Extreme Precipitation, Flooding, and Drinking Water Quality

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[a]US Environmental Protection Agency (EPA). The views expressed in this presentation are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA.
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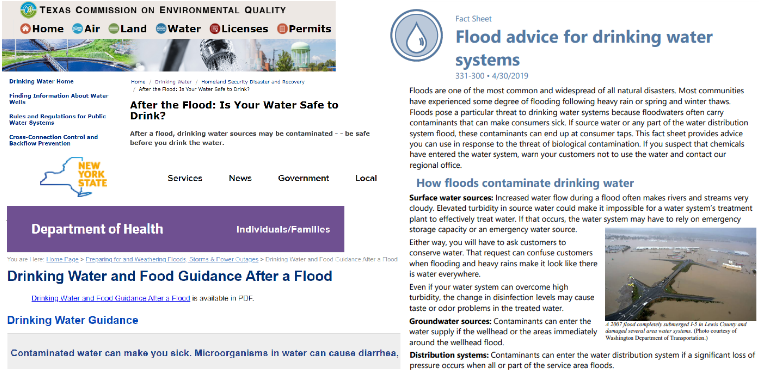
Motivation

Figure: Bennington Lake in Walla Walla, Washington after heavy rains in 2020.

State Awareness and Media Coverage



TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Home Air Land Water Licenses Permits

Drinking Water Home

Finding Information About Water Wells

Rules and Regulations for Public Water Systems

Cross-Connection Control and Backflow Prevention

Home / Drinking Water / Homeland Security Disaster and Recovery / After the Flood: Is Your Water Safe to Drink?

After the Flood: Is Your Water Safe to Drink?

After a flood, drinking water sources may be contaminated - - be safe before you drink the water.

NEW YORK STATE

Services News Government Local

Department of Health Individuals/Families

You are Here: Home Page > Preparing for and Weathering Floods, Storms & Power Outages > Drinking Water and Food Guidance After a Flood

Drinking Water and Food Guidance After a Flood

Drinking Water and Food Guidance After a Flood is available in PDF.

Drinking Water Guidance

Contaminated water can make you sick. Microorganisms in water can cause diarrhea,

Fact Sheet

Flood advice for drinking water systems

331-300 • 4/30/2019

Floods are one of the most common and widespread of all natural disasters. Most communities have experienced some degree of flooding following heavy rain or spring and winter thaws. Floods pose a particular threat to drinking water systems because floodwaters often carry contaminants that can make consumers sick. If source water or any part of the water distribution system flood, these contaminants can end up at consumer taps. This fact sheet provides advice you can use in response to the threat of biological contamination. If you suspect that chemicals have entered the water system, warn your customers not to use the water and contact our regional office.

How floods contaminate drinking water

Surface water sources: Increased water flow during a flood often makes rivers and streams very cloudy. Elevated turbidity in source water could make it impossible for a water system's treatment plant to effectively treat water. If that occurs, the water system may have to rely on emergency storage capacity or an emergency water source.

Either way, you will have to ask customers to conserve water. That request can confuse customers when flooding and heavy rains make it look like there is water everywhere.

Even if your water system can overcome high turbidity, the change in disinfection levels may cause taste or odor problems in the treated water.

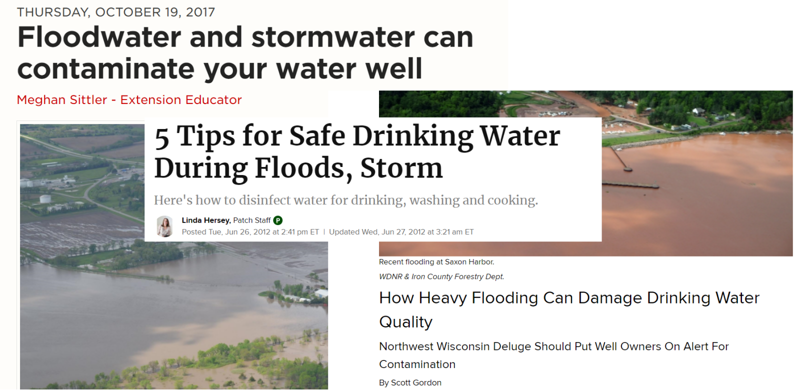
Groundwater sources: Contaminants can enter the water supply if the wellhead or the areas immediately around the wellhead flood.

