The use of stormwater management across cities and recharge response to stormwater infiltration

Ben Choat, Amber Pulido, Aditi Bhaskar, Chingwen Cheng, Jennifer, Cherrier, Carli Flynn, Rebecca Hale, Kristina Hopkins, Lauren McPhillips, Tom Meixner, Julie Ripplinger, Brianne Smith, and Harry Zhang

http://www.springfieldmontco.org/stormwater

Urban stream syndrome

(Askarizadeh et al., 2015)

Stormwater Control Measures

Basins

"Detention", "Detention Basin", "Storage Pond“, "Turf Basin", "Basin and Open Space", "Water Basins", "Landscape Buffer Basins", "Stormwater Detention", "Subsurface Stormwater Detention Tanks”, …

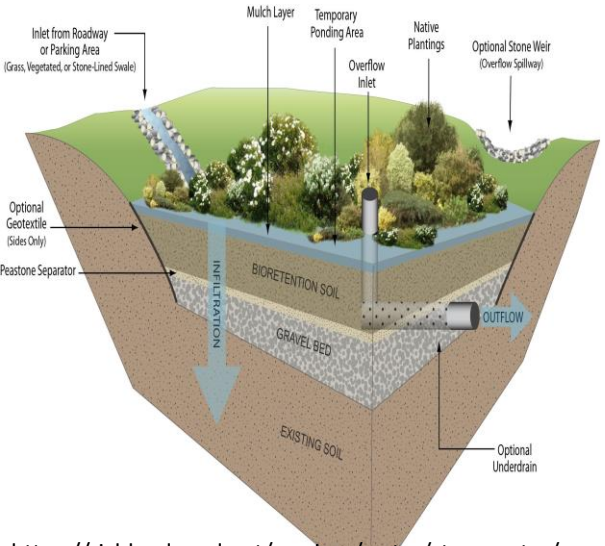
Swales & Strips

"Curbcut Bioswale", "Swale", "Grass Swale", "Bio-Swale", "Bioswale", "Dry Swale", "Grass Channel", "Vegetated Filter Strip", "Right-of-Way Bioswales", "ROW Greenstrip", "ROW Stormwater Greenstreet”, …

Filter

"Porous Landscape Detention", "Sand Filter Extended Detention Basin", "Bioretention", "Micro-Bioretention", "Perimeter (Sand) Filter", "Sand Filter", "Engineered Soil Tree Pit", "ROW Structural Soil", …

Stormwater Control Measures



https://richlandswcd.net/services/water/stormwater/epa-best-practices

https://www.epa.gov/soakuptherain/soak-rain-rain-gardens

Infiltration Facility

"Retention Basin", "Retention", "Dry Well", "French Drain", "Infiltration Basin", "Infiltration Chamber", "Stormwater Conveyence and Infiltration", "Retention Pond", "Infiltration Berms", …

Rain Garden

"Rain Garden", "Rain Gardens", "Raingarden", "Proprietary-Rain Garden", "ROW Rain Garden", "Roof Garden", "Bayscaping", "Residential Rain Garden", "Rain Garden-Bioretention"

Pervious Pavement

"Permeable Pavement", "Porous Pavement Detention", "Pervious Pavement", "Permeable Pavers", "Porous Asphalt", "Porous Concrete", "Pavers", "ROW Porous Concrete", …

Stormwater Control Measures

http://stormwatercenter.colostate.edu/underground-bmps/

Underground Filter

"Oil Grit Separator", "Underground Filter", "Sediment Manhole", "Trench", "U-G Detention", "U-G Retention", "Underground Sandfilter"

https://www.nps.gov/tps/sustainability/new-technology/green-roofs/chicago-case-study.htm

Green Roof

"Green Roof", "Combined Blue-Green Roof", "Rooftop Farm", "Green Roof & tree Box"

https://richlandswcd.net/services/water/stormwater/epa-best-practices

Rain Water Harvesting

"Catchment System", "Rainwater Harvesting", "Landscape Water Harvesting", "Water Harvesting", "Passive Water Harvesting", "Proposed Rainwater Harvesting", …

What is driving Stormwater Control Measure (SCM) selection at the City level?

- SCMs have different hydrologic and water quality functions
- They offer a tool to manage stormwater for our benefit
- There are no studies investigating implementation between cities at the national level
- Our goals are:
    1. Create a database of SCM implementation across several U.S. cities
    2. Understand what factors (e.g., climate, physiography, policy, etc.) are driving SCM selection, if any.

Methods

1. Collect data from climatically diverse U.S. cities

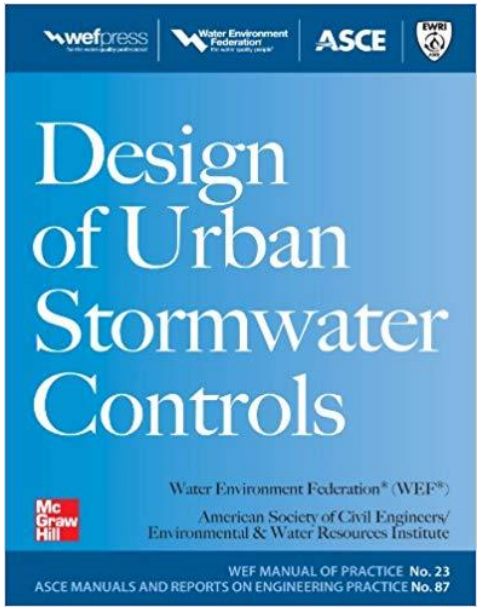
2. Classify terminology used by cities into broader categories for comparison

