CEE/EHS 597B

Class #8:

Regulations, Sampling and Reporting

Dave Reckhow

Regulations

- Pathogens: treatment technique & surrogates
  - CT
  - Coliforms
  - Turbidity
- Chemicals: MCLs
  - Pb/Cu
  - Fe/Mn
  - DBPs: THMs & HAAs
  - Nitrate/Nitrite
  - Others: VOCs, radioactives, perchlorate, sodium, fluoride, asbestos

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Current SDWA regulations

- Total trihalomethanes (TTHMs);
- Chemical rules (Phases I, II, IIb, and V);
- Surface water treatment rule (SWTR);
- Total coliform rule (TCR);
- Lead and copper rule (LCR);
- Stage 1 disinfectants/disinfection byproducts rule (Stage 1 DBPR);
- Interim enhanced surface water treatment rule (IESWTR);
- Radionuclides;
- Consumer Confidence Report rule;
- Arsenic;
- Filter Backwash Recycling Rule; and
- Long Term 1 Enhanced Surface Water Treatment Ru

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Chemical Rules

- ***Phase I, II, IIb, and V***. MCLs found in 40 CFR 141.61-.62.
  - The ***Phase I Rule*** (1987) 8 ***volatile organic chemicals (VOCs).*** The ***Phase II and IIb Rules*** (both published in1991) updated or created MCLs for 38 contaminants. The ***Phase V Rule*** (published in 1992) set standards for 23 more contaminants.
- Contaminants
  - Inorganic chemicals (IOCs) such as heavy metals and oxyanions
  - ***Synthetic organic chemicals (SOCs)*** such as pesticides.
  - Additional VOCs.
- All pose chronic health risks.
  - ***nitrate*** and ***nitrite*** also pose acute health risks, (limit the blood's ability to carry oxygen) s.

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"Bacteriological Analysis"

- Generally refers to the analysis of coliform organisms
- Coliform analysis and the total coliform rule is one of several ways we protect the public from waterborne disease agents
  - The coliforms are "surrogates" for possible fecal contamination and presence of human pathogens
  - Pathogens, themselves are very difficult to measure
- Another way is through treatment techniques (TT) and required operational performance measures

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Revised Total Coliform Rule (RTCR)

- Purpose: to reduce the risk of waterborne pathogens
  - bacteria, viruses & protozoa
- Implementation: April 1, 2016
- Sampling and Testing
  - **Routine**: total coliforms, and if positive (TC+), E. coli
  - **Repeat** (follow-up, if TC+) 3 more samples within 24 hrs for TC and, if TC+, also EC
- The next step: assessment report to DEP within 30 days
  - Level 1 assessment: done by the PWS
    - trigger: 2 TC+ samples in a month, or failure to do repeat sampling
  - Level 2 assessment: done by a consultant
    - trigger: EC MCL violation, or two level 1 assessments within 1 yr

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Number/frequency of samples

- Collected from sites representative of distribution system
- For community water systems:
  - From 1/month up to 480/month
  - Reduced frequency for ≤ 1000 is 1 per quarter
- MCL for coliforms (per month):
  - >1 TC+, if collecting ≤40 samples
  - Otherwise detection in >5% of samples

Population	# samples /month
≤ 1,000	1
1,001 – 2,500	2
2,501 - 3,300	3
3,301 – 4,100	4
4,101 – 4,900	5
4,901 – 5,800	6
5,801 - 6,700	7
6,701 – 7,600	8
7,601 – 8,500	9

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Log Removal

- **Meaning of "Log Removal or Inactivation"**
  - **Removal: remove organisms from the water**
  - **Inactivation: make organisms non-infectious by use of disinfection**
  - **Let N_0 be the number concentration of microorganisms in raw water**
  - **Let N be the number concentration of microorganisms after treatment**
  - **N/N_0 = fraction remaining after treatment**
  - **100 x $(N_0 - N)/N_0$ = percent removal (or inactivation)**
  - **Log (N_0/N) = the log removal (or inactivation)**
  - **Relation between % removal and log removal:**

% Removal	Log Removal	N, if N_0 = 10,000/L
90	1	1000
99	2	100
99.9	3	10
99.99	4	1

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SWTR (cont.)

- Requirements for Filtered Supplies
  - ≤0.5 NTU (≥95% of samples) combined filter effluent; ≤5 NTU always
  - ≥0.2 mg/L residual at EPTDS; detectable in ≥95% of samples

Earned removal credit →

Type of Filtration	Log_{10} Removal Allowed By Filtration		Remaining Log_{10} Inactivation by Disinfection	
	Giardia	Viruses	*Giardia*	Viruses
Conven-tional	2.5	2.0	0.5	2.0
Direct	2.0	1.0	1.0	3.0

- Requirements for Unfiltered Supplies
  - Meet source water quality criteria
  - Provide all Pathogen removal by Disinfection
    - 3 log *Giardia*, 4 log viruses

→ Requires a certain CT

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CT for Giardia & Free Chlorine

EPA Guidance Manual Disinfection Profiling and Benchmarking C-2 August 1999

Table C-1. CT Values for Inactivation of *Giardia* Cysts by Free Chlorine at 0.5°C or Lower

