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Understanding Disinfection Residuals

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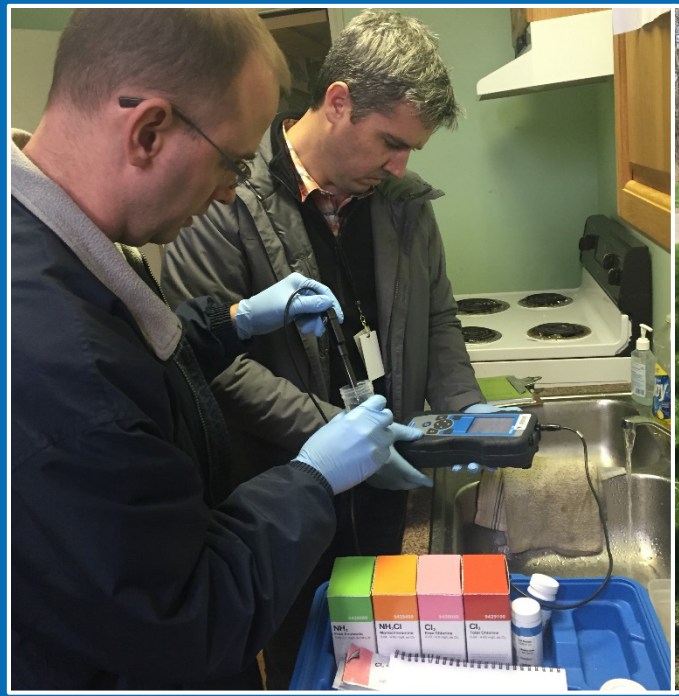

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Outline

- Chlorine residual concentration regulations
- Monitoring location considerations
- Deeper dive into available disinfectant residual data

Current Regulatory Language

- First Introduced in the Surface Water Treatment Rule, 6/1989, 40 CFR 141.72 (b)(3)(i)

The residual disinfectant concentration in the distribution system, measured as total chlorine, combined chlorine, or chlorine dioxide…cannot be undetectable in more than 5 percent of the samples each month, for any two consecutive months...a heterotrophic bacteria concentration less than or equal to 500/ml…is deemed to have a detectable disinfectant residual…

Intent of Residual Regulation

- US regulatory requirement → "detectable"
  - Surface water (SW)
  - Groundwater under direct influence (GWUDI) of SW
  - Heterotrophic plate count (HPC) < 500/mL ≡ "detectable"
- Intent behind regulations
  - Distribution system integrity
  - Proper system maintenance
  - Identify & limit outside contamination
  - Limit heterotrophic bacteria & *Legionella* growth
  - Provide quantifiable minimum target → action

Issues with Detectable

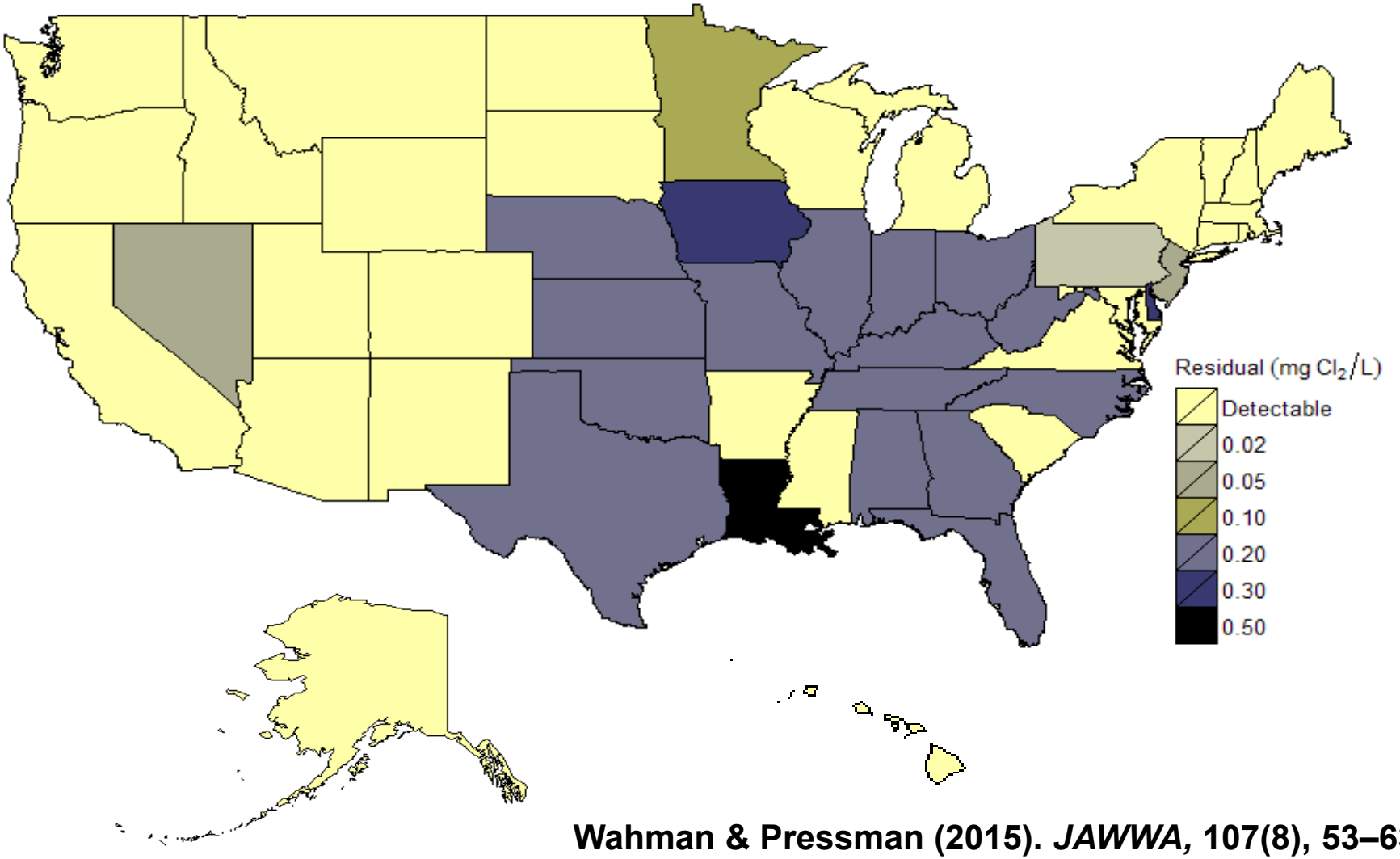
Free Chlorine

- Method Detection Limit
- Pathogenic organism continuous disinfection
- Premise plumbing concerns
- Is there really residual present?

