Overview of Endemic Illness Information and Implications for Possible Public Health Risks from Drinking Water

Christine Moe
Center for Global Safe Water
Rollins School of Public Health
Emory University

Outline

- What is endemic illness?
- Data on endemic AGI in the US
- Endemic waterborne AGI
- Endemic AGI illness associated with distribution systems
- Exposure: water quality in distribution systems

What is endemic illness?

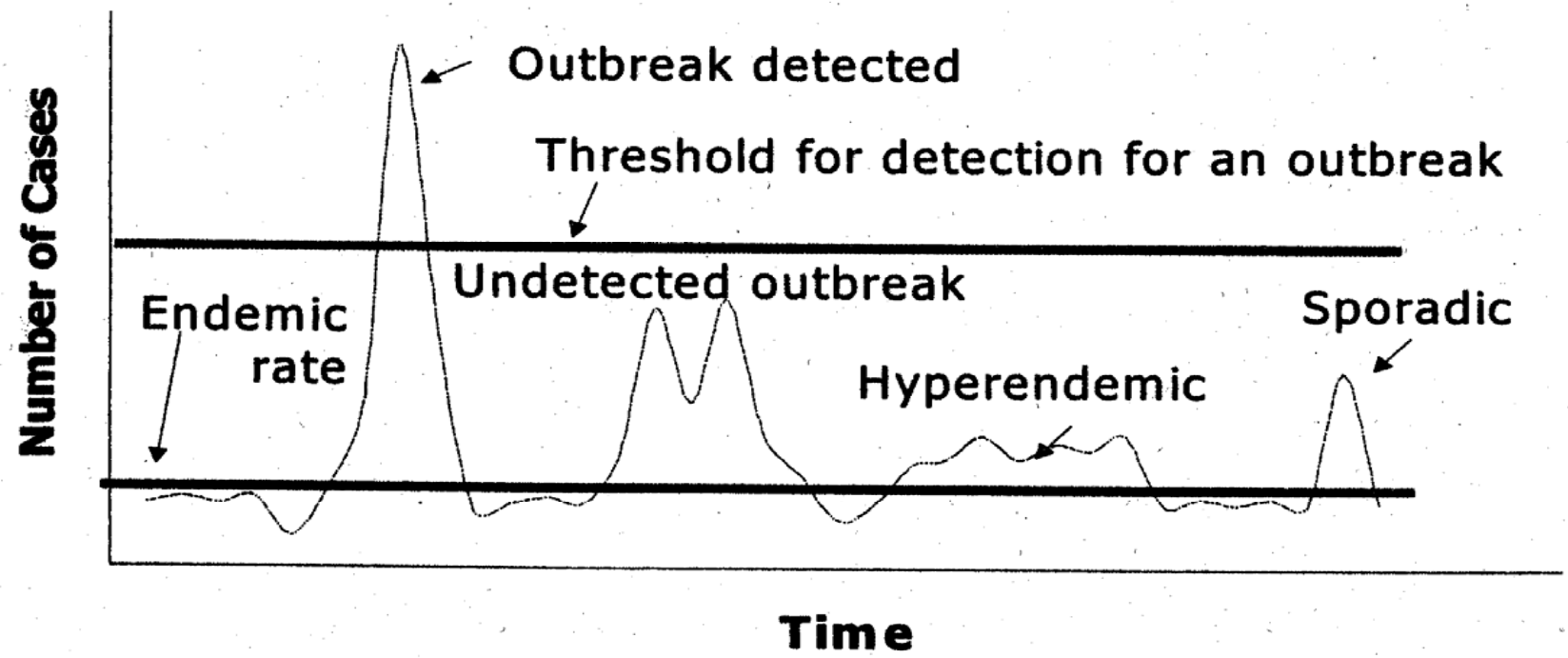


Figure 1.

Epidemic to endemic illnesses as detected by surveillance systems. Modified from Frost et al. (1996).

Acute Gastrointestinal Illness

- “AGI”
- Symptoms: diarrhea, nausea, vomiting, possibly abdominal cramps and fever
- Short duration (usually <1 week)
- Due to infectious agent - enteric viruses, bacteria or protozoa
- Can be waterborne, foodborne, contact with contaminated objects, person-to-person

Sources of Information on Endemic AGI

- FoodNet telephone surveys
- “Background” rates in epidemiology studies

FoodNet Data

- Cross-sectional surveys
- Random digit dialing sampling method
- Randomly choose one target household member
- Interview about health history of target household member (parents/guardians respond for children <12 years)
- Episodes of diarrhea in past month
- Some queries about vomiting and other symptoms, varied by cycle

FoodNet Survey Results

Year	No. of States	Total no. respondents in analysis	Prev of acute diarrhea* past 4 weeks	Estimated incidence episodes/ person/year	Diarrhea prev in children <5 yrs
1996-1997	5	8624	11%	1.4	10%
1998-1999	7	12,075	6%	0.72	9%
2000-2001	8	14,046	5%	NA	9%
2002-2003	9	15,578	5%	NA	9%

NA = the authors did not report an estimate of the incidence rate. SOURCES: Herikstatd et al., 2002; Imhoff et al., 2004; Hawkins et al., 2002; McMillan et al., 2004. *Respondents in first two cycles were only asked about vomiting and other symptoms **if** they reported diarrhea; **all** respondents in second two cycles were asked about vomiting.

AGI Rates Reported in Epidemiology Studies

Study type and reference	Year	Method of data collection	Reported prev of symptoms in control population
Shellfish feeding study North Carolina (Sobsey, Weber et al., unpublished results)	1987	1 week follow-up phone call (N= 291 Controls who did not eat shellfish; adults only)	Diarrhea 2.4% Naus/Vom 1.4% Abd pain 2.1%
Shellfish feeding study North Carolina (Sobsey, Weber et al., unpublished results)	1988	1 week follow-up phone call (N=180 Controls who did not eat shellfish; adults only)	Diarrhea 2.2% Vomiting 0.7% Abd pain 4.0% HCGI* 1.67% (*D+A, D+V, A+V)

AGI Rates Reported in Epidemiology Studies

Study type and reference	Year	Method of data collection	Reported prev of symptoms in control population
Recreational water study California (Colford et al., 2007)	2003	14 day follow-up phone call (N=3581 non-swimmers; 9% <5 yrs old, 74% 12-55 yrs old)	Diarrhea 3.4% Vomiting 1.7% Abd pain 4.0%
Recreational water study Great Lakes (Wade et al., unpublished results)	2003-2004	10-12 day follow-up phone call (N=6665 non-swimmers)	GI 6.0% (GI = D or V or N+A or N+A + impact on activity)

Rates of Highly Credible AGI from Household Intervention Studies

Study	Estimated rate of HCGI in tap water groups	Estimated rate of HCGI in purified water groups	Estimated rate of HCGI in all study participants
Laval, Quebec 1988-1989	0.76 N=1202	0.50 N=1206	0.66
Laval, Quebec 1993-1994	0.66 (tap) N=1296 0.70 (tap valve) N=1300	0.58 N=1360 purified N=1297 bottled plant	0.60
Melbourne, Aus 1997-1999	0.82 N=1399	0.79 N=1412	0.80
Contra Costa, CA 1999	3.48	2.63	3.05
Davenport, Iowa 2000-2002	2.12 N=650	2.20 N=646	2.16

*Rate expressed as episodes/person/year

NRC Report, 2006

Estimates of Endemic AGI

- Range in estimates
  - FoodNet:
    - Diarrhea prevalence 6 - 11% (first two cycles)
    - Diarrhea/vomiting prev 5% (second two cycles)
    - Estimated episodes/person/year ~ 0.7 (second two cycles)
  - Epidemiology studies with short recall and telephone follow-up:
    - Diarrhea prevalence 2.2 - 3.4%
    - AGI prevalence 1.7 - 6.0%
  - Prospective epidemiology studies with health diaries:
    - Episodes/person/year: 0.7 - 3.5