CHLORINE CONCENTRATION	pH<=6 Log Inactivation						pH=6.5 Log Inactivation						pH=7.0 Log Inactivation						pH=7.5 Log Inactivation					
(mg/L)	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	23	46	69	91	114	137	27	54	82	109	136	163	33	65	98	130	163	195	40	79	119	158	198	237
0.6	24	47	71	94	118	141	28	56	84	112	140	169	33	67	100	133	167	200	40	80	120	159	199	239
0.8	24	48	73	97	121	145	29	57	86	115	143	172	34	68	103	137	171	205	41	82	123	164	205	246
1	25	49	74	99	123	148	29	59	88	117	147	176	35	70	105	140	175	210	42	84	127	169	211	253
1.2	25	51	76	101	127	152	30	60	90	120	150	180	36	72	108	143	179	215	43	86	130	173	216	259
1.4	26	52	78	103	129	155	31	61	92	123	153	184	37	74	111	147	184	221	44	89	133	177	222	266
1.6	26	52	79	105	131	157	32	63	95	126	155	189	38	75	113	151	188	226	46	91	137	182	228	273
1.8	27	54	81	108	135	162	32	64	97	129	161	193	39	77	116	154	193	231	47	93	140	186	233	279
2	28	55	83	110	138	165	33	66	99	131	164	197	39	79	118	157	197	236	48	95	143	191	238	286
2.2	28	56	85	113	141	169	34	67	101	134	169	201	40	81	121	161	202	242	50	99	149	198	248	297
2.4	29	57	86	115	143	172	34	68	103	137	171	205	41	82	124	165	206	247	50	99	149	199	248	298
2.6	29	58	88	117	146	175	35	70	105	139	174	209	42	84	126	168	210	252	51	101	152	203	253	304
2.8	30	59	89	119	148	178	36	71	107	142	178	213	43	86	129	171	214	257	52	103	155	207	258	310
3	30	60	91	121	151	181	36	72	109	145	181	217	44	87	131	174	218	261	53	105	158	211	263	316

CHLORINE CONCENTRATION	pH=8.0 Log Inactivation						pH=8.5 Log Inactivation						pH=9.0 Log Inactivation					
(mg/L)	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0	0.5	1.0	1.5	2.0	2.5	3.0
<=0.4	46	92	139	185	231	277	55	110	165	219	274	329	65	130	195	260	325	390
0.6	48	95	143	191	238	286	57	114	171	228	285	342	68	136	204	271	339	407
0.8	49	98	148	197	246	295	59	113	177	236	295	354	70	141	211	281	352	422
1	51	101	152	203	253	304	61	122	183	243	304	365	73	146	219	291	364	437
1.2	52	104	157	209	261	313	63	125	188	251	313	376	75	150	226	301	376	451
1.4	54	107	161	214	268	321	65	129	194	258	323	387	77	155	232	309	387	464
1.6	55	110	165	219	274	329	66	132	199	265	331	397	80	159	239	318	398	477
1.8	56	113	169	225	282	338	68	136	204	271	339	407	82	163	245	326	408	489
2	55	115	173	231	288	346	70	139	209	278	348	417	83	167	250	333	417	500
2.2	59	118	177	235	294	353	71	142	213	284	355	426	85	170	256	341	426	511
2.4	60	120	181	241	301	361	73	145	218	290	363	435	87	174	261	348	435	522
2.6	61	123	184	245	307	368	74	148	222	296	370	444	89	178	267	355	444	533
2.8	63	125	188	250	313	375	75	151	226	301	377	452	91	181	272	362	453	543
3	64	127	191	255	318	382	77	153	230	307	383	460	92	184	276	369	460	552

Source: AWWA, 1991.

Portions of H&H Table 7-4 are extracted from this table

Source: EPA, 1999, Guidance Manual for Disinfection Profiling & Benchmarking

APPENDIX C. CT VALUES FOR INACTIVATIONS ACHIEVED BY VARIOUS DISINFECTANTS

Ct values for *Giardia lamblia* cysts

H&H, Table 7-4, pg.245

	pH	Log Inactivation	Water Temperature 0.5°C [(mg/l) · min]	5°C [(mg/l) · min]	10°C [(mg/l) · min]	15°C [(mg/l) · min]	20°C [(mg/l) · min]
Free chlorine[a]	6	0.5	25	18	13	9	7
	6	1.0	49	35	26	18	13
	7	0.5	35	25	19	13	9
	7	1.0	70	50	37	25	18
	8	0.5	51	36	27	18	14
	8	1.0	101	72	54	36	27
Preformed chloramine	6–9	0.5	640	370	310	250	190
	6–9	1.0	1300	740	620	500	370
Chloride dioxide	6–9	0.5	10	4.3	4.0	3.2	2.5
	6–9	1.0	21	8.7	7.7	6.3	5.0
Ozone	6–9	0.5	0.48	0.32	0.23	0.16	0.12
	6–9	1.0	0.97	0.63	0.48	0.32	0.24

[a]Free chlorine values are based on a residual of 1.0 mg/l.

Source: Adapted from *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*. U.S. Environment Protection Agency.

Ct values for Viruses

- For Viruses at various temperatures
  - pH 6-9

H&H Table 7-5, pg 245

	Log Inactivation	Water Temperature 0.5°C [(mg/l) · min]	5°C [(mg/l) · min]	10°C [(mg/l) · min]	15°C [(mg/l) · min]	20°C [(mg/l) · min]
Free chlorine	2.0	6	4	3	2	1
	3.0	9	6	4	3	2
	4.0	12	8	6	4	3
Preformed chloramine	2.0	1200	860	640	430	320
	3.0	2100	1400	1100	710	530
Chlorine dioxide	2.0	8.4	5.6	4.2	2.8	2.1
	3.0	25.6	17.1	12.8	8.6	6.4
Ozone	2.0	0.9	0.6	0.5	0.3	0.2
	3.0	1.4	0.9	0.8	0.5	0.4

Source: Adapted from *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*. U.S. Environmental Protection Agency.

