Laboratory #4: Drinking Water Treatment

This laboratory has Part A (point-of-use treatment) and Part B (community-scale treatment), which will be completed over two weeks.

Part A: Point-of-Use Drinking Water Treatment

Objective: To measure and compare inactivation of indicator bacteria by point-of-use drinking water treatment in multiple source waters

Introduction

Waterborne pathogens: One of our main motivations for treating drinking water is the removal and inactivation of human pathogens, which are microorganisms that can cause illness. Waterborne pathogens cause diseases through direct consumption (drinking or inhaling) of water containing the pathogen. Gastro-intestinal illnesses are the most common symptoms produced by infections with waterborne pathogens, although some can cause other symptoms such as pneumonia or stomach cancer. Waterborne pathogens can be classified into three main groups, with differing compositions, lifecycles, sizes, and surface characteristics:

- Viruses: (0.02 – 0.2 μm), genetic material (DNA or RNA), surrounded by a capsid; can survive outside of a host (ie in the environment) but must use a host (human, animal, microorganism) to replicate. Examples: *Rotavirus*, *Hepatitis* A and E, *Norovirua*, *Enterovirus* (polio)
- Bacteria: (0.2 - 5 μm), single-celled prokaryotic organisms; most common living things found in human and animal feces. Examples: *Vibrio cholerae* (cholera), *Shigella*, *Salmonella typhi* (typhoid)
- Protozoa: (4 - 20 μm), single-cellular eukaryotic organisms; may be able to form cysts, which are very resistant to disinfection. Examples: *Entamoeba histolytica, Cryptosporidium, Giardia*
- Helminths: (40 – 100 μm), worms and flukes; require a host and passed in human and animal feces. Examples: *Ascaris, Hookworm, Dracunculus medinensis* (guinea worm), *Schistosomiasis* (bilharzia).

Removal and inactivation of pathogens: Pathogens in the environment, such as in a water source, can be physically removed or can be inactivated. Physical removal can be achieved through settling, filtering, or absorption; however, the ability to do so depends on the size, density, and surface characteristics of the pathogen. Generally, the larger pathogen groups – including helminth eggs and protozoa cysts – are easier to remove, while removal of bacteria often depends on small pore sizes (in the case of filtering) or formation of flocs or adherence to other settleable particles (in the case of settling); viruses are very difficult to remove due to their small size. Water can also be treated through inactivating pathogens, in which the microorganisms lose viability (the ability to grow or cause infection) through destruction of cell membranes, proteins, nucleic acid, and cell walls. Inactivated pathogens are still physically present but can no longer cause disease. The term disinfection refers to reducing the concentration of pathogens to levels at which there is no significant risk to public health. Inactivation methods include physical (heat, cold, UV light, ionizing radiation), biological (predation, enzymatic degradation), or chemical (oxidizing agents such as chlorine, chloramines, and ozone, sunlight, high/low pH, ammonia, metals (e.g. Ag, Cu), antibiotics) mechanisms. Inactivation mechanisms can disrupt key cell processes, such as to the virus capsid or outer surface of cells, lipid membrane functions, or damage DNA or RNA, often in multiple and complex ways.

We have been learning about treatment processes that work at centralized water treatment plant. Water can also be treated at the point-of-use (POU) – immediately before consumption. POU treatment could include removal and/or inactivation mechanisms. For this lab, we will use two methods of inactivating pathogens at the POU: 1) household bleach and 2) a SteriPEN. The active ingredient in household bleach is sodium hypochlorite, which destroys chlorine by oxidizing molecules, including proteins, amino acids, or DNA. The SteriPEN uses an ultraviolet light, using UV-C of 100–280 nm to destroy molecules within cells and RNA and DNA.

Indicator organisms: We need to measure the presence or concentrations of pathogens in water, wastewater, sludge, or soil, to know whether it is safe for drinking, swimming, discharging to the environment, irrigating vegetables, and understanding whether treatment processes are working or where contamination is coming from. However, it is not feasible to test for all waterborne pathogens, as the methods are complex and expensive. Therefore, we use what are known as indicator organisms to represent classes of pathogens. Ideal indicators are useful for all types of water, present where enteric pathogens are also present, have a reasonably longer survival time than the hardiest pathogen, should be easy to detect, and should be a member of normal intestinal flora of warm-blooded animals. While no one organism meets all these criteria, there are appropriate indicators that depend on specific use.
Common indicator organisms for disinfection studies are bacteria – particularly total coliform and *E. coli.* The table below describes the expected concentrations of enteric pathogens, and the indicator organism *E. coli*, in water sources.