Chloramines

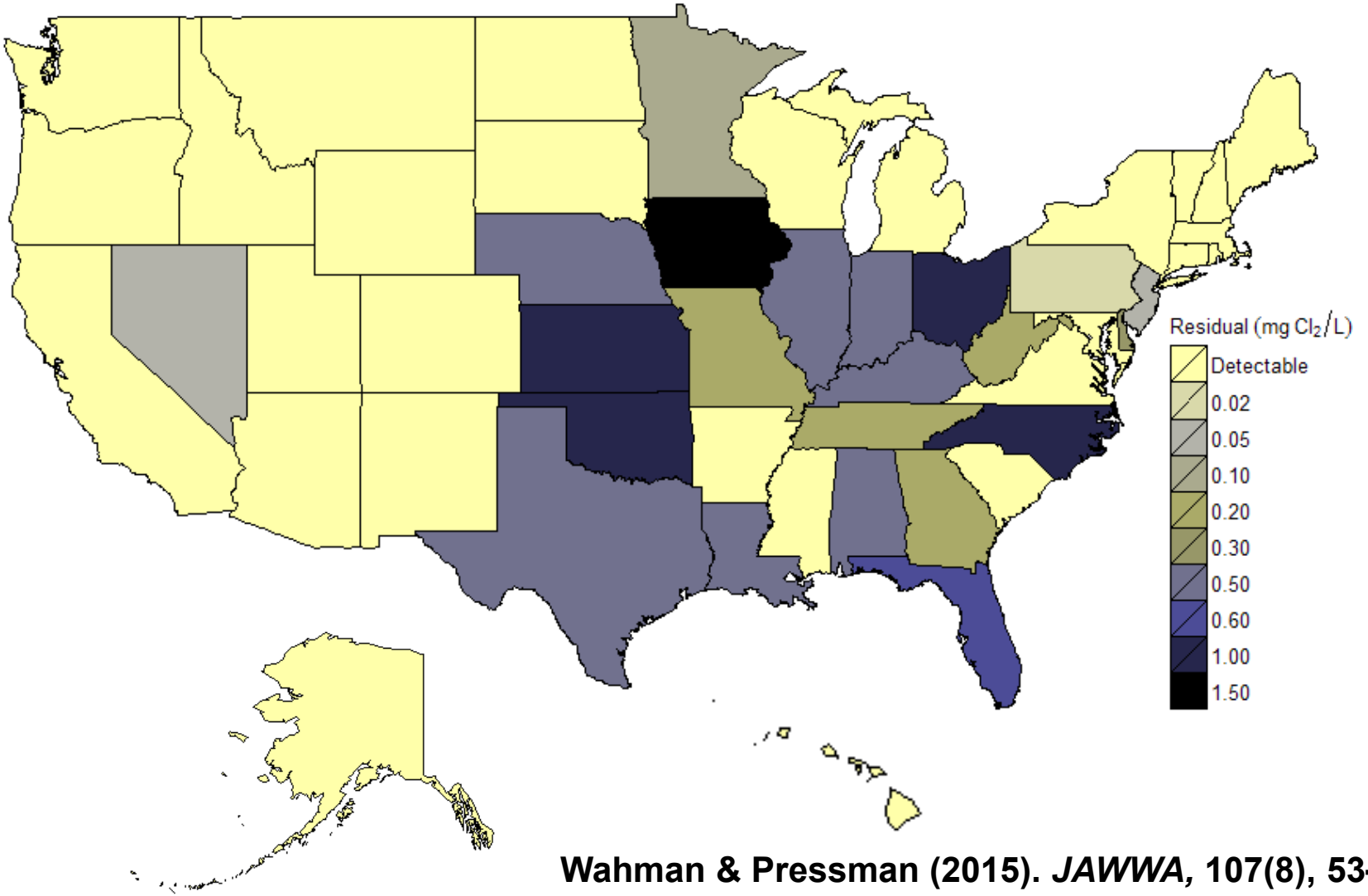
- Organic chloramines
  - Poor disinfectants
  - Interfere with analytical methods
- Nitrification/biofilm
- Premise plumbing concerns
- Pathogenic organism continuous disinfection

State Free Chlorine Residual



Wahman & Pressman (2015). *JAWWA*, 107(8), 53–63

State Total Chlorine Residual



Wahman & Pressman (2015). *JAWWA,* 107(8), 53–63

Residual Monitoring Locations

Total Coliform Rule

141.74C(3)(i) …….the residual disinfectant concentration must be measured at least at the same points in the distribution system and at the same time as total coliforms are sampled, …..

141.853 General monitoring requirements for all public water systems. (a) *Sample siting plans.* (1) Systems must develop a written sample siting plan that identifies sampling sites and a sample collection schedule that are representative of water throughout the distribution system …... These plans are subject to State review and revision…….

State RTCR Sample Site Requirements

- Conducted preliminary web–based search
- Three general categories
  - Prescribed minimum number of sample sites
    - Arkansas
    - Kansas
    - Louisiana
    - New Mexico
    - North Carolina
    - South Dakota
    - Texas
  - General guidance on “representative”
    - New Jersey
    - Oklahoma
    - Tennessee
  - No additional guidance

Specific Sample Site Number Requirements

- Based on population and # samples required
- Texas (RG-421):
- New Mexico:

Population Served	Minimum Number of Routine Distribution Coliform Samples	Number of Routine Sample Sites
1 to 1,000	1 per month	At least 5.
1,001 to 2,500	2 per month	
2,501 to 3,300	3 per month	
3,301 to 4,100	4 per month	
4,101 to 4,900	5 per month	
4,901 to 5,800	6 per month	Same number of sample sites as samples. *Example:* a system that collects 9 samples must have 9 sample sites.
5,801 to 6,700	7 per month	
6,701 to 7,600	8 per month	
7,601 to 8,500	9 per month	
8,501 to 12,900	10 per month	
12,901 to 17,200	15 per month	
17,201 to 21,500	20 per month	
21,501 to 25,000	25 per month	
25,001 to 33,000	30 per month	
33,001 to 41,000	40 per month	At least 30.
41,001 to 50,000	50 per month	
50,001 to 59,000	60 per month	Half the number of sample sites as samples. *Example:* a system that collects 240 samples must have at least 120 sample sites.
59,001 to 70,000	70 per month	
70,001 to 83,000	80 per month	
83,001 to 96,000	90 per month	
96,001 to 130,000	100 per month	
130,001 to 220,000	120 per month	
220,001 to 320,000	150 per month	
320,001 to 450,000	180 per month	
450,001 to 600,000	210 per month	
600,001 to 780,000	240 per month	
780,001 to 970,000	270 per month	

Population Range	Minimum Number of Samples per Month Required by Population	Multiplier to Obtain Minimum Number of Routine Monitoring Sites Required on the DSSP
25 to 2500	1 - 2	4
2501 to 12,900	3 - 10	3
12,901 to 33,000	15 - 30	2
33,001 or more	40 - 480	1.5

Specific Sample Site Number Requirements

- Louisiana (Rule - Title 51):
- §903. Coliform Routine Compliance Monitoring.
  - The monitoring plan shall include a minimum number of point of collection (POC) monitoring sites calculated by multiplying **1.5 times the minimum number** of samples required to be routinely collected…..

