Can Smart Stormwater Systems Outsmart the Weather? Stormwater Capture with Real-Time Control in Southern California

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Background and Research Question

Urban runoff: an environmental threat

- Storm drain systems quickly move stormwater (a valuable water resource) away from cities to prevent flooding.
- Urban runoff carries high pollutant loads to local streams, rivers, and the coastal ocean.
- Here we examine how **smart and green** stormwater infrastructure might be used to improve capture, retention and fit-for-purpose use of stormwater runoff in urban settings.

Green Stormwater Infrastructure

- Bioswales, biofilters, rain gardens, green roofs, etc. are an alternative to conventional piped storm drain systems.
- Main environmental goals are the reduction of stormwater velocity, stormwater volume, and stormwater pollutant loads released to the environment.
- These systems may also provide a new (and in many water scare areas much needed) water resource for human use

Overarching design challenge for stormwater management: Variable performance

Stormwater Runoff Variability
- Pollutant concentrations
- Timing and duration of storms
- Antecedent dry period
- Transient flow

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- Filter media
- Media amendments
- Submerged zone
- Invertebrate community
- Microbiome
- Age
- Maintenance
- Size

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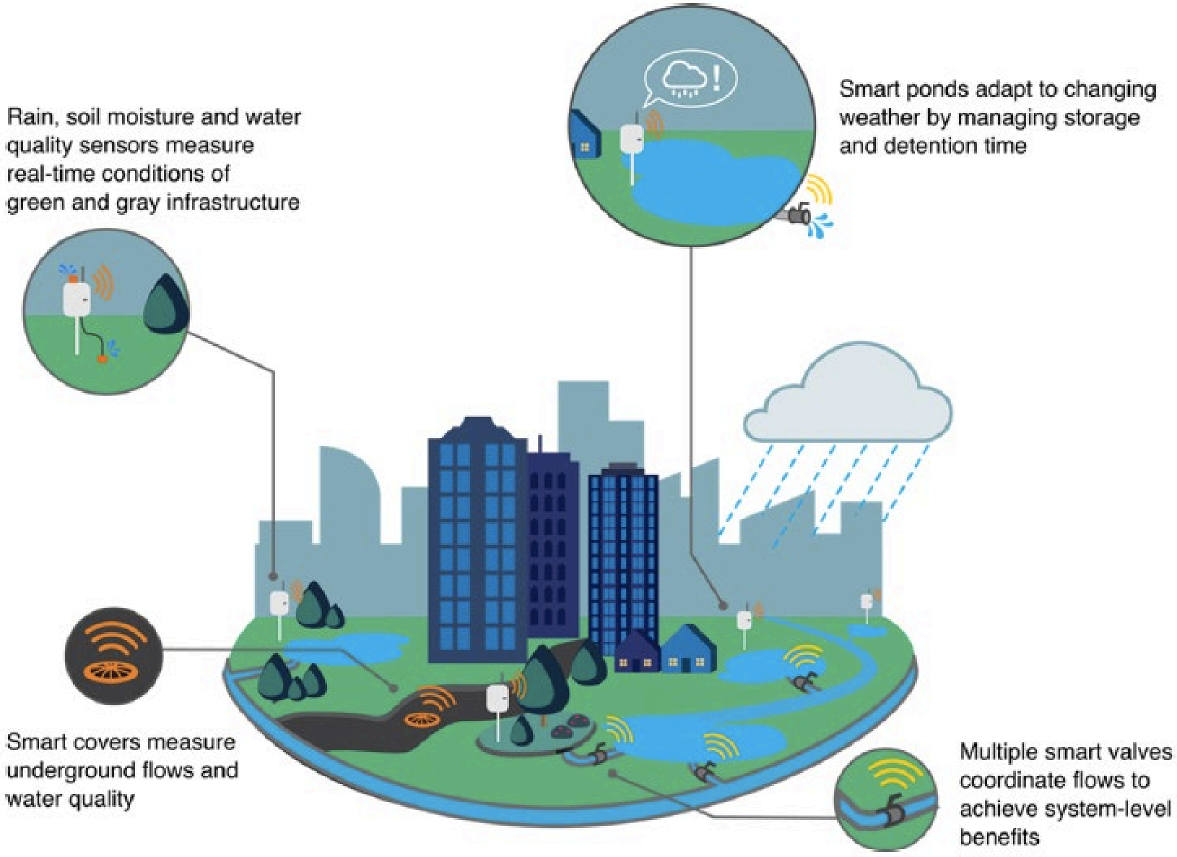
Smart Stormwater (Real-Time Control)



Kerkez, B.; Gruden, C.; Lewis, M.; Montestruque, L.; Quigley, M.; Wong, B.; Bedig, A.; Kertesz, R.; Braun, T.; Cadwalader, O.; Poresky, A.; Pak, C. Smarter Stormwater Systems. *Environ. Sci. Technol*. **2016,** *50* (14), 7267-7273.

