

CSOs, Climate Change, and Diarrheal Disease in Children in Milwaukee, WI



Water Resilient Cities
Cleveland, OH
4/21/2016

Combined Sewer System

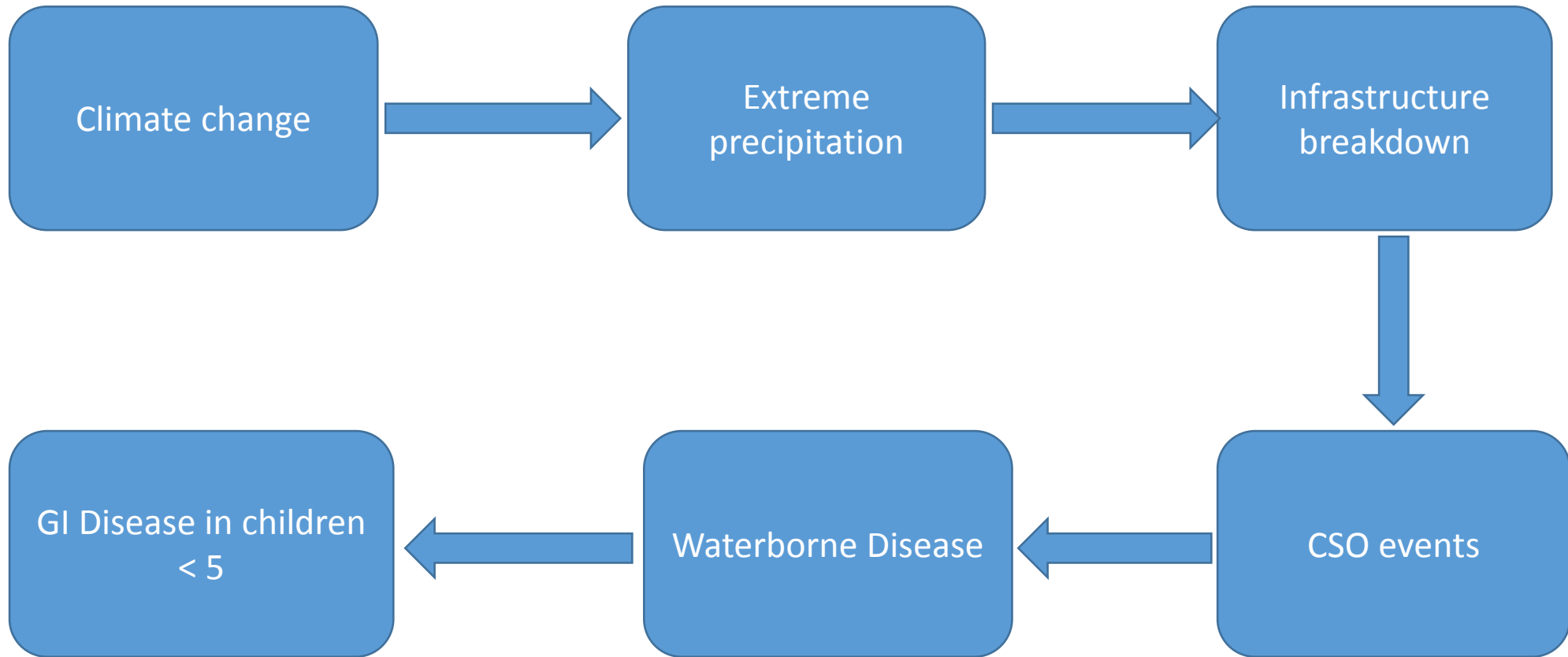
<http://www.hkywater.org/departments/wastewater/combined-sewer-system>

http://storage.hkywater.org/adobe/flash/HWU_combined_web.swf

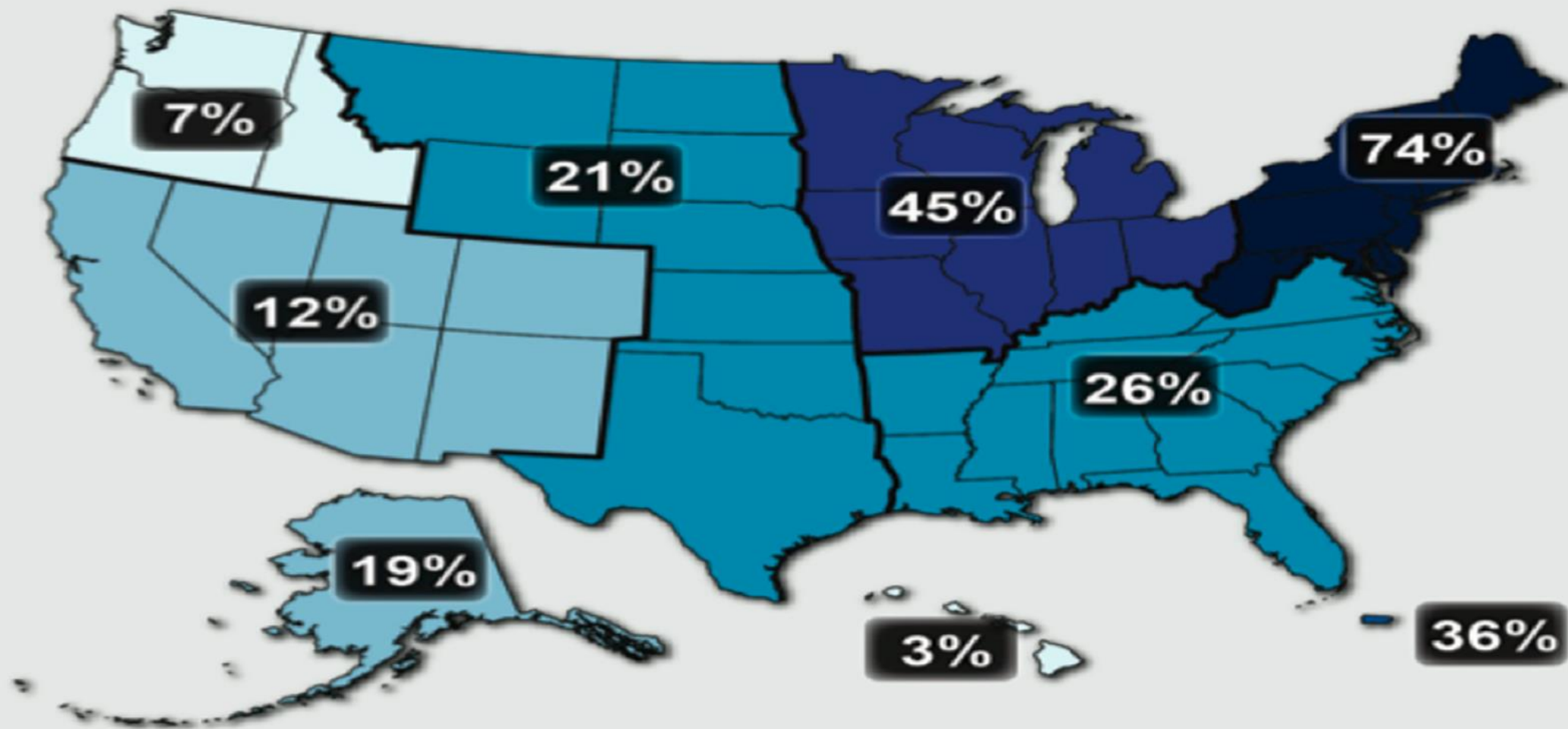
Forrest Gump.....it happens



...and that's all I have to say about that



Percentage Change in Very Heavy Precipitation



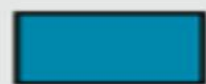
Percentage Change



0-10



10-20



20-30



30-40



40-50



>60

The role of climate change

- More intense and more frequent rainfall
- Southern WI projections:
 - extreme precipitation events to become 10-40% stronger
 - CSO frequency to rise 50 to 120% by the end of the century
- Significant associations exist between rain and children's diarrhea
 - more than half of the documented WBD outbreaks in the US have followed heavy storms
 - In WI, an increased ADI in children has been statistically documented following rain

The past can no longer predict the future



Combined sewer systems (CSSs) are typically found in the northeast, Great Lakes, and Pacific Northwest regions of the country.