- §367. Disinfectant Residual Monitoring and Record Keeping
  - B. Disinfectant Residual Monitoring in Distribution System. A public water system shall measure the residual disinfectant concentration within the distribution system:
  - 1. by sampling at the same points in the distribution system and at the same times that samples for total coliforms are required to be collected by the public water system under
  - this Part;
  - 2. by sampling at an **additional number of sites calculated by multiplying 0.25 times the number of total coliform samples** the public water system is required under this Part to take on a monthly or quarterly basis, rounding any mixed (fractional) number product up to the next whole number. These additional residual monitoring samples shall be taken from sites in low flow areas and extremities in the distribution system at regular time intervals throughout the applicable monthly or quarterly sampling period; and
  - 3. by sampling at the site that represents the maximum residence time (MRT) in the distribution system at least once per day

General Sample Site Number Requirements

- Oklahoma
- Areas of concern in the distribution system should be represented in the routine sample sites to ensure representative sampling. Such areas include:
  - Dead ends
  - Low pressure zones
  - Areas with longer retention times
  - Upstream and downstream of storage tanks
  - Areas serving water from different sources

- Tennessee

Systems may generally follow the procedure below when selecting sampling sites

1. Coliform samples shall be collected at sites, which are representative of water throughout the distribution system according to the written sample-siting plan.
2. Samples are to be collected from a free flowing outlet of the ultimate user of the public water system, a dedicated sampling station or other designated compliance sampling location.
3. The goal should be to collect at least 30% of the required samples from residential areas. For the purposes of this plan, residential areas are defined as locations in the distribution systems which are served by the smallest distribution lines.
4. The system some of the required samples from dead end lines, low use areas, and areas near large storage tanks.
5. A map of the system with designated sampling zones and sampling site locations should be developed and included in the plan.

Guidance

Developing a Bacterial Sampling Plan Guidance Manual

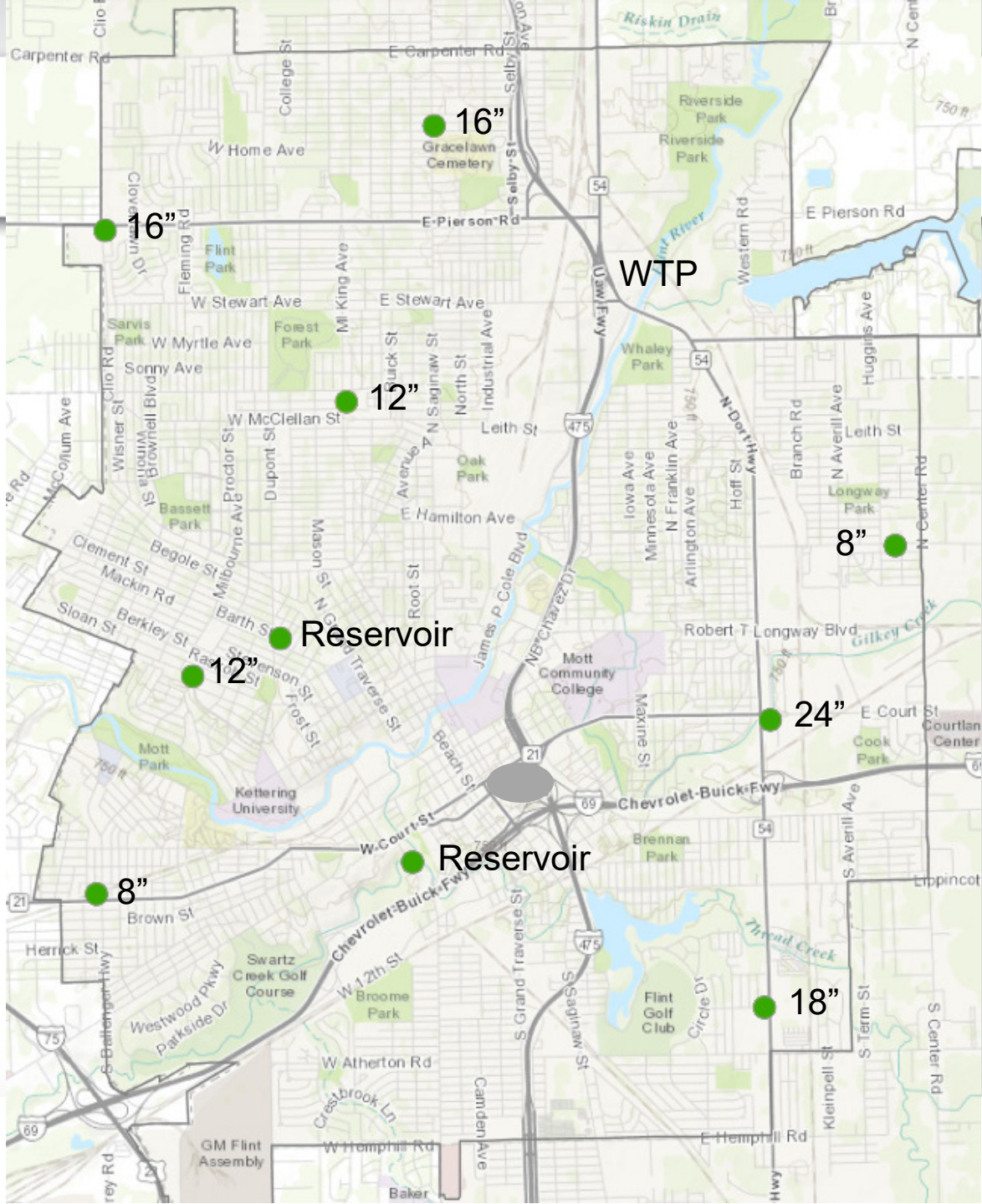
Narasimhan, R., Brereton, J., 2004, AwwaRF report 90989F

- The procedures used in setting up an effective bacterial monitoring program involve the following sequence of steps:
  - ***Step 1: Information Assessment*** - This involves gathering all relevant information and compiling system maps to be used in drawing out the monitoring plan.
  - ***Step 2: Development of Sectors*** - This provides techniques to divide the entire system into manageable sectors.
  - ***Step 3: Sample Distribution by Sectors*** - Based on the number of compliance samples required, the number of samples per sector is determined.
  - ***Step 4: Sector Characterization and Sample Siting Within Sectors*** - Critical elements impacting bacterial monitoring are identified and general monitoring locations are identified within each sector.
  - ***Step 5: Tap Selection Process*** - Specific sampling locations are identified according to recommended criteria that best provide representative results reflective of the bacterial water quality in the distribution system.
  - ***Step 6: Documentation of a Formal Bacterial Monitoring Plan***

