Indicators 101

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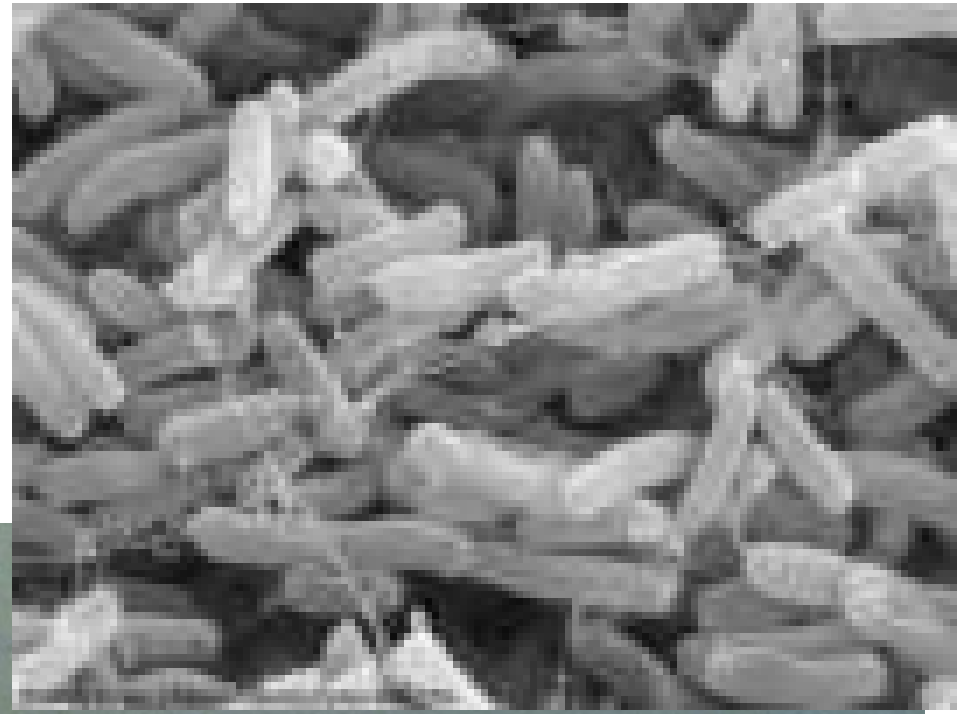
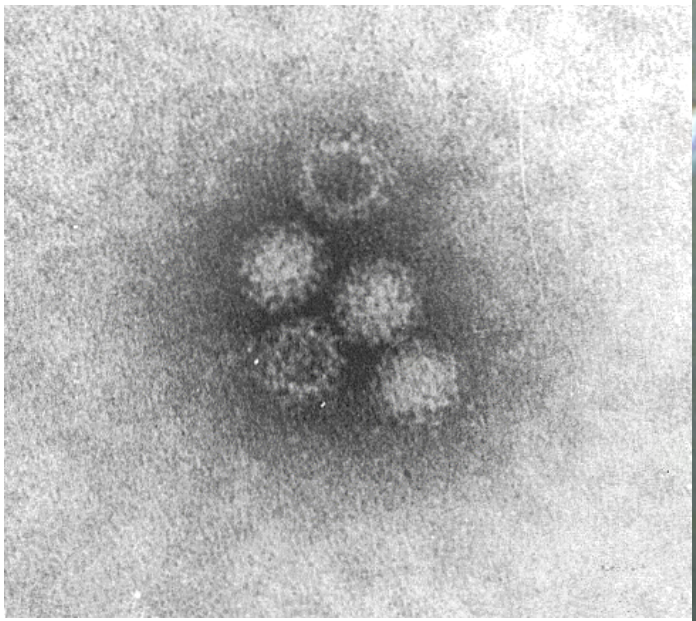




Photos courtesy Jennifer Best

Occurrence

Hamburger

Fecal Matter

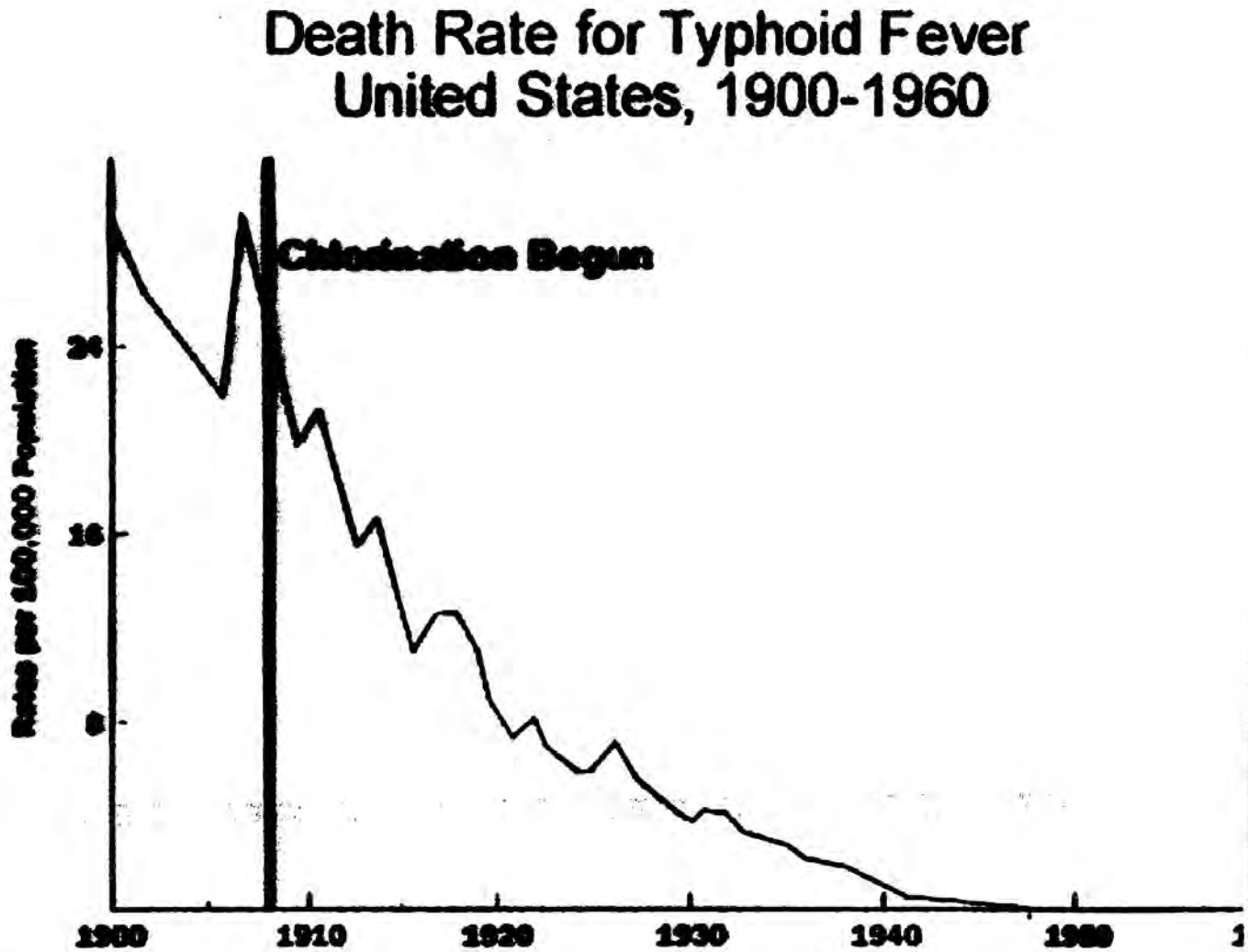
Exposure

"I don't think it's sanitary to drink from the same footprint."

Outcomes

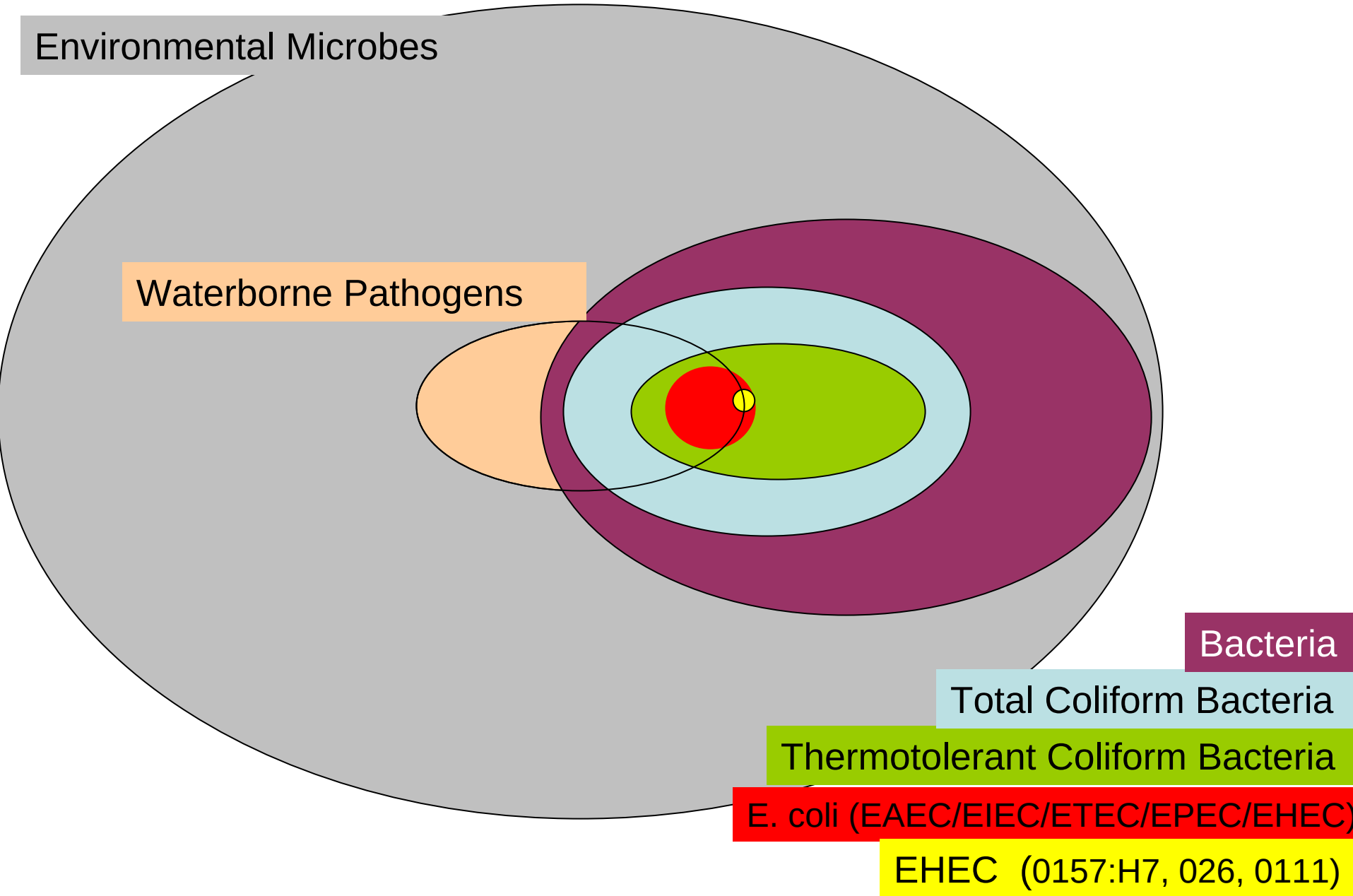
Table 3 | Etiology of waterborne outbreaks reported in the United States, 1991–2002