Research question

What are the best-case limits of stormwater capture with real-time control (RTC) on a university campus, and how do these benefits depend on the total rainfall each year and the region's seasonal patterns of precipitation?

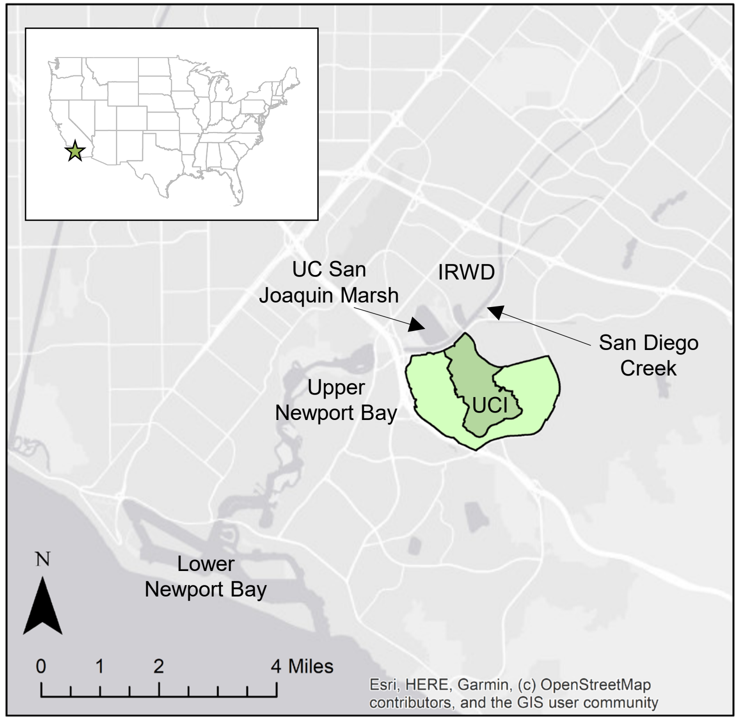
Hypothesis

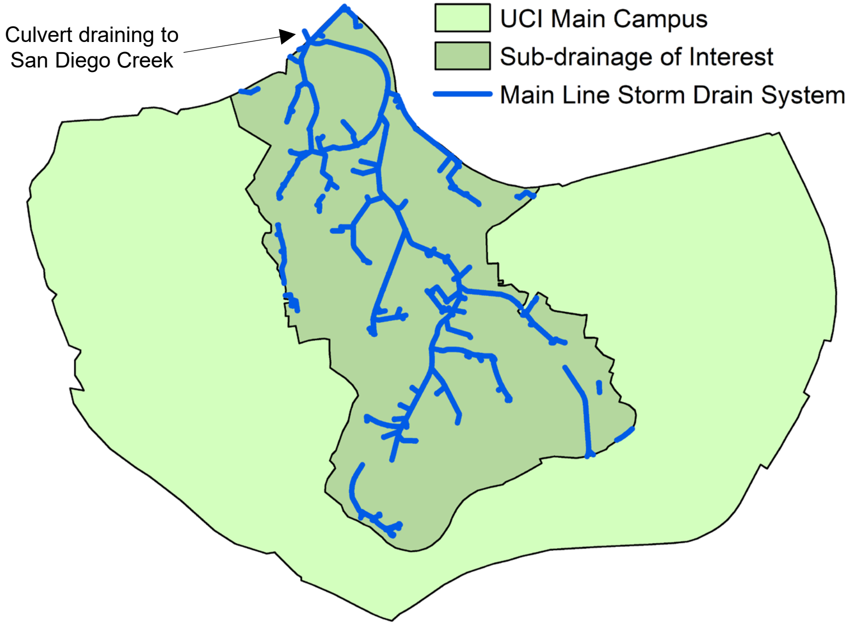
Benefits achieved will depend on rainfall seasonality ("unevenness") and the total annual rainfall in a given year (dry, median, or wet year)

Novelty

We describe the benefits of a campus-scale stormwater capture system (storage volume 10^4 m^3) intermediate in size between the more frequently studied household-to-neighborhood scale systems (1-50 m^3) and large-scale managed aquifer recharge systems (>10^7 m^3)