A 2007 flood completely submerged I-5 in Lewis County and damaged several area water systems. (Photo courtesy of Washington Department of Transportation.)

Distribution systems: Contaminants can enter the water distribution system if a significant loss of pressure occurs when all or part of the service area floods.

Figure: State advice for handling flood hazards to drinking water.

State Awareness and Media Coverage



THURSDAY, OCTOBER 19, 2017

Floodwater and stormwater can contaminate your water well

Meghan Sittler - Extension Educator

5 Tips for Safe Drinking Water During Floods, Storm

Here's how to disinfect water for drinking, washing and cooking.

Linda Hersey, Patch Staff
Posted Tue, Jun 26, 2012 at 2:41 pm ET | Updated Wed, Jun 27, 2012 at 3:21 am ET

Recent flooding at Saxon Harbor.
WDNR & Iron County Forestry Dept.

How Heavy Flooding Can Damage Drinking Water Quality

Northwest Wisconsin Deluge Should Put Well Owners On Alert For Contamination

By Scott Gordon

Figure: News reports highlight these concerns.

A Growing Problem

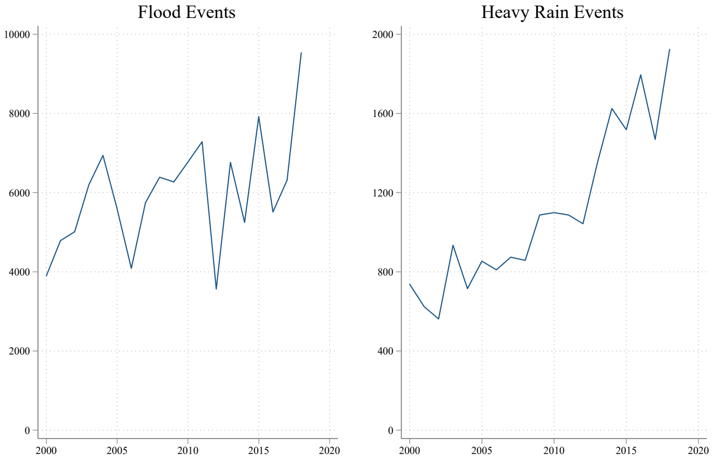


Figure: NOAA National Centers for Environmental Information (NCEI) Storm Events Database (2021). https://www.ncdc.noaa.gov/stormevents/ ▸ See More.

Mechanisms

How might extreme precipitation and flooding affect drinking water quality?

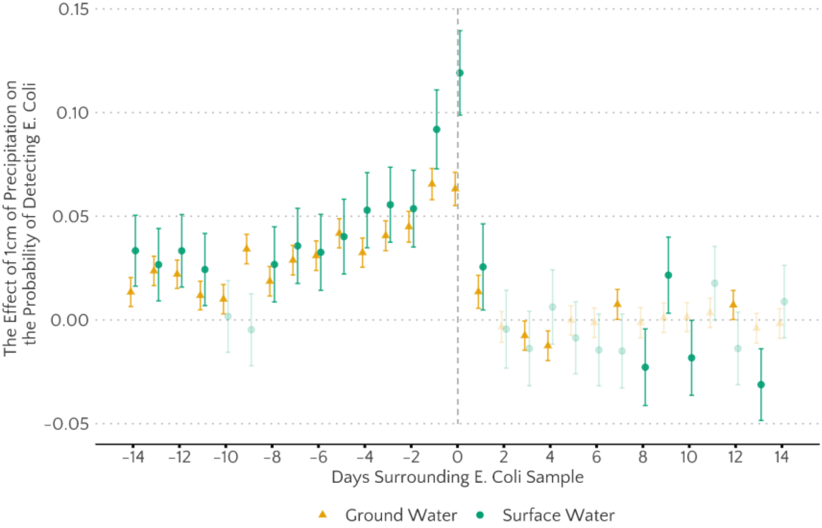
- Erosion and sediment mobilization impact source waters, decreasing water treatment effectiveness and increasing disinfectant byproduct formation (Liu et al., 2012) (Fakour et al., 2016).
- Human and animal waste runoff and less-effective disinfectants → risk of bacteriological contamination (Phan and Sherchan, 2020).
- Damage to infrastructure and capital equipment may cause leaks or drops in pressure → risk of bacteriological contamination. (Arrighi et al., 2017).
- Unexpected and large flood events may cause industrial spills (Thomas et al., 2018) or mobilize legacy pollution (Zak et al., 2009) .

