11.479J / 1.851J Water and Sanitation Infrastructure in Developing Countries
Spring 2007

Water Quality

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Water and Sanitation Infrastructure in Developing Countries

Week 6, 11.479 J / 1.851J

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Outline

- Does “Improved” = “Safe?”
  Two “Safe Water” Definitions
- Four Water Quality Categories
- Water Quality Lab
  - Bacterial Indicators
  - Turbidity
  - Residual Chlorine
- EPA & MWRA Water Quality Regulations
- Vietnam Water Quality Regulations

Are "Improved" Drinking Water Supplies Safe?

- Gundry et al (2006):
  - Rural South Africa and Zimbabwe
  - Randomized study – 254 children, aged 1-2 years
  - Dry and wet seasons

> 10 CFU/100ml E.coli		
	Improved (standpipe, borehole, protected well)	**Unimproved (unprotected well/spring, river/canal)**
At Source	**12%**	**71%**
Household Storage	**41%**	**81%**
Drinking Cup	**51%**	**82%**

“Safe Water” - Definition

- “We define safe drinking water as water that is safe to drink and available in sufficient quantities for hygienic purposes”

(UN Millennium Task Force, 2005)

"Safe Water" – Definition WHO GDWQ 3rd Ed.

- "Safe drinking water, as defined by the Guidelines, does not represent any significant risk to health over the lifetime of consumption, including different sensitivities that may occur between life stages." (p.1)
- "Those at greatest risk of waterborne disease are infants and young children, people who are debilitated or living under unsanitary conditions and the elderly." (p.1)
- "The judgment of safety - or what is a tolerable risk in particular circumstances – is a matter in which society as a whole has a role to play. The final judgment as to whether the benefit resulting from the adoption of any of the health-based targets justifies the cost is for each country to decide." (p.37)

Water Quality – 4 Broad Categories

Microbiological

- Bacteria
- Viruses
- Protozoa
- Helminthes

Chemical

- Organic / Inorganic
- Naturally occurring /
- Anthropogenic

Physical / Aesthetic

- Turbidity
- Odor
- Taste
- Appearance
- other…

Radionuclides

- Radium
- Uranium
- Radon

Microbiological Contaminants

- “Infectious diseases cased by pathogenic bacteria, viruses, protozoa and helminthes are the most common and widespread health risk associated with drinking water.”

- (WHO, 2004. *Guidelines For Drinking Water Quality* 3rd Ed. p. 123)

Indicator Organisms

- Organisms, whose presence indicate *likely* occurrence of waterborne pathogens:

[indicator] → fecal contamination → [pathogen] ≈ disease

- Ideal indicators should fulfill several criteria:
  - Always be present when pathogens are present;
  - Share similar persistence and growth characteristics;
  - Exist in larger concentrations for easy detection;
  - Detection tests should be relatively simple, inexpensive;
  - Detection tests should detect indicator org. only;
  - Detection tests should be applicable to all types of water.

Pathogens vs. Indicator Organisms

Pathogens	Indicator Organisms
Cause disease directly	Most are not pathogenic
Great variety	Specific target groups
Difficult to isolate	Easy to detect and enumerate, usually within 24-48hrs
Takes longer to detect	
Some are opportunistic	

Note !!! Direct detection of pathogens is inappropriate for routine water monitoring, because, based on methods available today, it is complex, time-consuming and expensive.

Instead, frequent and simple indicator tests are better, especially when contamination can be intermittent and/or undetectable.

What are coliforms? (WHO-GDWQ 3rd Ed.)

- "Gram negative, rod-shaped bacteria, grown in bile salts, fermenting lactose at 35-37ºC producing acid, gas, and aldehyde within 24-48hrs, oxidase negative, non-spore forming, display β-galactosidase activity."
- Operational, not taxonomic definition.
- First introduced ~120 years ago, based on its quantifiable relationship with potential health risks.

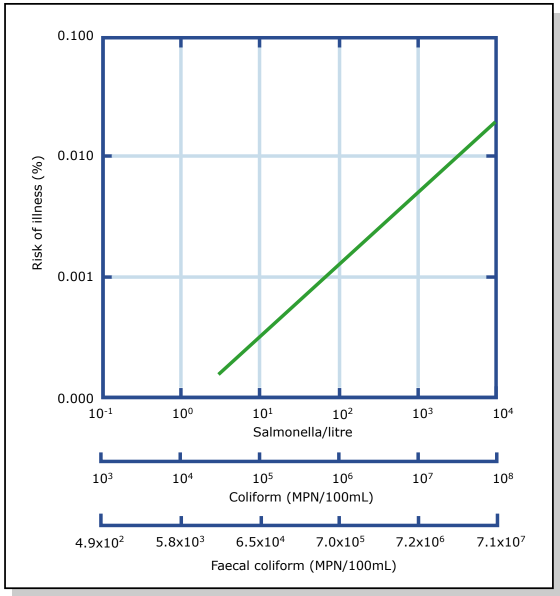


Figure by MIT OpenCourseWare.

Relationship between pathogen and coliform (Olson & Nagy, 1984)

Coliform Indicator Organisms

- The coliform group is the most common indicator group used in the world. It includes:
  - Total Coliform
  - Thermotolerant coliform (formerly known as “fecal”)
  - E.Coli
- Fecal coliforms are nowadays more properly referred to as “thermotolerant coliforms” Thermotolerant coliform are those able to ferment lactose at 44-45° C. The name-change is due to the fact that some in this group may be of non-fecal origin.
- For example, in tropical areas, total coliforms can originate from decaying vegetation and do not necessarily indicate the presence of pathogens in water
- Still, these indicators are used in the tropics due to lack of better methods
- Fecal streptococci and clostridia are other bacterial indicator groups commonly used in temperate climates.

E. coli

- Exclusively fecal in origin
- WHO defn: Thermotolerant coliforms with indole production and beta-glucuronidase activity and absence of urease activity
- Constitutes 90 - 95% of the coliform bacterial in mammalian fecal material
- Most sensitive and specific indicator of fecal pollution currently available as well as most widely used, world-wide

WHO-Guideline Value for Verification of Microbial Water Quality from: GDWQ – 3rd Edition

- *E.coli* or thermotolerant coliform bacteria must not be detected in any 100 ml sample for all water directly intended for:
  - Drinking;
  - Treated water entering the distribution system;
  - Treated water in the distribution system.

From Table 7.7 p. 143. See also Table 5.2. p. 97

E. coli Grading Schemes

"In many developing and developed countries, a high proportion of small-community drinking water systems fail to meet requirements for water safety. In such circumstances, it is important to set realistic goals… and classify water quality results in terms of an overall grading systems," as illustrated here: (WHO, GDWQ, 3rd Ed. 2004 p. 97)

Proportion (%) of Samples Negative for *E.coli*

Population Size-> Water Quality	< 5000	5,000 –100,000	> 100,000
Excellent	90	95	99
Good	80	90	95
Fair	70	85	90
Poor	60	80	85

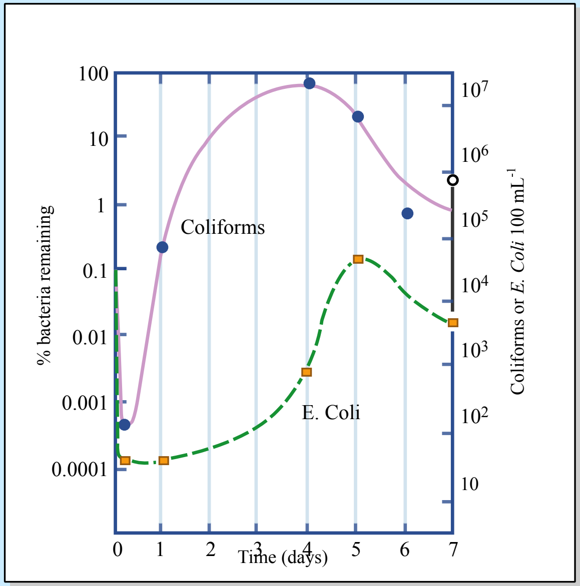
Thermotolerant (Fecal) Bacteria Risk Categories for Untreated Rural Water Supplies

Count per 100ml	Risk Category
0	Conforms with WHO Guidelines
1 – 10	Low Risk
10 – 100	Intermediate Risk
100 – 1000	High Risk
> 1000	Very High Risk

WHO. *Guidelines for Drinking Water Quality,* 2nd Ed. *Vol. III, Surveillance and Control of Community Supplies*, Geneva, 1997)

Why coliforms are imperfect indicators

1. Coliforms regrow (or are suppressed) in the environment
   – In enriched waters, even chlorinated sewage, on biofilms in distribution systems.
   – *E.coli* is 2,400 times more resistant to chlorine when attached to a surface (turbid water) than as free cells.
   – Presence of background antagonistic bacteria can reduce coliform counts up to 57%.



Regrowth of coliforms and *E.coli* in sewage effluent (Shuval et al., 1973)

Figure by MIT OpenCourseWare.

Coliforms imperfect (cont'd)

2. Inaccurate indicators of pathogens and waterborne diseases
   - Not necessary indicative of pathogenic bacteria, protozoa, and viruses → health threat.
   - Some outbreak studies show absence of coliform when there is a outbreak and vice versa. Pathogenic *Vibrio* sp. and *Salmonella* sp. have been recovered from waters containing few or no coliforms.
   - Non-fecal *Klebisella, Citrobacter* or *Enterobacter* can be found naturally.
   - Coliforms are not reflective of protozoan cysts and enteric viruses.

Coliforms imperfect (cont'd)

	Total coliforms	Fecal coliforms	*Cryptosporidium*	*Giardia*
Turbidity	**Moderate** (0.28)	**Moderate** (0.29)	**Low** (0.24)	**Moderate** (0.28)
Total coliforms		**High** (0.71)	**Low** (0.15)	**None** (0.02)
Fecal coliforms			**Moderate** (0.29)	**Low** (0.10)
Cryptosporidium				**High** (0.78)

Correlation for coliform, turbidity, and protozoa in a watershed. (Rose et al., 1988)

Coliforms imperfect (cont'd)

3. High probability of false positive and false negative results
   - Existence of non-coliforms with similar operational behavior e.g. Aeromonads, can give false positives.
   - Some 20% of coliforms are non-lactose forming.

4. Inappropriate as fecal indicators in tropical waters
   - Many coliforms, many thermotolerant, are naturally occurring in tropical waters → need alternative indicator
   - *E.coli* is preferred as it represents 90 - 95% of all coliforms found in feces.
   - Fecal streptococci, *clostridium perfringens* are almost certain of fecal origin can also be used.

WHO 3rd Edition GDWQ

- There is no single "ideal" indicator organism.
- The new 3rd Edition WHO *Guidelines for Drinking Water Quality* seek to address this with its risk-based approach

Appropriate health risk vs. cost of maintaining high level of water quality?

"... to encourage an incremental improvement in water quality at most affordable cost."

WHO 3rd Ed. GDWQ

1. Evaluate "acceptable risk"
   – Quantify risk of infection, infective dose, opportunistic pathogens.
   – Can be based on incremental benefit/cost ratios.
   – Require lots of epidemiological data.

2. Conduct proper sanitary surveys
   – Investigate and eliminate contamination near water source.
   – Require conscientious carrying out of maintenance (e.g. tubewell) programs.
   – Sanitation improvements go hand in hand.

Approaches (Cont'd)

3. Develop Water Safety Plans based on acceptable risk
   - Encourage attainable, incremental improvement in water quality.
   - Guidelines should be future goals, not immediate requirement.

4. Use simple, inexpensive monitoring tests
   - Encourage simple, yet frequent water monitoring practices.
   - Household kits adjusted to appropriate sensitivity to prevent false-positives.
   - Still, ultimate goal is direct detection of pathogens.

Water Quality Lab

Simple, Inexpensive Tests for Operational Monitoring

Turbidity

- Suspended and colloidal particles of clay, silt, organic and inorganic matter, minerals, plankton and microscopic organisms which impede the passage of light through water.
- Turbidity > 5 NTU is noticeable to the consumer
- Effective coagulation / filtration should removal turbidity