Estimates of Endemic AGI

Type of study	Number of studies	Years studies performed	Range of AGI estimates (episodes/ person-yr)
Retrospective data collection	6 US	1993 - 2003	0.6 - 3.2
Prospective data collection	7 US	1948 - 1999	0.3 - 3.5

Adapted from Roy et al., 2006

Estimates of Endemic AGI

- Reasons for differences: different symptom or AGI definitions, study population selection (random vs. volunteers), proportion of children in the respondent population, retrospective vs. prospective design, length of recall (1 week - 1 month), method of data collection (health diary and/or telephone interview)
- Strengths of data:
  - best data is likely to be from short recall (ie. 1-2 weeks) with active surveillance (ie. follow-up phone calls)
  - multiple locations, years and types of studies
- Limitations: self-reported symptoms, poor recall

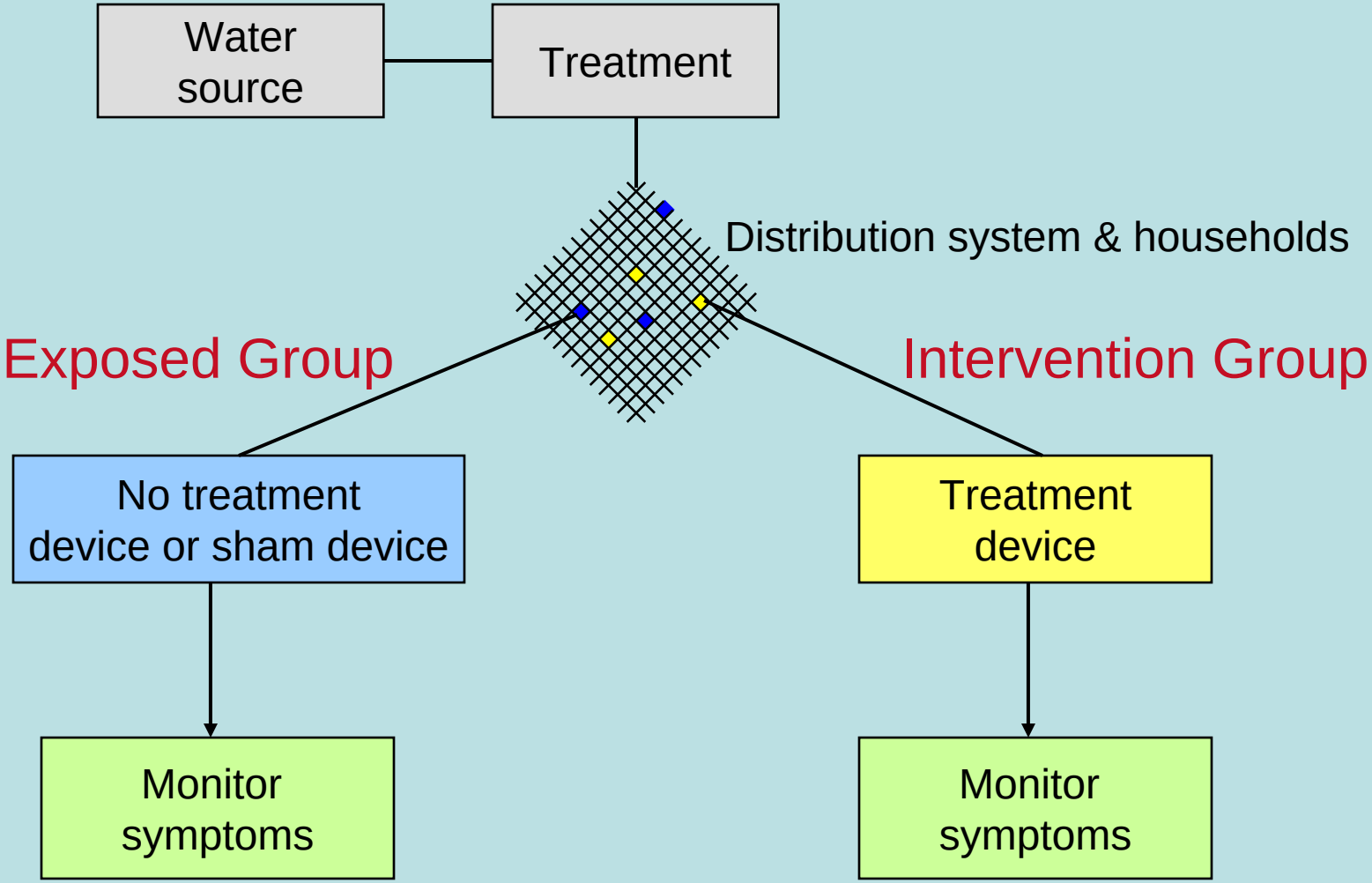
How much endemic AGI is associated with drinking water?

?

Sources of information

- Household intervention studies:
  - Laval, Quebec: 1988-1989 (Payment et al., 1991)
  - Laval, Quebec: 1993-1994 (Payment et al., 1997)
  - Melbourne, Australia: 1997-1999 (Hellard et al., 2001)
  - Davenport, Iowa: 2000-2002 (Colford et al., 2005)
- Community intervention studies
  - Massachusetts: 1996-1997 (Calderon 2001)
  - Washington: 2000-2001 (Frost et al., 2006)
  - Texas: 2002 (Kunde et al., 2006)
  - Wisconsin: 2006-present (Borchardt et al., 2007)

