EMORY UNIVERSITY | Center for Global Safe Water

Measures of Distribution System Water Quality and Their Relation to Health Outcomes in Atlanta

EPA RESEARCH FORUM: Advancing Public Health Protection through Water Infrastructure Sustainability

April 10-11, 2013

Arlington, Virginia

Christine Moe, Karen Levy, Mitch Klein, Stefanie Sarnat, Sarah Tinker, Jim Uber, Ethell Vereen, Samina Panwhar, Amy Kirby, Ashleigh Streby, Corey Jackson, Alexandra Huttinger, Paige Tolbert

This research is funded by U.S. EPA - Science To Achieve Results (STAR) Program

Grant # R834250

EMORY ROLLINS SCHOOL OF PUBLIC HEALTH

Health Concerns about Drinking Water Distribution Systems

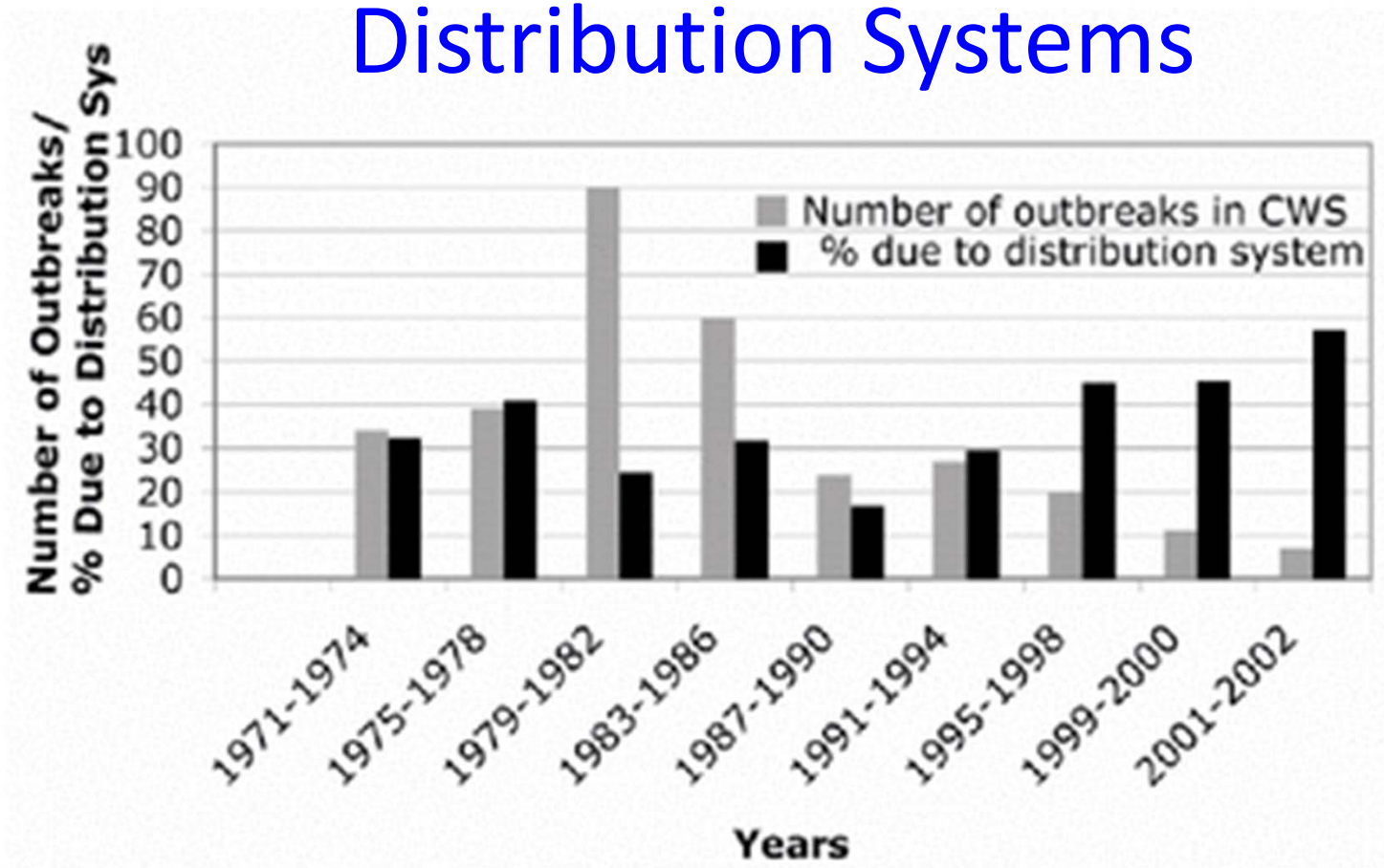


FIGURE 1-1 Waterborne disease outbreaks in community water systems (CWS) associated with distribution system deficiencies. Note that the majority of the reported outbreaks have been in small community systems and that the absolute number of outbreaks has decreased since 1982. SOURCE: Data from Craun and Calderon (2001), Lee et al., (2002), and Blackburn et al. (2004).

National Research Council, 2006

How much endemic waterborne AGI is associated with water distribution systems?

Previous Epidemiology Studies:
How much AGI is associated w/Distribution Systems?