Case Study

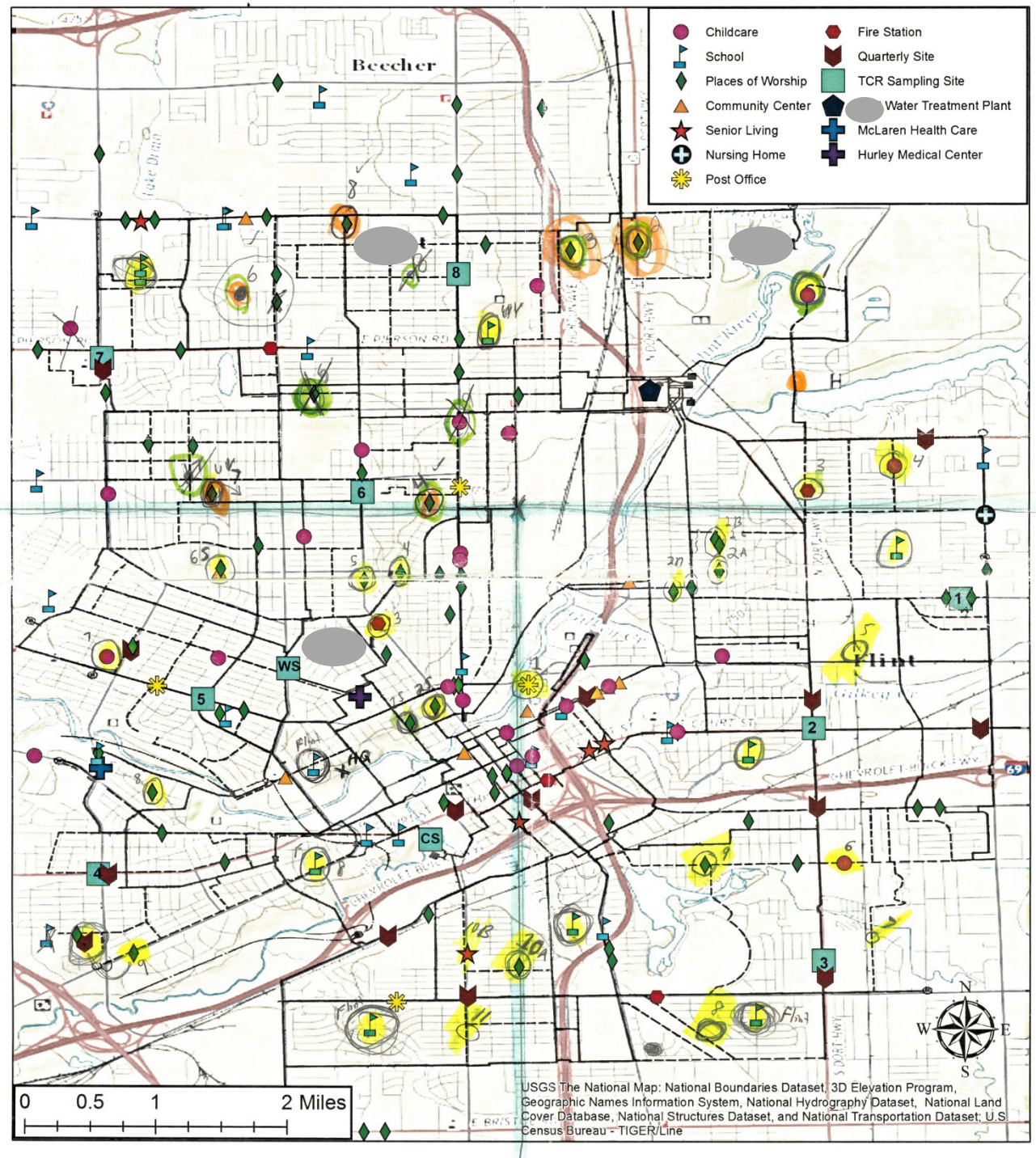
- Medium size city
- ~100,000 population
- 100 monthly TCR samples required
- 10 locations, 3× week

- EPA asked to assess chlorination in the DS to ensure the disinfection residual barrier and public health protection



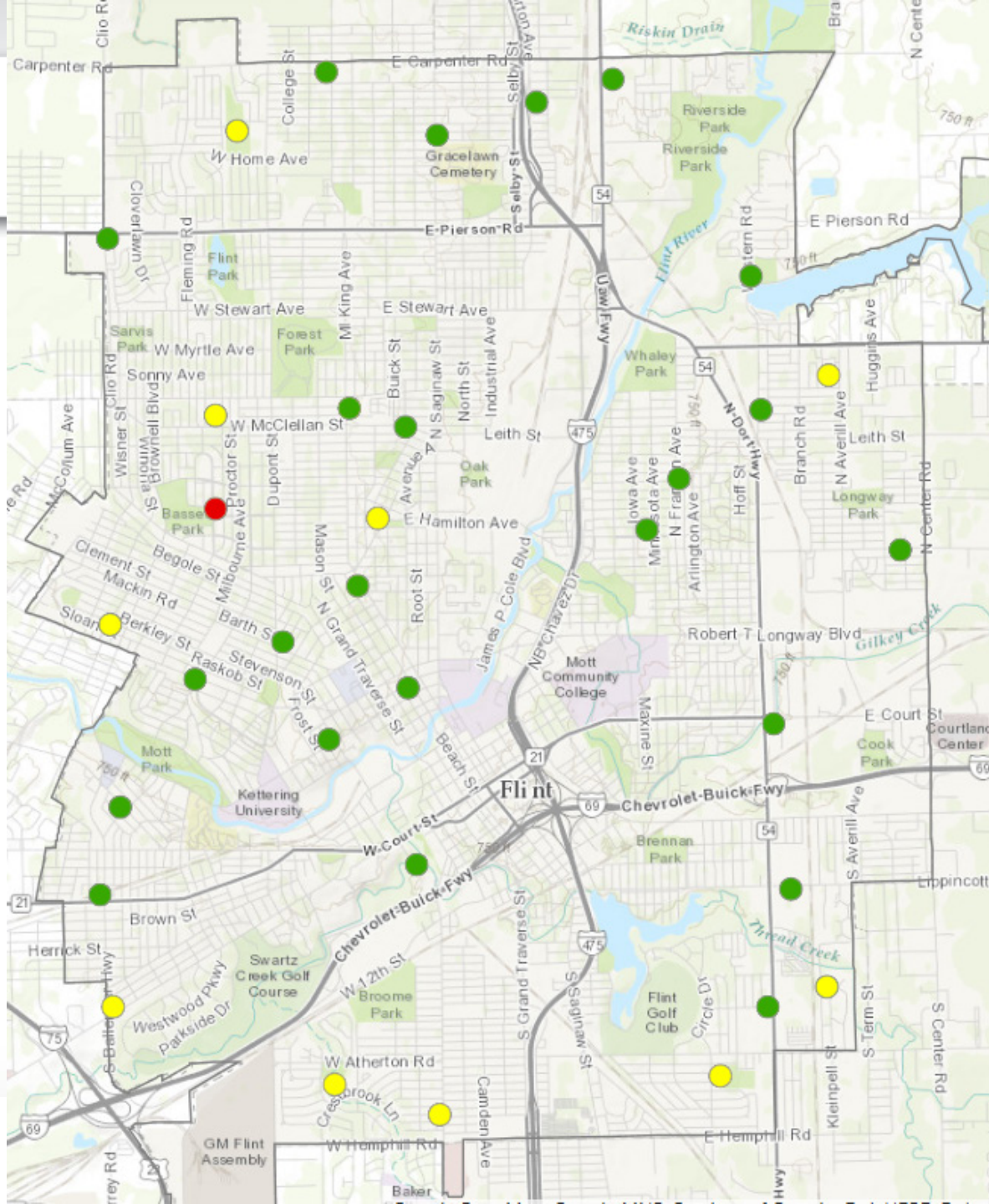
Case Study

- Additional Cl_2 monitoring locations justified:
  - Areas embedded with residences
  - Smaller diameter DS network/ representing ageing water
- 1 week implementation
- Mapped all public locations (i.e. schools, churches, etc.)
- Developed sectors
- Investigated areas closest to primary residential water usage
- Measured service lines and flow rates / calculated flush times