Field Site


UC San
Joaquin Marsh
IRWD
San Diego
Creek
Upper
Newport Bay
UCI
Lower
Newport Bay
N
0 1 2 4 Miles
Esri, HERE, Garmin, (c) OpenStreetMap
contributors, and the GIS user community


Culvert draining to
San Diego Creek
UCI Main Campus
Sub-drainage of Interest
Main Line Storm Drain System

Aerial view of UC Irvine and Newport Bay

Aerial view of the box culvert and proposed stormwater retention tank location

proposed underground tank location for stormwater capture

existing box stormwater culvert

Research Approach

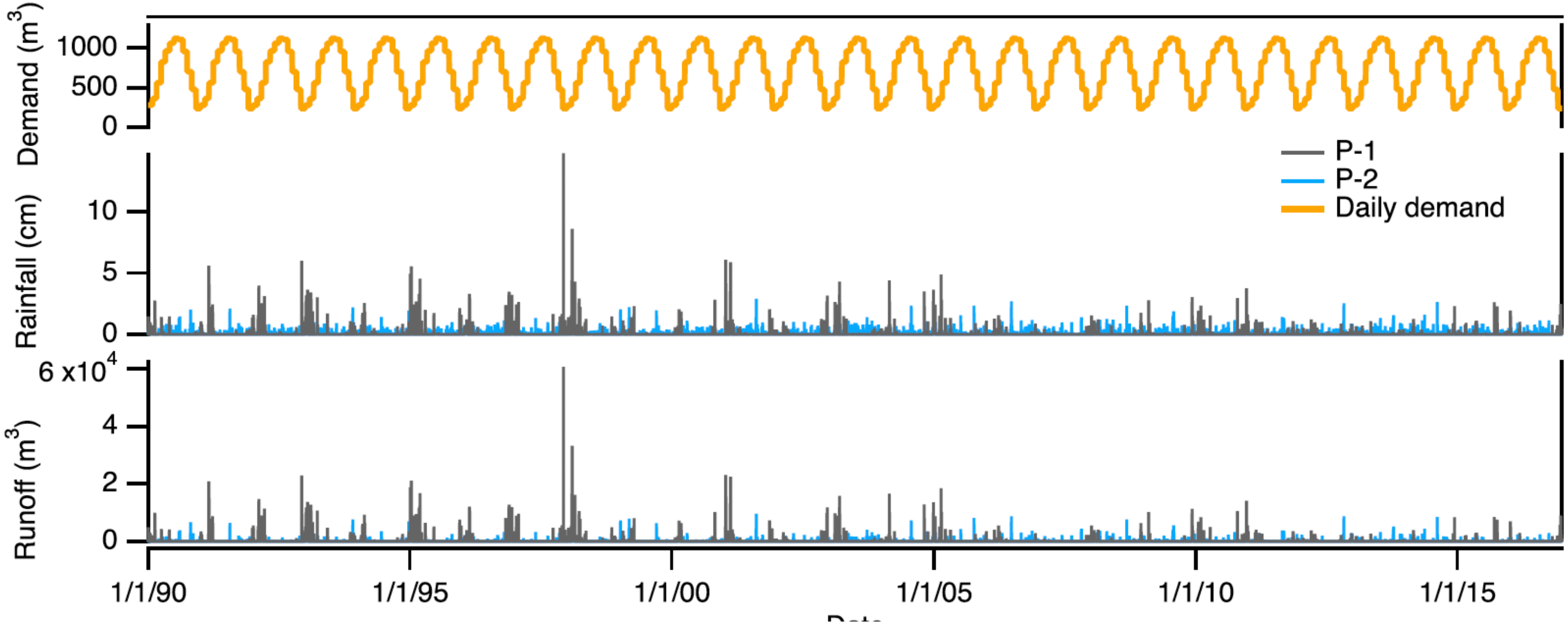
Joint probability distributions were derived to to evaluate tank performance under different:

- Annual rainfall conditions (dry, median, or wet years)
- Rainfall evenness (seasonal versus year-round rainfall)
- Choice of Real Time Control (RTC) ontology
    - no knowledge of future rainfall
    - perfect knowledge of rainfall 1 day in advance
    - perfect knowledge of rainfall 2 days in advance

