# A Nature-Based Solutions Planning Framework for Urban Flood Mitigation at Catchment-Scale

Wenhui Wu, Behzad Jamali, Kefeng Zhang, Ana Deletic

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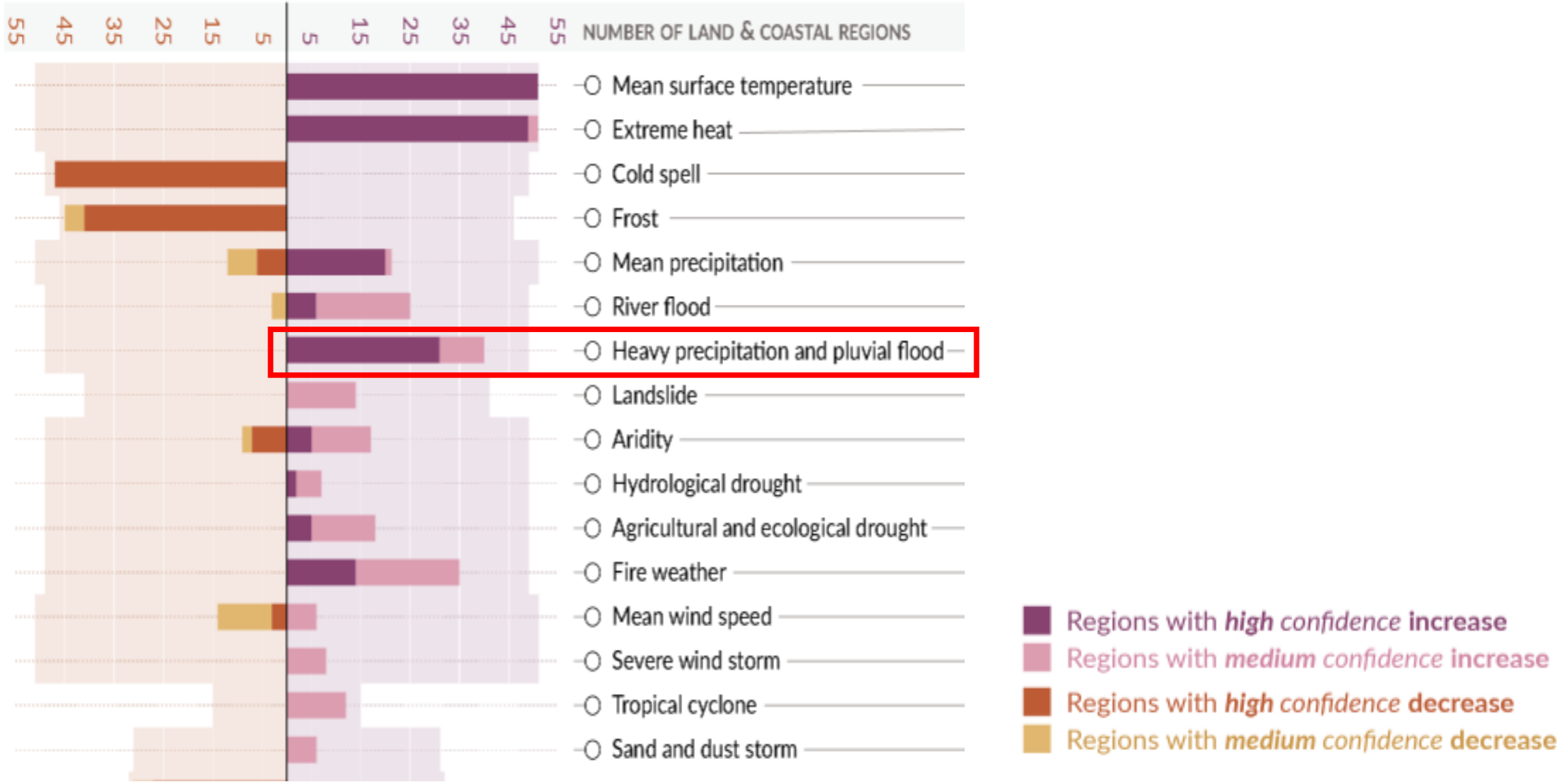
# A Nature-Based Solutions (NBS) Planning Framework for Urban Pluvial Flood Mitigation at Catchment-Scale

## Un dispositif pour planifier des solutions basées sur la nature pour réduire les effets des inondations urbaines à l'échelle d'un bassin versant

By Wenhui Wu, Kefeng Zhang, Behzad Jamali, Lucy Marshall and Ana Deletic

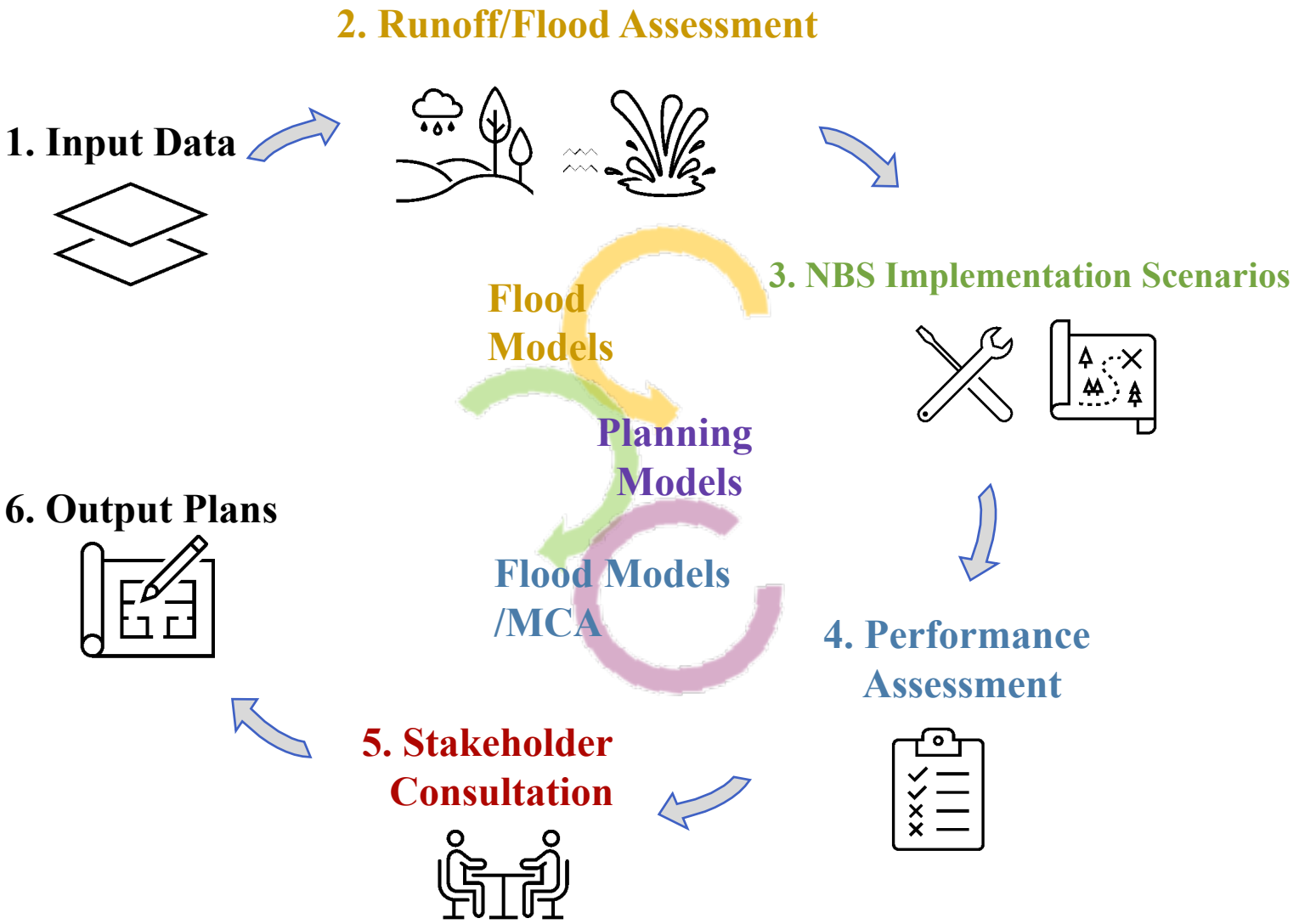
Green Technologies and Tools for Urban Water Management
WaterGUM