USA: Combined sewer overflows (CSOs)



Courtesy: Kellogg Schwab



**1.2 trillion gal of sewage & stormwater a year
discharged during combined sewer overflows
– would keep Niagara Falls roaring for 18 days**

Center for Water & Health, JHU Bloomberg School of Public Health

Data Collection Methods

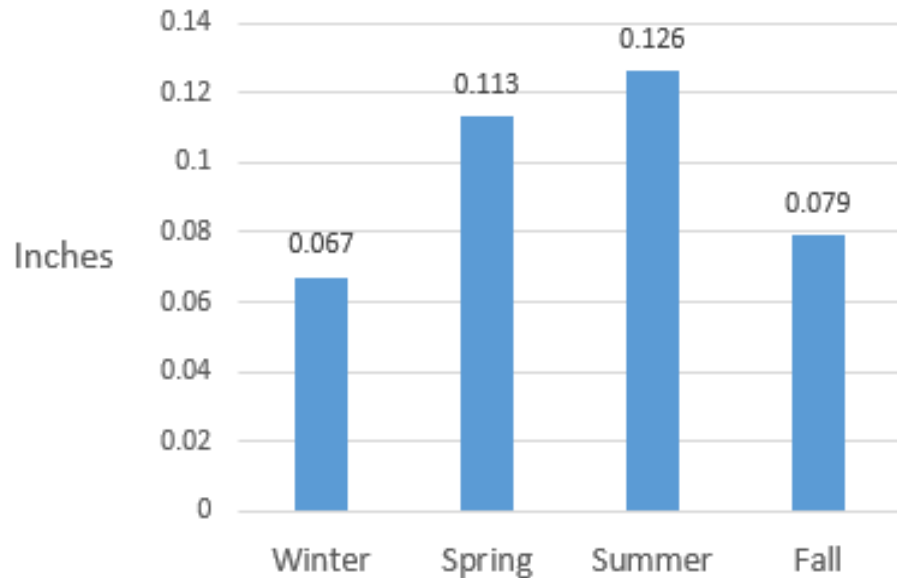
- Data sets:
 - ❖ NOAA-weather data (T, precip, wind, snowfall) (2004-2014)
 - ❖ MMSD-detail reports (daily events of CSOs, SSOs, rainfall amount, duration, amount discharged to water bodies for years 2004-2014)
 - ❖ Water quality/recreational exposures
 - ❖ Milwaukee Health department (monthly health data)

Precipitation, Seasonality, and Sewer Overflow Events

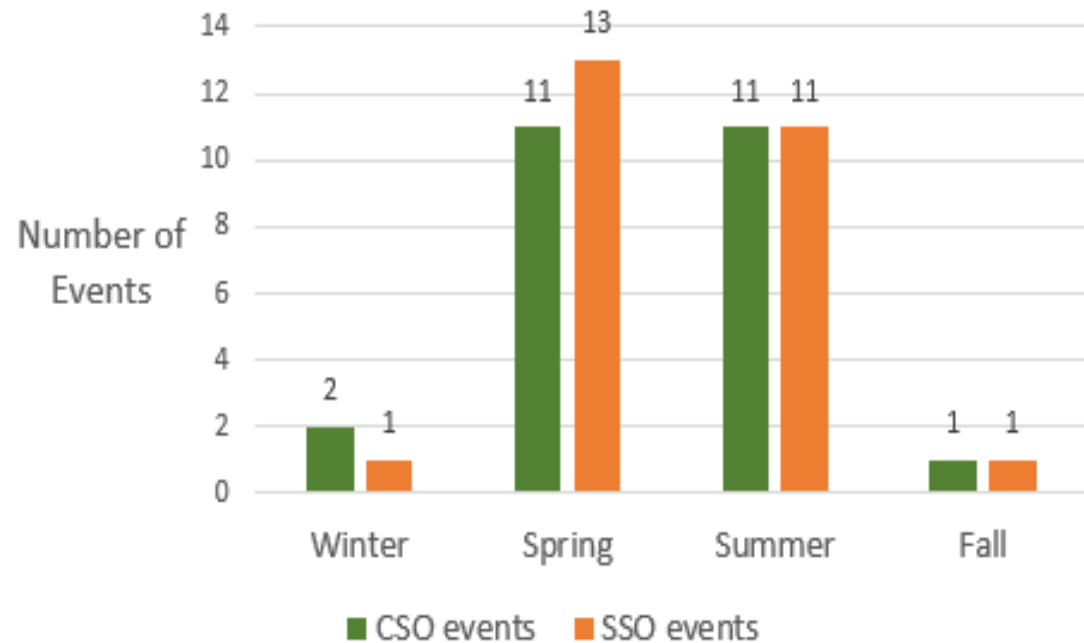
Sewer overflow events and daily precipitation data were classified by season, where
winter = December, January, and February
spring = March, April, and May
summer = June, July, and August
fall = September, October, and November

Average Daily Precipitation (2004-2014) by

Season



CSO and SSO events (2004-2014) by Season



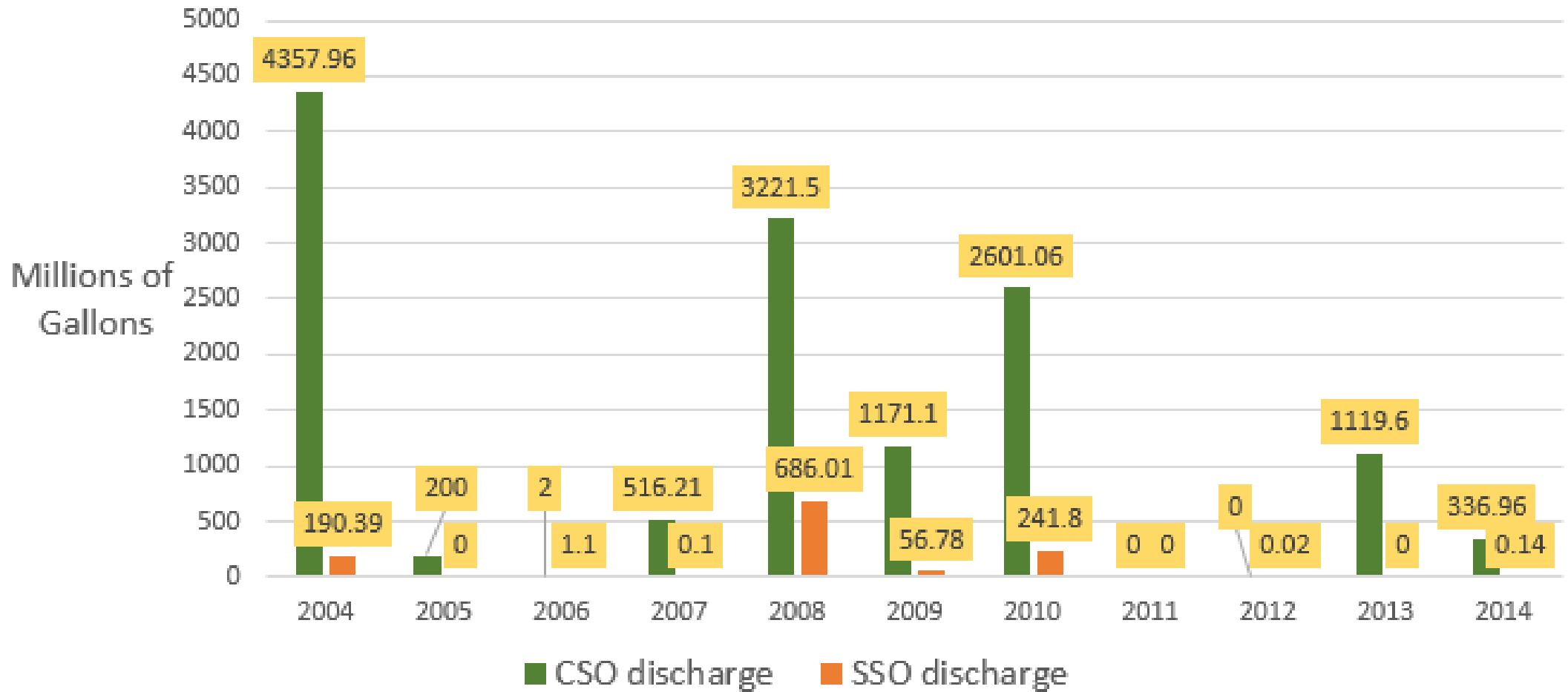
Overflow Events

CSO and SSO Events by Year



Overflow Volume Discharged

CSO and SSO Discharge by Year



Is there a Difference in Daily Precipitation on Days with a Sewer Overflow Event when Compared to Days Without an Event?

- Two-sample t-tests were run to answer this question. Results from the Satterthwaite's test are reported due to unequal variances.

Results:

When comparing days with a CSO to days without a CSO, daily precipitation was 1.32 (95% CI: 0.76, 1.88) inches higher on days with a CSO.

When comparing days with an SSO to days without an SSO, daily precipitation was 1.17 (95% CI: 0.58, 1.76) inches higher on days with an SSO.

