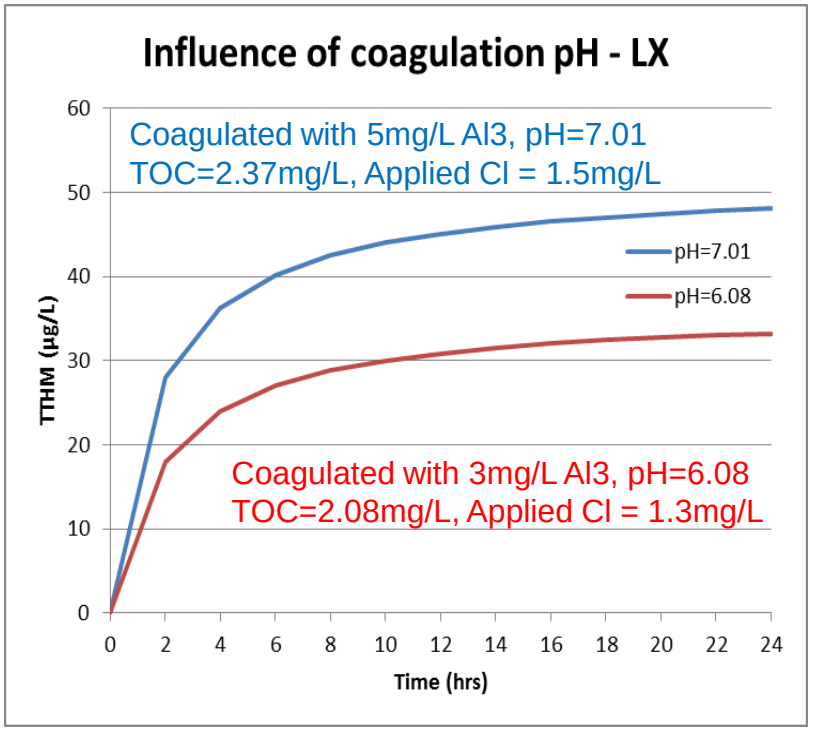
* Low alkalinity RW

Chua, 1996

RH, 2010

Optimising CFC for THM reduction





- pH optimisation:
  - *Improved THMFP reduction by up to 18%; and*
  - *Reduced required coagulant dose and chlorine demand*

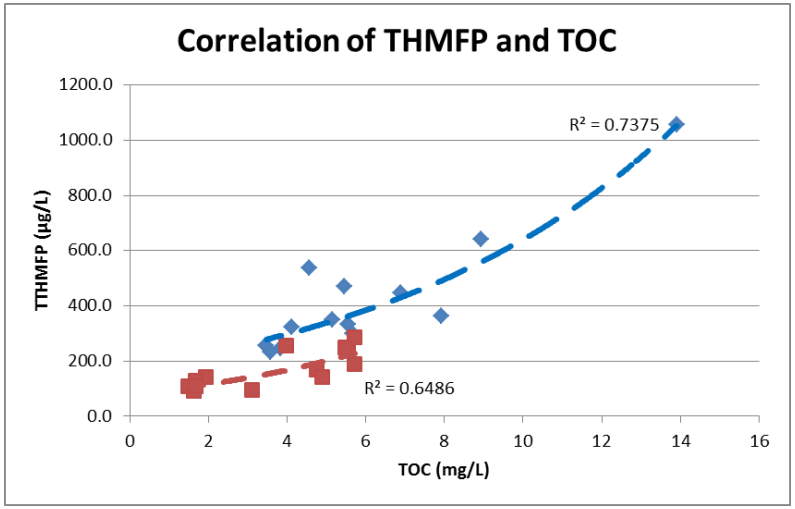
	Alum dose (mg Al/L)	CFC pH	THMFP reduction (%)
LX	5	7.01	59.6
LK	7	7.20	55.4
DA	5	7.68	17