3. Organize data into a shareable database

4. Investigate correlations between possible drivers and SCM selection (e.g., annual precipitation, imperviousness)

Collected Data from 23 U.S. Cities

Over 300 names from cities reclassified into 15 broad categories



City Descriptions

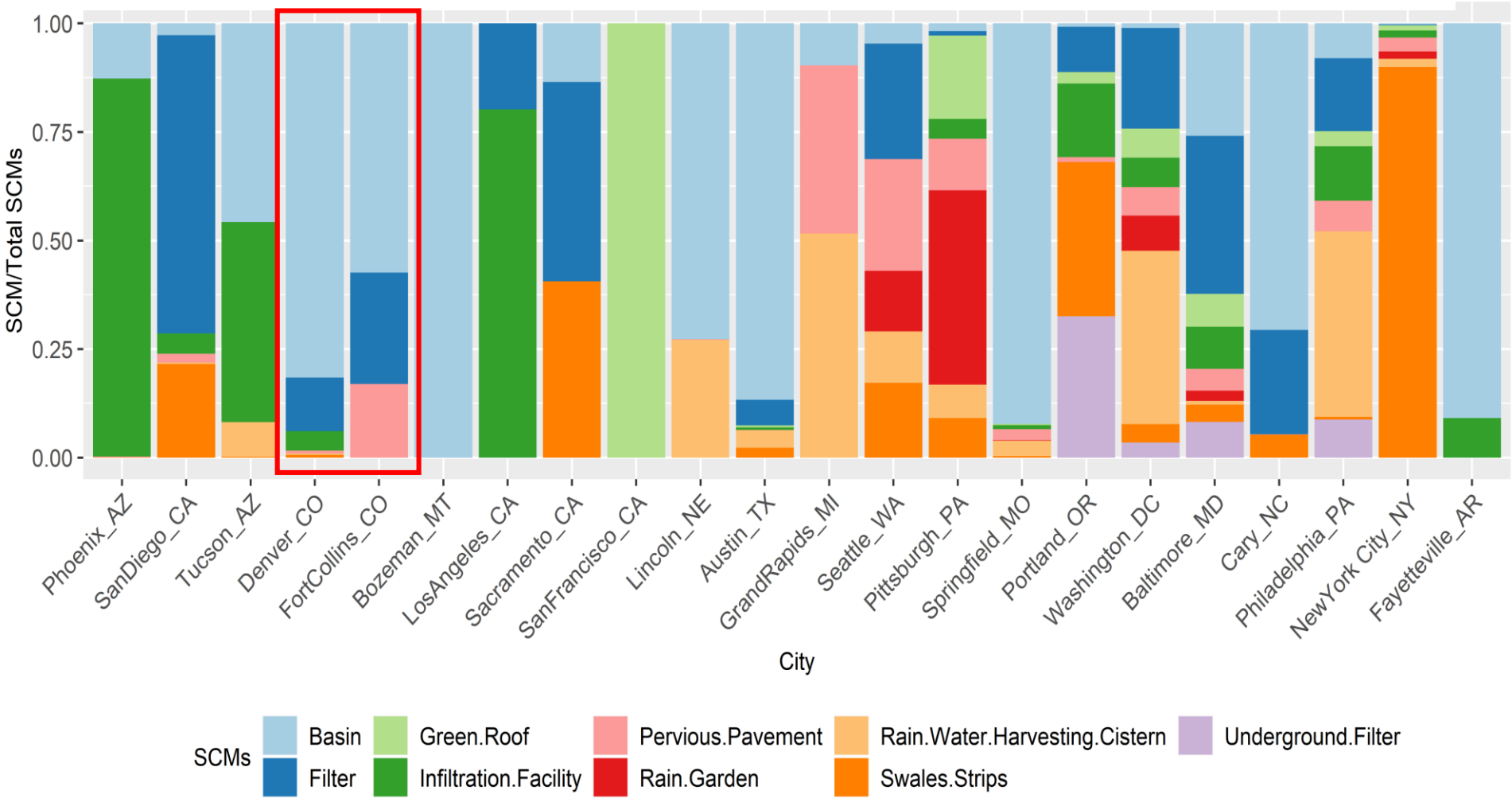
Basin	"Detention", "Detention Basin", "Storage Pond", "Underground", "Turf Basin", "Basin and Open Space", "Water Basins", "Landscape Buffer Basins", "Stormwater Detention", "Subsurface Stormwater Detention Tanks", "Stormwater Mitigation Basin", "Passive Basins", "Multi-Purpose Basin", "Buffer Basin", "Mitigation Basin", "Mitigation Tanks", "Tank", "Constructed Wetland", "Detention Pond", "Detention Ponds", "Underground Detention", "Water Quality Pond", "Water Quality Pretreatment Facility", "Detention Structure (Dry Pond)", "Extended Detention Structure-Dry", "Extention Detention Structure-Wet", "Micropool Extended Detention Pond", "Pocket Pond", "Constructed Wetland Pond", "Extended Dry Detention Basin", "Flood Control Basin", "Wet Detention Basin", "Blue Roof", "Detention System", "Reverse Seepage Basins", "Dry Pond", "Plunge Pool", "Step Pool", "Wet Pond", "Ponds - Wet Retention Basin", "Ponds-Dry Vegetated Detention Pond", "Parking Lot", "Parking Lot-Adjacent to GI Site", "Bumpout", "Stormwater Tree", "Subsurface Detention Basin", "Surface Detention Basin", "Wetland", "Flood Detention", "Parking Lot Detention", "Sedimentation Only", "Drainage Basin", "Non-infiltrating Bioretention", "Retention Structure", "CDA to a Shared BMP", "CMP Detention Structure", "Detention HDPE", "Ponds", "Storage", "Synthetic Turf-gravel storage and underdrain pipe", "Basin", "Stormwater Wetland", "Constructed Wetland Basin", "Extended Detention Basin", "Det-Ret Structures", "Detention Cells", "Detention Structure", "Extended Detention Dry Pond", "Extended Detention Wet Pond", "Landscape Detention Structure", "Proprietary-Water Quality Basin", "Regional Extended Detention Basin", "Storm Vault", "Subsurface Retention Tank", "swDetentionBasin","swDetentionBasinWaterQuality", "swsDetentionPond", "Tank Below Turf", "Underground Chambers", "WetlandPond", "ED", "Subsurface Storage System", "Storm Detention", "swDetentionPond"
Swales & Strips	"Curbcut Bioswale", "Swale", "Grass Swale", "Bio-Swale", "Bioswale", "Dry Swale", "Grass Channel", "Vegetated Filter Strip", "Right-of-Way Bioswales", "ROW Greenstrip", "ROW Stormwater Greenstreet", "Riparian Buffer", "Swales - Vegetated Filter Strips", "Vegetated Ditch", "Green Gutter", "Biofiltration Swale", "Conveyance Swale", "Dry Grass Swale", "Impervious Surface Disconnection", "Open Channel", "Open Channel BMPs", "Vegetated Swale", "Vegetative Buffer Strips", "Vegetative Grass-Turf Cover", "Water Quality Swale", "Vegetated Biofilter-Swale-Strip", "Filter Strip", "Filtration System"
Filter	"Bioretention Basin", "Porous Landscape Detention", "Sand Filter Extended Detention Basin", "Bioretention", "Micro-Bioretention", "Perimeter (Sand) Filter", "Sand Filter", "Engineered Soil Tree Pit", "ROW Structural Soil", "Filters (Leaf-Sand-Other)", "Bioinfiltration", "Tree Trench", "Biofiltration", "Filtration Only", "Downspout Planter", "Planter", "Biofiltration-Bioretention", "Infiltrating Bioretention", "Sedimentation Chamber-Sand Catcher-Sand Trap", "Underground Injection Cell-Drilled Drain", "Aboveground Sandfilter", "Brickpavers", "Delover Sandfilter", "Filtera-Tree Box", "Filtering System", "LID-Tree Pits and Plantings", "Open Sand Filter", "Planters", "Sandfilter", "StormFilter", "Surface Sandfilter", "Tree Pit", "Vegetated Landscape", "Manhole Sandfilter", "Aqua Guard Catch Basin Insert", "Catch Basins", "Bio-Infiltration", "Aqua Swirl", "Aqua-Shield-Swirl", "Aqua-Filter", "Aqua-Shield-Filter", "BayFilter", "BaySaver", "Catch Basin Insert", "CDS", "Hydrodynamic - CDS Structure", "CDS Units", "Downspout Filter", "Downstream Defender","Hydro-Kleen Filter System", "Inlet With Insert", "JellyFish", "Modified Manhole with Snout", "O-W Separator", "Oil Separating Incerts", "Oil-Grit Separator", "Single Chamber Sandfilter", "Snout", "Stormceptor", "Storm-Pure Filtering System", "Vortechnics", "Vortech", "Vortechs", "VortSentury", "Water Quality Dynamic Separator", "Water Quality Inlet Insert", "Stormwater Planter", "Stormwater Tree Pit", "Baffle Box", "Downspout Filtration(Flowgard)", "Drainage Insert", "Hydrodynamic Separator", "Hydrodynamic Separation Systems", "Interceptor", "Oil-Grit Separator (Vortechnics)", "Vortex", "Storm Filter", "Fossil Filter", "HYDSEP", "TreeFilter", "RiserPipe"
Infiltration Facility	"Retention Basin", "Retention", "Dry Well", "French Drain", "Infiltration Basin", "Infiltration Chamber", "Stormwater Conveyence and Infiltration", "Retention Pond", "Infiltration Berms", "Infiltration Trench", "ROW Infiltration Basin with Combination of Concrete and Grass Top", "ROW Infiltration Basin with Concrete Top", "ROW Infiltration Basin with Grass Top", "ROW Subsurface Pipe-Broken Stone", "Subsurface Detention System", "Subsurface Pipe", "Synthetic Turf Field Storage Layer", "Infiltration Facility", "Drainage Well", "Infiltration Storage Trench", "Surface Infiltration Basin", "Ex-Filtration Trench", "Gravel Storage", "Infiltration", "Infiltration BMPs", "Leaching Tank", "Modular Raintank","Retention Structure", "Retention-HDPE", "Storm Chamber System", "Infiltration-Storage Trench", "Bioinfiltration", "Subsurface Infiltration Basin","Infiltration - Basin", "Infiltration - Dry Well", "Retention Basin with Trees and Shrubs", "Retention Pond (Wet Pond)", "Subsurface Infiltration", "swsRetentionPond"
Green Roof	"Green Roof", "Combined Blue-Green Roof", "Rooftop Farm", "Green Roof & tree Box"
Pervious Pavement	"Permeable Pavement", "Porous Pavement Detention", "Pervious Pavement", "Permeable Pavers", "Porous Asphalt", "Porous Concrete", "Pavers", "ROW Porous Concrete", "Porous Pavement", "Pervious Paving", "Permeable Pavement System", "Perm Pave", "Permeable Pavements", "PermeablePaver"
Underground Filter	"Oil Grit Separator", "Underground Filter", "Sediment Manhole", "Trench", "U-G Detention", "U-G Retention", "Underground Sandfilter"
Rain Garden	"Rain Garden", "Rain Gardens", "Raingarden", "Proprietary-Rain Garden", "ROW Rain Garden", "Roof Garden", "Bayscaping", "Residential Rain Garden", "Rain Garden-Bioretention"
Rain Water Harvesting & Cisterns	"Catchment System", "Rainwater Harvesting", "Landscape Water Harvesting", "Water Harvesting", "Passive Water Harvesting", "Proposed Rainwater Harvesting", "Rain Harvesting", "Rain Barrel", "Rain Barrel-Cistern", "Cistern", "Cistern overflowing back to sewer", "Cistern Overflowing to Conveyance Channel", "Cistern Overflowing to Conveyance Furrow", "Cistern overflowing to Raingarden", "Raingarden & Cistern", "Cisterns for Recycling", "Roof Top Detention", "SW-Reuse", "Cistern-Rain Barrel", "Rain Garden", "Drywell_Rainwater Harvesting"
Gross Pollutant Trap	"Trench Drain", "Catch Basin Drain", "Curb Inlet", "Curb Inlet w-Grate", "Drop Inlet", "Grated Inlet", "Surface Slot Drains","Bar Screen - Outlet Screen", "Catch Basin", "Debris Basin", "Drain Box", "Inlets", "Water Quality Vault", "Inlet", "Catch Basin - Grated Top", "Junction Box with Sump", "Vault", "Water Quality Structure", "Water Quality Inlet", "BMP Vault", "Single Water Quality Inlet", "Double Water Quality Inlet", "Triple Water Quality Inlet", "Water Quality Manhole", "Water Quality Catch Basin", "Caltrans Drain", "Track Drain", "Grated End", "Restrictor Inlets - Drop Inlets", "swsInlet", "swInlet"
Other	"Flared End", "Headwall", "Condensate Capture", "Open Space and Mitigation", "Flood Prevention", "Stormwater Mitigation", "Flapgate", "Other", "Disconnection of Non-Rooftop Runoff", "Disconnection of Rooftop Runoff", "Impervious Surface Elimination (to pervious)", "Sheetflow to Conservation Areas", "Misc Structures", "Land Cover Change", "Tree Planting and Preservation", "ENVIROCHAMBER", "Modified Catchment Manhole", "Green Wall", "Naturalized Meadow", "Riparian Buffer-Stream Restoration", "Depaving", "Channel Modification", "Flood Gates", "Lakes and Ponds", "Lawn Reseeding", "Soil Quality", "Storage Practices", "swsManhole", "Naturalized Landscape", "Storm Energy Dissipators", "swDaylightDitch"
Stormwater Conveyance	"Spot Fix-Grading", "Storm Drain System", "Connection for Private Drain", "Channel", "Culvert", "Level Spreader", "Scour Hole", "Pipe End", "Cleanout", "Culvert Inflow", "Culvert Outflow", "Junction Box", "Maintenance Hole", "Area Drain", "Inlet-Pipe", "Sewer System", "Stormsewer", "Surface and Subsurface Conveyance", "RiserPipe"
Unknown	"Unknown", "Unregulated", "Plug", " ", "", "WQ Treatment Device", "Proprietary Practice", "Proprietary", "Proprietary Devices", "Subsurface Catchment", "0", "Storm Structures"
None	"Open lot-off campus. Potential GI Site", "Parking Lot-Potential GI Site", "Parking Lot", "Potential GI Site", "Water Utilities", "Manhole", "Node", "None", "Stormwater Treatment System", "Dry Well Removal", "Proposed", "TBD", "Proposed"
Multiple	"Water Conveyance-Detention-and Infiltration Features", "Multiple GI Components", "Filtration-Detention", "Infiltration-Detention", "Retention-Infiltration", "Retention-Irrigation", "Sediment-Detention", "Sediment-Filtration-Infiltration", "Sediment-Filtration-Irrigation", "Wet Pond-Irrigation", "French drain-V-Ditch & Drop inlet", "Detention Tank and Irrigation System", "Sediment-Biofiltration-Infiltration", "Sedimentation-Sand Filtration", "Storm Filter - StormVault", "Swale - Storm Filter"

Challenges

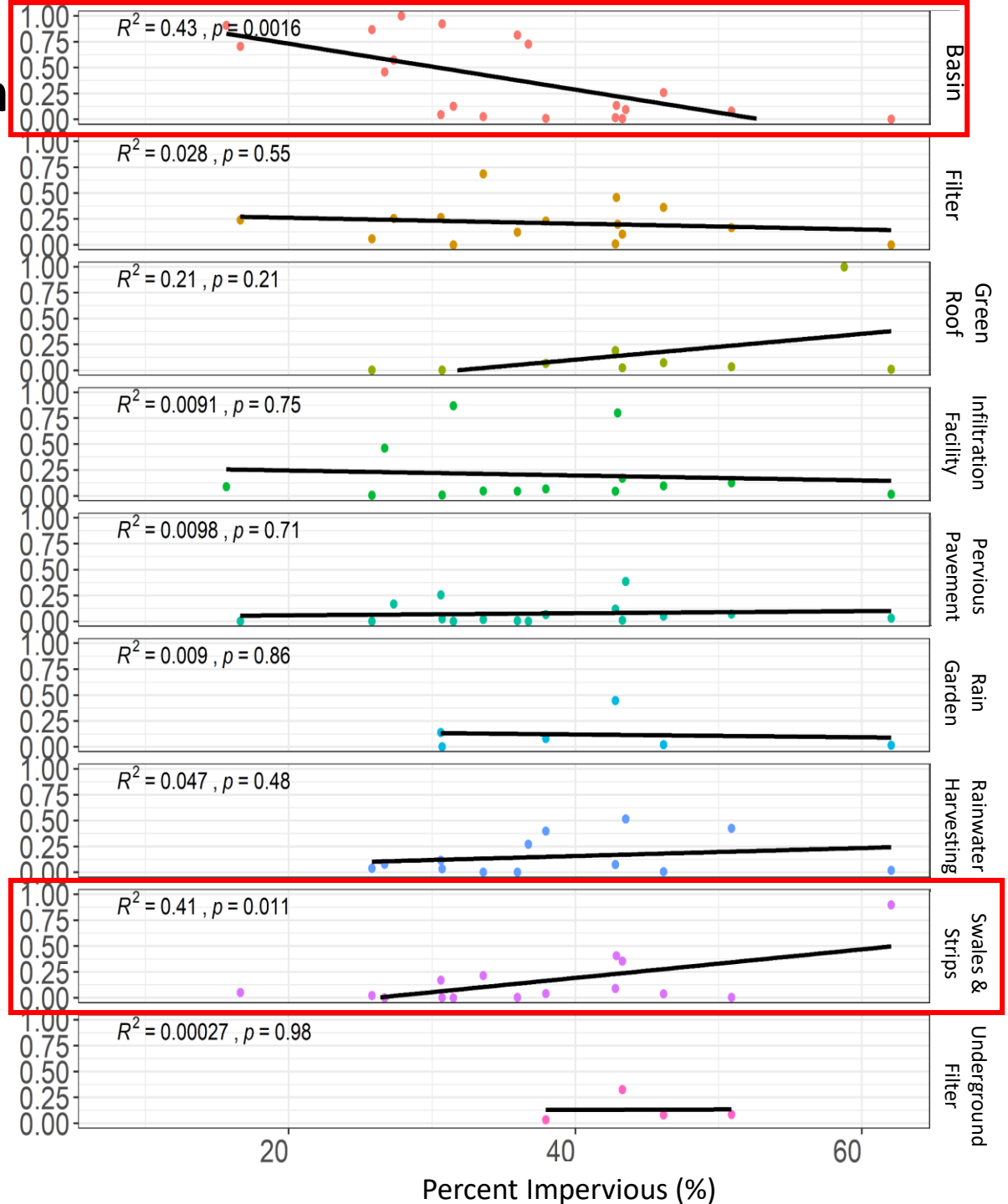
- SCM adoption and implementation has occurred at the city level
- Inconsistent terminology used between cities
- Inconsistent documentation of SCMs between cities
- Publicly owned SCMs more likely to be documented
- Overlapping function between SCMs (e.g., raingardens also encourage infiltration)