Table 7.5 Examples of high detectable concentrations (per litre) of enteric pathogens and faecal indicators in different types of source waters from the scientific literature

Pathogen or indicator group	Lakes and reservoirs	Impacted rivers and streams	Wilderness rivers and streams	Groundwater
Campylobacter	20–500	90–2500	0–1100	0–10
Salmonella	—	3–58 000 (3–1000)[a]	1–4	—
E. coli (generic)	10 000–1 000 000	30 000–1 000 000	6000–30 000	0–1000
Viruses	1–10	30–60	0–3	0–2
Cryptosporidium	4–290	2–480	2–240	0–1
Giardia	2–30	1–470	1–2	0–1

[a] Lower range is a more recent measurement.

From the (WHO, 2004)

Measuring total coliform and E. coli*:* Total coliform and *Escherichia coli* are common indicator organisms used as a proxy for waterborne pathogens in disinfection studies. The total coliform group represents rod-shaped, gram-negative bacteria defined by their ability to ferment lactose with the production of acid and gas when incubated at 35–37°C due to presence of enzyme β-galactosidase. *E. coli* are a member of the total coliform group and are gram-negative, rod-shaped, coliform bacteria commonly found in the lower intestine of warm-blooded organisms that can be detected with a defined-substrate method by their enzyme β-glucuronidase. Given the specificity of *E. coli* to the intestinal tract of warm-blooded organisms, it is considered a better indicator of potential fecal pollution (and therefore, higher likelihood of correlation with human pathogens).

Culture-based approaches for enumerating bacteria are based on growth – where the bacteria are isolated, given nutrients, time, and environment for growth, and then counted. While there are many

limitations with culture-based methods (not all bacteria are culturable, bacteria can clump together leading to miscounting of colonies), it is the most widely available and commonly used method of detecting and enumerating microorganisms. Two cultured-based approaches for enumerating total coliform and *E. coli* are the Most Probable Number (MPN) method and membrane filtration. In this lab, we will use an MPN method, the Colilert Quanti-tray/2000, manufactured by a company called IDEXX. This method uses the Colilert reagent, is Defined Substrate Method that can detect total coliform and *E. coli* at the same time. The premise behind the Quanti-Tray/2000 method is that the 100 mL sample containing the Colilert reagent is divided into 97 wells of two different sizes. Based on the number of wells of the two different sizes that are positive for TC/EC, the Most Probable Number (MPN) approach is used to determine the number of bacteria in the original sample using probability. This method has a counting range of 1–2,419 MPN/100 mL, with a narrow 95% confidence interval. Some of the steps are shown in Figure 1..

Figure 1. Quanti-tray procedure. https://www.idexx.com/en/water/water-products-services/quanti-tray-system/

Procedure

We will evaluate the efficacy of two POU-based methods in inactivating total coliform and *E. coli* (TC/EC) on multiple source waters containing TC/EC (Table 2).

Table 2. Source waters to be tested

	Source water
Monday	Surface water (Mill River)
Tuesday	Tap water inoculated with primary effluent
Wednesday	Surface water (Campus pond)
Thursday	Surface water (Puffers Pond)

Sample collection and preparation for measuring total coliform and *E. coli*

Sample collection

1. Samples will be collected in pre-sterilized 120 mL bottles.
2. Before collecting samples, label all sample bottles with a marker on the sides and top of the bottle. Include the sample name, your group name or initials, date, and, just before sampling, the time of collection
3. *Sterile technique must be used throughout this sampling procedure.* Hands, counter surfaces, everything may contain the indicator bacteria you wish to evaluate. To be sure you are testing the quality of water rather than the bacteria on your hand, you must be sure not to contaminate anything that will touch your sample, including the inside or inside lid of the sample bottle, the spout you use to sample from, and the Quanti-Trays.