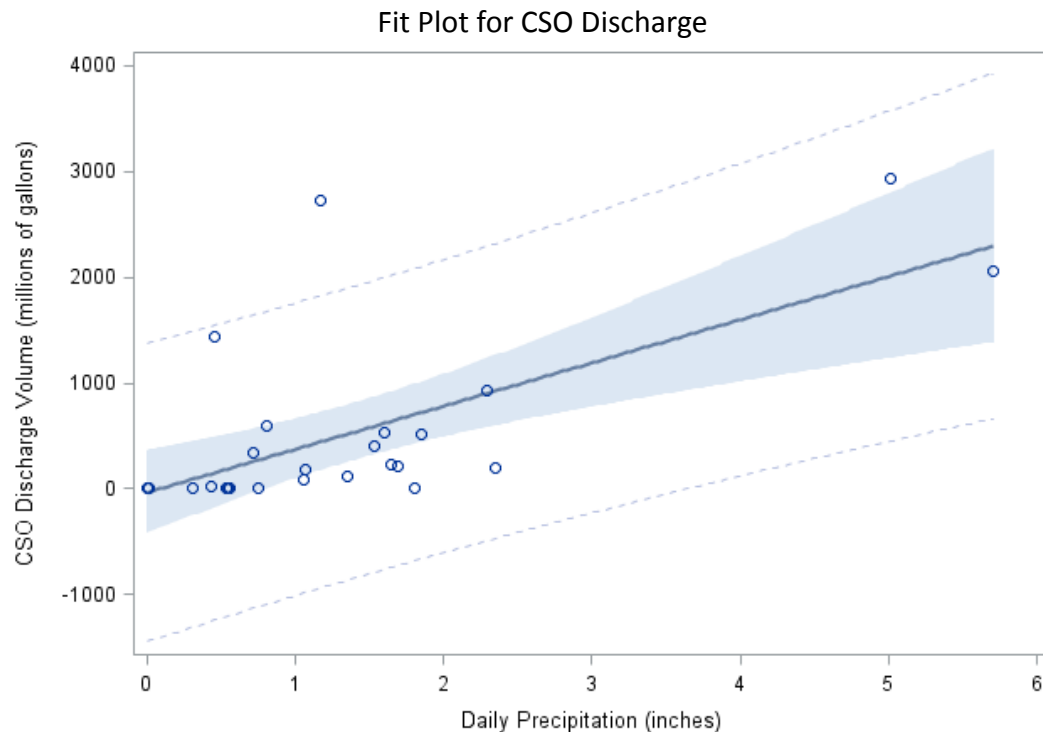
When comparing days with either a CSO or an SSO to days without a sewer overflow event, daily precipitation was 1.12 (95% CI: 0.68, 1.55) inches higher on days with either type of sewer overflow event.

Precipitation as a Predictor of Discharge Volume from Sewer Overflow Events

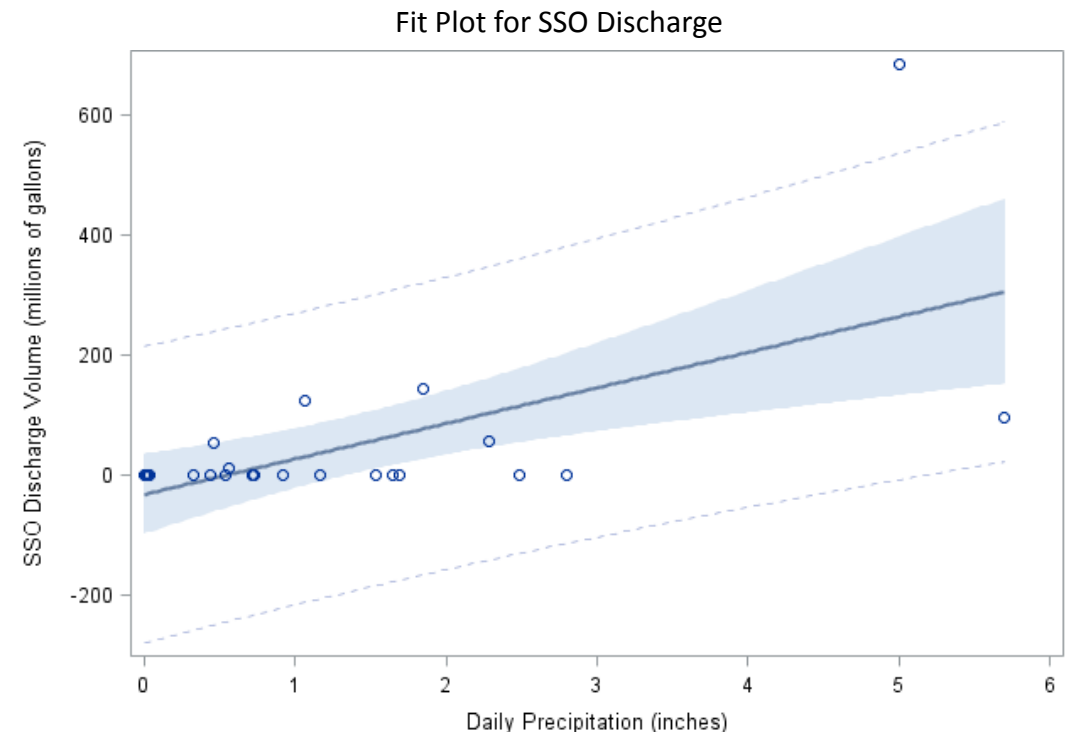
- Two generalized linear models were run:
 - Among CSO events, CSO discharge volume was regressed on daily precipitation.
 - Among SSO events, SSO discharge volume was regressed on daily precipitation.

Results:

Daily precipitation is a significant (p-value = 0.0004) predictor of CSO discharge volume ($R^2 = 0.43$)



Daily precipitation is a significant (p-value = 0.0008) predictor of SSO discharge volume ($R^2 = 0.38$)



Daily Precipitation Threshold

“For the Great Lakes region of the US, contamination events typically occur when daily rainfall levels exceed a threshold of about 5-6 cm (2-2.5 in).” (Patz et al. 2008)

- For the purposes of our relative risk calculations, we used 2 in. as the threshold

Results:

The risk of a CSO event on a day with 2 inches of precipitation or more is estimated to be 85 (95% CI: 36, 198) times the risk of a CSO event on a day with less than 2 inches of precipitation.

The risk of an SSO event on a day with 2 inches of precipitation or more is estimated to be 106 (95% CI: 51, 219) times the risk of an SSO event on a day with less than 2 inches of precipitation.

The risk of either sewer overflow event on a day with 2 inches of precipitation or more is estimated to be 89 (95% CI: 50, 160) times the risk of either sewer overflow event on a day with less than 2 inches of precipitation.

Daily Precipitation Threshold

Relative risks were also calculated using data specific to our study.

Results:

The mean daily precipitation during days with CSO events was 1.41 inches.

The risk of a CSO event on a day with 1.41 inches of precipitation or more is estimated to be 81 (95% CI: 39, 166) times the risk of a CSO event on a day with less than 1.41 inches of precipitation.

The mean daily precipitation during days with SSO events was 1.26 inches.

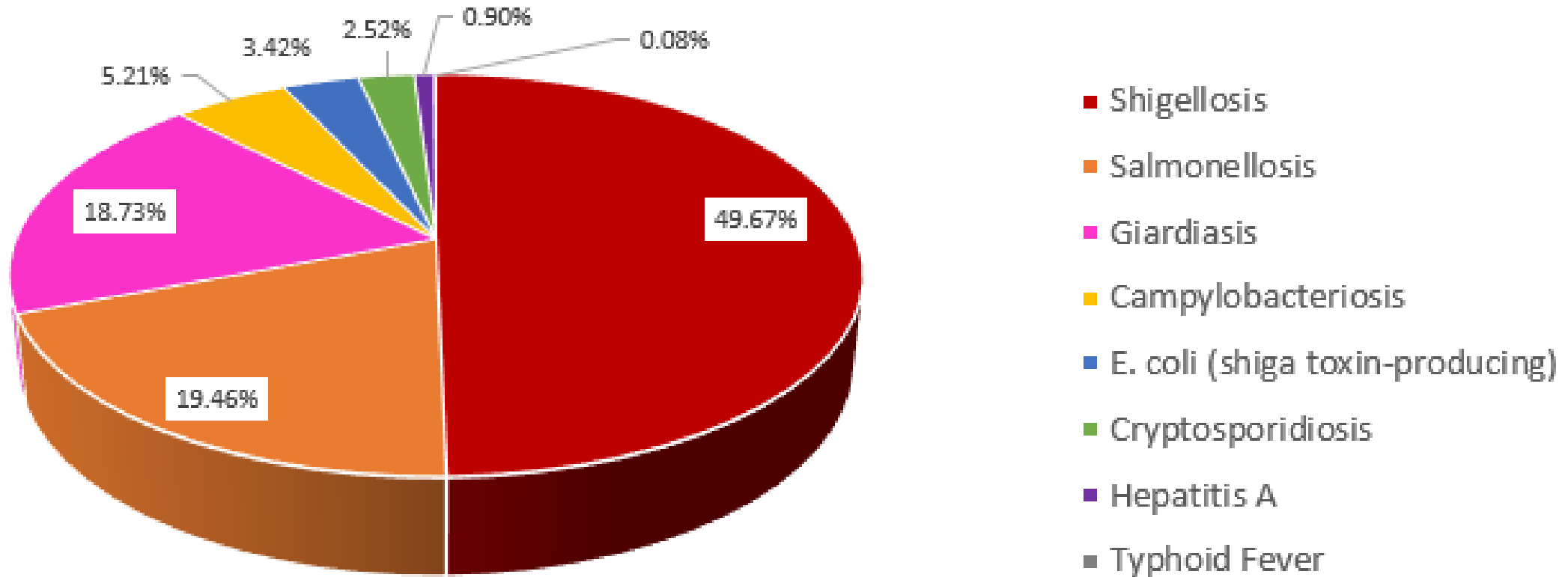
The risk of an SSO event on a day with 1.26 inches of precipitation or more is estimated to be 48 (95% CI: 23, 101) times the risk of an SSO event on a day with less than 1.26 inches of precipitation.

