CLIMATE CHANGE: IMPACTS AND CHALLENGES FOR GEOTECHNICAL ENGINEERING
PGS 15TH G.A. LEONARD'S LECTURE

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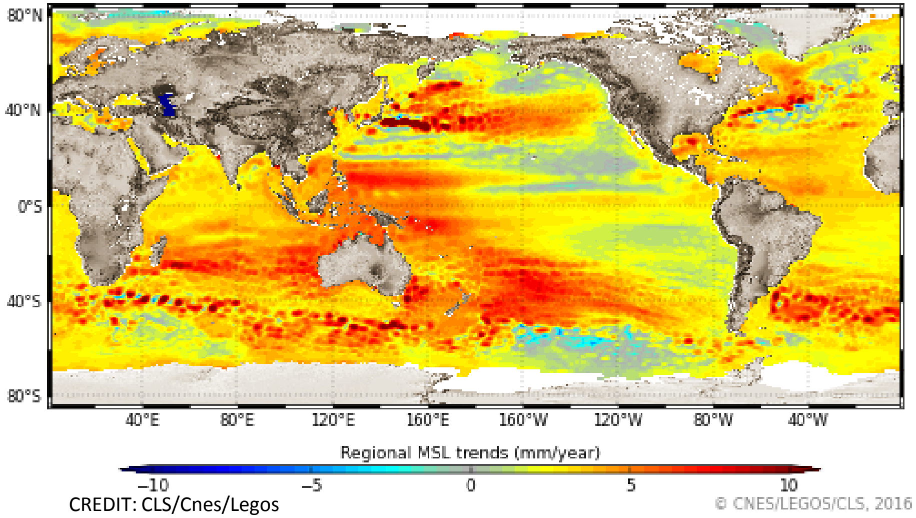


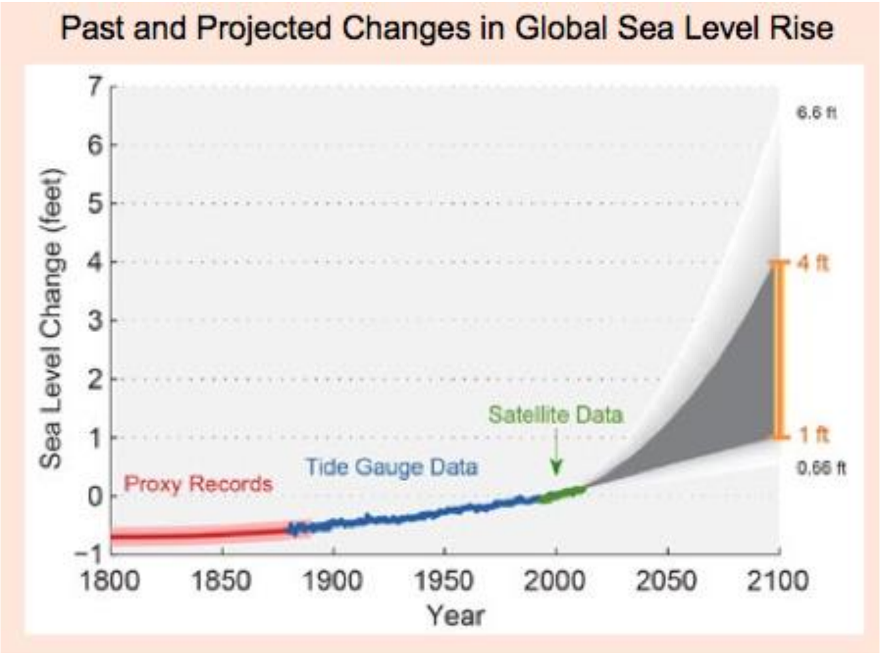
CREDIT: CLS/Cnes/Legos

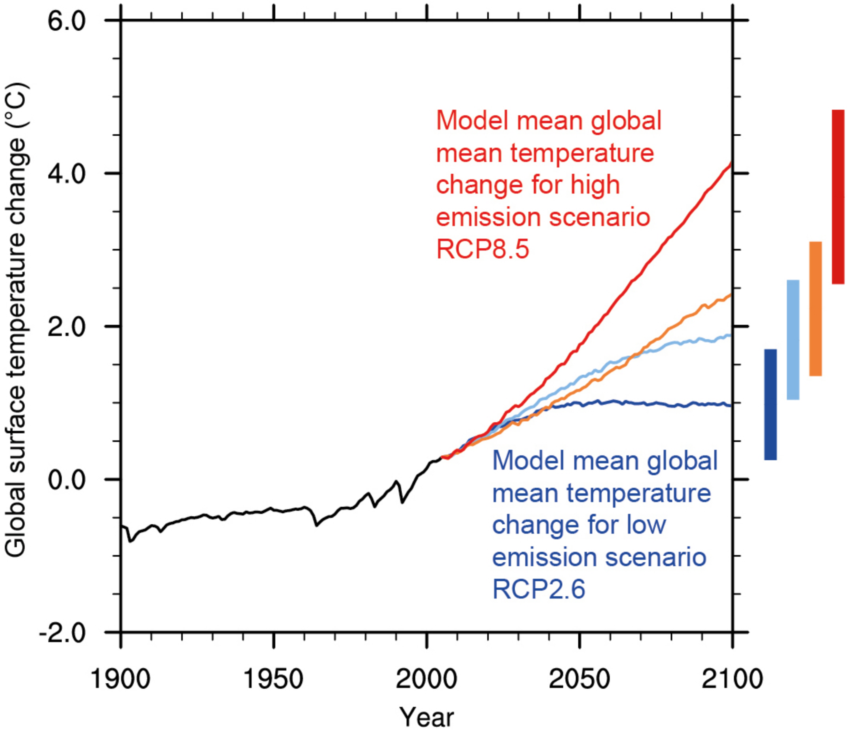
Overview

- Climate Change
  - Challenges, Impacts & Research Needs
- Climate Adaptation Case Study
  - New York City's Green Infrastructure Program
- Distributed/ Localized Infrastructure
- Future Needs

Climate Change Impacts

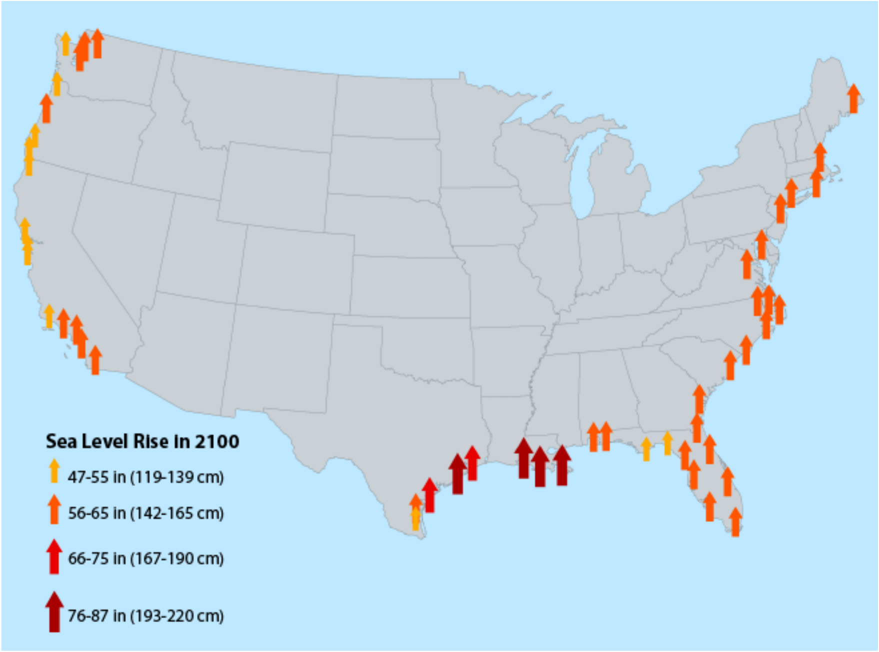
Global Sea-Level Rise and Temperature Rise

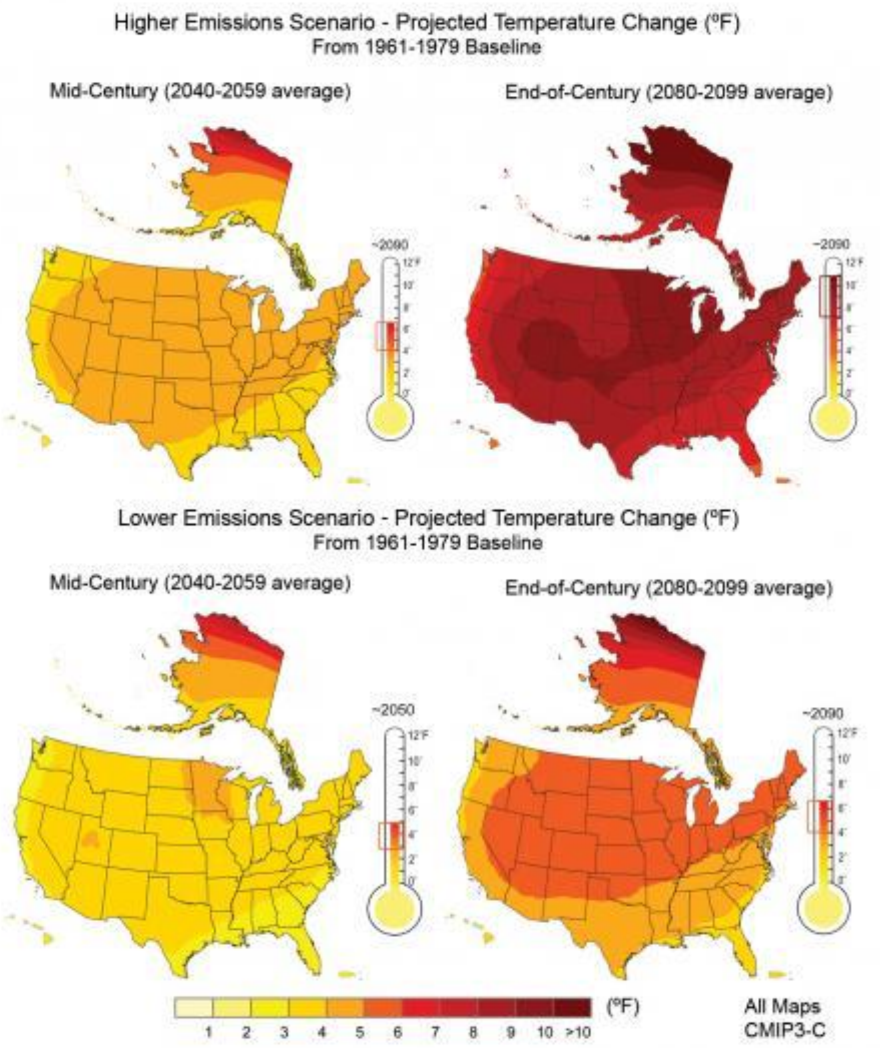




Images from EPA: https://www.epa.gov/climate-change-science/future-climate-change