SWTR (cont.)

- Requirements for Filtered Supplies
  - ≤0.5 NTU (≥95% of samples) combined filter effluent; ≤5 NTU always
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Earned removal credit

Type of Filtration	Log_{10} Removal Allowed By Filtration		Remaining Log_{10} Inactivation by Disinfection	
	Giardia	Viruses	*Giardia*	Viruses
Conven-tional	2.5	2.0	0.5	2.0
Direct	2.0	1.0	1.0	3.0

- Requirements for Unfiltered Supplies
  - Meet source water quality criteria
  - Provide all Pathogen removal by Disinfection
    - 3 log *Giardia*, 4 log viruses

Requires a certain CT

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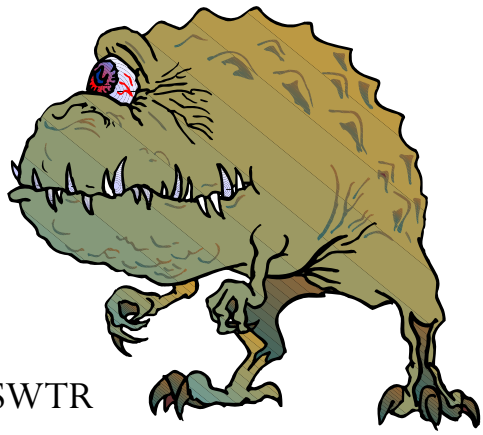
The "Enhancement"

- But then we learned about Crypto



- solution: The Enhanced SWTR
  - Long Term 1 ESWTR
  - Long Term 2 ESWTR

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LT1ESWTR

- Water Quality Provisions of the LT1ESWTR
  - Removal Criteria for Overall Treatment (like SWTR)
    - 99 percent (2 log) for *Crypto* in addition to:
      - 99.9 percent (3 log) for *Giardia*
      - 99.99 percent (4 log) for viruses
    - removal is from last untreated surface water input to first customer
  - Tighter turbidity standards and filtration performance criteria
    - ≤0.3 NTU (≥95% of samples) combined filter effluent
      - ≤1 NTU always
    - Turbidity monitoring for individual filters, in addition to combined FE
    - Intended to assure good *Crypto* removal

Became WQ based with LT2ESWTR

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LT2ESWTR

- Large & medium conventional SW plants (> 10,000)
  - **Source water Quality based**
  - Monitor Source Water *Crypto* monthly for 24 months
  - 3 log *Crypto* removal required of all
  - Additional Treatment requirements based on highest 12 month average *Crypto* in source water (add 0.5 log in bins 1-3 for direct filtration systems)

Bin	Crypto	Additional Requirements	# NE Systems
1	<0.075/L	None	110
2	0.075-1.0/L	1.0 log	2
3	1.0-3.0/L	2.0 log (w/ ≥1 log inactivation, etc.)	0
4	≥3.0/L	2.5 log (w/ ≥1 log inactivation, etc.)	0

  - Treatment/Management credits - many "tools", a few examples:
    - Watershed Control Program, pre-sed with coag, 2nd stage filtr.: 0.5 log
    - Filtration: 1.0 log (≤0.15 NTU for individual filters, 95% of time)
    - Disinfection/membranes: 0.5->2.5 log
      - etc = membranes, bank filtration, cartridges

Schedule 1-3 only

None of the MA schedule 4 systems have triggered crypto monitoring

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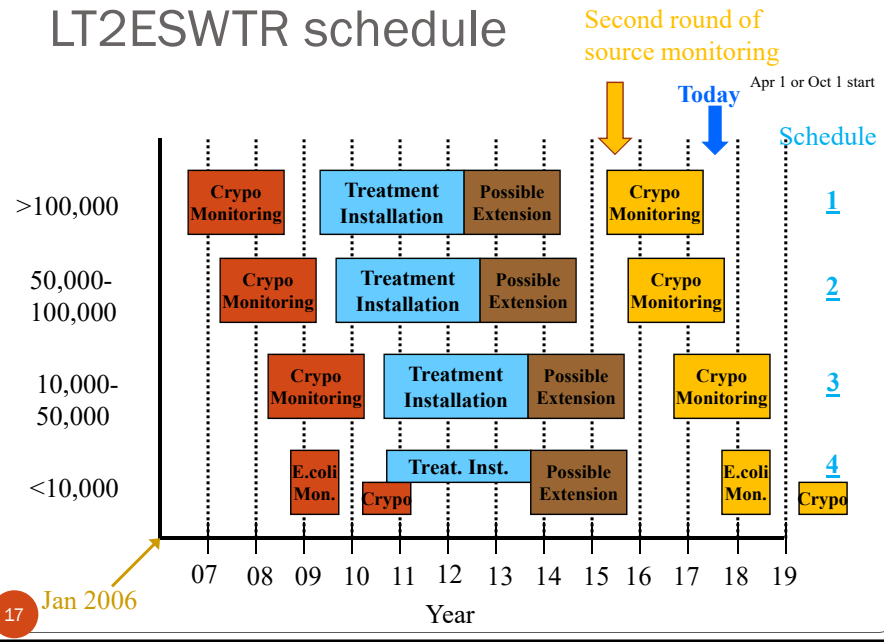
LT2ESWTR schedule