Etiological agent	Outbreaks	Cases
AGI	77	16 036
Chemical	33	577
Giardia	25	2283
Cryptosporidium	15	408 371
Norovirus	12	3361
E. coli O157:H7	11	288
Shigella	9	663
Campylobacter jejuni	7	360
Legionella	6	80
Salmonella, non-Typhoid	3	833
V. cholerae	2	114
Hepatitis A	2	56
Naegleria fowleri	1	2
Plesiomonas shigelloides	1	60
Campylobacter and *Yersinia*	1	12
E. coli O157:H7 & *Campylobacter*	1	781
Unidentified SRSV	1	70
Total	207	433947

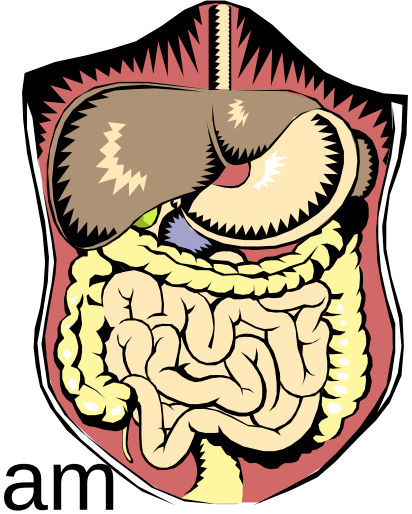


Source: U.S. Centers for Disease Control and Prevention, Summary of Notifiable Diseases, 1997.

Fig. 2. Correlation between the introduction of chlorine and the subsequent drop **in typhoid**


Environmental Microbes
Waterborne Pathogens
Bacteria
Total Coliform Bacteria
Thermotolerant Coliform Bacteria
E. coli (EAEC/EIEC/ETEC/EPEC/EHEC)
EHEC (0157:H7, 026, 0111)

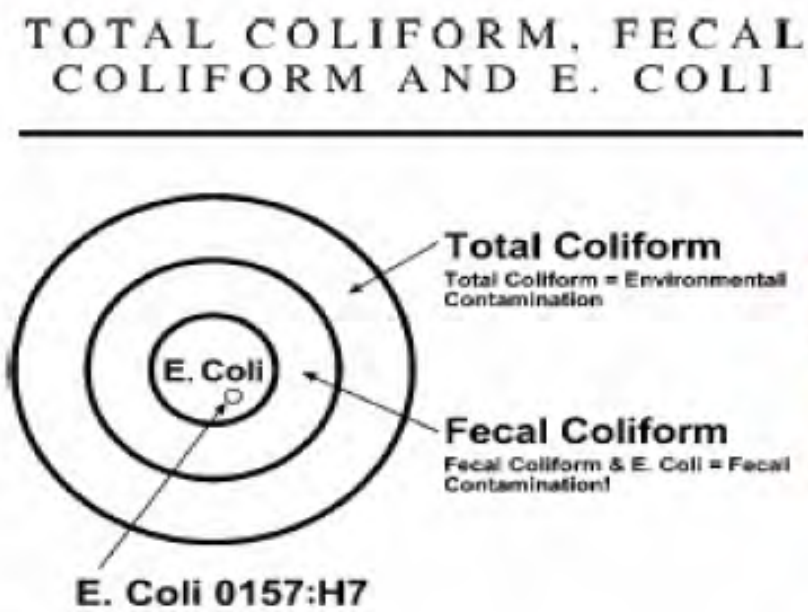
Human gut flora



- Human feces typically contain approximately 10^{11} bacteria per gram
  - up to 500 different strains have been isolated

- Of the coliform bacteria present in human gut:
  - *E.coli* majority – most not pathogenic
  - Other TC species represent only 1% of total population of bacteria in feces.

Total Coliform Bacteria Testing



Why use indicators?

- There is very, very little information about the occurrence and prevalence of pathogens in water distribution systems.

- Need a reliable method to test the microbiological quality of water that is do-able in real time

Characteristics of a good indicator organism; The search for fecal indicators (Pipes et al; Bacterial Indicators of Pollution. 1982. CRC Press.)

- Always present (in high numbers) in the feces of humans and warm-blooded animals
  - The indicator should always be present when the source of the pathogenic microorganisms of concern is present and the indicator should be absent in clean uncontaminated water.
  - The indicator should be present in numbers much greater than the pathogens whose possible presence it is intended to indicate.

- Easy to detect
  - The indicator should be easy to isolate, identify and enumerate

- Not normally present in natural waters
  - The indicator should respond to natural environmental conditions in a manner similar to the pathogens of interest

- Persists in water and has the same susceptibility to water treatment as the organisms for which it is an indicator
  - The indicator should respond to water and wastewater treatment conditions in a manner similar to the pathogens of interest

E. coli as an indicator

- 1892 Shardinger proposed the use of *E.coli* as an indicator of fecal contamination.
  - based on the premise that *E.coli* is abundant in feces and not typically found in other niches.
  - *E.coli* can easily be detected by ability to ferment lactose
  - Easier to isolate than other known gastrointestinal pathogens.

- Presence of *E.coli* in food/water became accepted as indicative of recent fecal contamination and possible presence of other pathogens.

Total Coliform and *E. coli*

History on the regulatory use of indicators of microbial contamination

Gary A. Burlingame 2007

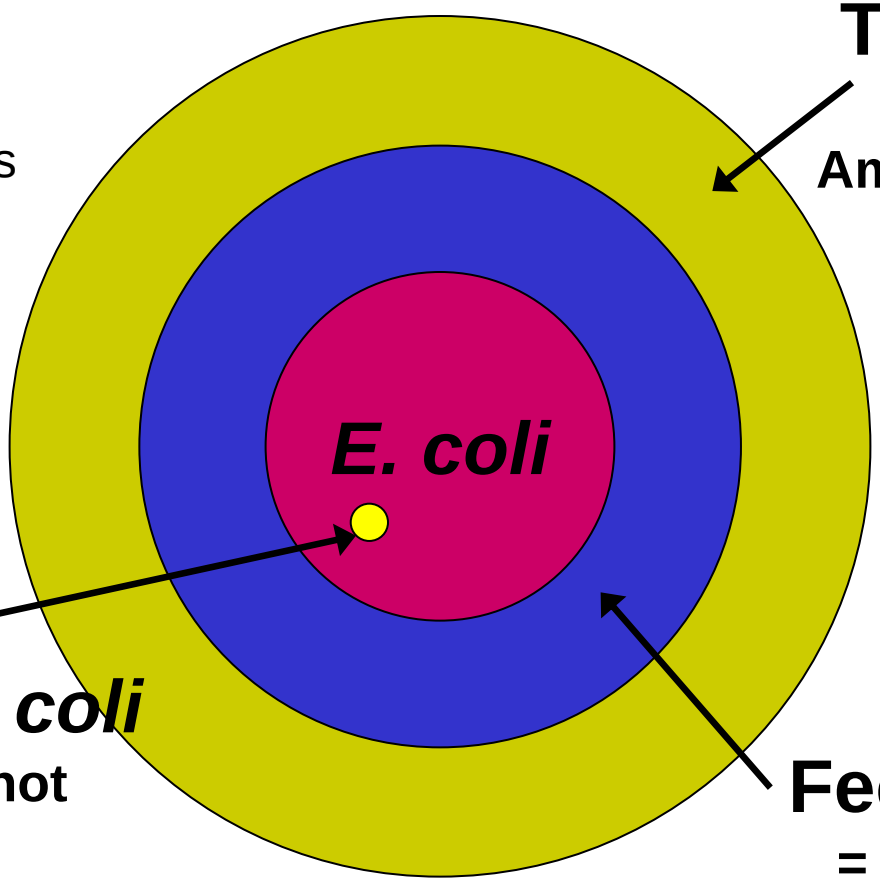
Late 1800s – The Germ Theory of Disease was proven

This launched a period of discovery of the bacterial causes of many diseases such as cholera and typhoid fever.

What is a Coliform?

Indicator Organisms indicate potential presence of disease-causing organisms

There are hundreds of pathogens and many cannot be detected or are expensive to measure



Total Coliform

Ubiquitous in Ambient Environment

Pathogenic *E. coli*

Some of which are not detectable by Total Coliform detection methods

Fecal Coliform

= Thermotolerant organisms, not definitively fecal

Escherichia *(genus)* *coli* *(species)*

- **1884 - Theodore Escherich found *Bacillus coli* in stools of cholera patients that was also present in the intestinal tract of healthy people.**

- **Note that healthy people also had *B. coli***

Treasury Standards

1893 – U.S. Public Health Service (USPHS)

- **Under the Interstate Quarantine Act**
- **Regulation prohibiting the use of a common drinking cup**
- **To protect passengers on commercial transportation carriers traveling between states.**

But… drinking water standards needed something to measure in a reproducible way.