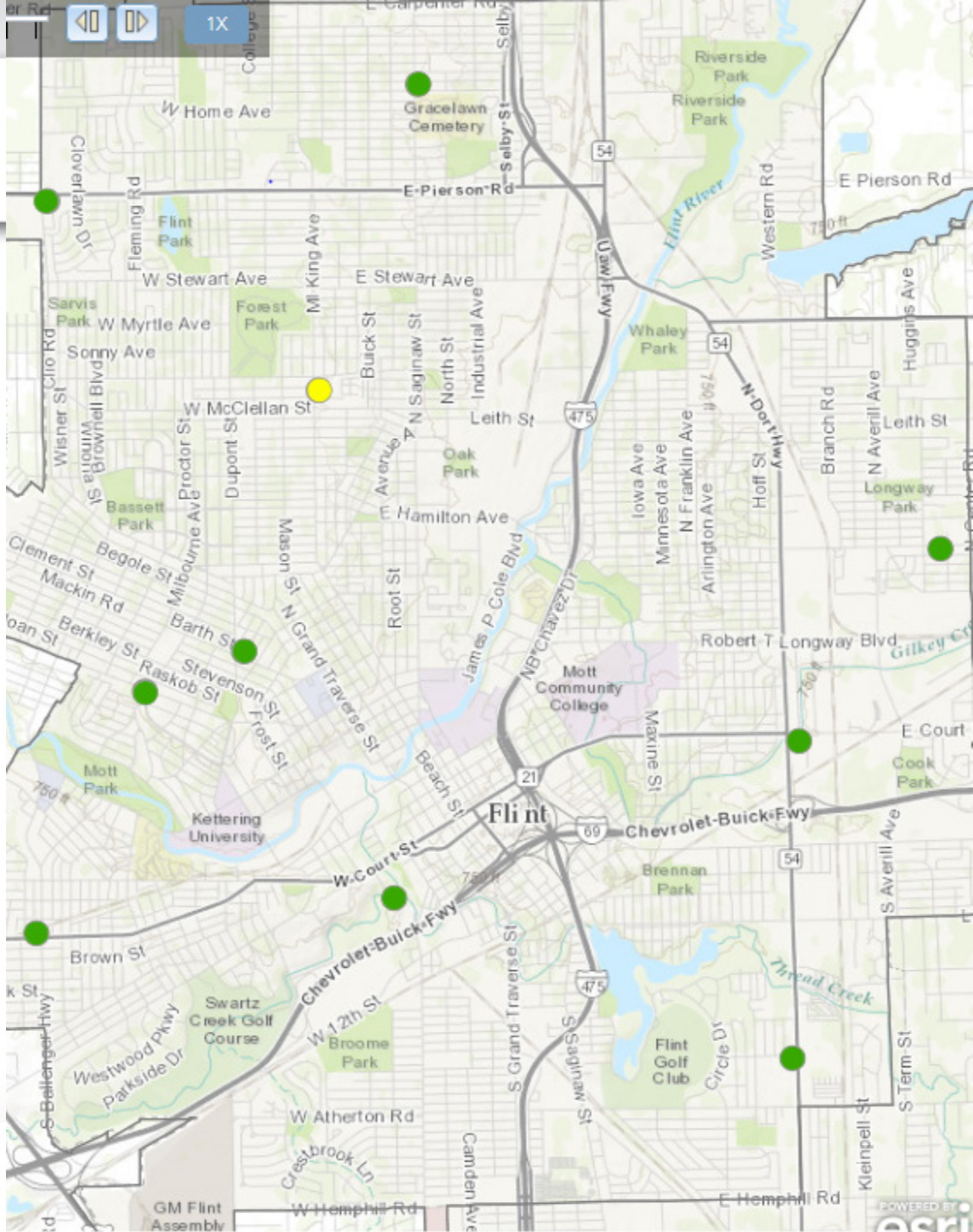
Case Study

- Added 24 Cl_2 monitoring sites
- Mostly churches, schools, childcares
- Combined with the 10 Utility sites, total = 34 Cl_2 monitoring locations weekly



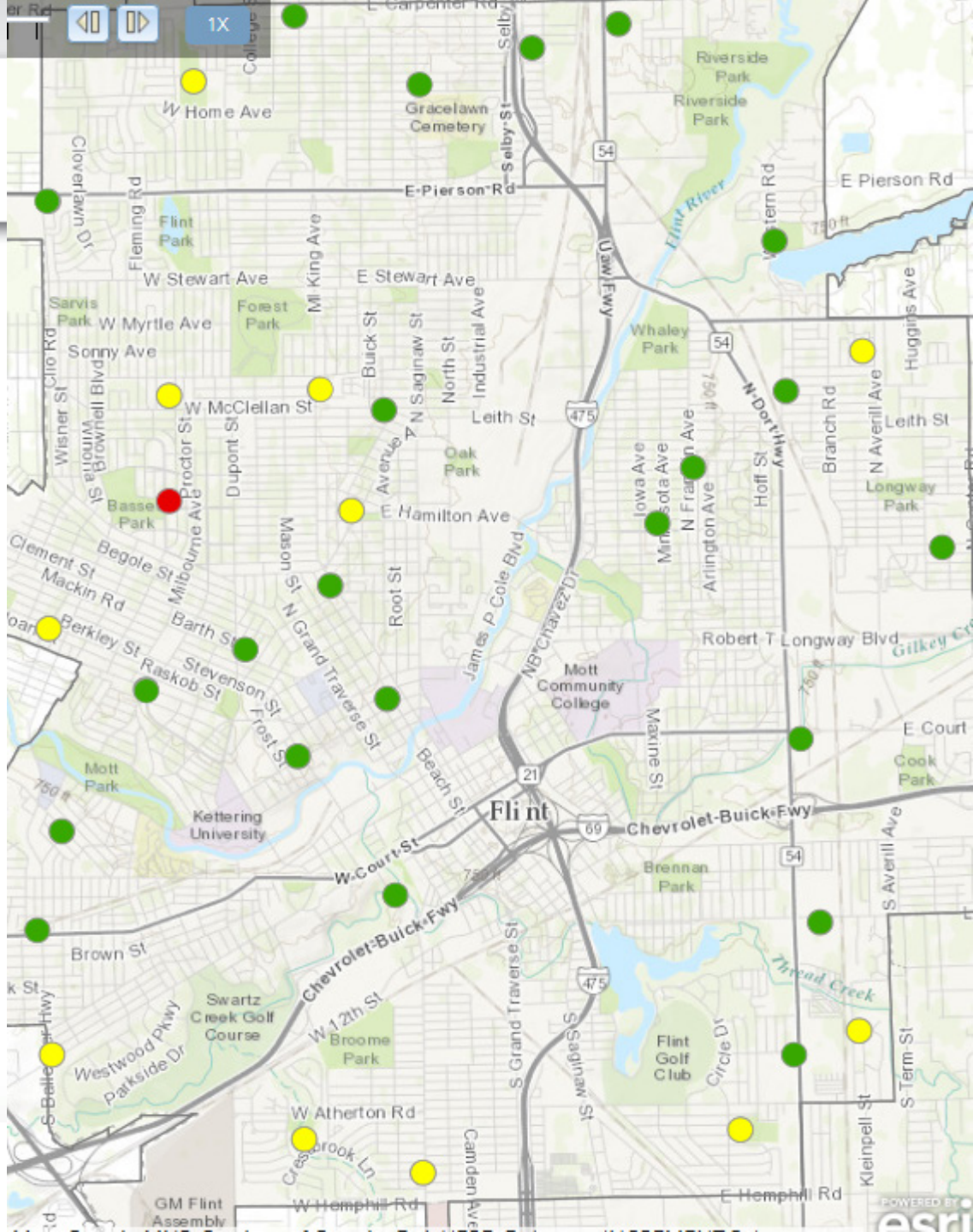
Case Study

- Cl_2 residuals
- 10 Utility TCR monitoring locations
- Working with Utility to implement best practices
- Including flushing program for localized low residual areas



Case Study

- Cl_2 residuals
- 10 Utility TCR monitoring locations + 24 EPA Cl_2 monitoring locations
- Enough Sites?