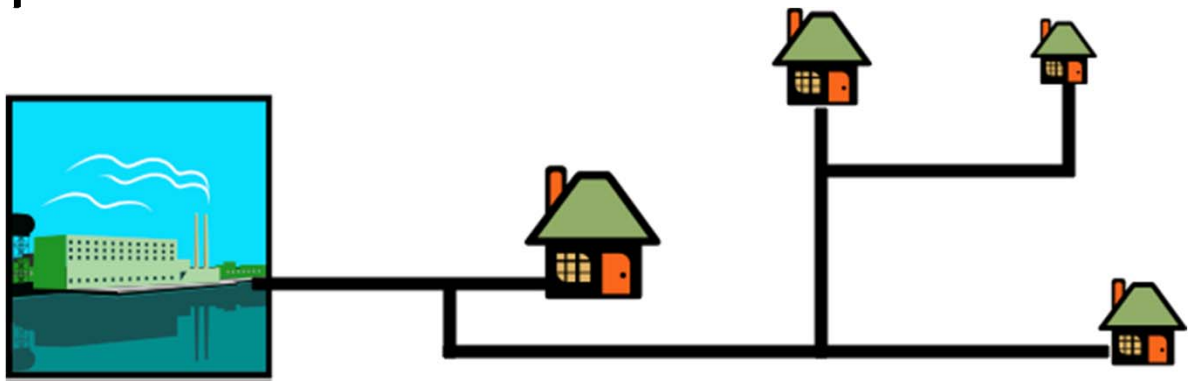
• Laval, Montreal, 1993-94 (Payment et al. 1997)	DS had a significant role, No correlation w/WRT
• UK, 2001-02 (Hunter et al. 2005)	15% of AGI assoc w/DS problems
• Norway, 2003-04 (Nygard et al. 2007)	37% due to low pressure events in DS
• Atlanta, 1993-2004 (Tinker et al. 2008)	Modest assoc w/raw water turbidity
• Atlanta, 1993-2004 (Tinker et al. 2009)	Modest assoc w/WRT

Overall Research Objectives

- Does water degradation in the distribution system contribute to sporadic gastrointestinal illness?
- Can we identify “more vulnerable” areas of the distribution system and
  - Characterize water quality in these areas
  - Characterize risk of waterborne disease in these areas

Objective 1

- Does water degradation in the distribution system contribute to sporadic GI illness?



- Does refined exposure assessment using more spatially refined data improve our ability to answer this question?

Gastrointestinal Disease Data

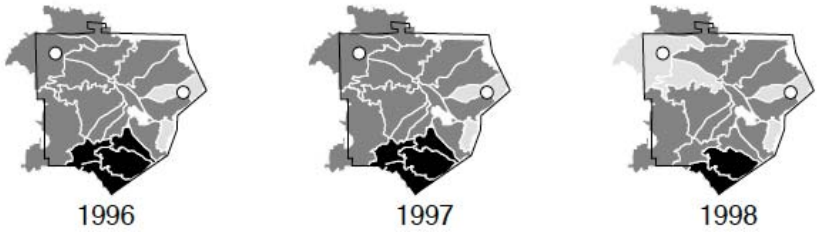
- 41 hospitals in Metro Atlanta
- 4.4 million ED records
- 254,760 GI illness records (based on ICD-9 codes)
- Non-injury visits = comparison group
- Address + zip-code data for majority of records

SOPHIA
Study of Particles and Health in Atlanta

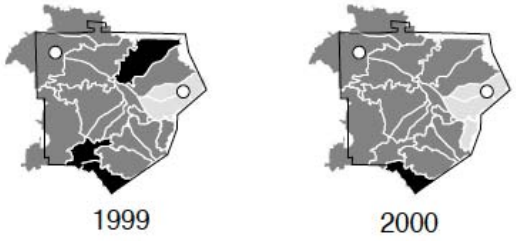
Water Utility Data

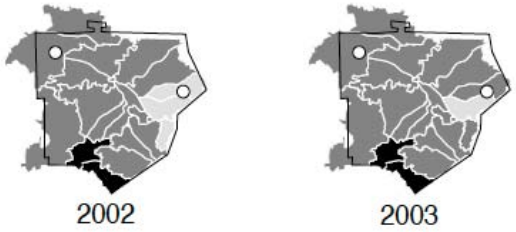
- Hydraulic Models
- Utility Coverage Areas
- Water Residence Time from plant to node (estimated through simulations of water flow through the distribution system)