The mean daily precipitation during days with either sewer overflow event was 1.20 inches.

The risk of either sewer overflow event on a day with 1.20 inches of precipitation or more is estimated to be 44 (95% CI: 24, 82) times the risk of either sewer overflow event on a day with less than 1.20 inches of precipitation.

Incidence of Waterborne Diseases in Children under 5 from 2004-2014

(Total number of cases = 1228)



Is there a Difference in Monthly Total Disease Incidence based on the Occurrence of Sewer Overflow Events?

A two-sample t-test was run to answer this question. Results from the Satterthwaite's test are reported due to unequal variances.

- Total disease incidence during months with- or during months following sewer overflow events (to account for the temporal lag) was compared to total disease incidence during months that neither contained, nor followed, an overflow event.

Results:

- The mean total disease incidence during months with-or during months following sewer overflow events was 13.6; while the mean total disease incidence during months that neither contained, nor followed, an overflow event was 7.0.
- This difference was significant with a p-value of 0.0013

Is there a Difference in Monthly Total Disease Incidence based on the Occurrence of Sewer Overflow Events?

The same test was run without accounting for the temporal lag. Total disease incidence during months with one or more sewer overflow events was compared to total disease incidence during months with no sewer overflow events.

Results:

- The mean total disease incidence during months with sewer overflow events was 12.5; while the mean total disease incidence during months without a sewer overflow event was 8.5.
- This difference was **not** significant (p-value = 0.1207).

Further Research/Next Steps

- Incorporate water quality data from MMSD into the analysis.
- Assess recreational exposures through beach monitoring data?
- GIS analysis?

Limitations/Challenges

- Water quality indicator
- Disease under-reporting
- HEALTH DATA!!

Recommendations

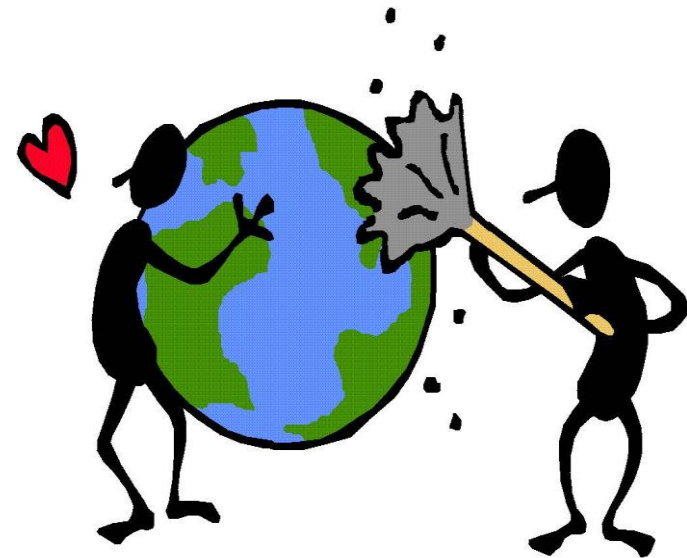
- Data collection/surveillance
 - better indicators
 - Disease surveillance/reporting system/predictive forecast models
 - Inventory infrastructure vulnerabilities to prioritize needs and alert to health risks
- Infrastructure improvements
 - landuse planning/green infrastructure/reduce I/I into sewer systems/separate systems
 - watershed protection/vegetated buffer zones
 - Zoning and development policies influence impervious surfaces
- Education and research & Training
 - Account for cc in planning phases and design/Build in a margin of safety in investments
 - Flood training/developing guidelines for utilities management plans
 - One health concept/Mobilize CCHHG as a group

Conclusions

- These results suggest an association between extreme precipitation and pediatric GI diseases (and climate change is expected to increase the frequency and severity of such extreme events)
- Understanding the relationship between climate and health is important if one is to integrate public health programs with adaptation measures and early warning systems.
- Practice the Precautionary Principle when Possible (4Ps)
- Associations between extreme precipitation and GI-disease could have important implications for public health and water professionals.



What if we change the world to
be a better place and climate
change is not real??





ADDITIONAL SLIDES

Is there a Difference in Daily Precipitation on Days with a Sewer Overflow Event when Compared to Days Without an Event?*

- Two-sample t-tests were run to answer this question. Results from the Satterthwaite's test are reported due to unequal variances.

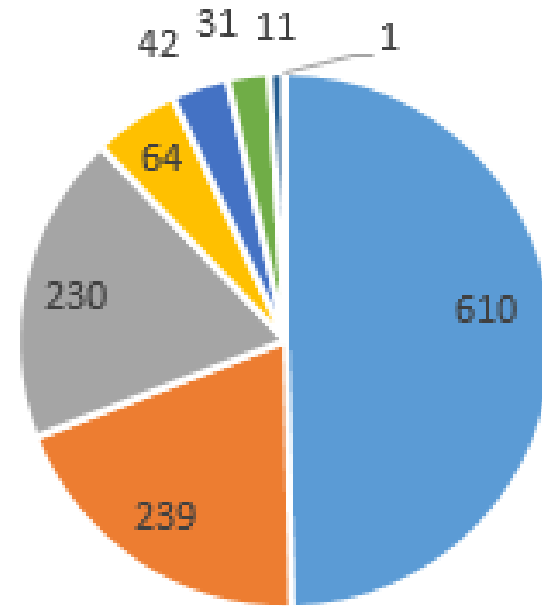
Results:

When comparing days with a CSO (mean = 1.41 inches) to days without a CSO (mean = 0.09 inches), daily precipitation was 1.32 (95% CI: 0.76, 1.88) inches higher on days with a CSO.

When comparing days with an SSO (mean = 1.26 inches) to days without an SSO (mean = 0.09 inches), daily precipitation was 1.17 (95% CI: 0.58, 1.76) inches higher on days with an SSO.

When comparing days with either a CSO or an SSO (mean = 1.20 inches) to days without a sewer overflow event (mean = 0.09 inches), daily precipitation was 1.12 (95% CI: 0.68, 1.55) inches higher on days with either type of sewer overflow event.

Incidence of Waterborne Diseases in Children under 5 from 2004-2014



- Shigellosis
- Salmonellosis
- Giardiasis
- Campylobacteriosis
- E. coli (shiga toxin-producing)
- Cryptosporidiosis
- Hepatitis A
- Typhoid Fever

Incubation Periods

- **Shigellosis:** usually 1-3 days, but may range from 12 to 96 hours; up to 1 week for *S. dysenteriae*
- **Salmonellosis:** from 6 to 72 hours, usually about 12-36 hours
- **Giardiasis:** usually 3-25 days or longer; median 7-10 days
- **Campylobacteriosis:** usually 2-5 days, with a range of 1-10 days, depending on dose ingested
- **E. coli (shiga toxin-producing):** relatively long, 2-10 days, with a median of 3-4 days
- **Cryptosporidiosis:** not known precisely; 1-12 days is the likely range, with an average of about 7 days
- **Hepatitis A:** average 28-30 days (range 15-50 days)
- **Typhoid Fever:** depends on the inoculum size and on host factors; from 3 days to over 60 days – usual range 8-14 days; the incubation period for paratyphoid is 1-10 days

Heymann, D.L. 2004. *Control of Communicable Diseases Manual*. 18th ed: American Public Health Association.