- 0.5 mg/L and greater
- 0.2 mg/L to less than 0.5 mg/L
- Less than 0.2 mg/L

Six–Year Review (SYR) Process

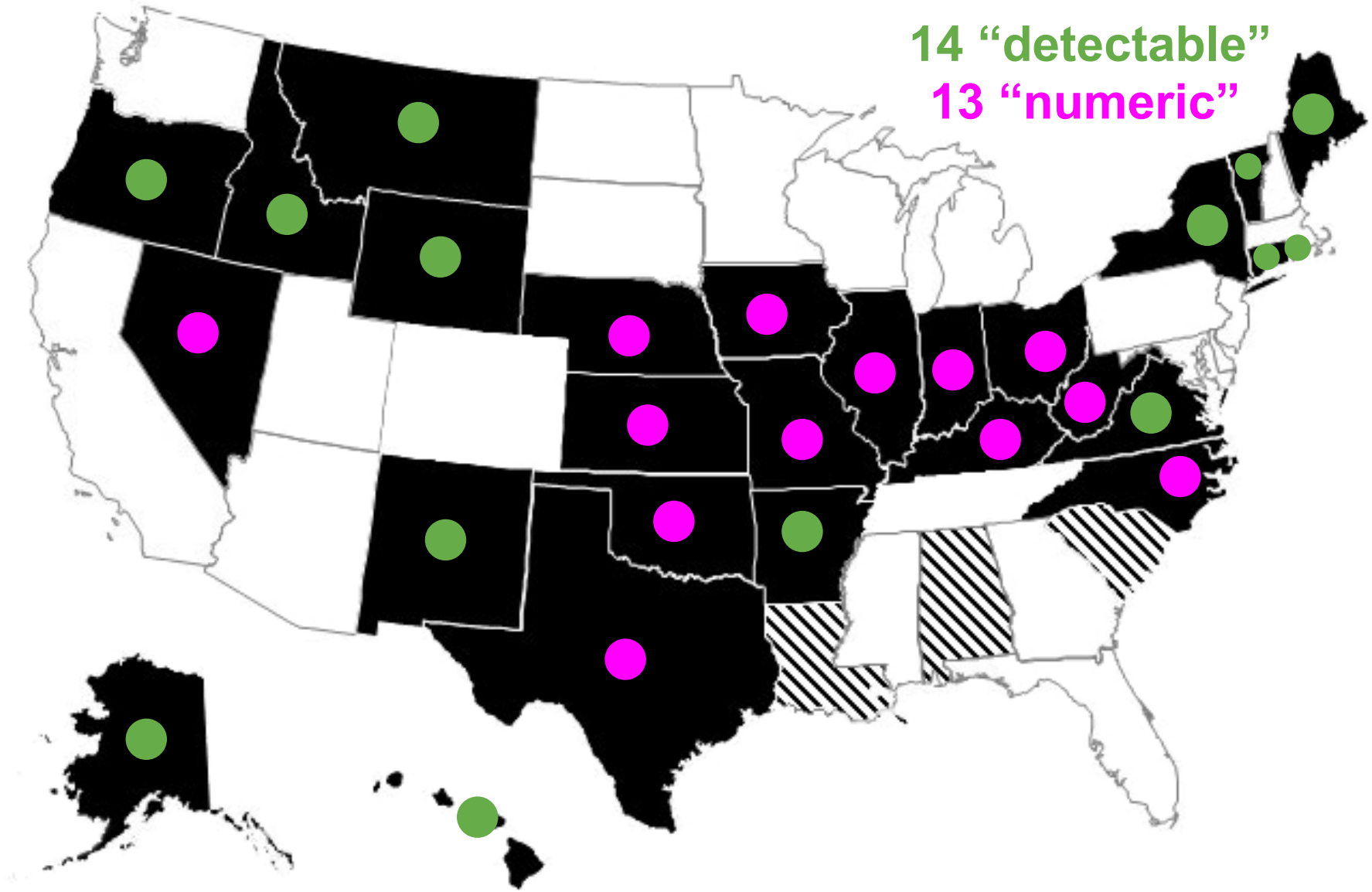
https://www.epa.gov/dwsixyearreview

- 1996 Safe Drinking Water Act (SDWA) requirement
- Review primary drinking water regulations every six years
- Third Six–Year Review (SYR3) completed December 2016
  - Occurrence data (2006–2011)
  - Included Microbial and Disinfection By–Product (DBP) regulations
  - Revision candidates
    - Chlorite
    - *Cryptosporidium* (under IESWTR, LT1)
    - *Giardia Lamblia* (under SWTR)
    - HAA5 & TTHM
    - HPC
    - *Legionella*
    - Viruses (under SWTR)

SYR3 Microbial Dataset

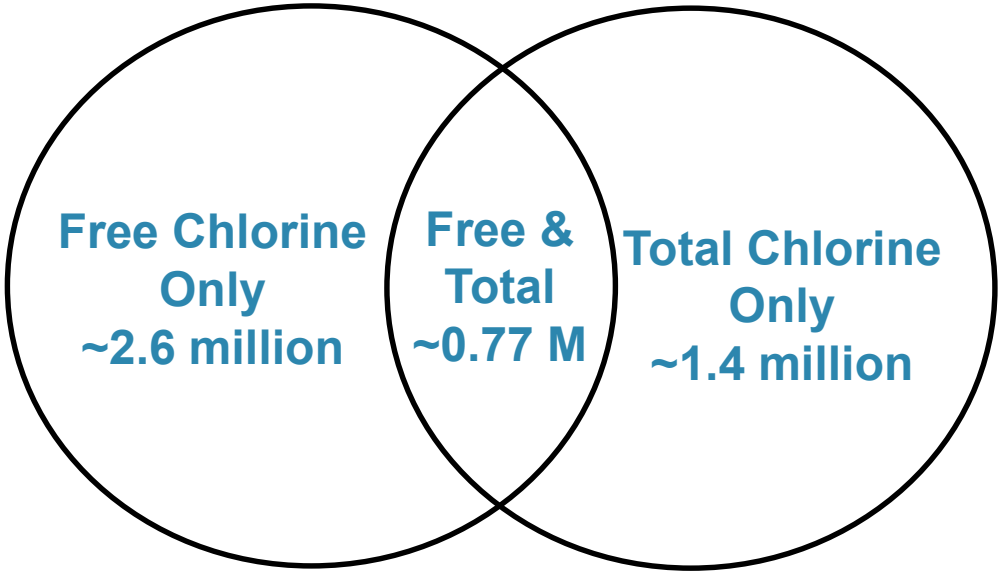
- 2006–2011 occurrence data collection
  - 46 states/entities
  - 47 million compliance & water quality records
  - Initial QA processing → Full Dataset
    - 12 million microbial → total coliform (TC), *E. coli* (EC), or fecal coliform (FC)
    - 9 million residual → free chlorine or total chlorine
- Additional QA/QC processing
  - Paired disinfectant residual & microbial data
  - 5.5 million paired records → Reduced Dataset
  - 34 states/entities
    - 27 states
    - 7 tribes/territories
- Datasets available online