Hydrus 1D runoff simulations

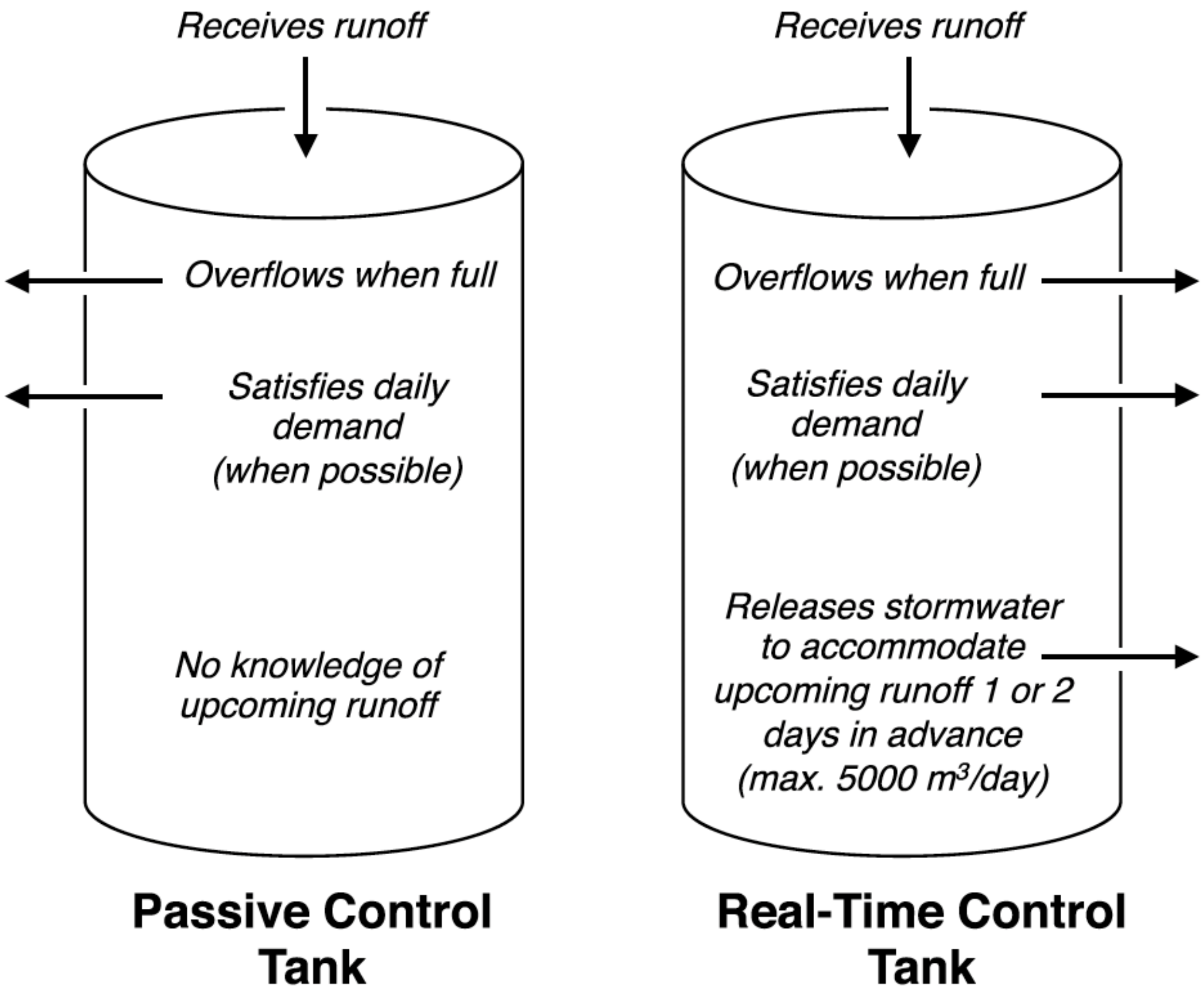
- Daily volume of runoff generated by the campus was estimated with a field-calibrated stochastic hydrologic framework implemented in Hydrus 1D
- 100,000 realizations of daily runoff volume from the campus were stochastically generated
- 27-years of daily runoff simulations were repeated 10 times. For each simulation:
  - probability distributions of soil texture and depth to groundwater were randomly sampled
  - rainfall timeseries was perturbed by a multiplier drawn randomly from a uniform distribution ranging from 0.8 to 1.2

Demand and rainfall timeseries



- **Seasonal demand:** intended to simulate the water demand needed to irrigate a nearby wetland
- **P1: seasonal rainfall** (actual precipitation measured in Southern California)
- **P2: even rainfall** (Washington DC with annual average rainfall adjusted to match Southern California)