US Gastroenteritis/diarrhea's impact on US society

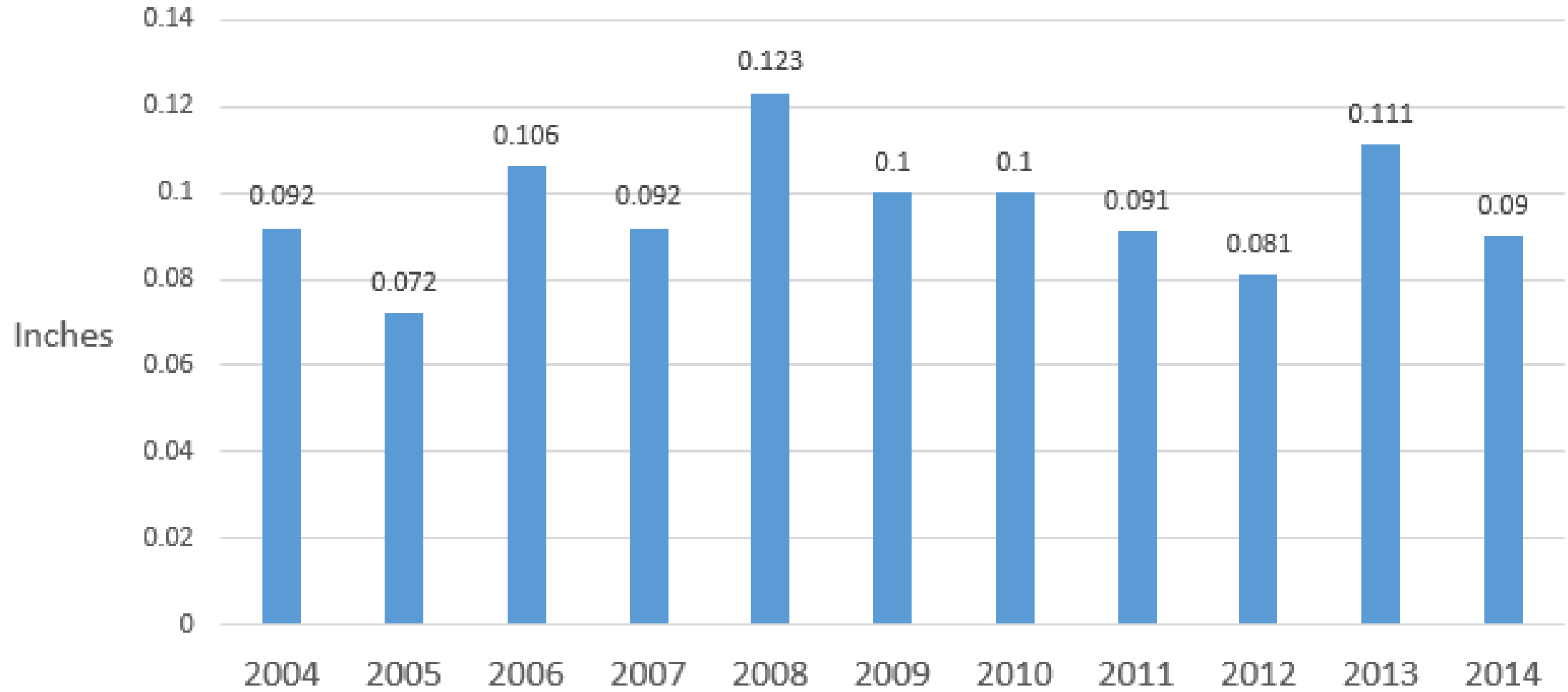
- 1.5 million health care visits /year
- 200,000 hospitalizations/year
- ADI over 20 million childhood cases
- GI in children result in 1.5 million healthcare visits
- Up to 12% of GI cases may be due from waterborne diseases
- 10% of hospital admissions
- 300 children's deaths
- \$1 billion annual costs to society
- > 20 million cases ADI/year in the USA. GI in children results in 1.5 million healthcare visits and 200 000 hospitalizations/year

Three components have the potential to cause a temporal lag between water contamination and disease reporting

1. Environmental Transport
 - Influenced by hydrology, season of the year, and the geographic context (urban vs. rural)
 - Precipitation events flush pathogens into groundwater over the course of a day to weeks
2. The Disease System (disease-specific incubation periods as well as virulence of the organism)
3. Health-seeking Behaviors
 - In Milwaukee, families typically waited 2 days after experiencing symptoms to visit a clinic

Uejio, C. K., S. H. Yale, K. Malecki, M. A. Borchardt, H. A. Anderson, and J. A. Patz. 2014. "Drinking water systems, hydrology, and childhood gastrointestinal illness in Central and Northern Wisconsin." *Am J Public Health* no. 104 (4):639-46. doi: 10.2105/AJPH.2013.301659.

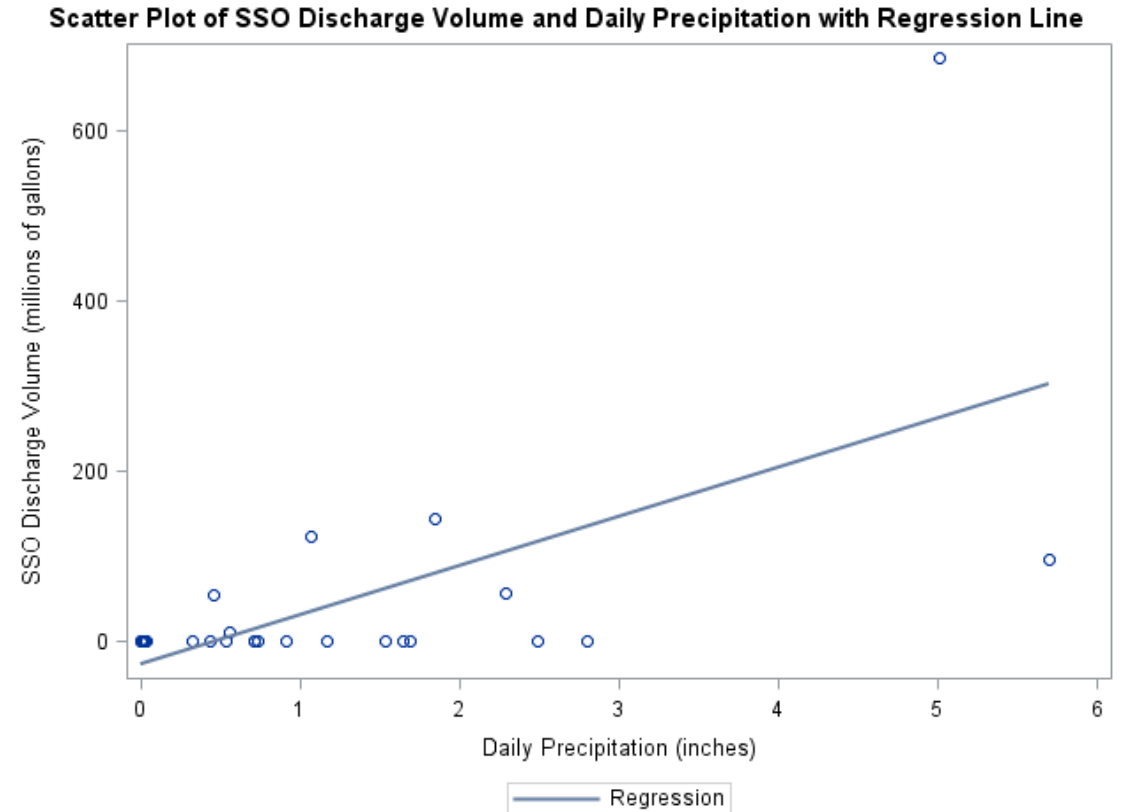
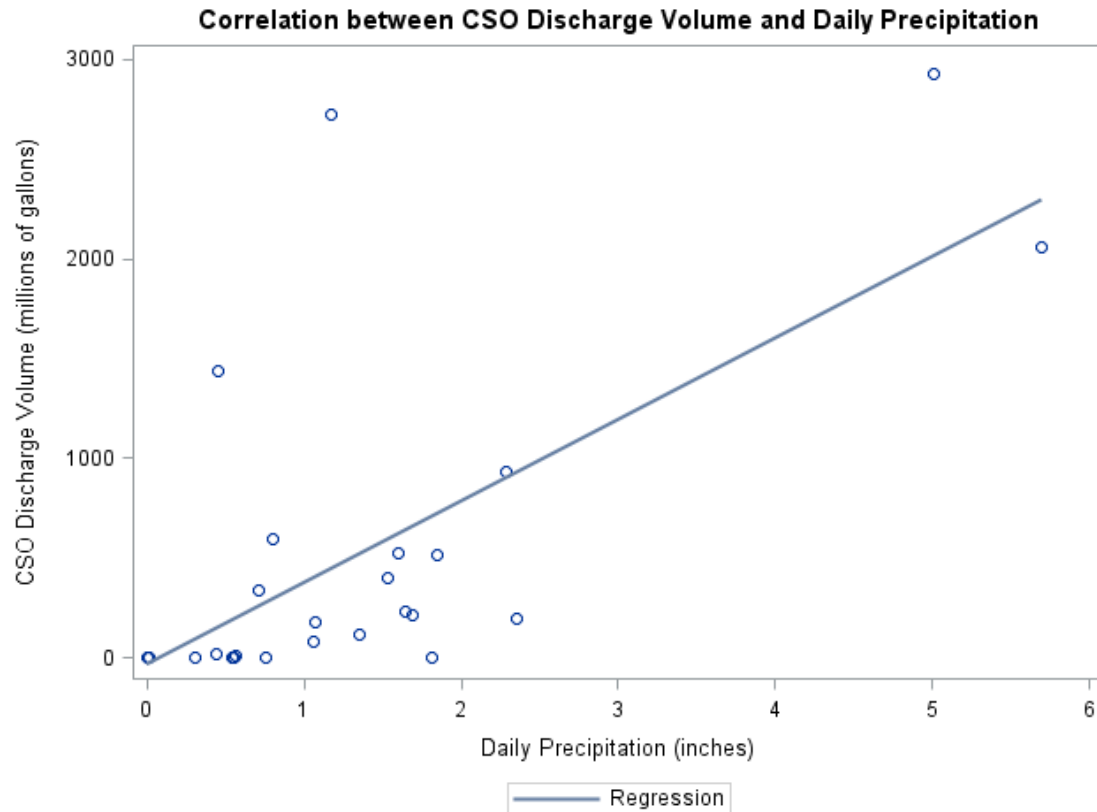
Average Daily Precipitation by Year