Household Intervention Study Design



Household Intervention Studies

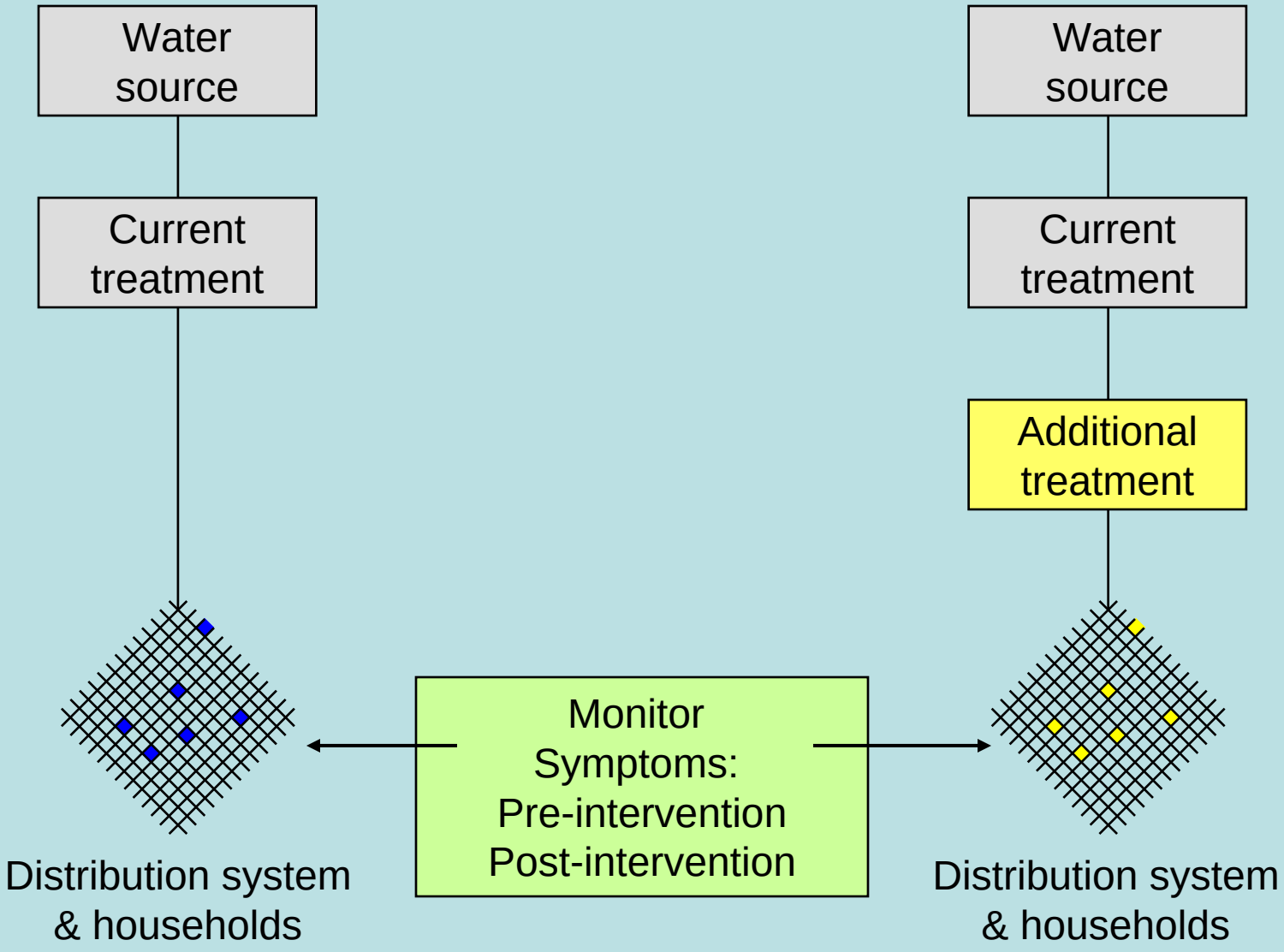
- Randomized, clinical trials
- Longitudinal studies
- Intervention = point-of-use water treatment device (or bottled water Laval II)
- Communities with surface water supplies
- Health outcomes monitored by health diary
- Can not separate effect of source water quality and treatment from effect of DS

Proportion of AGI Attributed to Drinking Water in Household Intervention Studies

Study	Attributable risk to drinking water (Rate Difference)	Main Results	Limitations
Laval 1988-1989	0.26	34% of AGI attributed to tap water. *Large sample size	Unblinded
Laval 1993-1994	0.08 tap water 0.12 tap valve 0.02 plant	12% excess AGI in tap water 17% excess AGI in tap valve *Large sample size, children	Unblinded, High dropout rate in some groups
Melbourne 1997-1999	0.03	4% of AGI attributed to tap water *Large sample size, children	Highly protected watershed- limited generalizability
Contra Costa, CA 1999	0.85	24% of AGI attributed to tap water *Blinded trial	Small sample size, short follow up time
Davenport 2000-2002	-0.02 -0.14	-0.08 to -0.008% AGI attributed to tap water * Blinded trial, crossover	Short follow up time; Low proportion of HHs with children?

Adapted from Colford et al., 2006

Community Intervention Design



Community Intervention Studies

- Single community OR multiple communities (with intervention and without intervention) compare GI outcomes before and after intervention
- Cohort studies
- Study population = families with children
- Community level water treatment intervention
  - MA and WA: added filtration to surface water system
  - Texas: added membrane filtration to GW under influence
  - WI: added UV disinfection to GW at wellhead
- Monitor GI outcomes before and after intervention
- Short follow-up times (4-6 months for MA, WA & TX)

Proportion of AGI Attributed to Drinking Water in Community Intervention Studies

Study	No. of communities	No. of households	Attributable risk to drinking water
Massachusetts 1996-1997	1	316 pre-intervention 254 post-intervention	RR=1.8 Attributable risk associated with unfiltered surface water = 34%
Washington 2000-2001	3 (1 intervention, 2 control)	A = 277 B = 164 C = 124	NA
Texas 2001-2002	2	A= 52 B = 37	NA
Wisconsin 2006-present	8		In progress

Adapted from Calderon and Craun, 2006

Estimates of Endemic Waterborne AGI

- Range in estimates of attributable risk due to drinking water
  - Household intervention studies:
    - Attributable risk: -0.08 - 34% in five studies of communities with surface water supplies
  - Community intervention studies:
    - Attributable risk from drinking unfiltered surface water = 34% in one study

Estimates of Endemic Waterborne AGI

- Reasons for differences:
  - Make up of study population: e.g. proportion of children
  - Study methods
  - Health outcomes
    - defined differently
    - measured differently: health diaries, telephone interview
  - Exposure
    - Is there a difference in water quality between control and intervention groups?
    - Opportunities for misclassification - e.g. in household studies, some individuals may consume more water outside of the household
    - Tap water quality may differ in different parts of the study area
- **Strengths:** controlled, randomized trial is a powerful study design for measuring the effect of a specific exposure on illness; prospective cohort design, multiple studies in different locations, populations and years.
- **Limitations:** self-reported symptoms, poor recall, noncompliance with study protocol, potential exposure misclassification

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

Sources of Information

- Laval: 1993-1994 (Payment et al., 1997)
- UK Study: 2001-2002 (Hunter et al., 2005)
- Norway Study: 2003-2004 (Nygard et al., 2007)
- Atlanta Study: 1993-2004 (Tinker et al., in preparation)

Laval 1993-1994

- Household intervention study
- Four study groups

1. Tap water 2. Tap water from continuously purged tap
3. Bottled treatment plant effluent 4. Bottled treatment plant effluent + RO

- Compare AGI rates in groups 1 and 2 to group 3 to estimate effect of water quality in the DS on health. Found groups 1 & 2 had higher AGI rates than groups 3 & 4
- Results suggest 14-40% of AGI attributed to tap water and DS had a significant role
- No correlation between estimated water residence time (0.3 - 34 hrs) and household AGI rate.

UK Study

- Case-Control Study
- Wales and Northwest England, 2001-2002
- Postal survey of 423 subjects
- Asked about diarrhea risk factors (foreign travel, eating habits, contact with animals and young children, etc.)
- Very strong association between self-reported diarrhea and reported low water pressure at the household tap
- Study population in 2 large regions with about 240 water treatment plants and good overall water quality
- Concluded that up to 15% of AGI may be associated with drinking water contamination in DS

Norway Study

- Cohort study, 2003-2004
- Study population served by 7 water utilities
- Each utility identified up to 2 low-pressure events per month
- Selected 10 HH exposed to the event and 10 HH unaffected by the event per utility
- Telephone interview of exposed and unexposed HHs 8-14 days after event asked about tap water consumption, tap water problems, AGI symptoms and multiple AGI risk factors
- Concluded that 37% of AGI in exposed HH was due to low-pressure events in DS. Greater risk in HHs with higher ave water consumption.