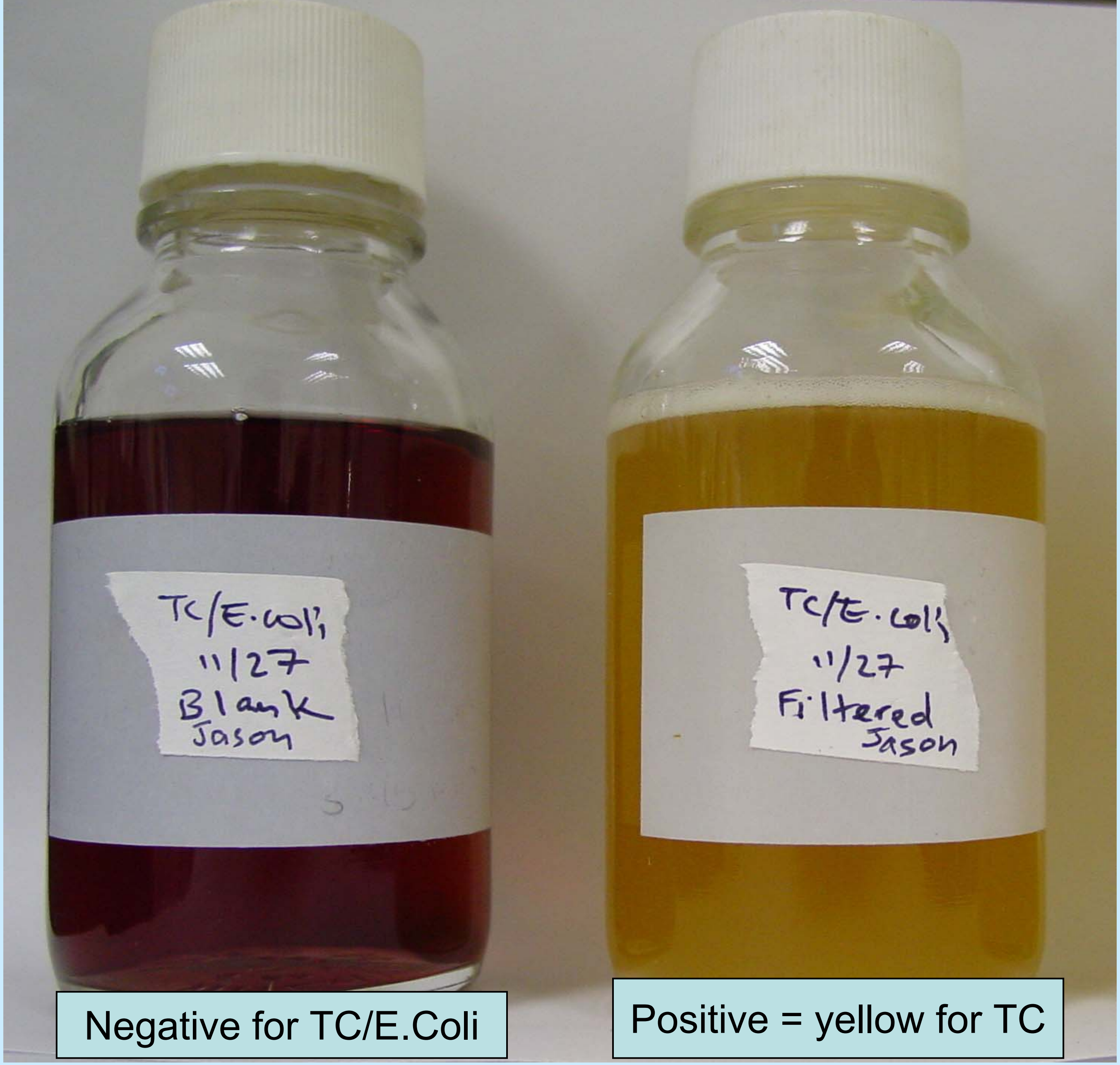
Turbidity Measurement & Units

- Jackson Candle Units – the historic standard method, however the lowest value measured is 25 Jackson Turbidity Units (JTU) and treated water usually falls in the range 0 – 1 JTU.
- -> So… electronic nephrelometers were developed
- Nephrelometers are turbidimeters which measure intensity of light scattered at 90° to the incident beam.”
- There is no standard type of turbidity, so an arbitrary standard is used in electronic nephrelometers, composed of an aqueous suspension of formazin polymer.
- Unit of measurement = nephrelometric turbidity unit (NTU)

Coliform Indicator Tests

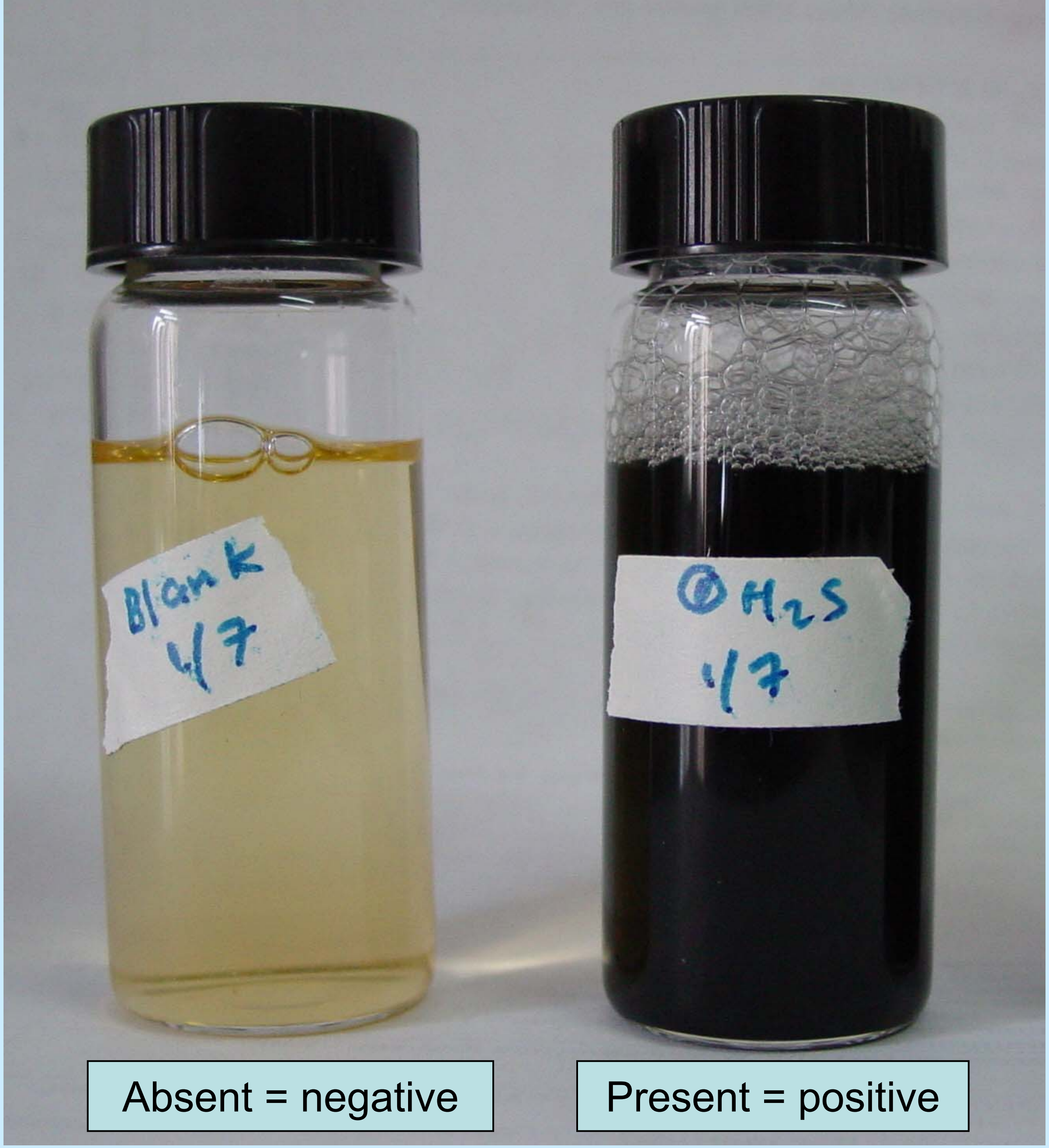
3 common methods

- Presence/Absence
- Most Probable Number (MPN)
- Membrane Filter (MF)

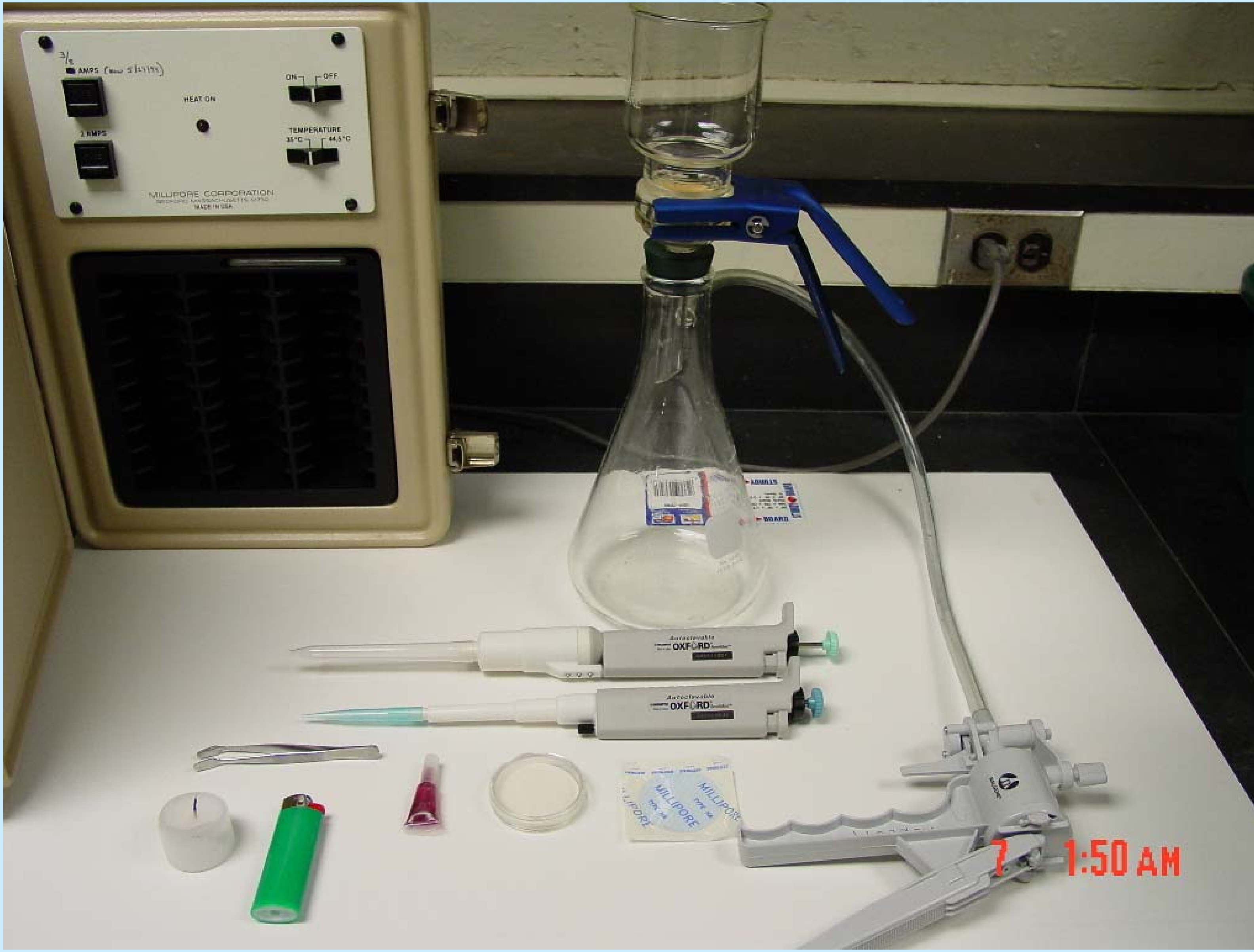


Total Coliform / E.Coli Presence Absence Test Result

Total Coliform/E.Coli P/A Test showing fluorescence for E.Coli (= + for E.coli)