Total SCM Counts for each city

Breakdown of SCMs per total SCMs for each city



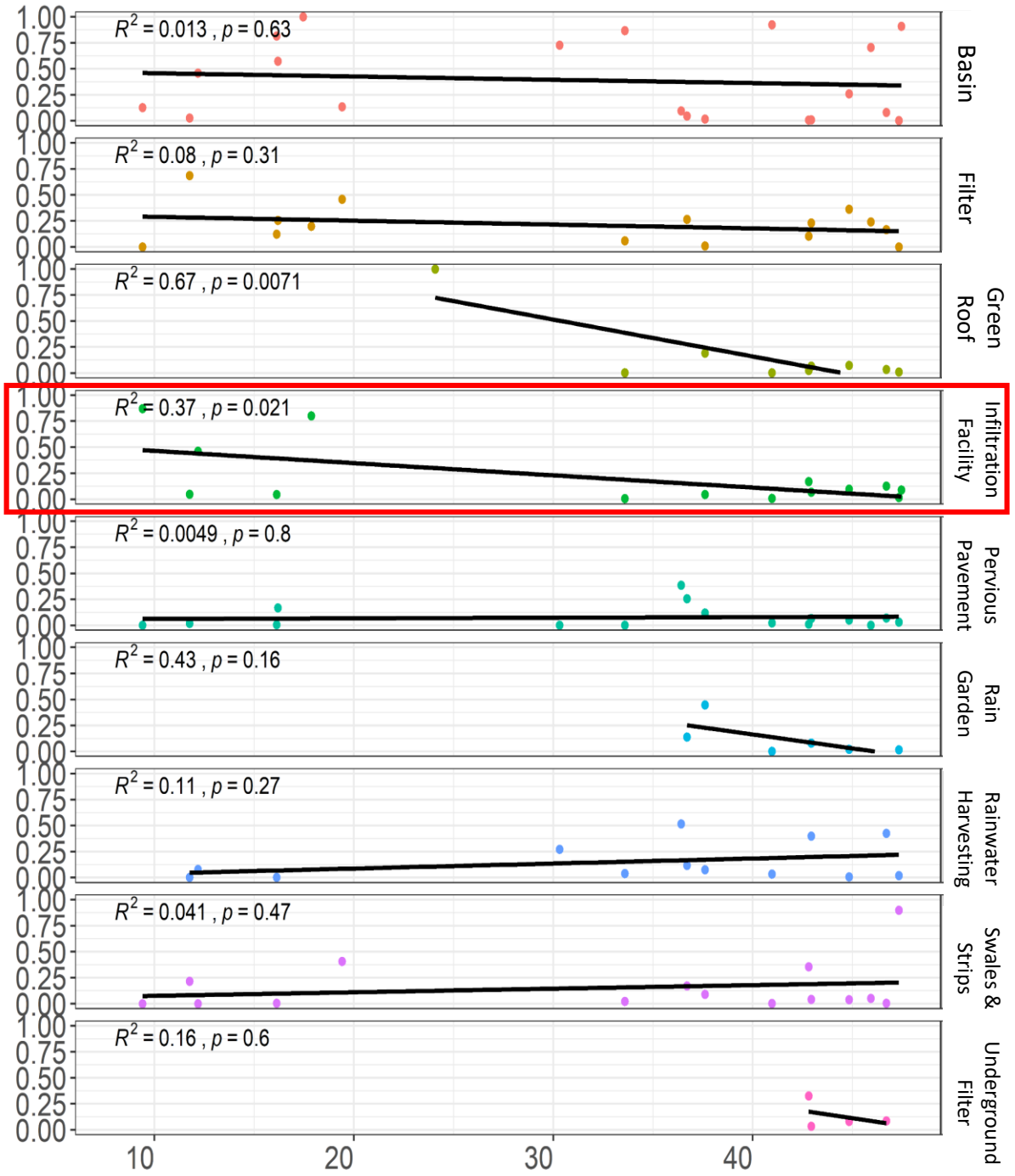
Ratio of each SCM type to total SCMs vs. Percent impervious



Basins tend to decrease with increasing percent impervious

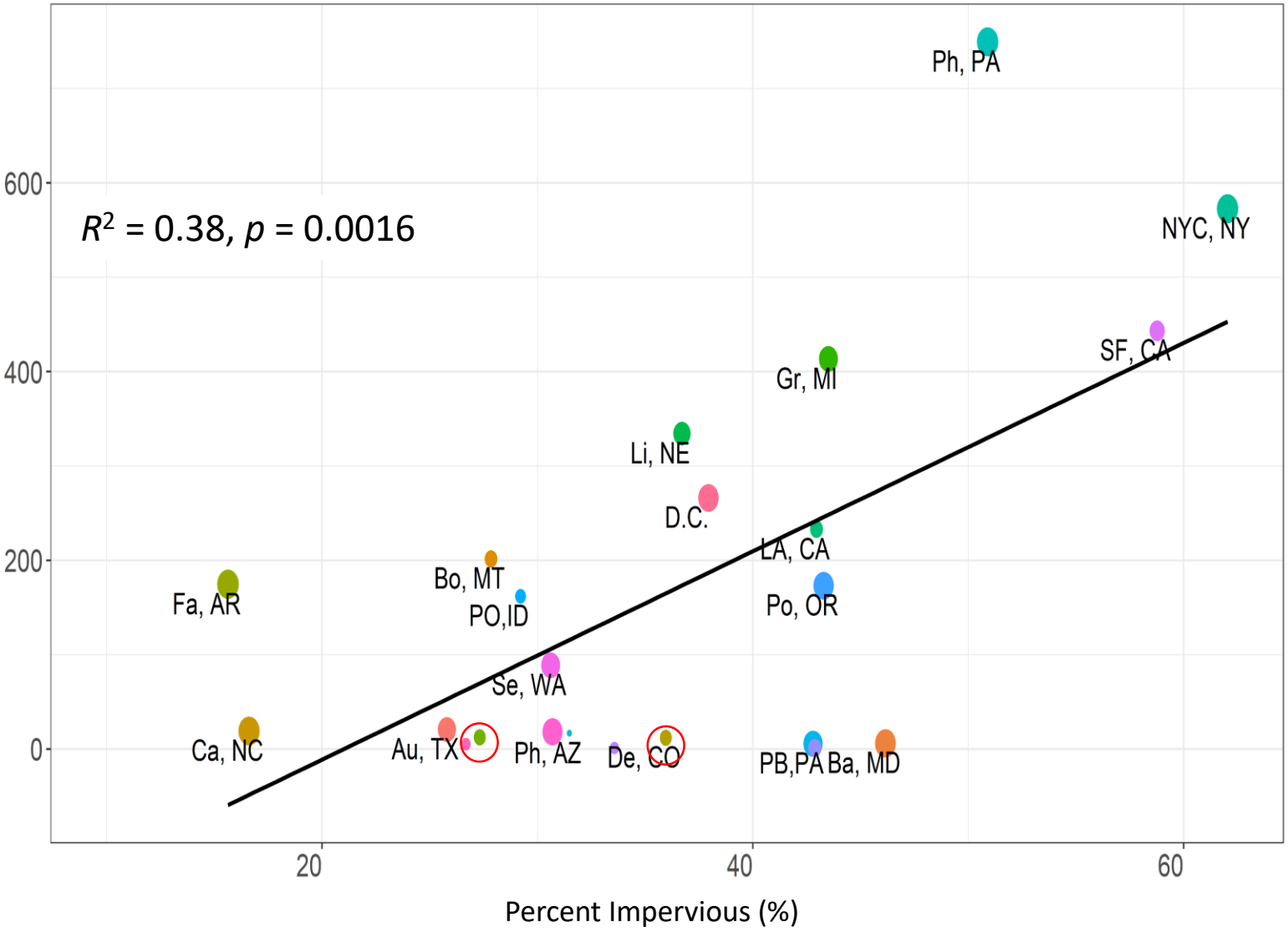
Swales and Strips tend to increase with increasing percent impervious

Ratio of each SCM type to total SCMs vs. Annual Precipitatio



Infiltration facilities tend to decrease with increased annual precipitation

SCM density (#/mi²) Vs Percent Impervious (%)



Takeaways

- Wetter cities are using more diverse suites of SCMs
- Infiltration is more of a focus in drier cities
- Basins are implemented more in cities with lower percent impervious
- Swales & strips are implemented more in cities with greater percent impervious
- Standardizing terminology and SCM documentation between cities would make sharing information much easier!

Future Directions

- Continue gathering/assessing data on possible drivers of SCM selection (e.g., combined sewer?, other climatic data, DTWT, slope, soils, development age, income, etc.)

- Run analysis with different classifications (e.g., hydrologic function, typical SCM footprint, water quality implications)

- If you have access to SCM data we do not have yet, PLEASE SHARE YOUR DATA WITH US!!

What is an infiltration based stormwater control measure (I-SCM)?

- An engineered system intended to mitigate effects of stormwater runoff by collecting and infiltrating stormwater into subsurface flow paths

https://www.americanrivers.org/threats-solutions/clean-water/green-infrastructure/what-is-green-infrastructure/