Tank Ontology



- **"Dumb Tank"** has no knowledge of upcoming runoff
- **"Real-Time Control" Tank"** has perfect knowledge of runoff either 1 or 2 days in advance

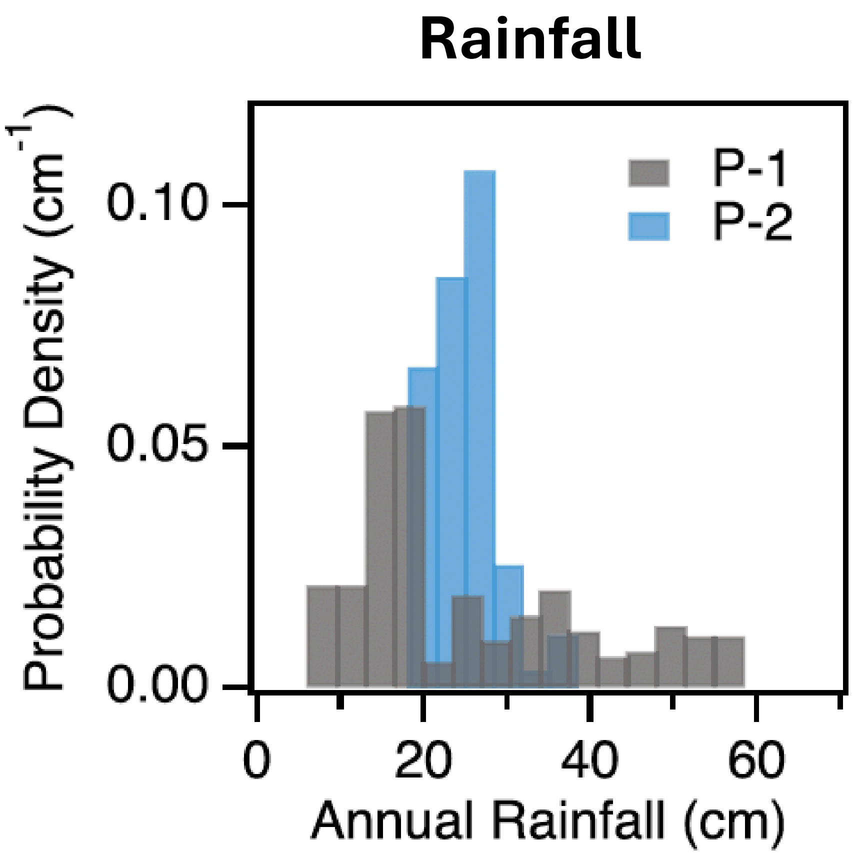
Tank performance was evaluated based on…

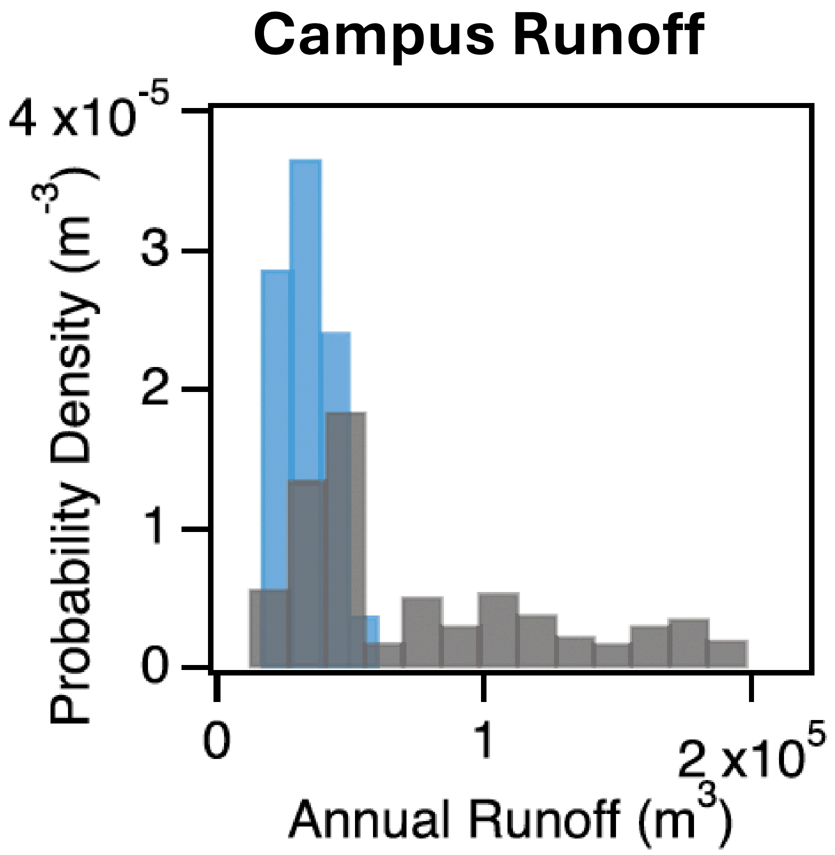
- **Water Supply Benefit**: fraction of annual demand satisfied by the tank under various tank ontologies and precipitation scenarios
- **Stormwater Retention Benefit**: fraction of annual stormwater runoff volume captured by the tank under various tank ontologies and precipitation scenarios
- **Marginal probability distributions** for the two types of benefits were generated using a copula analysis of 100,000 daily tank performance realizations (b=benefit, r=annual rain percentile)