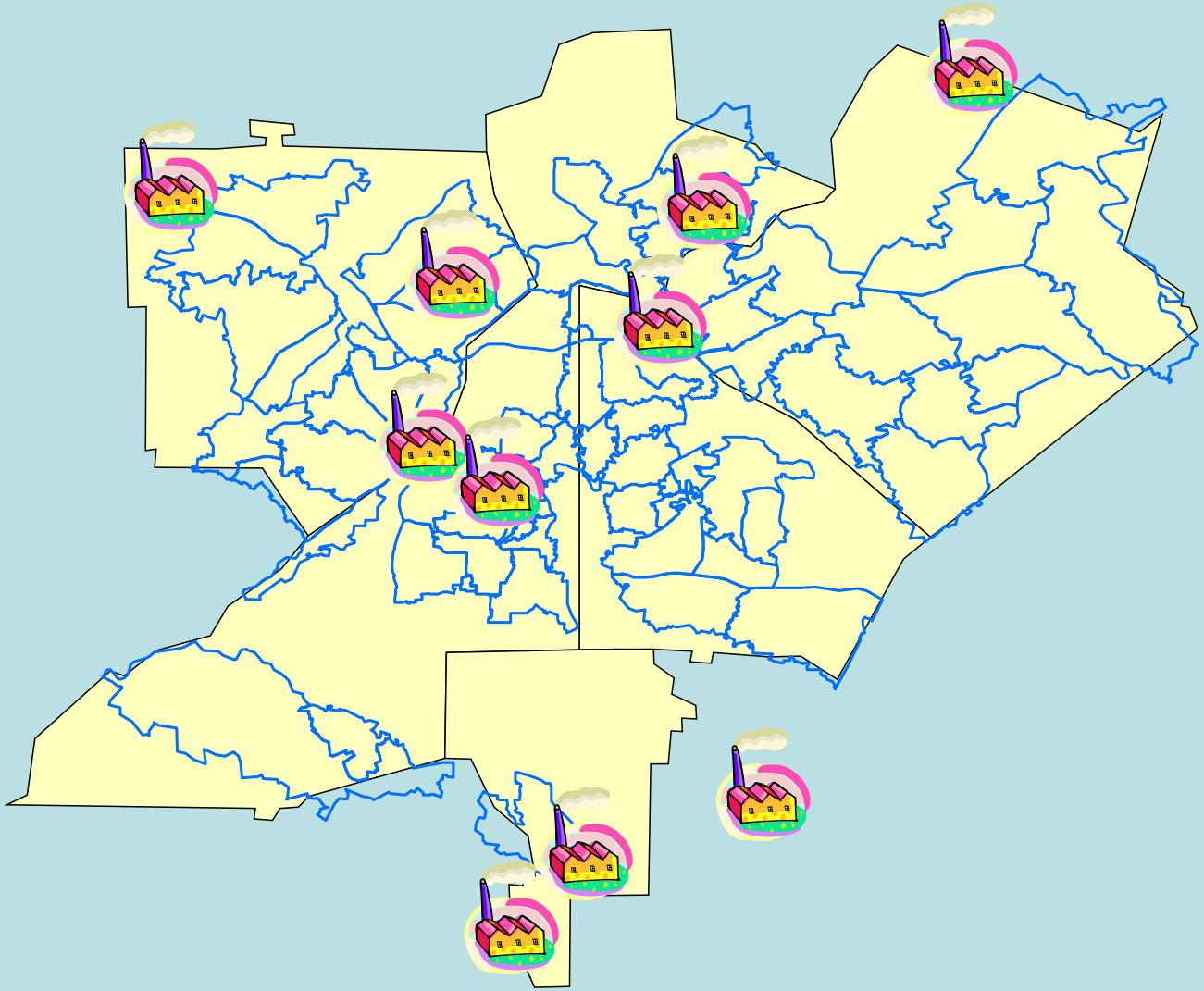
Metro Atlanta Study

- Multi-year time series study of water quality and health
- Funded by USEPA STAR
- Paige Tolbert, PI
- Research team: Tinker, Moe, Klein, Flanders, Uber, Singer, Amirtharajah
- Objective: Examine spatio-temporal relationships between drinking water quality and ED visits for enteric illness in Atlanta from 1993-2004

SOPHIA

Study of Particles and Health in Atlanta

Drinking Water Treatment Plants and Zip Codes Included in Study

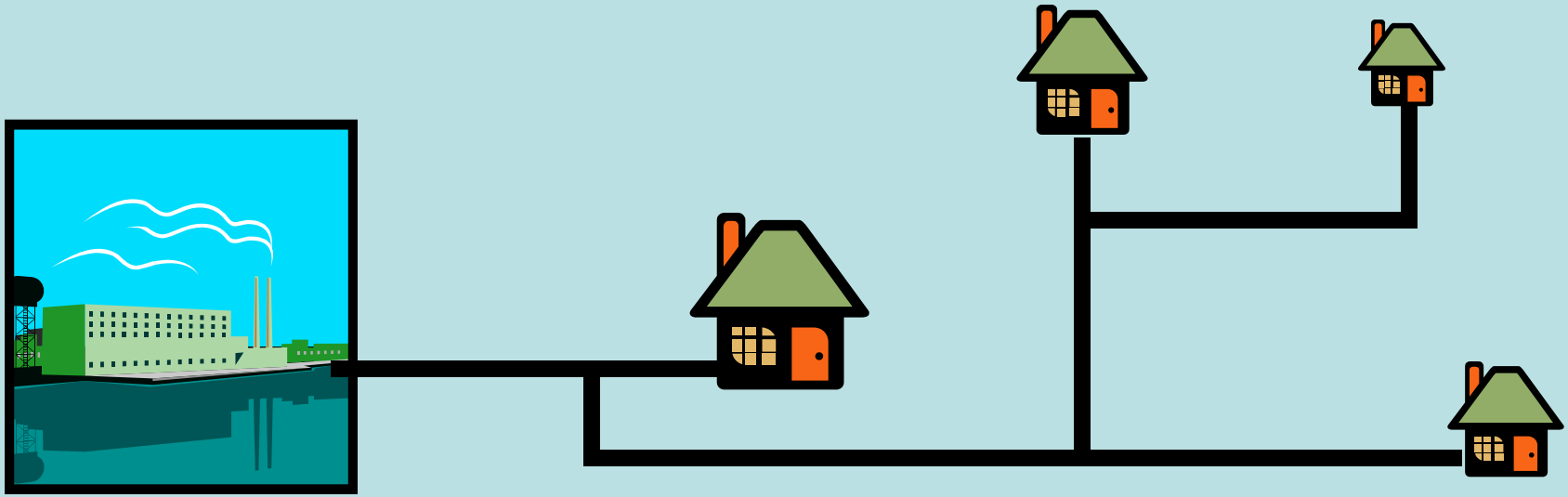


SOPHIA Data Sources: 1993-2004

- 6 water utilities provide:
  - Description of water treatment process (including changes during study period)
  - Zip codes in service area
  - Records of regularly measured indicators of water quality
    - Including turbidity, chlorine residual, bacterial levels
  - Distribution system maps and hydraulic models (if available)
- 20-county hospital ED database
  - 41 out of 42 hospitals contributing data for at least part of the study period
  - Total observations in analytical dataset: **4,441,203**
    - GI illness: 254,760 (5.7%)

Study Goal 1: Assess the role of the distribution system

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



Methods

Water Residence Time Estimates

- Used hydraulic models developed for the distribution systems of two drinking water utilities
  - Utility 1
    - 2 hydraulic models considered
      - 1996 – 1999: Only larger pipes included in model
      - 2000 – 2003: All pipes in distribution system included in model
  - Utility 2
    - One hydraulic model covered 1993 – 2004
  - Models ran simulations of water flow through the distribution system in order to estimate the time it took water to flow from the treatment plant to pipe intersections (nodes)
    - Utility 1: Water residence time estimated for 272,782 nodes
    - Utility 2: Water residence time estimated for 240,480 nodes
  - Water residence time of nodes in each zip code averaged
    - Separate estimates were produced for each year in order to accommodate changes in water demand over time