Research Questions

We ask three research questions:

1. How does flooding and extreme precipitation affect the risk of drinking water bacteriological contamination?
2. How does flooding and extreme precipitation affect the concentration of disinfectant byproducts?
3. What water system types, states, and communities are most at risk?

Preview of Findings



Preview of Findings

1. How does flooding and extreme precipitation affect the risk of bacteriological contamination of drinking water?
    - A recent flood or heavy rain event increases the likelihood of Coliform detection by $14 - 25\%$ and E. Coli detection by $17 - 26\%$.
2. How does flooding and extreme precipitation affect the concentration of disinfectant byproducts?
    - A recent flood or heavy rain event increases the concentration of TTHMs by $5 - 6\%$ and HAA5s by 6%.
3. What states, water system types, and communities are most at risk?
    - Groundwater and surface-water sourcing systems both see increased bacteriological risk, although smaller systems and GW systems bear disproportionate risk.
    - Larger and surface water-sourcing systems have the largest increases in DBP formation.

Contribution

Vast literature on flooding:

- Costs of floods to employment, displacement, property damage, crop damage, and other outcomes.
- FEMA Hazus model calculates flood costs to utility infrastructure and disruption of service but not drinking water quality changes from extreme precipitation or flood events (FEMA Hazus 2.1, 2018).

We quantify the average relationship between extreme precipitation and drinking water quality by leveraging:

- 20 year data time horizon → impacts from rare events.
- Near national sampling coverage → distributional analysis across water system types, states, and communities.
- Use of drinking water samples escapes endogenous behavior relevant to SDWA violations (Bennear, Jessoe, Olmstead, 2009).

Empirical Approach

Data

1. Drinking Water Quality Samples (2000-2019)

- Publicly available samples over 30 states from 2000-2019.
- Six-year Review 4 Samples over 48 states from 2012-2019.

Samples by County

2. National Oceanic and Atmospheric Association Storm Events Database (2000-2019)

- All flood or heavy rain events causing loss of life, injuries, significant property damage, and/or disruption to commerce. Map of Floods in the US

3. Parameter-elevation Regressions on Independent Slopes Model (PRISM) (2000-2019)

- Daily county and HUC12 precipitation and temperature.

4. Others

- Hydroshare U.S. Community Water Systems Service Boundaries, v2.0.0.
- National Hydrography Dataset Plus version 2.0.
- Safe Drinking Water Information System (SDWIS) for water intake locations (HUC12-level) and system characteristics.

Summary Statistics

	Mean	s.e.	Min	Max	Observations
Drinking Water Quality					
Total Coliform (TCR)	2.19	14.63	0	100	33,129,011
E. Coli	1.13	10.58	0	100	9,642,038
Total Trihalomethanes (TTHM)	30.12	27.92	0	1617.1	1,882,045
Haloacetic Acids (HAA5)	18.90	18.74	0	2900	1,612,642
Disaster Frequency by County					
Floods	55.24	129.83	0	2,084	2,999
Heavy Rains	13.06	31.00	0	586	2,999
Average Daily Weather by County					
Precipitation (cm)	0.28	0.66	0.00	34.91	21,396,570
Temperature (celcius)	12.87	10.63	-34.56	39.76	21,396,570

Floods, Rainfall, and Drinking Water Quality

Let y_{imst} represent whether a drinking water sample detected a bacteriological contaminant or the concentration of TTHM or HAA5 in county i, day d, month m, state s, and year t.

$$y_{idmt} = \beta Disaster_{idmt} + X'_{idmt}\gamma + \eta_i + \eta_m + \eta_t + \nu_{idmt}$$

Core Terms:

- $Disaster_{idmt}$ is an indicator equal to one if a flooding event occurred within $\delta \in 3, 10$ days prior in the county of the water system.
- In some specifications, $Disaster_{idmt}$ is the sum of precipitation in the HUC12 over the prior 3 days.
- X includes controls for daily temperature and two lagged daily temperature variables.
- Fixed effects for drinking water system, month, and year.