Correlation between Discharge Volume from Sewer Overflow Events and Precipitation*

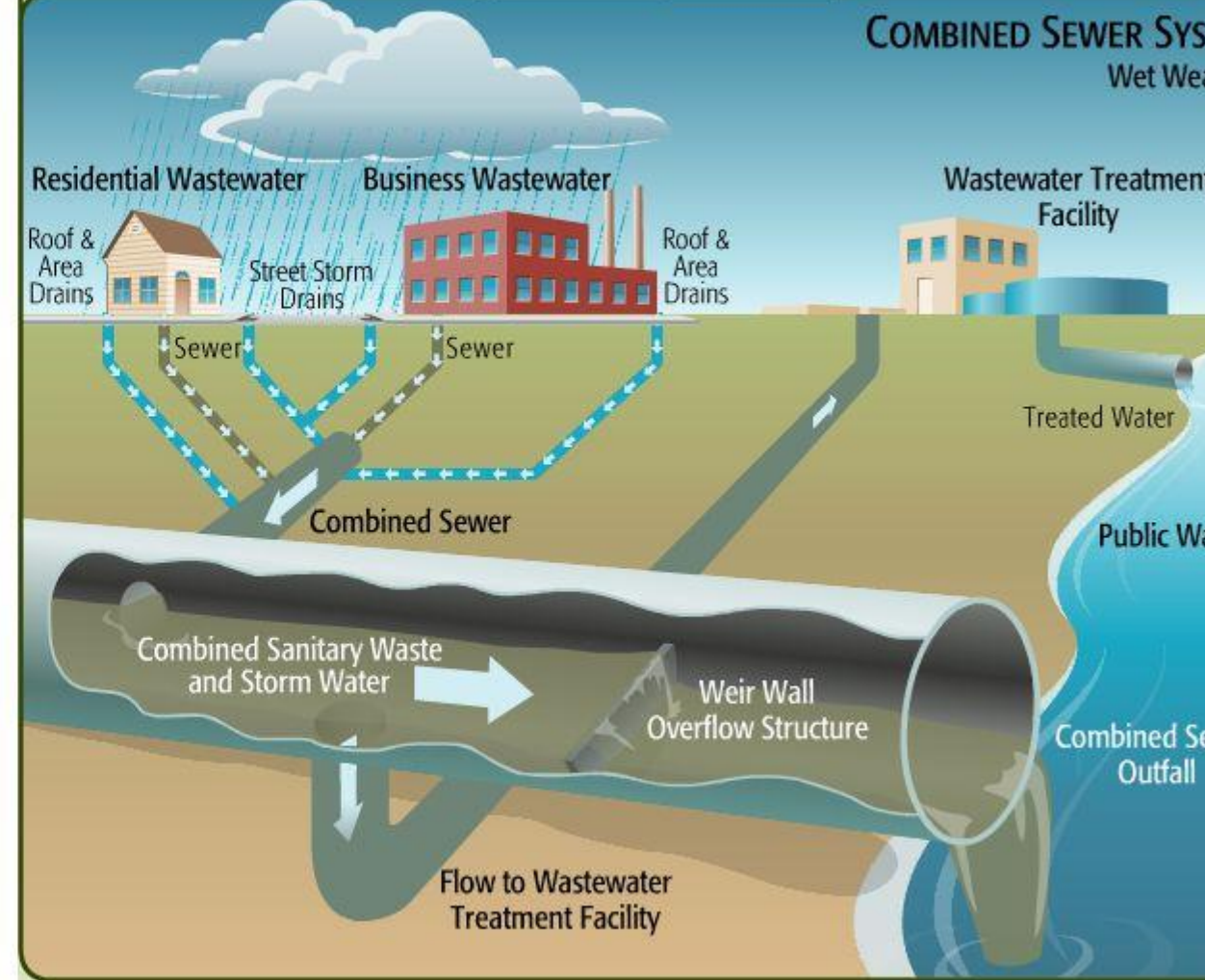
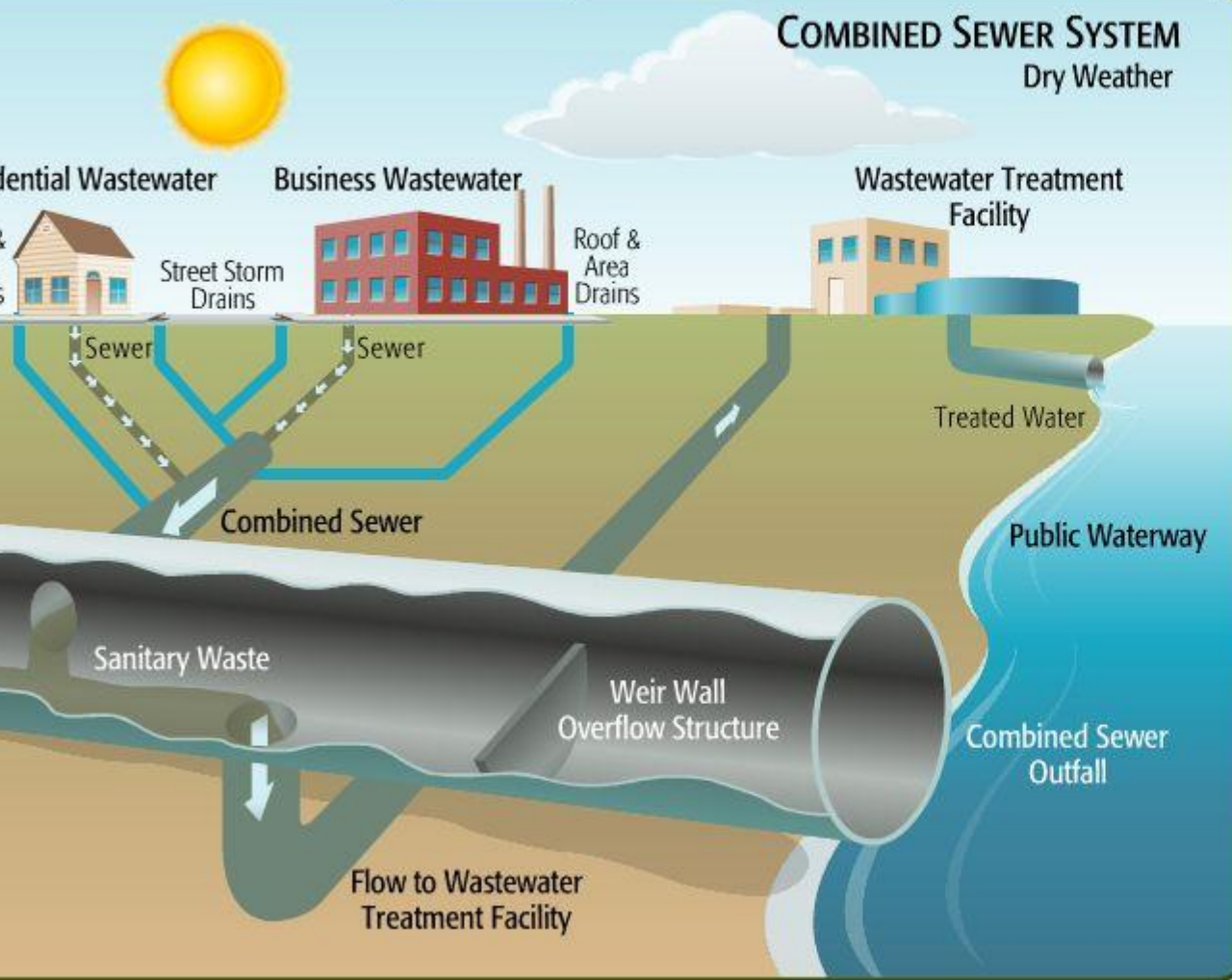
- Pearson's correlation coefficient was calculated to quantify the relationship between discharge volume and precipitation:
 - **Among CSO events, $r = 0.655$**
 - **Among SSO events, $r = 0.615$**