States in SYR3 Reduced Microbial Dataset



Source: Exhibit A.3 Six-Year Review 3 Technical Support Document for Microbial Contaminant Regulations, EPA 810-R-16-010, 12/2016

Residuals in Reduced Dataset

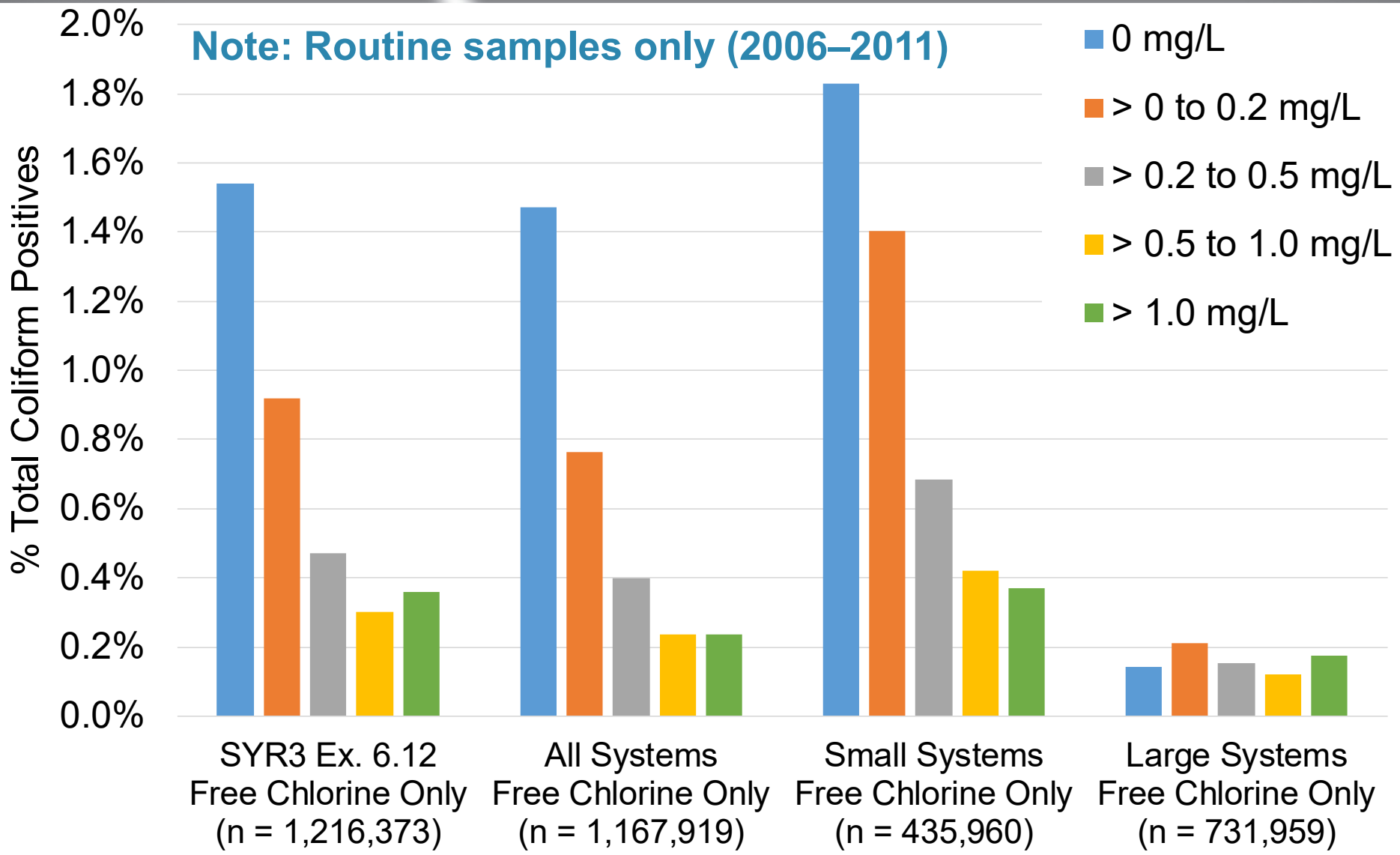


- 5.5 million records
  - 3.3 million free chlorine
  - 2.2 million total chlorine
- Free chlorine only → free chlorine system
- Total chlorine only → chloramine system?
- Both → system?