Utility 1



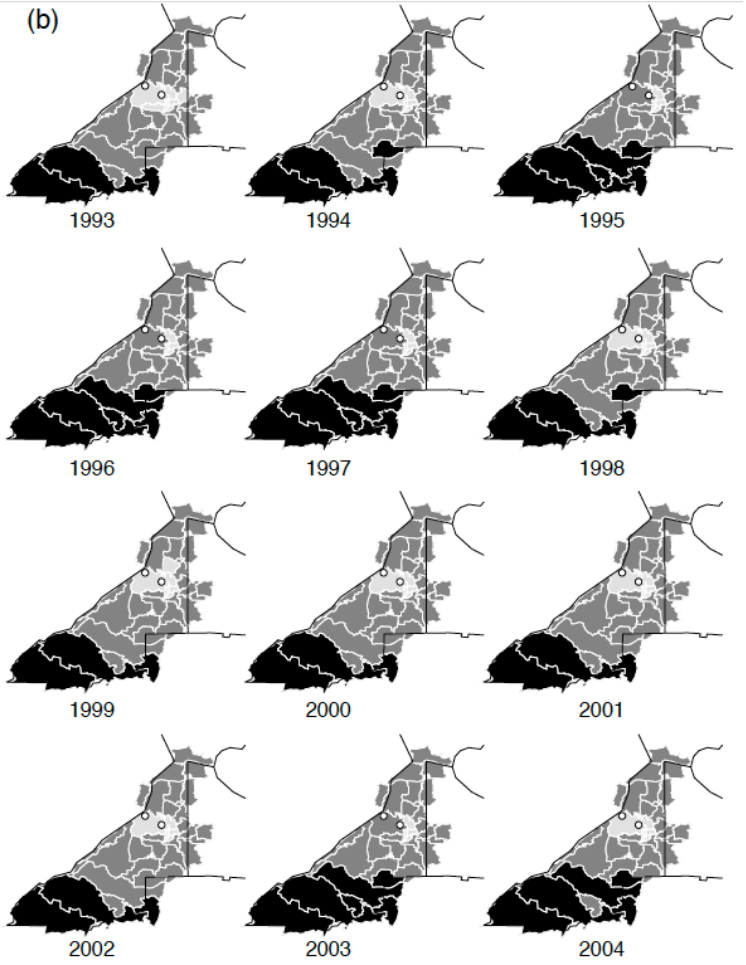
WRT: short 6.8 /intermediate 22.0 / long 47.4 hrs



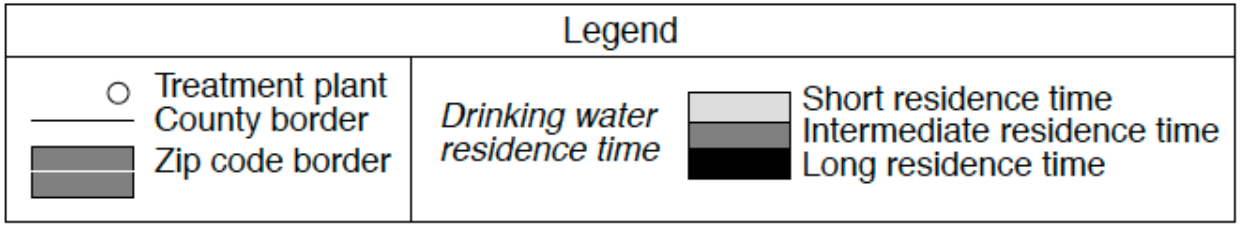


WRT: short 10.1 / intermediate 33.4 / long 74.4 hrs

Utility 2



WRT: short 5.9 / intermediate 18.5 / long 60.4 hrs



Control Variables

(Census Data & ED records)

- Age
- Season
- Year
- Hospital
- Distance from zip code centroid to hospital
- Zip code median income
- Zip code percent minority
- Medicaid payment status
- Age*Medicaid
- Age*Distance to hospital
- Medicaid*Distance to hospital

Controlling for these factors means that, ideally, any association we might see between residence time and ED visits for GI illness is not the result of uneven distribution of these factors between zip codes.