THE INDICATOR CONCEPT provided *something* to measure

- Coliforms became the best available indicator of fecal pollution.

- Coliforms, which are found in a healthy human's intestines, were assumed to provide a conservative estimate of the risk of more serious contamination.

As lab methods improved, terminology became more precise:

- *"B. coli"* from Standard Methods of Water Analysis up to the 6th edition.

- "*Coli-aerogenes*" group (*B. coli* or *B. aerogenes*) from Standard Methods of Water Analysis in the 6th-8th editions.

- *B.coli* or *coli-aerogenes* group became the "Coliform group" in the 1946 or 9th edition of Standard Methods for the Examination of Water and Wastewater

Pre-1946 Attempts to use B. coli to indicate Safe Water

Estimating *B.coli* or degree of impurity

mL of water =	0.01	0.1	1.0	10.0	100.0
in 100 mL tubes					
• *Safe*	*0*	*0*	*0*	*0*	+
• *Reasonably Safe*	*0*	*0*	*0*	+	+
• *Questionable*	*0*	*0*	+	+	+
• *Probably Unsafe*	*0*	+	+	+	+
• *Unsafe*	+	+	+	+	+

(positive gas +)

1946 - 9th Edition of Standard Methods for the Examination of Water and Wastewater

Introduction of Most Probable Number (MPN) table using fermentation tubes and a variety of dilutions so that regulatory agencies could require the measurement of coliform numbers in a reproducible way.

Fermentation tube test for acid and gas production

Gary A. Burlingame 2007

Fermentation Tubes (MPN) for a *Quantitative Estimate* of Fecal Contamination

	Volume in 100 mL			
Coliforms per 100 mL	**10mL**	**1**	**0.1**	**0.01**
10	+	-	-	-
100	+	+	-	-
1000	+	+	+	-
10000	+	+	+	+

Today we have multiple methods for TCR compliance:

- Membrane filter with m-Endo medium
- Multiple tube fermentation
- Presence/absence test using P-A medium
- Readycult®
- MMO-MUG or Colilert®
- Colisure®
- E*Colite®
- Others

New methods for *E. coli* provided simultaneous or faster subsequent testing for *E. coli* under the TCR

E. coli **produces an enzyme, beta-D-glucuronidase which breaks down 4-methylumbelliferyl-beta-D-glucuronide or MUG and fluoresces under UV light.**

History on the use of Coliform Bacteria as an indicator for drinking water regulations

Gary A. Burlingame 2007

1925 - "Standards for Drinking and Culinary Water Supplied by Common Carriers in Interstate Commerce"

administered by US PHS

1925 – USPHS Standards

- ***B.coli*** **estimates became the legal standard (using 5 fermentation tubes of 10 mL each per sample)**

- **A concept of 5% positive was used**

- **These 1925 regulations were the first to incorporate, depending on population served, the number of samples to be collected per month.**

1946 - USPHS Standards for Public Water Supplies

- **Required samples to be taken from throughout distribution at “representative points”**
- **“From source of supply to the free-flowing outlet of the ultimate consumer.”**
- **Acknowledged faulty plumbing, cross connections, interconnections and distribution system operations.**

1946 - USPHS Standards for Public Water Supplies

Adjusted the wording of the 1942 standards so that the standards *could be* applied to ALL public water supplies.

Federal standards, though, could not be required for *all* water supplies. It was up to each State to make the change.

1946 - USPHS Standards for Public Water Supplies

Received input and support from the drinking water community through the American Water Works Association:

"That the 1946 Drinking Water Standards proposed for adoption by the United States Public Health Services be voluntarily accepted by our Association as the Standards for all public water supplies."

As of 1970 we had a tradition for the use of an indicator, Total Coliform:

- The best-available indicator
- Representative sampling throughout distribution
- Population-based sampling
- Monthly regulatory review
- Check sampling after positive samples
- Numerical and percent positive limits
- Lab certification
- More than one test method was available
- 100 mL standardized sample volume

The 1970s

- The formation of the US EPA
- The passage of the Safe Drinking Water Act

NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS

1974-1979

Interim MCLs set for coliform bacteria and turbidity, radionuclides, 10 inorganics, and 6 pesticides.

Interim MCL for Total Coliform

- Membrane Filter Test
- Fermentation Tube Test
- Numerical limits (such as monthly average) and percent positive limits according to method used

Total Coliform Rule of 1989

- **Only the presence/absence of coliform bacteria is now reported.**
- **"Repeat" sampling after positive samples laid out in greater detail.**
- **Positive coliform samples must be tested for fecal coliforms (or *E. coli* once new methods for *E. coli* were developed).**

Ground Water Rule – 2006

- **Total coliform detection in distribution triggers fecal indicator (E. coli) testing at sources (wells) within 24 hours.**

1989 Total Coliform Rule: Requirements, Rationale, and Subsequent Developments (Part 1)

Tom Grubbs (EPA)
and
Alan Roberson (AWWA)
July 17, 2007

Purpose and Objectives

- Purpose
  - To gain a common understanding of the basic TCR requirements and the rationale for those requirements
  - To highlight which requirements may result in variations in implementation and in the level of public health protection provided by the TCR

- Objectives
  - Understand rationale and assumptions underlying key provisions of the current Total Coliform Rule
  - Begin a discussion of how the rule is being implemented now and why and whether it is serving its stated intent

Drivers for Modifying the 1975 TCR in 1989

- 1983 Expert Workshop raised concerns
  - Inadequately documented technical basis for MCLs
  - Complexity of the MCLs
  - Monitoring frequency for small systems
  - Invalidation of TC positive samples
  - Follow-up to a total coliform positive
  - Representative sampling
- 1986 SDWA amendments required EPA to regulate total coliforms (among 83 contaminants specified)

General Purpose of 1989 TCR
(as stated in the 1987 proposal)

- Help ensure integrity of distribution system (DS)
  - In complement with SWTR for surface water supplied systems
- Indicate effectiveness of treatment
- Indicate possible fecal contamination

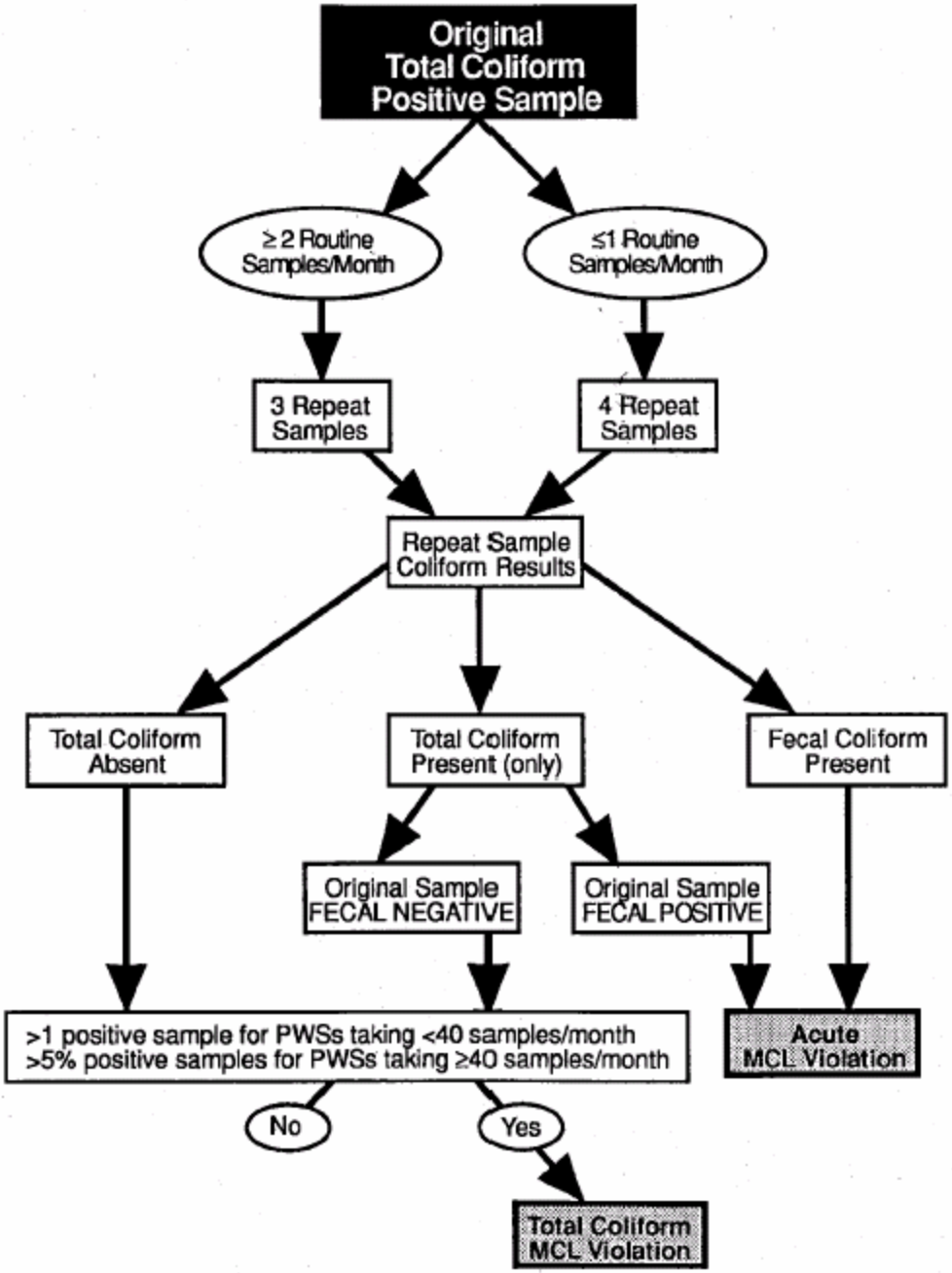
TCR Applicability (1989)