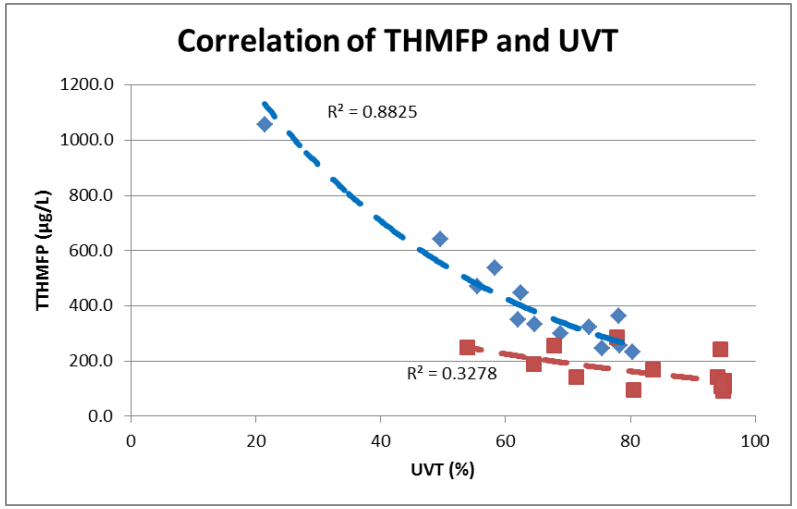
pH adjustment

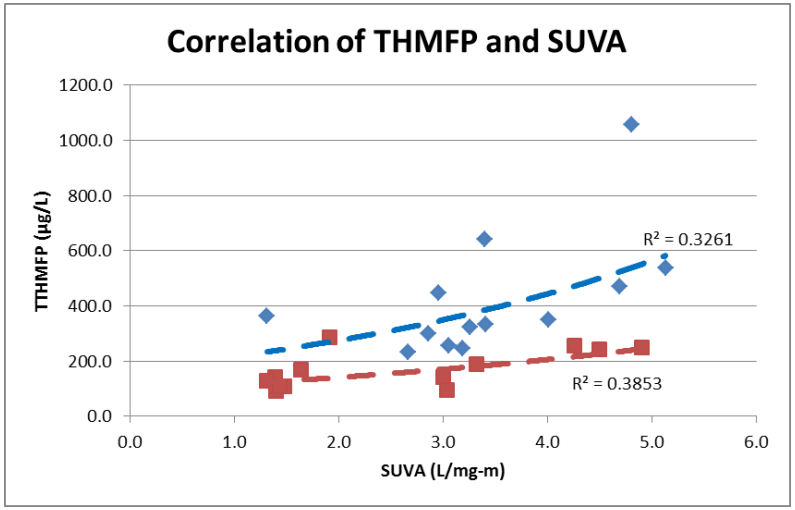
	Alum dose (mg Al/L)	CFC pH	THMFP reduction (%)
LX	3	6.08	68
LK	4	5.51	67
DA	3	6.10	35