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LT2ESWTR

- Small Systems (<10,000)
  - Same treatment requirements, but reduced monitoring
    - Twice per month *Crypto* sampling for 12 months, if system exceeds *E. Coli* trigger level (below)
      - Mean >10/100 mL for lakes/reservoirs
      - Mean > 50/100 mL for flowing streams
- Unfiltered Systems
  - *Crypto* inactivation required for all
    - 4 log virus
    - 3 log *giardia*
    - 2 log *crypto* (3 log if *crypto* > 1/100 L)
  - Must use 2 disinfectants

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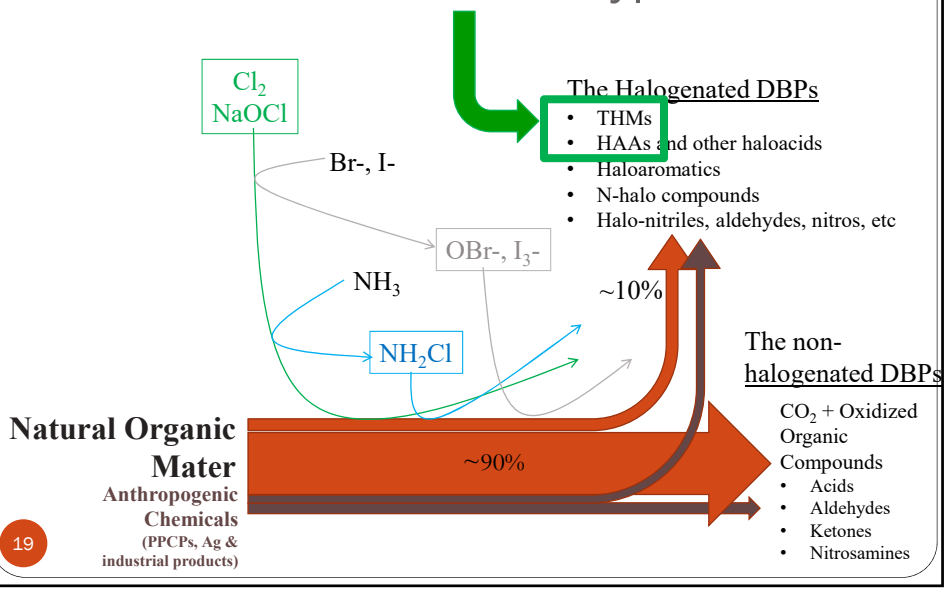
Chlorine - Disinfection Byproducts



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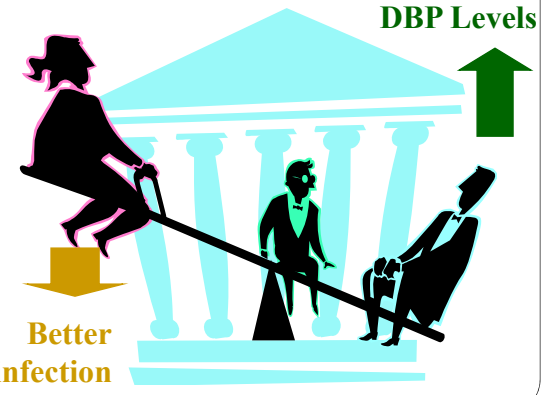
The US regulatory approach

- A balancing act between adequate disinfection and minimizing disinfection byproducts

But there are ways we can improve both



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The Microbial/DBP Cluster: Status

Pathogens

- Older
  - Surface Water Treatment Rule (SWTR) - 1989
  - Interim Enhanced Surface Water Treatment Rule (IESWTR) - 1998
  - Filter Backwash Recycle Rule (FBR) - 2001
  - Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) - 2002
- Newer: Jan 4-5, 2006
  - Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)

DBPs

- **Total Trihalomethane Rule (TTHMR) - 1979**
- **Stage 1 Disinfectant-Disinfection Byproducts Rule (S1 D/DBPR) - 1998**
- **Stage 2 Disinfectant-Disinfection Byproducts Rule (S2 D/DBPR)**

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D/DBP Rule (cont.)

Also MCLGs for specific DBP species, and chloral hydrate (0.04 mg/L)

- Specific Requirements (cont.)
  - Establish new MCLs and MRDLs

Published Values (all in mg/L):

Compound(s)	Stage 1 & 2
TTHMs	0.080
HAA5	0.060
Bromate	0.010
Chlorite	1.0
Chlorine	4.0
Chloramines	4.0
Chlorine Dioxide	0.8

Stage 1: System-wide Running Annual Avg. (RAA)

Stage 2: Locational Running Annual Avg. (LRAA)

MRDLs for chlorine and chloramines may be exceeded in response to public health problems

(HAA5 = sum of monochloro, dichloro, trichloro, monobromo, and dibromo)

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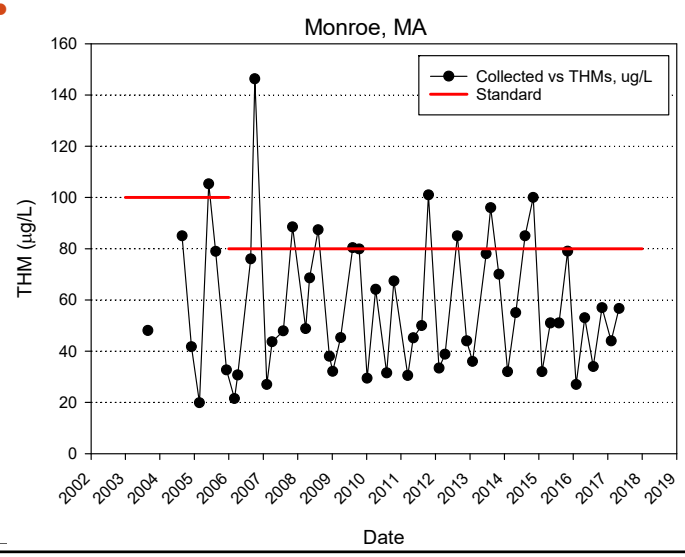
Monroe: quarterly THMs