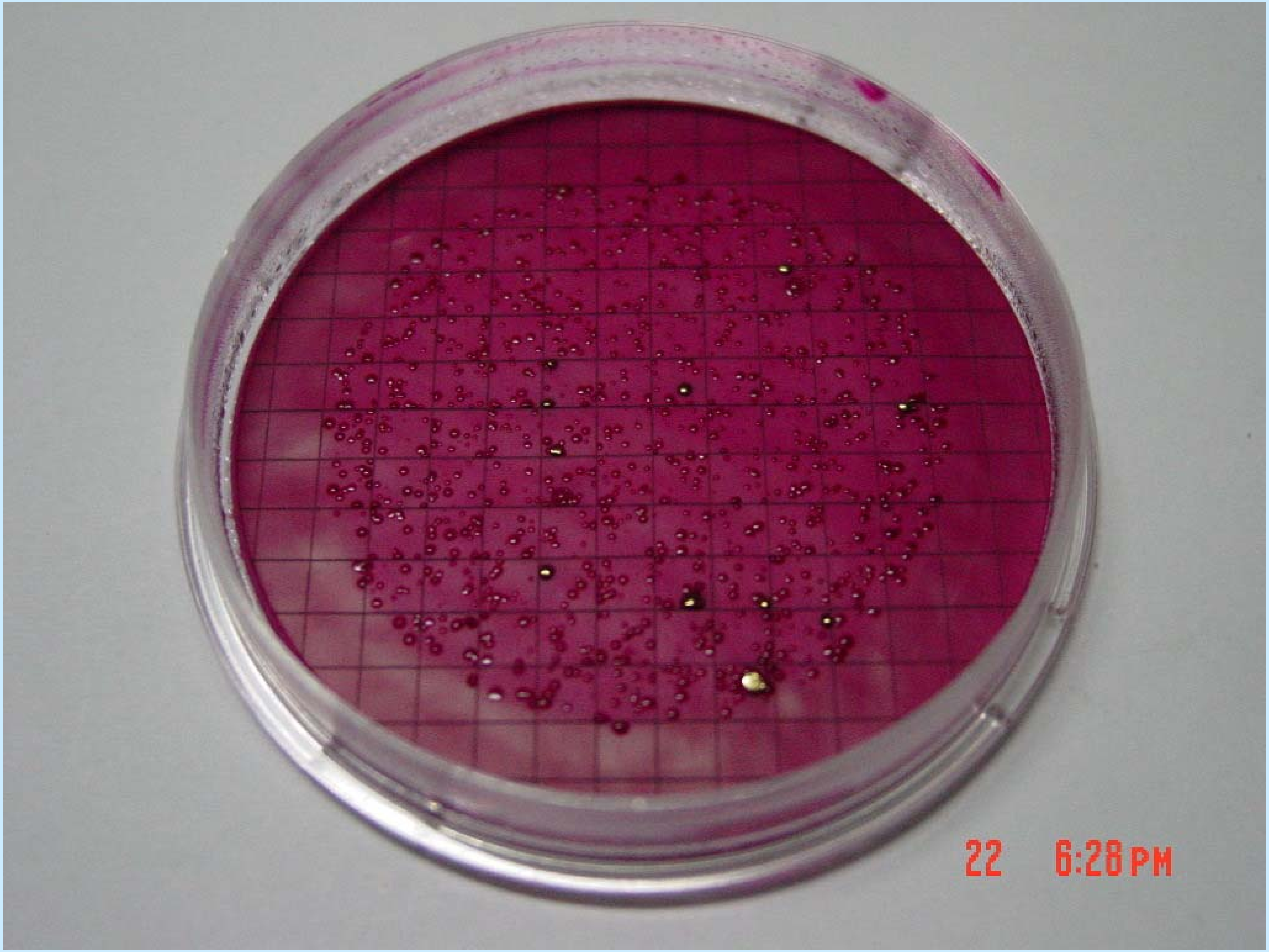


Hydrogen Sulfide Bacteria Presence/Absence Results

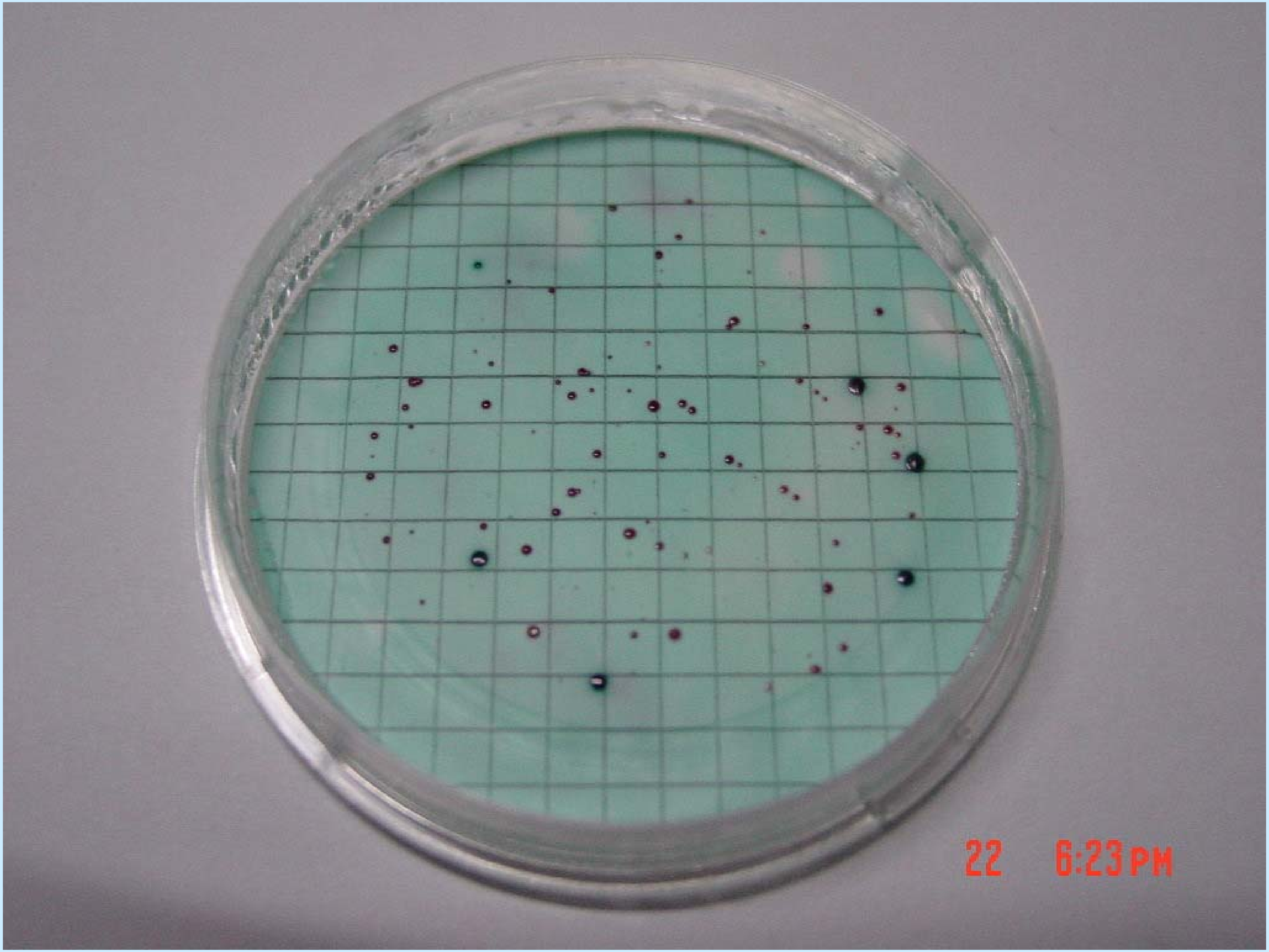


Simplified Membrane Filtration Set-up

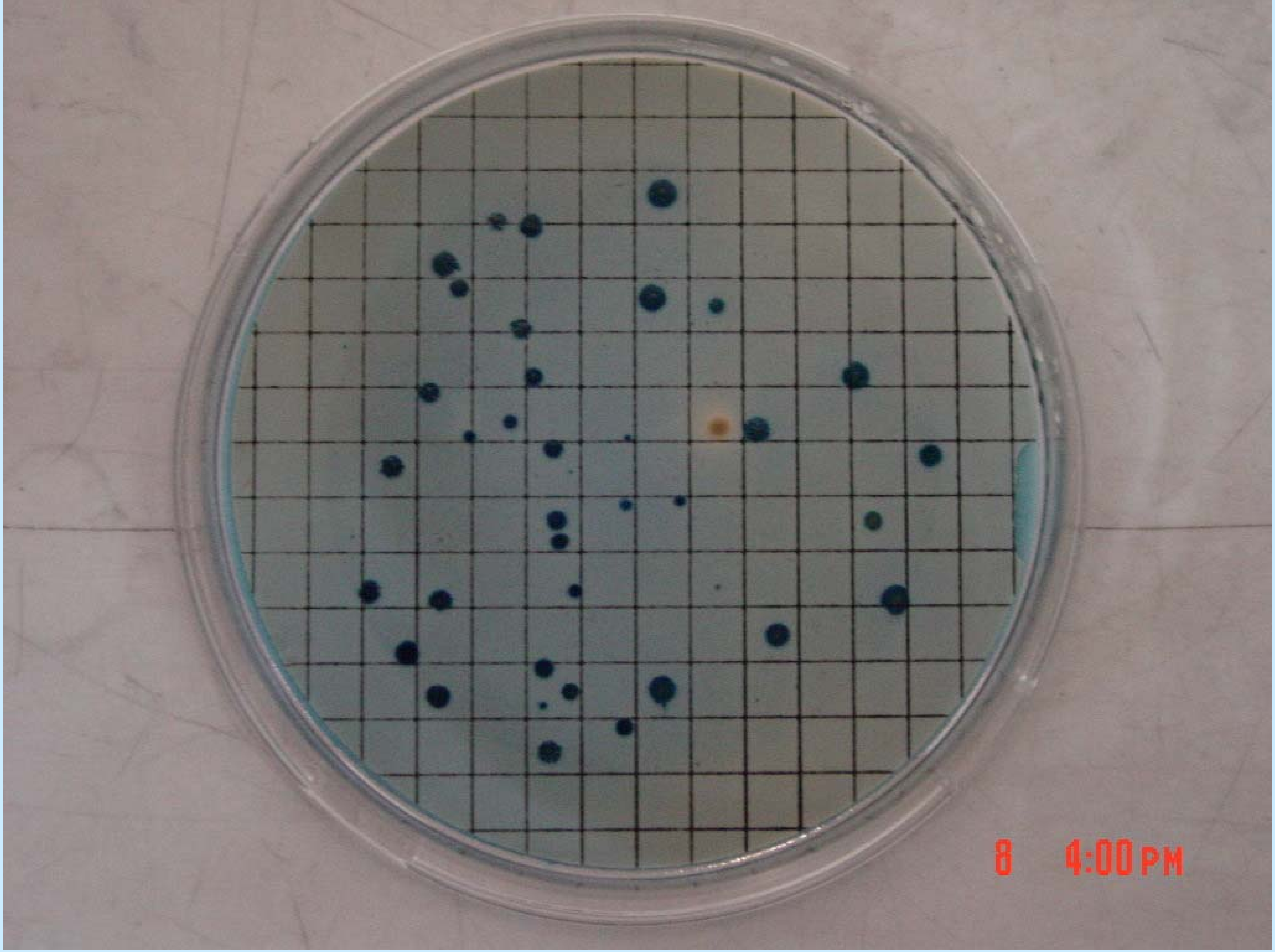
Membrane Filtration Setup with Portable Filtration Unit



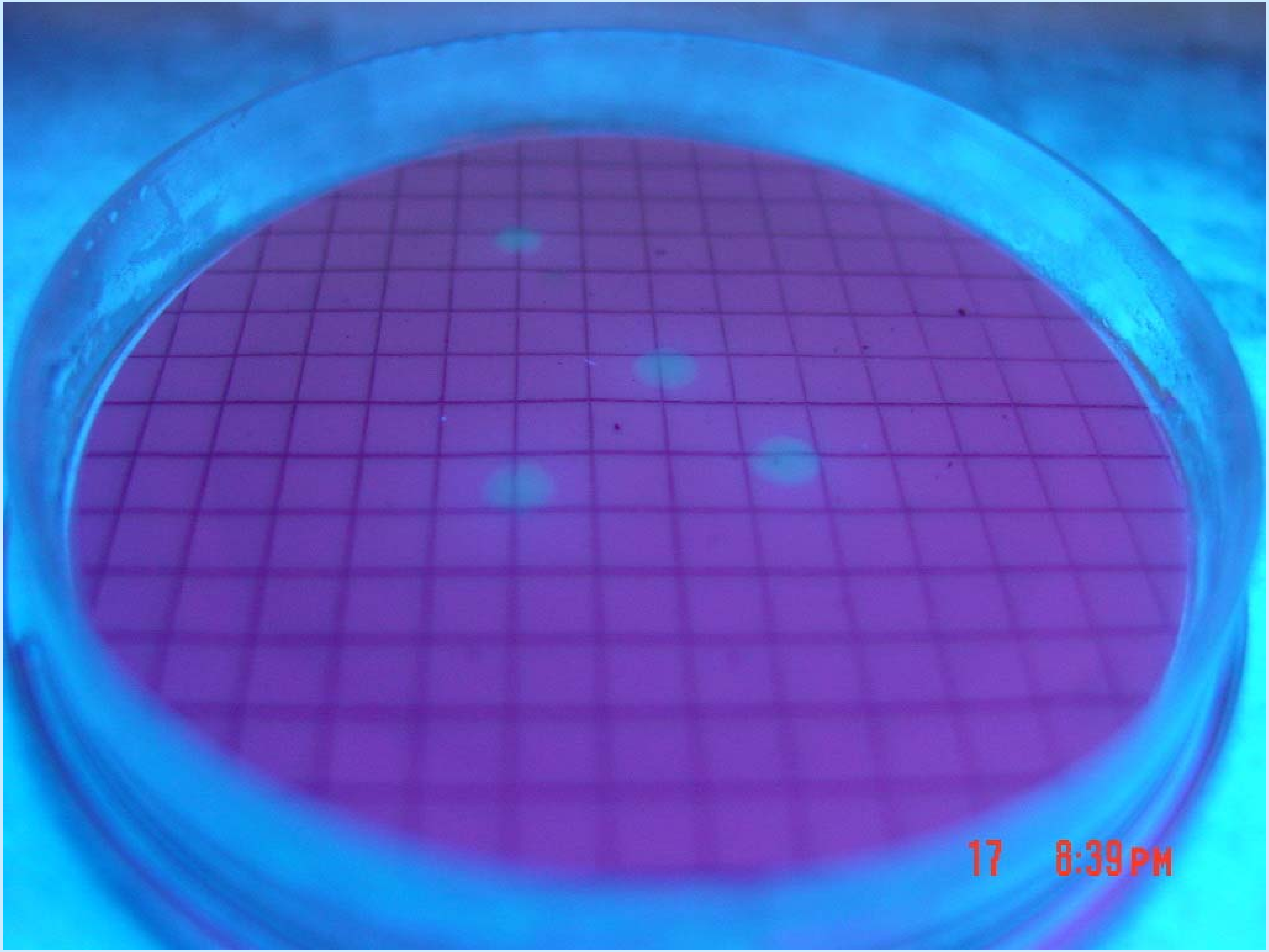
m-Endo broth medium for Total Coliform (TC). Colonies are gold-green with sheen after incubation at 35 degrees C for 24 hours



m-Coli blue broth medium for simultaneous TC/E.coli. TC are red; E.Coli are blue colonies after incubation at 35 degrees C for 24 hours



m-FC broth for thermotolerant coliform -> blue colonies after incubation at 44.5 degrees C for 24 hours