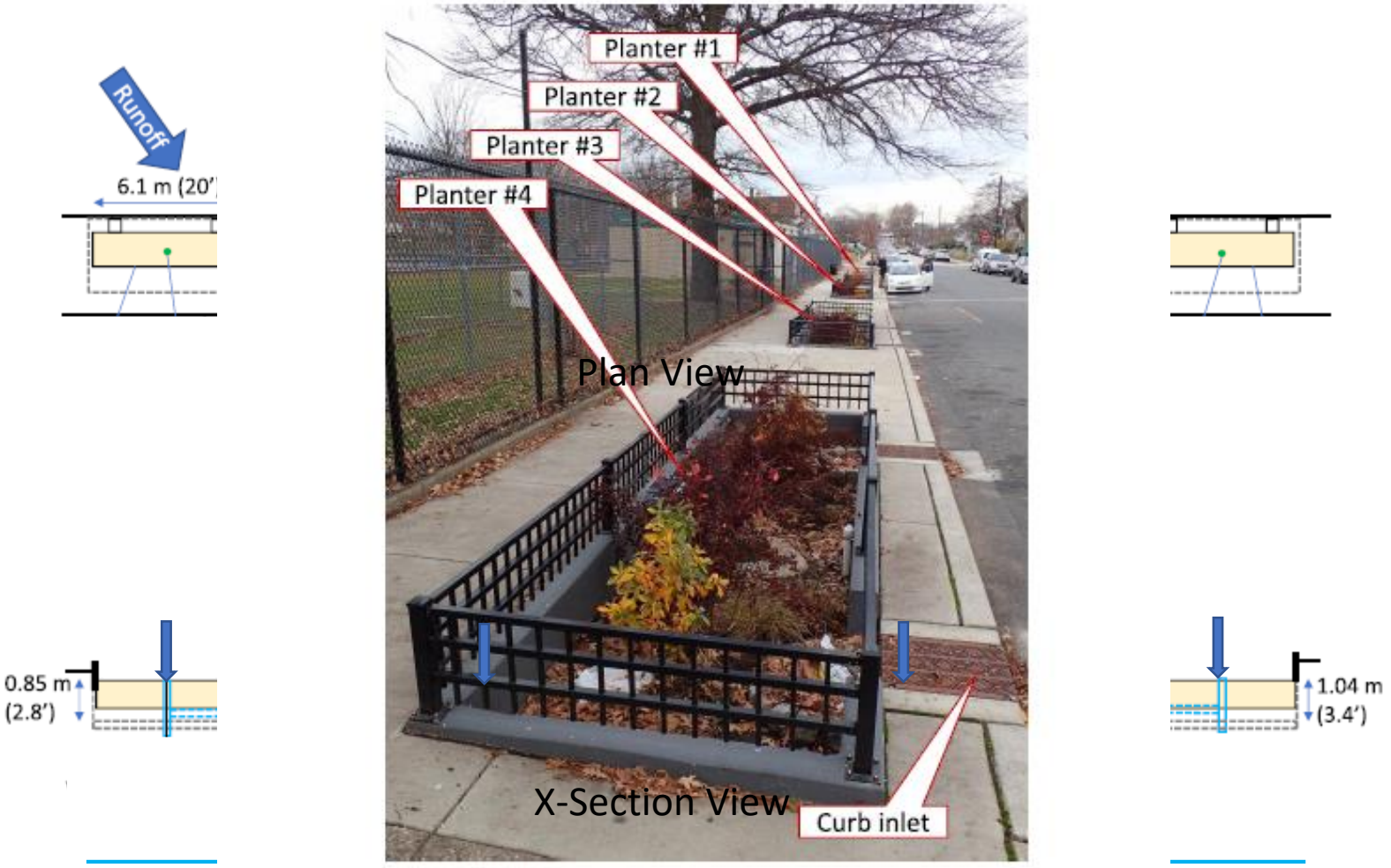
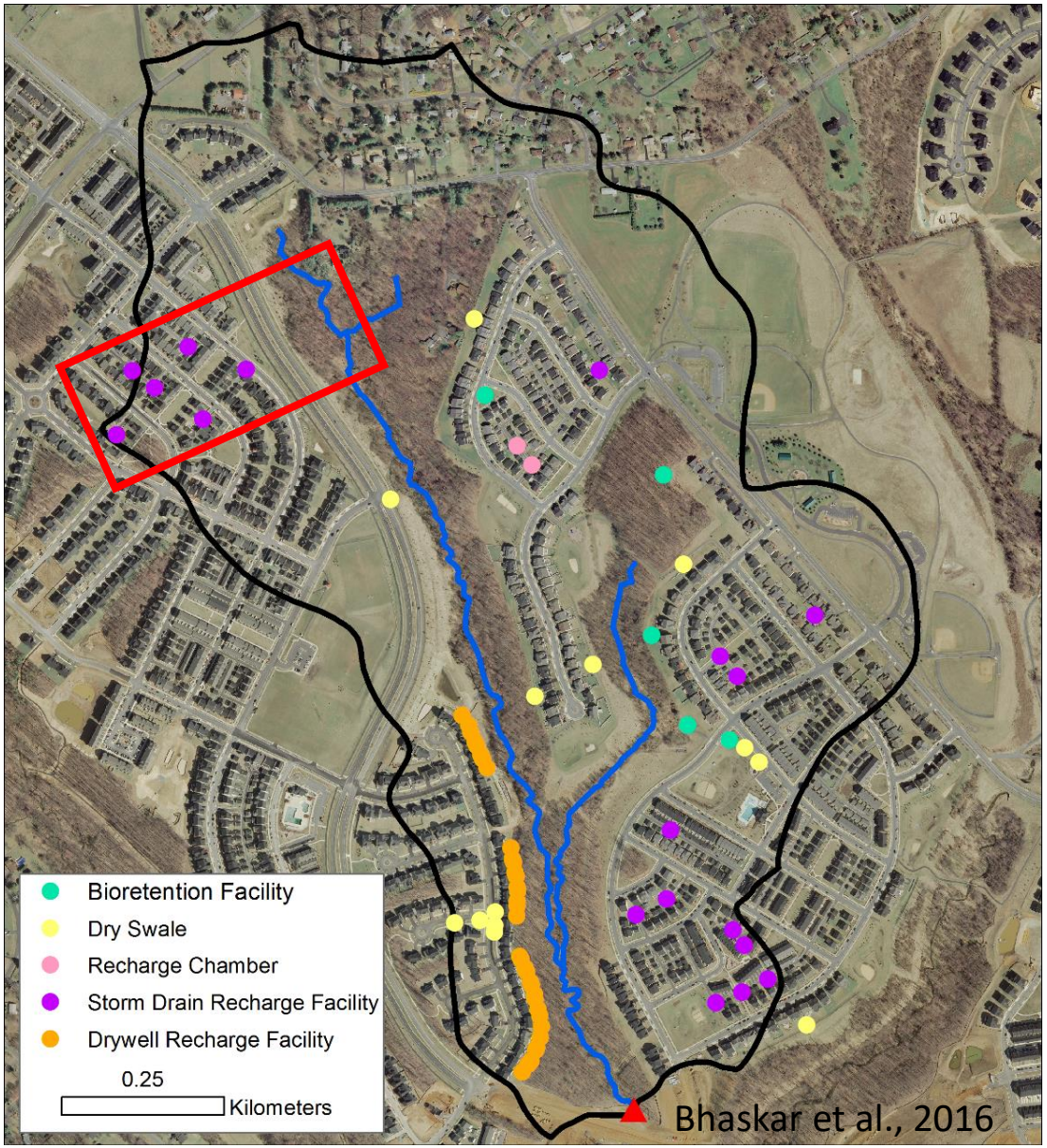


Fig. 1. Green infrastructure sidewalk planters under investigation (photo date: December 6, 2016). (Image by Min-Cheng Tu.)

Modified from Tu and Traver 2019

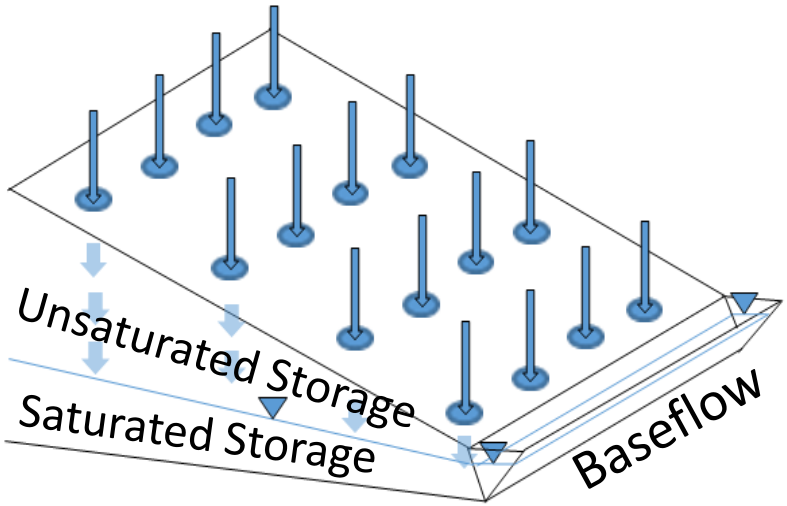
Tu and Traver 2019

In empirical studies I-SCM location cannot be altered

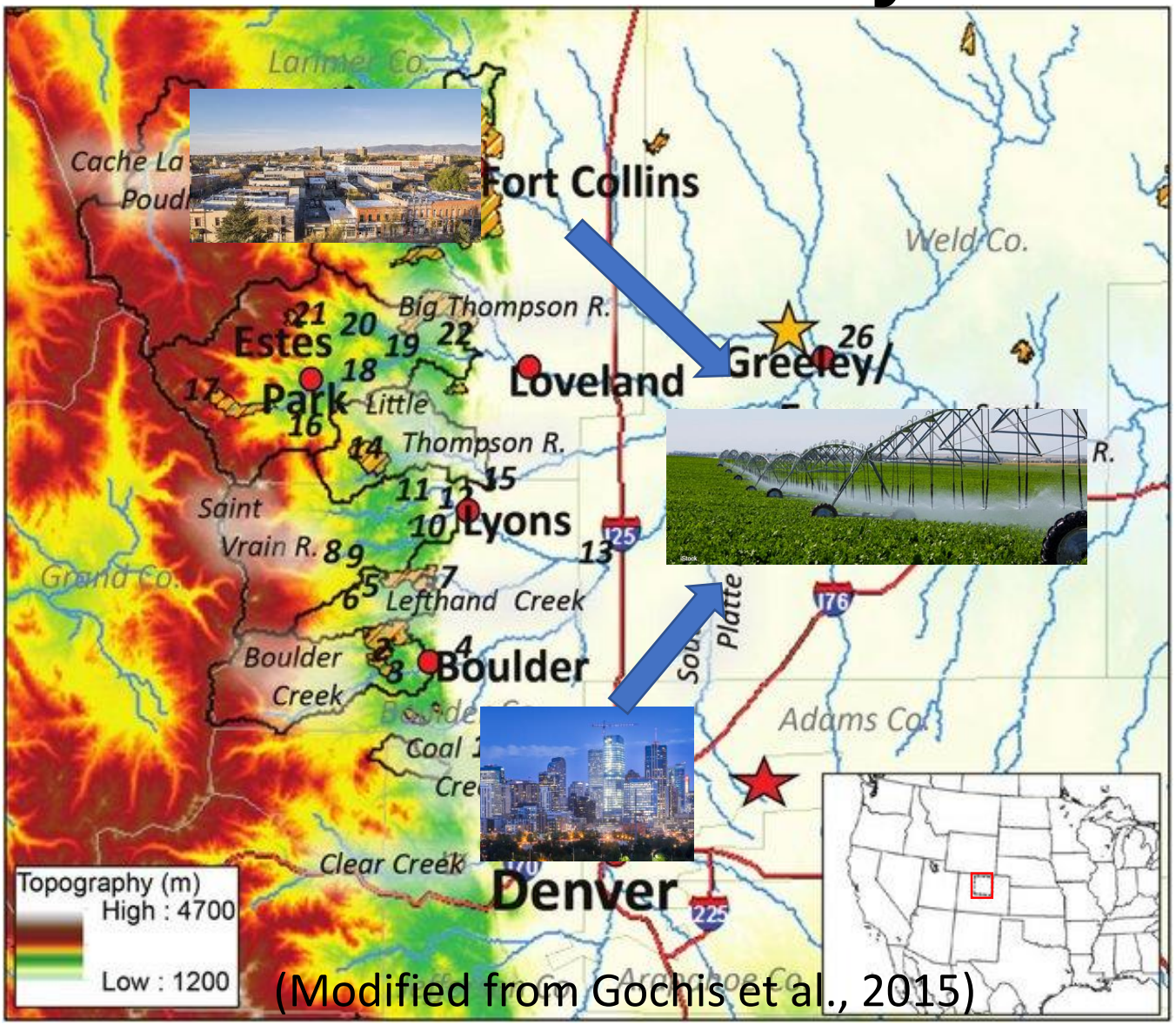


Bhaskar et al., 2016

Conceptual Model



Baseflow and aquifer storage can be critical for water availability



(Modified from Gochis et al., 2015)

Research Questions

1. How does spatial arrangement of I-SCMs affect partitioning of subsurface storage between unsaturated and saturated zones?

2. How do these effects vary between soil types?

+ Management implications

Methodology

1. Use physically-based watershed modeling code that simulates variably saturated subsurface flow tightly coupled to overland flow

    a) ParFlow

2. Develop catchment, boundary conditions, and initial conditions

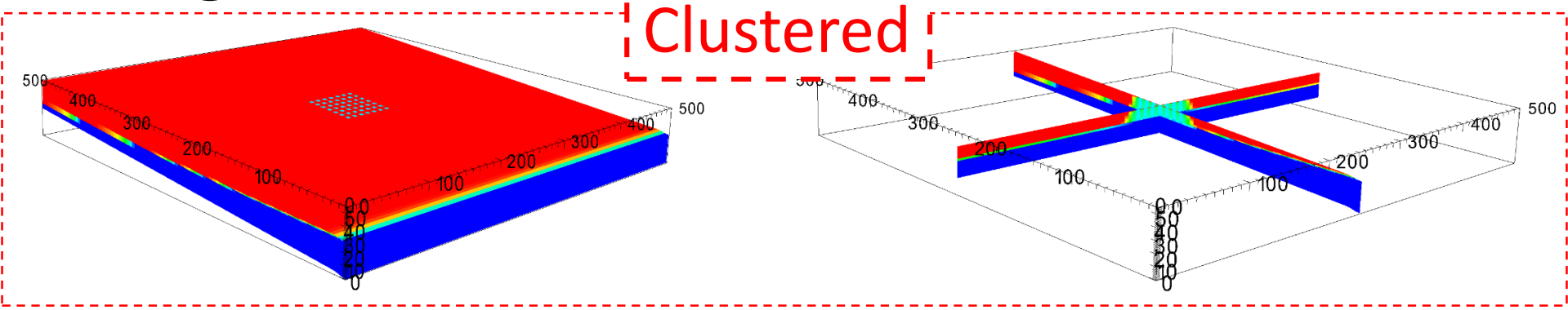
    a) 500 m x 500 m catchment
    b) ET:Precip. = 0.4
    c) Spatially clustered vs distributed infiltration

3. Simulate transient precipitation-evapotranspiration (ET) cycles

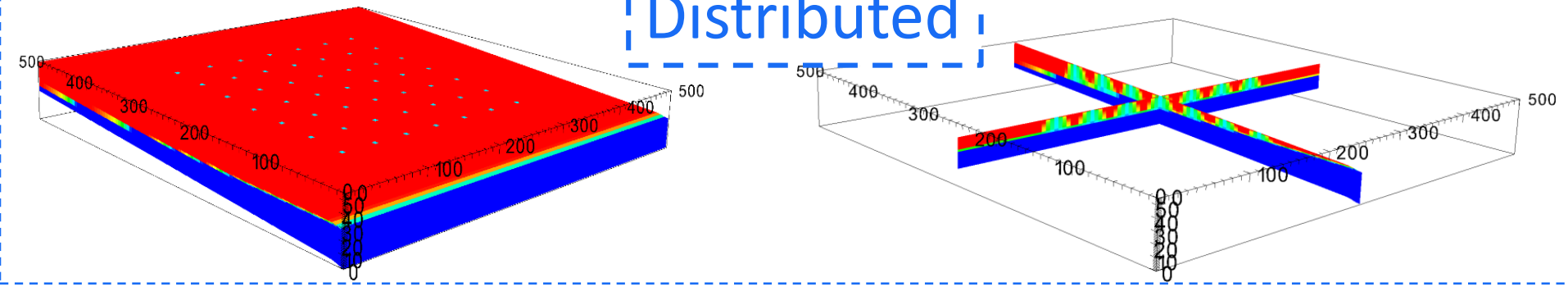
4. Compare results from each scenario

In sand, the thickness of the unsaturated zone was maintained under both spatial arrangements.