# Pluvial Flooding: A Growing Challenge




(Source: IPCC, 2021)

# NBS for Pluvial Flood Mitigation




## Trends

- Place NBS where feasible
- High computational demand in detailed flood modelling
- Lack target-oriented planning at catchment scale

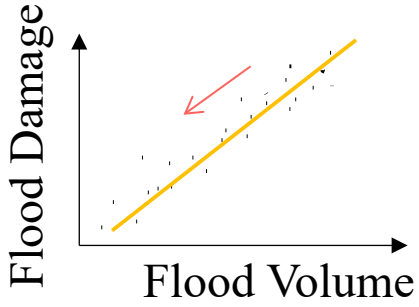
# Framework for Planning NBS to Meet Catchment Flood Mitigation Targets

1. Quantify Catchment Flood Volume vs. Flood Damage

Flood models: SWMM + CA-ffé (Rossman, 2010; Jamali et al., 2019)

2. Set Catchment Flood Damage Reduction Targets

- Targets: reduce flood damage return periods




3. Set Catchment Flood Volume Reduction Threshold

- Filter scenarios of effective impervious area reduction in priority subcatchments

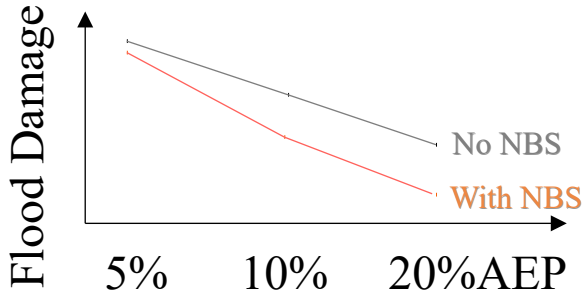
4. Set Subcatchment Runoff Volume Reduction Targets

- Calculate required % reduction in runoff volume in subcatchments

5. Select NBS Using Design Curves

- NBS sizing according to subcatchment runoff volume reduction targets

6. Check Reduction in Flood Damage



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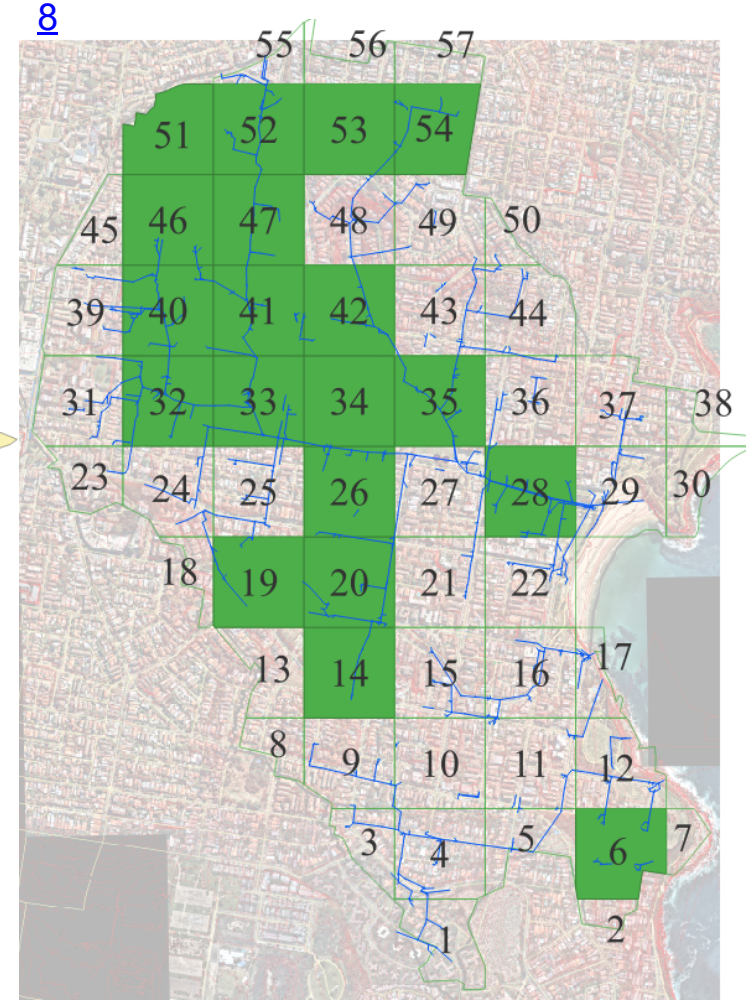
# Case Study: Coogee Catchment, Sydney, Australia

https://doi.org/10.1016/j.watres.2023.119888


Highly urbanised catchment 2.9km$^2$ in size, 5-10% Slope. Priority subcatchments for NBS implementation in Green.

(Source: Coogee Bay Flood Study Final Report - Randwick City Council, 2013)



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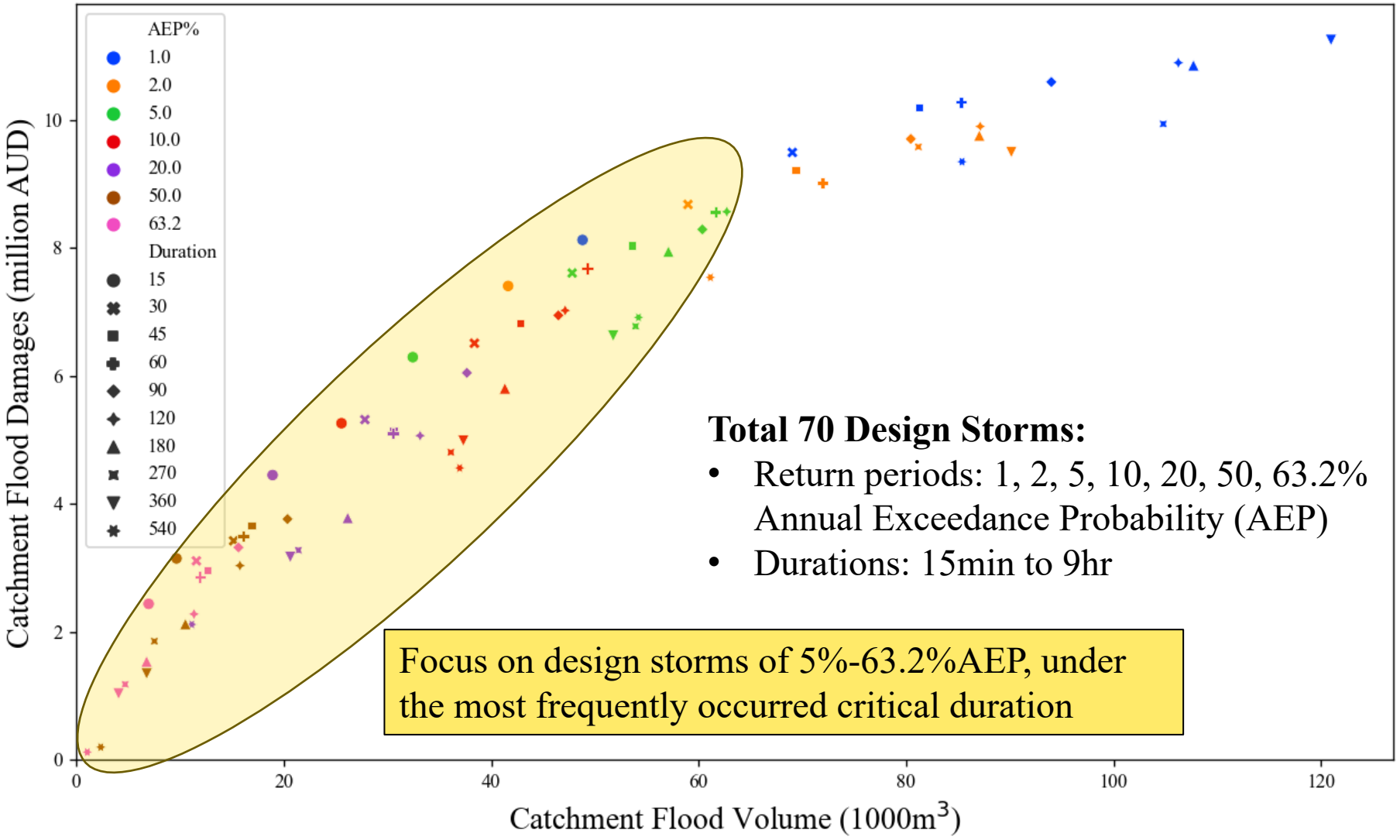
# 1. Catchment Flood Volume vs. Flood Damage