Identifying assumption: Conditional on controls for temperature and fixed effects for county, month, and year, drinking water quality is uncorrelated with extreme precipitation events except through the effect of interest.

Event Study Identification Strategy

Results

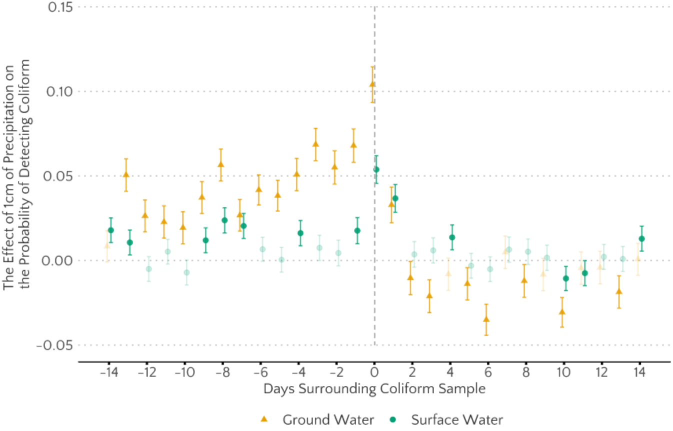
Floods, Rainfall, and Total Coliform Detection

	Floods		Heavy Rains		Rainfall (cm)
	3-day	10-day	3-day	10-day	3-day
Precipitation Event	0.312***	0.291***	0.569***	0.351***	0.0813***
	(0.0528)	(0.0336)	(0.140)	(0.0574)	(0.00354)
Dep Var Mean	2.22	2.22	2.22	2.22	2.22
Pct. Change	14.06	13.11	25.67	15.84	3.67
Water System FEs	✓	✓	✓	✓	✓
Year and Month FEs	✓	✓	✓	✓	✓
Observations	30,888,176	30,888,176	30,888,176	30,888,176	30,888,176

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at the water system.

▸ Results by water source. ▸ Results by system size.

Coliform Detection Event Study – Precipitation



Floods, Rainfall, and E. Coli Detection

	Floods		Heavy Rains		Rainfall (cm)
	3-day	10-day	3-day	10-day	3-day
Precipitation Event	0.322***	0.343***	0.0175	0.208***	0.0749***
	(0.0645)	(0.0457)	(0.157)	(0.0748)	(0.00629)
Dep Var Mean	1.21	1.21	1.21	1.21	1.16
Pct. Change	26.73	28.45	1.45	17.26	6.45
Water System FEs	✓	✓	✓	✓	✓
Year and Month FEs	✓	✓	✓	✓	✓
Observations	8,069,499	8,069,499	8,069,499	8,069,499	8,903,963

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at the water system.

▸ See results by water system source ▸ See results by water system size

Floods, Rainfall, and Total Trihalomethanes ($\mu g/L$)

	Floods		Heavy Rains		Rainfall (cm)
	3-day	10-day	3-day	10-day	3-day
Precipitation Event	1.458***	1.787***	1.550***	1.648***	0.236***
	(0.408)	(0.244)	(0.487)	(0.257)	(0.0210)
Dep Var Mean	30.40	30.40	30.40	30.40	30.40
Pct. Change	4.76	5.76	4.95	5.30	0.76
Water System FEs	✓	✓	✓	✓	✓
Year and Month FEs	✓	✓	✓	✓	✓
Observations	1,778,963	1,778,963	1,778,963	1,778,963	1,778,963

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at the water system.

▸ See results by water system source ▸ See results by water system size

Floods, Rainfall, and Haloacetic Acids ($\mu g/L$)

	Floods		Heavy Rains		Rainfall (cm)
	3-day	10-day	3-day	10-day	3-day
Precipitation Event	1.058***	1.165***	0.0273	0.191	0.122***
	(0.289)	(0.143)	(0.462)	(0.167)	(0.0143)
Dep Var Mean	18.90	18.90	18.90	18.90	18.90
Pct. Change	5.59	6.16	0.10	0.96	0.65
Water System FEs	✓	✓	✓	✓	✓
Year and Month FEs	✓	✓	✓	✓	✓
Observations	1,551,814	1,551,814	1,551,814	1,551,814	1,551,814

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Clustered standard errors at the county or water system.