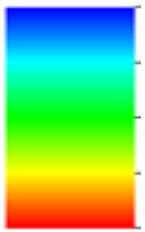
Clustered



Distributed



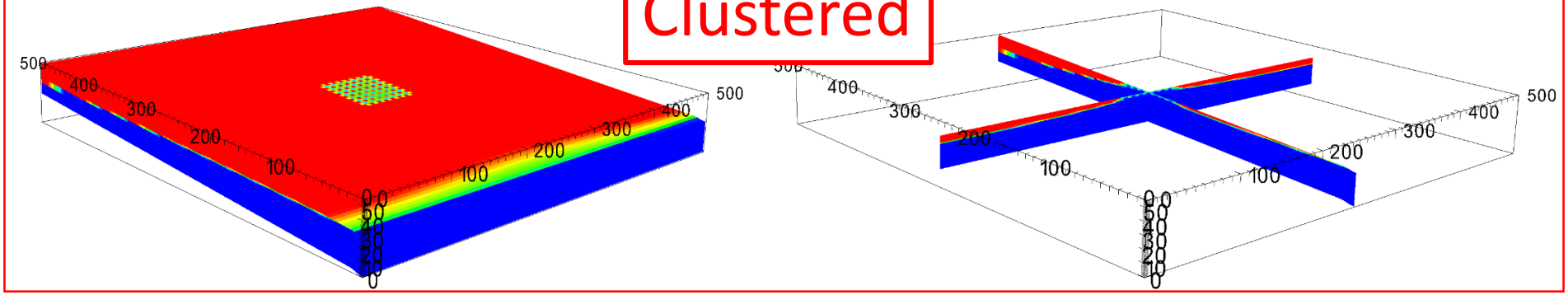
Pressure Head



Storage	Distr. W/More	Volume [gal]
Unsaturated	Distributed	2.64 E 6
Saturated	Clustered	1.06 E 6
Total	Distributed	1.59 E 6

In loamy sand, the water table rises close to the surface beneath and around the clustered infiltration facilities.

Clustered



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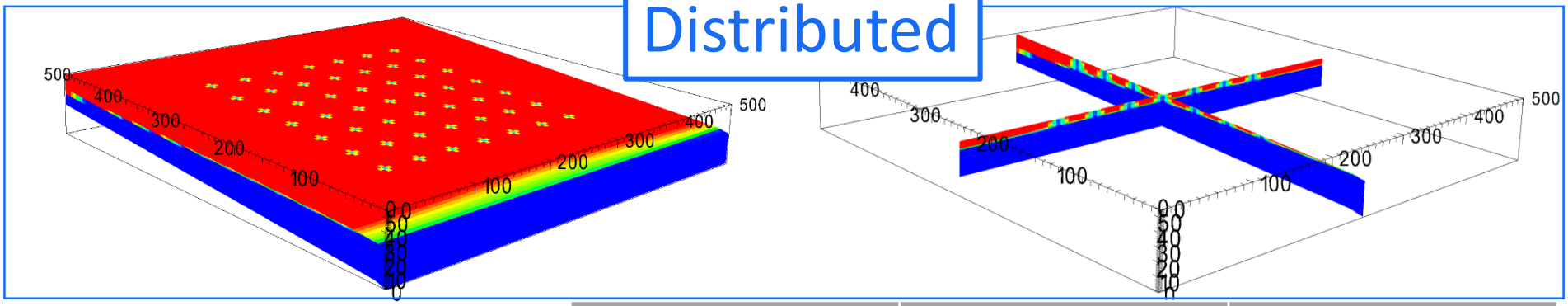

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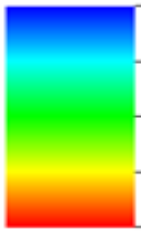


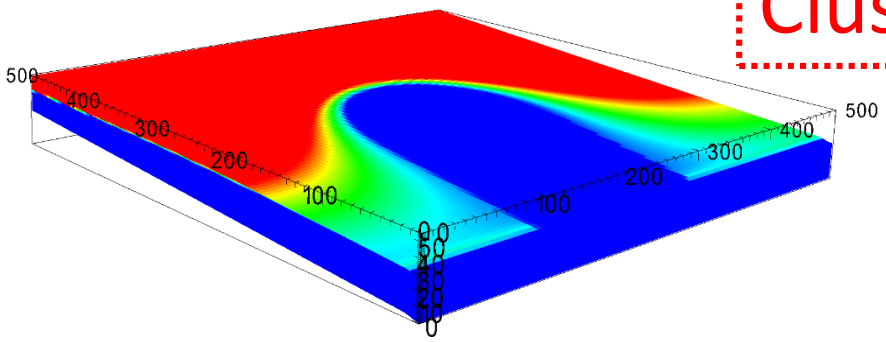
0 m

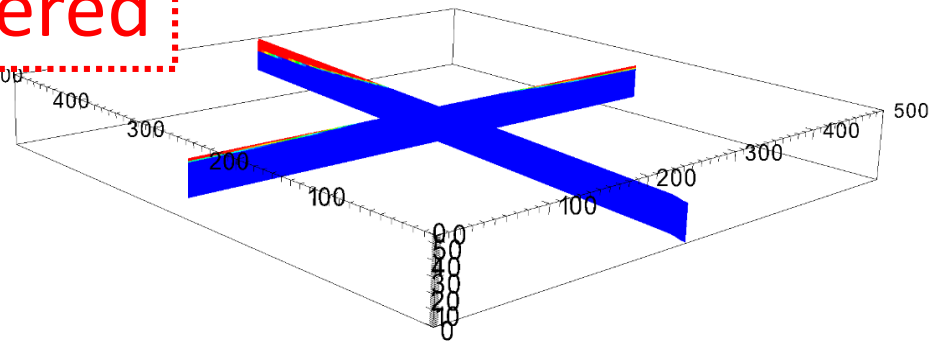
-1.5 m

Storage	Distr. W/More	Volume [gal]
Unsaturated	Distributed	5.28 E 6
Saturated	Clustered	4.49 E 6
Total	Distributed	0.79 E 6

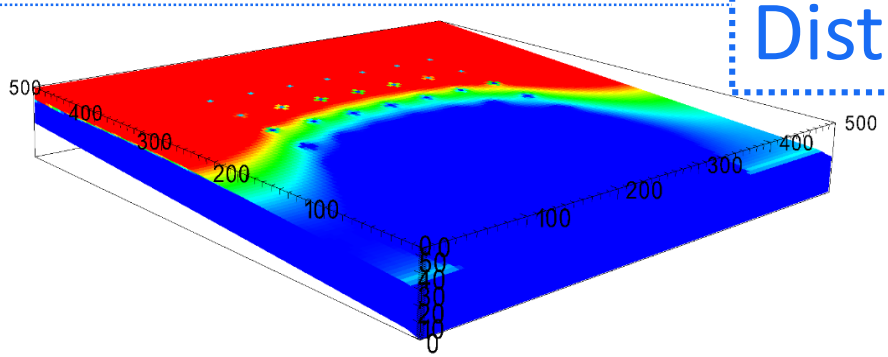
In silt, there was widespread surface ponding for both clustered and distributed arrangements.

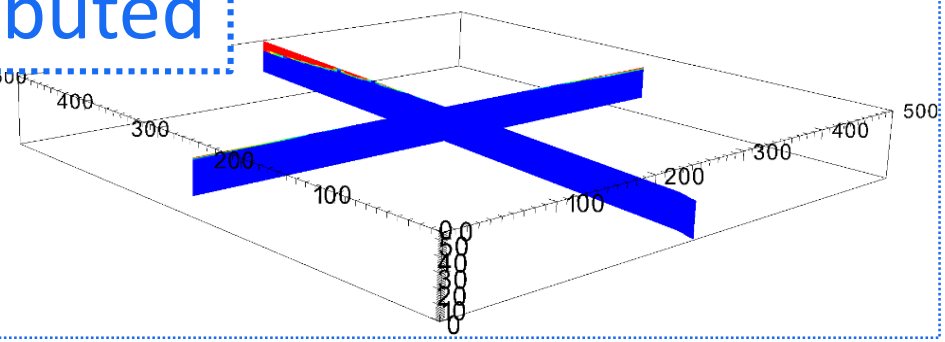
Clustered



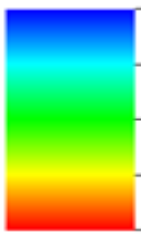


Distributed





Pressure Head

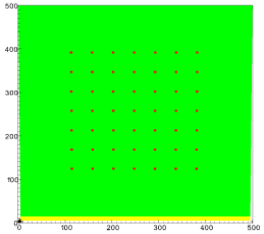


Storage	Distr. W/More	Volume [gal]
Unsaturated	Distributed	-
Saturated	Clustered	-
Total	Distributed	-

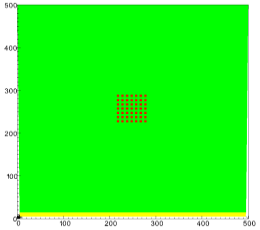
Research Answers

1. How does spatial arrangement of I-SCMs affect partitioning of storage between unsaturated and saturated zones?

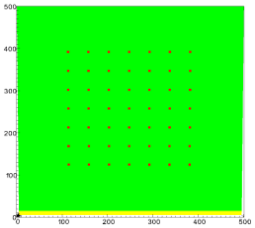
Unsaturated Storage:



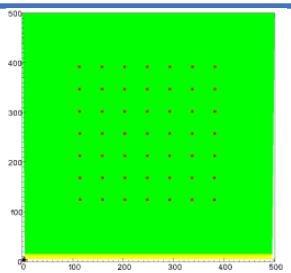
Saturated storage:



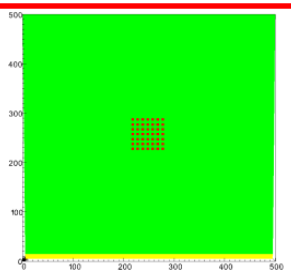
Subsurface Storage:



Management Implications



- Greater retention in subsurface and unsaturated zone
- Maintain greater infiltration capacity



- Greater aquifer recharge
- Risk of reduction of infiltration capacity, may demand greater surface ponding depths

Research Answers

2. How do the effects of spatial arrangement of I-SCMs on subsurface storage vary among soil types?

Subsurface storage: More sensitive to I-SCM arrangement in lower permeability soils (e.g. loamy sand)

Management goals should be appropriate to catchment and soils you are working in

Low Perm. (e.g. Silt)

- Stormwater infiltration will be limited
- Distributed I-SCMs provide best opportunity though

Moderate Perm. (e.g. Loamy Sand)