4. To collect a sample for analysis, pour water into a pre-sterilized, unopened 120 mL sample bottle up until the 100 mL line. *Do not put the lid down while sampling, and do not touch anything to the inside of the lid or the rim of the container.*
5. Keep sample in the fridge until you have collected all your samples.

Sample analysis

1. Add a snap pack of Colilert reagent to the sample bottle. *Again, be careful to not contaminate the sample.*
2. Gently invert the bottle several times to allow the reagent to dissolve into the sample.
3. When fully dissolved, carefully take a sterile Quanti-Tray from the bag. Hold it open with your hands and pull the tab back. *Again, be careful not to contaminate the tray*. Pour your sample into the tray. Holding the tray with the plastic side towards you, gently tap it to get rid of the bubbles.
4. Place tray in red rubber holder on sealer. Place the open side of the tray outwards (not directly into the sealer). Push tray through sealer to seal tray.
5. Write the same information that was on the sample bottle onto the back of the tray once it come out of the sealer. Be sure this includes your group name, sample name, and date.
6. Place trays in incubator set at 35C for 24 hours.

Counting trays

1. Remove trays from incubator.
2. If there are any total coliform present, some of the wells will be yellow. Mark the wells with a marker if they are yellow.
3. Count the large yellow wells, including the very large one at the end of the tray, and count the small wells separately.
4. Put the tray under the UV light. If any of the total coliform are also *E. coli*, they will fluoresce. Count the number of large and small wells that are fluorescent.
5. Look up the values for TC and EC using the table.

Part A. Characterize source (challenge) water

1. Measure and record turbidity, temperature, and pH of your raw water (challenge water)
2. Take a sample of your challenge water for analyzing total coliform and *E. coli,* following the sample above. Make sure your sample is properly labeled.

Part B. Treat the challenge water

Household bleach

Safety note: Bleach can ruin clothing so be careful to keep the bleach away from your clothes.

1. Fill a beaker with your challenge water.
2. Each group will use a different dose of chlorine
    a. The Center for Disease Control (CDC) states that: "Add 1/8 teaspoon (or 8 drops) of regular, unscented, liquid household bleach for each gallon of water, stir it well, and let it stand for 30 minutes before you use it."
    b. Group 1: Full recommended dose
    c. Group 2: Half of the recommended dose
    d. Group 3: 1/8 of the recommended dose
    e. Group 4: Double the recommended dose
3. Calculate the dose of chlorine to add to your water based on the volume of water you intend to disinfect.
4. Add your calculated amount of bleach to your water and follow the instructions.
5. Measure free and total chlorine. Immediately after adding it, take a sample in a 10mL vial and

test the free and total chlorine residual.

6. After the 30 minutes have finished, re-measure free and total chlorine and collect a sample of your treated water in a 100mL sample bottle for measuring total coliform and *E. coli.*

Steripen

1. Fill the 1 L Nalgene bottle with your challenge water.
2. Each group will use a slightly different testing procedure
    a. Group 1 and 2: Regular dose of UV from Steripen (treat 1 L of water)
    b. Group 3 and 4: Double dose of UV from Steripen (do two rounds of treatment)
3. Read the instructions on the Steripen instructions sheet and follow them. You may wish to practice first on DI water.
    a. Follow the directions carefully. Make sure Steripen is fully immersed in water and that blue light is on throughout the dose. Do not lift it out of the water until it is finished.
4. Take a 100mL sample from the Nalgene bottle for measuring total coliform and *E. coli*

Steps for completing the lab write-up

Sharing of Data

a) Transfer your data to the Google Docs spreadsheet linked in Moodle within 48 hours of your lab period.

Presentation of your data

a) Disinfection with chlorine: Graph inactivation of total coliform and *E. coli* as $\log_{10}(N/N_0)$, where N is the number of organisms (on the y axis) versus chlorine dose on the x axis, with separate lines for each source water.
    a. Fit a line to the curve. What is the slope of this line?
b) Disinfection with UV: Graph inactivation of TC and EC as bar plots based on UV dose.
c) Graph turbidity of samples versus TC and EC (separately) inactivation for both chlorine and UV.
d) Calculate your chlorine demand in the first 30 minutes.