Tinker et al. 2009

2 Water Utilities

↓

Node-level water residence time estimates

Utility 1: 272,782 nodes
Utility 2: 240,480 nodes

↓

Average WRT by zipcode

Separate estimates for each year of study

28 Atlanta Hospitals

↓

ED visits 1993-2004

164,937 GI illness visits
2,092,735 non-injury (control) visits

↓

Zipcodes with 80% coverage by utility service area

Utility 1: 785,634 total visits
Utility 2: 1,307,101 total visits

Zipcode-level census data on covariates

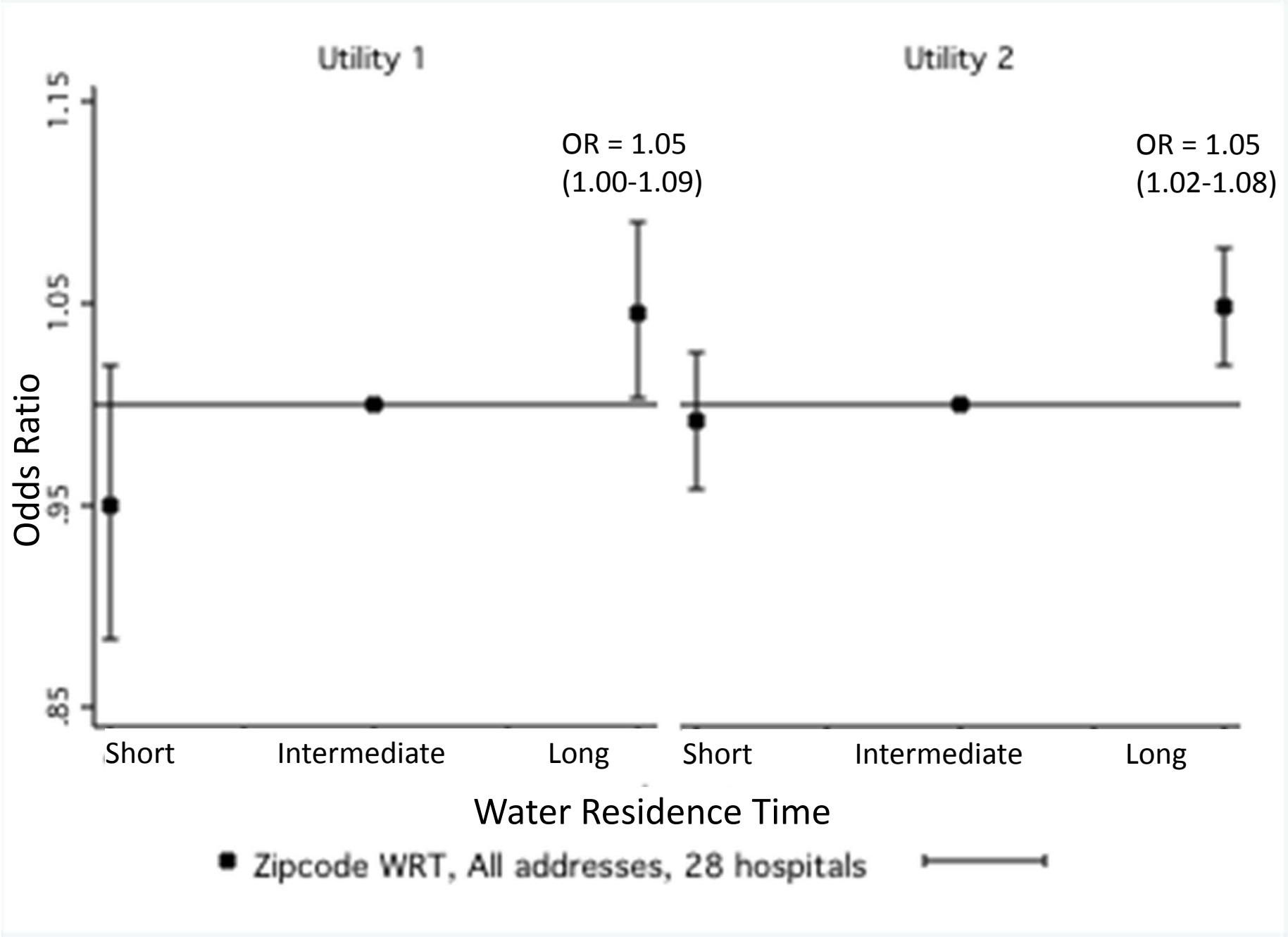
↓

Logistical regression models

This method allowed us to assess the relationship between the category of water residence time (short, intermediate, long) assigned to a zip code and the incidence of ED visits for GI illness in that zip code, controlling for the effects of other factors that might contribute to GI illness in the zip code.

Drinking water residence time in distribution networks and emergency department visits for gastrointestinal illness in Metro Atlanta, Georgia

Sarah C. Tinker, Christine L. Moe, Mitchel Klein, W. Dana Flanders, Jim Uber, Appiah Amirtharajah, Philip Singer and Paige E. Tolbert



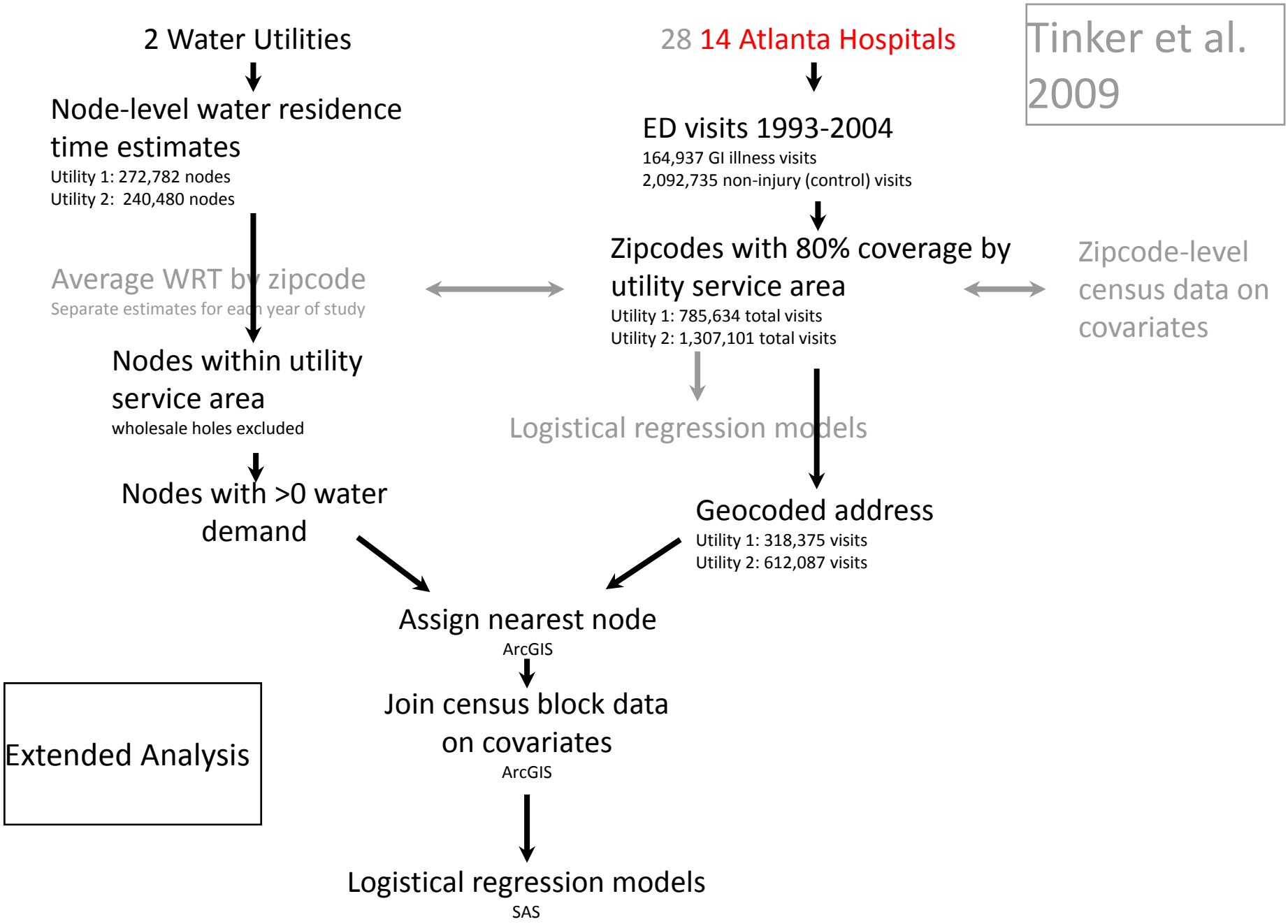
Based on Tinker et al. 2009. JWH 7(2): 332-343