- Requirements apply to all public water systems
  - 54,000 community water systems
  - 18,000 nontransient noncommunity water systems
  - 85,000 transient noncommunity water systems
- Only rule that applies to transient PWSs in a comprehensive manner
  - Monitoring at least annually (monthly for many)
  - Sanitary survey
  - Fosters connection between system and State
  - Nitrate/nitrite require annual or less frequent monitoring

1989 TCR and Components

- Indicator framework
- Routine monitoring and sample siting plans
- Repeat monitoring – routine/repeat samples
- MCLGs
- Non-acute (monthly)/acute Maximum Contaminant Level (MCL)
- Analytical methods
- Variance provision (added in 1991)
- Public Notification
- State response/involvement with positive samples, MCL violations

Role of Routine and Repeat Monitoring in TCR Compliance Determination



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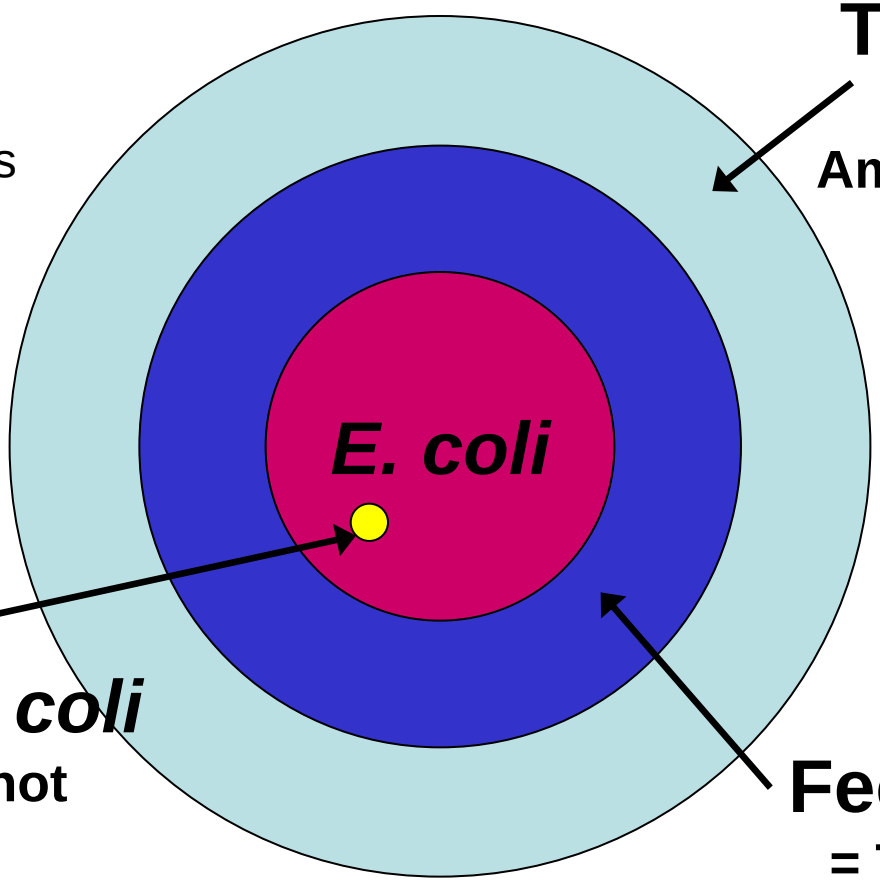

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Pathogenic *E. coli*

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Fecal Coliform

= Thermotolerant organisms, not definitively fecal

Basis for Indicator Framework (1989)

- Advantages:
  - Total coliforms (TC) are numerous in environment and serve as Indicator of a possible breach in water system integrity
  - TC are a conservative indicator of potential contamination
    - Provides basis for investigation
  - Analytical methods are simpler and lower cost than 1975 methods
  - Fecal indicators, i.e. fecal coliform and *E. coli*, can be analyzed directly from TC samples
  - Indication of fecal contamination shows more immediate concerns and requires prompt investigation

Basis for Indicator Framework (cont.)

- Limitations:
  - TC provides no definitive linkage to public health risk
  - Absence of TC does not mean absence of risk
    - Indicator limitations, e.g. absence of TC does not indicate absence of protozoa
  - TC may grow and release in distribution systems (biofilm) and mask indicator value (i.e., don't know if TC positive is coming from either DS breach or biofilm)
  - Cost of sampling constrains volume and frequency of monitoring and limits the sensitivity of detecting potential contaminant events

Rationale for Presence/Absence Analytical Requirement

- Requirement was changed from coliform density to presence/absence because:
  - Data in the literature did not demonstrate a quantitative relationship between coliform densities and either pathogen density or the potential for waterborne disease outbreak
  - Revised MCL was easier to understand
  - Simpler to understand the presence or absence of coliforms and not have to consider the uncertainties associated with estimates of coliform density
  - Less concern about coliform die-off during the time between sample collection and analysis because any decrease in coliform density will seldom result in complete die-off of all coliforms in the sample

Knowledge on Indicator Framework Since 1989

- Measurement of *E. coli* is now lower cost and more widely and provides quicker response time
- Recognition of regrowth in the distribution system led to 1991 variance provision

Routine Monitoring Requirements

- Systems must develop written sample siting plans
  - Representative of DS
  - Subject to State review/revision
- Indicator presence/absence (rather than concentration measure)
- Test all TC+ samples for fecal coliform or *E. coli*
- Number of samples are based on population served and system type

Routine Monitoring Requirements (cont.)

- Sampling frequency based on population served
  - Total of 34 population categories, for example:
    - ≤ 4,900 people -- 5 samples/month (exceptions may be applied to systems serving ≤4,100 people)
    - 8,501-12,900 – 10 samples/month
    - 33,001- 40,000 – 40 samples/month
    - 96,001-130,000 – 100 samples/month
    - 450,001-600,000 – 210 samples/month
    - ≥3,960,001 – 480 samples/month

Rationale for Routine Monitoring Provisions (1989)

- Ongoing routine sampling at representative locations on a regular basis is needed to identify potential contamination and to assess potential for acute risk
  - Statistical analysis showed if 60+ samples were collected AND 95% are TC-negative, there is 95% confidence that the fraction of water with coliforms present <10%
  - Assumes sampling is representative of water being sampled
- Increased frequency of sampling by size reflects potential for more contamination pathways
- Routine sampling results also indicate where additional sampling may be needed

Routine Monitoring Provisions for Small Systems (based on State approval)

- Systems serving ≤4,100 people may take < 5 samples/month if State conducts periodic sanitary surveys, for example:
  - Systems serving ≤1000 people: one sample/month
  - Systems serving 3301-4100 people: 4 samples/month
- Systems may collect all samples on a single day if taken from different sites

Routine Monitoring Provisions for Small Systems (based on State approval) (cont.)

- GWS free of sanitary survey defects & unlikely to be contaminated may further reduce monitoring frequency:
  - **CWS serving ≤ 1,000 people may have sampling reduced to quarterly**
  - **NCWS serving ≤ 1,000 people may have sampling reduced to annual**
- Systems must collect ≥ 5 samples in month following a total coliform-positive sample unless
  - **State performs site visit and determines that additional sampling and/or correction is not needed or**
  - **State determines why the total coliform sample was positive and establishes that the system has corrected or will correct the problem**

Rationale for Routine Monitoring Provisions for Small Systems (1989)

- Cost saving while still protective
- Reduced monitoring allowed based on State's knowledge of least vulnerable GWS (only available for the smallest systems)
- By collecting at least 5 samples in consecutive months (routine and repeat samples), systems with TC-positive samples collect more samples to increase the confidence to assess corrective action effectiveness and current microbiological quality

Routine Monitoring Since 1989

- Some states require monitoring plans to be submitted for approval
- Most systems serving ≤4,100 people, with State approval, are collecting fewer than 5 samples per month
- Sanitary surveys are now required for all systems
  - Under IESWTR for surface water supplies
  - Under GWR when it becomes effective (2009 or 2011)

Repeat Monitoring Requirements

- Within 24 hours of learning of a total coliform-positive ROUTINE or REPEAT sample, system must collect at least 3 REPEAT samples and test for TC
  - Required to sample original tap, within 5 service connections upstream and downstream of original tap
  - If total coliform-positive sample occurs at end of distribution system, State may waive the +/- 5 service connection requirement and take repeat samples from the same tap
  - Systems that collect ≤ 1 ROUTINE per month must collect a 4th REPEAT sample at a location of system's choice
  - State may grant exceptions for 24 hour requirement
- Within 24 hours, must test the total coliform-positive sample for either *E. coli* or fecal coliforms

Repeat Monitoring Rationale

- The basis for 24 hour requirement is to optimize the possibility for identifying initial potential contamination
- Monitoring upstream and downstream is to help identify the source and/or extent of potential contamination
- One extra repeat sample (4 rather than 3 repeat samples) for systems that collect ≤ 1 routine sample per month is to compensate for lower monthly routine sampling requirements
- For systems serving ≤4,100 people, the systems take at least five routine samples during month after a TC+ sample
  - **To help ensure higher likelihood that systems with low routine monitoring frequency are no longer contaminated**
  - **State may increase # of samples to assess corrective action and current microbial quality of water**

Repeat Monitoring since 1989

- Substantial number of small systems take repeat samples beyond 24 hours
  - Data are being collected to evaluate the effect of this delayed repeat sampling (6-year review)
- Data are available to also evaluate the requirement for all systems

MCLG and Rationale (1989)

- EPA required to set MCLG at level at which no known or anticipated human health effects occur, with an adequate margin of safety
- EPA set the MCLGs at zero for total coliform, fecal coliform, and *E. coli* because any value other than zero was assumed to have potential risk implication

Non-Acute (monthly) MCL Compliance Requirement (1989)

- The results of ROUTINE and REPEAT samples are used to calculate compliance
  - Compliance determined each month a system serves water to the public or each month that sampling occurs (for those systems on reduced monitoring)
- System in compliance if:
  - <2 total coliform-positive samples for systems taking <40 samples/month
  - ≤5.0% total coliform-positive samples for systems taking 40+ samples/more

Rationale for Non-Acute (monthly) MCL Compliance (1989)

- Non-acute (monthly) determinations address concerns about long-term operation, distribution system integrity, and potential acute health effects
- TC occurrence used to define non-acute MCL violation since it indicates a pathway of potential fecal contamination (even if fecal contamination is not present)
- Two positive or >5.0% used to indicate confidence that TC are occurring in the distribution system and there is the potential of a contamination event

Non-Acute (monthly) MCL since 1989

- Significance of violation difficult to understand for public and public health community
- Better recognition that TC is an indicator and not a contaminant

Acute MCL Requirements

- Acute violation based on two TC positives (routine and repeat), with one of the two also fecal/*E. coli* positive
- The results of ROUTINE and REPEAT TC+ and FC/Ec+ samples are used to calculate compliance
- Large systems can have an acute MCL violation without a non-acute violation and vice versa
  - Small systems with an acute violation will also violate the non-acute MCL

Rationale for Acute MCL Compliance (1989)

- Measurement for fecal coliform (FC) or *E. coli* for acute violation determination because many pathogens of concern are of direct fecal origin
  - Allows for FC because more protective than *E. coli* and analysis costs less (at time of promulgation)
  - Allows for *E. coli* to better target potential presence of human pathogens
- Concern for acute risk to public addressed by system being required to notify State by end of day when FC/Ec is positive (even if before violation); State can then determine what action is necessary

Acute MCL since 1989

- Since promulgation in 1989, low cost methods for Ec determination have been developed (see methods discussion)

- Response time reduced from 72 to 24 hours, but lag time still a concern.