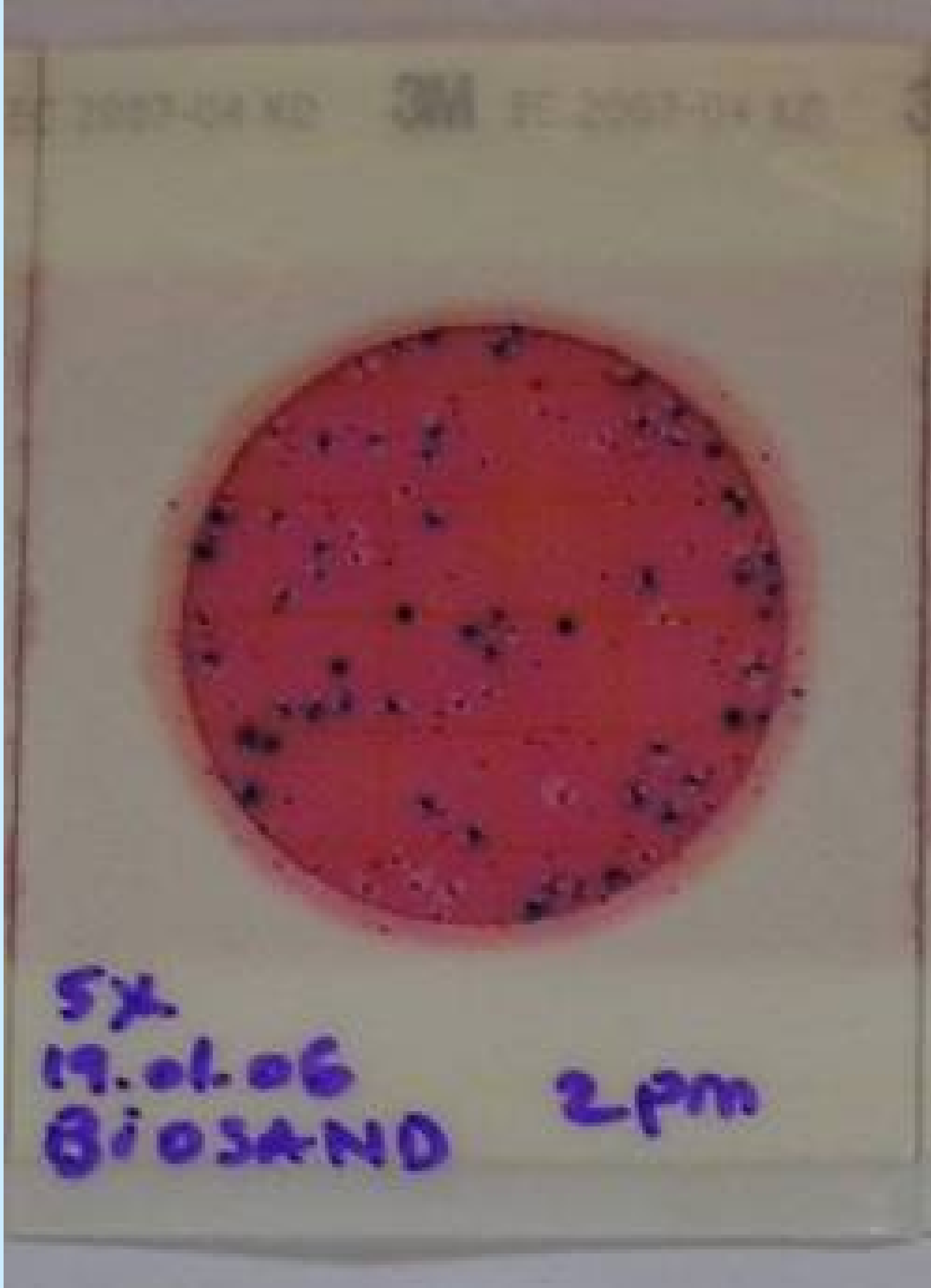
E Coli bacteria fluoresce under UV light due to MUG in medium

3M Petri-film: a new membrane filtration method

E. coli

&

Total coliform



Chlorination

Most common forms of chlorine:

- Dry (calcium hypochlorite – [Ca(OCl2)]
- Liquid (sodium hypochlorite – (NaOCl)=bleach
- Chlorine gas (Cl2)

Chlorination Chemistry

- Free residual chlorine (a.k.a. free available chlorine) = quantity of hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) in the water. The relative distribution of these two species is very important, because the killing efficiency of HOCl is about 40 – 80 x greater than OCl^- .

- Ammonia, commonly present in natural waters, will react with HOCl or OCl^- to form monochloraine, dichloramire and trichloramine, depending on factors such as temperature and pH.

- Chlorination of water to the extent that all ammonia is converted to either trichloramine or oxidized to nitrogen or other gases is referred to as **"breakpoint chlorination."**

- Before breakpoint, "combined" chlorine predominates (monochloramine + dichloramine)

- After breakpoint, free available chlorine predominates (hypochlorous acid + hypochlorite)

- Combined Residual Chlorine (ppm) + Free Residual Chlorine = Total Residual Chlorine

Breakpoint Chlorination Curve

Combined Residual + Free Residual = Total Residual Chlorine

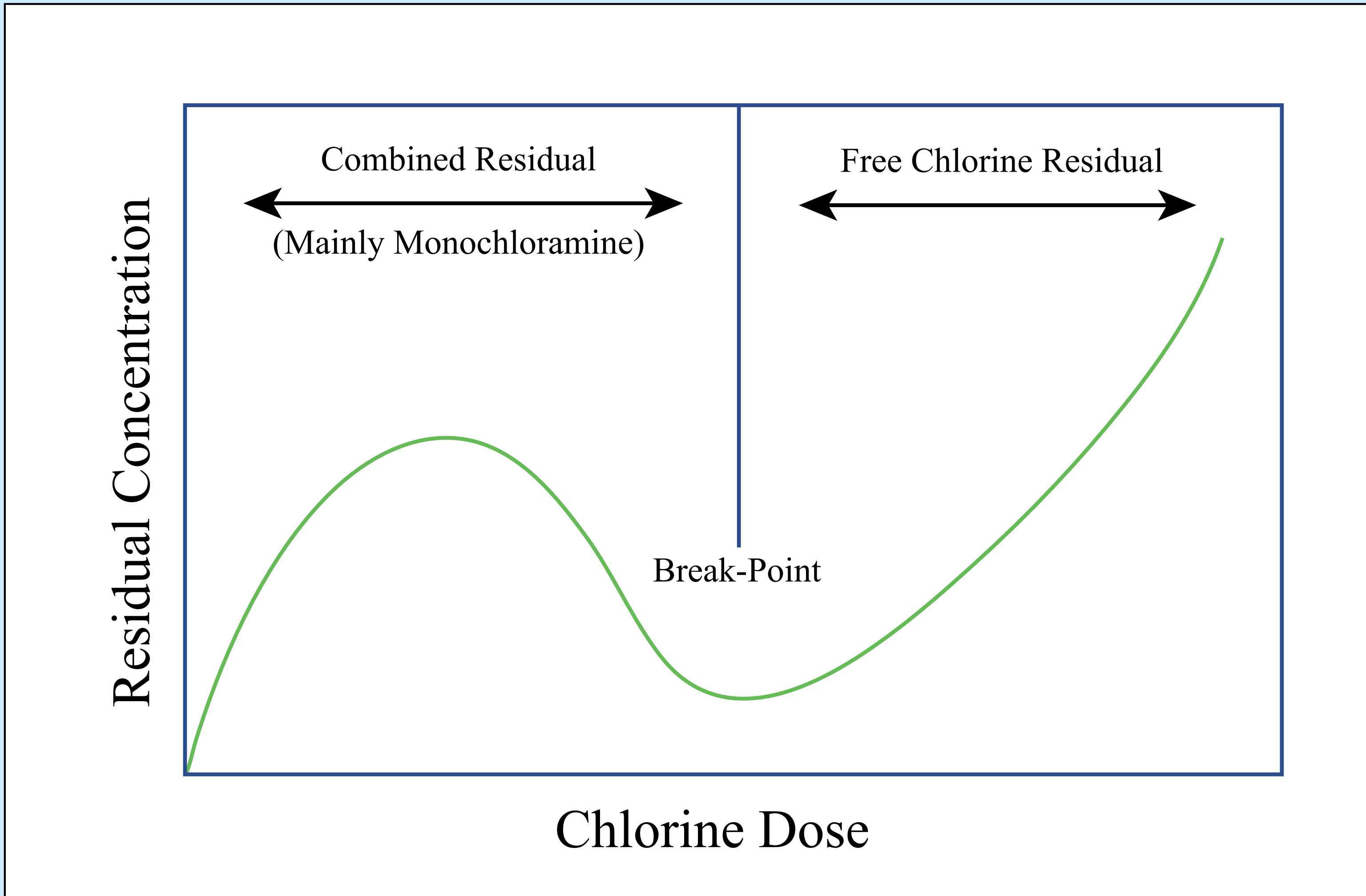


Figure by MIT OpenCourseWare.

(Hach, undated)

Breakpoint Chlorination Curve

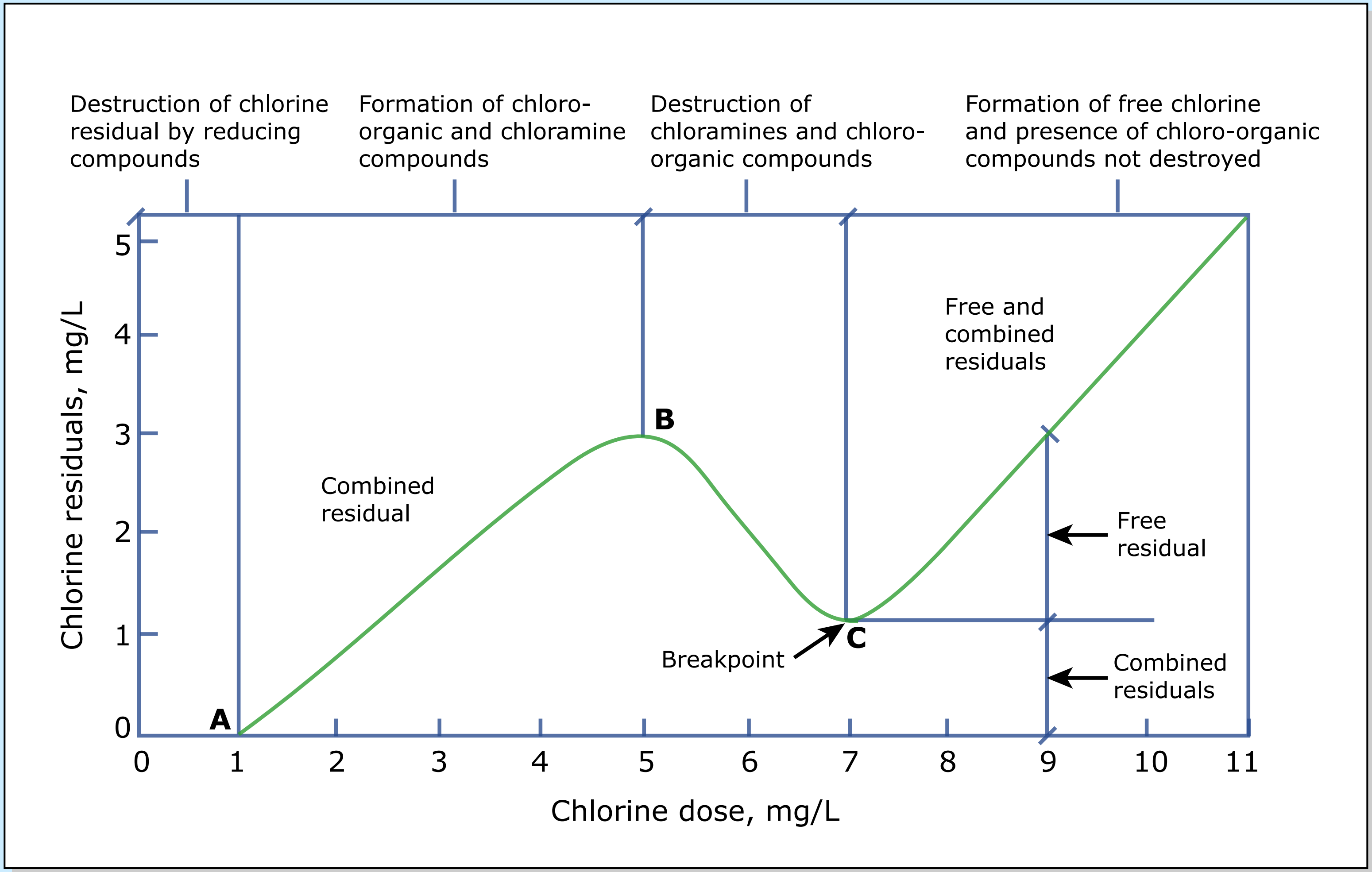


Figure by MIT OpenCourseWare.

(Metcalf & Eddy, 2003)

How to Chlorinate your Water?

Site Specific Context!!!

- Chlorine dose must be determined using local chlorine product with local water supply. This is because different waters have different “chlorine demand” characteristics.

General Procedure (in emergency or remote location situation and bleach is of unknown concentration):

- Add known amount of bleach (for example, 1 capful;
- After 30 minutes, measure free residual chlorine.
- If free residual chlorine is between 0.5 and 1.0 mg/l, the dose is appropriate.
- For a 20 L vessel, the required dose of a 0.5% chlorine solution could, for example, typically be between 5-10 ml.

Water Quality Regulations

National Safe Drinking Water Act (SDWA)

- Enacted into law - Dec. 1974
- Designed to achieve uniform safety and quality of drinking water in the U.S. by identifying contaminants and establishing maximum acceptable levels for contaminants
- Primary Drinking Water Contaminants
- Secondary Drinking Water Contaminants

Primary and Secondary Drinking Water Contaminants

- Primary Contaminants – those which have an **adverse affect on public health**

- Secondary Contaminants – those related to **taste, odor or appearance**

Safe Drinking Water Act – Regulatory Definitions

- EPA Administrator is directed to prescribe MCLs for contaminants (if economically and technically feasible), according to her/his best judgment (given > thousands of chemical compounds used commercially)
- Maximum Contaminant Levels “maximum permissible level of a contaminant in the water delivered to a user of a public water system.”
- Maximum Contaminant Level Goals
- Public Water System – at least 15 service connections or a system that regularly services at least 25 individuals at least 60 days/year.

What are the definitions?

