



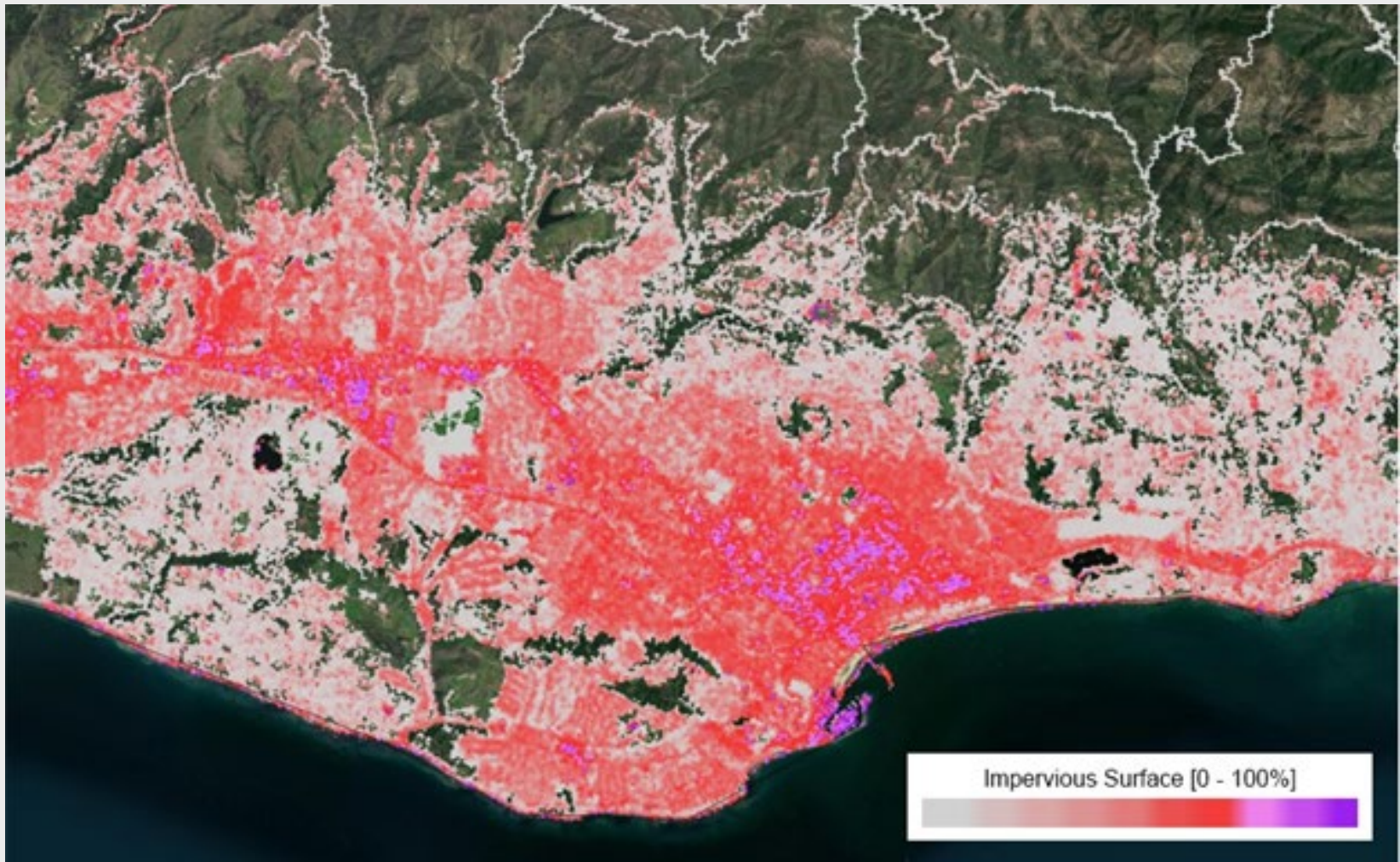
SUSTAINABILITY & RESILIENCE DEPARTMENT

CREEKS DIVISION

LONG-TERM PERFORMANCE OF PERMEABLE INTERLOCKING CONCRETE PAVERS: A 10-15 YEAR UPDATE FROM THE CITY OF SANTA BARBARA

Tim Burgess, Caroline Shepherd, Laurie Van De Werfhorst, Jill Murray

Impervious Surfaces in Santa Barbara



Retrofitting Existing Infrastructure Accepting Rain Where it Falls



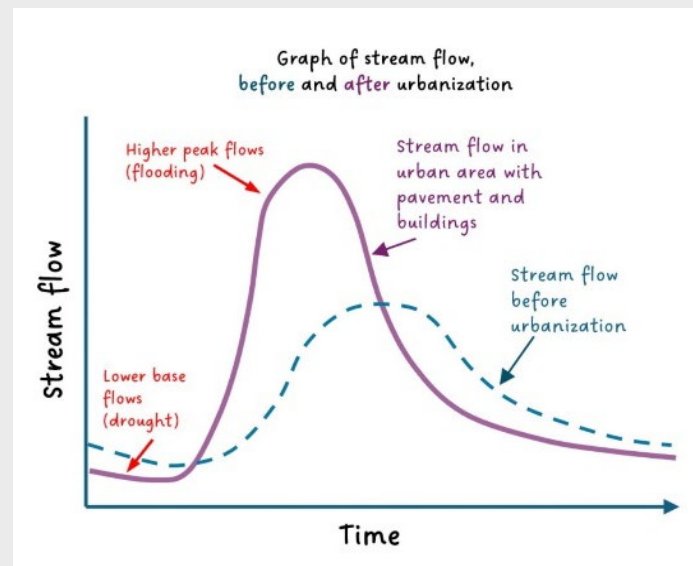
December 21, 2023



Storm Water Management through Infiltration

Santa Barbara is a built-out City – redevelopment is the opportunity to improve the situation