**Total 70 Design Storms:**

- Return periods: 1, 2, 5, 10, 20, 50, 63.2% Annual Exceedance Probability (AEP)
- Durations: 15min to 9hr

Focus on design storms of 5%-63.2%AEP, under the most frequently occurred critical duration



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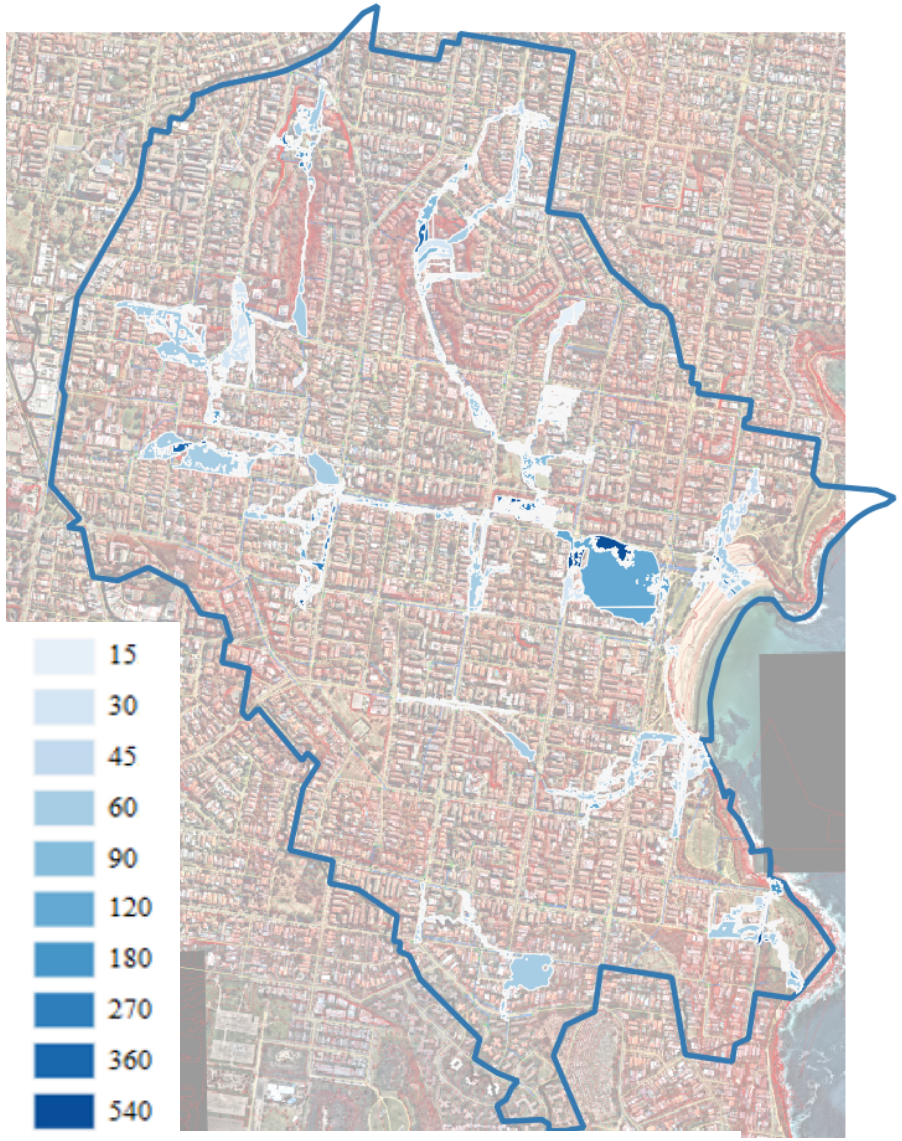
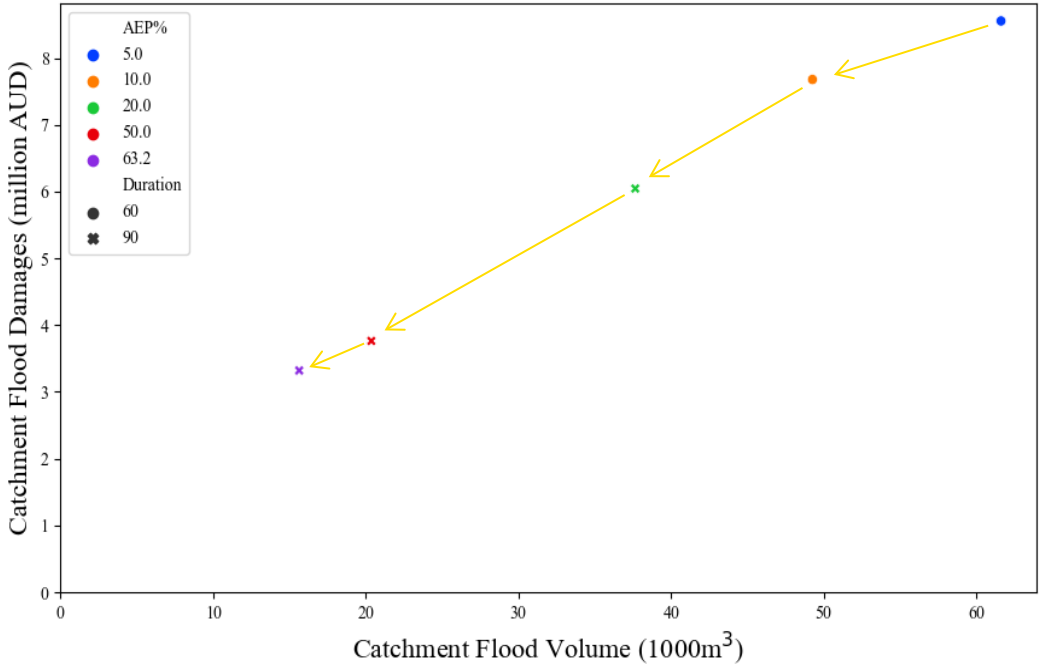
# 2. Flood Damage Reduction Targets

| Targets | Reduction in Flood Damage Return Period |
|---|---|
| 1 | 5%AEP (60min) to 10%AEP (60min) |
| 2 | 10%AEP (60min) to 20%AEP (90min) |
| 3 | 20%AEP (90min) to 50%AEP (90min) |
| 4 | 50%AEP (90min) to 63.2%AEP (90min) |