$$f_{B|R}\left(b|r\right)=c\left[F_B\left(b\right),F_R\left(r\right)\right]f_B\left(b\right)$$

Results

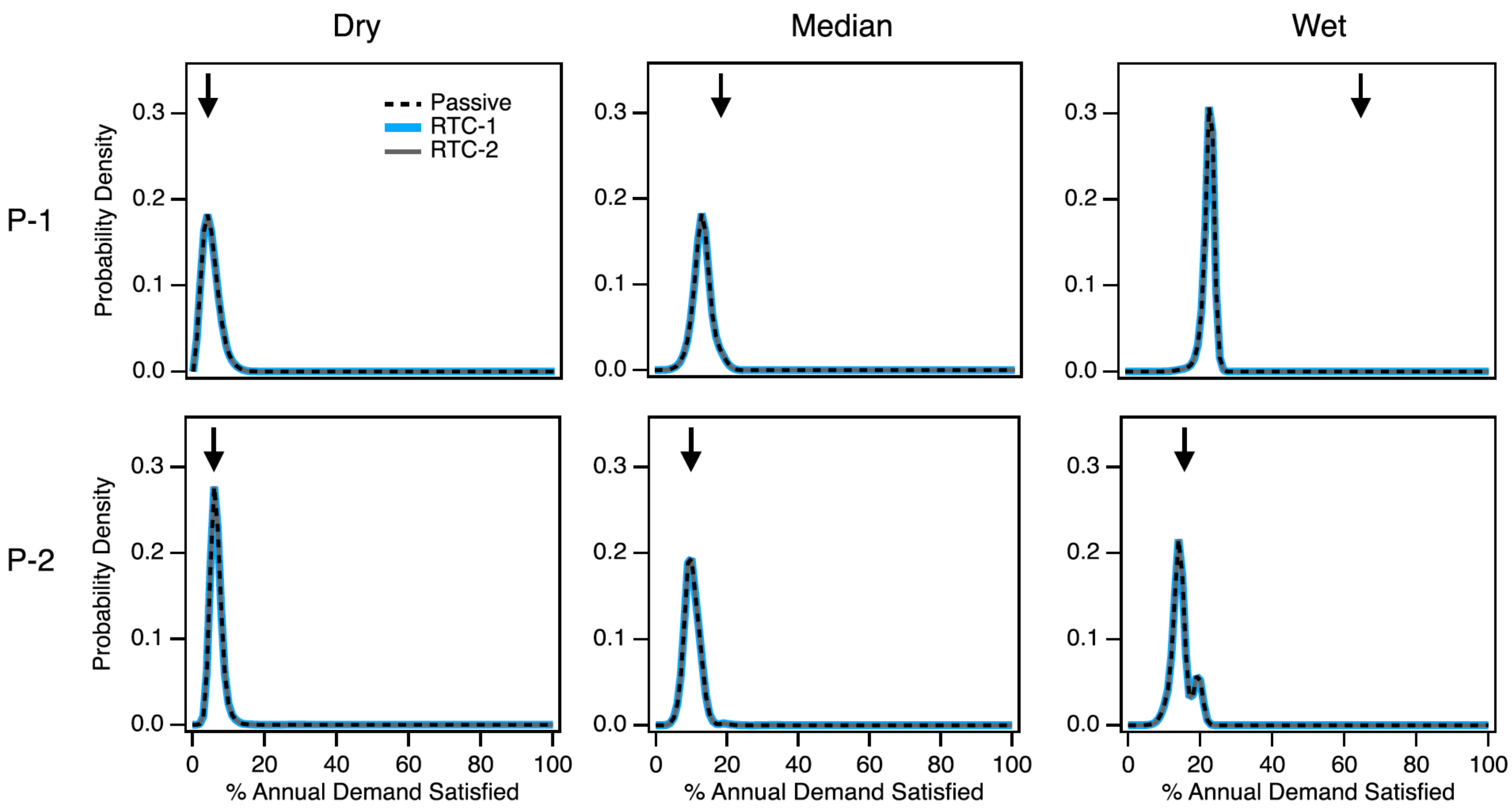
Distributions of annual rainfall and simulated annual campus stormwater runoff