Discussion questions

In addition to other items included in the lab report guidance, also reflect on:

- How does the original range compare to table 7.5 from the WHO Guidelines document (in the lab handout).
- How did source water affect disinfection efficacy? Reflect on how turbidity or chlorine demand may have effected how well the disinfectants worked.
- If your method successfully inactivated the indicator bacteria, does that mean it is now safe to drink? Why or why not?
- What are the advantages and disadvantages of POU treatment of water versus treatment at a centralized drinking water treatment plant?

DATA SHEET

Date:_____ Raw Water:_____

Initial Conditions of Raw Water:

Turbidity (NTU)		
pH		
Temperature (C)		
Other observations		
Total coliform (MPN/100 mL)	Large wells: Final number:	Small wells:
E. coli (MPN/100 mL)	Large wells: Final number:	Small wells:

Steripen

Dose used: _____

Bleach

Dose used: _____ drops / _____ mL

Free chlorine (mg/L) initial: _____
Total chlorine (mg/L) initial: _____

Minutes after dosing of re-measuring chlorine: _____
Free chlorine (mg/L) final: _____
Total chlorine (mg/L) final: _____

	Steripen			**Bleach**		
	Large wells	Small wells	MPN/100 mL	Large wells	Small wells	MPN/100 mL
Total coliform						
E. coli						

Part B: Community-scale Drinking Water Treatment

Objective: To determine if the Robert's Meadow Reservoir meets the current water quality standards established by the US EPA for water supply.

Introduction

Current Drinking Water Standards in the US

The most common and economical treatment for drinking water is "conventional treatment" which includes coagulation followed by gravity settling and granular media (most often sand and anthracite) filtration. When the raw water supply is of sufficient quality, this level of treatment will result in water that meets federal standards for pathogen control and for chlorinated disinfection byproducts (DBPs).

The USEPA Surface Water Treatment Rule requires **0.5 log removal of *Giardia*** and **2.0 log removal of *viruses*** by disinfection when combined with conventional treatment with coagulation and filtration. To achieve this level of removal, water suppliers are required to provide a certain "**CT**" (the product of disinfectant concentration and contact time; see Table 1). The values of CT depend on the disinfectant, the temperature and the pH. To account for short- circuiting in chlorine contact tanks, the USEPA requires that the t_{10} be used to calculate the "effective" retention time rather than the calculated mean hydraulic retention time (MHRT=V/Q). This t_{10} is essentially the time it takes for the fastest 10% of the influent water to exit the tank. It is determined by a tracer study on the full-scale tank, and it is usually represented as a percentage of the HRT. A well-baffled tank can reach t_{10} levels up to 50% of the MHRT or more.

US EPA's Disinfectants/Disinfection Byproduct Rule (D/DBPR) requires that disinfection byproducts (DBPs) be kept below 80 µg/L for trihalomethanes (THMs) and 60 µg/L for haloacetic acids (HAAs). This means that the amount of precursor organic matter in the water after coagulation/filtration must be low enough so these DBPs do not exceed these limits even when the water has reacted with the chlorine for many days (the typical maximum value for distribution system residence times).

Problem Description

The Robert's Meadow Reservoir (also referred as Hoxie Reservoir or the Leeds Reservoir) in the Leeds section of Northampton served for 34 years as the principal water supply for the town, and later as a supplemental supply. Following two large fires in Northampton in 1870, it was decided (February 1871) that the community should look to Roberts' Meadow Brook as a reliable water supply for its first municipal system. Construction of the reservoir began in May 1871 and by September of that year it was filled with about 4 million gallons of water. By 1873 there were 517 families that had been supplied with piped water, not to mention a large number of businesses and 107 fire hydrants. Eventually two more dams would be constructed in Roberts' Meadow system.

Recognizing the need for more water than could be supplied by Roberts' Meadow, the city began planning for two new supplies in Whately and Williamsburg, the West Whately Reservoir and the Mountain Street reservoir, respectively. Construction proceeded in the first few years of the 20th century. On March 30, 1905, the city started using the new upland sources exclusively. The Whately system would later be improved with the construction of the much larger Francis P. Ryan Reservoir immediately adjacent to the West Whately Reservoir.