Scatterplots:



CSO Control Policy

- National framework to control CSOs through NPDES
- Contains 4 principles to ensure that CSO controls are cost-effective and meet local environmental objectives
 - Clear levels of control to meet health and environmental objectives
 - Flexibility to consider site-specific nature of CSOs and find the most effective way to control them
 - Phased implementation of CSO controls to accommodate a community's financial capability
 - Review and revision of water quality standards during the development of CSO control plans to reflect the site-specific wet weather impacts of CSOs
- Nine min controls: measures that can reduce the prevalence and impacts of CSOs
- Communities to develop LTCP



Hypotheses and Definitions

Hypotheses:

- ❖ We hypothesize that CSO events will occur when a precipitation threshold is reached.
- ❖ We further hypothesized that CSO events (amount of discharge) would be associated with an increase in GI disease in children.

Definitions:

- ❖ Extreme precipitation: >95th percentile rainfall that is > 1 in/24hr or 1.5in/48hr.
- ❖ CSO initiating threshold: 2.5 in of daily precip for Milwaukee.

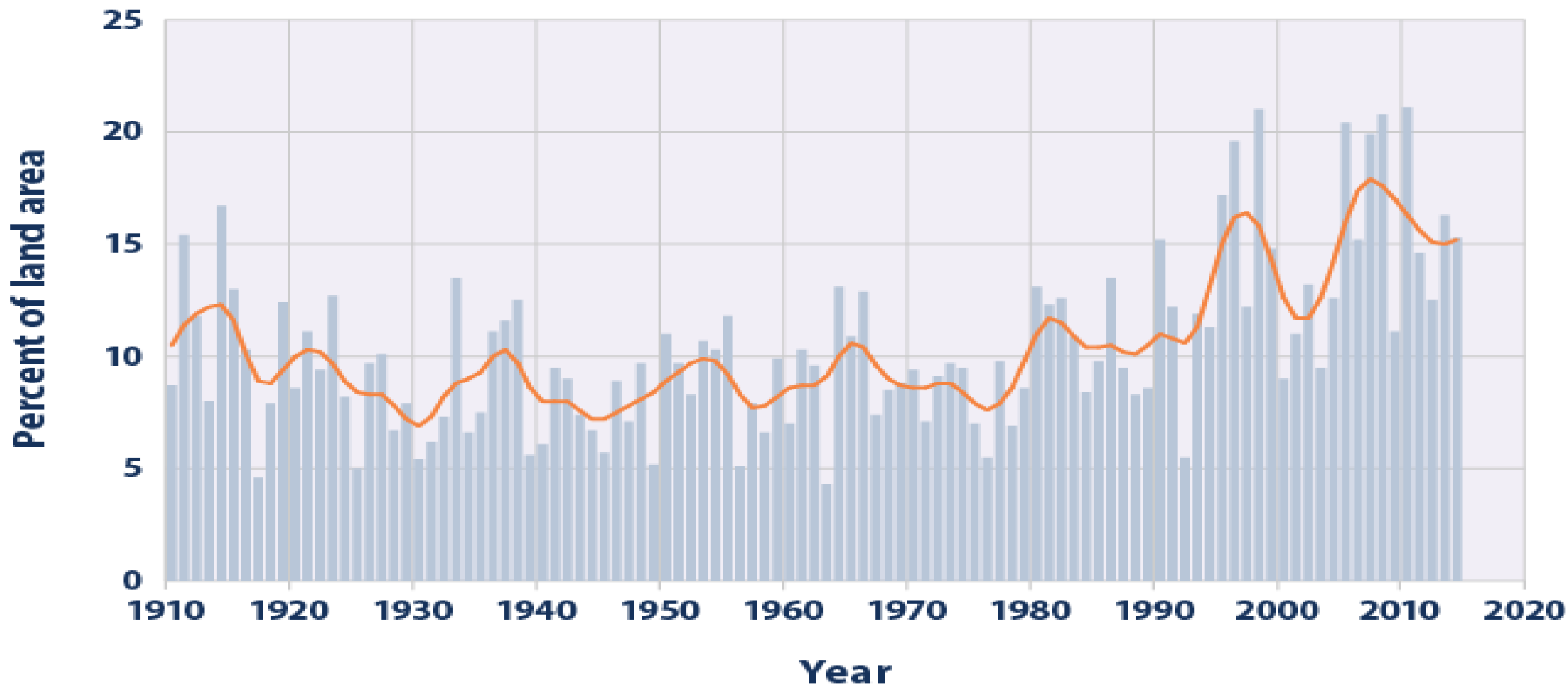
Reported waterborne diseases, US, from 1948-1994

- 67% of waterborne disease outbreaks were preceded by precipitation above the 80th percentile (across a 50 yr. climate record), $p < 0.001$
- 51% of outbreaks were preceded by precipitation above the 90th percentile, $p < 0.002$
- Surface water-related outbreaks had strongest correlation with extreme precipitation in the month of outbreak; groundwater-related outbreaks lagged 2 months following extreme precipitation.

MORE ON POOP...

- Diarrhea-causing viruses are routinely found in groundwater and groundwater wells throughout Wisconsin. Viruses are more commonly the cause of diarrhea in children than other pathogens.
- One study revealed that well water was more associated with increased diarrhea than surface water.
- Another linked children's diarrhea with how many septic tanks were near their residences.
- Most recently, researchers found solid evidence linking precipitation to virus prevalence in groundwater. Viruses from human sewage showed up in deep groundwater serving Madison, Wisconsin. Virus levels were correlated with recent rain: when it rained, more viruses showed up in groundwater wells.

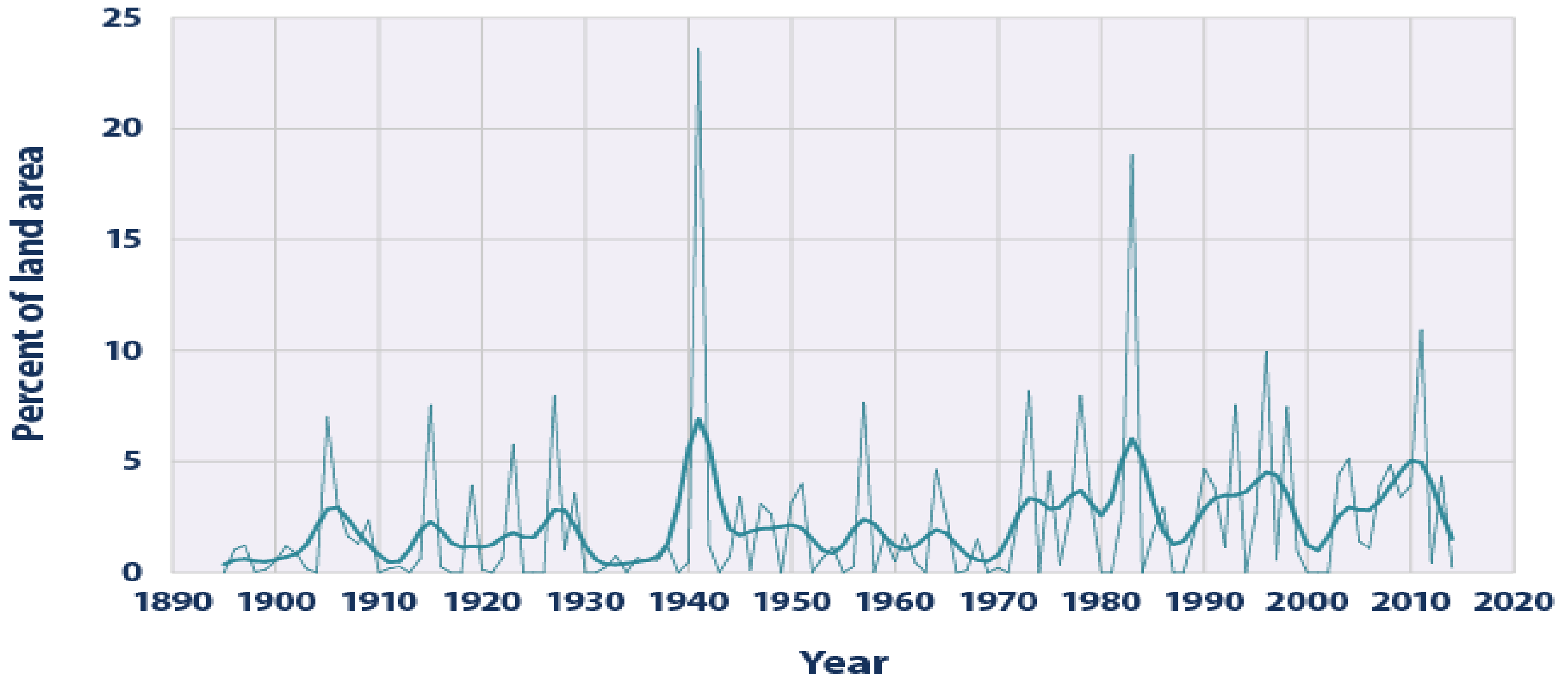
Extreme One-Day Precipitation Events in the Contiguous 48 States, 1910–2014