Linkage between TCR and Other Rules

- SWTR (1989) complements TCR by including treatment technique requirements and disinfectant residual requirements in DS
  - **Disinfectant residuals measured at TC sample locations**
- Stage 1 DBPR (1998) uses TCR monitoring sites to define where and when disinfectant residual must be monitored in DS
- GWR (2006) will complement TCR when implemented
  - **2006 GWR requires 1) source fecal indicator monitoring if TC detected in DS; 2) corrective actions if fecal contamination is detected in source**
- Appendix contains regulatory crosslinks

1989 Total Coliform Rule Requirements, Rationale, and Subsequent Developments (Part 2)

Ken Rotert (EPA)

July 17, 2007

Analytical Methods (1989)

- Total coliform (100 mL analyzed for presence/absence)
  - 1989 methods - membrane filter technique, multiple tube fermentation, presence-absence coliform test, Minimal medium ONPG-MUG (Colilert)
- Fecal coliform – method specifies how to analyze TC-positive sample for fecal coliform
- *E. coli* – no methods included; EPA plans to add methods
- Sample invalidated if State determines TC+ due to domestic plumbing or is not reflective of DS water quality; or lab invalidates based on certain method results.

Rationale for Analytical Methods

- Total coliform
  - **Standardized volume analyzed to ensure uniform sensitivity of measurement**
  - **Presence/absence (rather than pre-1989 concentration based standard) assumed more relevant indicator for potential contamination occurrence**
    - **Simplified interpretation of data and follow up**
  - **Added new methods as developed**
- Fecal coliform/*E. coli* – Allowed for flexibility and development of new and less costly methods for *E. coli*
- Invalidation criteria needed to control previous practice of invalidating routine total coliform-positive samples when repeat samples were TC-negative

Analytical Methods (since 1989)

- Total coliform
  - Since 1989, six new methods added
- *E. coli* – 10 methods listed after 1989
  - Colilert, Colitag, mColiBlue, EColite, Colisure, Readycult
- EPA has process for adding new methods and approving laboratories – see Appendix

Public Notification and Reporting Requirements

- Systems with MCL violation must report the violation to the State no later than end of next business day after it learns of the violation, and notify the public
  - Within 30 days of a non acute MCL violation
  - Within 24 hours of an acute violation
- Systems with routine or repeat samples that are fecal coliform or *E.coli* positive (regardless of violation determination) must notify State by the end of the day they are notified of the result
- Monitoring violations must be reported to the State within 10 days after the system discovers the violation
- 1989 and current PN language included in Appendix

Rationale for Public Notification and Reporting Requirements

- Non-acute (monthly) MCL violation
  - Alerts consumer of potential contamination to system
  - Non-acute violation does not require immediate notification since no immediate evidence of fecal contamination
- Acute MCL violation requires short term notification since fecal contamination indicates that pathogens posing acute risk may be present
  - If routine or repeat samples are fecal coliform or *E.coli* positive, system notifies State by end of the day notified of FC+/Ec+ result to allow for appropriate State action
- Monitoring violations generally seen as less significant, so more time to report

Public Notification and Reporting since 1989

- Language changed in 2000 by Public Notification Rule
  - Non Acute - Notify public per Public Notification Rule: Tier 2 Public Notification (within 30 days of learning of a violation)
  - Acute - Notify public per Public Notification Rule: Tier 1 Public Notification (within 24 hours)
- Concern about overload of information to public
- New communication avenues available
  - CCR, website, emergency notification plans
  - Some not available or practical for NCWS

Variance (added in 1991)

- The State may grant a variance to a system that demonstrates that "… the violation of the total coliform MCL is due to a persistent growth of total coliforms in the distribution system rather than fecal or pathogenic contamination, a treatment lapse or deficiency, or a problem in the operation or maintenance of the distribution system."

Rationale for Variance

- Total coliform positive results may be due to biofilm, rather than treatment or operational deficiencies
- State may use its discretion to issue a variance where it determines that there is no health threat
  - NOTE: Very few utilities have used this variance provision

State Discretion

- States may approve systems taking < 5 samples per month after periodic sanitary surveys
  - **At least every five years (or every 10 years if it is a NCWS using protected and disinfected GW as determined by the State)**
  - **Note: under IESWTR and GWR, sanitary surveys required for all systems within 3 years for CWS (up to 5 years for GWS if certain conditions are met) and 5 years for NCWS**
- Notification of FC+ and Ec+ by system before violation determination
- Violation notification by system to State much quicker than for other rules to recognize potential for acute risk

State Discretion Rationale

- Rationale for sanitary survey provisions
  - Provides means for lowering monitoring costs to small systems while helping ensure they are still adequately protected with minimal monitoring provisions
- State discretion on action required by system after early notification allows for system-specific responses to potentially acute pathogens
- State can take into account system knowledge

State Discretion Since 1989

- Many new rules and responsibilities add to State burden
- Discretionary elements allow for system-specific decisions but can be burdensome
- Large differences in how States implement discretionary elements
- Large numbers of monitoring and reporting violations

APPENDIX

Process for Approval of New Analytical Methods

- EPA Microbiological Alternate Test Procedure (ATP) Protocol for Drinking Water, Ambient Water, and Wastewater Monitoring Methods
  - (http://www.epa.gov/waterscience/methods/EPA 821B03004.pdf)

Process for Laboratory Approval

- Manual for the Certification of Laboratories Analyzing Drinking Water - Criteria and Procedures Quality Assurance (Fifth Edition)
- EPA certification program establishes procedures for laboratories to follow and QA/QC procedures to ensure data quality

1989 Public Notification Language

- For total coliform violations: Coliform bacteria are common in the environment and are generally not harmful themselves. Their presence in drinking water, however, indicates that there is a problem at the water treatment plant or in the pipes which distribute the water, and that the water may be contaminated with organisms that cause disease. These diseases may cause symptoms, including headaches, fatigue, diarrhea, cramps, nausea, and jaundice.

Current Public Notification Language

- For total coliform violations: “Coliforms are bacteria that are naturally present in the environment and are used as an indicator that other, potentially harmful, bacteria may be present. Coliforms were found in more samples than allowed and this was a warning of potential problems.”

1989 Public Notification Language

For fecal coliform and E. coli violations: Fecal coliforms are an acute health risk ….The presence of fecal coliforms intreated water drinking water is a serious concern because they are usually associated with the presence of sewage or animal wastes. Drinking water contaminated with fecal coliforms may place the consumer at high risk for acute diseases such as hepatitis, typhoid fever, and dysentery. Acute diseases are marked by rapid onset of symptoms …. Protective action includes boiling water or using alternate sources. Local and State health authorities are the best source for detailed information.

Current Public Notification Language

- For fecal coliform and *E. coli* violations: "Fecal coliforms and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Microbes in these wastes can cause short-term effects, such as diarrhea, cramps, nausea, headaches, or other symptoms. They may pose a special health risk for infants, young children, some of the elderly, and people with severely compromised immune systems."

Stage 1 DBPR

- Disinfected CWSs and NTNCWSs are required to take disinfectant residual samples at same time/place as total coliform samples
  - 141.132(c)(1)
- Must comply with chlorine/ chloramine MRDL as an RAA
  - 141.133(c)(1)
  - Subpart H systems may use SWTR monitoring to meet the Stage 1 monitoring requirement

Surface Water Treatment Rule

- Subpart H systems (surface water and ground water under the direct influence) are required to take disinfectant residual samples at same time/place as total coliform samples
  - 141.74(b)(6) for unfiltered systems; 141.74(c)(3) for filtered systems
- Must have detectable residuals in at least 95% of samples monthly
  - 141.72(a)(4) for unfiltered systems; 141.72(b)(3) for filtered systems

Ground Water Rule

- Undisinfected or inadequately disinfected (< 4-log virus inactivation) systems must take source water sample(s) following TC+ TCR compliance sample [141.402(a)]
- If source water sample is Ec+, system must take corrective action [141.403(a)]

State Implementation of the Total Coliform Rule

TCRDS Advisory Committee
Washington DC

July 17, 2007

Purpose

- Show what it takes to implement the Total Coliform Rule in the States
- Cover the more common implementation practices and point out variations where appropriate
- Identify state concerns along the way

Background

- Each state has their own set of laws and regulations which are used to implement the TCR (at least as stringent as EPA, but not always the same).
- Regardless of the specific practices of states, their goal is always the same – use the resources available to provide maximum public health protection

More TCR Background for States

- TCR is one of two rules that applies to all public water systems – CWS and NCWS
- There are more MCL violations and more Monitoring and Reporting violations resulting from the TCR than any other rule
- More state resources are dedicated to TCR than any other single rule