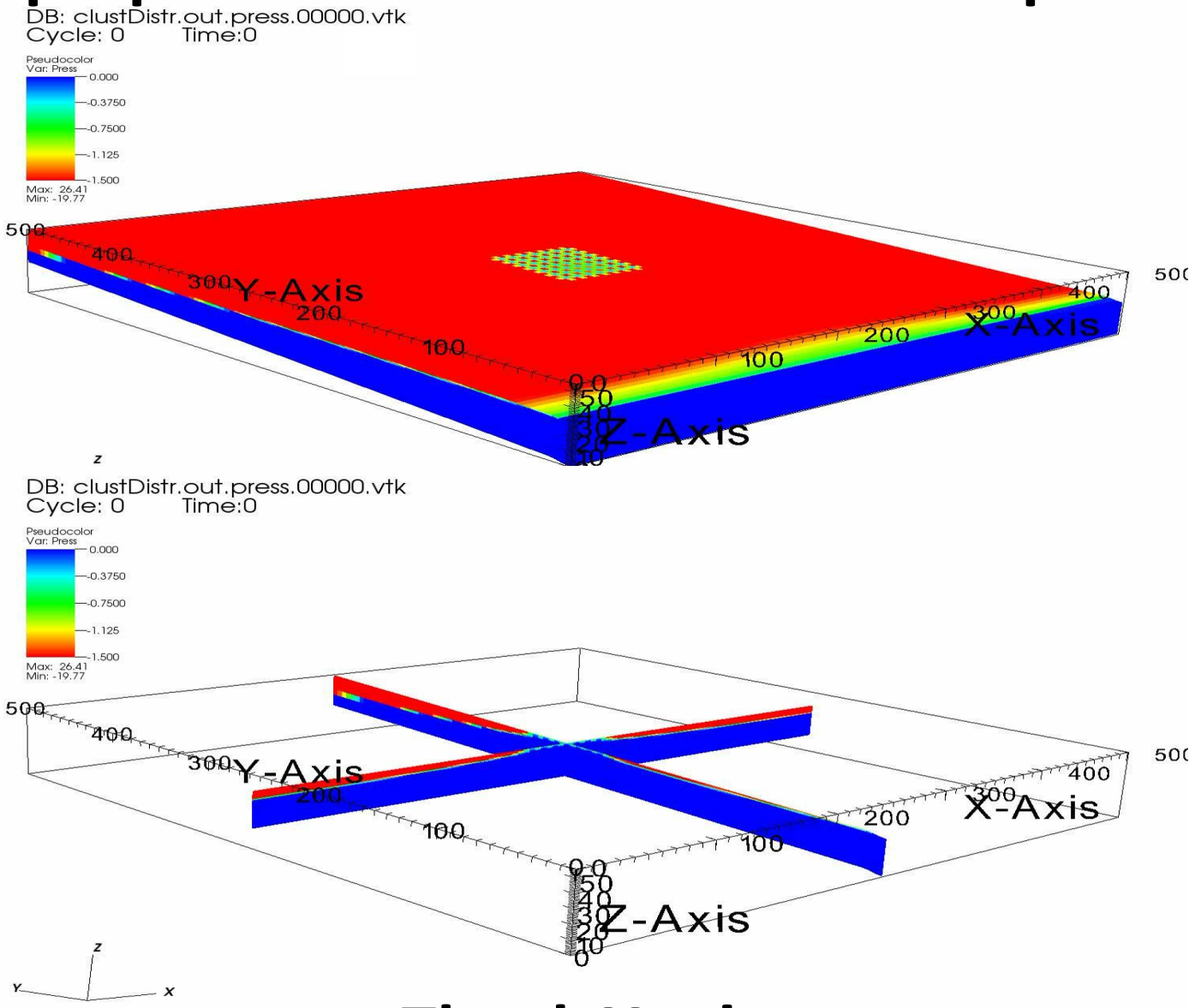
- Management of subsurface storage
- Use of vegetation placement relative to I-SCM placement to alter catchment outputs (i.e. increasing ET)

High Perm. (e.g. Sand)

- Use of harvest based SCMs to manage magnitude of subsurface storage

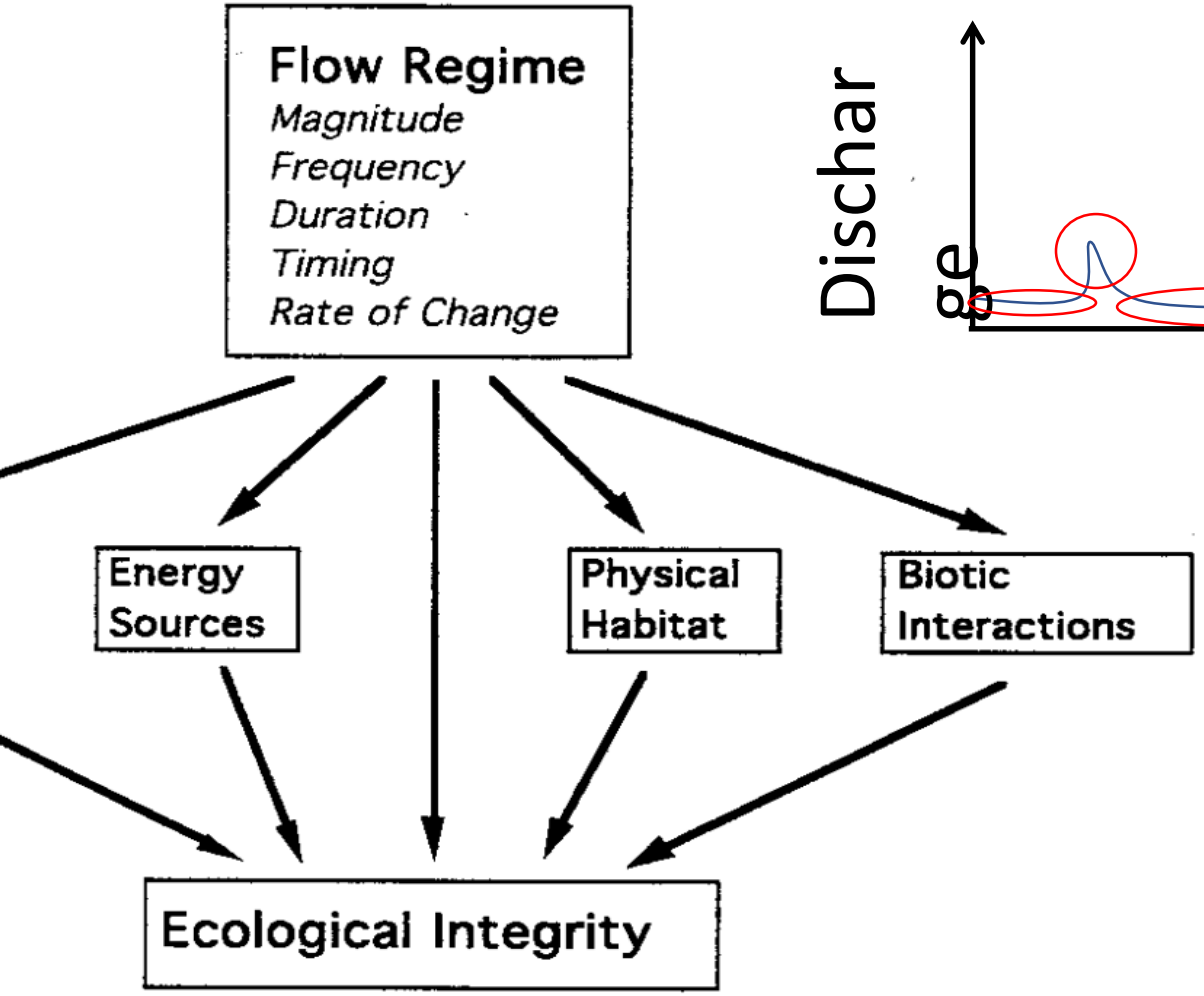
Acknowledgements

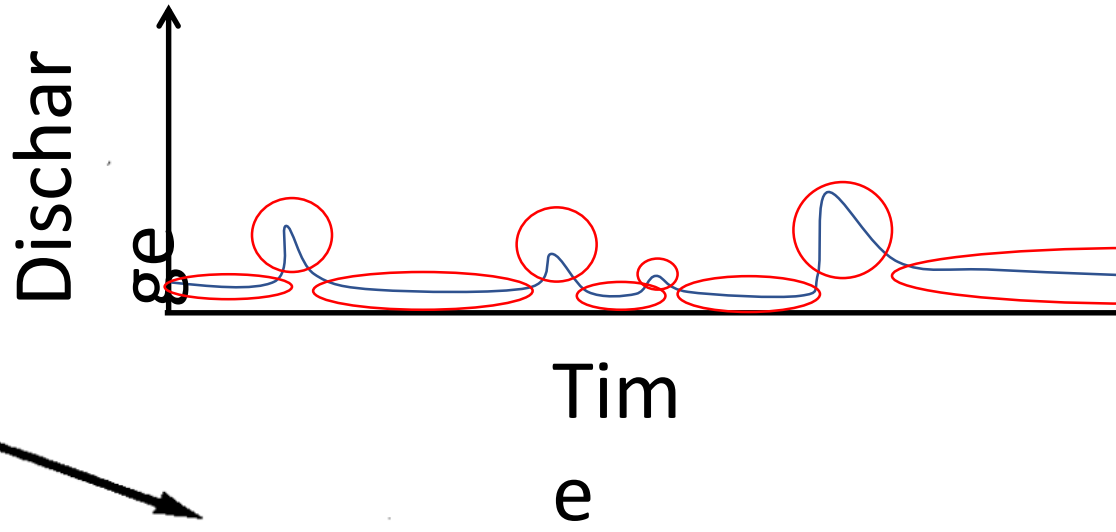
Management goals and SCM selection should be appropriate to catchment and soils present



Thank You!

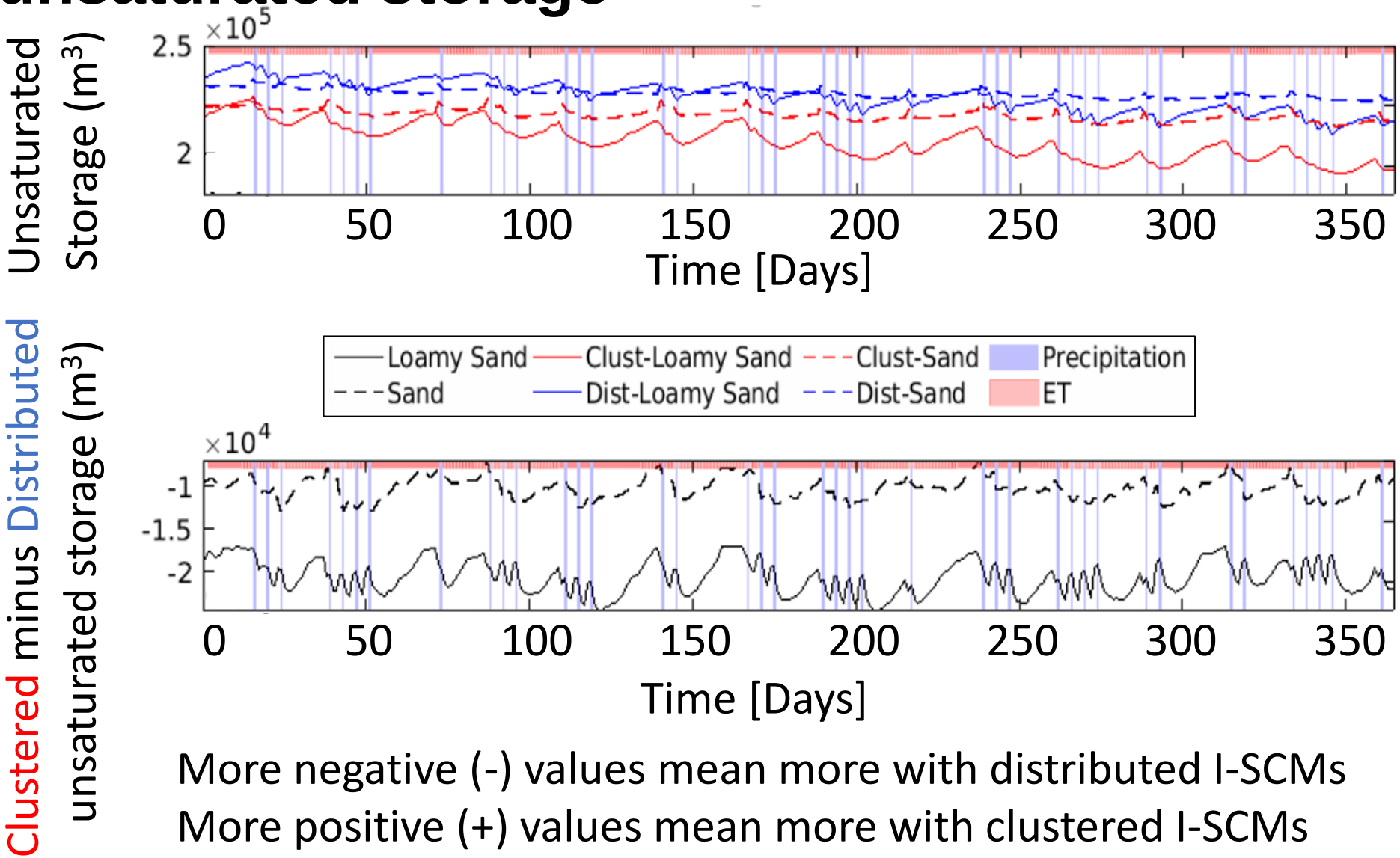
ed baseflow impairs ecological integrity