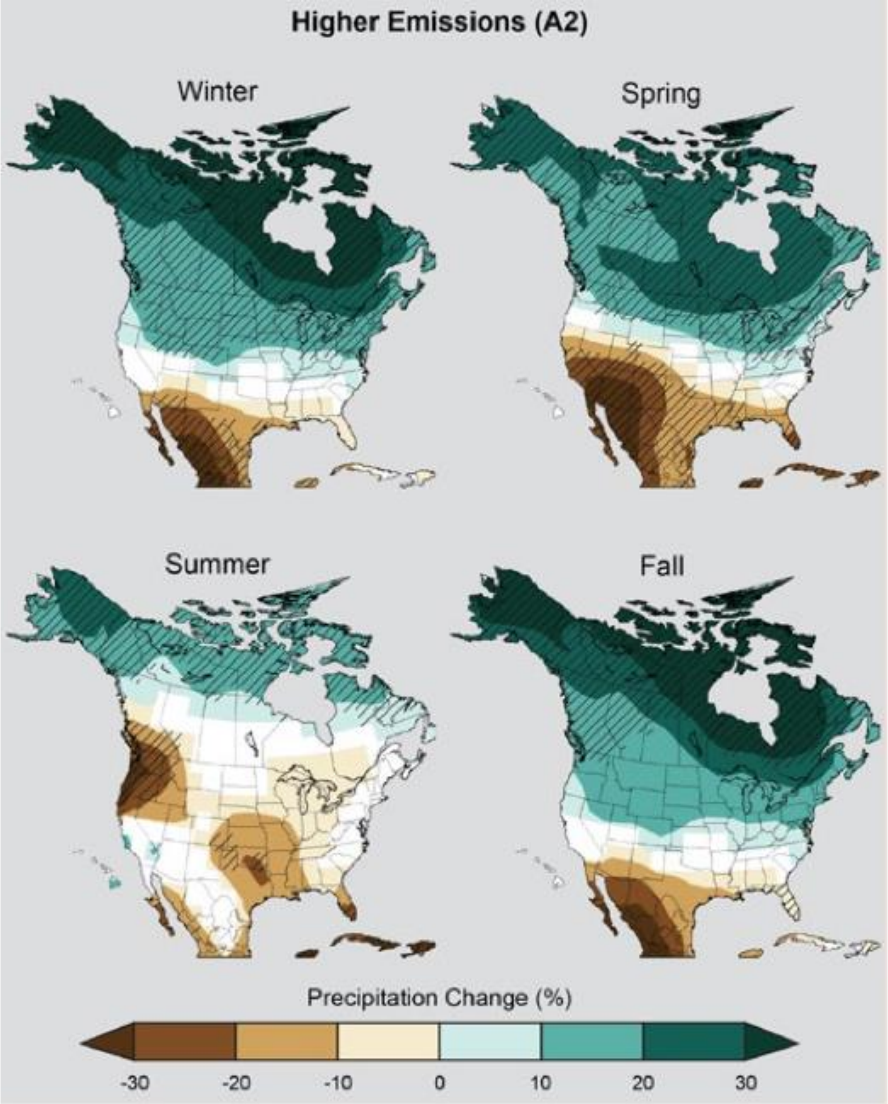
Projections for the U.S: Sea-Level & Temperature





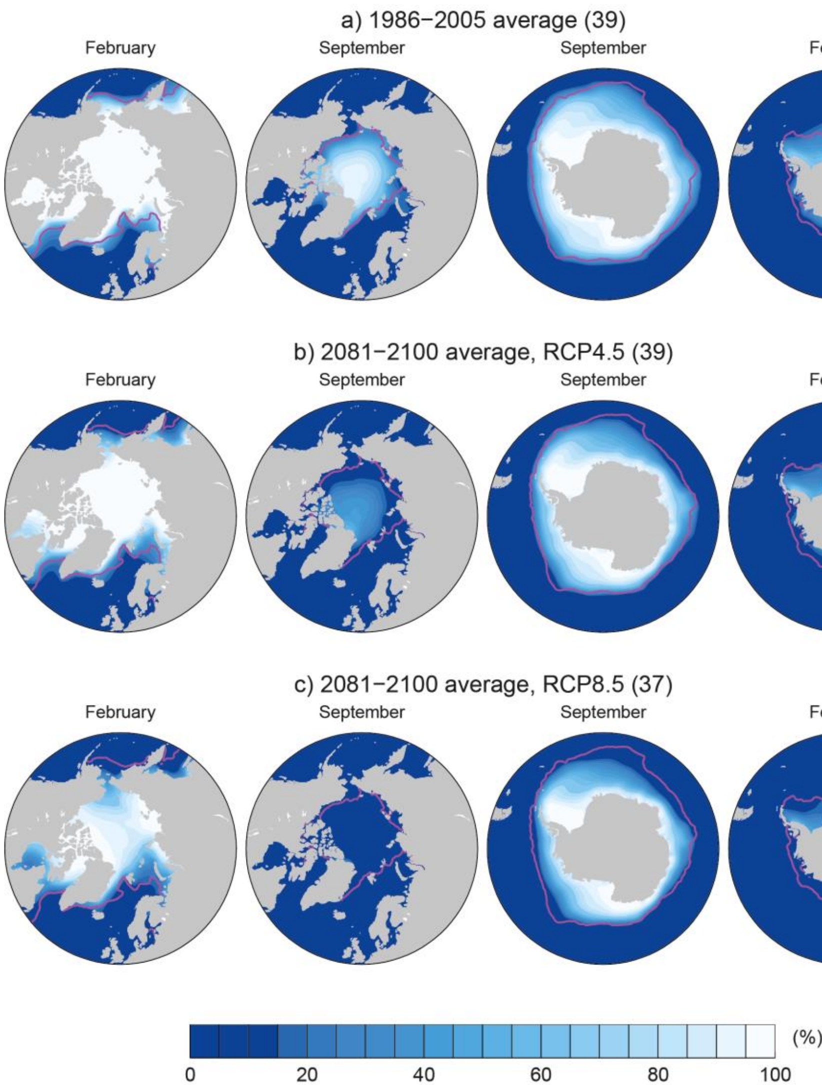
Images from EPA: https://www.epa.gov/climate-change-science/future-climate-change

Projections for the U.S: Precipitation



Images from EPA: https://www.epa.gov/climate-change-science/future-climate-change

Projections for the Arctic and Antarctica



Images from EPA: https://www.epa.gov/climate-change-science/future-climate-change

Summary Climate Change Projections & Impacts

- Raise in sea-levels
- Increase in average temperatures
- Change in patterns and amounts of precipitation
- Decline in snow-cover, permafrost and sea-ice
- Acidification of the oceans
- Increase frequency, intensity & duration of extreme events
- Change eco-system characteristics

- Water resources
- Infrastructure
- Food supply
- Ecosystems
- Human Health & Well Being

From EPA: https://www.epa.gov/climate-change-science/future-climate-change

Image from :https://pixabay.com/en/earth-blue-planet-globe-planet-11009/

Research Challenges

- Improving global scenarios, predicting **local** scenarios
- Developing adaptation strategies
- Achieving emissions reductions
  - Clean energy technologies
  - Energy efficiency
  - CO_{2e} Storage options
  - Measuring progress
- How to communicate?

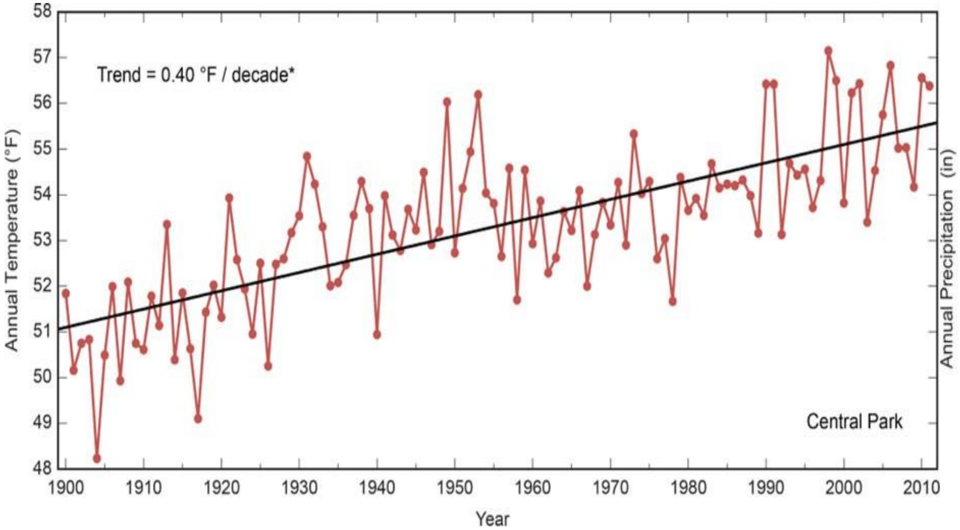
http://www.archdaily.com/493406/the-big-u-big-s-new-york-city-vision-for-rebuild-by-design

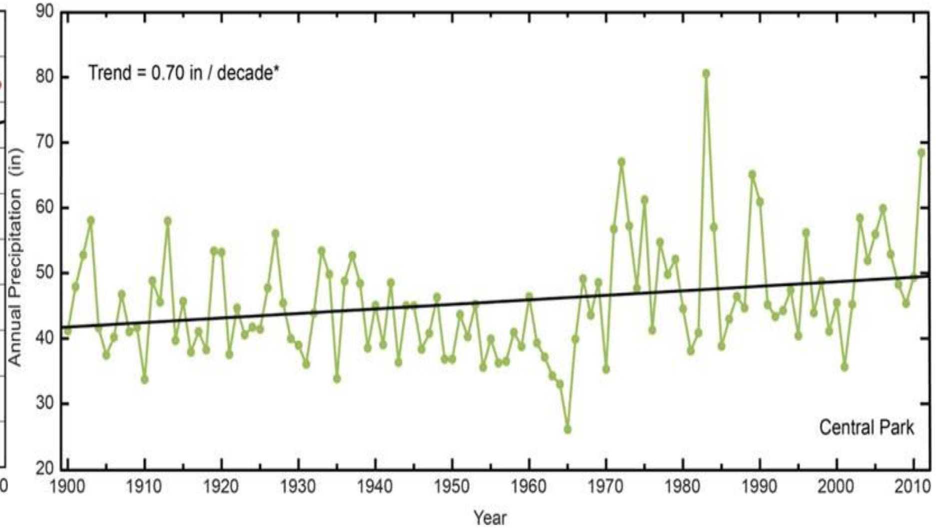
Geotechnical & Geo-environmental Challenges

- **Rising and Falling Groundwater Levels**
  - Under-ground structures & services
  - Foundations, retaining walls, embankments
  - Groundwater contamination, remediation & containment schemes
- **Adaptation strategies for sea-level rise**
  - Raising structures
  - Protecting tunnels
  - Tide and storm surge barriers
- **Achieving emissions reductions**
  - Geothermal energy
  - Wind & Hydro-power
  - Natural gas
  - CO_{2e} Sequestration & storage