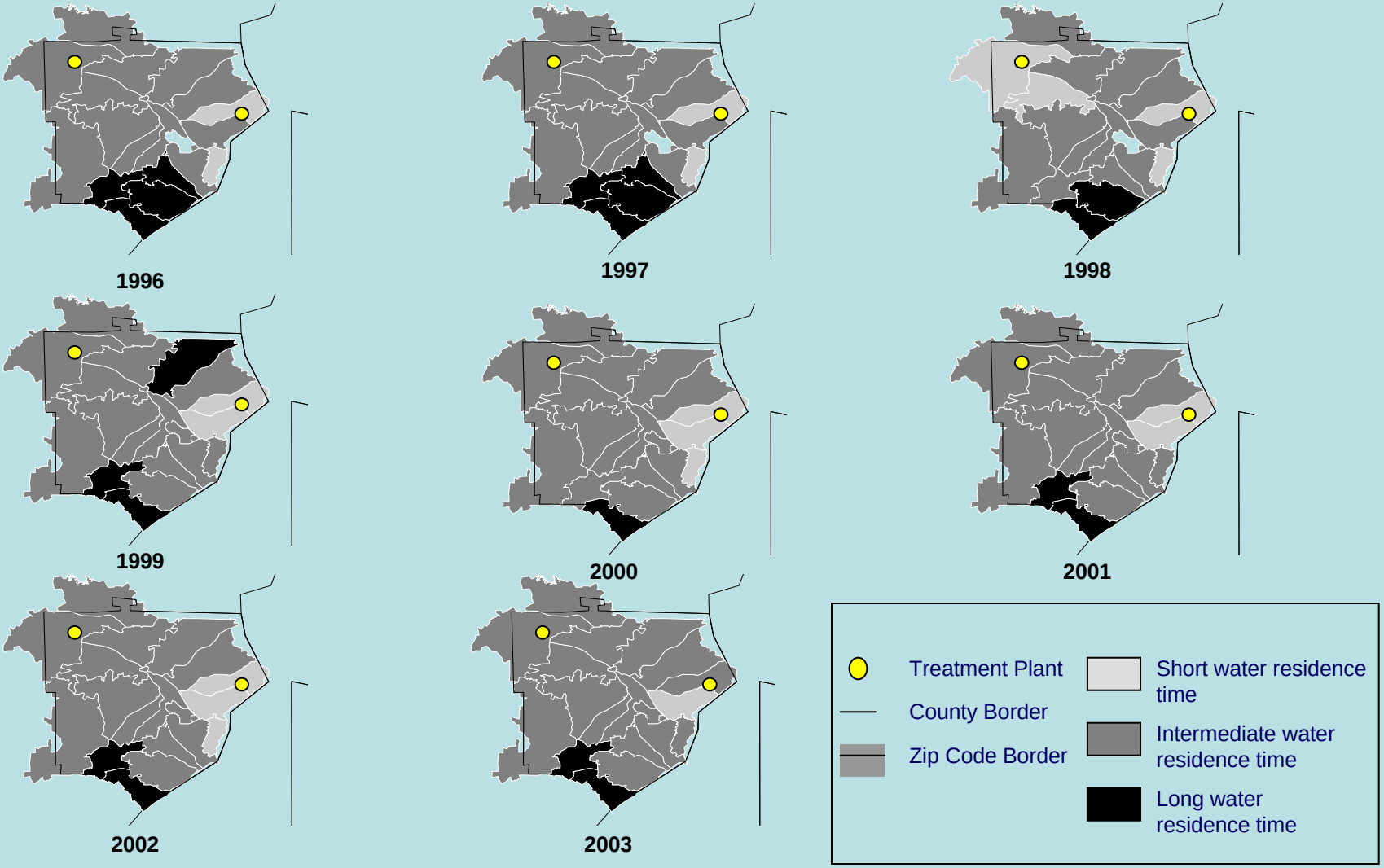
Methods

- We grouped zip codes into categories according to their estimated water residence time.
  - <10th percentile
    - Shorter water residence time = less opportunity for pathogen contamination
    - Less contact time with disinfectant
  - Middle 80 percent (referent)
  - >90th percentile
    - Longer water residence time = more opportunity for pathogen contamination
    - Disinfectant decreases as distance increases

	Short water residence time Mean (Min – Max)	Intermediate water residence time Mean (Min – Max)	Long residence water time Mean (Min – Max)
Utility 1 Hydraulic Model 1	6.8 (4.5 – 8.3)	22.0 (8.3 – 36.4)	47.4 (37.6 – 68.5)
Utility 1, Hydraulic Model 2	10.1 (9.1 – 11.2)	33.4 (11.2 – 51.8)	74.4 (52.2 – 88.4)
Utility 2	5.8 (4.7 – 8.6)	18.4 (8.6 – 40.3)	60.4 (40.3 – 144.1)