KEY: **MCL** = Maximum Contaminant Level - The highest level of a contaminant allowed in water. MCLs are set as close to the MCLGs as feasible using the best available technology

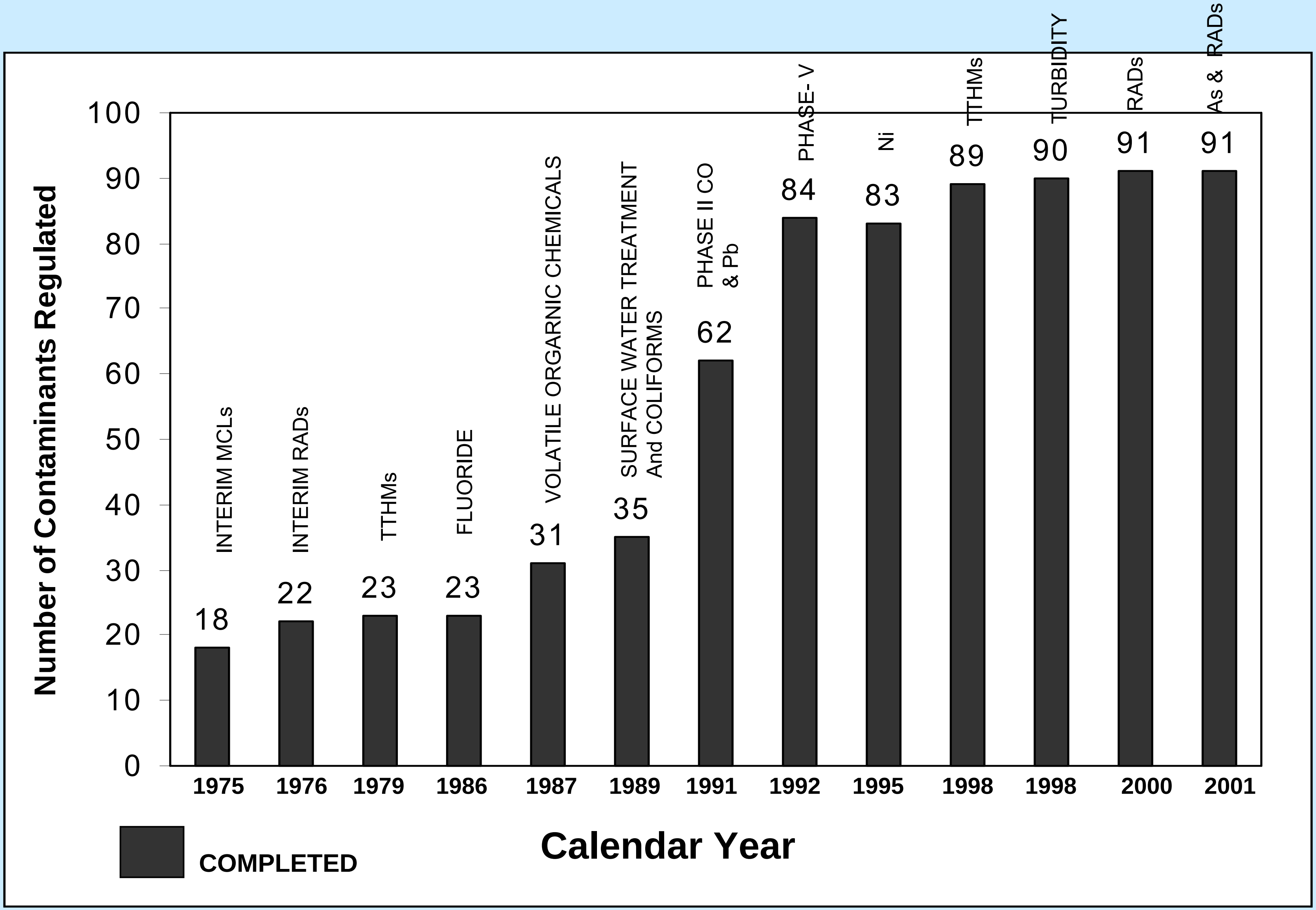
MCLG = Maximum Contaminant Level Goal - The level of contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety

MRDL - Maximum residual disinfectant level. The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG - Maximum Residual Disinfectant Level Goal. The level of a drinking water disinfectant below which there is no known or expected health risk. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contamination.

ppm = parts per million **ppb** = parts per billion **Avg** = Average

DRINKING WATER REGULATIONS - PAST



Excerpt: EPA Primary Drinking Water Contaminants
http://www.epa.gov/safewater/consumer/pdf/mcl.pdf

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
R	Beta particles and photon emitters	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation	zero
DBP	Bromate	0.010	Increased risk of cancer	Byproduct of drinking water disinfection	zero
IOC	Cadmium	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints	0.005
OC	Carbofuran	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa	0.04
OC	Carbon tetrachloride	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities	zero
D	Chloramines (as Cl_2)	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort, anemia	Water additive used to control microbes	MRDLG=4[1]

LEGEND

D	Dinsinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

MWRA Water Testing and Water Regulations

What is regulated in the US?

What does MWRA test for?

(Note: Some of the following MWRA slides are provided by Joshua Das 3/8/06)

Regulated Contaminant Groups

- Radioactive
- Microbiological
- Inorganic
- Secondary and Process Control
- Chlorine and Chlorine By-products
- Lead and Copper
- Volatile Organic Compounds
- Synthetic Organic Compounds
- Unregulated Contaminant Monitoring Rule – VOCs, SOCs, DBPs, Inorganic, Other

Radioactive, Microbiological, Inorganic

Radioactive Contaminants

- Beta/photon emitters particles
- Alpha emitters
- Combined radium
- Uranium
- Gross Alpha Particle Activity
- Radium-226
- Radium-228

- **Microbiological**
- TOTAL COLIFORM
- E. COLI
- GIARDIA
- CRYPTOSPORIDIUM
- VIRUSES
- TURBIDITY
- Heterotrophic Bacteria Plate Count

Inorganic Contaminants

- ANTIMONY
- ARSENIC
- ASBESTOS
- BARIUM
- BERYLLIUM
- CADMIUM
- CHROMIUM
- COPPER
- CYANIDE
- FLUORIDE
- LEAD
- MERCURY
- NICKEL
- NITRATE
- NITRITE
- SELENIUM
- SODIUM
- SULFATE
- THALLIUM

Secondary, Process Control, Chlorine/By-products, Pb & Cu

Chlorine and Chlorine By-Products

- CHLORINE
- CHLORAMINE
- BROMATE
- TOTAL
- TRIHALOMETHANES
- HALOACETIC ACIDS

Process Control

•pH
•Alkalinity
•Color
•Conductance
•Free Chlorine
•Total Chlorine
•Monochloranime
•Free Amonina
•Nitrate/Nitrite
•Total Organic Carbon
•UV-254
•Fluoride

Secondary Contaminants

•TURBIDITY (NTU)
•TDS
•COLOR (COLOR UNIT)
•ODOR (TON)
•PH
•ALKALINITY-TOTAL (CaCO3)
•HARDNESS (CaCO3)
•CALCIUM (Ca)
•MAGNESIUM (Mg)
•ALUMUNUM (Al)
•POTASSIUM (K)
•IRON (Fe)
•MANGANESE (Mn)
•SULFATE (SO4)
•SILVER (Ag)
•COPPER (Cu)
•ZINC (Zn)

Lead and Copper

•LEAD (Pb)
•COPPER (Cu)

EPA Secondary Standards

Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

VOCs

Volatile Organic Contaminants -Regulated Contaminants

- 1,1,1-TRICHLOROETHANE
- 1,1,2-TRICHLOROETHANE
- 1,1-DICHLORETHYLENE
- 1,2,4-TRICHLOROBENZENE
- 1,2-DICHLOROETHANE
- 1,2-DICHLOROPROPANE
- BENZENE
- BROMATE
- CARBON
- TETRACHLORIDE
- CHLORITE
- CHLORINE DIOXIDE
- CIS-1,2-DICHLOROETHYLENE
- DICHLOROMETHANE
- ETHYLBENZENE
- MONOCHLOROBENZENE
- O-DICHLOROBENZENE
- PARA-DICHLOROBENZENE
- STYRENE
- TETRACHLOROETHYLENE
- TOLUENE
- TRANS-1,2-DICHLOROETHYLENE
- TRICHLOROETHYLENE
- TTHMS
- VINYL CHLORIDE
- XYLENES (TOTAL)

Volatile Organic Contaminants -Unregulated Contaminants

- 1,1,1,2-TETRACHLOROETHANE
- 1,1,2,2-TETRACHLOROETHANE
- 1,1-DICHLOROETHANE
- 1,1-DICHLOROPROPENE
- 1,2,3-TRICHLOROBENZENE
- 1,2,3-TRICHLOROPROPANE
- 1,2,4-TRIMETHYLBENZENE
- 1,3,5-TRIMETHYLBENZENE
- 1,3-DICHLOROPROPANE
- 1,3-DICHLOROPROPENE
- 2,2-DICHLOROPROPANE
- BROMOBENZENE
- BROMOMETHANE
- CHLOROETHANE
- CHLOROFORM
- CHLOROMETHANE
- DICHLORODIFLUOROMETHANE
- FLUOROTRICHLOROMETHANE
- HEXACHLOROBUTADIENE
- ISOPROPYLBENZENE
- M-DICHLOROBENZENE
- METHYL TERTIARY BUTYL ETHER
- NAPHTHALENE
- N-BUTYLBENZENE
- N-PROPYLBENZENE
- O-CHLOROTOLUENE
- P-CHLOROTOLUENE
- P-ISOPROPYLTOLUENE
- SEC-BUTYLBENZENE
- TERT-BUTYLBENZENE

SOCs

Synthetic Organic Contaminants - Regulated Contaminants

- 2,3,7,8-TCDD (DIOXIN)
- 2,4,5-TP (SILVEX)
- 2,4-D
- ALACHLOR
- ATRAZINE
- BENZO(A)PYRENE
- CARBOFURAN
- CHLORDANE
- DALAPON DI(ETHYLHEXYL)ADIPATE
- DI(ETHYLHEXYL)PHTHALATES
- DIBROMOCHLOROPROPANE (DBCP*)
- DINOSEB
- DIQUAT
- ENDOTHALL
- ENDRIN
- EPICHLOROHYDRIN
- ETHYLENE DIBROMIDE (EDB)*
- GLYPHOSATE
- HEPTACHLOR
- HEPTACHLOR EPOXIDE
- HEXACHLOROBENZENE
- HEXACHLOROCYCLOPENTADIENE
- LINDANE
- METHOXYCHLOR
- OXAMYL (VYDATE)
- PCB AROCLOR 1016
- PCB AROCLOR 1221
- PCB AROCLOR 1232
- PCB AROCLOR 1242
- PCB AROCLOR 1248
- PCB AROCLOR 1254
- PCB AROCLOR 1260
- PCB'S (DECACHLOROBIPHENYL)
- PENTACHLOROPHENOL
- PICLORAM
- SIMAZINE
- TOXAPHENE

Unregulated Contaminants

Synthetic Organic Contaminants - Unregulated Contaminants

- 3-HYDROXYCARBOFURAN
- ALDICARB
- ALDICARB SULFONE
- ALDICARB SULFOXIDE
- ALDRIN
- BUTACHLOR
- CARBARYL
- DICAMBA
- DIELDRIN
- METHOMYL
- METOLACHLOR
- METRIBUZIN
- PROPACHLOR

Disinfection By-Products - Unregulated Contaminants

- Haloacetilenitriles
- Haloketones
- Chloropicrin
- Chloral Hydrate
- Total Organic Halides
- Cyanogen Chloride
- Chlorate
- Bromate
- Aldehydes

Unregulated Contaminants

Unregulated Contaminant Monitoring Rule Contaminants (*List 1)*

- 2,4-dinitrotoluene
- 2,6-dinitrotoluene
- Acetochlor
- DCPA mono-acid degradate
- DCPA di-acid degradate
- 4,4'-DDE
- EPTC
- Molinate
- MTBE
- Nitrobenzene
- Perchlorate
- Terbacil

Unregulated Contaminant Monitoring Rule Contaminants *(List 2)*

- 1,2-diphenylhydrazine
- 2-methyl-phenol
- 2,4-dichlorophenol
- 2,4-dinitrophenol
- 2,4,6-trichlorophenol
- Diazinon
- Disulfoton
- Diuron
- Fonofos
- Linuron
- Nitrobenzene
- Prometon
- Terbufos
- Aeromonas
- Alachlor
- ESA
- RDX

Unregulated Contaminants (con’d)

- **Unregulated Contaminant Monitoring Rule Contaminants *(List 3)***
- Lead-210
- Polonium-210
- Cyanobacteria
- Echoviruses
- Coxsackieviruses
- Helicobacter pylori
- Microsporidia
- Caliciviruses
- Adenoviruses
- **Other**
- Chloide
- Bromide
- Silica
- Total Phosphorous

What Does MWRA Find?

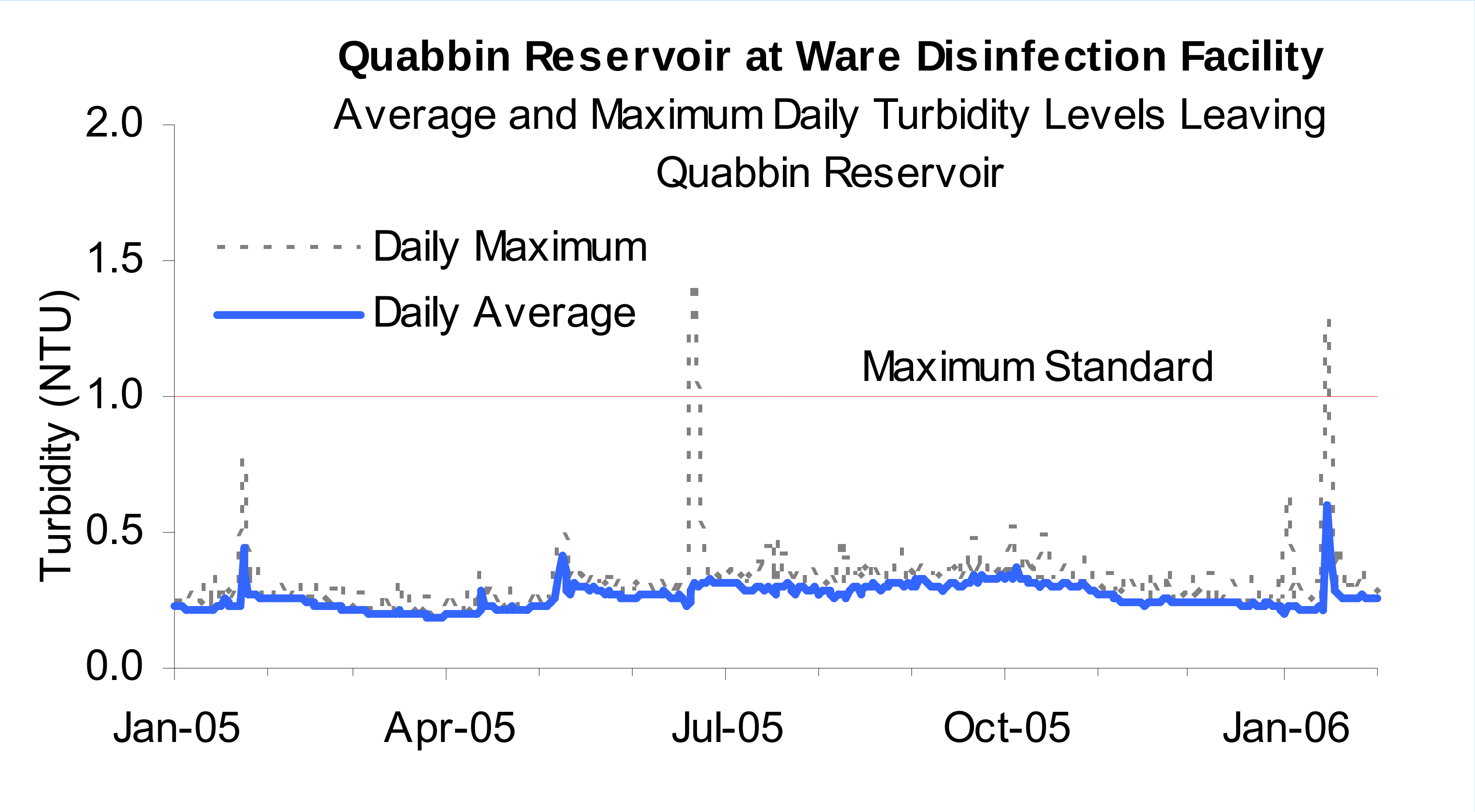
Compound	Units	**MCL**	Detected Level	Range	**MCLG**	Violation	How it Gets in the Water
Barium	ppm	2	0.011	0.009 - 0.011	2	No	Common mineral in nature
Benzene	ppb	5	2.1	1.6 - 2.1	0	No	Not Known - See Below
Chloramine	ppm	4 - MRDL	Avg = 1.26	0.03 - 2.20	4 - MRDLG	No	Water disinfectant
Fluoride	ppm	Avg = 4	Avg = 1.21	0.03 - 7.7*	4	No	Additive for dental health
Nitrate	ppm	10	0.15	0.03 - 0.15	10	No	Breakdown of disinfectants
Nitrite	ppm	1	0.005	0.005	1	No	Breakdown of disinfectants
Total Trihalomethanes	ppb	Avg = 80	Avg = 74.4	44.2 - 110	0	No	Byproducts of water disinfection
Haloacetic Acids - 5	ppb	Avg = 60	Avg = 36.6	0.6 - 61.7	0	No	Byproducts of water disinfection