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

CHLORINE CONCENTRATION (mg/L)	pH<-6						pH=6.5						pH=7.0						pH=7.5					
Log Inactivation	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	27	44	87	131	174	218	261	53	105	158	211	263	316

CHLORINE CONCENTRATION (mg/L)	pH=8.0						pH-8.5						pH-9.0					
Log Inactivation	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:EPA, 1999, Guide Manual for Disinfection Profiling & Benchmarking

Table 2. Northampton's Surface Water Supplies (Northampton Watershed Resource Protection Plan, PVPC, June 1994)

Source reservoir	Drainage Area (acres)	Safe Yield (MGD)	Reservoir Storage (MG)
Roberts Meadow	6,900	2.00	85
West Whately	1,182	3.79	750
Ryan	2,762		
Mountain Street	541	1.17	375

Low water levels in the Mountain Street Reservoir forced the city to begin using Roberts Meadow again in October 1932. The state Department of Health found high bacterial counts from the Roberts Meadow supply, so the city installed a chlorination system for that supply that went into service on Nov 9, 1932. At this time, it was also recognized that the water had high levels of organic matter (color) and algae (Gazette, May 4, 1932). The general water degradation was probably exacerbated by runoff from upstream farms. From this point on, the Roberts Meadow system was used only when the levels in Mt. Street Reservoir were low and the overall supply needed a supplement. In late 1950, two wells were constructed in the Florence section of Northampton to help provide some additional water. Roberts Meadow Reservoir was finally taken out of service in 1978- 1979, after 108 years of use. After this point it was still listed as a back-up source for emergencies, but it was apparently never used again.

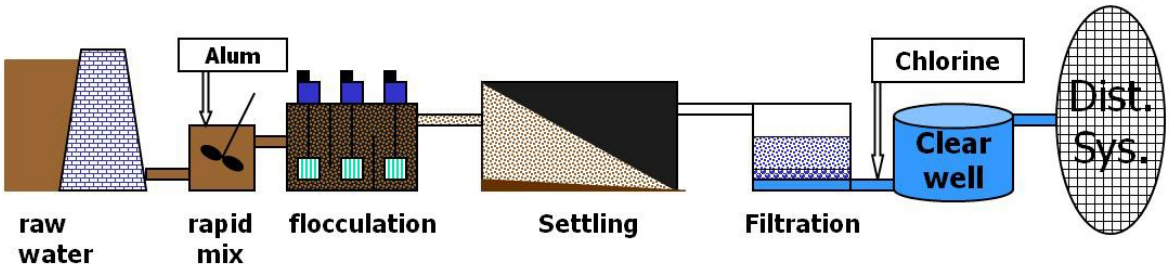
With the near failure of the Whittenton Pond Dam in Taunton in 2005, the Commonwealth of Massachusetts began an aggressive campaign to inspect major public dams. At this time they decided that the Upper Roberts Meadow Dam was at risk and needed to either be repaired or removed. Following careful analysis by the city's consultant, the decision was made to remove it based largely on economic considerations. More recently (Hampshire Daily Gazette; October 29, 2010), the Northampton Board of Public Works voted to have it removed. However, experience will tell you that in politics as with sports, "it is never over until it is over". There may still be appeals and possibly legal challenges to this decision. Nevertheless, the major portion of the Roberts Meadow supply is impounded by the Middle Roberts Meadow Dam which will remain regardless of the fate of the Upper Dam.

The purpose of this laboratory study is **to determine if the Roberts Meadow supply could be treated using conventional (i.e., low cost) technology and meet existing standards for disinfection and disinfection byproducts**. Specifically, it would need to be of high enough quality so that after coagulation with alum and filtration, the remaining dissolved organic matter (DOM) is below a key threshold. That threshold is not defined by a simple UV_{254} absorbance nor is it fully defined by a total organic carbon level (TOC). Instead it is defined as a level that will not produce excessive THMs and HAAs in the distribution system when chlorine is added at sufficient dose and contact time to meet "CT" regulations for disinfection.

(The US EPA requires that conventional treatment plants meet a certain percent removal of TOC. For the Roberts Meadow Supply, it would probably be 35% when the raw water TOC is below 4 mg/L and *45% when it is above this value).