Data source: NOAA (National Oceanic and Atmospheric Administration). 2015. U.S. Climate Extremes Index. Accessed March 2015. www.ncdc.noaa.gov/extremes/cei.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/indicators.

Unusually High Annual Precipitation in the Contiguous 48 States, 1895–2014



Data source: NOAA (National Oceanic and Atmospheric Administration). 2015. Standardized Precipitation Index data files. Accessed March 2015. <ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv>.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/indicators.

EPA CSO Control Policy Objectives

- Design standard: 4 events per year-but fail to plan for climate change- there could be an average of 237 events/year above the control policy's objectives across 182 communities
- Executive order 13653 (11/2013)- "Preparing the US for the impacts of cc"

The Risks are Manageable

- Calculations of system size should not be based on current hydrology and historic precipitation data.
- A *policy* decision must be made about additional investments to build in a margin of safety.
- Integrate considerations of climate change impacts and adaptation into GLR projects etc....

Heavy Downpours and Exposure to Disease

Climate change increases heavy downpours.

Streams and rivers rise which contributes to flooding of homes, businesses, and critical infrastructure like sewer and storm water systems.

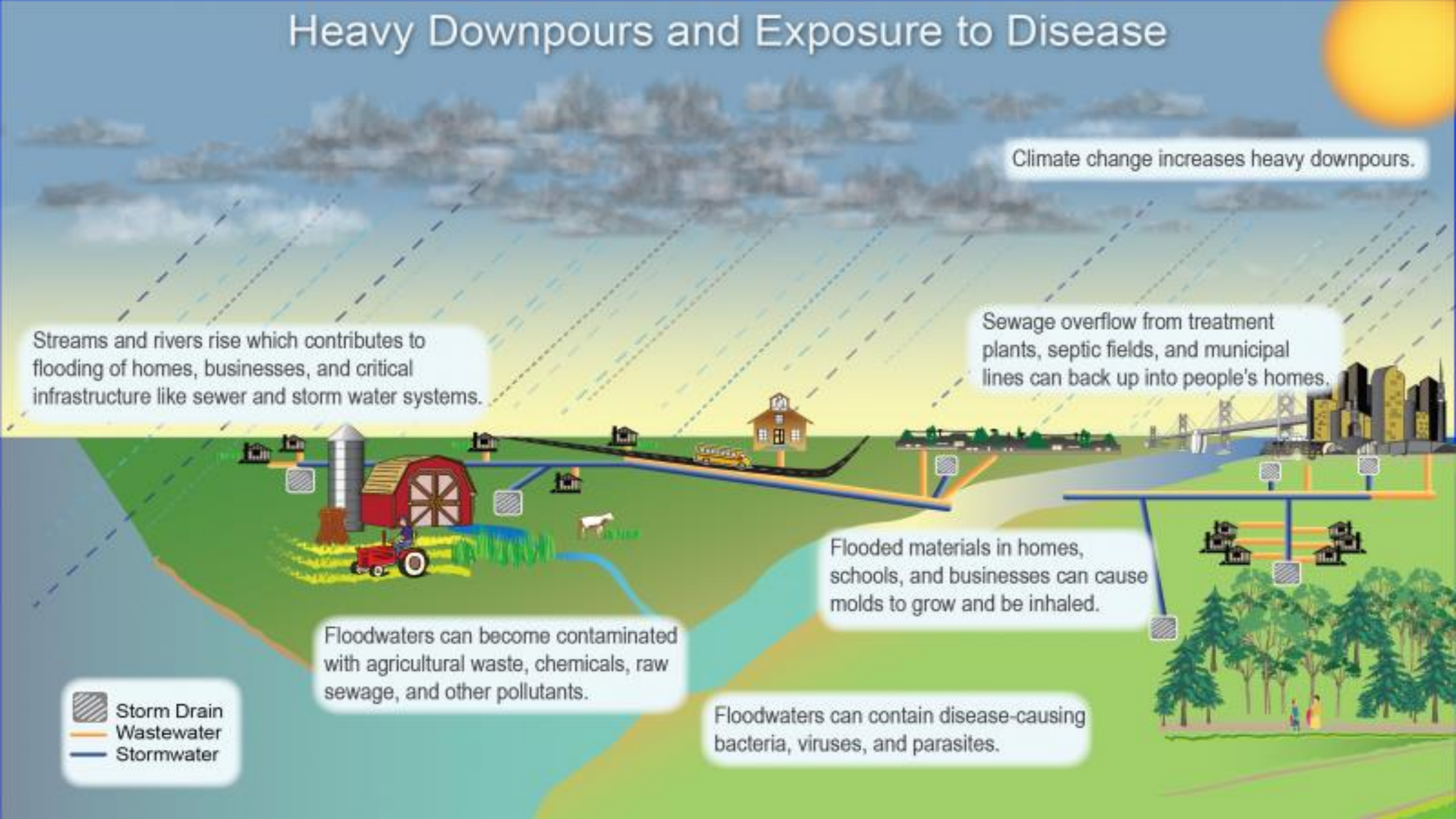
Sewage overflow from treatment plants, septic fields, and municipal lines can back up into people's homes.

Flooded materials in homes, schools, and businesses can cause molds to grow and be inhaled.

Floodwaters can become contaminated with agricultural waste, chemicals, raw sewage, and other pollutants.

Floodwaters can contain disease-causing bacteria, viruses, and parasites.

 Storm Drain
 Wastewater
 Stormwater



CSOs in the Great Lakes Region

- There are 182 combined sewer systems in the Great Lakes Region.
- The U.S. Great Lakes region provides approximately 40 million people with water used for drinking, fishing, recreation, and industry and encompasses 1000 beaches
- If combined sewer systems are designed to meet the EPA's CSO Control Policy design standard of 4 events per year, but fail to plan for climate change: climate change may result in failure to meet the standard
- **there could be an average of 237 events per year above the control policy's objectives across 182 communities**
- Communities must transform the way they plan for the future and design combined sewer systems.

Diarrhea's Impact on American Society

- 10% of hospital admissions
- 300 children's deaths
- \$1 billion annual costs to society
- > 20 million cases ADI/year in the USA. GI in children results in 1.5 million healthcare visits and 200 000 hospitalizations/year
- up to 12% of cases of GI in the US may be due to waterborne disease

Examples of success stories

- Onondaga county, N.Y. uses green infrastructure to decrease CSOs; mixed approach of green/gray infrastructure can save the county up to \$20 million compared to using traditional stormwater management techniques alone.
- Mass- raised the water treatment plant to account for the potential sea level rise.
- Philly-Green city-clean waters- creation of new green jobs/engage community/return on investment
- Better-than-expected performance at Villanova University (evapotranspiration)
- Pick projects with already planned construction etc...

What can be done

- Stormwater management
- Rainwater harvesting
- Bioretention facilities/retention basins (2-120 MG capacity)
- Watershed management (runoff; agr); IWM; LID;
- Focus on pollution prevention not pollution treatment
- Added challenge and unique opportunity
- International BMP(Best Management Practices) database
- CSOs (Civil Society Organizations) best suited to create adaptive capacities within communities

What can be done

- Public-private partnerships
- Centralized vs non-centralized systems/solutions
- Scales and levels (municipal; state; local agencies...)use of science/evidence

John Muir

**"When we try to pick out anything by itself,
we find it hitched to
everything else in the Universe."**

Forrest Gump...it happens....



▶ 0:13

Shit Happens- Forrest Gump Quote - YouTube

<https://youtu.be/edmqTODMZC4>

<https://www.youtube.com/watch?v=edmqTODMZC4>

<https://youtu.be/edmqTODMZC4>

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