▸ See results by water system source ▸ See results by water system size

Back-of-the-Envelope Cost Estimates

Damages from clinic visits, stomach illness purchases, sick children stay-at-home days, and bottled water purchases were $7.7m from TCR violations in North Carolina (2005-2014) (Marcus, 2020):

- 424 detections of E. Coli and 16,482 detections of Coliform $\rightarrow$ $145 per E. Coli detection and $461 per total coliform detection.
- 0.5 floods and 0.1 heavy rains per water system annually, 56,000 water systems, and risk of detection per extreme precipitation event.
- $5.1m annually in costs from flooding and $1.1m annually from heavy rains.

Un-quantified potential mortality costs from gastrointestinal illness as well as bladder cancer cost of illness and mortality.

Conclusion

Extreme precipitation and flooding events pose a risk to drinking water quality.

- Flooding events and extreme precipitation increase the likelihood of Coliform and E. Coli detection.
- Flooding events and extreme precipitation increase disinfectant byproduct concentrations.
- Combined, these results demonstrate the extent to which extreme precipitation complicates the water treatment process and poses a threat to public health.
- Flood mitigation and storm runoff collection strategies have economically meaningful and yet unquantified public health benefits.

Thank you!
Questions/comments?

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Appendix

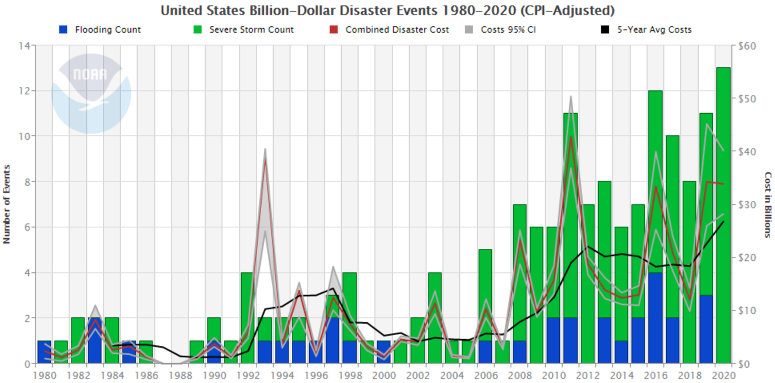

Figure: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021). https://www.ncdc.noaa.gov/billions/ Go back

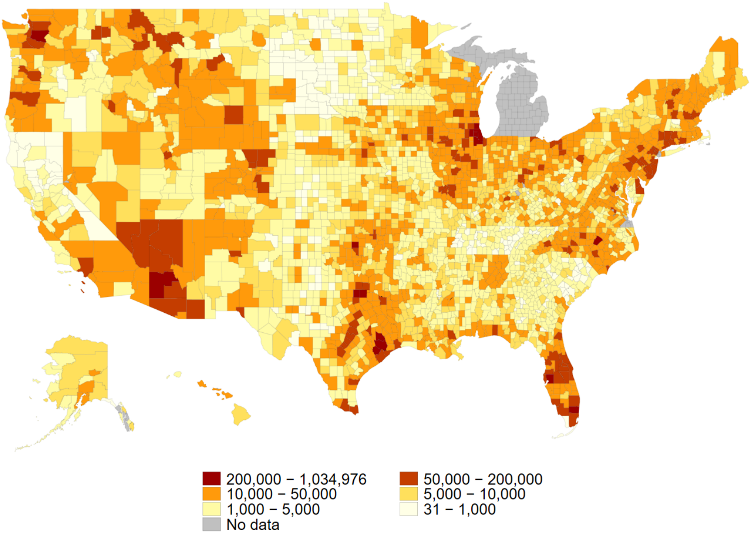

Figure: Number of Coliform, E. Coli, TTHM, and HAA5 samples by county (2000-2019) Go back