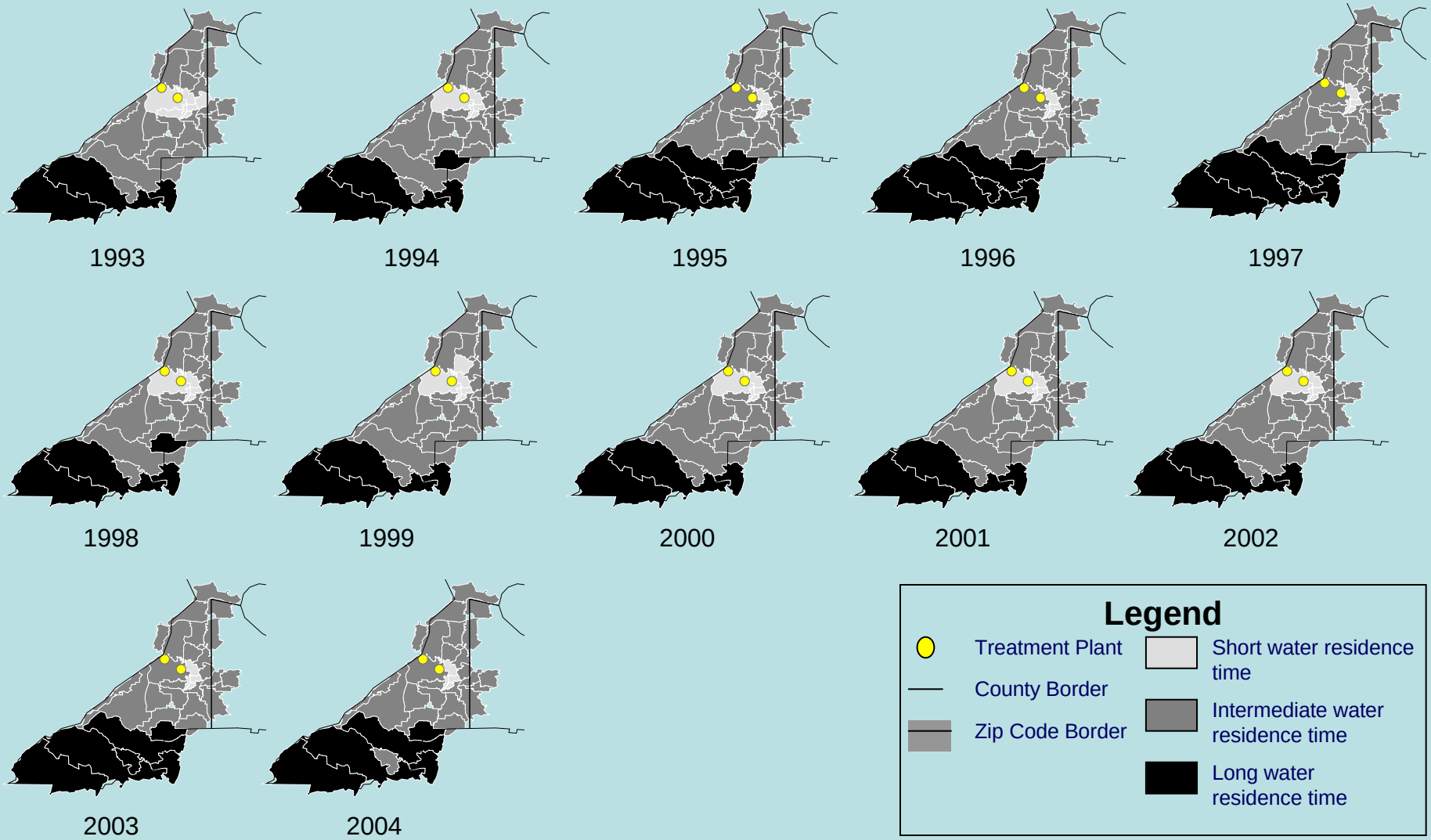
Methods

Classification of water residence time by zip code by year – Utility 1



Methods

Classification of water residence time by zip code by year – Utility 2



Methods

- We calculated the rate of emergency department (ED) visits for GI illness in each zip code.
  - Total Non-Injury ED Visits: 2,092,735
  - GI Illness ED Visits: 164,937 (7.9%)

Methods

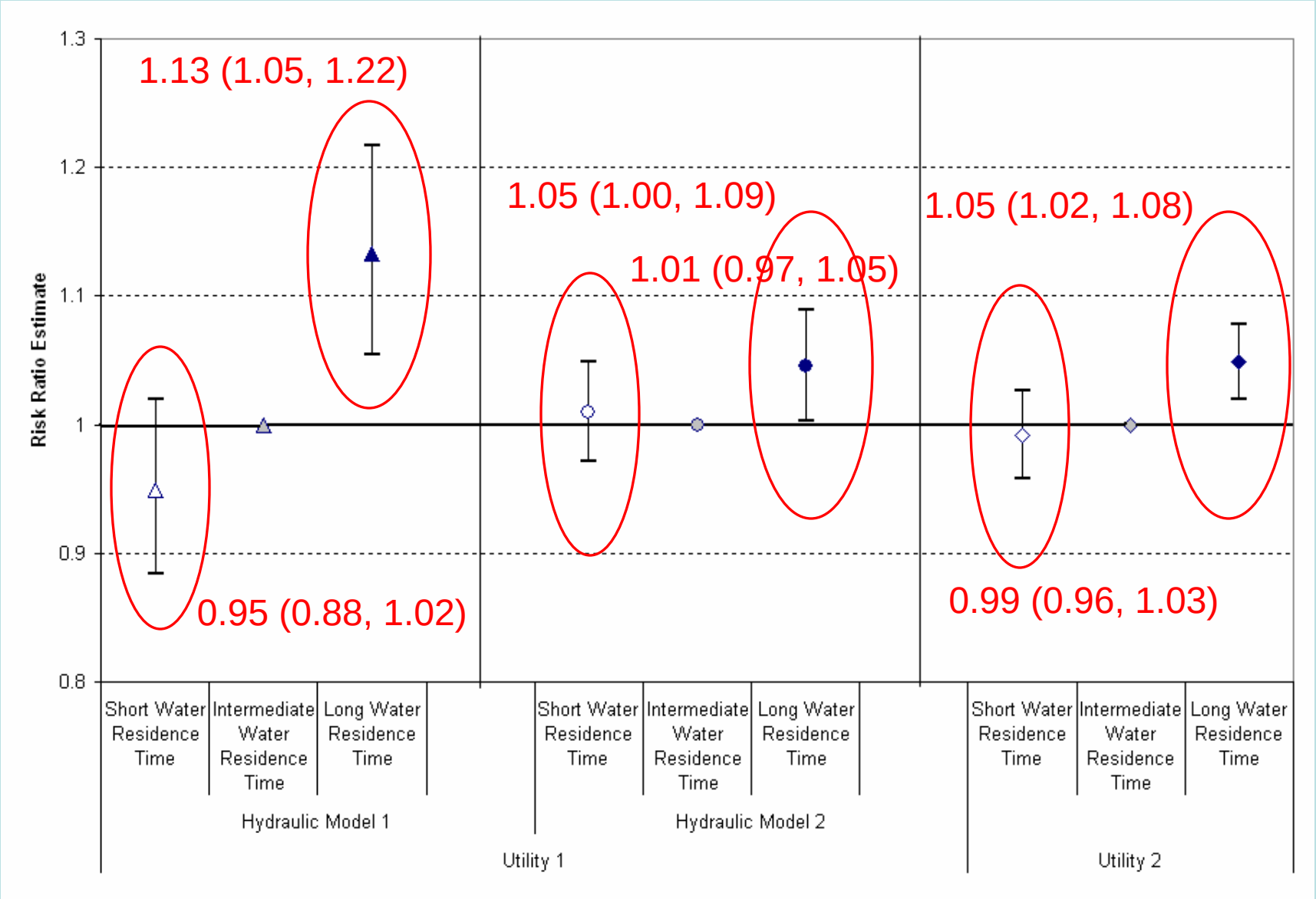
- Statistical method: Logistic regression
  - This method allowed us to assess the relationship between the category of water residence time (short, intermediate, long) assigned to a zip code and the incidence of ED visits for GI illness in that zip code, controlling for the effects of other factors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

Methods

- We controlled for the following factors:
  - Age category
  - Season
  - Year
  - Hospital
  - Distance from zip code centroid to hospital
  - Zip code median income
  - Zip code percent minority
  - Medicaid payment status

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

Preliminary Results



Conclusion

People living in zip codes receiving water that has spent the longest amount of time in the distribution system may be at increased risk of GI illness.

Exposure: What do we know about microbiological water quality in distribution systems?

Current Studies of Water Quality in Distribution Systems

- FRESHWATER Study in Florida
- WAHTER Study in Wisconsin
- Both studies of groundwater systems

Determinants of Water Quality in Drinking Water Distribution Systems

- Multi-year study of determinants of water quality in drinking water distribution systems (DS), DS vulnerability and consumer drinking water habits
- Funded by the USEPA STAR and the American Water Works Assoc Research Foundation
- Collaboration with Hillsborough County Water Dept and FL Dept of Health
- Research team: Moe (PI), Hooper and Nilsson
- Overall Objective: Study the impact of specific risk factors on microbiological quality of distribution system water quality

Observed low pressure events (<20 psi)

Event	Date	Number loggers affected	Minimum recorded pressure (psi)		Location of minimum pressure
			At POE	In DS	
1	3/15/06	1	66	**0**	E (Low Elev.)
2	4/2/06	All (5)	12	**0**	F (South)
3	4/4/06	All (5)	10	28	E (North)
4	4/7/06	All (6)	12	19	B (High Elev 1)
5	4/8/06 #1	All (6)	9	**0**	E (North)
6	4/8/06 #2	All (6)	**6**	13	B (High Elev 1)
7	4/11/06 #1	All (6)	19	24	B (High Elev 1)
8	4/11/06 #2	1	65	15	E (North)
9	4/12/06	1	68	**9**	E (North)
10	4/19/06	1	73	12	E (North)
11	4/20/06	1	65	17	E (North)
12	5/23/06	All (2)	ND[2]	13	B (High Elev. 1)
13	5/26/06	All (2)	ND[2]	20	B (High Elev. 1)
14	5/27/06	All (2)	ND[2]	18	B (High Elev. 1)
15	8/9/06	All (3)	ND[2]	**6**	E (North)
16	8/30/06	1	ND[2]	16	E (North)
17	9/6/06	1	ND[2]	19	E (North)
18	11/21/06	All (4)	13	19	B (High Elev. 1)
19	2/2/07	All (3)	19	33	B (High Elev. 1)