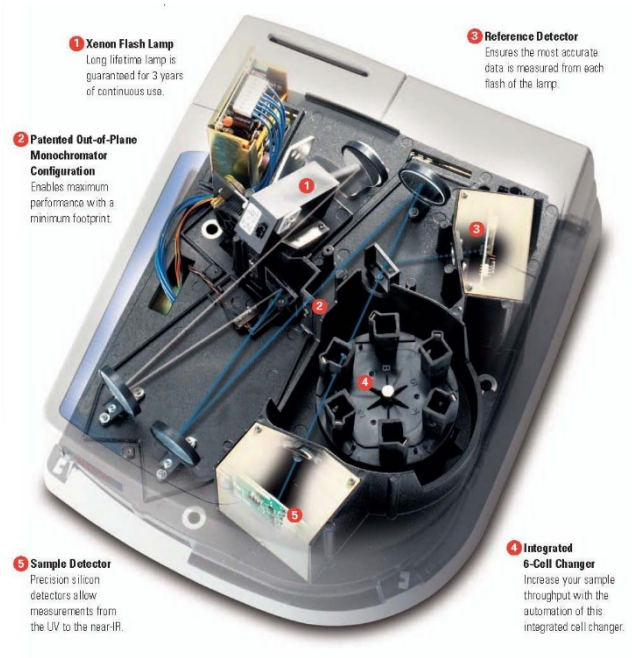
<u>Conventional Treatment</u>

Conventional treatment in the US involves the addition of a coagulant during a rapid mix stage, followed by a flocculation period (slow mix), gravity settling or clarification and granular media (sand etc) filtration. The water is then treated with a disinfectant (usually chlorine) prior to a holding tank for achieving CT and then sent into the distribution system.



In the laboratory, this can be simulated with the classic Jar Test Procedure outlined below, followed by filtration using a glass fiber filter and then addition of chlorine. It must be done in this order to accurately reproduce what would occur in a full-scale water treatment plant. The chlorinated sample is then held for a period of time to simulate the residence time in the clear well (CT tank) and the distribution system.

Measurement of Natural Organic Matter



We will use a Genesys 10s Ultraviolet-Visible (UV-Vis) Spectrophotometer for monitoring the concentration of natural organic matter in the coagulated water. This instrument has a light source (Xenon lamp,1), a monochromator (2) that selects for the desired wavelength, a cell compartment with changer (4), and a pair light detectors, one to monitor the lamp output (3) and one to measure the light transmitted through the sample (5).

This instrument must be turned on and warmed up well before use. The first step in its use is to set the wavelength using the panel controls. It is then "calibrated", or more accurately, "zero-ed" by placing a cuvette with distilled water into the cell changer and pressing the "B" button (stands for "Blank"). Make sure you've selected the "Absorbance" readout. Then place your sample in a separate cuvette and press the button on the cell changer indicating the position of the sample. You will see a read out in absorbance units per centimeter. Also on the screen will be a reminder of the wavelength that this instrument is tuned to.

The concentration of any absorbing compound is linearly related to its absorbance in accordance with Beer's Law:

$$Abs = A*C*x \quad (1)$$

Where "Abs" is the measured absorbance, A is the absorptivity ($M^{-1}cm^{-1}$ in which case it is called the molar absorptivity), C is the concentration and x is the light path length of the sample cell (usually 1 cm, which is what we'll be using). In this case, we're using **absorbance as a "surrogate" measure of the amount of dissolved natural organic matter** (NOM) remaining in a treated sample. Thus, the sample must be filtered prior to analysis. While we could pick almost any wavelength as our "surrogate" parameter, we normally use 254 nm by virtue of an arbitrary convention.

Measurement of Chlorine Residual

See method for measuring free and total chlorine using Hach Free Colorimeter in separate handout.

Relationship between Chlorine Residual and DBP Concentration

Actual measurement of disinfection byproduct (DBP) concentrations is beyond the scope of the CEE 370 lab. However, it is possible to use chlorine residual measurements to estimate DBP formation from coagulated and filtered waters.