Distribution of Critical Duration (min)
Under Design Storm of 5%AEP



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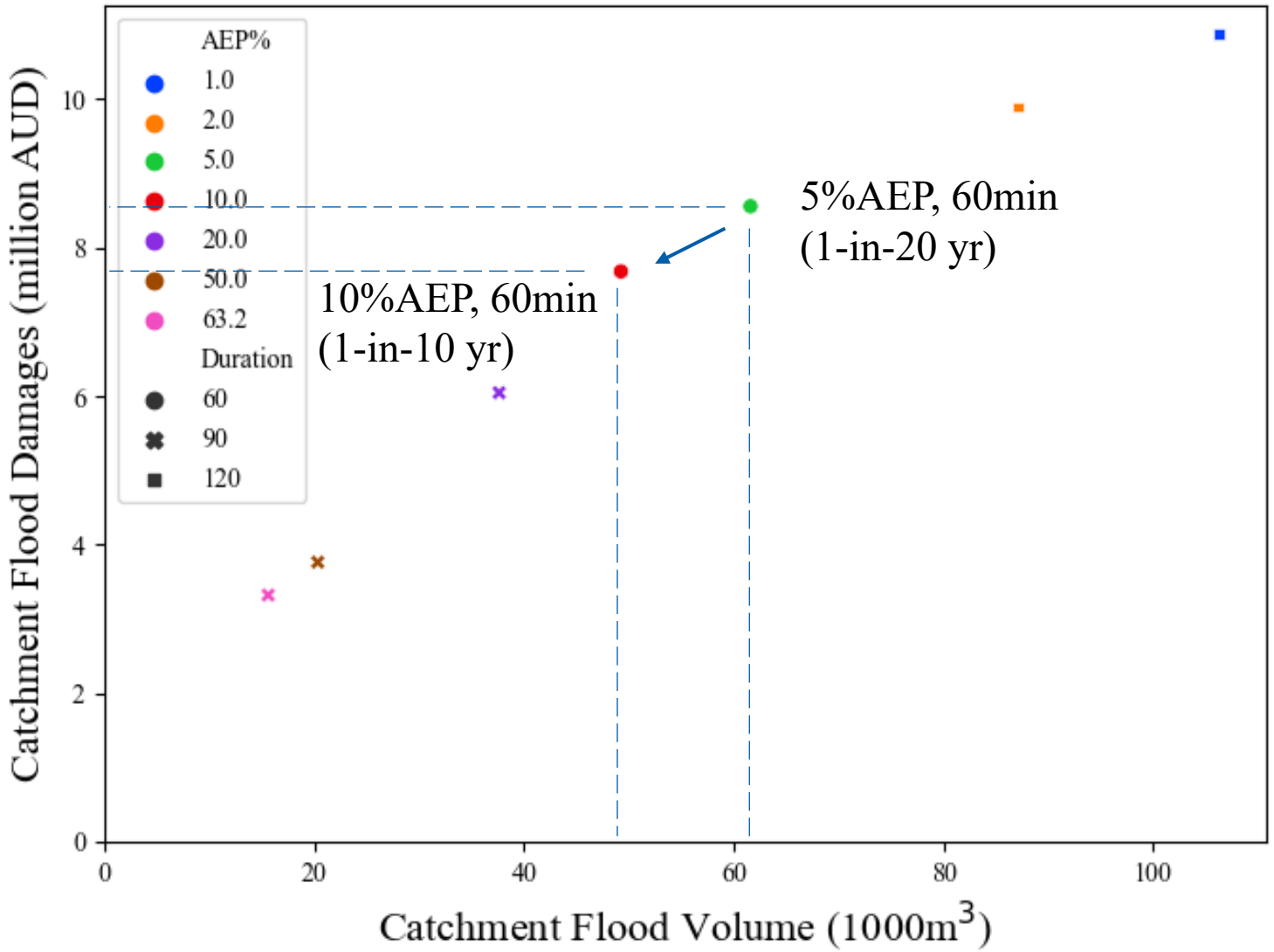
# 3. Set Catchment Flood Volume Reduction Threshold




| Flood Damage Reduction Target (million AUD) | Flood Volume Reduction Target (1000m³) |
|---|---|
| 0.88 (10.25% reduction) | 12.4 (20.05% reduction) |



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# Generate Flood Volume Reduction Scenarios under 5%AEP 60min Design Storm

- Monte Carlo: Sobol sampling sequence
- Sample 0-100% reduction in Effective Impervious Area (EIA) in each priority subcatchment

Scenario 1:
- Sub 1 – 20% EIA Reduction
- …
- Sub 19 – 40% ….

…

Scenario X:
- Sub 1 – 10% EIA Reduction
- …
- Sub 19 – 50% ….

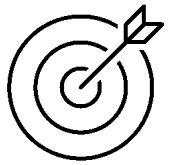
| Scenario | Reduced Flood Volume (1000m$^3$) |
|---|---|
| 1 | <12.353 |
| … | |
| X | ≥12.353 |

Total Number of Scenarios X = 10240

- Top 100 Scenarios

## 4. Set Subcatchment Runoff Volume Reduction Targets

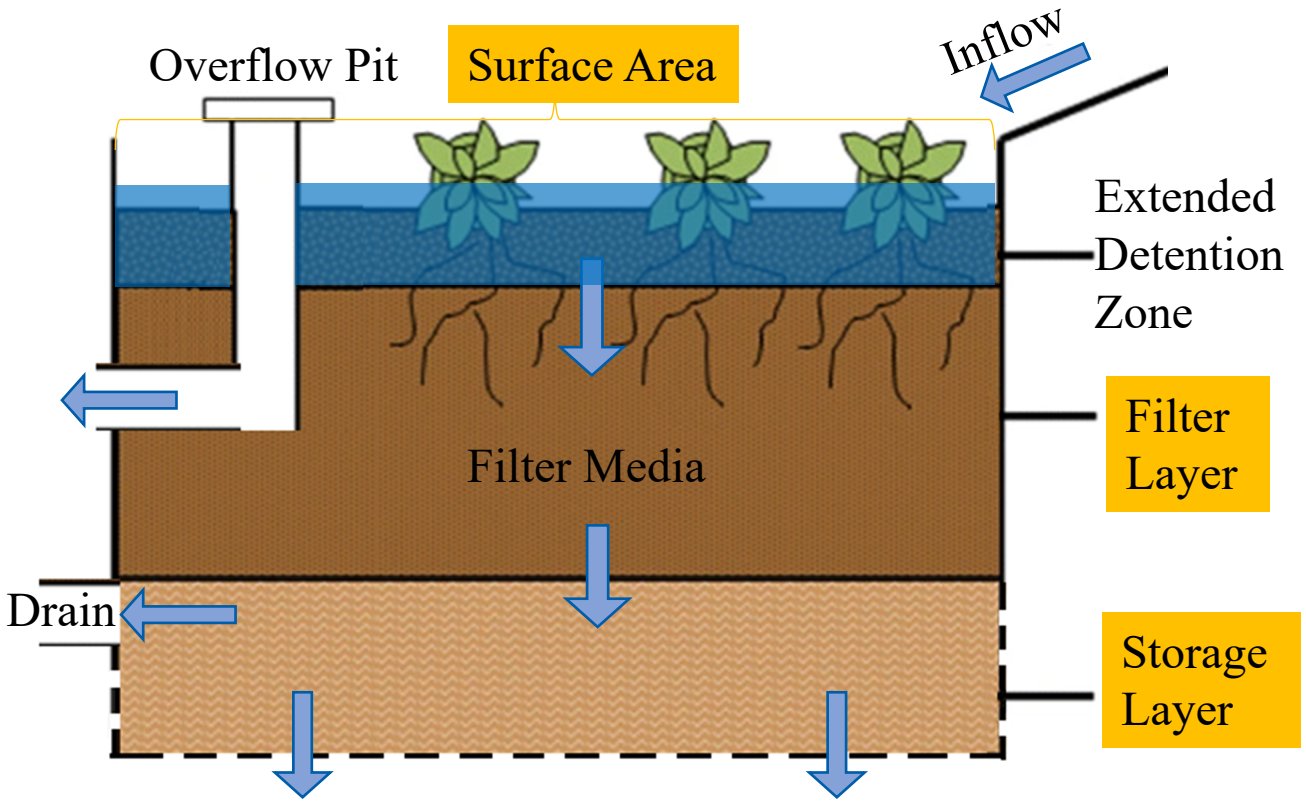
| Top 100 Scenarios | % Reduction in Subcatchment Runoff Volume | | |
|---|---|---|---|
| | Sub 1 | … | Sub 19 |
| 1 | 20 | | 40 |
| … | | | |
| 100 | | | |