Adaptation Case Study

New York City





	Baseline 1971-2000	**2020s**	**2050s**	**2080s**
Air Temperature Central Range[2]	**55˚F**	**+ 1.5 to 3.0˚F**	**+ 3.0 to 5.0˚F**	**+ 4.0 to 7.5˚F**
Precipitation Central Range	**46.5 in[3]**	**+ 0 to 5 %**	**+ 0 to 10 %**	**+ 5 to 10%**
Sea level rise[3] Central Range	**NA**	**+ 2 to 5 in**	**+ 7 to 12 in**	**+ 12 to 23 in**
Rapid ice-melt scenario[4]	**NA**	**~ 5 to 10 in**	**~ 19 to 29 in**	**~ 41 to 55 in**

Source: Columbia University Center for Climate Systems Research

From: Building the Knowledge Base for Climate Resiliency: Horton et al. 2015

Increased Flooding and Urban Heat Island Impacts

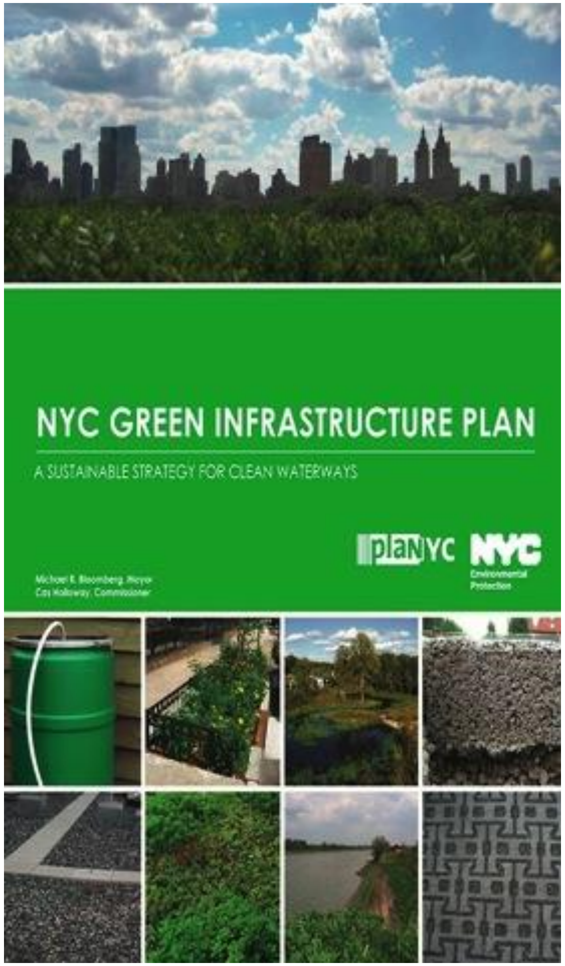
Photo from: http://inhabitat.com/nyc/torrential-rains-leave-new-york-and-new-jersey-drenched-with-rail-and-road-closures/
Image courtesy of Gaffin, Columbia University

Vegetation as an Adaptation Strategy

Image from: http://ngm.nationalgeographic.com/2009/09/manhattan/miller-text

New York City's Green Infrastructure Plan

Implemented to address the City's storm-water management issues



~ 20 year implementation plan, at an estimated cost of $2.4 billion

Primarily based on reducing volume rain entering sewer system

Co-benefits include climate resilience

http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml

Example Green Infrastructure Strategies

CREDIT: Columbia University Researchers

Green Roof Technology

Intensive

Thick “engineered soil” depths (100 to 200mm), heavy, support diverse vegetation and human traffic

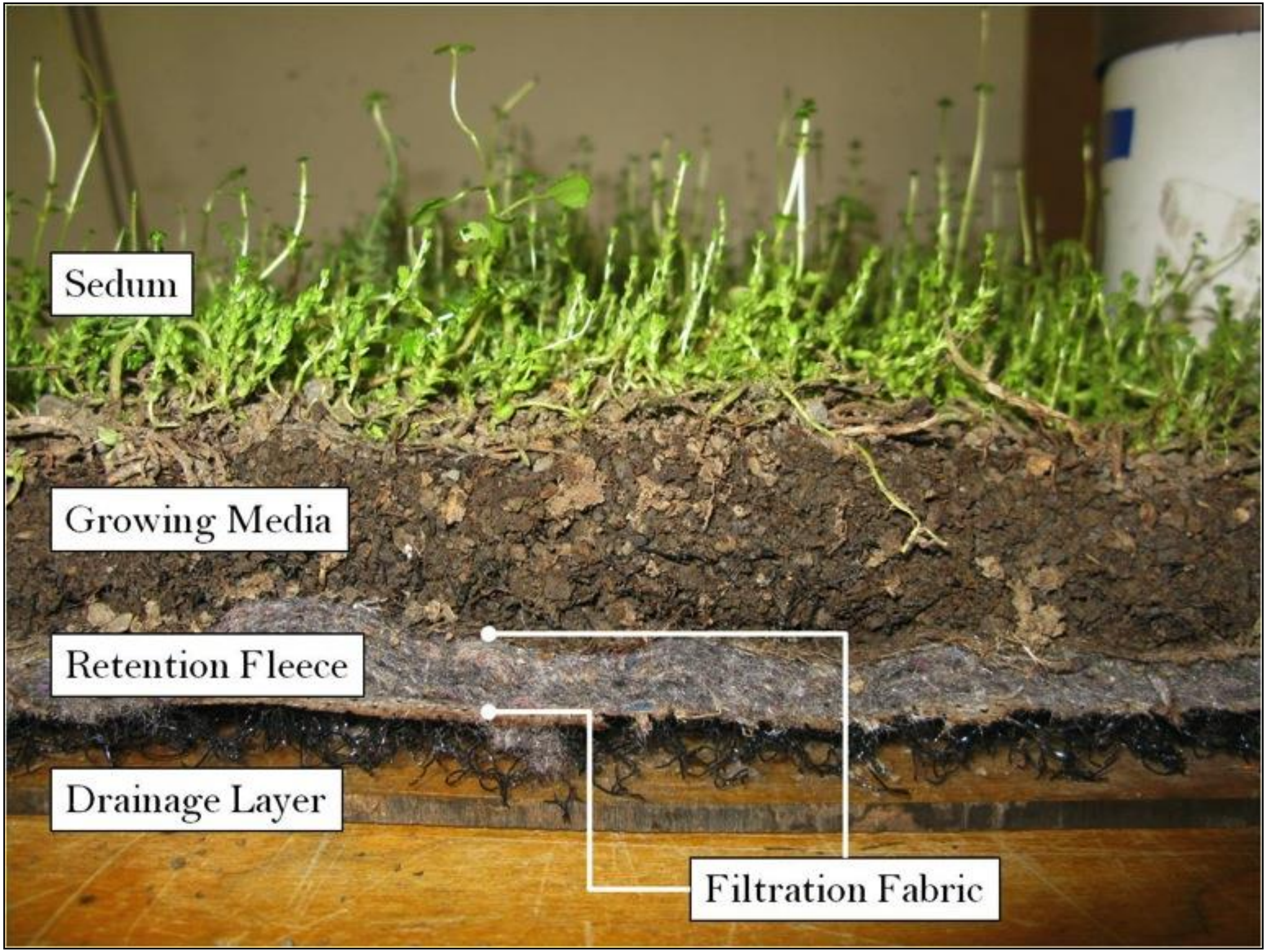
http://www.museumofthecity.org/project/green-roofs-in-cities/

Extensive

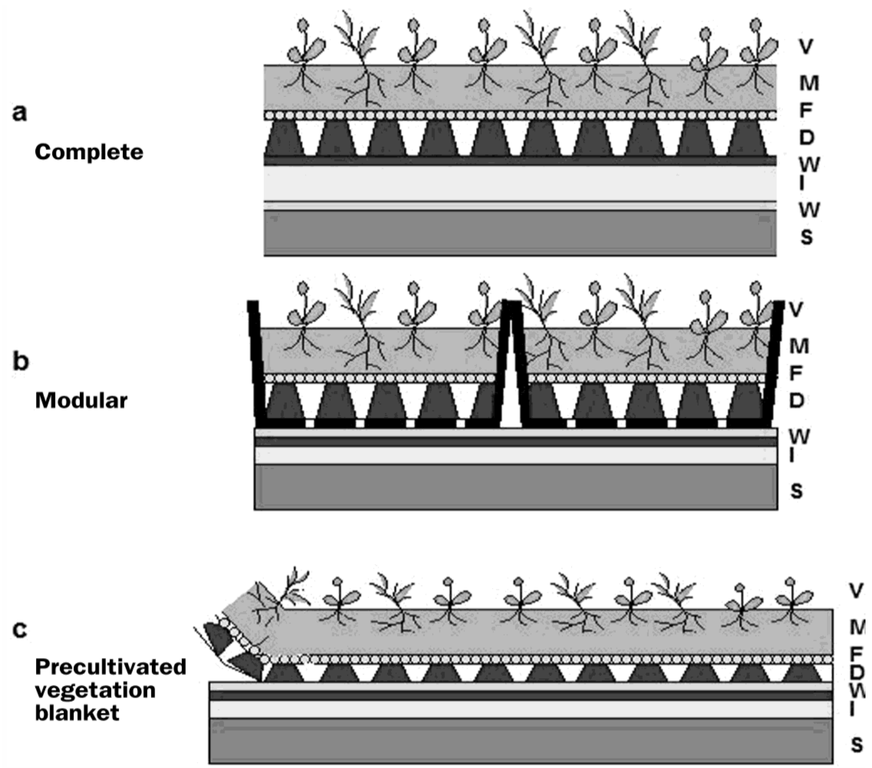
Thin “engineered soil” depths (30 to 150 mm), light, fragile, often employ sedum vegetation

CREDIT: Columbia University Researchers

Layers of an extensive green roof



Common extensive green roof types



CREDIT: E. Oberndorfer, 2007)