First, we need to define an important water quality parameter know as chlorine demand:

Cl_2 Demand (mg/L) = Chlorine Dose (mg/L) – Chlorine Residual (mg/L) (2)

From this we can estimate DBP formation. The reason is that waters with almost entirely "organic" chlorine demand, such as this one, will result in a certain percent conversion of reacted chlorine to organic chlorine by-products. The correlation we will use comes from research studies conducted at UMass. Equations 3 and 4 give estimates of the THM and HAA formation under the same conditions that were used for chlorine demand test (i.e., same pH, time, and temperature).

$$THM = 1.919\ (Cl_2\ demand)^{0.47}\ (pH)^{1.245}\ (time)^{0.053}\ (temp)^{0.204} \quad (3)$$

$$HAA = 35.24(Cl_2\ demand)^{0.178}\ (pH)^{-0.314}\ (time)^{0.141}\ (temp)^{0.125} \quad (4)$$

where both THM and HAA are in units of µg/L, chlorine demand is in mg/L, time is in hours, and temperature is in degrees centigrade.

Procedure

Table 3. Summary of Test Conditions for Each Lab Period

Set #	Bicarbonate Addition (mLs of a 78g/L $NaHCO_3$	Alum Doses (mg/L)
Group 1	none	0, 5, 10, 15, 30, 60
Group 2	2.0 mL/L	0, 5, 10, 15, 30, 60
Group 3	none	0, 10, 20, 45, 60, 100
Group 4	2.0 mL/L	0, 10, 20, 45, 60, 100

Part A1. Jar Testing

6. Receive testing assignment (Set #) from TA
7. Measure out 1-L (or 700 mL if smaller beakers are used) volumes of the raw water by pouring from a carboy to a plastic 1L graduated cylinder and dispense to the each of the six beakers
8. Add Bicarbonate ($NaHCO_3$) solution as needed (for sets #2 and #4) to each beaker
9. Measure out an additional volume (e.g, 250 mL) of raw water into a separate 500- mL beaker and add the same dose ratio of Bicarbonate solution to this, accounting for the smaller volume. Use this sample for measurement of raw water pH, temperature and UV-Vis scan. While you're taking the scan, record the raw water UV absorbance at 254 nm. You may wish to do this while the 6 beakers are in their slow mix (#8) or settling phase (#10).
10. Place beakers under the 6-paddle stirrer (jar test machine) and stir at high speed (~100 rpm).
11. One-by-one add the requisite volume of alum stock to achieve the desired doses for your set# (rapid mix phase)
12. Once the last beaker has been dosed, wait 60 seconds and reduce the mixer speed to 20 rpm. Maintain this slow mix phase for 20 minutes (flocculation). During this time you may wish to make the

measurements on the small sample in the 500 mL beaker (e.g., raw water pH, temperature, UV_{254} and the UV-Vis scan).

13. Remove the six beakers from the 6-paddle stirrer. Gently measure **coagulated pH** of each coagulated sample and the raw water from step 5.
14. Allow all 6 beakers to sit quiescently (settling phase) for 30 minutes.
15. One-by-one, carefully decant (pour, without disturbing settled solids) ~500-700 mL into a graduated cylinder. Stop pouring once the settled solids (if any) begin to flow out of the beaker

Part A2. Analysis of Settled and Filtered Water

16. Pour a small volume from the graduated cylinder into a turbidimeter cell and measure turbidity (**settled turbidity)**.
17. Place a new glass fiber filter (GF/C) into the Millipore filtration apparatus. Re-assemble the apparatus and turn on the vacuum pump. Then pour the full remaining decanted sample volume from the large graduated cylinder into the reservoir.
18. Once filtration is complete, withdraw a few mL with a pasteur pipet and use this to measure absorbance on the filtered sample (filtered UV_{254} absorbance).
19. Pour the filtered sample from the vacuum flask back into the graduated cylinder and record the exact volume. Then pour this into a 500-mL amber bottle. If the volume of water equal or exceeds 500 mL, pour about 490 mL, leaving a few mL of headspace in the bottle. In either event, it is important that you know exactly what the volume of sample is in the bottle. Label it, and set aside for chlorine demand testing.
20. Repeat Steps 12-15 for each settled sample