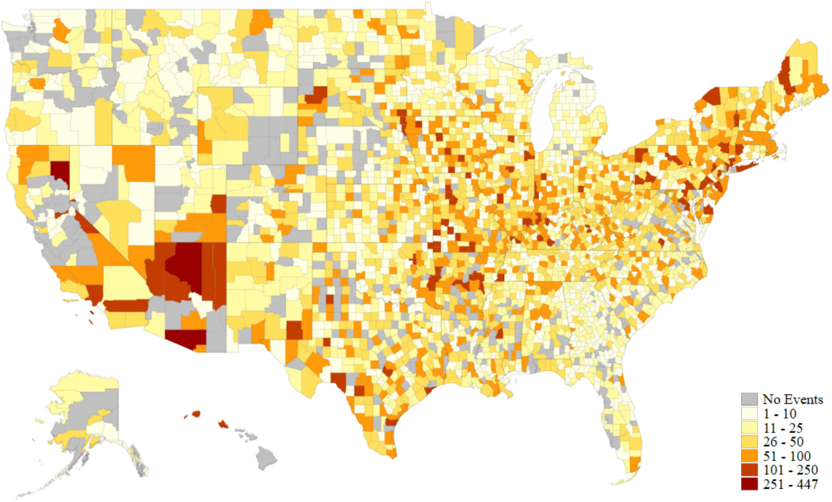

Figure: Number of NOAA Floods by County (2000 - 2019) Go back

Event Study Empirical Approach

Let y_{imst} represent whether a sampling test detected a bacteriological contaminant or the continuous level of disinfectant byproduct detected by the sample in water system i, day d, month m, state s, and year t.

$$y_{idmt} = \sum_{t \in -14}^{14} \beta_t Precipitation_{idmt} + X'_{idmt}\gamma + \eta_i + \eta_m + \eta_t + \nu_{idmt} \quad (1)$$

Core Terms:

- $Precipitation_{idmt}$ is the sum of precipitation in the watershed of the water system intake on day t.
- X includes controls for daily temperature and two lagged daily temperature variables.
- Fixed effects for drinking water system, month, and year.

Identifying assumption: The drinking water sampling outcome is uncorrelated with precipitation except through the impact of precipitation itself conditional on controls for temperature and fixed effects for county, month, and year. Go back