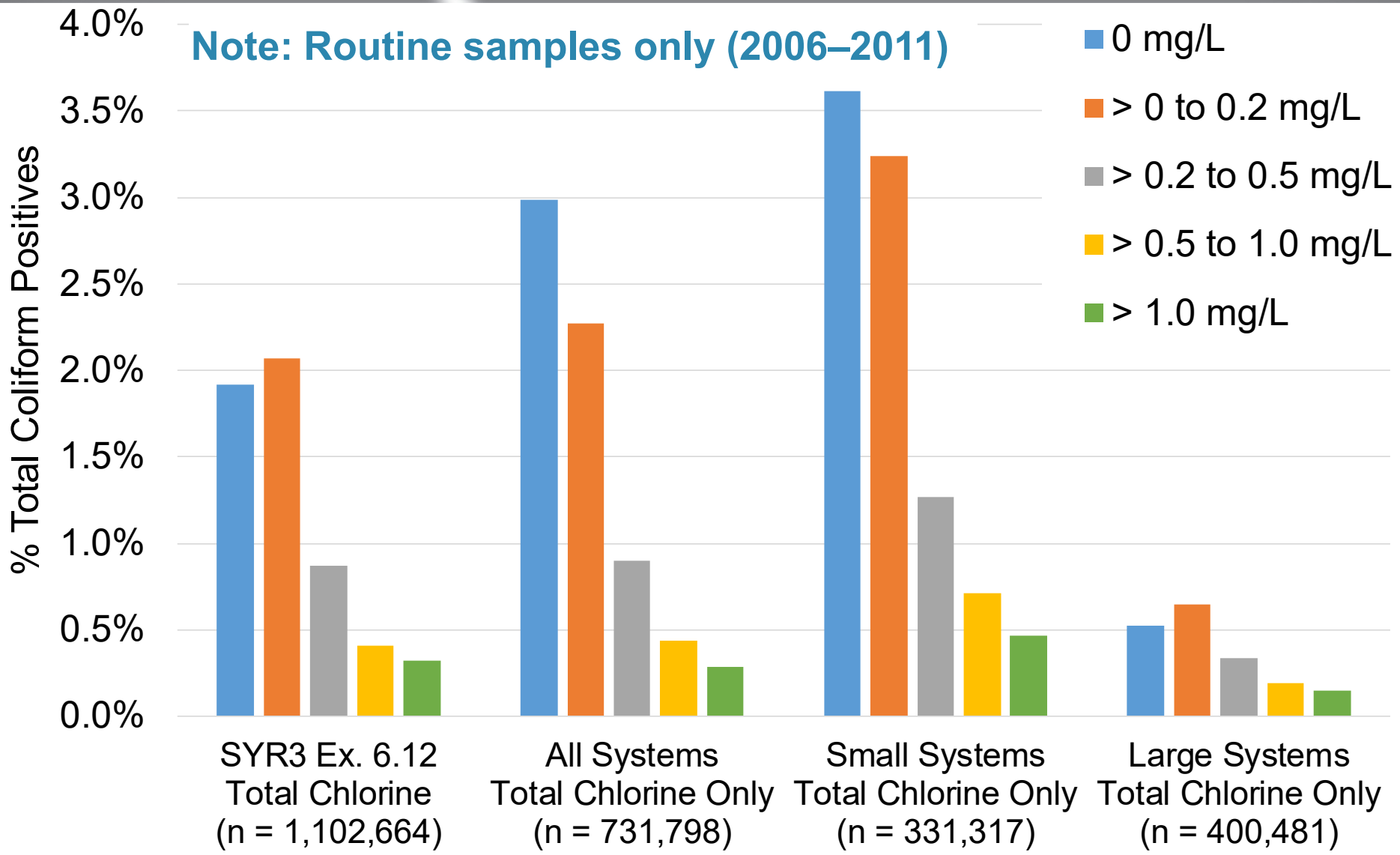
Further Dataset Reductions

- Reported residual
  - Free chlorine only → free chlorine system
  - Total chlorine only → chloramine system
  - Both free & total chlorine → excluded
- Systems
  - Small: ≤ 17,200 (less than 20 samples/month)
  - Large: > 17,200 (20 minimum samples/month)
  - Community water systems (CWSs) only
  - Surface water systems (SW) only
- System–month screening
  - Months where ≥ 50% of total coliform rule (TCR) required samples were collected
  - Exclude months not meeting standard

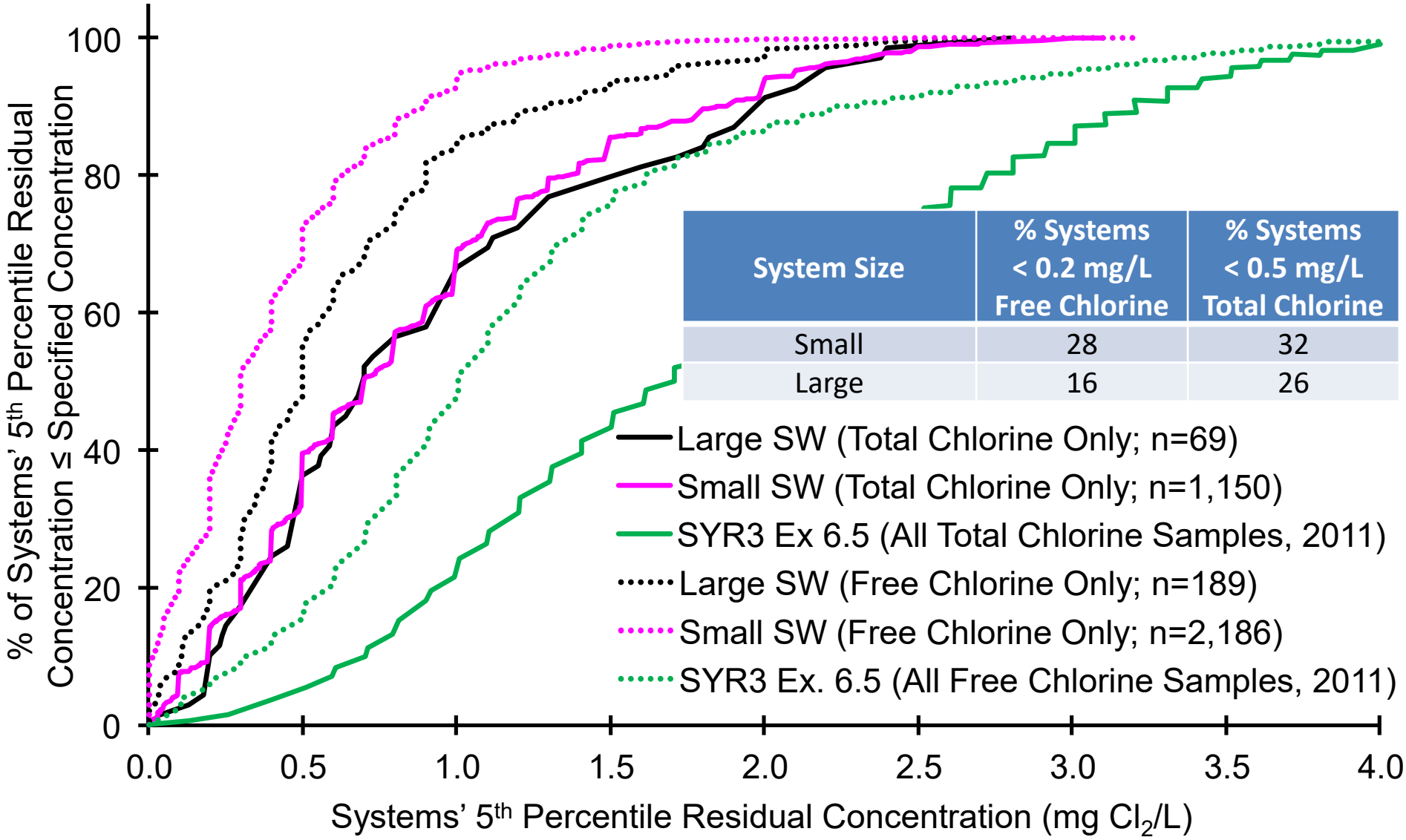
Total Coliform Positives
Free Chlorine SW CWSs by Size



Total Coliform Positives
Total Chlorine SW CWSs by Size



Cumulative % Residual in SW (2006–2011) – System Level



System Size	% Systems < 0.2 mg/L Free Chlorine	% Systems < 0.5 mg/L Total Chlorine
Small	28	32
Large	16	26

Increasing Residuals and DBPs

- Water samples from 21 utilities tested to determine impact of increasing residual chlorine on DBPs
- Trace chlorine residuals insufficient to fully react with organics
  - DBP formation potential remains
  - suggests insufficient chlorine to fully react with introduced pathogens or other contaminants
- Increasing chlorine residuals:
  - Trace to 0.2-0.5 mg/L results in large DBP increases
  - Once demand is met, DBP increases are modest

Roth, D.K., Cornwell, D.A. DBP Impacts From Increased Chlorine Residual Requirements. JAWWA, 110(2) 13-28, 2018

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Questions?

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