(Poff et al., 1997)

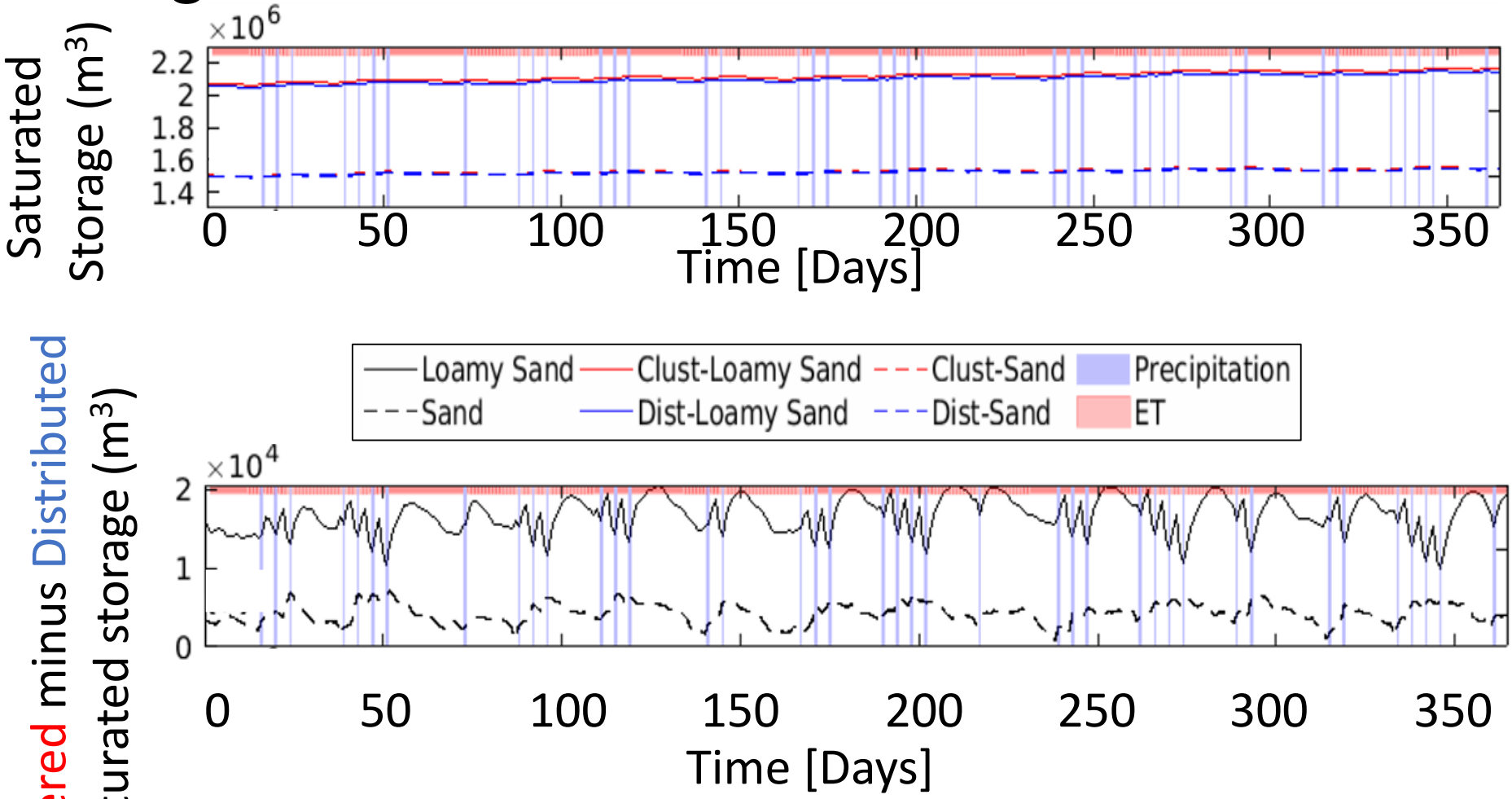
Distributed I-SCMs produced greater unsaturated storage



More negative (-) values mean more with distributed I-SCMs

More positive (+) values mean more with clustered I-SCMs

Clustered I-SCMs produced greater saturated storage



More negative (-) values mean more with distributed I-SCMs

More positive (+) values mean more with clustered I-SCMs

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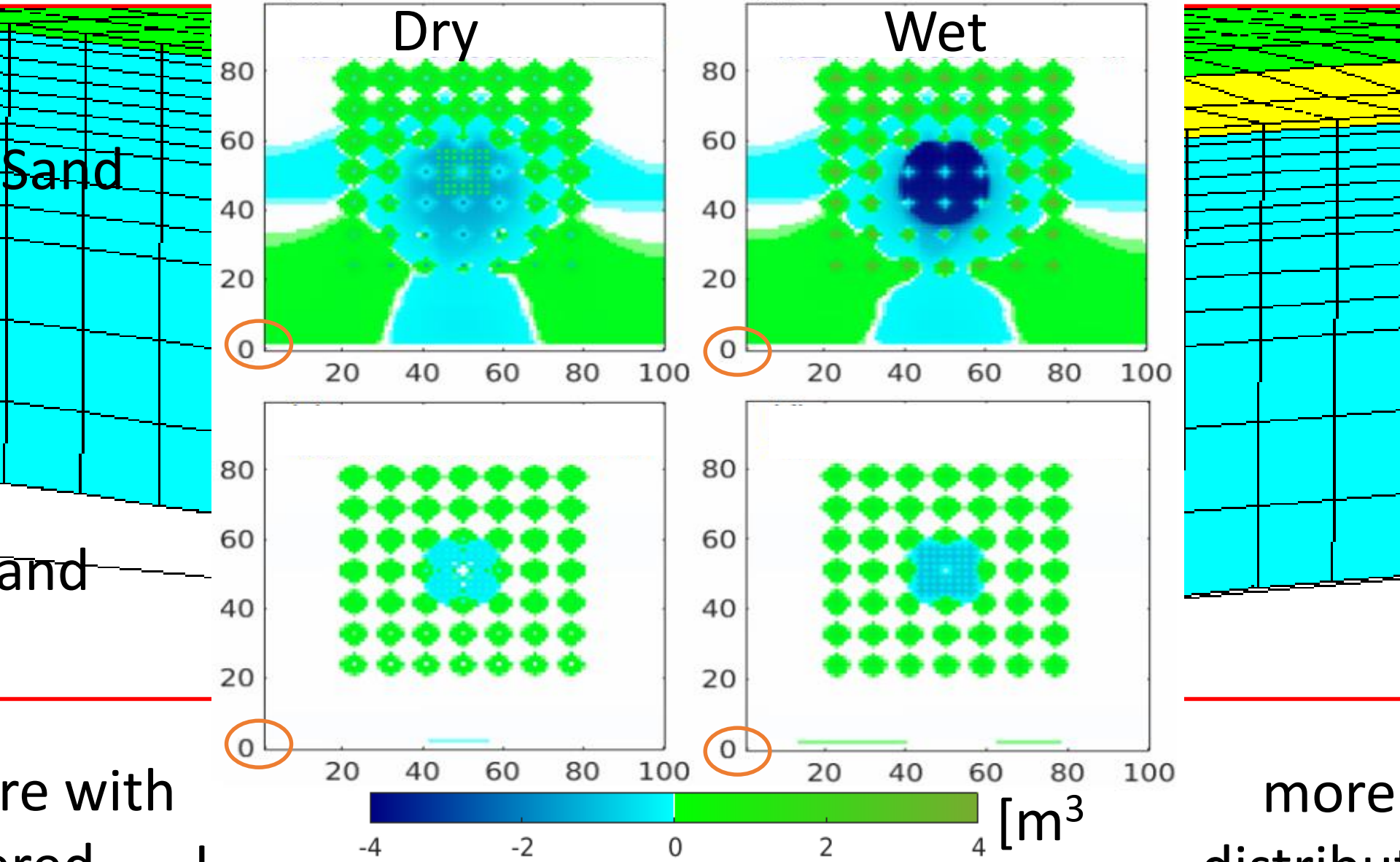

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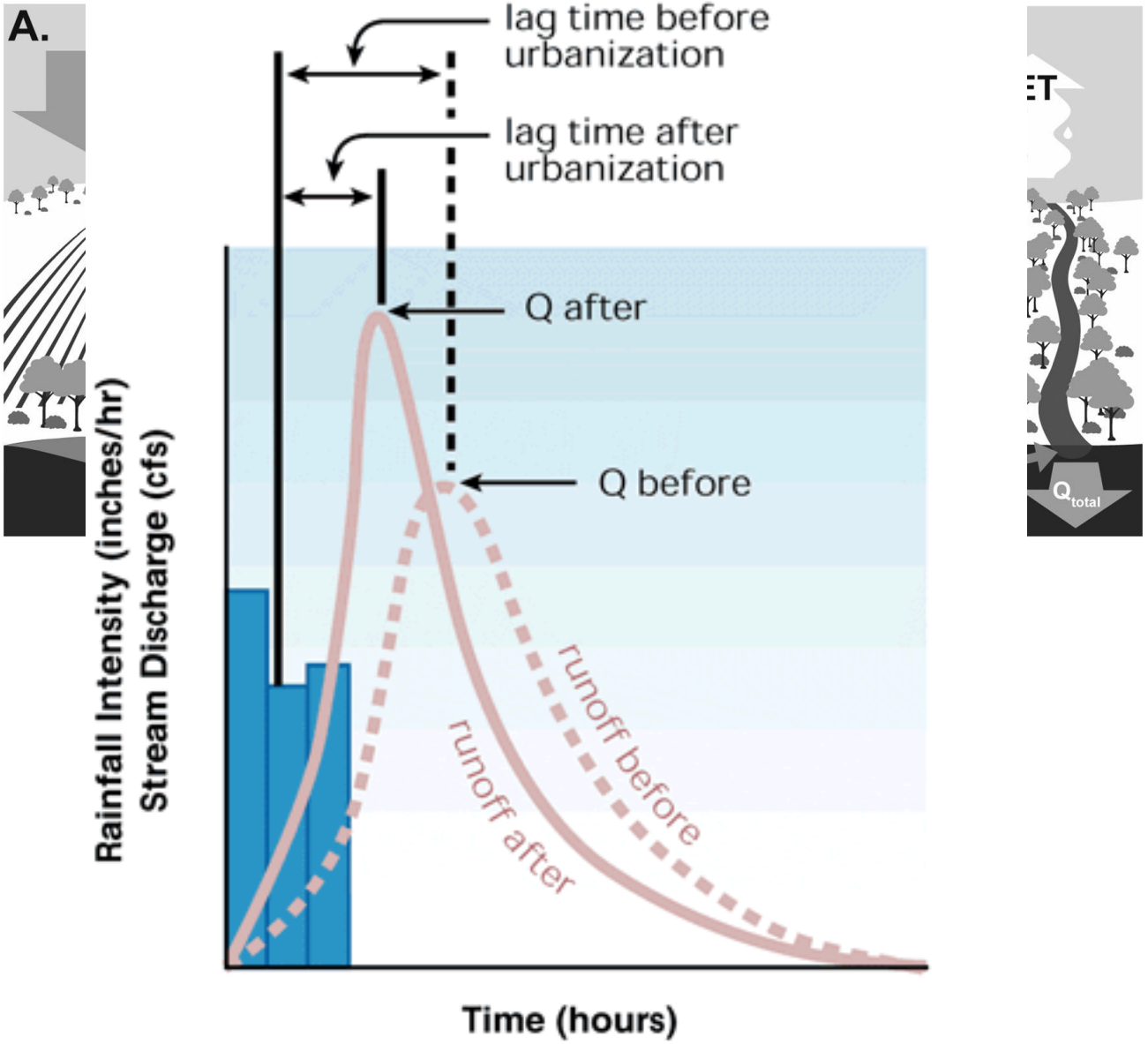
Urbanization and Watershed Hydrology