More TCR Background for States

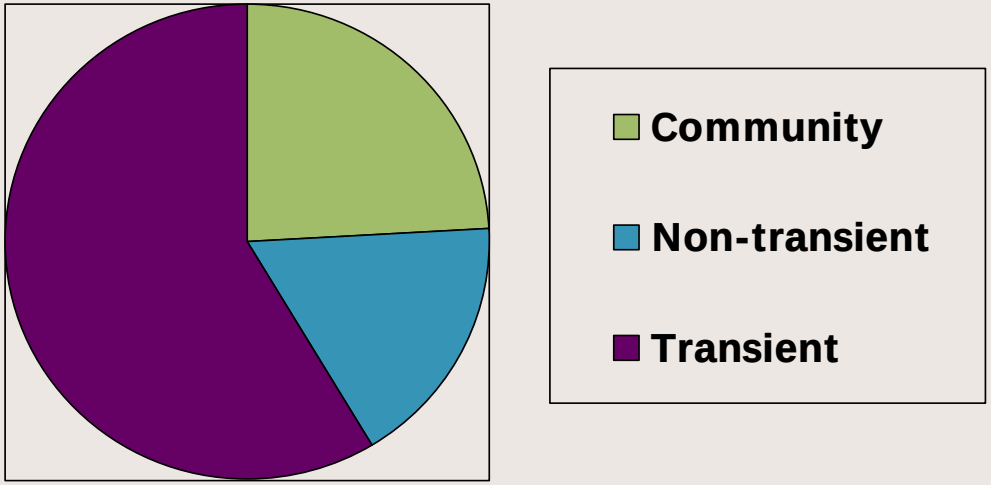
- In spite of its flaws, States and most water systems have learned the rule and adapted to it
- The implementation of the rule has helped identify water system contamination problems and led to their correction
- States use many other tools besides the TCR to identify problems and assure their resolution
  - Sanitary surveys
  - Citizen complaints
  - Construction approvals and inspections
  - Source water monitoring and other special monitoring programs

More TCR Background for States

States also have many other tools to prevent contamination in the first place that make TCR violations less likely

- well siting requirements
- well construction standards
- well driller and pump installer certifications
- cross-connection control

State Example
Ohio PWS



CWS	NTNC	TNC	Total
1291	917	3128	5336

Typical NCWSs

Major State Roles in TCR Implementation

- Assign monitoring schedules
- Assure appropriate monitoring is conducted
- Manage response to TC positive samples
- Determine violations
- Assure appropriate violation response
- Assist PWS with treatment, distribution system operation, monitoring and corrective action as necessary
- Lab Certification – labs must be certified for TC analysis (not always the primacy agency)

Assigning TCR Monitoring

- State assigns TCR monitoring schedules to all systems
- Typical monitoring
  - Monthly monitoring for most CWS
  - Quarterly monitoring for most NCWS
- Actual schedules may range from weekly to annual depending on type of system and specific state requirements
- States notify systems of monitoring schedules and may provide periodic reminders

Managing the Monitoring Process

- States provide guidance and assistance to PWS in preparing site sampling plans
- States review site sampling plans and make recommendations
- States provide training to operators in sample collection techniques
- States review monitoring schedules, sampling plans and collection protocols during sanitary surveys
- Many states provide laboratory services for TCR and some even collect the TCR samples

Monitoring Issues Requiring Additional Technical Assistance

- Operator turnover leading to missed samples, use of unapproved sites, and poor sample collection technique
- NCWS with only premise plumbing and no repeat sample locations
- Small systems have difficulty interpreting the rule's sampling scheme, especially repeat samples and "5 the next month"
- Potential for additional repeat samples resulting from a positive repeat sample

Monitoring Issues Causing More Implementation Challenges

- PWSs in remote areas have difficulty meeting sample holding times
- States must manage around 4 million coliform sample results a year
- Many states don’t have the resources to track whether all samples are collected according to the site sampling plan

Total Coliform Positive Samples

- Depending on the relationship between PWS, laboratory, and state, the state may <u>not</u> be involved in the initial response to a positive TC sample until 45 days later
- Tracking the positive samples and appropriate response is a major work load for states, especially related to small PWSs

Managing the TC Positives

- In some cases, States may collect the repeat samples
- Positive samples may be invalidated or a variance given
  - problem sample sites
  - biofilms
- States work with PWSs to identify cause of the problem and correct
- States may conduct an onsite investigation, depending on circumstances

Additional TA Caused by Positive Samples

- PWSs without enough sampling points have difficulty collecting repeat samples
- Causes for TC positives may be difficult to identify
- Systems that do not collect repeat samples (to avoid an MCL violation) make it even more difficult to identify contamination
- Notification of small water systems is often difficult and delays repeat sampling
- Waiting for sample bottles to be mailed from labs also delays repeat sampling

More Positive Sample Issues

- Systems that do not collect repeat samples (to avoid an MCL violation) make it even more difficult to identify contamination
- Notification of small water systems is often difficult and delays repeat sampling
- Waiting for sample bottles to be mailed from labs also delays repeat sampling

More Positive Sample Issues

- Sometimes issues are not fully resolved with seasonal PWSs before they shut down and violations carry over into the next season

Violations

- States determine violations based on reports for water systems or sample results from labs
  - Acute MCL violations during the month
  - Non Acute and Monitoring violations at the end of the monitoring period

Managing Violations

- Many states have automated compliance determination (SDWIS/State and other data systems)
- Systems must be notified of violations and appropriate response required, particularly Public Notification
- Response to the violations must be tracked
- Violations must be reported to EPA electronically and also the return to compliance
- Multiple violations may put the PWS in Significant NonCompliance (SNC)

Violation Issues

- States that require more frequent monitoring for NCWS (monthly vs. annual) can potentially have many more monitoring violations
- Volume of TCR violations, especially for monitoring, is a major burden on state resources

Notifying the Public

- As a response to a violation, states must be sure the public is notified
- Notice is also required in CCR (also implemented by States)

More on Notifying the Public

- Some states may issue routine public notice if the PWS fails to provide
- Depending on circumstances, states may require mandatory boil order or boil water advisory in the case of acute violations
- States may issue these orders directly or require the system to issue
- Most states do not have resources for extensive PN Rule tracking

Public Notification Issues

- Many systems fail to do adequate or timely public notification
- Notification, even for acute violations, is normally after the contamination is long gone
- What is appropriate public notification for TNCWS violations - the people served water during the violation period are no longer there?
- Required language for the nonacute MCL Public Notice can be alarming
- The health significance of a nonacute MCL is difficult to explain to the public

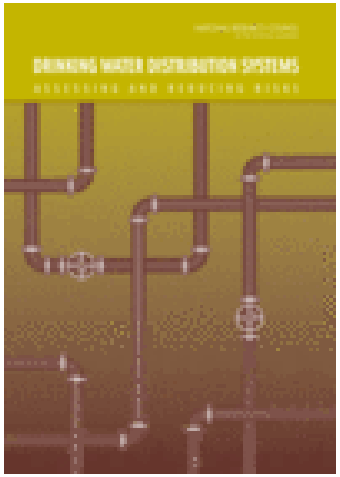
Other Issues that Impact TCR Implementation

- Small systems usually don’t have full time operators and have high turnover
- Not all systems are required to disinfect
- A few states have assigned responsibility for CWS and NCWS to different agencies
- Water supply is not the primary business of NCWSs
- The GWR will have an impact on TCR implementation and vice versa but it is too early to tell the extent

Assessing Distribution System Integrity:
physical, hydraulic, and water quality

Mark W. LeChevallier, Ph.D.
Director, Innovation & Environmental Stewardship

Background

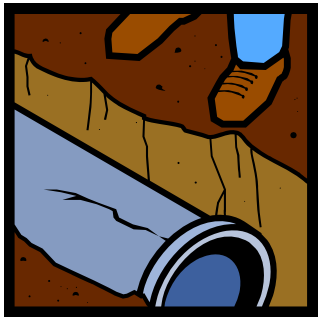


- NAS report developed under EPA contract
- NRC developed two reports
  - The first identified distribution system issues of high priority and was released in April 2005
  - The second provided information on preventive and corrective strategies and was released to the public on September 7, 2006
  - Available at: http://water.nationalacademies.org/