# 5. Select NBS Using Design Curves

- Bioretention as an example
- Global sensitivity analysis (Sobol) on site characteristics and NBS design parameters

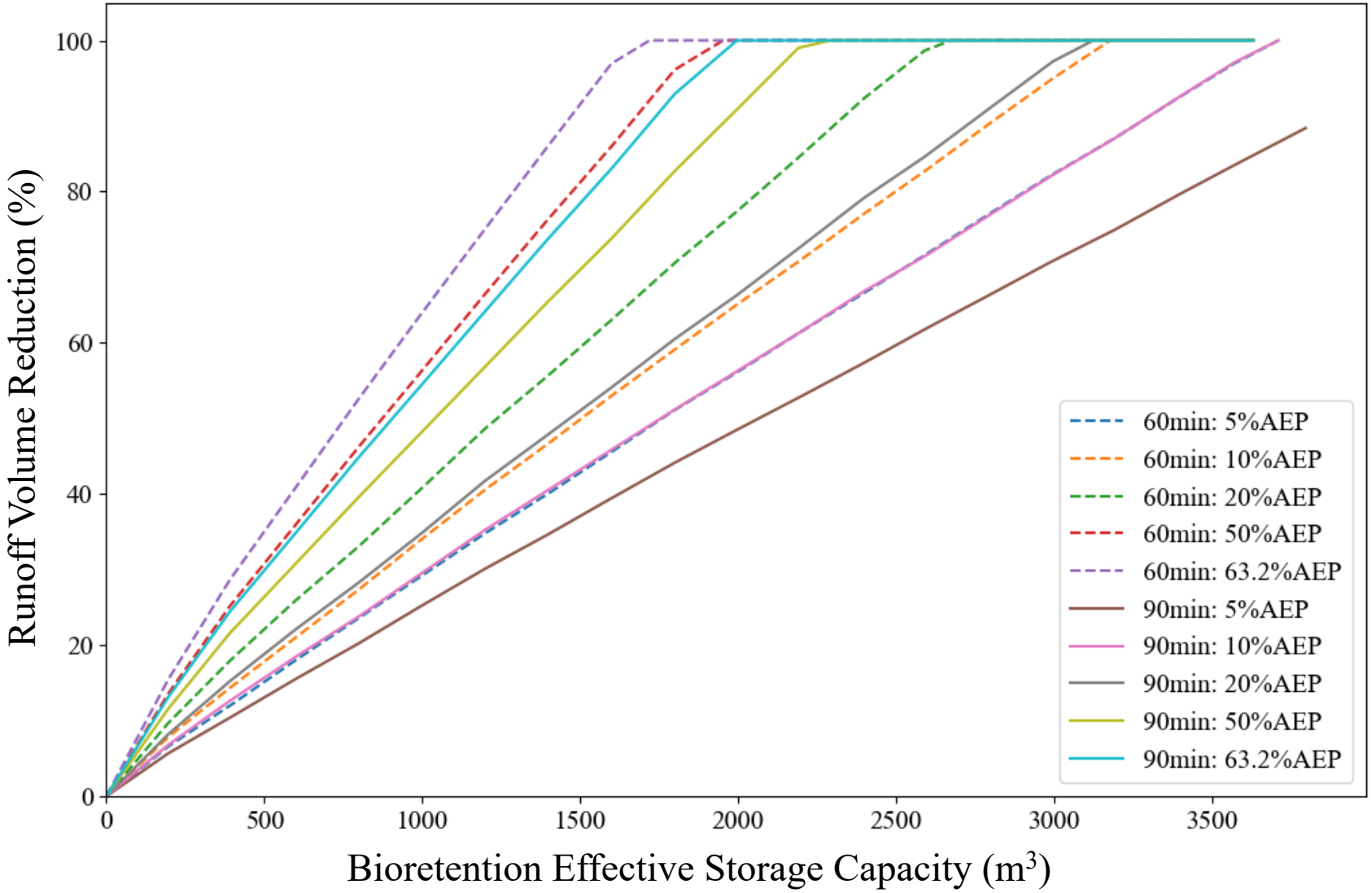
| Group | Parameters | |
|---|---|---|
| Site Characteristics | Rainfall | |
| | Subcatchment Size (100% impervious) | |
| | Subcatchment Width | |
| | Subcatchment Slope | |
| | Manning's n for impervious area | |
| | Depression storage for impervious area | |
| | Subcatchment Soil Minimum infiltration rate | |
| Bioretention Design | Effective Storage Capacity | Surface area (% of subcatchment area) |
| | | Filter layer depth |
| | | Storage layer depth |
| | Extended detention depth | |
| | Hydraulic conductivity | |




**Bioretention Structure**

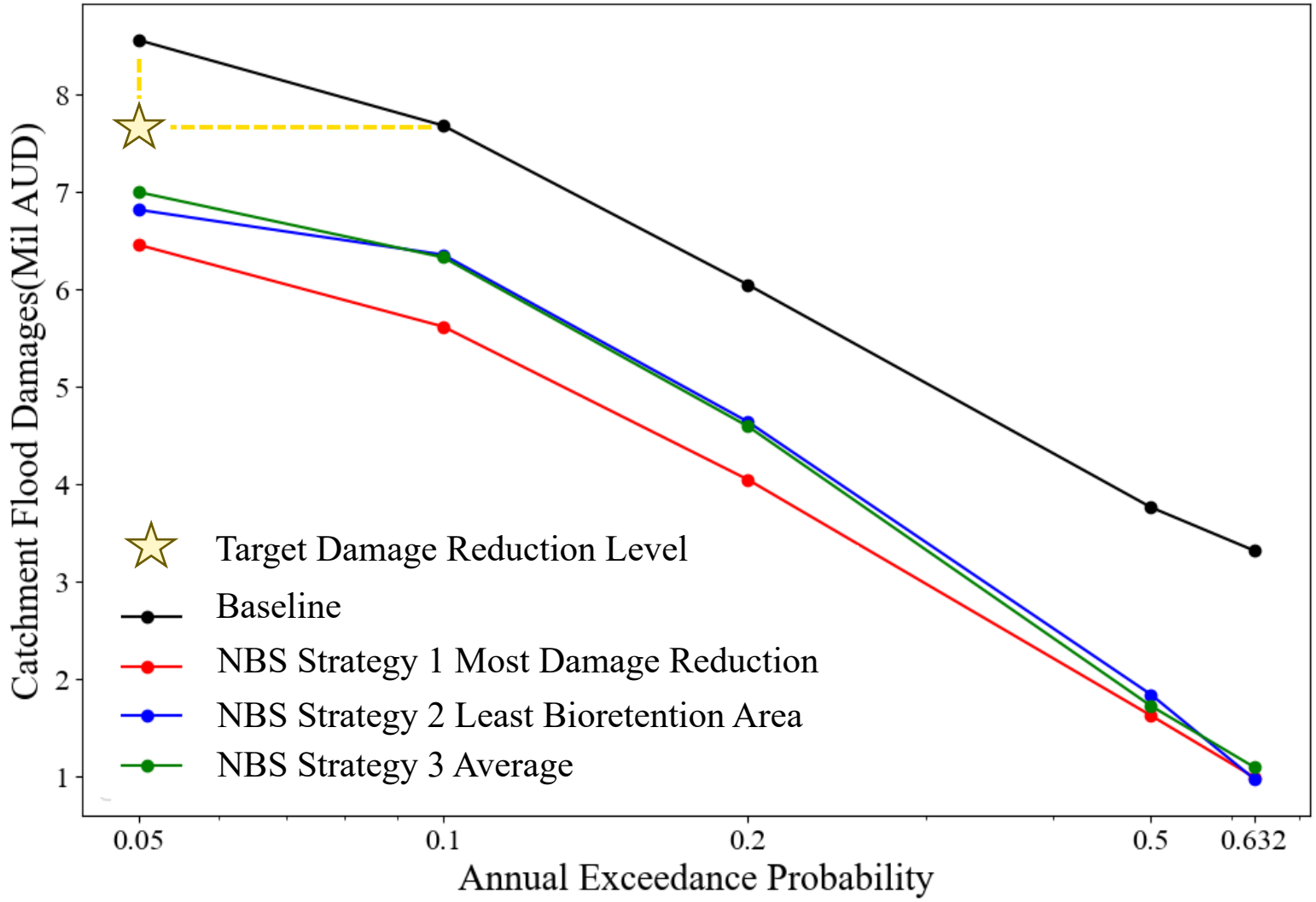
(Adopted from Goh et al., 2019)