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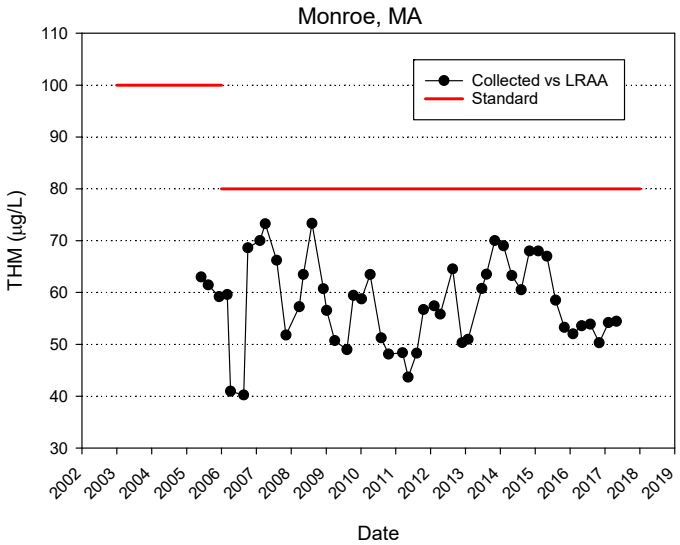
Monroe: LRAA

- XCV



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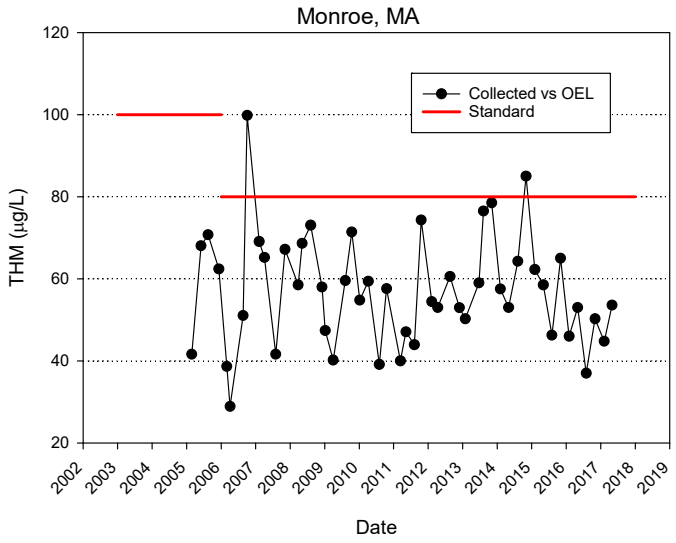
Monroe: OEL

- dsf



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D/DBP Rule (cont.)

- Specific Requirements (cont.)
  - Require Best Available Technology:
    - Enhanced Coagulation or Enhanced Precipitative Softening (under Stage 1)
      - Applicability: SW systems using conventional treatment
      - Step 1: Performance Criteria

Required Percent Removal of TOC (between source water and combined filter effluent)

Source Water	Source Water Alkalinity (mg/L as $CaCO_3$)		
TOC (mg/L)	0 - 60	>60 - 120	> 120
≤2	No Action	No Action	No Action
>2 - 4	35	25	15
>4 - 8	45	35	25
> 8	50	40	30

D/DBP Rule (cont.)

- Specific Requirements (cont.)
  - Require Best Available Technology (cont.)
    - » Avoidance Criteria
      - Treated or Source water: TOC < 2.0 mg/L
      - Source water: TOC < 4.0 mg/L, Alk > 60 mg/L, and
        - TTHM and HAA5 < 50% of MCLs, or
        - commitment to technologies that will achieve <50% of MCLs
      - Treated or Source water: SUVA ≤ 2.0 L/mg-m
      - TTHM and HAA5 < 50% of MCLs and only chlorine used for disinfection
      - Systems remove > 10 mg/L magnesium hardness by precipitative softening
      - Softened water alkalinity < 10 mg/L

For softening systems only

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D/DBP Rule (cont.)

- Specific Requirements (cont.)
  - Require Best Available Technology (cont.)
    - GAC Adsorption
      - Implementation
        - Stage 1: in place of enhanced coagulation, when chlorine is the disinfectant
        - Stage 2: in addition to enhanced coagulation or enhanced softening
    - Nanofiltration
      - Membrane with MWCO = 1000 Daltons or less

Generally when TOC removal criteria or avoidance criteria can't be met

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D/DBP Rule: Stage 2

- Overview
  - Designed to reduce peak occurrences in distribution systems by changing compliance monitoring from system average to each location (LRAA)
  - One-year IDSE conducted to select site-specific optimal sample points to capture peaks and limit THM/HAA variations
- Locational Running Annual Average (LRAA)
  - MCLs: 80/60 - for each monitoring location
  - Monitoring for Large SW systems (> 10,000)
    - quarterly sampling
    - at least one quarterly sample at peak month
    - 4-20 DS locations determined by initial distribution system evaluation (IDSE) and stage 1 locations
      - 2-8 at high THM sites, and 1-7 at high HAA sites
  - Monitoring for small SW systems (< 10,000)
    - 2 locations as determined by IDSE