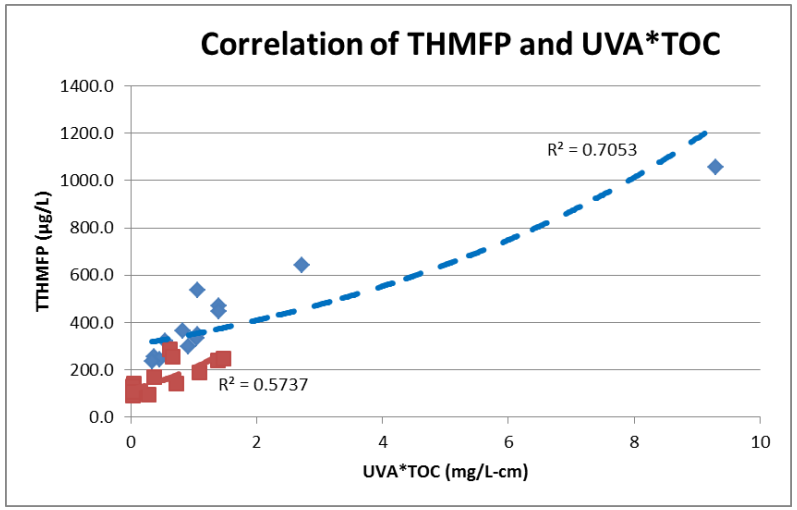
Chua, 1996

Surrogate parameters for THMFP









RW

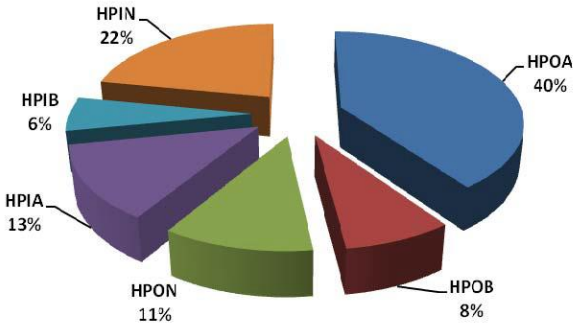
TW

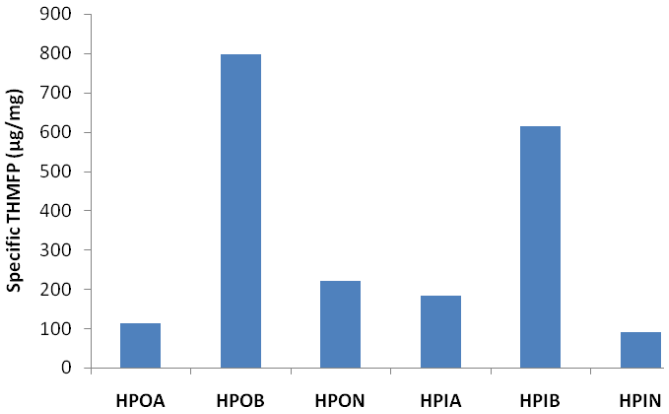
Chua, 1996

- RW - Correlation of THMFP to TOC, UVT, SUVA or UVA*TOC indicates UVT is the better surrogate parameter
- TW - ?

NOM Characterisation

- Role of hydrophobic and hydrophilic of NOM in the formation of DBPs:
  - *Imai et al. (2003) obtained a significant relationship between the formation of THMs and HAAs and the content of hydrophilic acids (R^2 =0.63, P<0.01).*
  - *Liang and Singer (2003) found that hydrophilic NOM is a more important source of the formation of THMs and HAAs than the corresponding hydrophobic NOM.*
  - *Lim Fang Yee et al. (2009) - the major fractions (hydrophobic acid and hydrophilic neutral) were not the reactive organic fractions in the formation of THMs. Hydrophobic base and hydrophilic base were found to be the most reactive fractions of concern with respect to the formation of THMs.*

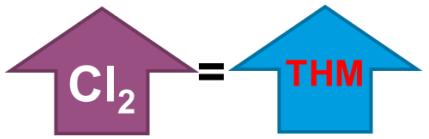




- *Lim Fang Yee et al. (2009) - This shows that NOM characteristics vary from different water sources. It is influenced by the natural photosynthetic activities of terrestrial and aquatic plants, algae and photosynthetic bacteria. The trophic status of the sampling environment also influences the concentration and composition of NOM.*

Summary

1) Chloroform – between 87% to 98% of total THM;
2) THM formation curves show initial rapid growth 0 to 8hrs, slow growth after 10hrs;
3) Chlorine decay curves show initial rapid rate of chlorine consumption 0 to 2hrs;
4) THM formation is a function of chlorine dose;
5) THM formation in distribution system is chlorine limited;



6) THM formation increases after each chlorine dose (booster chlorination);
7) TW THMFP (SW or GWUDI abstractions) will more than likely exceed parametric limit;
8) THMFP removal of SSF, GAC and ozone is poor (<30%);
9) Optimising CFC pH improves THMFP reduction by up to 18% (less coagulant, sludge);
10) TOC, UVA and SUVA may not be suitable surrogate for TW THMF;
11) Water treatment processes for DOC reduction may not necessarily achieve commensurate THMF reductions in drinking water[1]. NOM characteristics vary from different water sources[2].

[1] How DOC composition may explain the poor correlation between THMFP and SUVA, Fram et al.
2 Hydrophobicity chracteristics of NOM and THMF. Yee et. Al., 2009

Alternative disinfectants and DBPs

- Alternative primary or secondary disinfectants to chlorine (e.g. chloramines, chlorine dioxide, ozone, ultraviolet) that minimize the formation of some of the regulated DBPs may increase the formation of some of the emerging (unregulated) by products.

- Recent studies have identified emerging DBPs (e.g. iodinated trihalomethanes (THMs) and acids, haloacetonitriles, halonitromethanes (HNMs), haloacetaldehydes, nitrosamines) that may be more toxic than some of the regulated ones (e.g. chlorine- and bromine containing THMs and haloacetic acids [USA]).