# Representative Design Curves

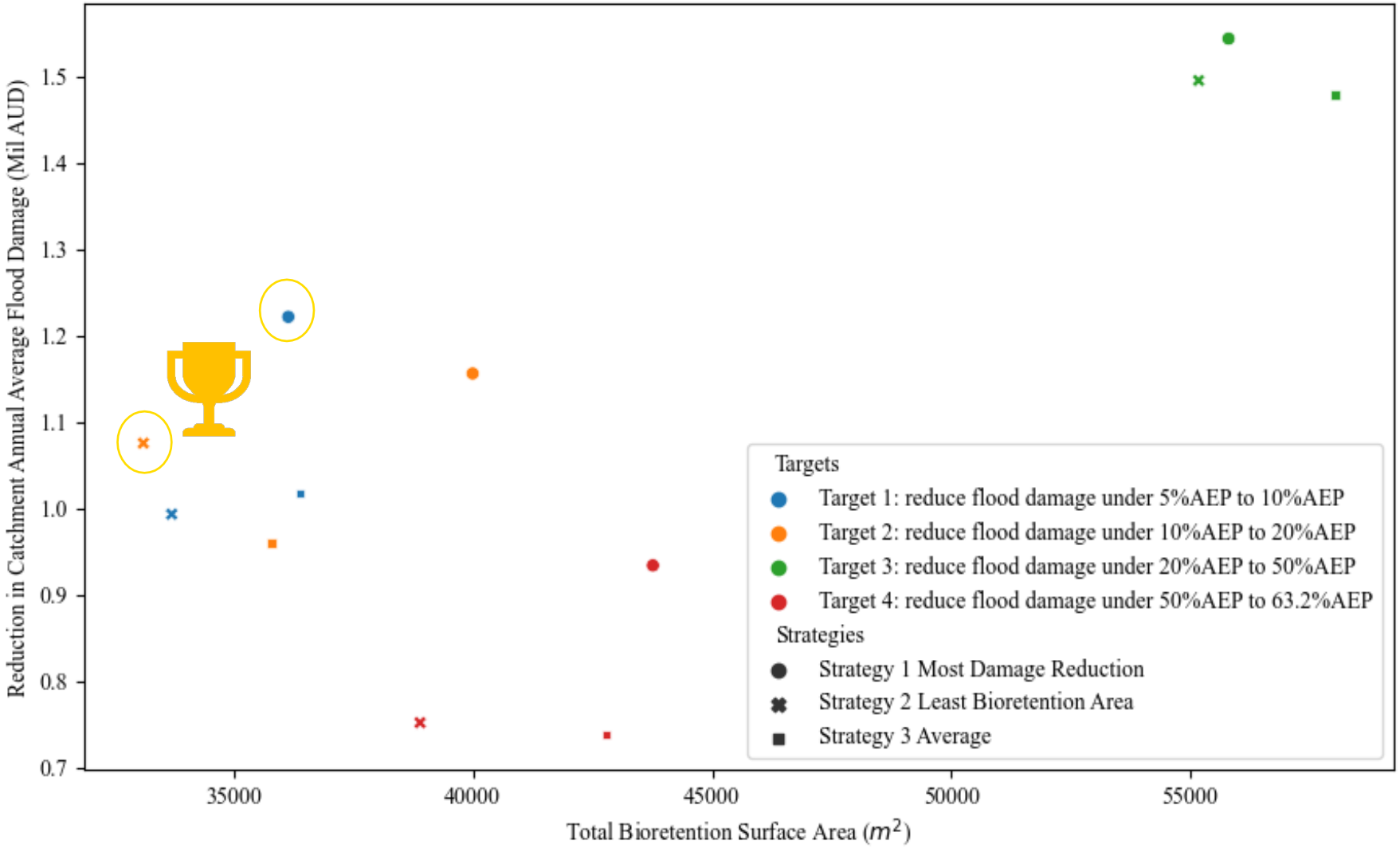


# 6. Reduction in Flood Damage

- Representative NBS strategies for Flood Damage Reduction Target 1 (5%AEP → 10%AEP)



# Cost: Bioretention Surface Area
# Benefit: Reduction in Flooding Annual Average Damage



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# Implications and Future Work

- An effective framework for selecting NBS strategies to meet catchment-scale flood damage reduction targets
- Easy to understand message: to reduce the damage level from one AEP to another
- Flexibility in choice of NBS using design curves

- ➢ Damage reduction targets are catchment-specific (importance of design storm selection)
- ➢ More comprehensive cost-benefit analysis (Life Cycle Cost)
- ➢ Need to consider long-term performance – continuous simulation using rainfall records