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D/DBP Rule: Stage 2: Compliance

- Population-based monitoring
  - **Surface Water Systems** (Sub-part H)

Surface Water System Size	DS Monitoring Locations				Monitoring Frequency
	Stage 1 Compliance	Highest TTHM	Highest HAA5	**Total**	
<500	0	1	1	**2**	**Yearly**
500-3,300	0	1	1	**2**	**Quarterly**
3,301-9,999	0	1	1	**2**	**Quarterly**
10,000-49,999	1	2	1	**4**	**Quarterly**
50,000-249,999	2	3	3	**8**	**Quarterly**
250,000-999,999	3	5	4	**12**	**Quarterly**
1M - <5M	4	6	6	**16**	**Quarterly**
≥5M	5	8	7	**20**	**Quarterly**

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D/DBP Rule: Stage 2: Compliance

- Population-based monitoring
  - **Groundwater Systems**

Groundwater System Size	DS Monitoring Locations				Monitoring Frequency
	Stage 1 Compliance	Highest TTHM	Highest HAA5	**Total**	
<500	0	1	1	**2**	**Yearly**
500-9,999	0	1	1	**2**	**Yearly**
10,000-99,999	1	2	1	**4**	**Quarterly**
100,000-499,999	1	3	2	**6**	**Quarterly**
≥500,000	2	3	3	**8**	**Quarterly**

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D/DBP Rule: Stage 2 (cont.)

- Operational Evaluation Level — formerly called "Significant Excursions"
  - What is an OEL?:
    - If the next quarter's HAA & THM values were the same as the current one, would you still be in compliance with the 80/60 LRAA?
    - If no, you have an OEL exceedance
    - Determined quarterly; not a violation, but needs to be reported to the state
  - What to do if you have an OEL exceedance?
    - Conduct an Operational Evaluation to determine "cause" of exceedance
    - Submit a report to the state ≤90 days from notification of DBP values causing the exceedance
  - What's covered in an Operational Evaluation
    - Treatment & distribution practices that might have caused the exceedance
      - Storage tank operations, excess storage capacity distribution system flushing, source water quality, treatment processes & operation

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D/DBP Rule: Stage 2 (cont.)

- Operational Evaluation Level (cont.)
  - When does this provision start?:
    - As soon as the 3rd quarter of Stage 2 compliance data are received
      - i.e., between 2013 and 2014 depending on size
  - Provision for "limited" OE if exceedance is due to
    - A localized phenomenon or of known cause
- Operational Evaluation
  - Components
    - Distribution system evaluation
    - Treatment Process evaluation
    - Source water evaluation
    - Steps to minimize future exceedances
  - EPA Guidance Manual
    - http://www.epa.gov/ogwdw/disinfection/stage2/pdfs/draft_guide_stage2_operationalevaluation.pdf

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Fluoride

- Balance between Dental Caries and Fluorosis
- Recommended dose
  - 0.7 to 1.2 mg/L
  - Based on temperature

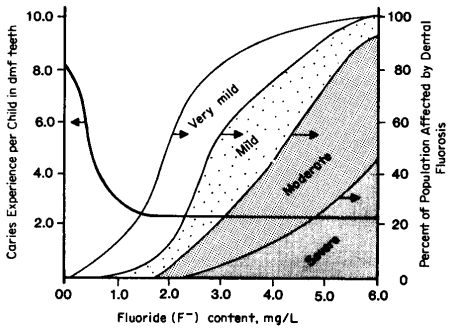

Fig. 15.3 from Water Quality & Treatment, 1999 (5th edition)

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Iron & Manganese (Fe/Mn)

- Secondary MCLs
  - 0.3 mg/L for iron (0.1 mg/L preferred)
  - 0.05 mg/L for manganese (0.02 mg/L preferred)
- Possible health concerns for Manganese

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Why remove Fe/Mn

- No known adverse health effects associated with typical levels of Fe or Mn in drinking water
- "High" (relative) levels can lead to water discoloration complaints and staining of laundry & fixtures
- US Treated Water Standards
  - (recommended goals address chronic water quality problems)

	IRON (mg/L)	MANGANESE (mg/L)
EPA Secondary MCLs	0.3	0.05
Recommended Goals	0.1	0.015

Based on: J.E. Tobiason
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David Reckhow

Sources of Fe & Mn

Based on: J.E. Tobiason

- Groundwater:
  - **mineral dissolution under reducing (anoxic) conditions**
  - **concentration relatively stable over time, but can vary widely between different wells in same "well field" (aquifer location)**
- Surface Waters:
  - **occurrence of reducing conditions in influent waters**
  - **i.e., thermal stratification leading to anoxic hypolimnion in lakes or reservoirs (possible control via multiple depth intake options)**
  - **significant seasonal variations in concentrations likely**
  - **Fe or Mn in river sources is usually in particulate form**
- Treatment Plant Sources
  - **Anoxic sludge blankets in clarifiers (i.e., if solids not continuously removed from clarifier)**
  - **Recyle flows from backwash lagoons, dewatering systems, etc**
  - **Mn as contaminant in Fe coagulants (might add 20 to 50 µg/L)**
- Other: acid mine drainage, landfill leachate

Treatment Approaches

- Oxidation & Precipitation
  - **Strong Oxidants ($KMnO_4$, ClO_2, O_3)**
  - **Weak Oxidants - Fe only (O_2, Cl_2)**