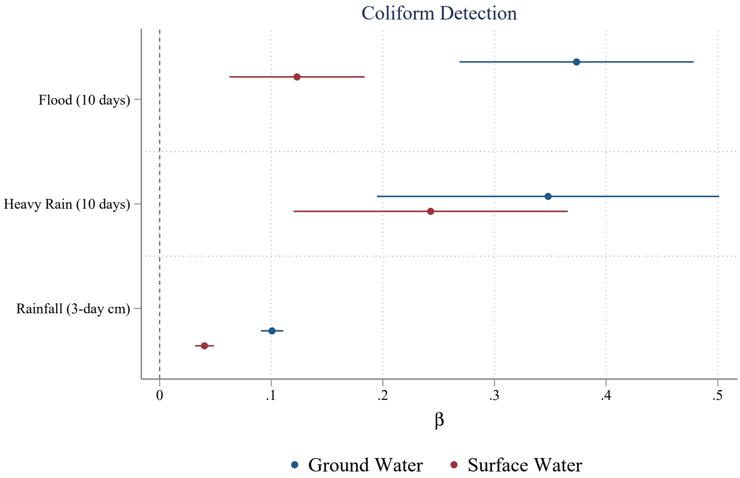

Figure: Extreme Precipitation and Coliform Detection by Source

Go back

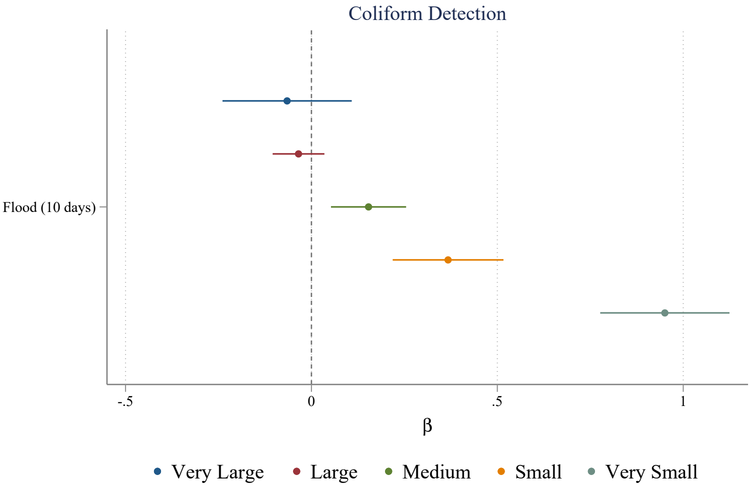

Figure: Flooding and Coliform Detection by System Size

Go back

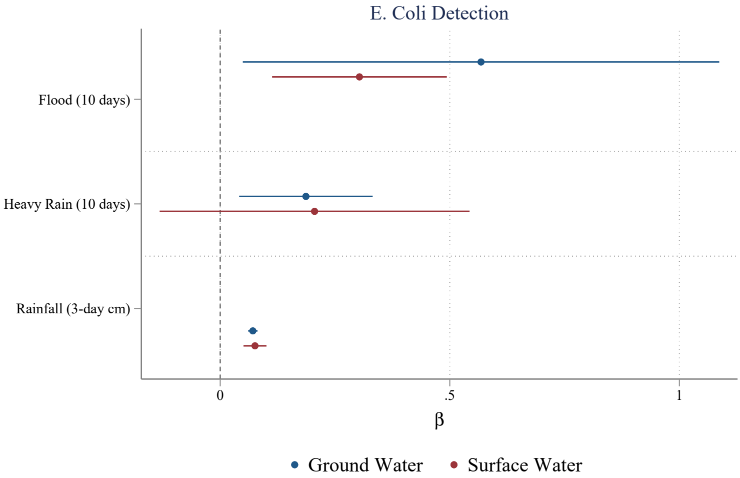

Figure: Extreme Precipitation and E. Coli Detection by System Source Go back

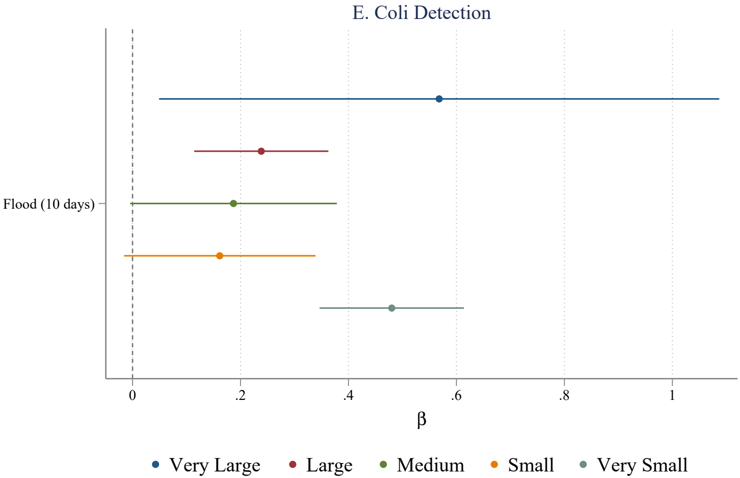

Figure: Flooding and E. Coli Detection by System Size Go back

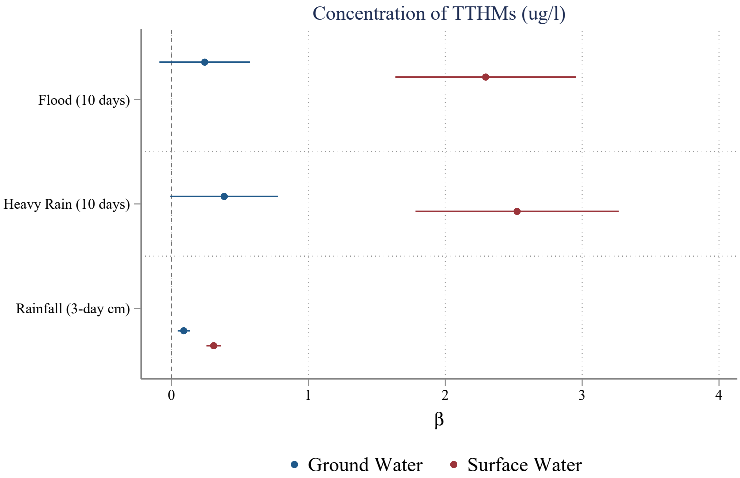