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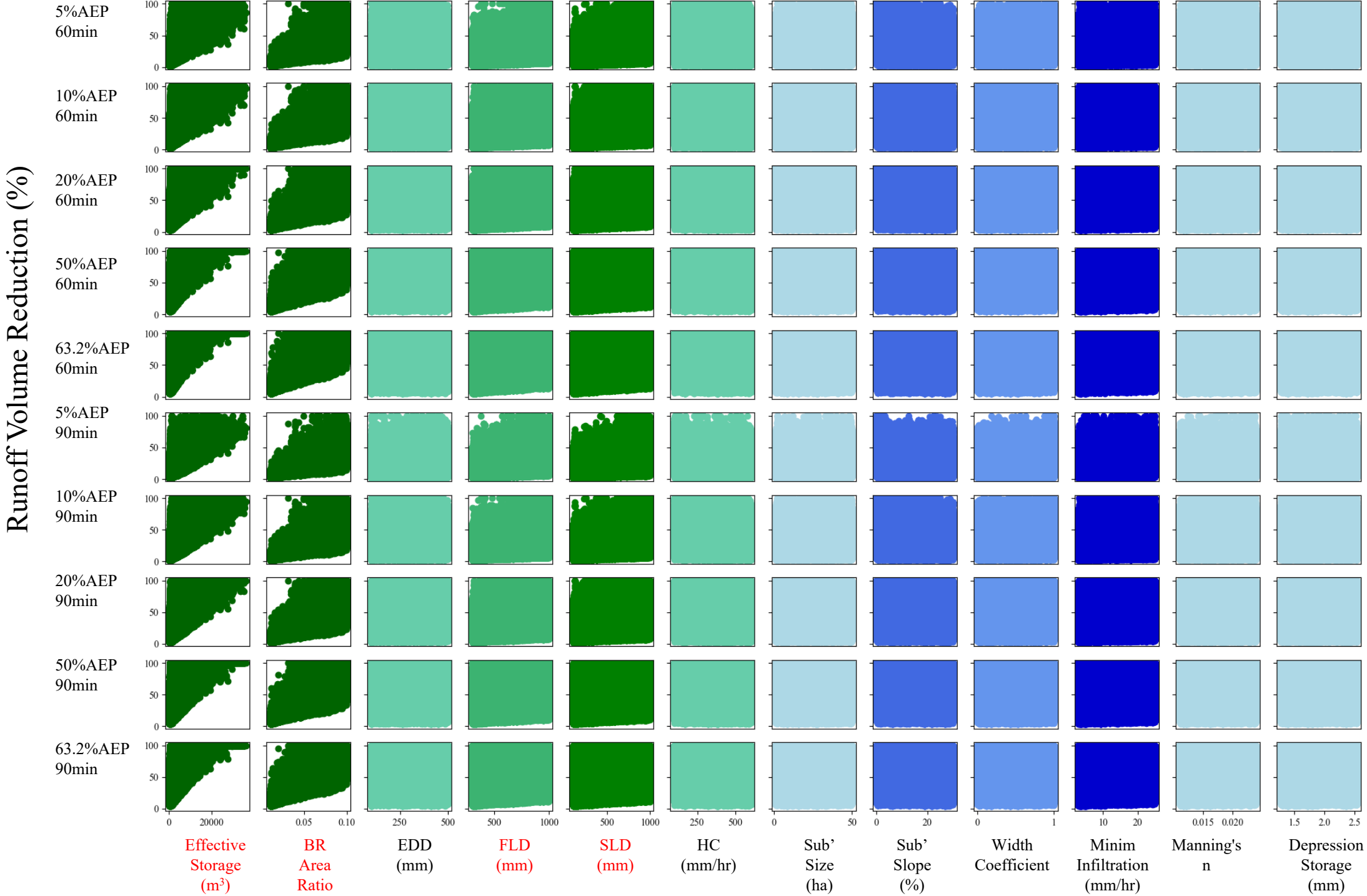
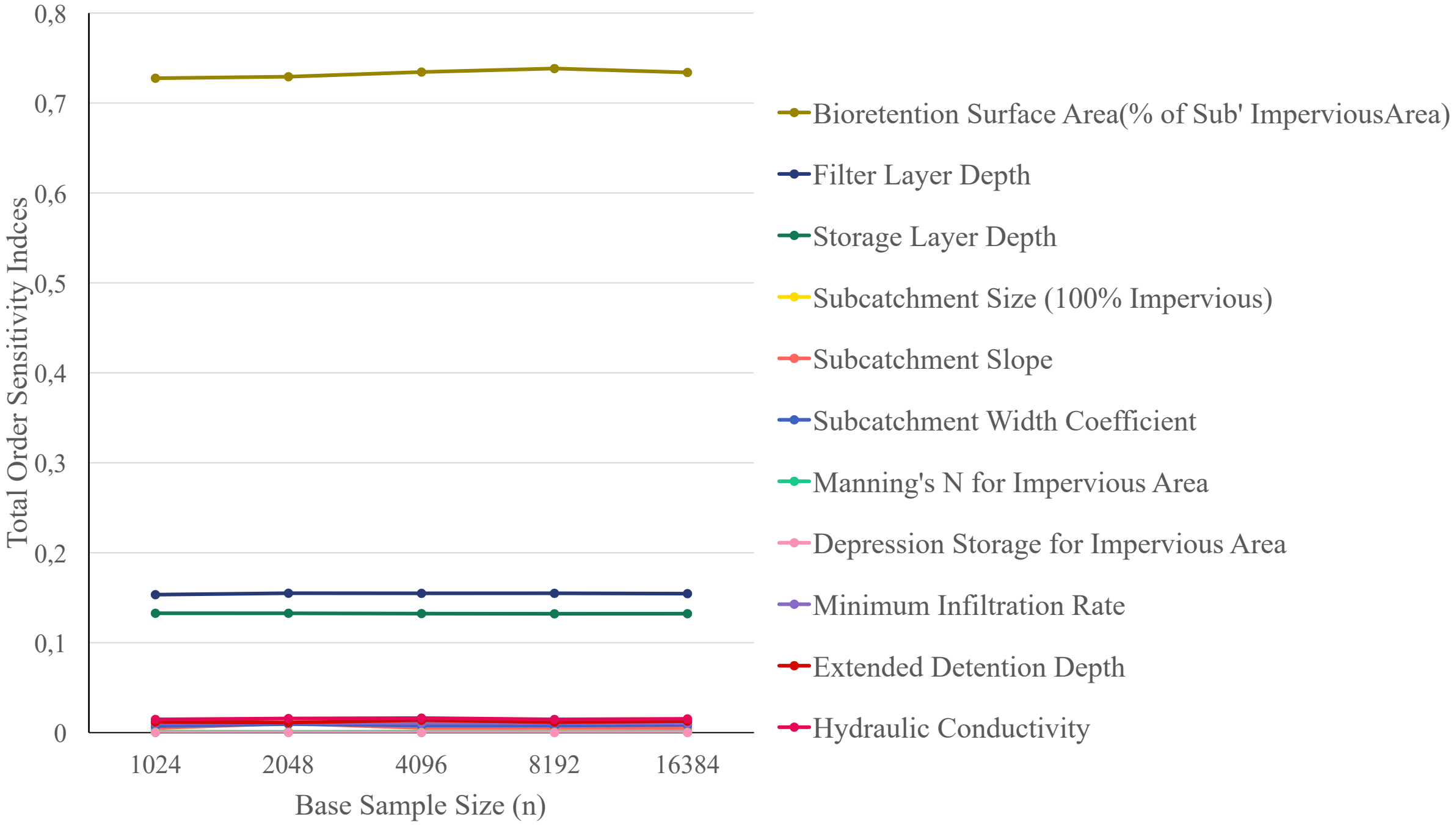
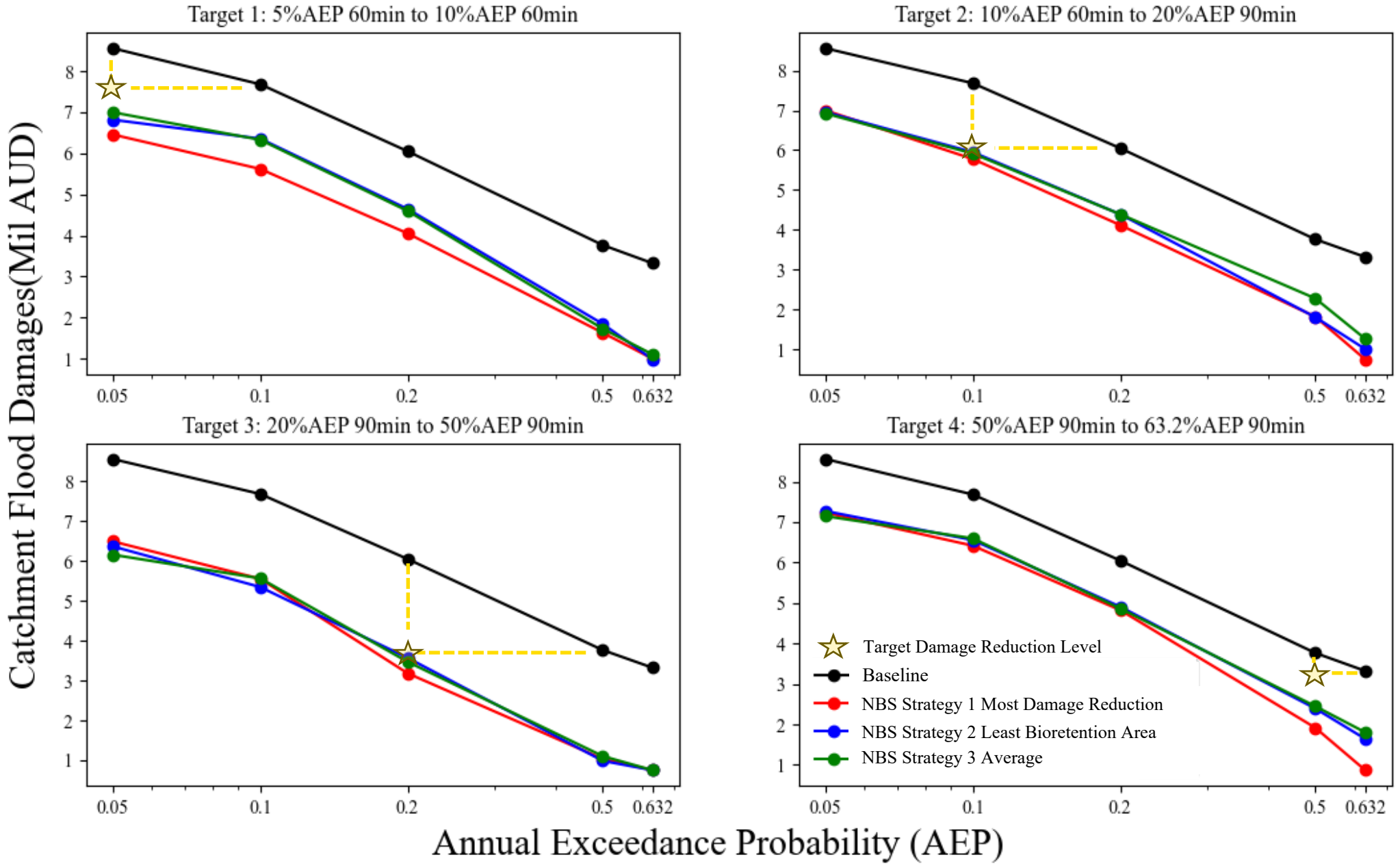
# Supplementary