Charge to the NRC for the Second Report

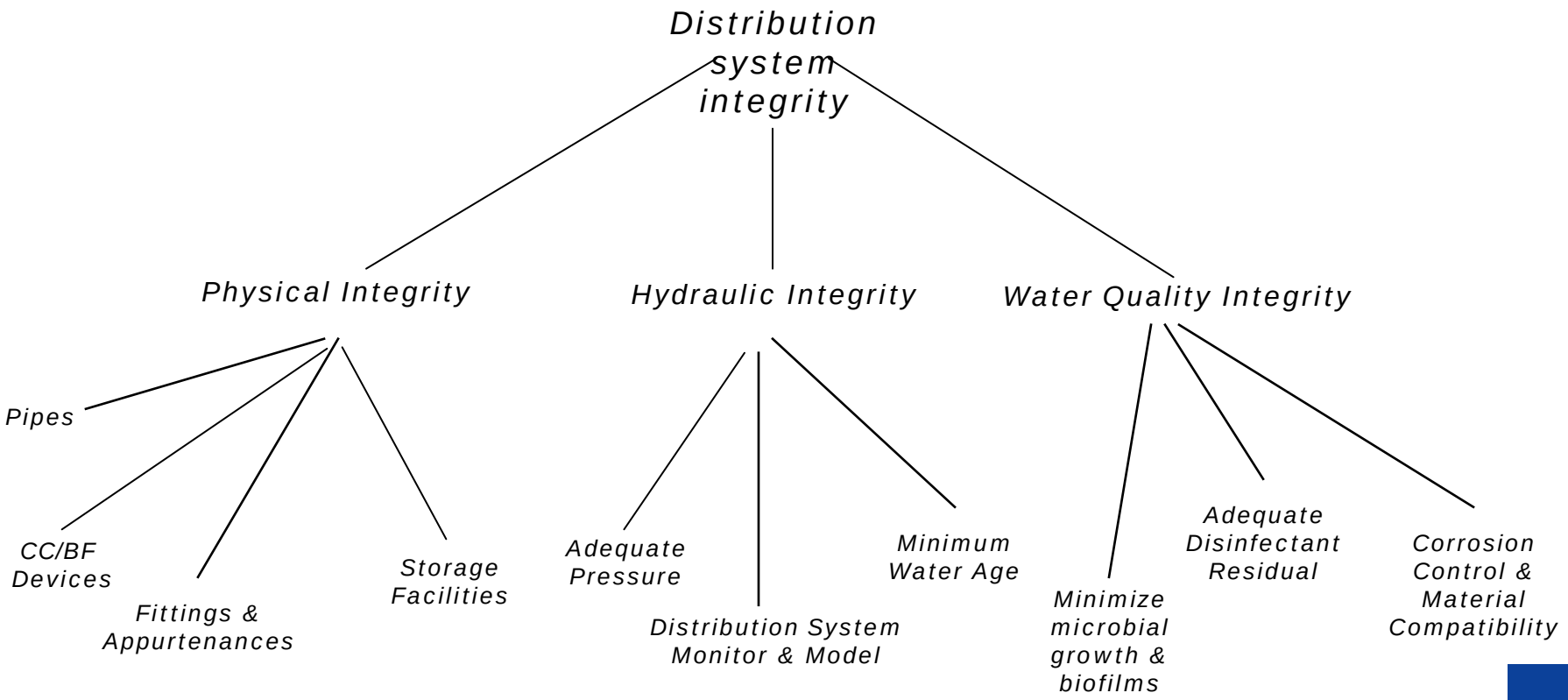
- Evaluate different approaches to characterization of public health risks posed by distribution system contamination events.
- Identify and evaluate the effectiveness of relevant existing codes and regulations
- Identify general actions, strategies, performance measures, and policies that could be considered to reduce distribution system risks.
- Identify advances that will enable the water supply industry to further reduce risks associated with distribution systems

Public Health Conclusions and Recommendations



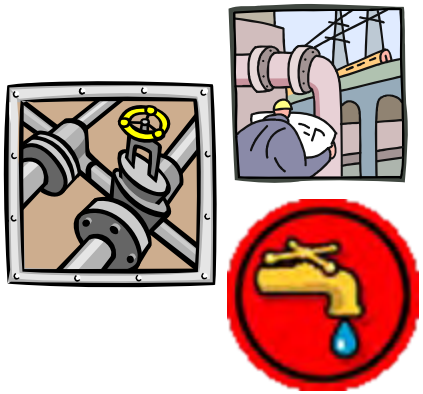
- The distribution system is the remaining component of public water supplies yet to be adequately addressed in national efforts to eradicate waterborne disease
- Distribution system ecology is poorly understood, making risk assessment via pathogen occurrence measurements difficult
- Epidemiology studies that specifically target the distribution system component of waterborne disease are needed

Distribution System Integrity



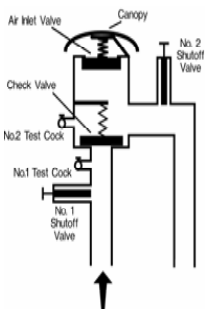
National Research Council. 2006. *Drinking Water Distribution Systems: Assessing and Reducing Risks*. National Academies Press. Washington, DC.

Physical Integrity



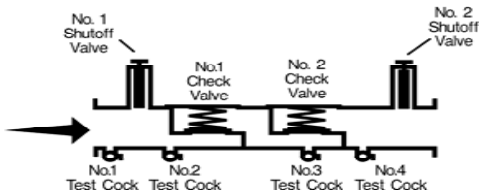
- According to water industry statistics, it will take 300 years to renew the existing pipes at the current rate of replacement.
- The USEPA has indicated that $300 billion will be needed to replace or repair aging infrastructure over the next 20 years.
- The American Society of Civil Engineers reports that an average of 6 billion gallons per day of potable water are lost through the leaky pipes and services in the United States everyday.
- The loss of physical integrity – where the system no longer acts as a barrier that prevents external contamination from deteriorating the internal, drinking water supply
- When physical integrity is compromised, the drinking water supply becomes exposed to contamination that increases the risk of negative public health outcomes.

Cross Connection Control



CDC data: 1981-1998

- 57 waterborne disease outbreaks related to cross-connections
- 20 from microbiological contaminants
- 15 from chemical contaminants



Craun and Calderon (2001) data: 1971-1998

- 50.6% of distribution system-related outbreaks were caused by cross connections

Storage Facilities

Problems due to….

- *Salmonella*, *Campylobacter*, coliforms
- Chlorine loss, microbial regrowth, sediment accumulation, nitrification

Causes

- Faulty or missing hatches and vents
- Insufficient maintenance
- Inadequate mixing and turnover

Infrastructure

Sources of Contamination:

- In the USA, about 4,400 miles of pipe are replaced every year
- About 13,200 miles of new pipe are installed every year
- About 237,600 water main breaks occur every year
- Asset management refers to a strategy of operating, maintaining, rehabilitating, and replacing infrastructure in order to sustain a cost-effective level of service to customers.

Physical Integrity Recommendations

- Storage facilities should be inspected on a regular basis..
- Better sanitary practices are needed during repair, replacement, and rehabilitation.
- Although it is difficult and costly to perform, condition assessment of buried infrastructure should be a top priority for utilities.
- External and internal corrosion should be better researched and controlled in standardized ways.
- Cross-connection control should be in place for all water utilities.
- Research is needed on new materials for water distribution systems.

Hydraulic Integrity

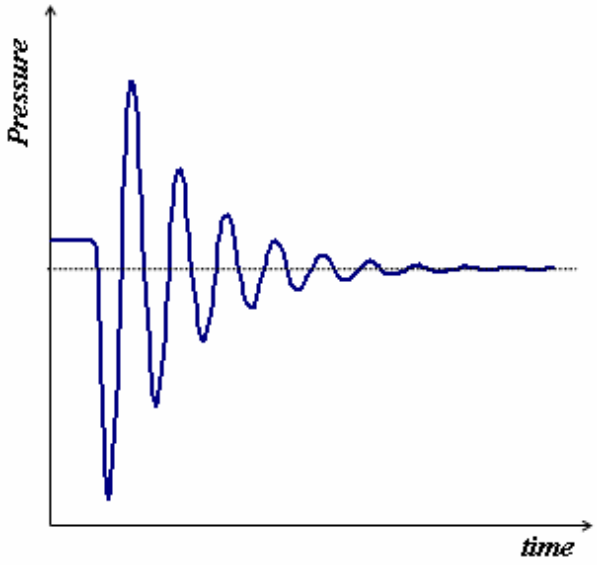
- The hydraulic integrity of a water distribution system is defined as its ability to provide a reliable water supply at an acceptable level of service—meeting all demands for adequate pressure, fire protection, and reliability of uninterrupted supply.

- The most critical component of hydraulic integrity is *adequate pressure* defined in terms of the minimum and maximum design pressure.

- A second element of hydraulic integrity is the *reliability of supply,* which refers to the ability of the system to maintain the desirable flow rate even when components are out of service.

Maintenance of Adequate Pressure

- Hydraulic surges can result in transient periods of low or negative pressures
- Intrusion of outside water into the distribution system may potentially occur during these periods
- Backflow of water could occur through unprotected service lines



- Studies (Karim et al. *JAWWA* 95(5): 134-146, 2003) have shown that soil and non-potable water surrounding distribution pipes can contain a variety of microbiological pathogens, including fecal indicators and culturable human viruses

Water Age

High residence time in reservoirs

- Loss of disinfectant residual
- Microbial regrowth
- Increased DBP levels

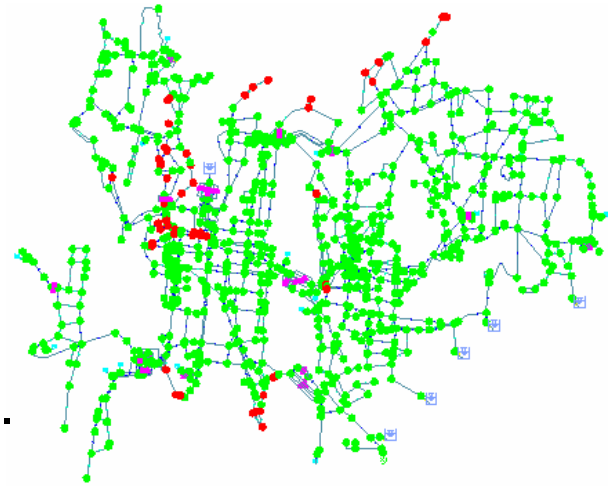
High residence time in pipelines

- Depletion of oxygen, corrosion, black water
- Reduced carrying capacity, High pressures

Distribution Systems Models

- Computer based mathematical models provide the most effective and viable means of analyzing hydraulic and water quality conditions in water distribution systems.
  - Spatial and temporal variations of flow, pressure, velocity, reservoir level, water age, source contribution
  - Determine the adequacy of system fire flows under a variety of demand loading and operating conditions.
  - Sedimentation, resuspension, and discoloration investigations
  - Surge models, water quality modeling
  - Computational Fluid Dynamics modeling can be used to investigate hydraulic mixing characteristics in reservoirs and system operational conditions.

Hydraulic Integrity Recommendations



- Residence times in pipes, storage facilities, and premise plumbing should be minimized to the extent possible.
- Positive water pressure should be maintained.
- Sufficient surge protection devices should be installed.
- Distribution system monitoring and modeling are critical to maintaining hydraulic integrity, particularly for the detection and control of negative pressure transients.