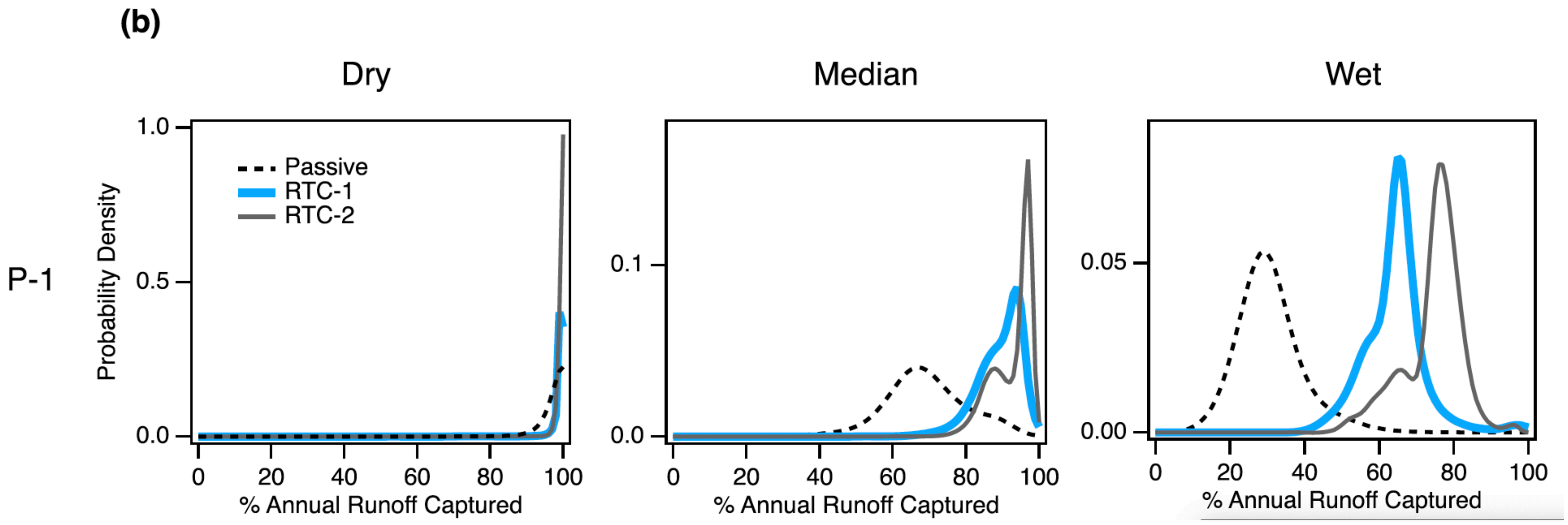
- **Annual Rainfall** is more variable under P1 (actual) compared to P2 (counterfactual). By design the annual average of the two rainfall distributions are equal.
- **Annual Runoff** is similarly distributed under P1 & P2, but the annual average campus runoff is greater under P1 compared to P2