Based on: J.E. Tobiason

- Greensand Filtration
  - **naturally occurring or manufactured zeolite**
  - **adsorption & oxidation**
- Oxide-Coated Filter Media
  - **coatings on normal media; adsorption & oxidation**
- Biological Oxidation
- Membrane Filtration (RO, NF; if dissolved)

Oxidation & Precipitation

- *Stoichiometry:*
  - **need to add sufficient oxidant to react with metal**
  - **see Tables for reactions with various oxidants**
  - **must also satisfy competing oxidant demand (NOM, other reduced species), so add in excess of stochiometric amount**

Based on: J.E. Tobiason

- *Rate of reaction (kinetics):*
  - **need sufficient time for oxidation**
  - **rate can be affected by pH, temperature, etc.**
- *Removal of precipitated (oxidized) metals*:
  - **Use various solid/liquid separation processes**
  - **Clarification (often preceded by coagulation)**
  - **Media filtration: requires destabilized particles/colloids**
  - **MF/UF membrane filtration**

Stoichiometry of Fe Oxidation

Based on: J.E. Tobiason

Oxidant	Reaction for Oxidation of Fe(II) to Fe(III)	Stoichiometry (mg ox/mg Fe)
O_2 (aq)	$2Fe^{2+} + ½\ O_2 + 5H_2O \rightarrow 2Fe(OH)_3(s) + 4H^+$	0.14
$O_3 \rightarrow O_2$ (aq)	$2Fe^{2+} + O_3 + 5H_2O \rightarrow 2Fe(OH)_3(s) + O_2 + 4H^+$	0.43
Cl_2 (HOCl)	$2Fe^{2+} + HOCl + 5H_2O \rightarrow 2Fe(OH)_3(s) + Cl^- + 5H^+$	0.64
$ClO_2 \rightarrow ClO_2^-$	$Fe^{2+} + ClO_2 + 3H_2O \rightarrow Fe(OH)_3(s) + ClO_2^- + 3H^+$	1.20
MnO_4^-	$3Fe^{2+} + MnO_4^- + 7H_2O \rightarrow 3Fe(OH)_3(s) + 2MnO_2(s) + 5H^+$	1.41

Iron Control

Based on: J.E. Tobiason

- Fe^{2+} is rapidly oxidized by dissolved oxygen (a very weak oxidant) at pH > 7 (if not complexed with natural organic matter (NOM))
- *For groundwater, often have Fe(II) oxidation along with aeration to strip elevated CO_2 (this raises pH as well)*
- Strong oxidants result in almost instantaneous oxidation of Fe(II)
- *Oxidants always react much faster with Fe(II) than Mn(II); impacts on sequencing of oxidant addition*
- Usually Fe removal is very good if Mn removal is done well

Stoichiometry of Mn Oxidation

Based on: J.E. Tobiason's notes

Oxidant	Reaction for Oxidation of Mn(II) to Mn(IV)	Stoichiometry (mg ox/mg Mn)
O_2 (aq)	$Mn^{2+} + ½\ O_2 + H_2O \rightarrow MnO_2(s) + 2H^+$	0.29
$O_3 \rightarrow O_2$ (aq)	$2Mn^{2+} + O_3 + H_2O \rightarrow MnO_2(s) + O_2 + 2H^+$	0.88
Cl_2 (HOCl)	$Mn^{2+} + HOCl + H_2O \rightarrow MnO_2(s) + Cl^- + 3H^+$	1.30
$ClO_2 \rightarrow ClO_2^-$	$Mn^{2+} + 2ClO_2 + 2H_2O \rightarrow MnO_2(s) + 2ClO_2^- + 4H^+$	2.45
MnO_4^-	$3Mn^{2+} + 2MnO_4^- + 2H_2O \rightarrow 5MnO_2(s) + 4H^+$	1.44

Lead & Copper Rule (LCR)

- ***Action levels*** for lead and copper — 0.015 mg/L and 1.3 mg/L
  - An action level is different from a MCL. While an MCL is a legal limit on a contaminant, an action level, as the name suggests, is a trigger for additional prevention or removal steps.
- Samples and triggers:
  - Must collect "**first draw**" water samples (water that has been standing in plumbing pipes at least six hours and is collected without flushing the tap) at points throughout the distribution system that are vulnerable to lead contamination, including regularly-used bathroom or kitchen taps.
- Trigger: When the level of lead or copper reaches the action level in **ten percent** of the tap water samples, the water system must take certain steps. These steps can include:
  - Source water monitoring and treatment of source water, if lead or copper are present in the source water;
  - Use of a ***corrosion control treatment*** (by increasing the water's pH or alkalinity, water systems can make their water less corrosive, and therefore less likely to dissolve the lead or copper from the pipes or fixtures);
  - Measures to educate the affected public about reducing its lead intake; or
  - Replacement of lead water mains and service lines (if source water and corrosion control treatment are not effective in lowering levels of lead and copper at the tap).