Summary: Low pressure events

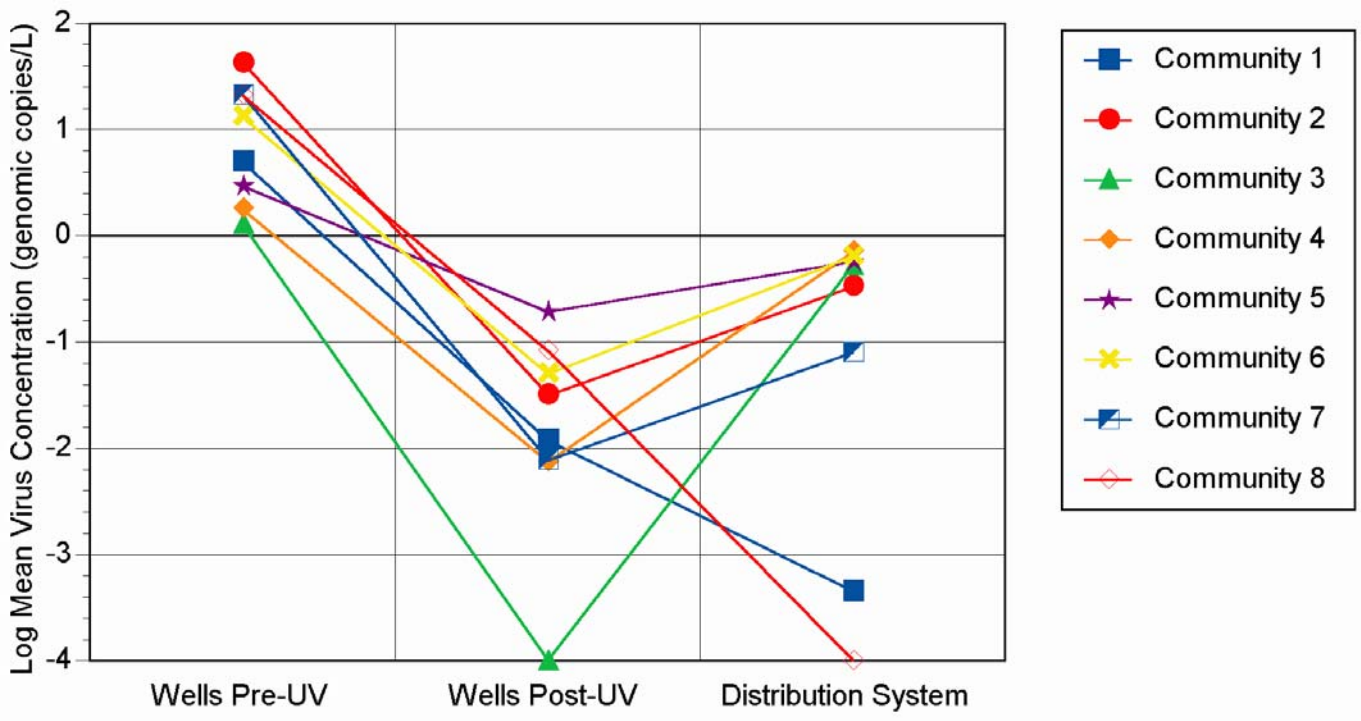
- 19 events with plant or DS pressure < 20 psi (2/5/06 – 3/18/07)
- 6 events with plant or DS pressure < 10 psi
- 3 events with plant or DS pressure down to 0 psi
- 12 system-wide events (<20 psi)
- 7 isolated events (<20 psi)
- Many system-wide events associated with power outages at plant

Wisconsin WAHTER Study

- 8 communities, pop range 1283-8320
- All groundwater systems
- Community intervention study with UV disinfection
- Monitoring groundwater quality for viruses: pre-UV, post-UV and in distribution system
- Monthly testing for enterovirus, norovirus, hepatitis A virus, rotavirus and adenovirus by PCR
- Monitoring GI symptoms in families

Borchardt et al., 2007

Virus Concentrations: Source to Tap



- Each data point represents the mean total virus concentration for the six months sampling period. N varies by community because of differences in the number of wells and number of households samples.
- Except for two communities, the mean virus concentration increased approximately 1 log in the distribution system after UV disinfection

Borchardt et al., 2007

Prelim Results: Association of Events and Viruses in Distribution Systems

Event		Number Samples	Proportion Samples Virus Positive	P-Value Proportions Comparison	Number Samples Virus Positive	Mean Virus Concentration (GC/L) Among Positives	P-Value Means Comparison
Times Chlorinated	>0	146	0.19	0.086	28	3.7	0.284
	0	178	0.09		16	2.1	
Water Main Breaks	>0	116	0.17	0.412	20	3.4	0.746
	0	208	0.12		24	2.9	
Water Main Cut Open	>0	129	0.21	0.038*	27	4.4	0.028*
	0	145	0.09		17	1.1	
Water Tower Maintenance	>0	108	0.19	0.23	20	2.9	0.428
	0	216	0.11		24	3.3	
Cross Connections	>0	16	0.19	0.647	3	2.7	0.835
	0	308	0.13		41	3.1	
Times Hydrant Flushed	>0	215	0.15	0.575	32	3.1	0.876
	0	109	0.11		12	3.1	
Times Valves Exercised	>0	88	0.09	0.370	8	1.2	0.096
	0	236	0.15		36	3.5	
Total Coliform Detects	>0	102	0.21	0.126	21	4.3	0.159
	0	222	0.10		23	2.0	

Borchardt et al., 2007

Summary and Conclusions

- Range of estimates of AGI
- Range of estimates of waterborne AGI
- Four studies in industrialized countries (Canada, UK, Norway, US) indicate risk of endemic AGI associated with distribution system - pressure drops, main breaks, longer residence time. Range of risk estimates.
- DS monitoring data indicate that pressure drops are not rare occurrences and provide evidence of post-treatment water contamination

Acknowledgements

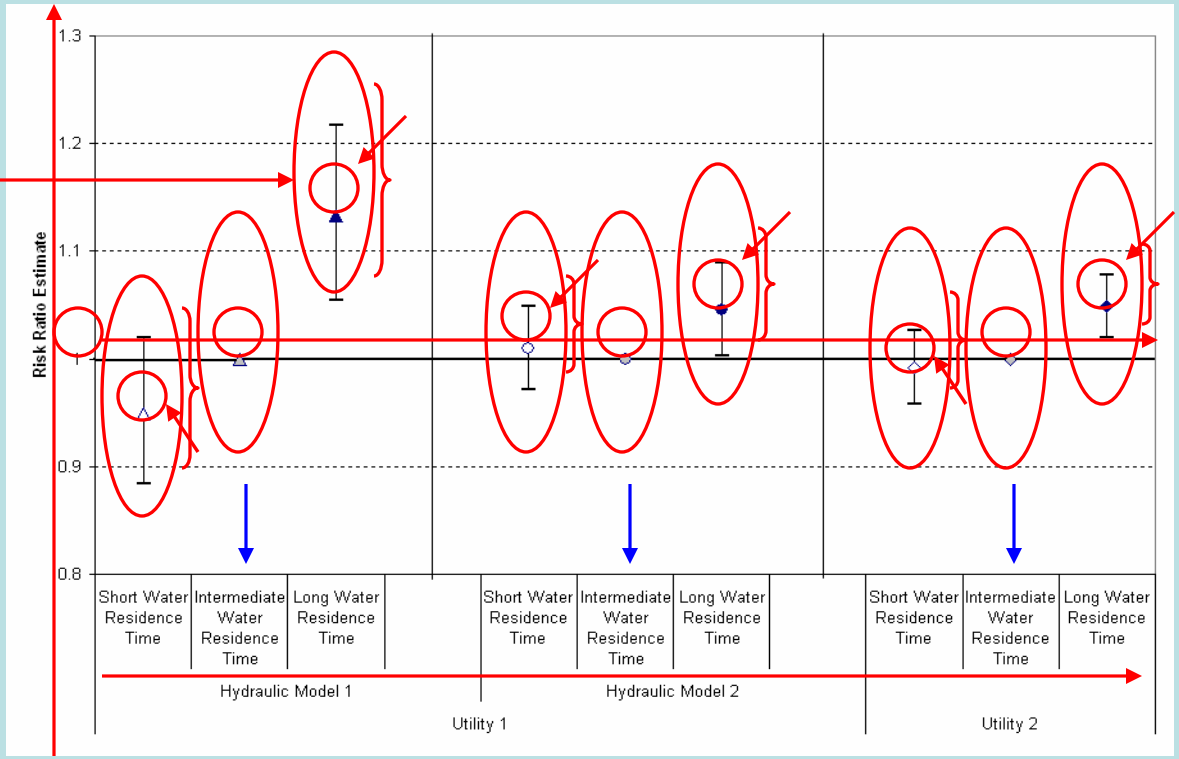
- Mark Borchardt
- Sarah Tinker and Paige Tolbert
- Stuart Hooper
- Laura Kovalchick
- EPA STAR Grants
  - FRESHWATER R830376
  - SOPHIA R831629
- National Institute of Environmental Health Sciences (R01ES011294)
- EPA (R82921301-0)
- Electric Power Research Institute (W03253-07)