Annual wetland irrigation demand satisfied



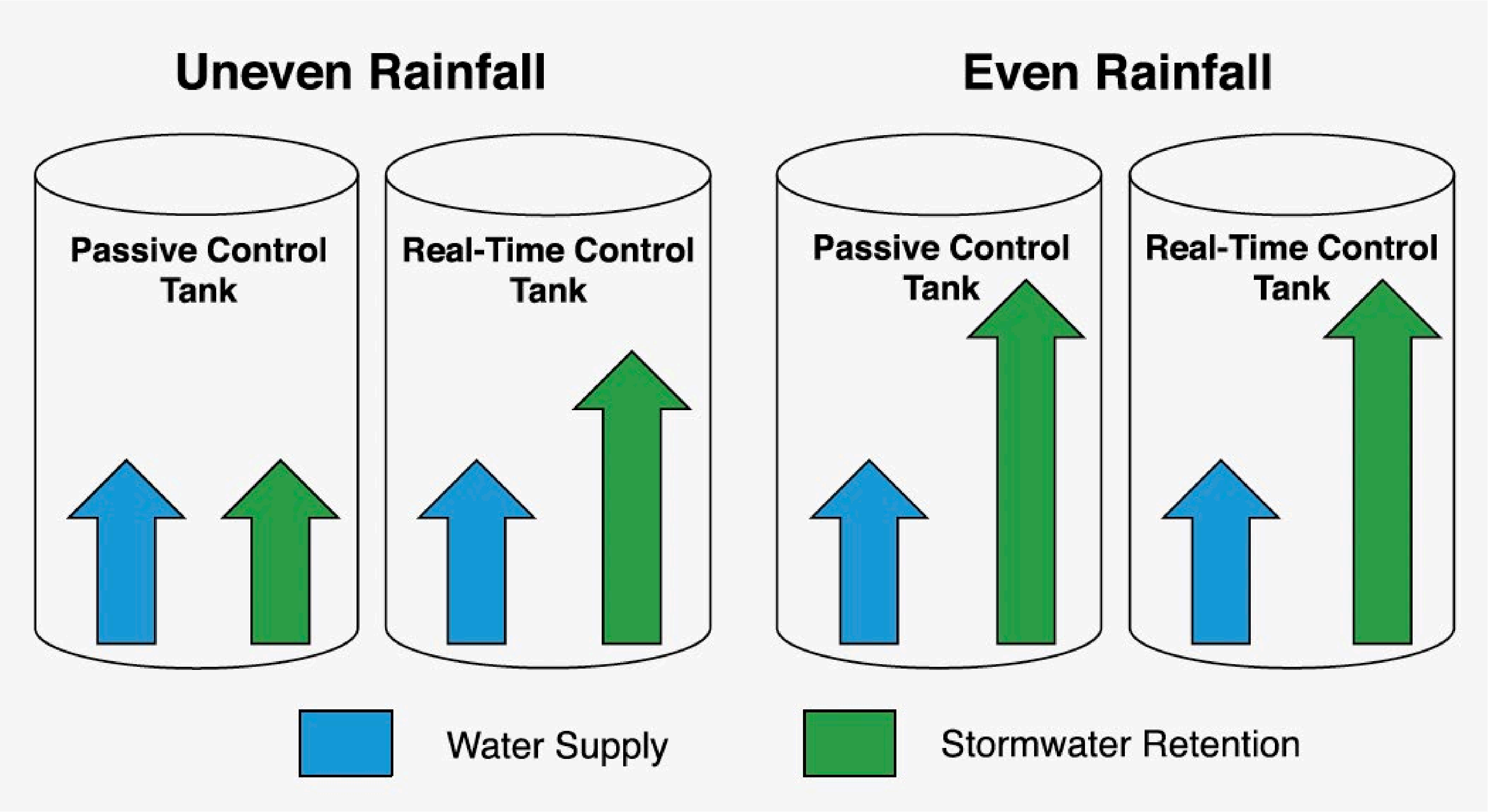
- **10 to 20% of irrigation demand** is satisfied by the tank
- **More irrigation demand** is satisfied during wet years (black arrows are theoretical maximum)
- **More water is spilled** under P1 compared to P2
- **Tank ontology** (smart or dumb tank) does not influence the demand satisfied (compare dashed, blue and black lines)

Annual stormwater retention benefit



- **100% of stormwater captured** under P2 (because runoff events are small)
- **Stormwater benefit under P1** depends on annual rainfall and tank ontology
- **During dry years,** 100% of runoff is captured
- **During wet years,** retention benefits increase: Passive < RTC (1-day) < RTC (2-day)

Conclusions



Conclusions

- RTC does not improve water supply benefits under any of the scenarios evaluated
- Water supply benefits depend on whether rainfall is seasonally or evenly distributed throughout the year:
  - **Seasonally distributed (P1)**: Water supply benefits can fall substantially below the theoretical limit, especially during wet years
  - **Evenly distributed (P2)**: Water supply benefits closely approximate theoretical upper limits
- Under seasonally variable rainfall (P1), RTC substantially increases stormwater retention benefits
- Under evenly distributed rainfall (P2), nearly all campus runoff is captured by the dumb tank, and so RTC confers no additional benefits
- Many of the limitations identified here can be addressed by including stormwater capture as part of a distributed network of stormwater solutions

Thank you!

Questions?