Part B. Chlorine Demand Testing

21. Add the requisite volume of chlorine stock to achieve the desired chlorine dose (see Table 4 below). Cap and mix by inverting several times.
22. Make sure the amber bottle is fully-labelled (group name, jar#, conditions) and place it on the bench for room-temperature incubation (reaction).
23. At the end of each of the 5 chlorine contact times, locate your bottles, pour out 100 mL and measure **residual chlorine** for each of the five. After you are done, cap the bottles and return them to the bench to continue incubating. Except for the first recording time (@1 hr), you will have to return during a non-lab time to make the measurement. Please make arrangements for this with your lab partners. Only one person from each group need be present to make these measurements. Please contact the instructor or TA if the door is locked. Be aware that you can modify the reaction time for your convenience, but it is important you record the exact time of analysis. Also you should be aware that some bottles may run out of chlorine before the last scheduled reaction time. If you notice one that has dropped to zero residual, there is no need to continue measuring the chlorine residual at later times.
24. Measure and record **final pH** in each sample after the last chlorine measurement.
25. When the last measurement is made, measure and record the **final water temperature** for at least one sample.

Table 4. Summary of Test Conditions for Each Lab Period

Day	Chlorine Dose	Approximate Reaction Times
Group 1	1.5 mg/L	1 hr, 14 hrs, 26 hrs, 2 days, 3 days
Group 2	2.5 mg/L	1 hr, 14 hrs, 26 hrs, 2 days, 3 days
Group 3	3.5 mg/L	1 hr, 38 hrs, 3 days, 5 days, 7 days
Group 4	5 mg/L	1 hr, 2 days, 3 days, 5 days, 7 days

Steps for completing the lab write-up

Sharing of Data

a) Transfer your coagulation data to the Google Docs spreadsheet linked in Moodle **within 24 hours of your lab period.**
b) Continue to fill in the chlorine residual portion of the spreadsheet as you collect more data.
c) Send the completed Google Doc (including chlorine residual data) to the TA by the date and time specified by the TA.

Presentation of your own Data and Discussion

a) Graph the raw water absorbance spectrum and a spectrum of a coagulated/filtered water (use the one with the highest dose). Graph both on the same set of axes with wavelength (200-400 nm) on the x-axis. Are they similar? What does this tell you about using 254 nm as an indicator of organic matter concentration?
b) Graph settled water turbidity and UV absorbance (254 nm) versus alum dose in mg/L. Alum dose is the independent variable, and therefore it should be identified with the x-axis.

Interpretation Regarding Current EPA Regulations

a) The instructor and Lab TAs will provide you with the entire class's data at some point during the second week of the lab. You should incorporate this dataset into your group's lab writeup.
b) Use the power function equations (#2 and #3) to estimate THM and HAA levels for the various treatment scenarios (alum dose, pH, chlorine dose) with special attention to the 3 day chlorine reaction time as this is the normal maximum water age in the Northampton system.
c) Comment on the feasibility of meeting both THM and HAA standards while still maintaining a measureable chlorine residual (i.e., >0.1 mg/L) for the 3-day reaction time.
d) Propose at least 2 scenarios (chlorine dose and soda ash addition) that will meet these requirements. If none do, propose at least 2 scenarios that come closest. Comment on the "optimal" alum dosage for this scenario.
e) Calculate a chlorine contact tank volume for the two scenarios needed to meet the "CT" requirement assuming a flow of 2 MGD at Roberts Meadow. Use 0.5°C as a conservative design condition (Table 1). Although the USEPA requires an additional 0.5 log Giardia removal by chlorination, assume the City wants to achieve a full 1 log removal credit to provide an additional margin of safety. You should also assume a t_{10} of 50% of the mean hydraulic retention time of the tank.

JAR TEST DATA SHEET

Date:_____

Raw Water:_____

Initial Conditions of Raw Water;

Turbidity (NTU)	
pH	
Temperature	
Other observations	

Test Conditions;
Sample Volume per Jar:_____
Rapid Mix:_____ Slow Mix:_____

COAGULANTS: (type and stock concentration)
_____
_____

Parameter	JAR NUMBER					
	1	2	3	4	5	6
Coagulant dose						
Vol. of stock						
pH						
Clarified Turbidity						
UV254 Absorbance (After filtering)						