Conclusions (Tinker et al. 2009)

- People living in zip codes receiving water with the longest residence time (>90 %ile) in the distribution system may be at modestly increased risk for GI illness

Extended Analysis

- How does a more refined exposure assessment using more spatially refined patient data (geocoded addresses rather than zipcode-level data) affect the results?

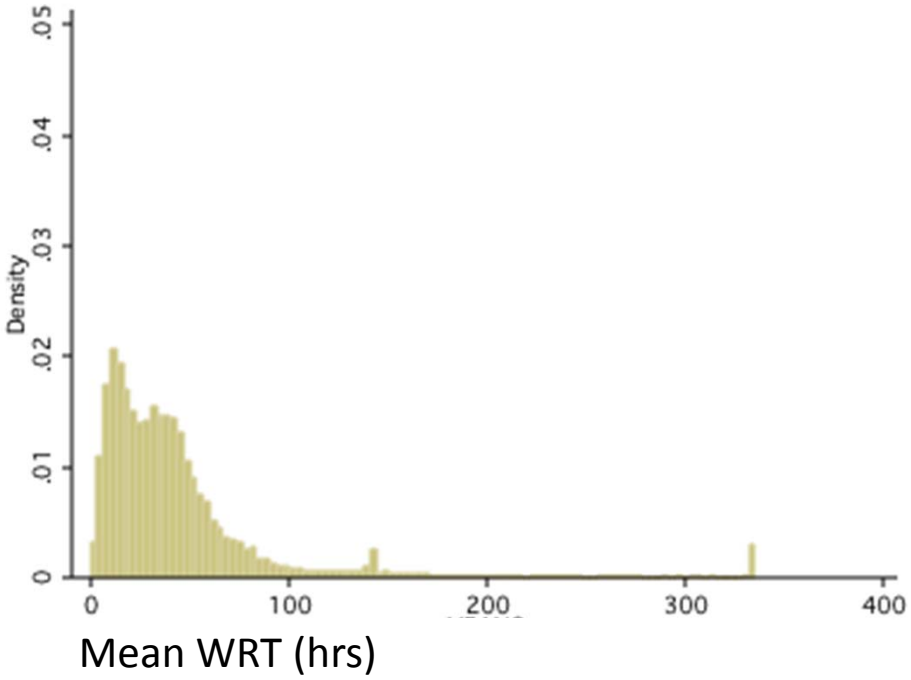


Water Utilities

Utility 1	Utility 2
680,000 customers	1.2 million customers
650 square miles	348 square miles
“Hub and Spoke”	“Plate of Spaghetti”
50 years old	>100 years old
Higher median income	Lower median income
65% Caucasian	85 % African American