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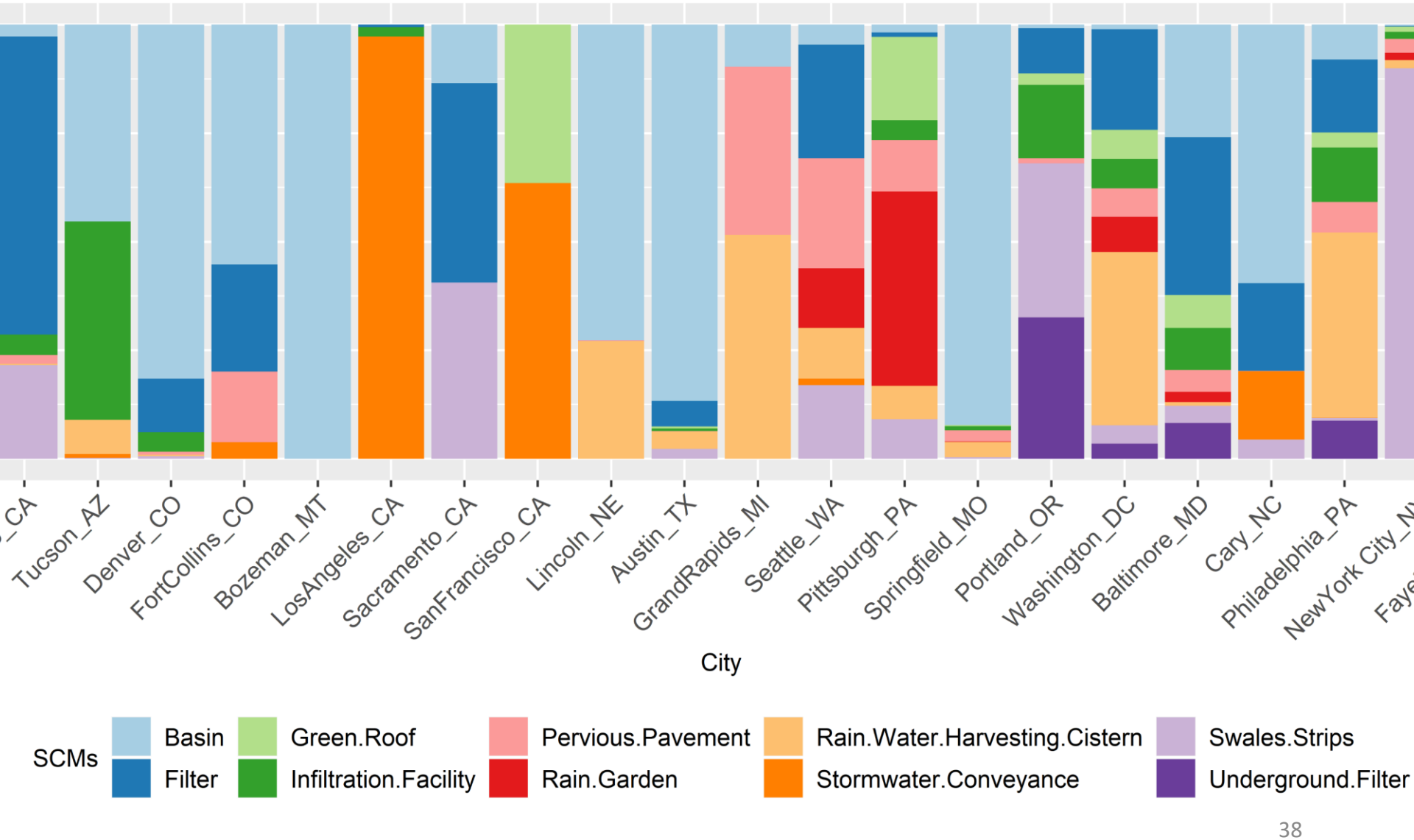
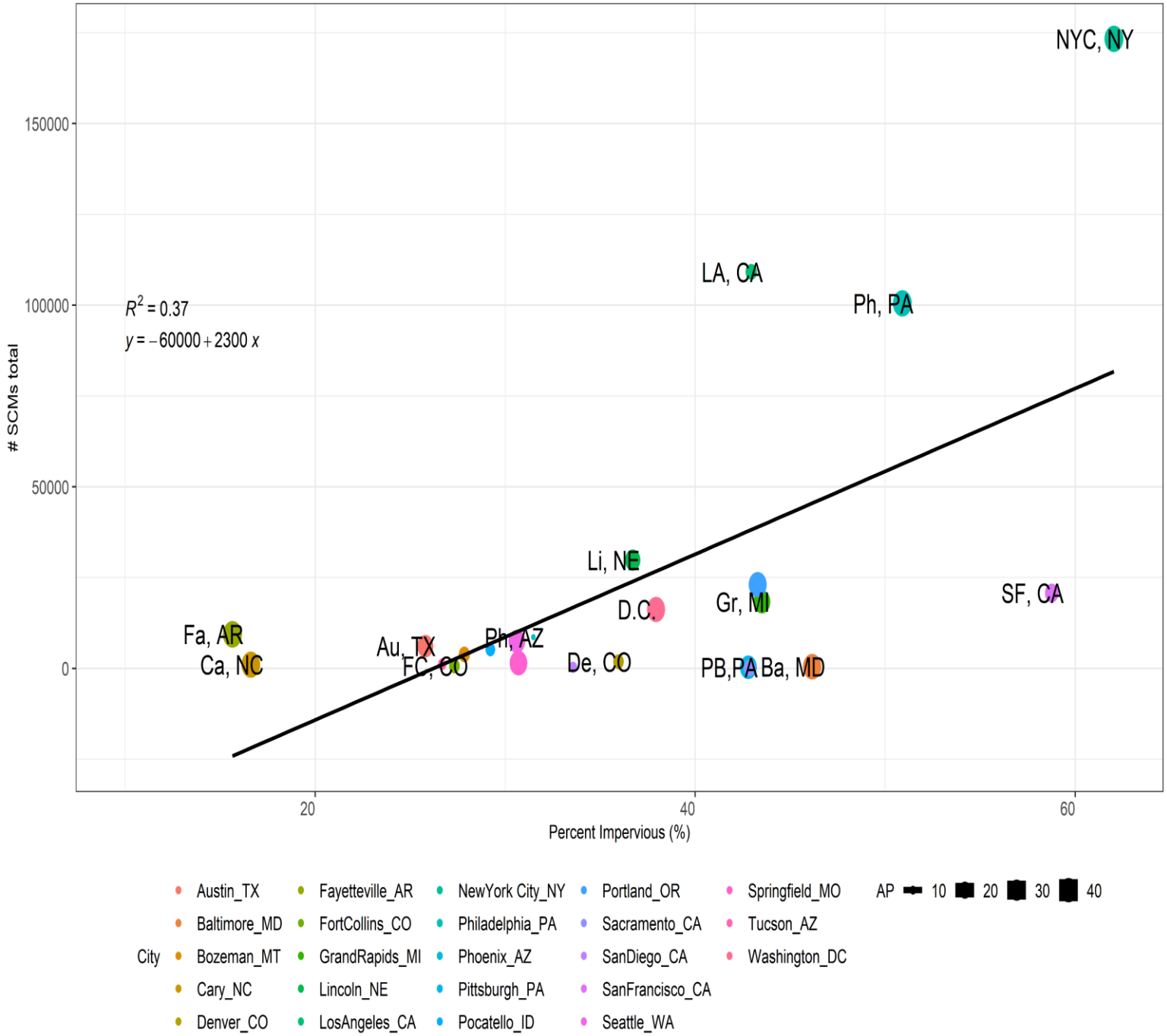
Breakdown of SCMs per total SCMs for each city



Total SCM count Vs Percent Impervious (%)



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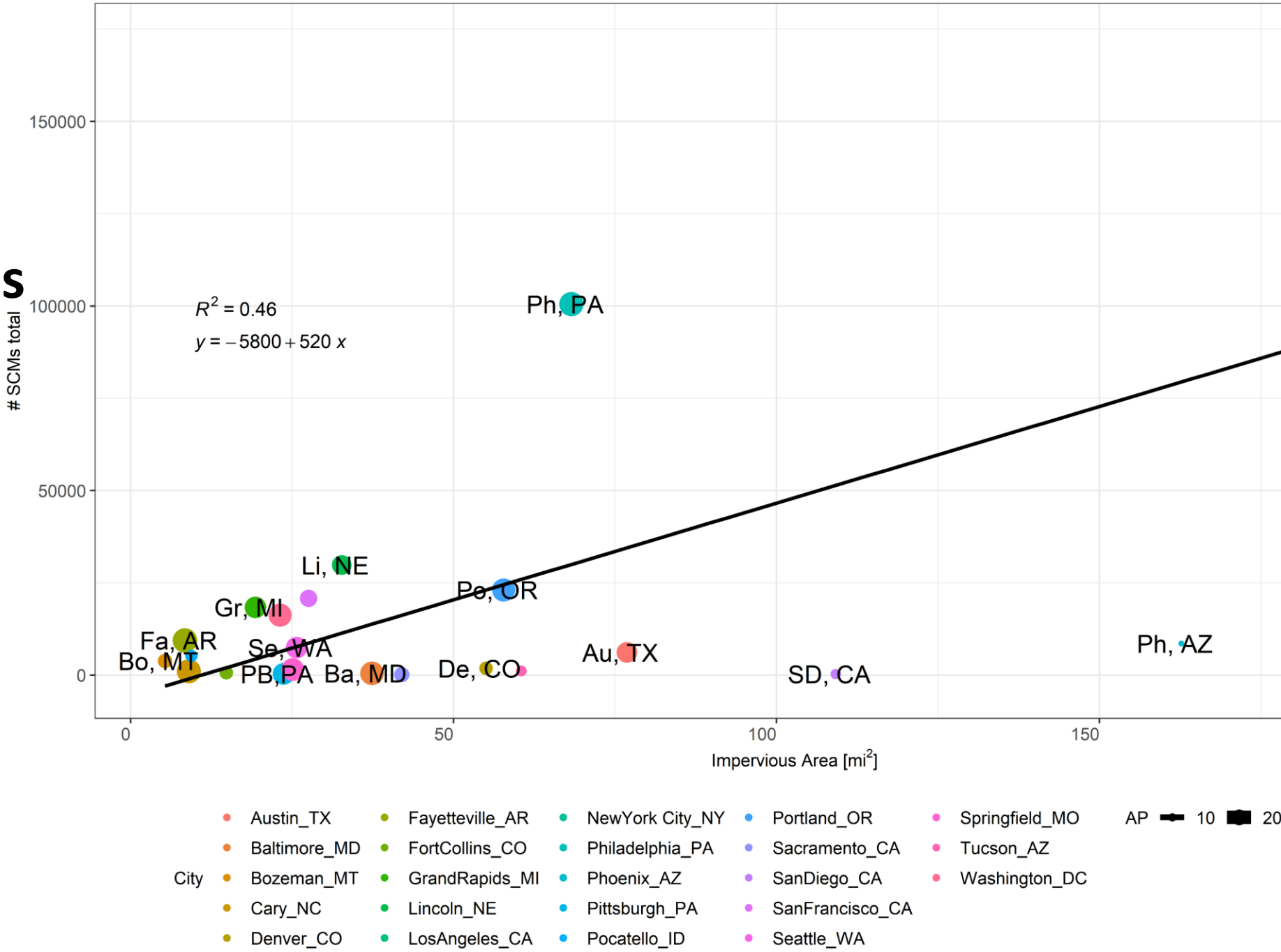
150000
100000
50000
0
SCMs total
$R^2 = 0.46$
$y = -5800 + 520\,x$
Ph, PA
Li, NE
Po, OR
Gr, MI
Fa, AR
Se, WA
Bo, MT
PB, PA
Ba, MD
De, CO
Au, TX
SD, CA
Ph, AZ
0
50
100
150
Impervious Area [mi²]
City
Austin_TX
Baltimore_MD
Bozeman_MT
Cary_NC
Denver_CO
Fayetteville_AR
FortCollins_CO
GrandRapids_MI
Lincoln_NE
LosAngeles_CA
NewYork City_NY
Philadelphia_PA
Phoenix_AZ
Pittsburgh_PA
Pocatello_ID
Portland_OR
Sacramento_CA
SanDiego_CA
SanFrancisco_CA
Seattle_WA
Springfield_MO
Tucson_AZ
Washington_DC
AP
10
20

Breakdown of SCMs per total SCMs for each city