What else does MWRA test for?

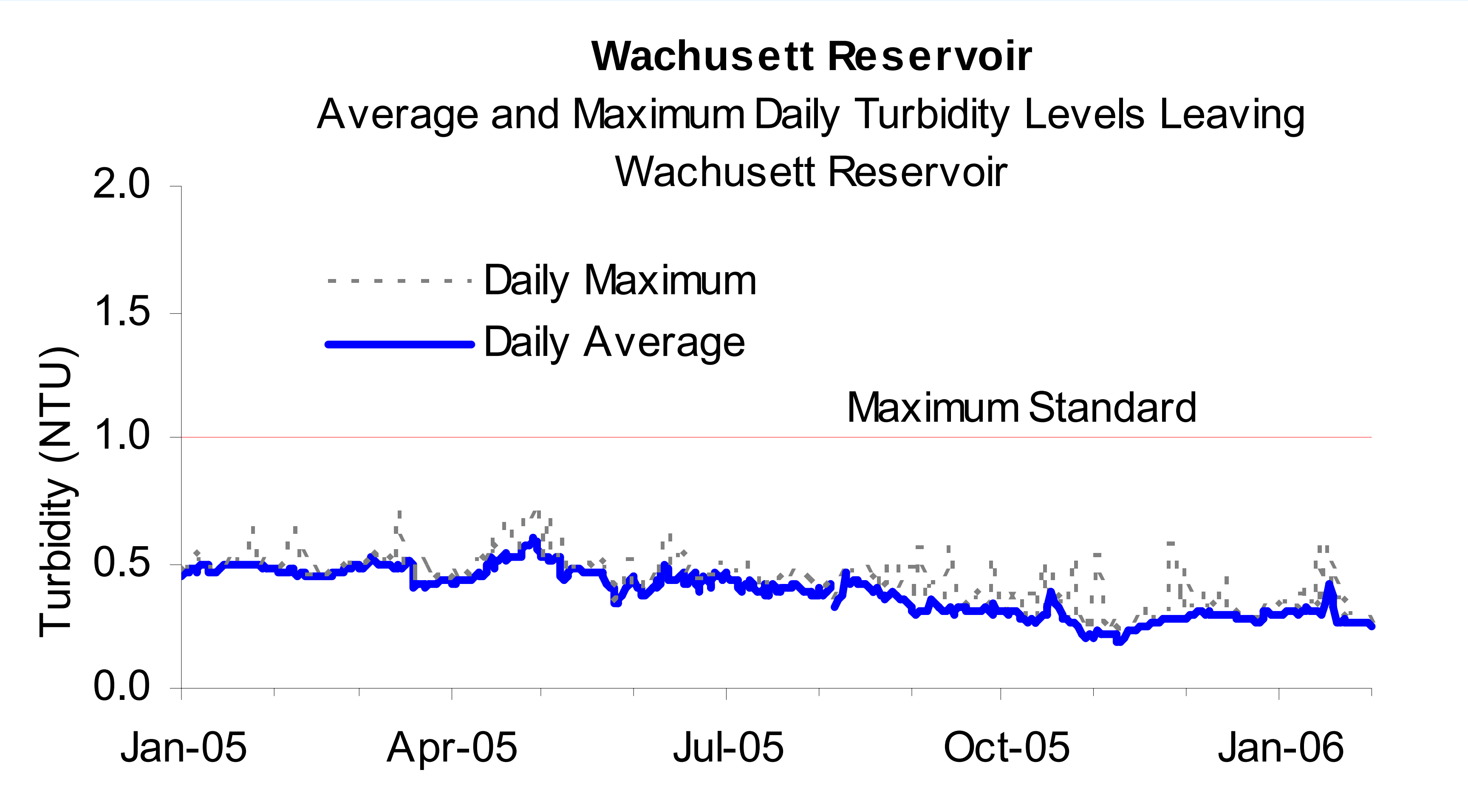
Source Water

- Turbidity
- Fecal Coliform – Pre-treatment
- Algae
- UV-254

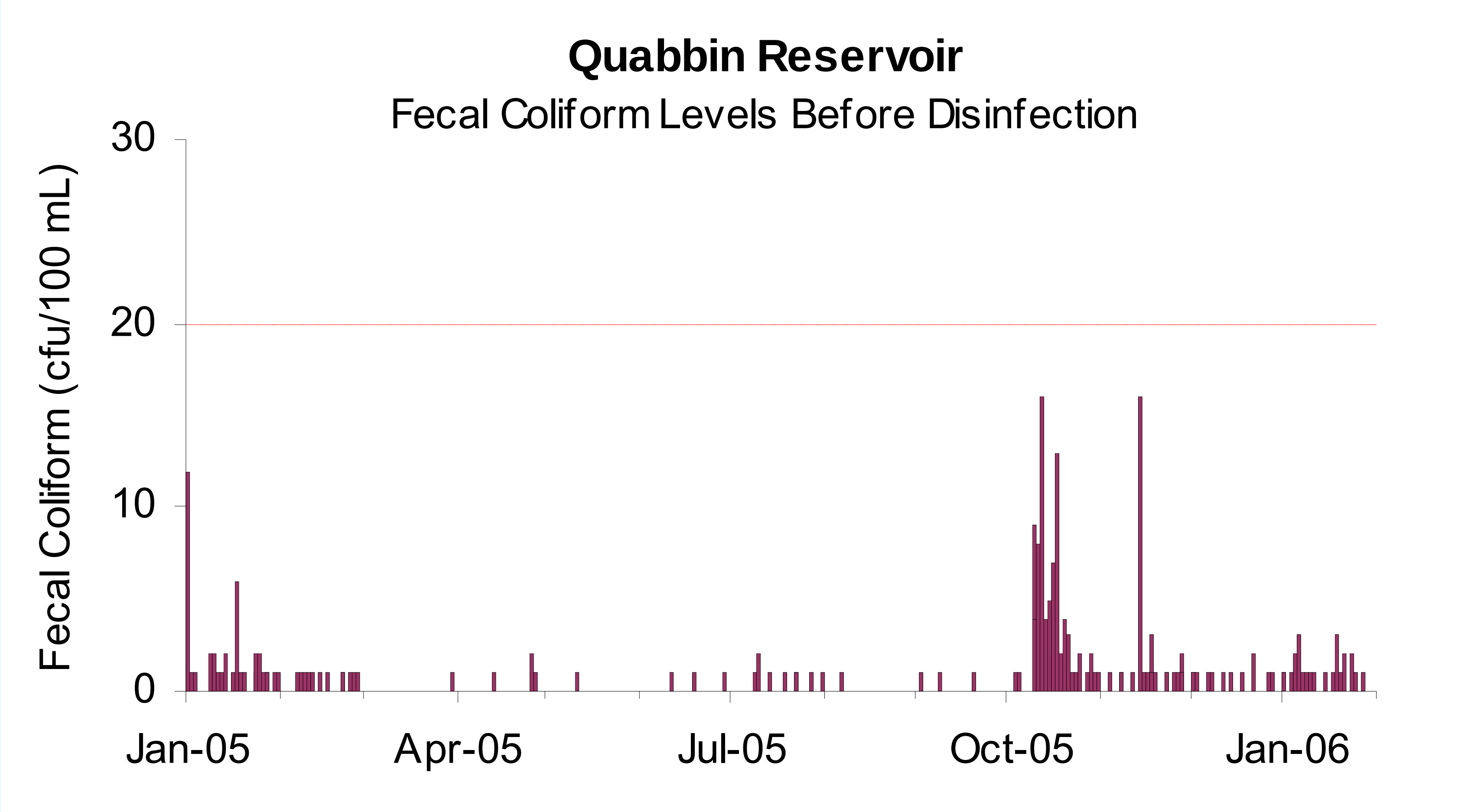
Turbidity Results – Quabbin



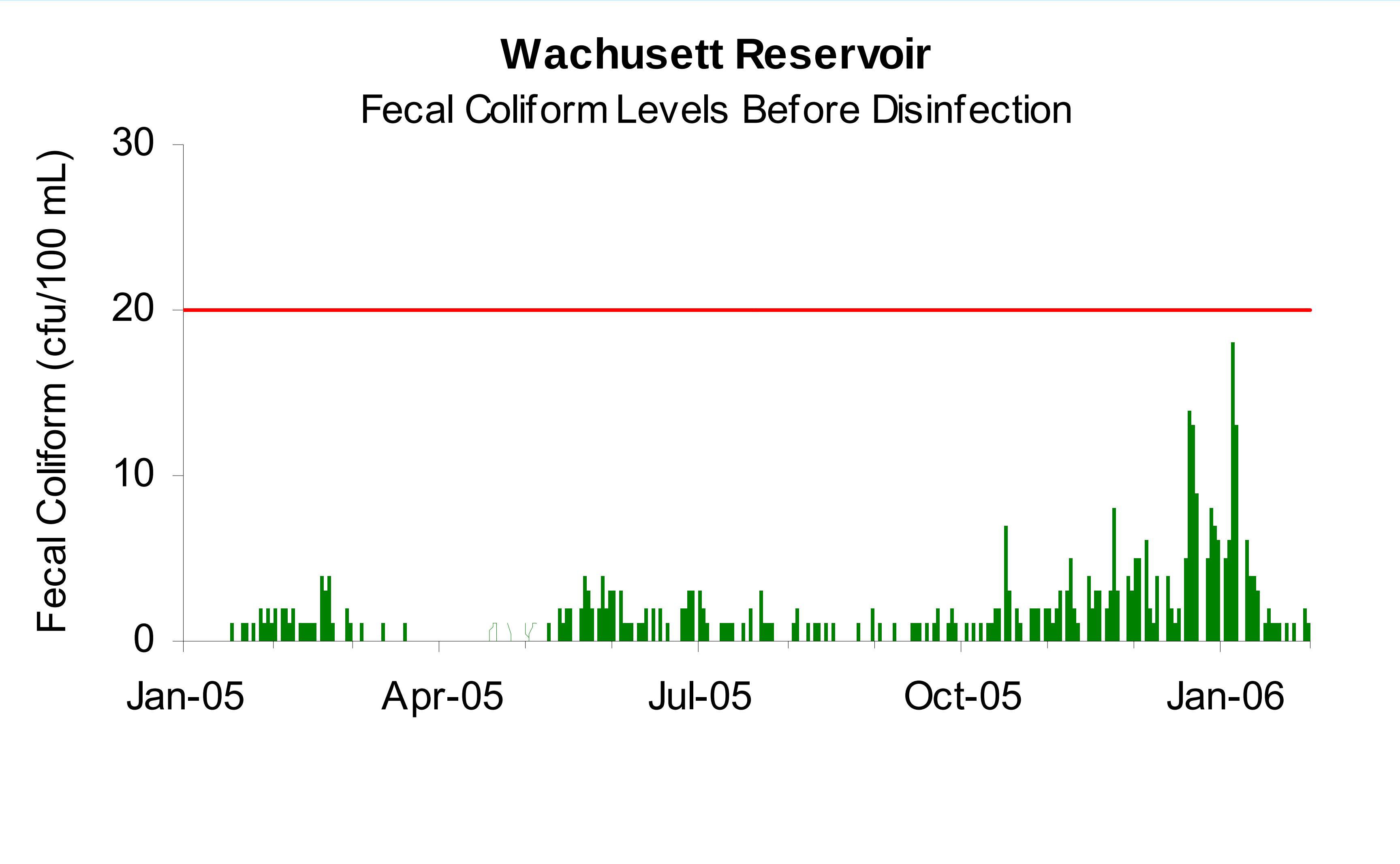
Turbidity Results - Wachusett



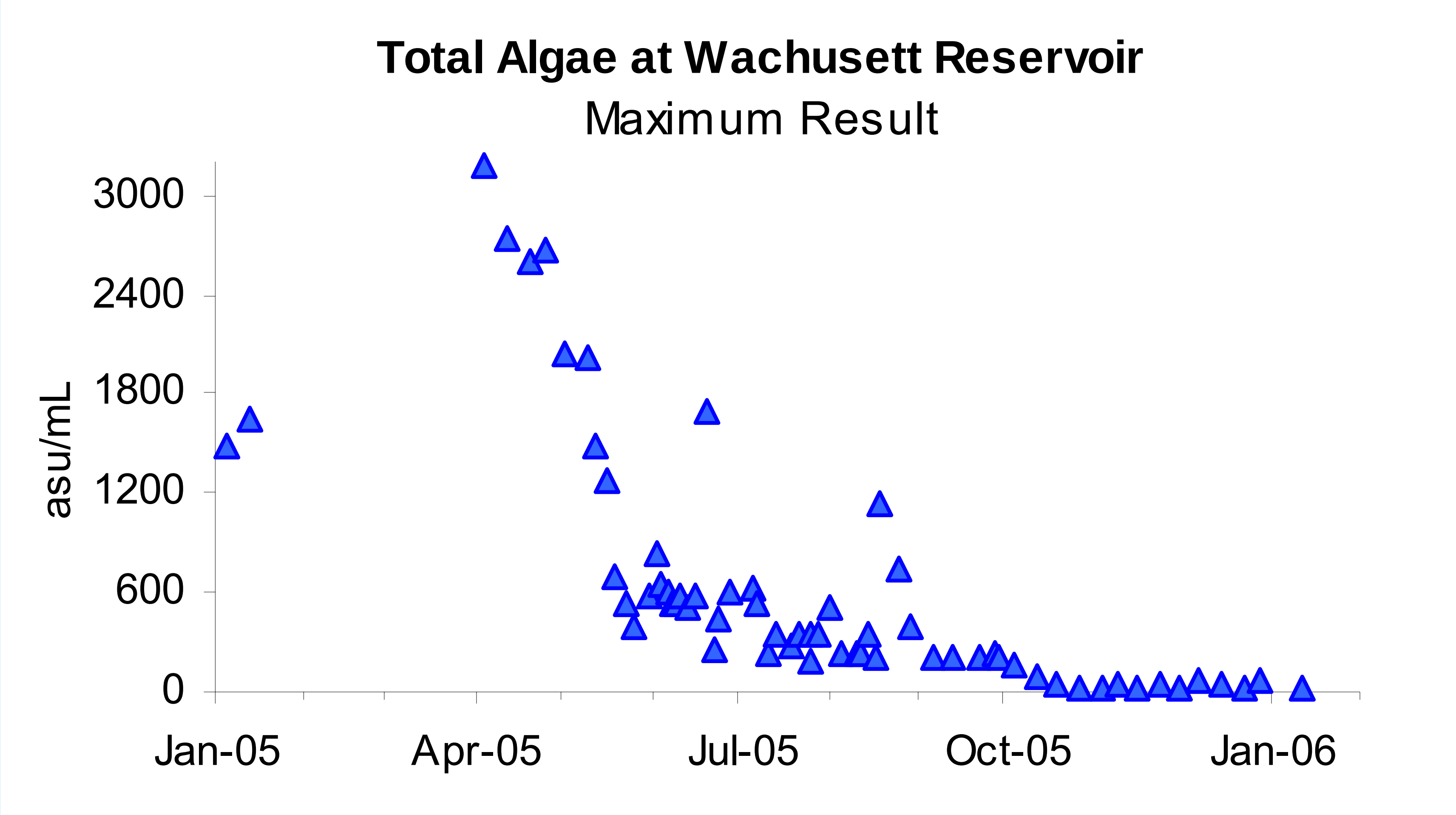
Fecal Coliform Results – Pre-Treatment



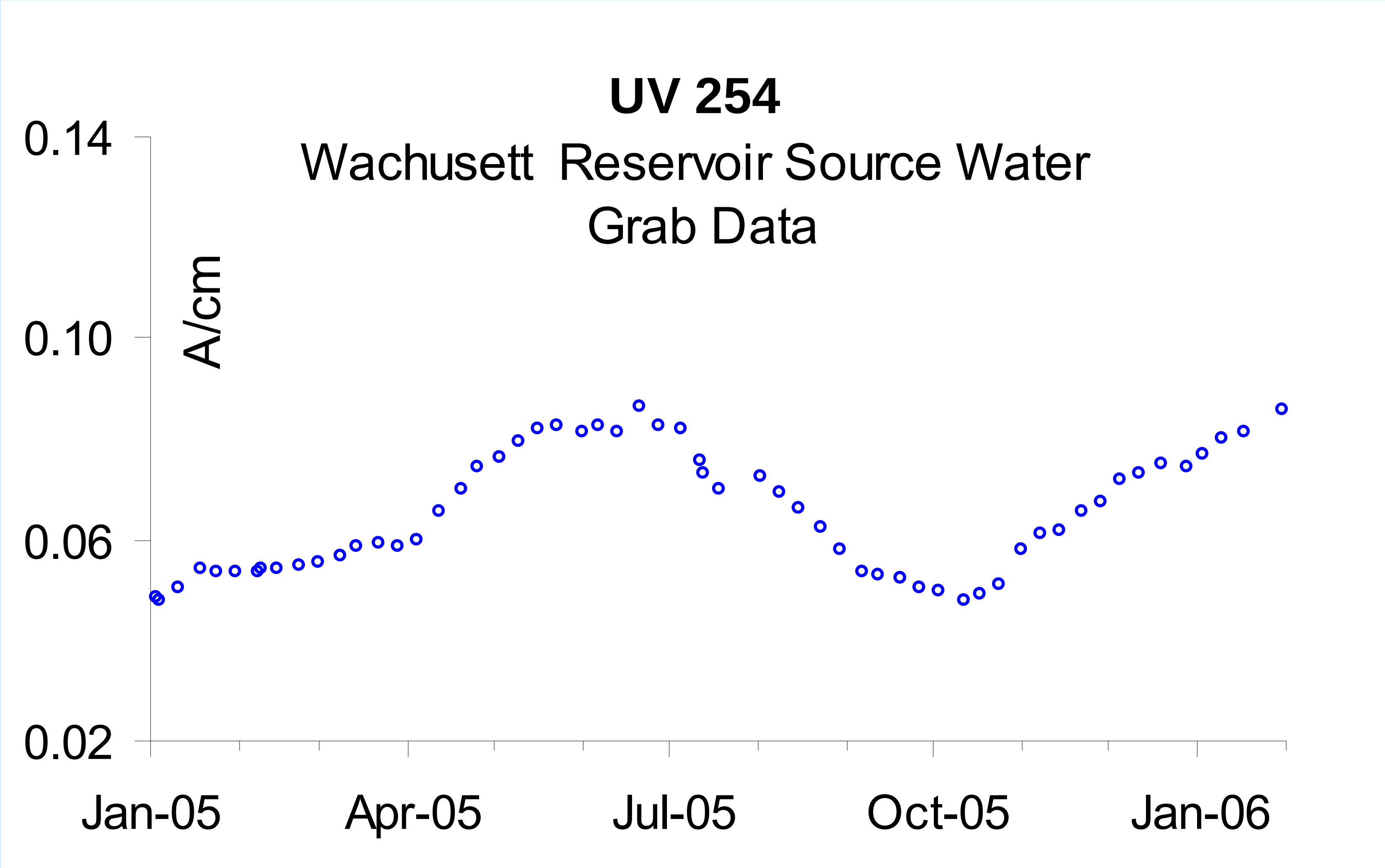