Runoff Volume Reduction (%)
5%AEP 60min
10%AEP 60min
20%AEP 60min
50%AEP 60min
63.2%AEP 60min
5%AEP 90min
10%AEP 90min
20%AEP 90min
50%AEP 90min
63.2%AEP 90min
0
50
100
0
20000
0.05
0.10
250
500
500
1000
500
1000
250
500
0
50
0
20
0
1
10
20
0.015
0.020
1.5
2.0
2.5
Effective Storage (m3)
BR Area Ratio
EDD (mm)
FLD (mm)
SLD (mm)
HC (mm/hr)
Sub' Size (ha)
Sub' Slope (%)
Width Coefficient
Minim Infiltration (mm/hr)
Manning's n
Depression Storage (mm)


0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Total Order Sensitivity Indces
1024
2048
4096
8192
16384
Base Sample Size (n)
Bioretention Surface Area(% of Sub' ImperviousArea)
Filter Layer Depth
Storage Layer Depth
Subcatchment Size (100% Impervious)
Subcatchment Slope
Subcatchment Width Coefficient
Manning's N for Impervious Area
Depression Storage for Impervious Area
Minimum Infiltration Rate
Extended Detention Depth
Hydraulic Conductivity



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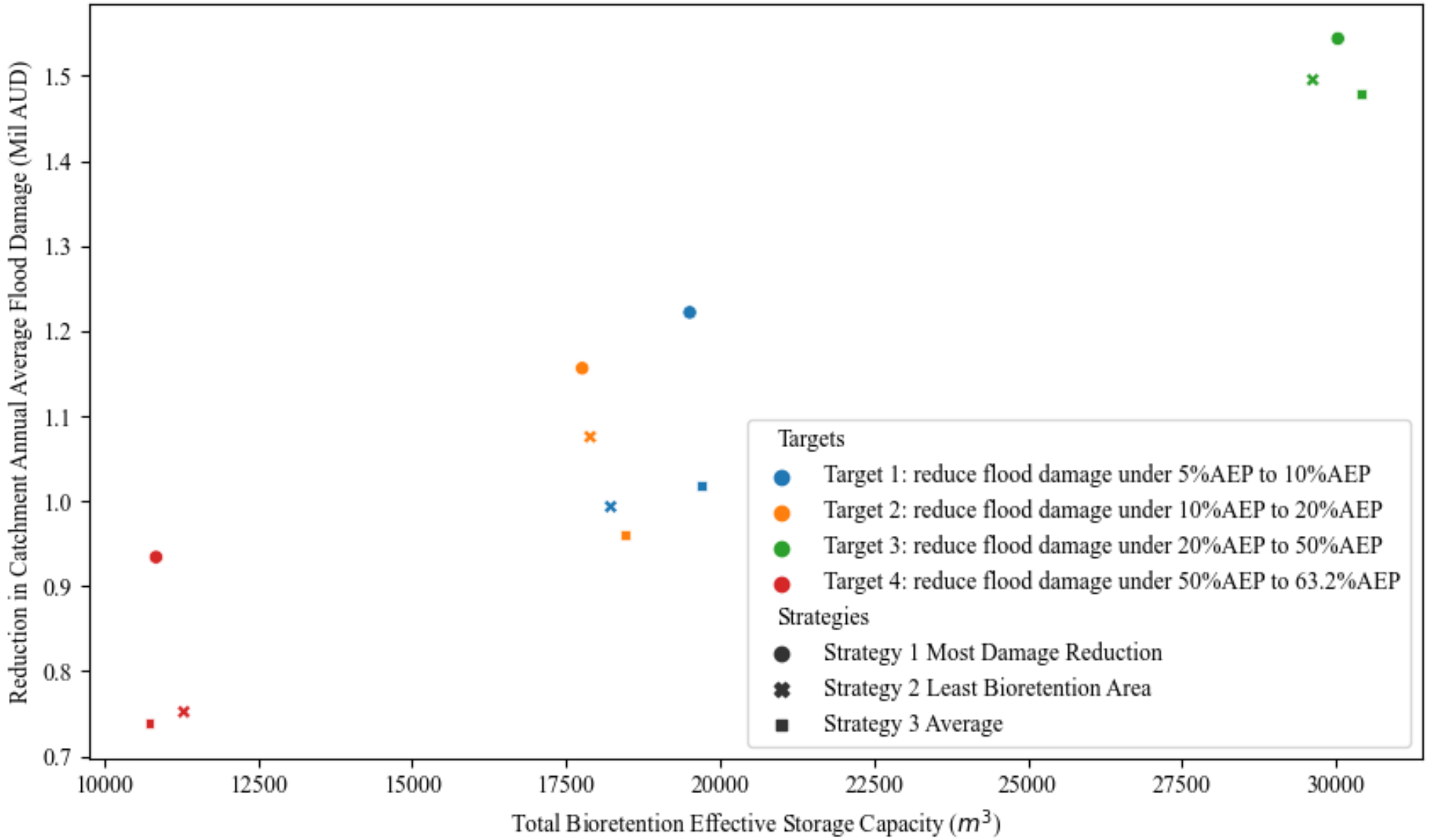
# Reduction in Annual Average Damage of Flooding

| Flood Damage Reduction Targets | | Representative Strategies | | |
|---|---|---|---|---|
| | | NBS Strategy 1<br>Most Damage Reduction | NBS Strategy 2<br>Least Bioretention Area | NBS Strategy 3<br>Average |
| 1 | 5%AEP (60min) to 10%AEP (60min) | 1.222 | 0.994 | 1.018 |
| 2 | 10%AEP (60min) to 20%AEP (90min) | 1.156 | 1.076 | 0.960 |
| 3 | 20%AEP (90min) to 50%AEP (90min) | 1.544 | 1.495 | 1.479 |
| 4 | 50%AEP (90min) to 63.2%AEP (90min) | 0.934 | 0.752 | 0.738 |

# Reduction in Annual Average Damage vs. Bioretention Effective Storage Capacity



# Distribution of Sub' Runoff Volume Reduction Targets under two most cost-effective NBS implementation strategies