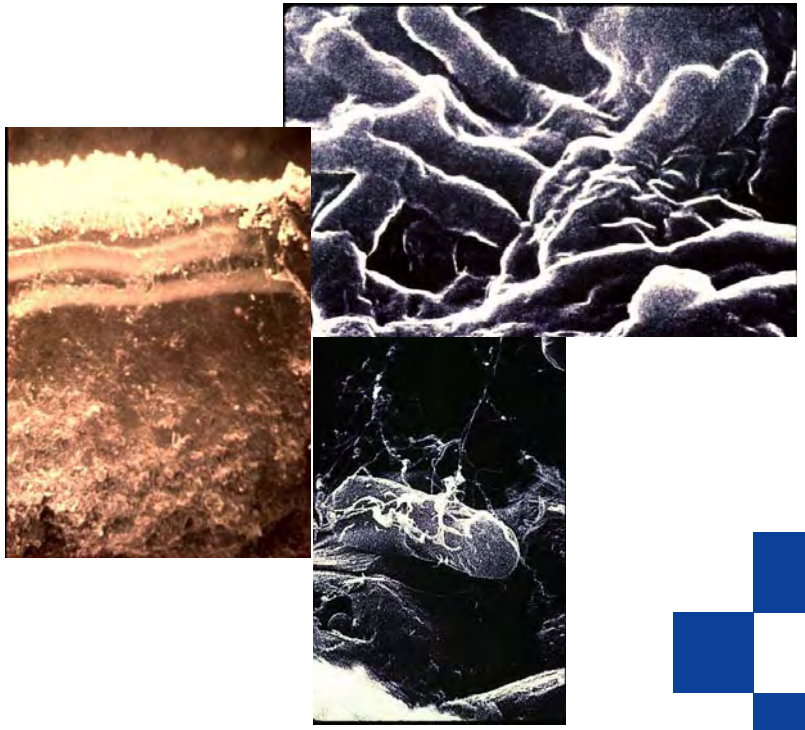
Water Quality Integrity

- For water quality integrity to be compromised, specific reactions must occur that introduce compounds or undesirable microbes into the bulk fluid of the distribution system.
- Even in the absence of external contamination, however, there are situations where water quality is degraded due to transformations that take place within piping, tanks, and premise plumbing

Control of Biofilms

Studies based on biofilm control show a complex interaction:

- Treatment process, filtration
- Temperature
- Disinfectant type, concentration
- Biodegradable organic matter
- Pipe material, corrosion
- Water chemistry
- System maintenance, flushing
- Flow velocity, reversal, hydraulic shear



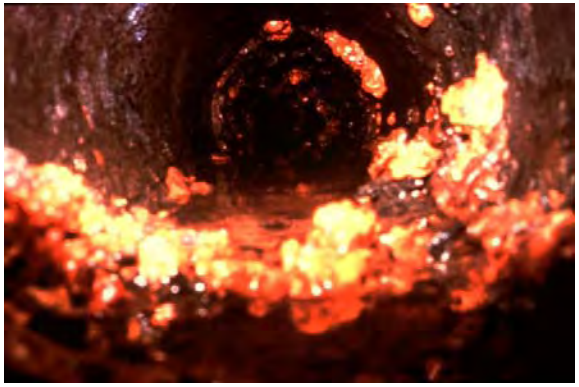
Disinfectant Residual & By-Product Control

- Maintenance of a disinfectant residual is an important element in a multiple barrier strategy.

- Control of Disinfectant By-Product
  - Free chlorine
    - ICR data showed 300 percent increase in total trihalomethane
  - Chloramine
    - ICR data showed 50 percent increase in THM4
  - Biodegradation in DS can reduce HAA levels
- Monitoring of disinfectant residuals can indicate loss of integrity

Internal Corrosion / Leaching

- Corrosion Manifests as:
  - destruction of metal pipes by both uniform and pitting corrosion
  - buildup of scales of corrosion products that hamper the flow of water



- Corrosion Products include:
  - dissolved and particulate metals,
  - aesthetic problems due to color and turbidity
  - lead and copper
  - asbestos particles
  - iron particles
  - adsorbed chemicals such as arsenic
- Leaching controlled through ANSI/NSF Standard 61

Water Quality Integrity Recommendations

- Prior to distribution, the quality of treated water should be adjusted to minimize deterioration of water quality.
- Microbial growth and biofilm development in distribution systems should be minimized.
- Residual disinfectant choices should be balanced to meet the overall goal of protecting public health.
- Methods to rapidly detect and quantify pathogens in distribution systems are needed.
- Distribution system materials and water chemistry should be balanced to minimize adverse effects from corrosion, color, taste and odor, microbial growth, and disinfectant decay.
- Standards for materials used in distribution systems need to be updated to address their impact on water quality, and research is needed to develop new materials that will have minimal impacts.

Reducing Risk Recommendations

- Distribution system integrity should be evaluated using online, real-time methods to provide warning against any potential breaches in sufficient time to effectively respond and minimize public exposure.
- Research is needed to better understand how to analyze data from on-line, real-time monitors in a distribution system.
- A rigorous standardized set of network model development and calibration protocols should be developed.
- Additional research, development, and experimental applications in data integration are needed so that distribution system models can be used in real-time operation.

Premise Plumbing Recommendations

- The occurrence of *Legionella* should be addressed via changes to the plumbing code and new technologies.
- Cross connections in premise plumbing should be reduced through inspections.
- Customer education should provide mitigation strategies that can be implemented to reduce the magnitude of the risk.
- Research projects are needed that specifically address potential problems arising from premise plumbing.
  - Data on water quality degradation in premise plumbing systems in geographically diverse regions and climates.
  - Research on exposure routes other than ingestion, including inhalation of bioaerosols from water.
  - Studies to assess the health risks of contaminated premise plumbing should be undertaken in high risk communities.

What the Technical Workgroup could be Charged by the Advisory Committee

- Develop a framework for identifying data and research that could help inform distribution system risk and strategies for mitigation
  - Characterize existing research and data collection efforts (completed and ongoing)
  - Develop recommendations for possible additional research across different focus areas
  - Develop and recommend potential data collection by utilities that would complement the research

- FAC would direct TWG with above task and ask TWG to provide updates for FAC decision making
- FAC would draw on analysis and presentations by TWG to make final recommendations

Data Sources and Possible Preliminary Analysis for TCR

Stig Regli (EPA) and

Steve Via (AWWA)

July 18, 2007

Overview

- Purpose of presentation
- Overview of June technical meeting
- Available data sources
- Possible questions that TWG could explore

Purpose of Presentation

- Inform scope and type of analysis that TWG could provide to FAC in near term
- Stimulate discussion to develop FAC charge for near term TWG presentations and analysis

Overview of June 2007 Technical Meeting

- 63 participants met at Resolve June 13 and 14th
  - 30 Interested stakeholder experts
  - 33 EPA staff and contractors
- Topics of discussion
  - TCR requirements and rationale
  - Federal, state, and utility data that can inform different aspects of the TCR
  - CDC reported waterborne disease outbreak data and what it can tell us
  - Distribution system inventory data and possible areas of focus to better understand related risk and data/research needs

Overview of Data Sources for Preliminary TCR Analysis

- Community Water System (CWS) information
  - Monitoring Data, Surveys, Case studies
- State
  - TCR compliance data (raw data used to determine compliance)
    - Compiled by EPA through a Information Collection Request (6 year review)
    - Compiled from EPA SDWIS data audits
  - State regulatory practices
    - ASDWA and AWWA surveys
- EPA
  - National TCR violation data (SDWIS)
  - TCR White Papers
- Papers and Information from on-going research projects
  - AwwaRF and EPA ORD projects

Initial Questions to Explore With Available Data

- How well are systems complying with TCR?
- What type of systems are having problems with compliance?
- What does available data tell us about how TCR protects public health?
- What linkages pertain to health data and indicator data?
- How effective are the monitoring provisions of the current TCR?
- What factors most influence relevance of monitoring sites?
- How are TCR monitoring results currently being used to inform risk management decisions?
- What responses are CWSs and States currently making to TCR MCL violations? Acute violations?
- What are the sampling and non-sampling costs associated with implementing the current TCR?

Appendix

June Technical Meeting Attendees

- Stuart Asay (City of Virginia Beach)
- Tony Bennett (TCB AECOM)
- Gail Bingham (RESOLVE)
- Erica Brown (Association of Metropolitan Water Agencies)
- Gary Burlingame (Philadelphia Water Department)
- Chun-Ming Chen (IDEXX)
- James Cherry (City of Virginia Beach Public Utilities)
- Rich Giani (DC Water and Sewer Authority)
- Kathy Grant (RESOLVE)
- Mike Keegan (National Rural Water Association)
- Dawn Kristof Champney (Water and Wastewater Equipment Manufacturers Association)
- Dan Kroll (HACH Homeland Security Technologies)
- Mark LeChevallier (American Water)
- Debbie Lee (RESOLVE)
- Frank Letkiewicz (CADMUS group)
- Carrie Lewis (Milwaukee Water Works)
- Gary Lynch (Park Water Company)
- Rose Odom (Environomics)
- Darrell Osterhoudt (Association of State Drinking Water Administrators)
- Chris Owen (Tampa Bay Water)
- Doug Owen (Malcom Pirnie)
- Alan Roberson (AWWA)
- Jeff Rosen (Clancy Environmental Consultants, Inc.)
- Sharon Roy (CDC)
- Tom Schaeffer (American Metropolitan Water Agencies)
- John Scheltens
- Charlotte Smith (Charlotte Smith & Associates)
- Vanessa Speight (Malcom Pirnie)
- Anne Spiesman (Washington Aqueduct)
- Scott Summers (Univ. of Colorado at Boulder)
- Lynn Thorp (Clean Water Action)
- Steve Via (AWWA)
- Paul Whittemore (Pembroke Water Works)
- Scott Biernat (CADMUS Group)
- Eva Nieminski (Utah Department of Environmental Quality)
- Sarah Clark (HDR)

June Technical Meeting Attendees (Cont.)

U.S. EPA

- Sarah Bahrman
- Pamela Barr
- Jeremy Bauer
- Jimmy Chen
- Sean Conley
- Cesar Cordero
- Tom Grubbs
- Yu- Ting Guilaran
- Andrew Hanson
- Bryan Heninger
- Margo Hunt
- Maggie Lavay
- Clint Lemmons
- Audrey Levine
- Jini Mohanty
- Stig Regli
- Kenneth Rotert
- Lesley Vazquez-Coriano
- Erik Winchester
- Ted Florival-Victor
- Nicole Shao
- Mike Messner