CREDIT: Columbia University Researchers

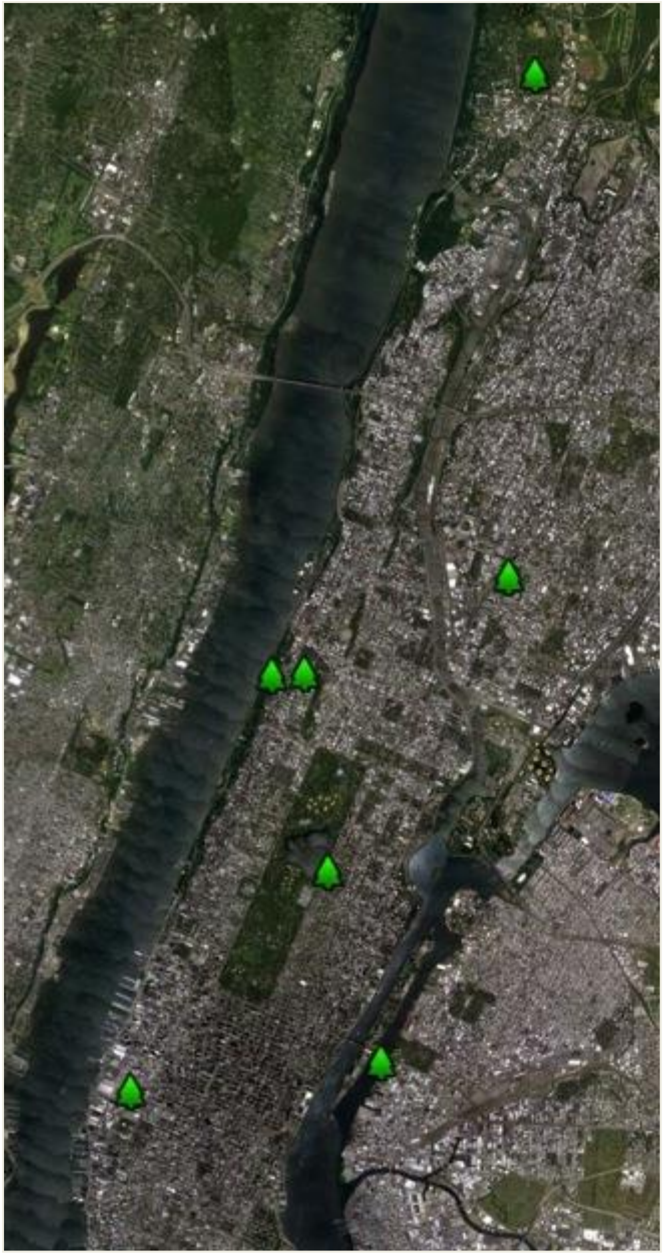
Columbia University Green Roof Network

(7) Full-scale green roofs. (3) Pilot-scale test boxes

Large suite of data collection instruments: Runoff, ET, Climate, CO_2, PM2.5

CREDIT: Columbia University Researchers

Columbia Green Roof Network – Runoff Quantity



CU 118 Residence

Xeroflor 1- 2" Matt System

3,200 sf

CU 115 Environmental Stewardship

Xeroflor 1 - 2" Matt System

650 sf

ConEdison Learning Center

Modular 4" Tray System

10,000 sf

USPS Morgan General Mail Facility

Complete 4 - 6" System

108,900 sf

Bronx Design & Construction Academy

Modular 4" Tray System

1,200 sf

Regis High School

Complete 4-6" System

20,000 sf

Ethical Cultural Fieldston School

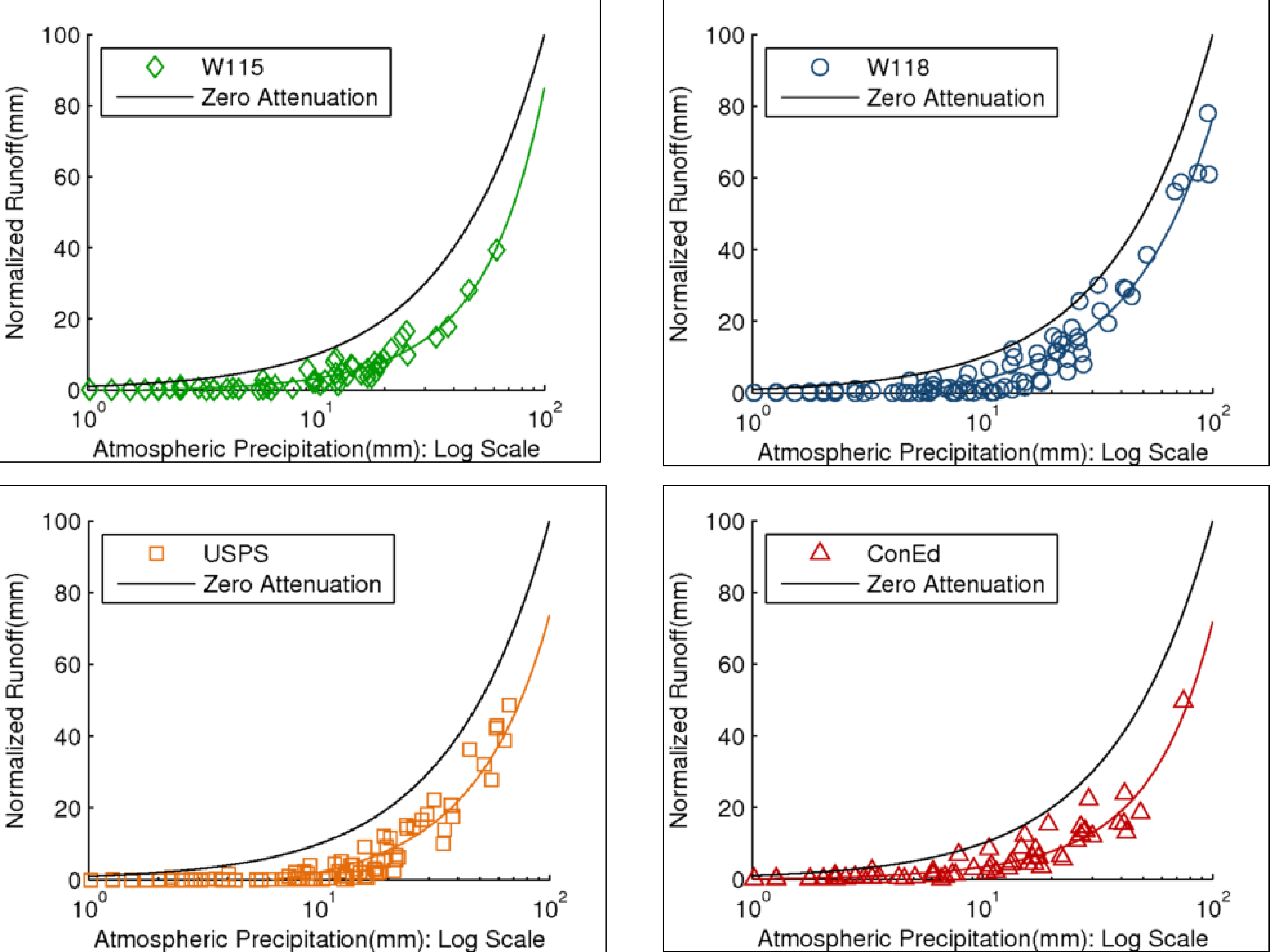
Complete 4 - 6" System

5,100 sf

Stormwater Volume Retention: W115, W118, ConEd, USPS

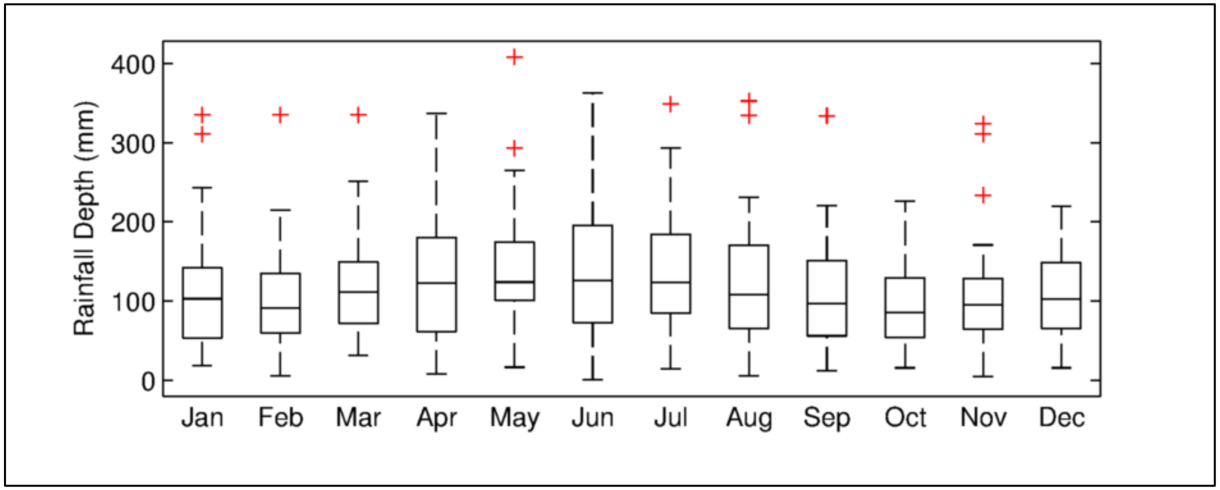


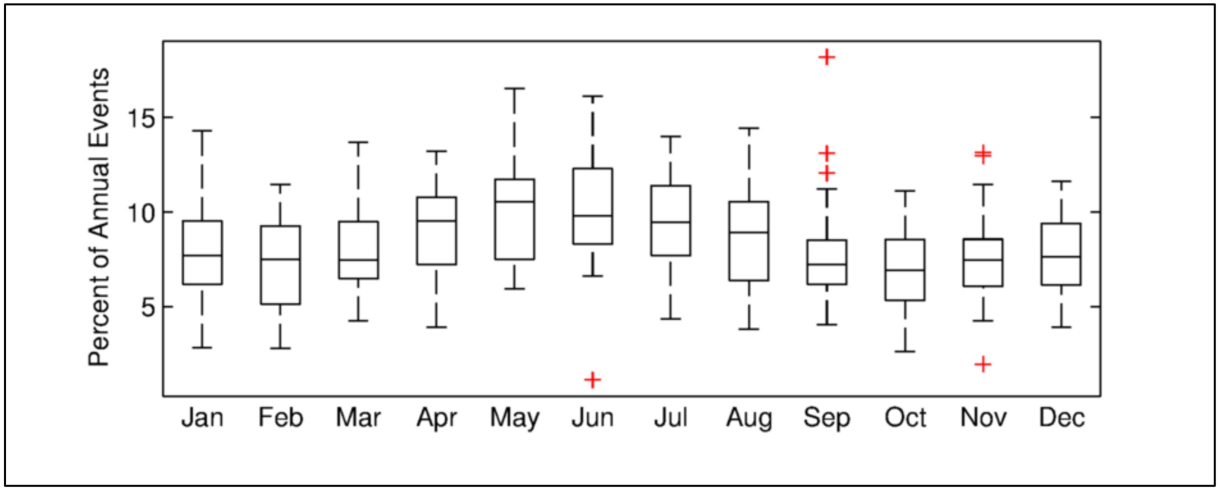

CREDIT: Columbia University Green Roof Consortium



W115
Zero Attenuation
W118
Zero Attenuation
USPS
Zero Attenuation
ConEd
Zero Attenuation
Normalized Runoff(mm)
Atmospheric Precipitation(mm): Log Scale
0
20
40
60
80
100
10^0
10^1
10^2