Figure: Extreme Precipitation and TTHM Concentrations by Source

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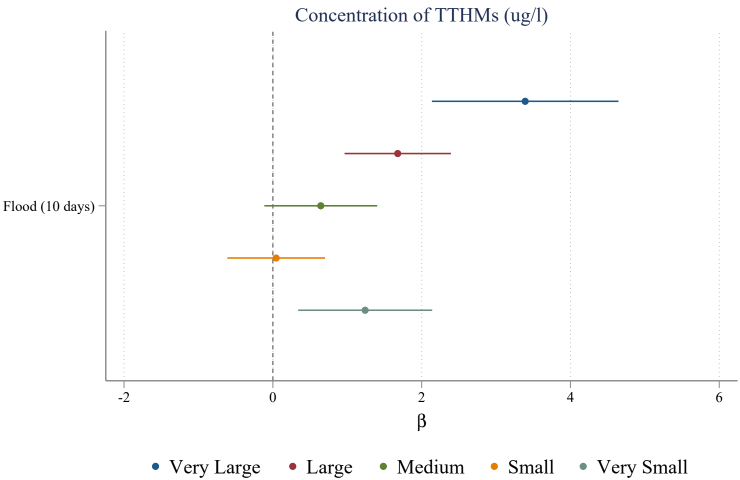

Figure: Flooding and TTHM Concentrations by System Size Go back

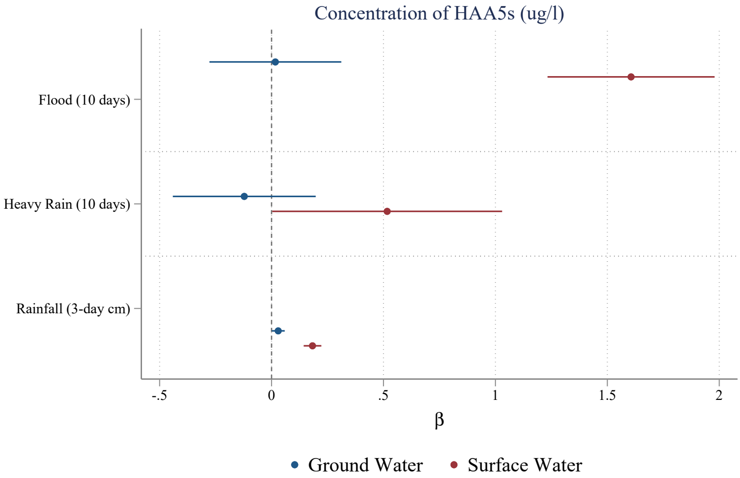

Figure: Extreme Precipitation and HAA5 Concentrations by Source

Go back

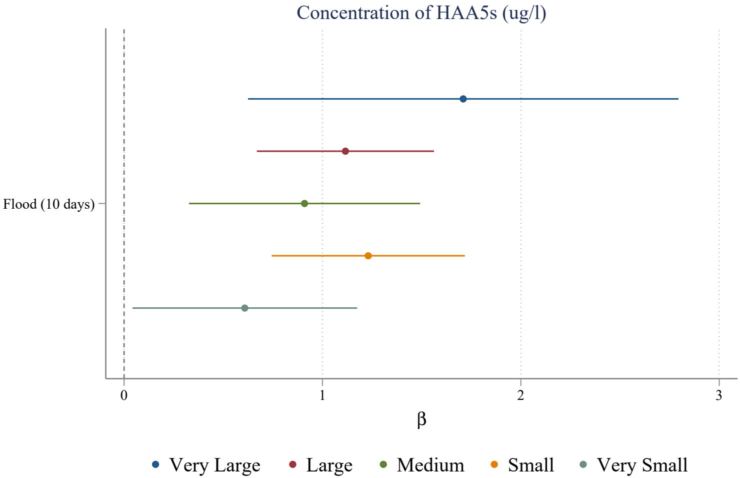

Figure: Flooding and HAA5 Concentrations by System Size ▸ Go back