Preliminary Results:

Risk ratio estimates for ED visits for GI illness among people living in zip codes with short drinking water residence times and long drinking water residence times compared to intermediate drinking water residence times, stratified by hydraulic model used to estimate residence time

RR = 1.13

13% higher risk among exposed group than referent group



Risk ratio (RR) estimate from statistical model.

Interpreted as the ratio of the risk of GI illness among residents of zip codes in the water residence time category indicated on the X axis compared to the risk among residents of zip codes in the intermediate residence time category.

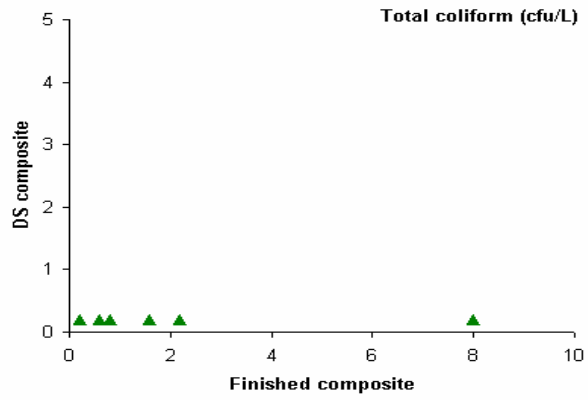
RR > 1 → increased risk of GI illness given exposure; RR < 1 → decreased risk of GI illness given exposure

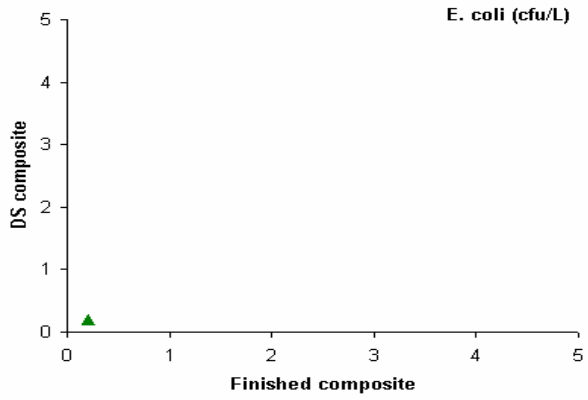
95 % confidence intervals

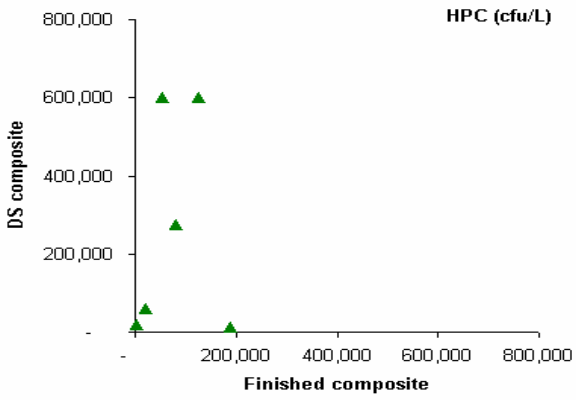
By standard epidemiological practice, If the null value of 1 (meaning that the risks are the same between the two groups being compared) falls outside of the confidence interval then there is only a small likelihood that the association is due to chance. In this case the risk ratio estimate is called “statistically significant”.

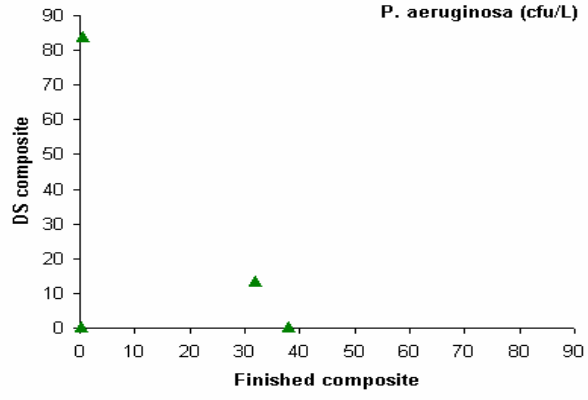
Treated vs. DS water quality

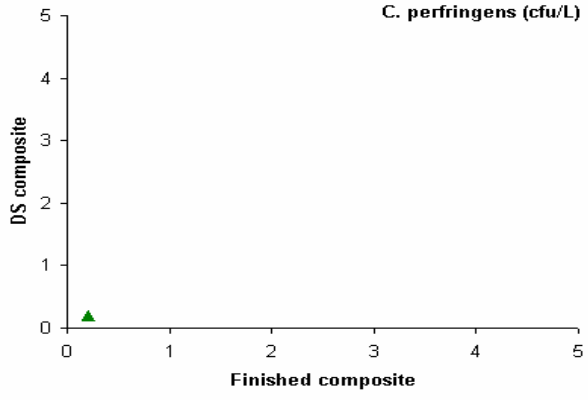
(100 liter samples)

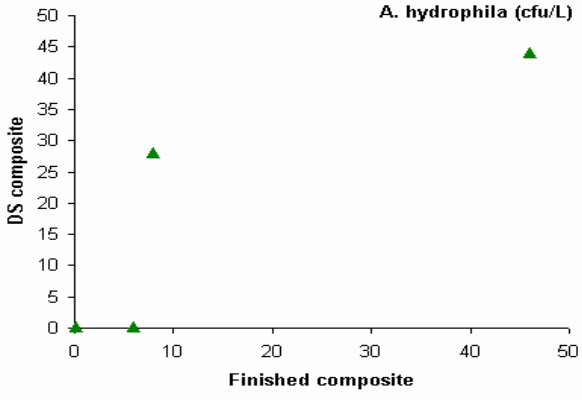












Estimating AGI incidence from FoodNet prevalence data

- FoodNet results from 3rd and 4th cycles

  ~5.4% AGI during 1 month recall

  = 5.4 AGI episodes in 100 person-months

  = 5.4 X 12 months = 64.8 AGI episodes in 100 person-years of follow-up

  = 0.65 episodes per person-year