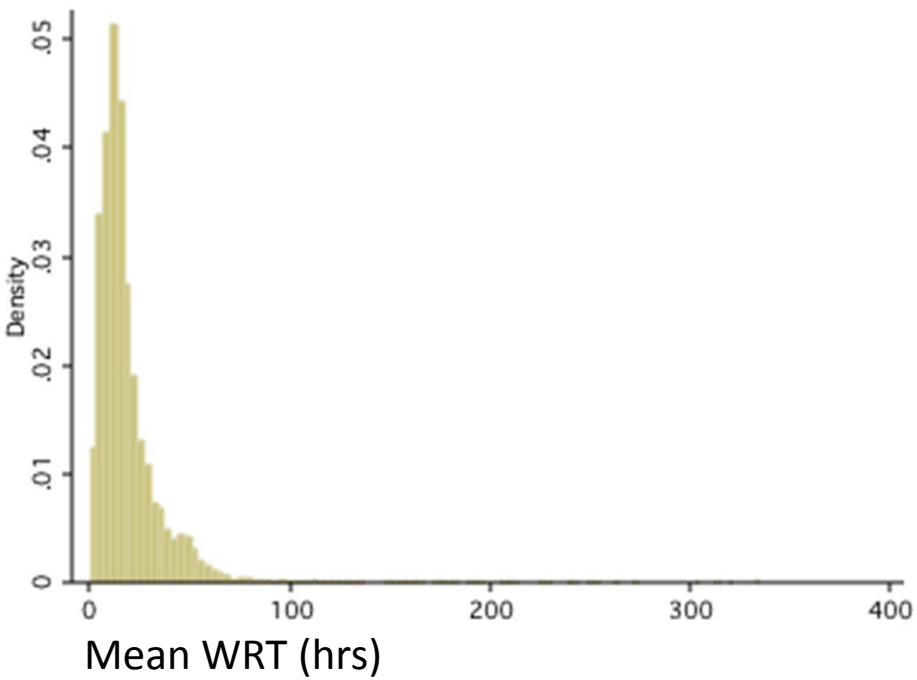
Water Residence Times

Utility 1



Min: 0.08 hrs
Max: 336 hrs
Avg: 47.2 hrs

Utility 2



Min: 0.24 hrs
Max: 336 hrs
Avg: 18.9 hrs

Conclusions of Spatially Refined Analyses

- No consistent relationship between water residence time and risk of gastrointestinal illness
  - Limited data for “longer” water residence time (>72 hours) for Utility 2

- WHY?

Limitations of Exposure Assignment

Zip & Geocode

–Node-level data (not going all the way to the tap)

–Household water consumption patterns

–One WRT measurement per node per year (true WRT is time-varying by season/day/hour based on differential demand)

–Mixing of water of different ages

–Misspecifications of the hydraulic model

Zip

–Heterogeneous WRT across nodes within a zipcode

–Small # of zipcodes &/or hospitals could have large influence on results

Geocode

–Errors in address assignment

–Assigning WRT to node might assume too much specificity (i.e., nearest node might not be where household gets water)... zipcode averages out these errors

Overall Research Objectives

- Does water degradation in the distribution system contribute to sporadic GI illness?
- Can we identify "more vulnerable" areas of the distribution system and
  - Characterize water quality in these areas
  - Characterize risk of waterborne disease in these areas

Methods

- Working definition of “more vulnerable” areas
  - Long water residence time
  - High incidence of main breaks
  - Frequent fluctuations in pressure

- Monitoring and sampling sites chosen based on cluster analyses of data provided by the water utility

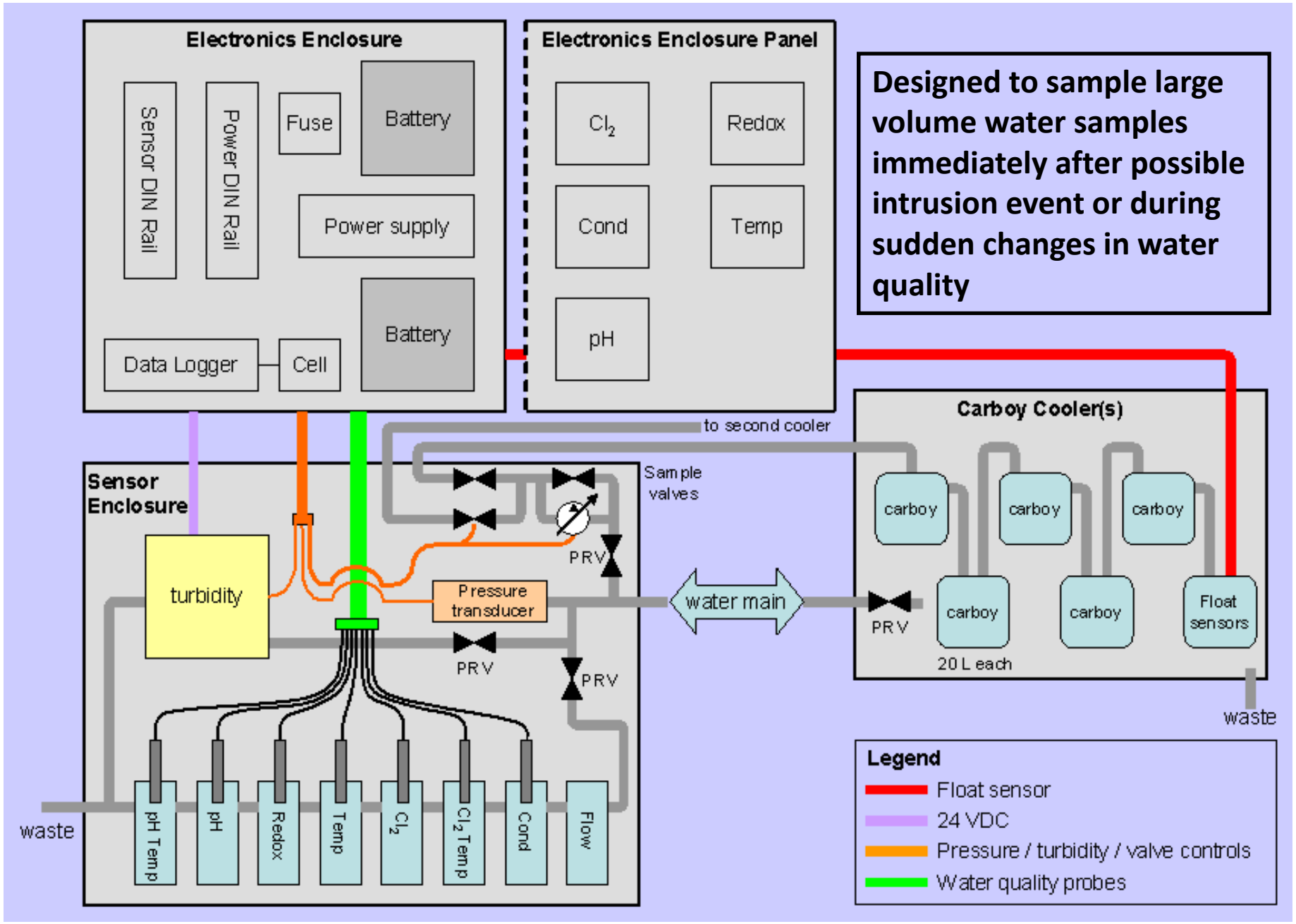
Methods

- Use remote sensing device to monitor physical and chemical parameters of the distribution system water quality
- Routinely collect and concentrate large volume (90 L) water samples and analyze for microbial indicator organisms and pathogens