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Number of samples

- Number of sites depends on population served
- Minimum number of tap samples under LCR

Population served	Regular monitoring	Reduced monitorig
≤ 100	5	5
101 - 500	10	5
501 – 3,300	20	10
3,301 – 10,000	40	20
10,001 – 100,000	60	30

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Where to collect the samples

- All residence sampling locations must be from Tier 1 sites if there are enough. 1000-mL samples must be collected from each:
  - **Tier #1 sites**: Single family structures that contains copper pipes with lead solder installed between 1983 and 1988, or contain lead pipes and/or served by a lead service line (LSL). If the PWS has LSLs, then it must collect 50% of the samples from the LSL. If there are not enough LSLs for 50%, the PWS must sample at all sites with LSLs.
- If the PWS does not have enough Tier 1 sites, then it must collect LCR samples from Tier 2 sites, and if not enough then Tier 3:
  - **Tier #2 sites**: Buildings (i.e. apartment buildings) that contain the Tier #1 materials
  - **Tier #3 sites**: Single family structures that contain copper pipes with lead solder installed before 1983
- CWS that serve **schools/childcare facilities** are also required to rotate through their schools/childcare list, collecting two 250-mL samples (kitchen and bubbler/fountain) from each of two schools during the monitoring period.

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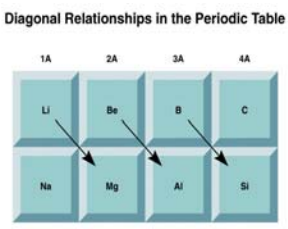
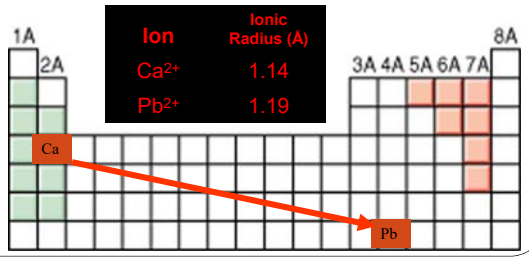
Why is Pb^{2+} Toxic?

- There is a chemical resemblance between an element and the element one down and to the right
- Diagonal relationships result from similarity in charge density (ratio of charge to ion size)
- Because of the lanthanide contraction Ca^{2+} and Pb^{2+} have similar sizes.
- So Pb^{2+} can interfere with Ca^{2+} metabolism, particularly in neuronal signaling.





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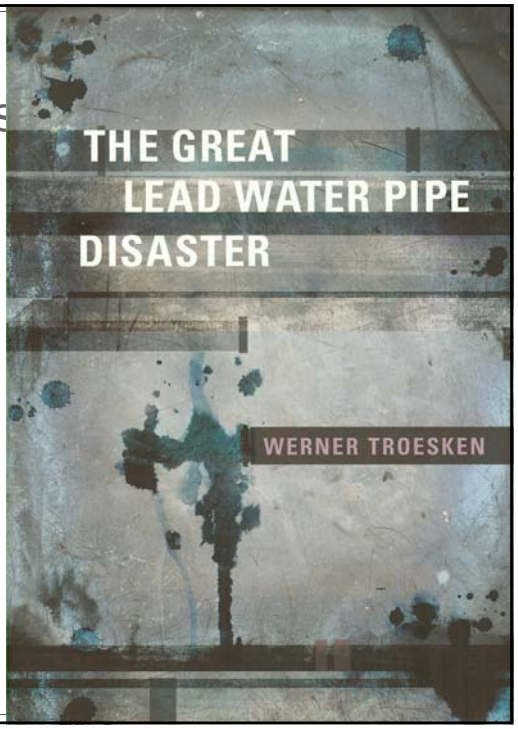
- Long history of man's self-inflicted exposure to lead and resulting deaths, dementia, denial, etc.



Abbreviations #1

- **Alk**=Alkalinity
- **BAT**=Best Available Technology
- **CPE**=Comprehensive Performance Evaluation
- **CWS**=Community Water Systems
- **D/DBP**=Disinfectant – Disinfection Byproducts
- **D/DBPR**=Disinfectant – Disinfection Byproducts Rule
- **DBP**=Disinfection Byproducts
- **DCAA**=Dichloroacetic Acid
- **DE**=Diatomaceous Earth
- **DF**=Direct Filtration
- **DS**=Distribution System
- **EBCT**=Empty Bed Contact Time
- **FACA**=Federal Advisory Committee Act
- **FBR**=Floc Blanket Reactor
- **FC**=Fecal Coliform
- **GAC**=Granular Activated Carbon
- **GW**=Groundwater
- **HAA**=Haloacetic Acid
- **HPC**=Heterotrophic Plate Count
- **ICR**=Information Collection Rule
- **IESWTR**=Interim Enhanced Surface Water Treatment Rule
- **IDSE**=Initial Distribution System Evaluation

Abbreviations #2

- **LRAA=**Locational Running Annual Average
- **LT2ESWTR=**Long Term 2 Enhanced Surface Water Treatment Rule
- **LT1ESWTR=**Long Term 1 Enhanced Surface Water Treatment Rule
- **MCL=**Maximum Contaminant Level
- **MCLG=**Maximum Contaminant Level Goal
- **MRDL=**Maximum Residual Disinfectant Level
- **NTNCWS=**Non-Transient Non-Community Water Systems
- **OGWDW=**Office of Groundwater and Drinking Water
- **PODR=**Point of Diminishing Return
- **PQL=**Practical Quantitation Limit
- **RegNeg=**Regulatory Negotiations
- **RT=**Residence Time
- **S1D/DBP=**Stage 1 Disinfection – Disinfectant Byproducts
- **S2D/DBP=**Stage 2 Disinfection – Disinfectant Byproducts
- **SUVA=**Specific UV Absorbance
- **SW=**Surface Water
- **SWTR=**Surface Water Treatment Rule
- **THM=**Trihalomethane
- **TNCWS=**Transient Non-Community Water Systems
- **TOC=**Total Organic Carbon
- **TOX=**Total Organic Halides
- **TTHM=**Total Trihalomethanes

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