Krasner, 2009

Drinking Water Safety Plan Approach

Traditional Approach

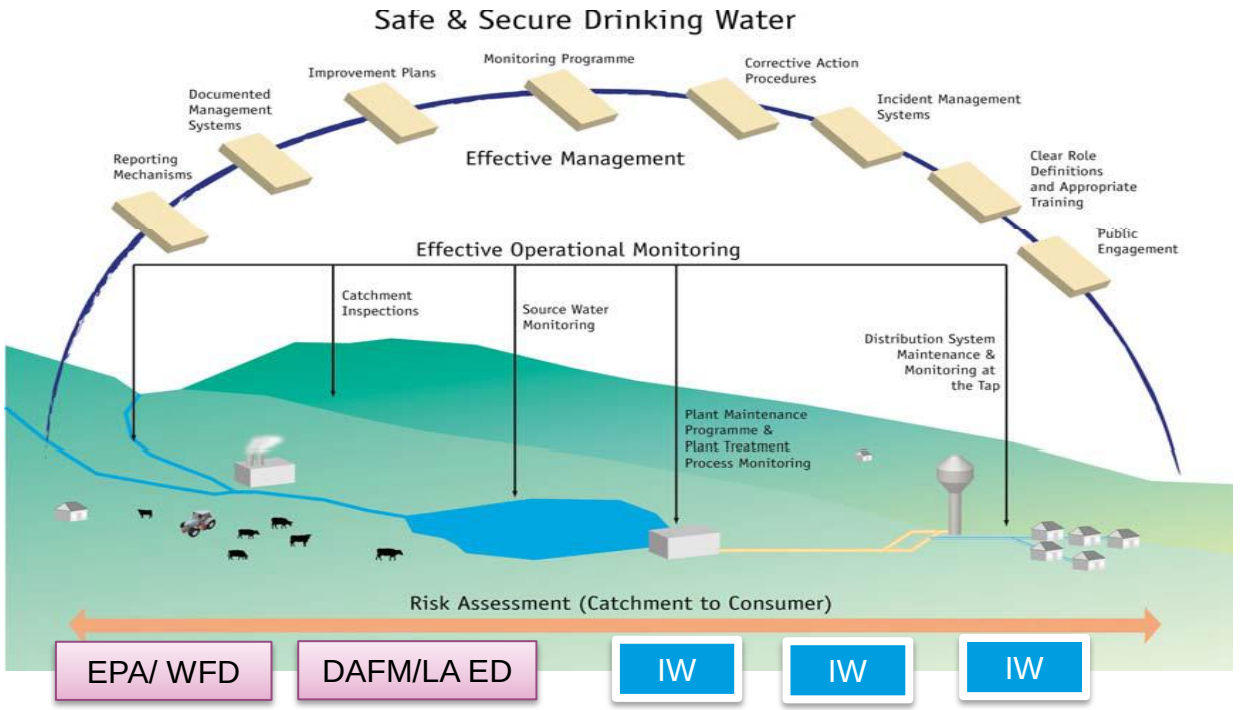
End-product monitoring approaches are insufficient for ensuring drinking water safety

DWSP Approach

1. Risk assessment and management approach to lower risk of contaminants entering drinking water supplies

+

2. End-product monitoring to verify drinking water safety



THM Reduction Programme - Implementation Plan Overview

1. THM Risk Assessment
   - a. Water Quality Risk Analysis
   - b. THM Non-compliance Map
2. Sampling and Monitoring
   - c. THM Investigation Monitoring
   - d. Operational Monitoring
3. Water Treatment Mitigation Measures
   - e. Ground Water
   - f. Catchment Management
   - g. Optimise Disinfection
   - h. TOC Removal
   - i. Alternative Disinfectants
   - j. THM Removal
4. Storage and Distribution Mitigation Measures
   - k. Storage
   - l. Distribution

Customer Notification

EPA Drinking Water Guidance on Disinfection By-Products. Advice Note No. 4. Version 2.

Disinfection Policy

Irish Water

- Removal (filtered water)
  - *Turbidity*
    - <1.0ntu – 100%
    - 3-log Crypto <0.3ntu – 95%
    - 4-log Crypto <0.1ntu – 95%
  - *$TTHM_t$ < 40 to 80µg/l (t > 10hrs)*
- Chlorination (WTP final water)
  - *WTP final water > 0.5mg/l*
  - *Customer tap = detectable FCR*