Estimated Water Residence Time at Monitoring Locations

Site	Estimated Water Residence Time
Pressure Location	17 hours
Long WRT location	274 hours
Mains Break Location w/ AMS	0 hours
Mains Break Location, no AMS	22 hours
AMS Location 1	42 hours

Automated Monitoring & Sampling System (AMS) device



AMS Device Capabilities

- Continuously monitor and log water quality data:
  - Pressure (-15 to >185psi) - Conductivity (uS/cm)
  - Turbidity (NTU) - Temperature (^{o}C)
  - Total chlorine residual (mg/L) - Oxidation Reduction Potential (ORP)
  - pH
- Portable, Indoor or outdoor installation
- Main power source: 110 VAC; backup power: 24 VDC
- Programmable (sampling delay, sampling flow rate, event trigger)
- Collect 100-L samples (1-2) after water quality event
  - (15 min – 10 hours)
- Two-way communications (sampling alert, current status, force sample collection, download data, modify programming)
- Autoclavable (parts associated with microbial sampling)

Comparing Selected Physical and Chemical Water Quality Parameters at the Water Treatment Plant and in the Distribution System

AMS device installed at:

1)Water treatment plant: Jan-Sept 2012

2)DS monitoring site 1 (Fire station A): Sept 2012-March 2013

3)DS monitoring site 2 (Fire station B): April 2013 –

Large dataset:

- Redox, conductivity, pH, & temperature data collected once per minute with AMS
- Chlorine, turbidity collected once every 5 seconds with AMS
- Pressure collected once every second with AMS

Summary of AMS Results

- Challenging to clean very large dataset
  - Some probe data included >3 million data points
  - Difficult to determine what data extremes represented a water quality "event" of interest (such as a turbidity spike or chlorine residual drop) versus a glitch in the probe performance

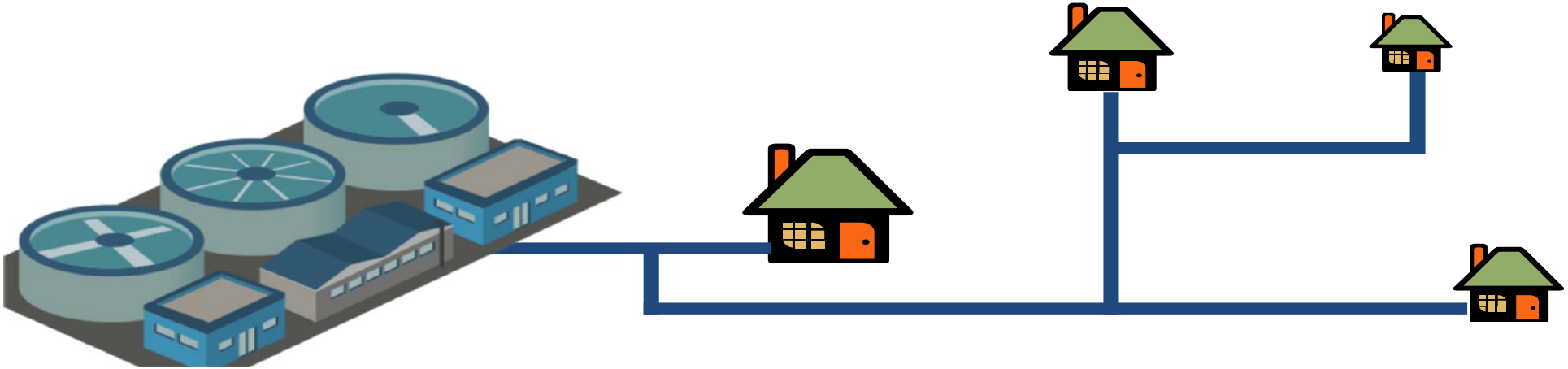
Summary of AMS Results

- Clear differences in water quality between WTP and distribution system site 1.
  - Higher pH in distribution system
  - Higher pressure at WTP
  - Higher turbidity in distribution system
  - Smaller range in chlorine residual in distribution system