Fecal Coliform Results – Pre-Treatment



Algae Results



UV-254



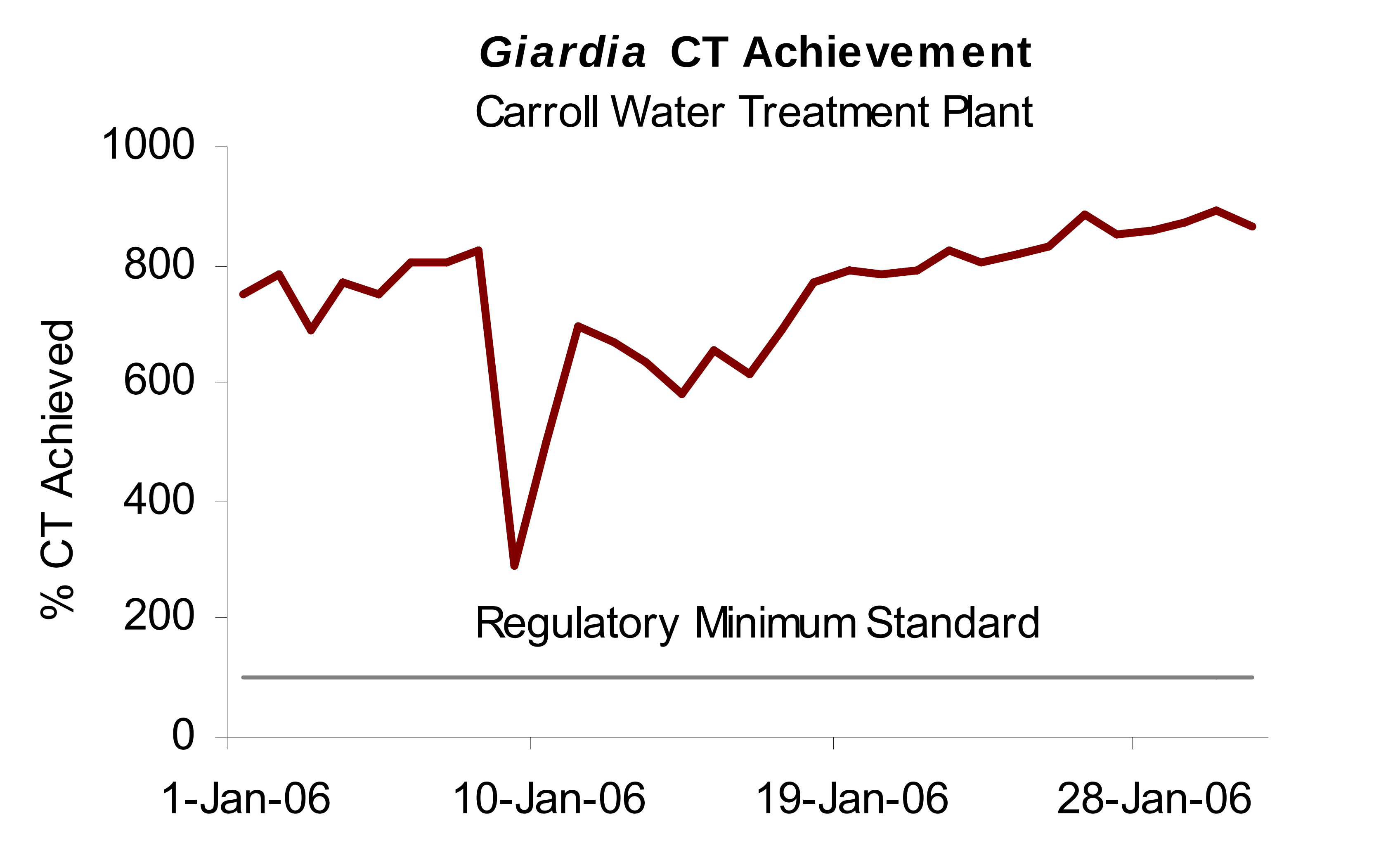
UV 254
Wachusett Reservoir Source Water
Grab Data
A/cm
0.14
0.10
0.06
0.02
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06

What does MWRA test for?

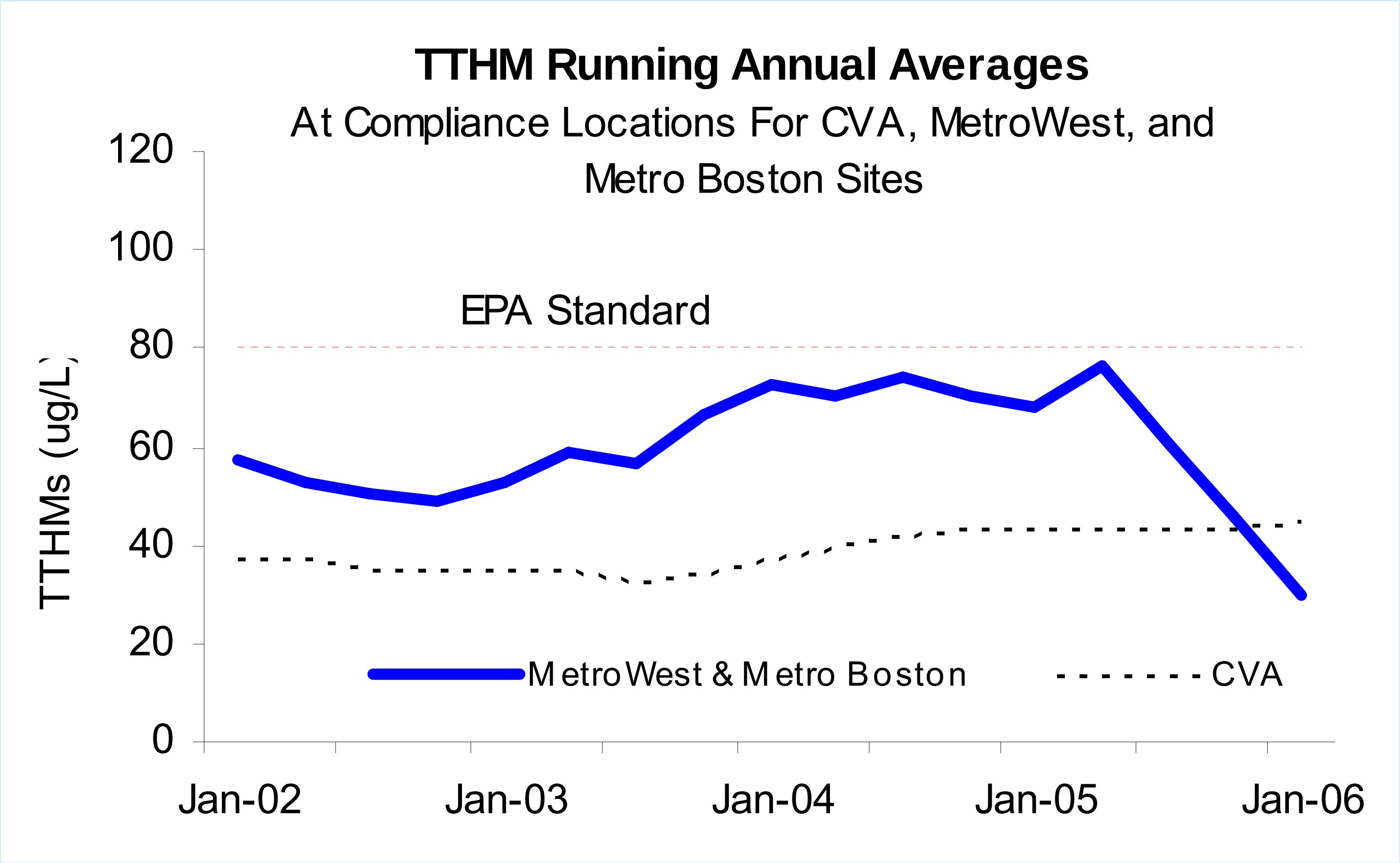
After Treatment

- Disinfection Contact Time (CT)
- Total Coliform
- Chlorine Residual
- DBPs
- Contaminants (again)