New York City Historic Rainfall Data





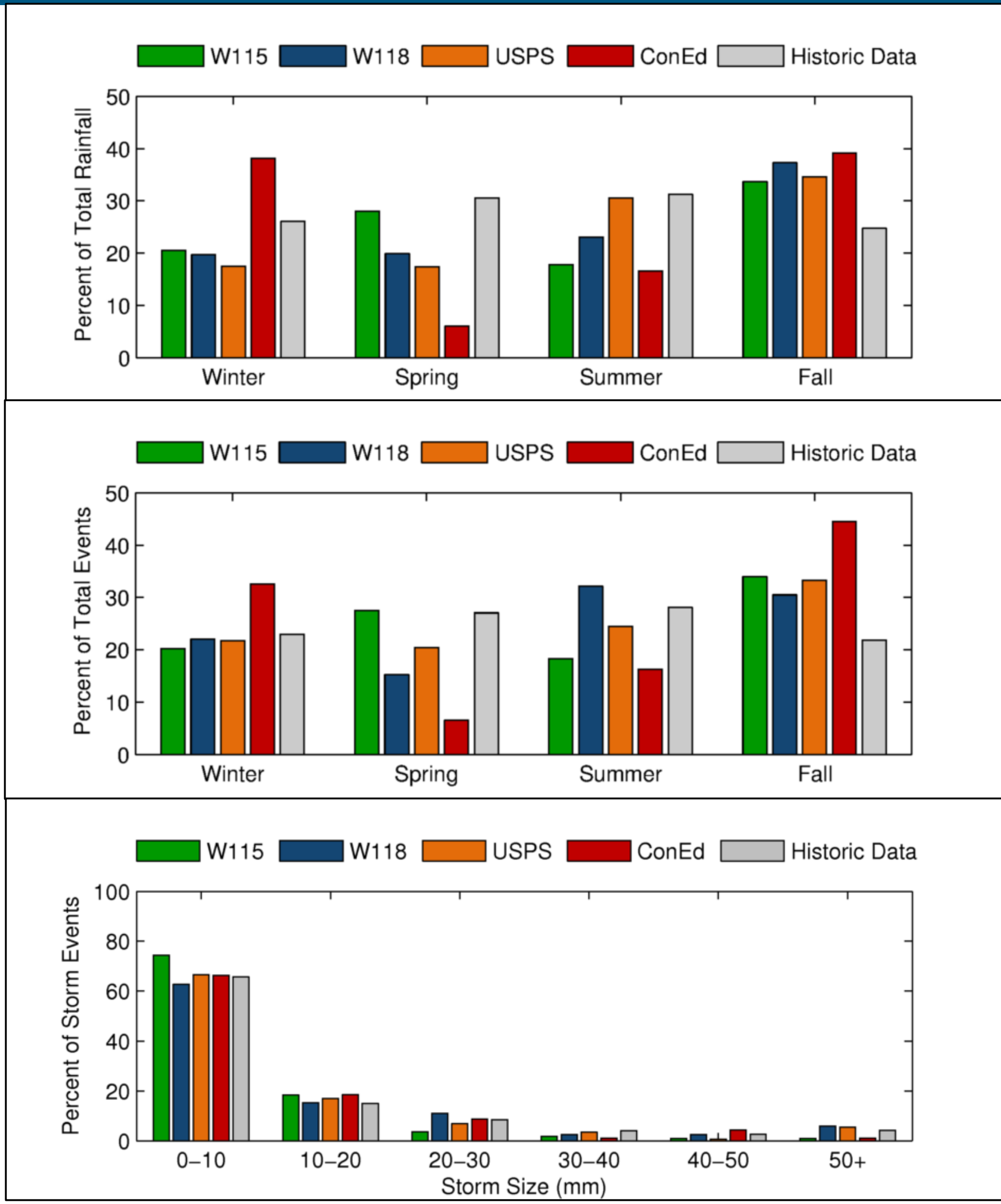
Past 40 Years of Data From Central Park Land Station

~ 1.2 m of rainfall per year;