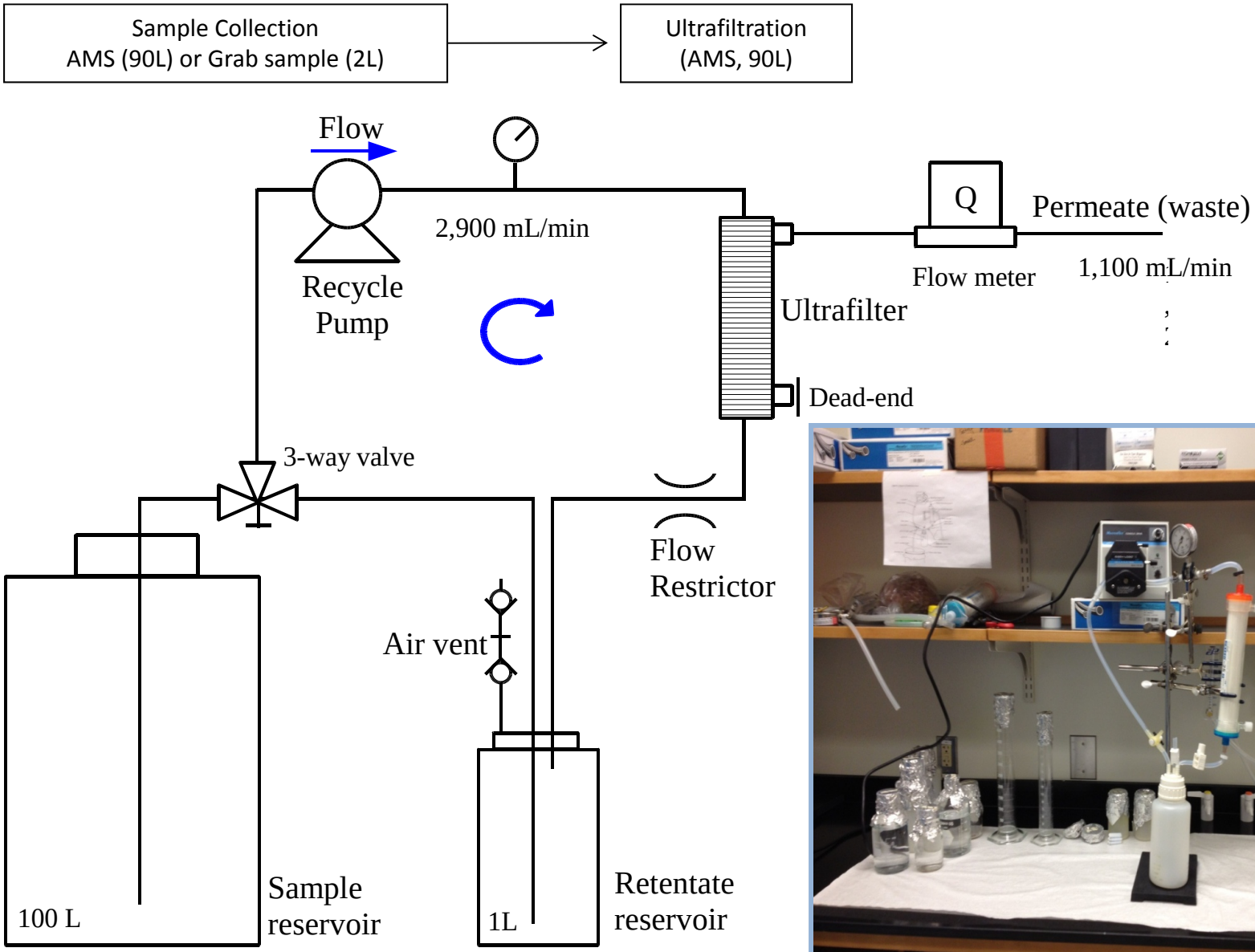
Water Sampling Protocol

Sample collection

- Bi-monthly between 7:00 AM and 9:00 AM
- Employed a rotating sample collection schedule beginning with WTP to distribution system (February 2012)
- Large (composite) volume samples (90 liters) collected by AMS over 4-hour period
  - Carboys contained dechlorinating agent Sodium thiosulfate
- AMS Data logger records water quality parameters
- S::can TOC analyzer records TOC and turbidity



Sample Processing: Microbiological Analyses
Emory Lab Recirculating Ultrafiltration



Sample Processing: Microbiological Analyses
Emory Lab

Sample Collection
AMS (90L) or Grab sample (2L)

Ultrafiltration
(AMS, 90L)

~400 ml
Concentrate + Back flush

Membrane Filtration

PEG

60 to 100 mL

100 mL

E. coli; Total coliforms; *C. perfringens*;
HPC; *P. aeruginosa; A. hydrophila*

0.1 mL | 1 mL | 10 mL

Actual volume filtered for each

Male-specific (MS2) and Somatic Coliphage

10^3 | 10^4 | 10^5

25 ml actual volume pour plate each

Dr. Nick Ashbolt lab
US EPA Cincinnati
Mycobacterium spp. (NTM), Legionella +amoebae, Cryptosporidium, Giardia, Salmonella, Campylobacter, NoV, enterovirus, adenovirus

Standard Methods for the Examination of Water and Wastewater; 20th Edition, 1999 American Public Health Association Publications

EMORY UNIVERSITY | Center for Global Safe Water

Acknowledgements

- Water sampling, ultrafiltration and microbiological analyses supported by Water Research Foundation (WRF) Project Number 04350
  - *Water Industry Contribution to Epidemiological and Health Effects Studies Involving Distribution System Water Quality*
- Field and Lab Support Staff: Sara Carmichael, Vijay Ram, Meredith Lichtenstein, Ashleigh Streby, Courtney Weil, Emmanuel Lozado
- FIRST Postdoctoral Fellowship for Ethell Vereen, Emory University

This research is funded by U.S. EPA - Science To Achieve Results (STAR) Program Grant # R834250