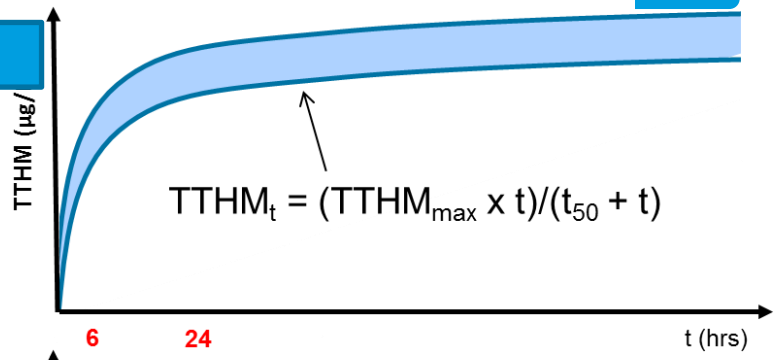
Scottish Water

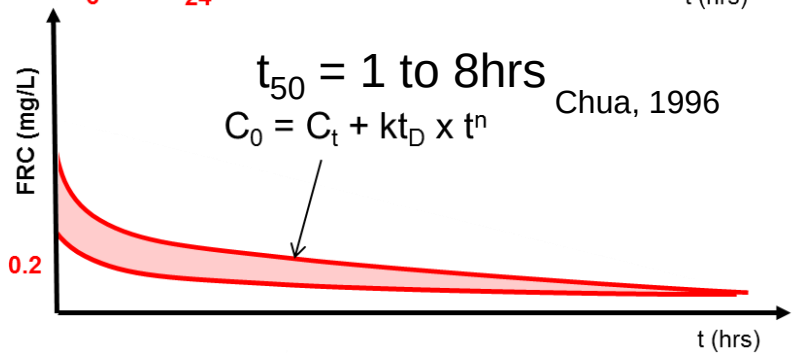
- Removal (WTP final water)
  - *Turbidity*
    - <1.0ntu – 100%
    - <0.5ntu – 99%
    - <0.4ntu – 95%
  - *TTHM < 40µg/l*
- Chlorination (WTP final water)
  - *WTP final water > 0.5mg/l*
  - *Reservoir outlet > 0.25mg/l*
  - *Customer tap = detectable FCR*

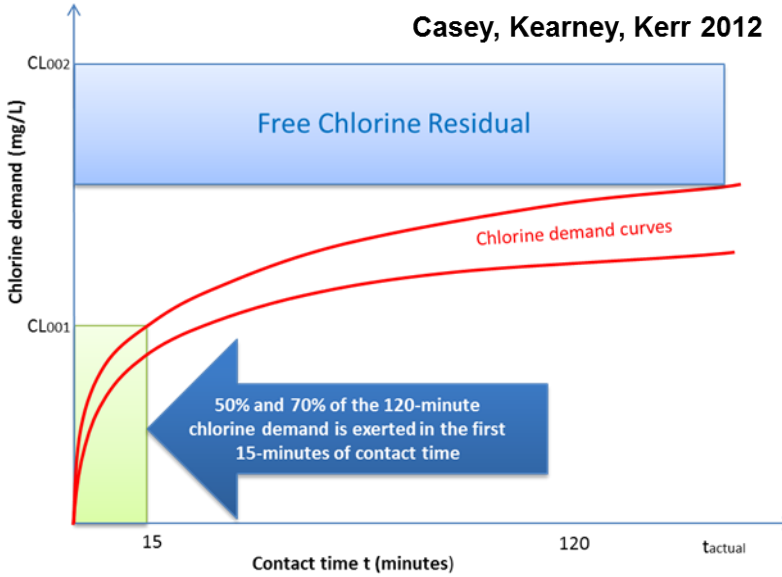
THM formation and chlorine demand

d **Operational Monitoring at WTP**

- Sampling frequency – monthly and ±5% change in RW UVT
- RW: THMF (24hrs)
  - *5mg/l Cl_2, 15°C*
- TW: TW THMF (6 + 24hrs)
  a) C_{24hrs}, 15°C
  b) C_{48hrs}, 15°C
  c) C_{72hrs}, 15°C
  } Booster chlorination
  - *C_{0hrs}, $C_{0.25hrs}$ and $C2_{hrs}$,*
  - *Min FCR at 24, 48 and 72hrs ≥ 0.2mg/L*







Knowledge Management + Collaboration

- Developing national standards
- Building and developing Communities of Practice
  - *Group of people who share:*
    - Common interest
    - Common practice
    - Commitment to share and expand knowledge base for that practice

High Level – Policy/Strategy	Standards	RAMs	SOP	Planned Maintenance
Irish Water DRINKING WATER SAFETY PLAN: DISINFECTION Document No: IW-TEC-900-05 Revision: 0.5	Irish Water DESIGN SPECIFICATION: DISINFECTION Document No: IW-TEC-900-05 Revision: 0.1	Irish Water REMOTE ASSET MANAGEMENT POLICIES: DISINFECTION Document No: IW-TEC-900-05	Irish Water STANDARD OPERATING PROCEDURES: DISINFECTION Document No: IW-TEC-900-05 Revision: 0.	Irish Water PLANNED MAINTENANCE STANDARD: DISINFECTION Document No: IW-TEC-900-05 Revision: 0.

Community of Practice
(business focussed, consistency, collaboration, performance)

Community of Practice = SUCCESS!

CONNACHT CLAN
OFFICIAL CONNACHT RUGBY SUPPORTERS' CLUB

Proposed research projects

1. Toxicology and epidemiology of emerging (unregulated) DBPs;
2. Investigate relationship between characteristics of NOM and THMF;
3. Chlorine demand-based predictive modelling of THM formation; and
4. Building and operating low disinfectant demand and/or disinfectant free distribution systems