~ 95 events per year

CREDIT: Carson et al., 2013

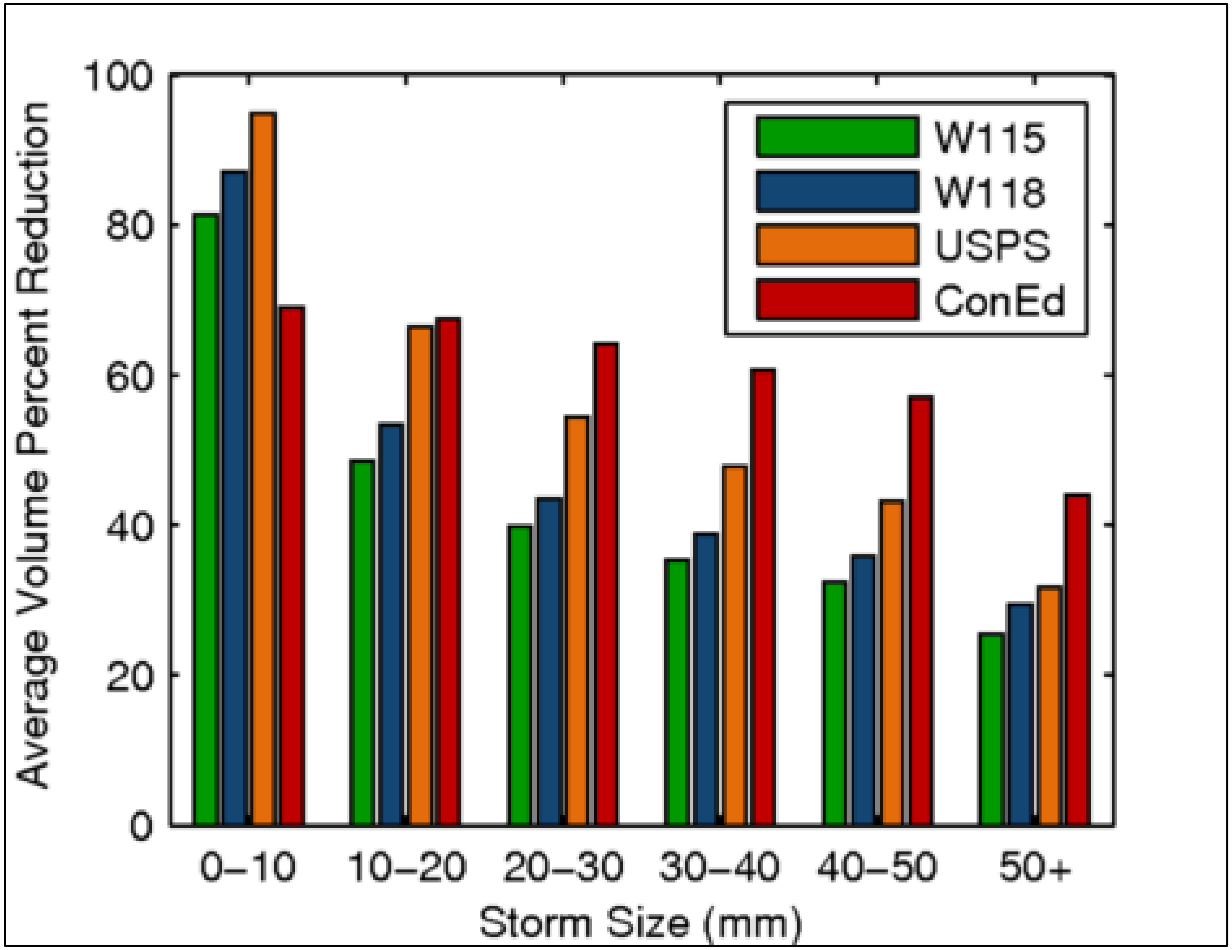
Study Period versus Historic Period



Cannot draw general conclusions from the study period data alone

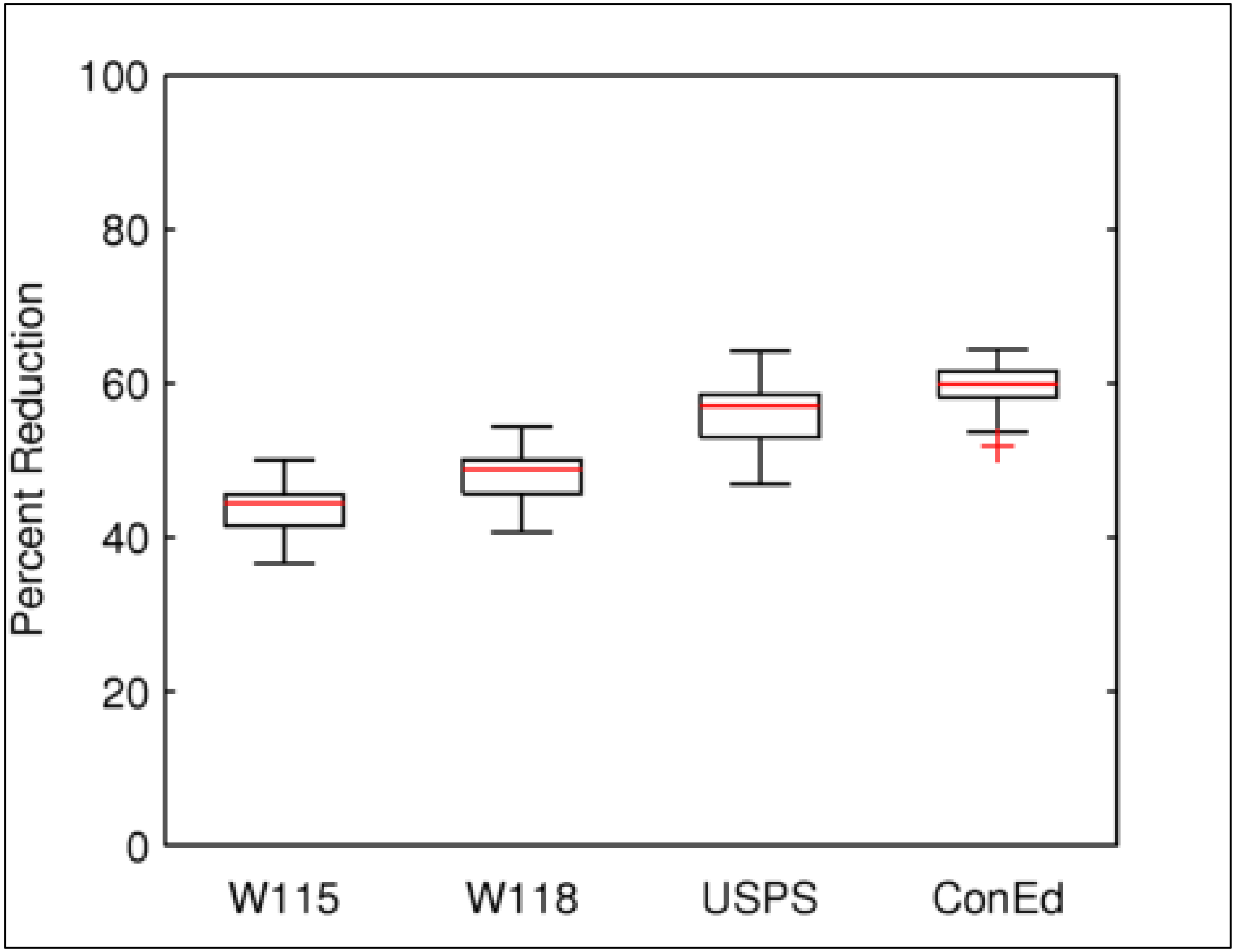
CREDIT: Carson et al., 2013

Stormwater Volume Reduction – Modeled Behavior



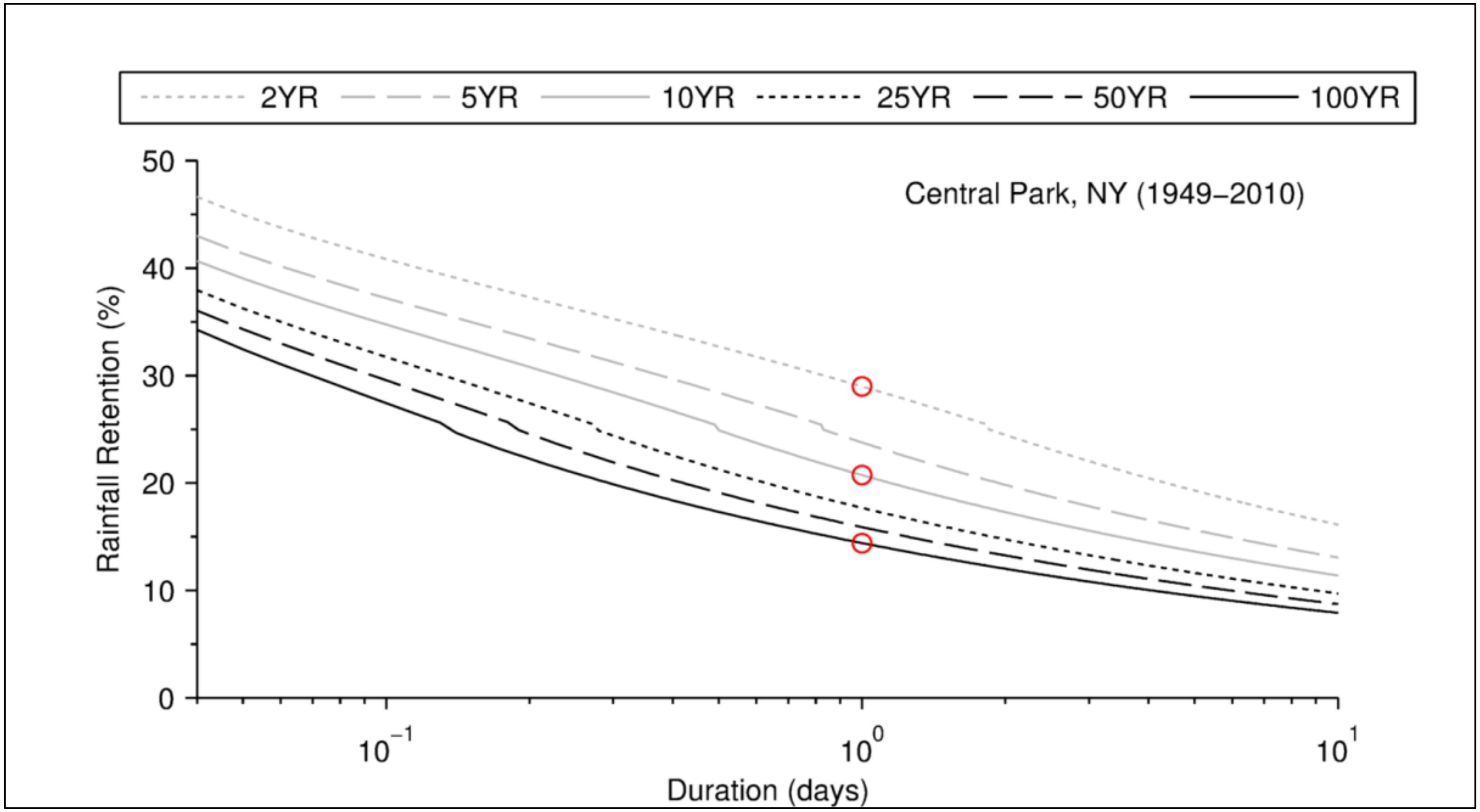
CREDIT: Carson et al., 2013

Stormwater Volume Reduction – Averaged Behavior



CREDIT: Carson et al., 2013

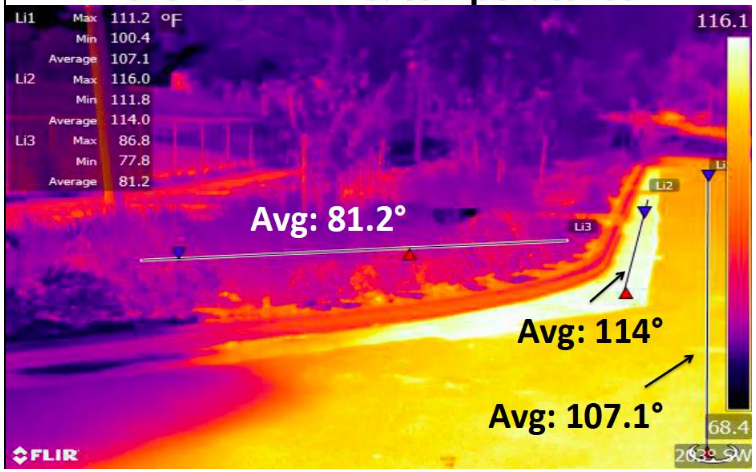
Retention Design Curves - ConEd



CREDIT: Carson et al., 2013

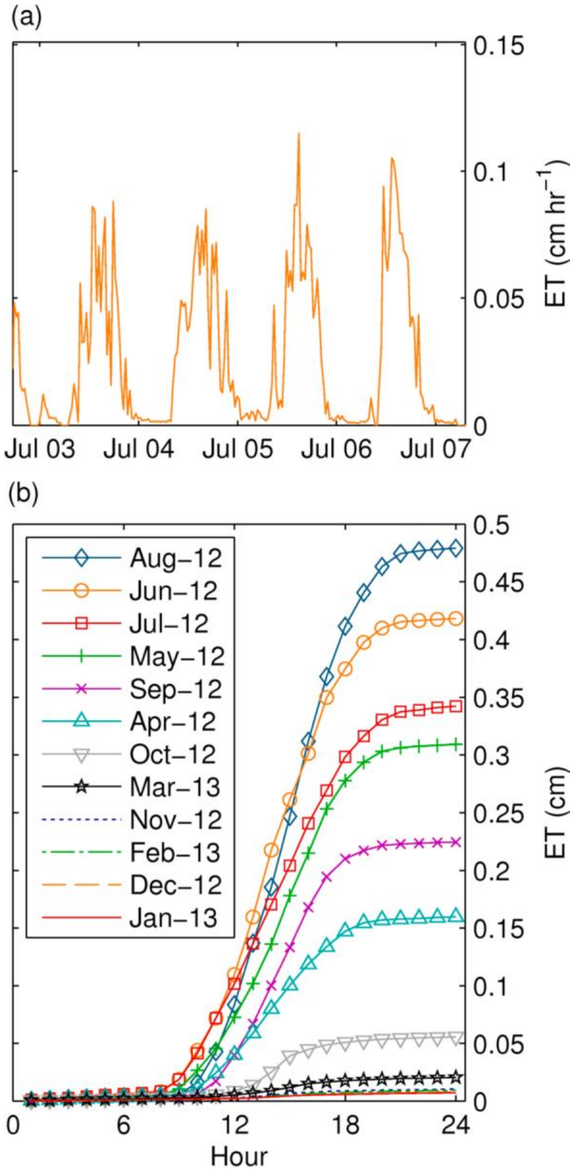
Evapotranspiration – W118

Stormwater green street (“SGS 11”) in the Bronx NY & temperatures

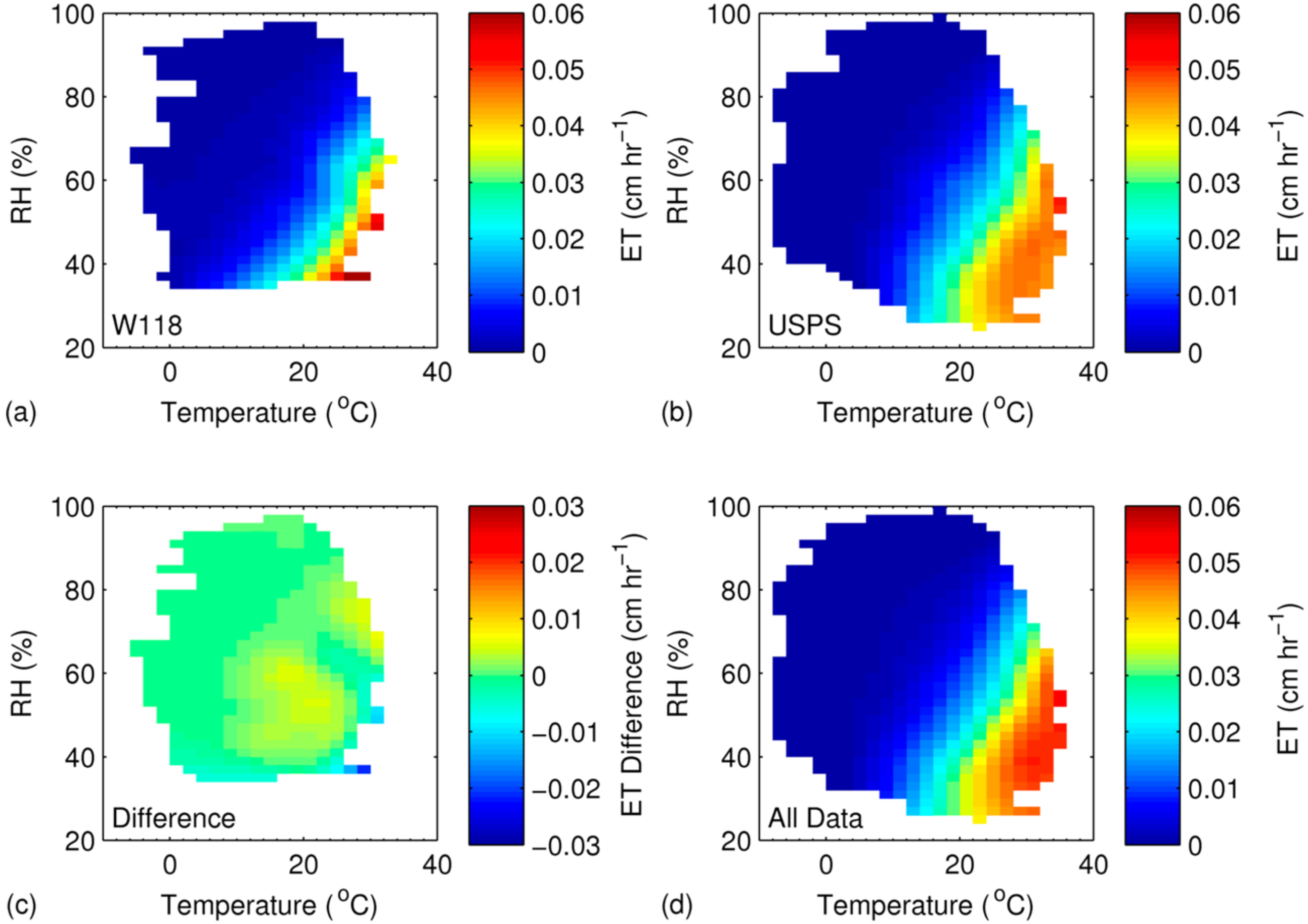


CREDIT: Gaffin, Columbia University

CREDIT: Marasco et al., 2014



ET Model for Sedum Green Roofs

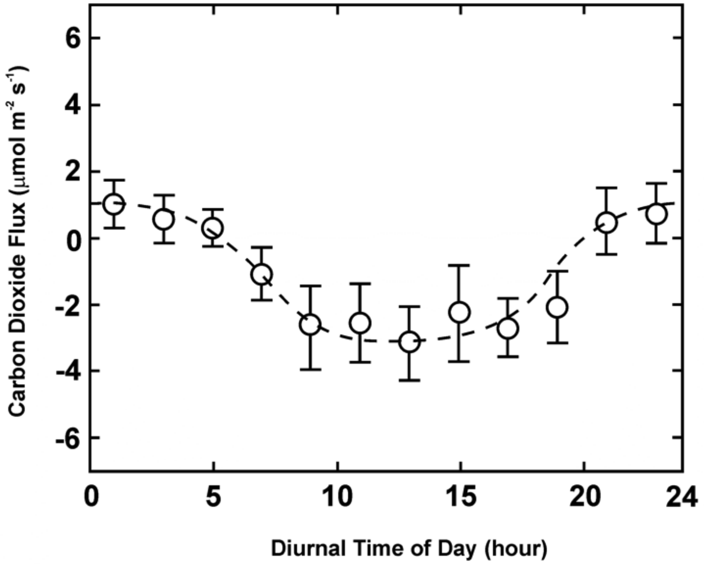


CREDIT: Marasco et al., 2014

Summary Results to Date

Engineered Green Infrastructure can:

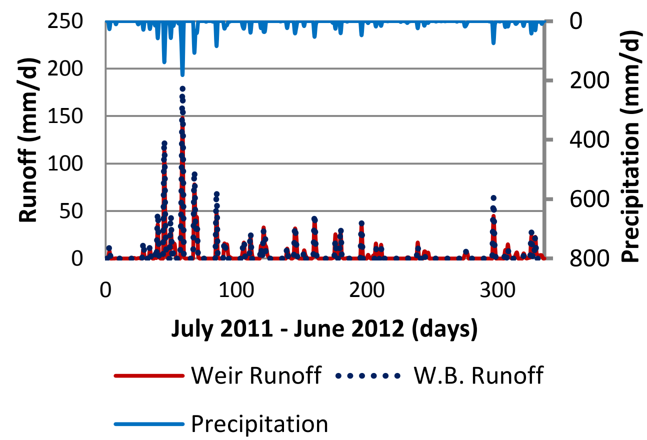
- Help mitigate impacts of increased precipitation (40%+ stormwater capture locally – can be improved)
- Reduce surface temperatures
- Sequester CO_2



CREDIT: McGillis, Columbia University

Challenges

- Scale of implementation needed
  - Public-private partnerships
  - New zoning & buy out policies
- Siting requirements
  - Geotechnical conditions
  - Local neighborhood conditions
- Maintenance requirements
  - Increased workforce
  - Stewardship programs
  - Low cost-monitoring technology
- Long-term performance
- Public/ Stakeholder acceptance



Public Acceptance

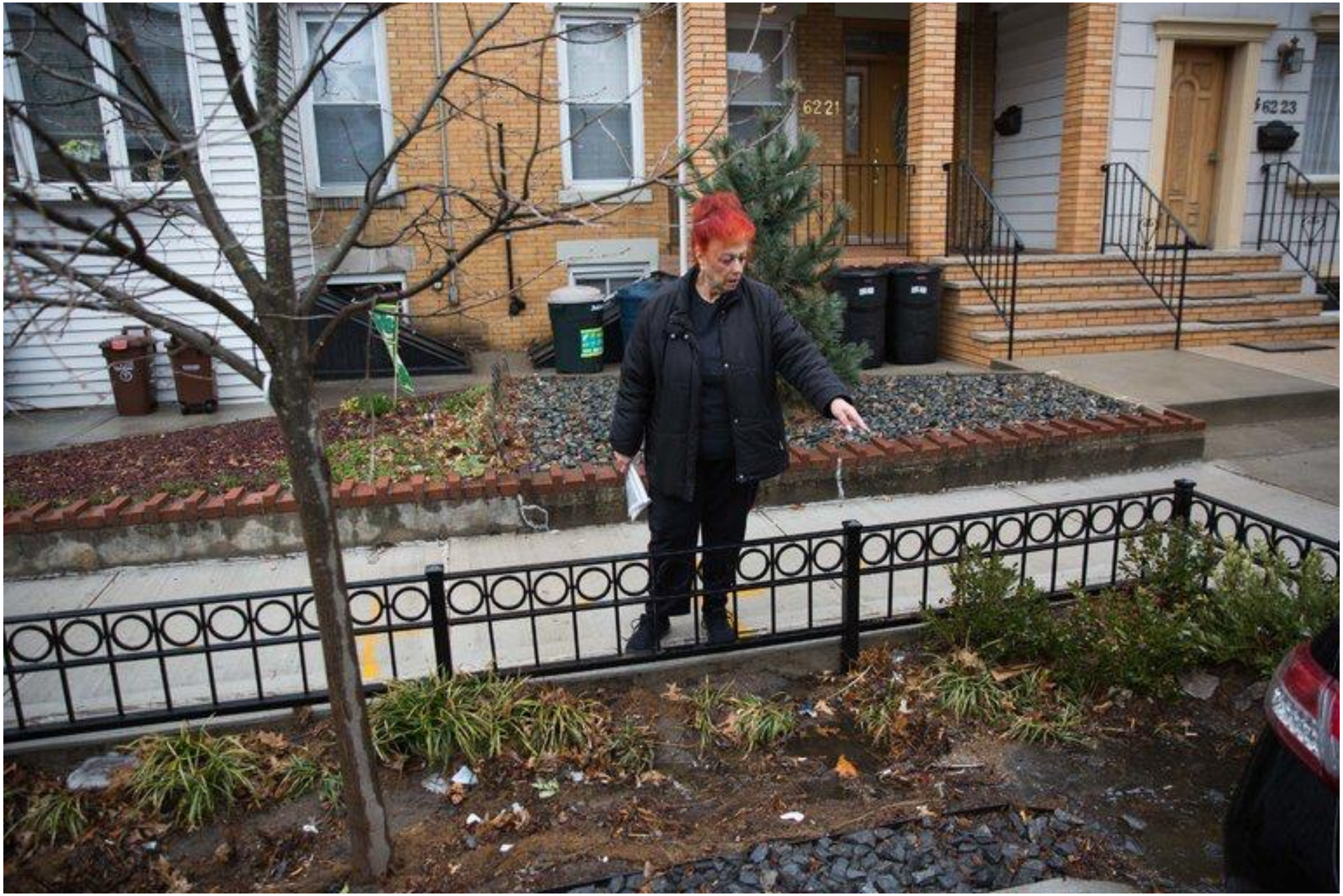
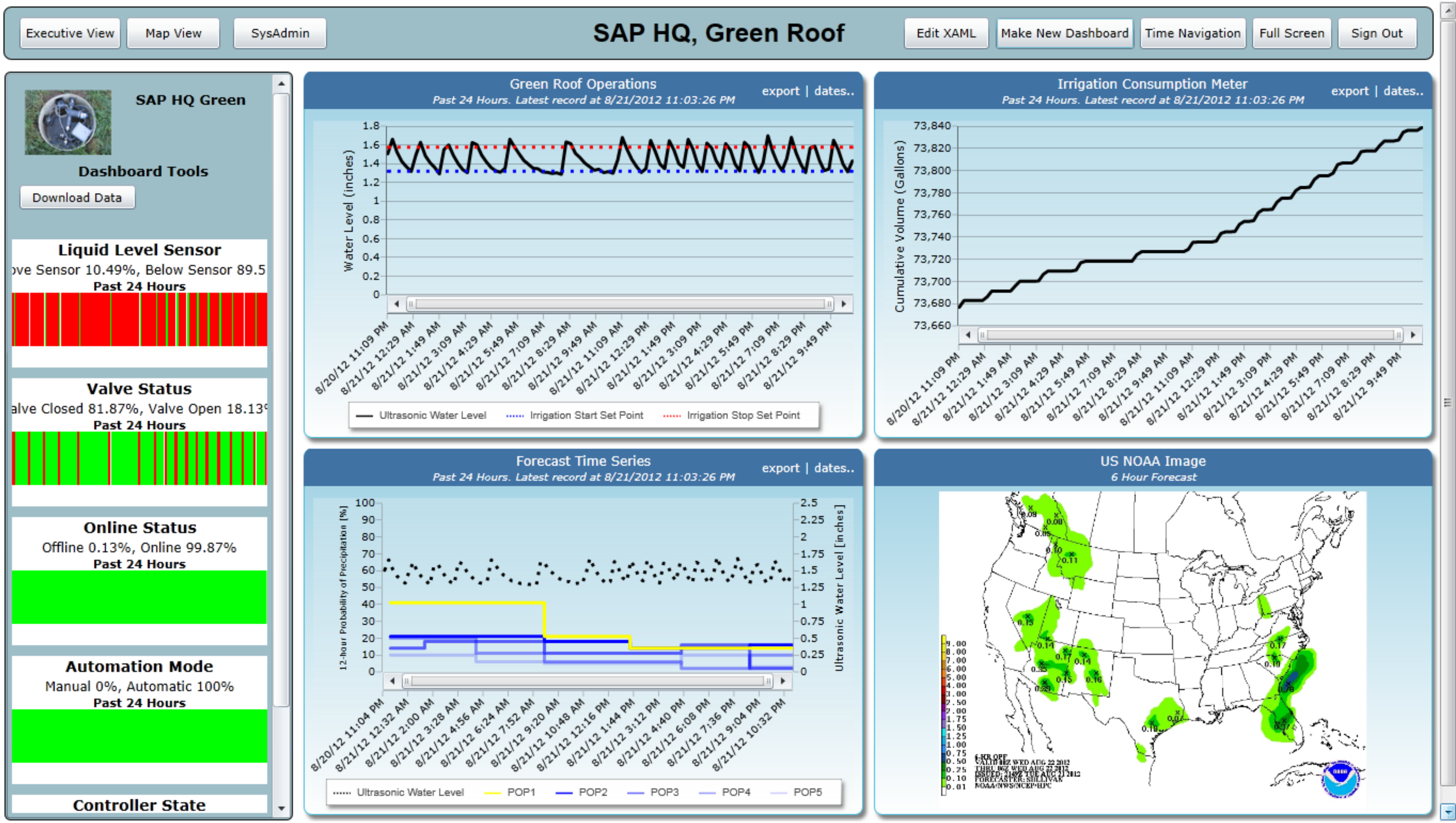