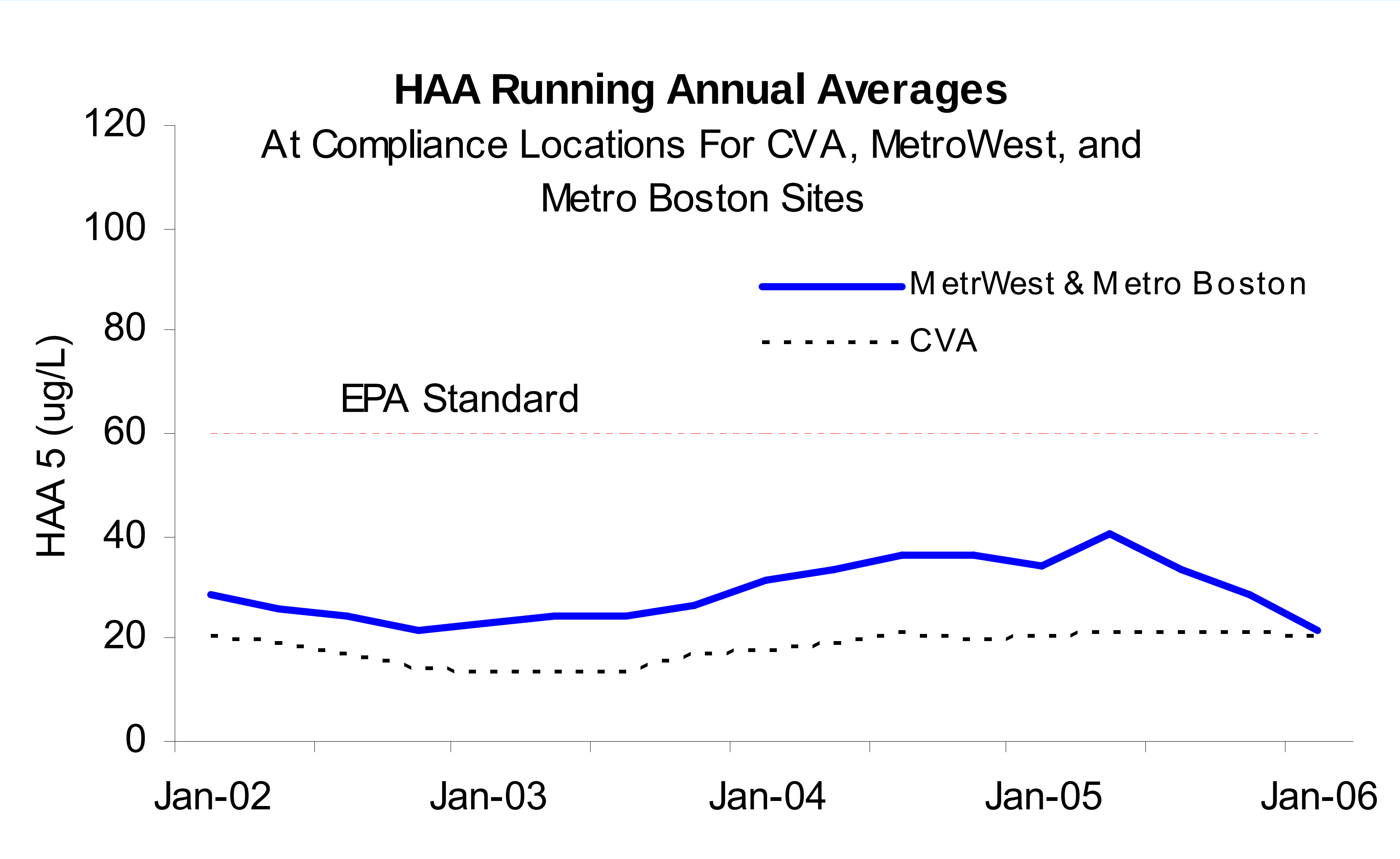
Disinfection Contact Time Standard



Disinfection By-Products
Total Trihalomethanes



DBPs - HAAs


HAA Running Annual Averages
At Compliance Locations For CVA, MetroWest, and Metro Boston Sites
120
100
80
60
40
20
0
HAA 5 (ug/L)
EPA Standard
MetrWest & Metro Boston
CVA
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06

Developed vs. Developing Country Water Quality Standards and Compliance

- In the previous slides, we have learned about the US EPA Safe Drinking Water Act and looked closely at the example of water quality at the Massachusetts Water Resources Authority (MWRA) which provides drinking water to the cities and towns of Greater Boston.
- The graph to the right shows the contrast between developed and developing country circumstances when it comes to compliance with drinking water standards.
- Let’s now look at an example of challenges toward achieving water quality compliance in a developing country – Vietnam.

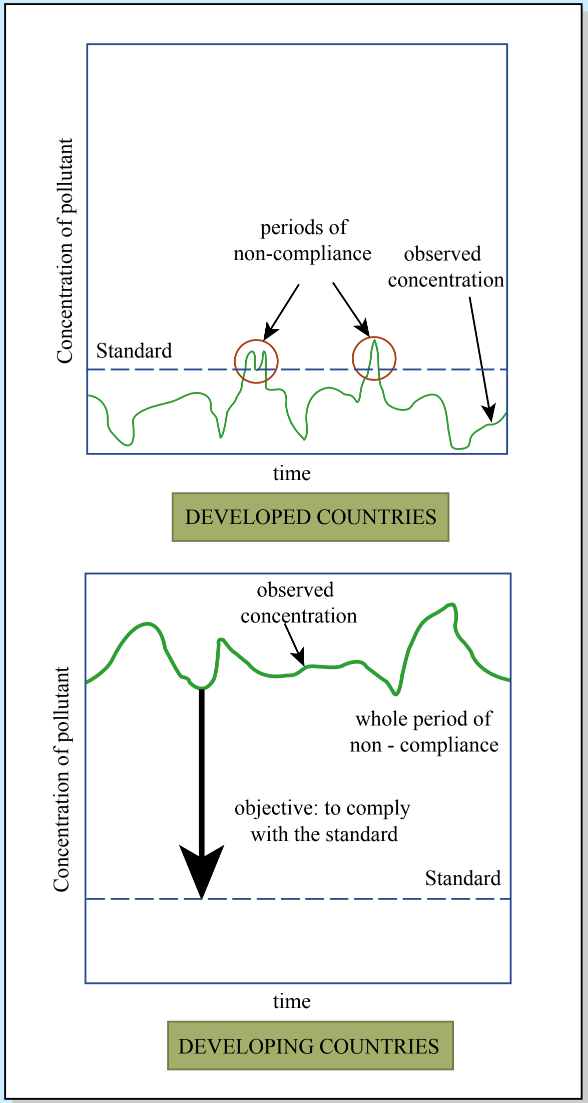


Figure by MIT OpenCourseWare.

WHO Water Quality Guidelines

- Application of guidelines
  - Develop national laws, regulations, and standards, based on guidelines and local conditions
  - Implement a national compliance and surveillance program
  - Surveillance and regulatory authorities should be separate from local water authorities due to conflicting priorities
- National standards may differ significantly from WHO guidelines
- “Stepwise” improvement

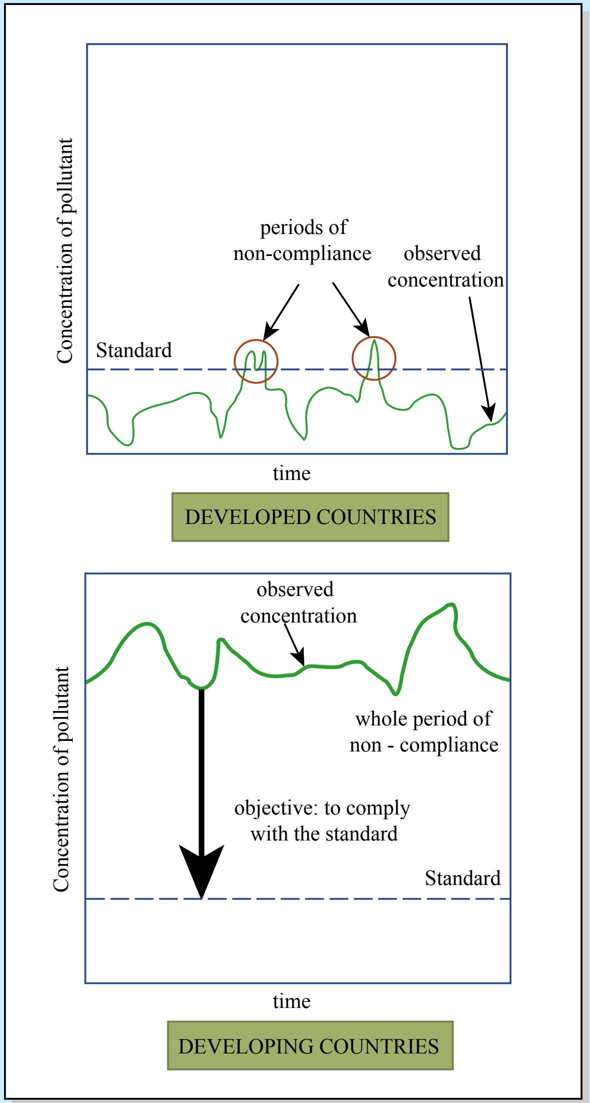


Figure by MIT OpenCourseWare.

Vietnam – Some Stats

- Population = 83 million
- GDP/capita ≈ $400/capita
- % Access to Drinking Water = 77%
- Urban with Access to Improved Sanitation = 84%
- Estimated # affected by arsenic contamination of drinking water supplies = 6 – 10 million

Vietnam - Water Quality Management

- **Ministry of Natural Resources and Environment (MONRE)** is responsible for federal management of natural resources (land, water, air). This is a newly established ministry that has taken authority from the Ministry of Rural Development to streamline overall management.
- **Ministry of Health (MOH), Dept of Preventive Medicine**, is responsible for National Water Quality Standards, which in Vietnam includes more than 50 water quality parameters – microbiological, chemical, physical.

Examples of National Environmental Strategy Programs (35 total) 2010 - 2020

Program	Priority	Date to Finish	Agencies
Hazardous Medical Waste Treatment	Highest	Phase 1 2010	MoH
Targets for rural clean drinking water	Higher	Phase 1 2010	MARD
Seriously polluted waterways	High	Phase 1 2010	MoC, MoT
Env. Consequence of American chemical warfare	highest	2010	MoNRE

Vietnam - Water Quality Regulations

- Vietnam follows essentially the same water quality limits as recommended by the WHO *Guidelines for Drinking Water Quality*
- Vietnam’s water quality regulations describe 3 groups of drinking water contaminants: A, B, and C.
- Group A (15 parameters) requires monthly reporting.
- Group B requires one-time reporting at the time of the installation of the water supply. (Arsenic, for example, is in this group).
- Group C is done on request.
- There is currently no national database of water quality.
- All 64 provinces should be sending monthly reports for Group A contaminants to MOH. In practice, about 25-30 out of 64 provinces send in monthly reports.

Vietnam Water Quality

- Large urban areas (e.g. Hanoi, Haiphong, Ho Chi Minh City), supplied by the state water systems, have treated water supplies with fairly good microbiological water quality, except during exceptional events, such as flooding.
- Distribution System Contamination: Water discharged from WTPs may be of good microbiological quality, but it becomes contaminated in the distribution system.
- Rural Water - almost 70% of provinces don't meet the microbiological (total coliform/E.Coli) standard of 0 CFU/100 ml – There is the need for new standards for rural areas.
- Some Water-Related Health Problems: typhoid, diarrhea, dengue fever, arsenicosis.
- Unfortunately, there are very few actions to address these health problems because there is no budget to do so.
- Provincial Centers have very small budgets for water quality.
- Disease outbreaks are comparatively easy to control; however, Chemical Contamination is a big problem because provincial centers don't have the capacity to address chemical contamination.

Financing of Ministry of Health, Dept. of Preventive Medicine

- DANIDA supports MoH Dept of Preventive Medicine from 2000-2005. In 2006 -2010, DANIDA will provide $100M to Vietnam overall. 30-50% of this $100M is expected to go to the MOH for sanitation projects.
- UNICEF provides the MOH with $200,000 - $300,000/year, and that money goes to support 15 District offices.
- The Gov't of Vietnam provides MOH with a budget of $70,000/year (= 1 B VND/year). The gov't budget covers nominal salaries and running costs of the office. It also supports their hygiene behavior change/IEC (Information, Education and Communication) program.
- Dept. of Preventive Medicine Staff = 30 people. Government salary of Mr. Dang is typical – about $200/month. This is barely enough to support a family in Hanoi.

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