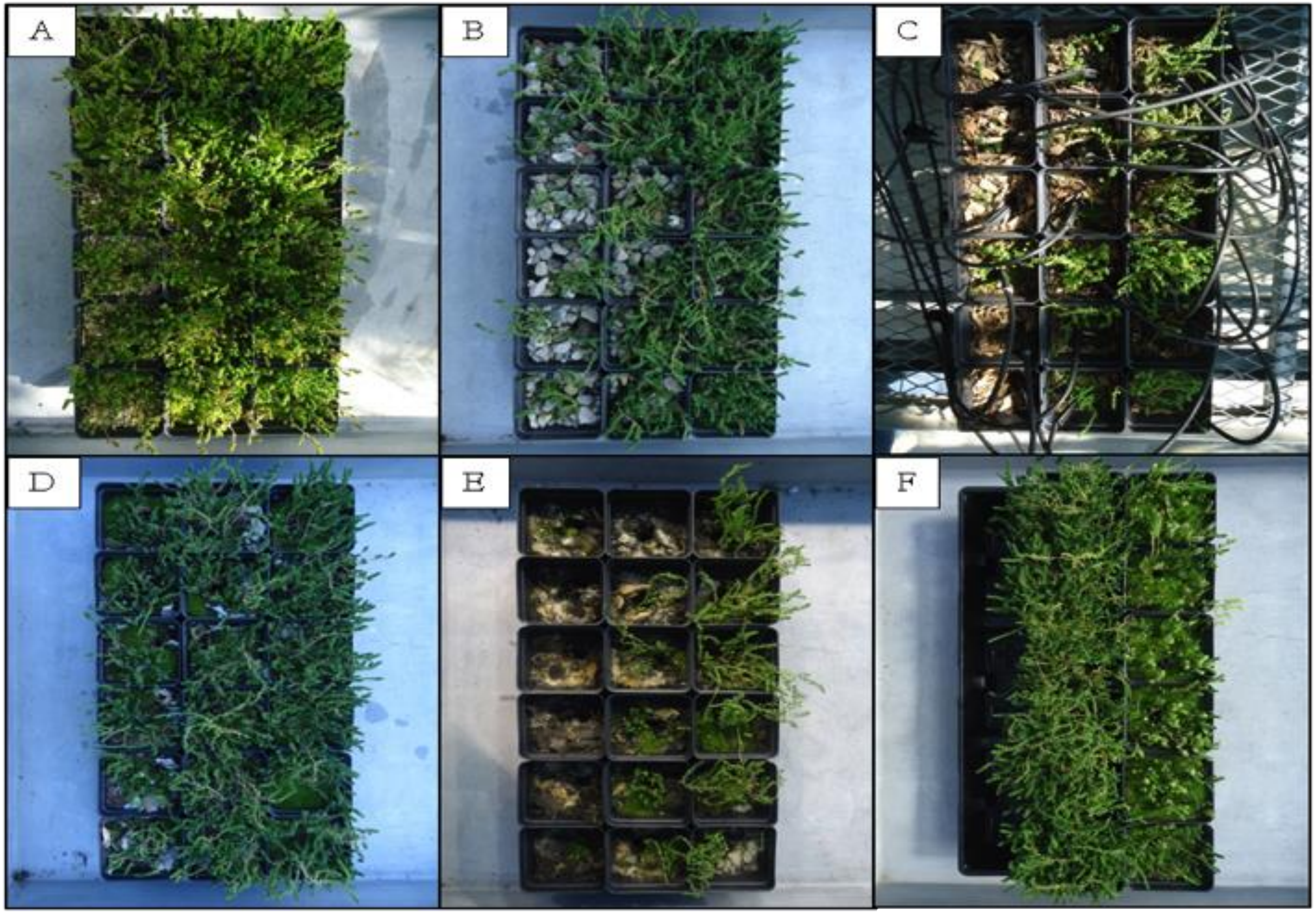
Image from: https://www.nytimes.com/2017/03/23/nyregion/bioswale-rain-gardens-new-york.html

Smart Control – Geosyntec & Opti-RC



CREDIT: Geosyntec and Opti

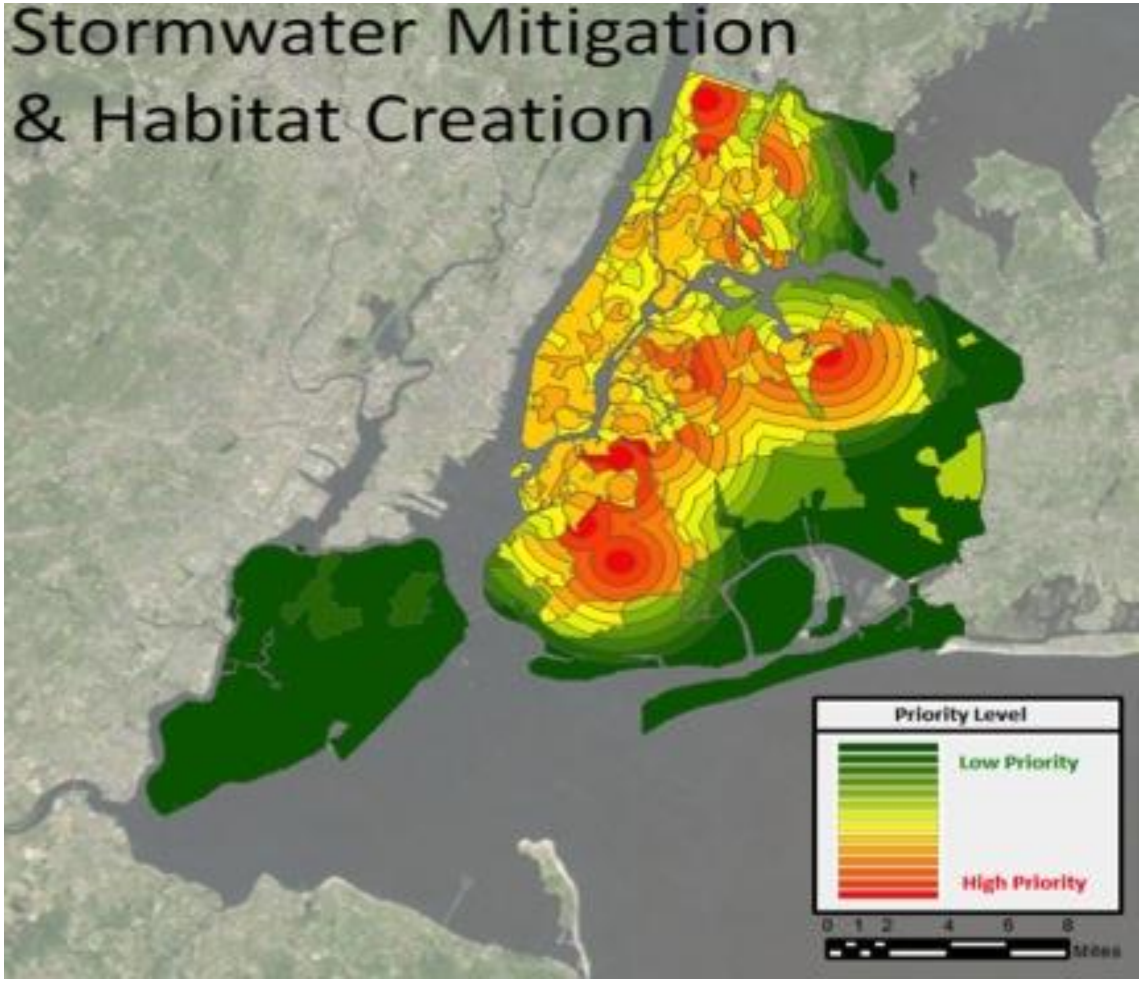
New Growing Media – use of local waste materials



(a) drywall, (b) recycled concrete, (c) timber cuttings, (d) glass, (e) roof shingles, (f) 100% compost control.

CREDIT: Tyler Carson

Stakeholder Engagement



CREDIT: Robert Elliott

Distributed/ Neighborhood Infrastructure

Example systems for local resilience/ adaptation

CREDIT: Images obtained from SRN: Integrated Urban Infrastructure Solutions for Environmentally Sustainable, Healthy, and Livable Cities

Changes in Approach Move Away from Centralized Systems

- Infrastructure systems with very, many components
  - How to define performance,
  - Quantify performance,
  - Monitor performance,
  - Maintain performance?

http://www.busitelce.com/data-visualisation/30-word-cloud-of-big-data

- Infrastructure systems that interface with the public
  - Public understanding
  - Responsibility?

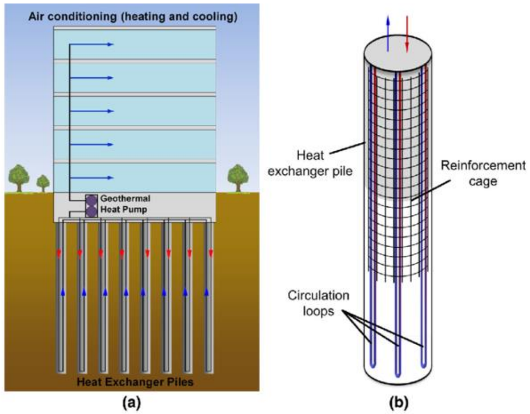
CREDIT: Clip Art

- Scale issues?
- Trade-offs between different infrastructure investments?
- Equity?

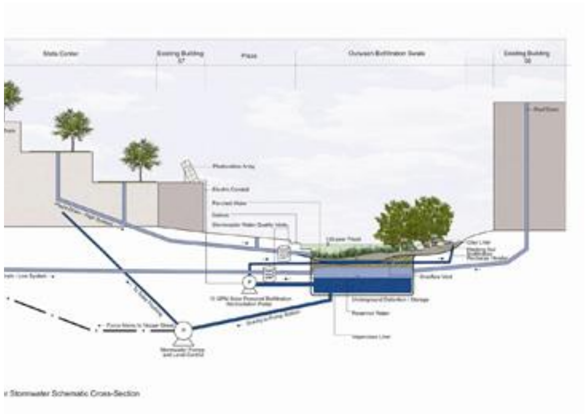
https://www.worldwildlife.org/pages/wwf-s-green-headquarters

Geotechnical & Geo-environmental Examples

- Green infrastructure
- Geothermal systems, energy piles and energy walls
- Localized flood protection
- Rainwater storage



CREDIT: Olgun et al.



MIT Underground Detention Systems CREDIT: J. Nitsch

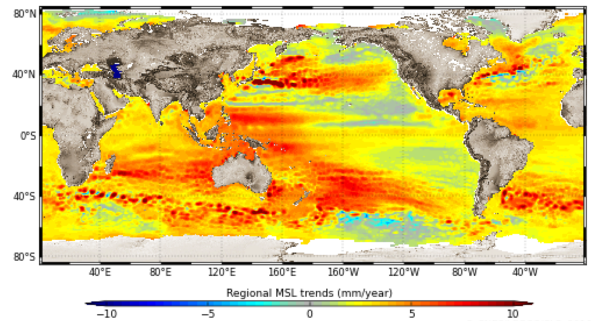
Needs in Future Practice, Research & Training

- Awareness of climate change predictions, models and assumptions
  - What do we need out of these models?

- Develop a better understanding of impacts of climate change on geotechnical engineering structures and practice
  - vulnerability/ hazard index?
  - What is progress to reduce vulnerability?
  - How is this measured?

- Learn how to integrate engineering, ecosystems and social strategies

- Engage Stakeholders



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