- Reduces peak runoff and flooding during storms
- Reduces erosional forces and channel downcutting in our creeks
- Increases groundwater recharge and creek base flow
- Reduces landscape irrigation needs
- Reduce water pollution from runoff
- Storm water as a resource – offset potable needs, groundwater recharge, increased creek flow, etc



Non-Infiltrative Design



Infiltrative Design

Summary of Presentation

- Why We Chose Permeable Interlocking Concrete Pavers
- Learned Lessons in Design and Construction
- Monitoring Results 10-15 years later, how are they performing?
- Maintenance
- Cost
- Take Away Lessons

LID Designs Considered

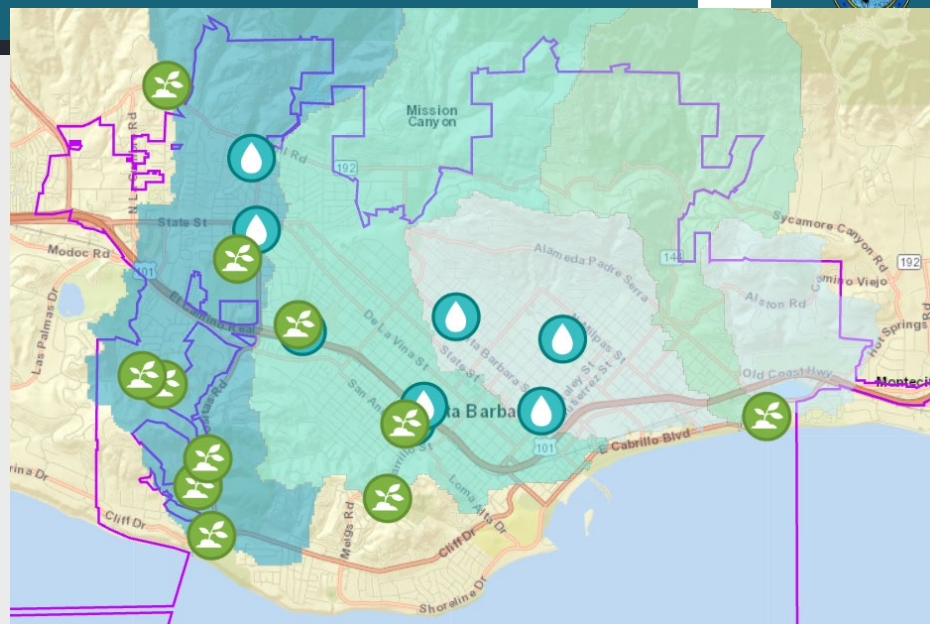
- Different Designs Considered and Evaluated
 - Subsurface Infiltration Chambers
 - *Underground is difficult to inspect and clean*
 - Porous asphalt
 - *Hydrocarbon based, wears down fast*
 - Porous concrete
 - *Complex to install, hard to control variability in admixture and installation*
 - *Difficult to repair*
 - Porous concrete pavers
 - *Pores are small, initial infiltration rate is not sufficient since clogging will diminish it over time.*
 - **Permeable Interlocking Concrete Pavers (PICP)**
 - ***Gaps between allow for higher infiltration, durable, replaceable***

Why Permeable Interlocking Concrete Pavers

- Relatively shallow excavation – low disturbance (Archeology)
- Durable
- High initial infiltration rate through gaps between pavers
- Passive stormwater treatment
- No extra space required, allowing for existing uses
- Restores natural site hydrology
- Easy to repair
- Elimination of hydrocarbon based asphalt and slurry
- Cost comparable to asphalt and concrete over life of project
- Aesthetics

Eleven sites since 2011

Locations



Site	BMP Location	BMP Area = Area of Pavers (square feet)	Catchment area plus BMP Area (square feet)	Year Installed
MacKenzie Park Parking Lot	Parking stalls and pathway	15,375	445,221	2011
Oak Park Main Parking Lot and Stage Area	Parking Lot and Paved Plaza Area	36,883	100,900	2013
Oak Park BBQ Area	Paved Plaza Area	22,889	43,282	2013
Oak Park Tennis Court Lot	Parking Lot	9,705	9,705	2013
Stevens Park Lot	Parking Lot	14,527	108,200	2013
Westside Neighborhood Center	Parking Lot	9,922	16,000	2013
Plaza de Vera Cruz	Park Service Road	9,000	29,837	2015
Alice Keck Park Surrounding Sidewalks	Sidewalks	21,400	21,400	2015
Quarantina Street 700 block	Street and Sidewalks	35,000	75,860	2016
Quarantina Street 800 block	Street and Sidewalks	27,000	96,600	2016
Total		201,701	947,005	

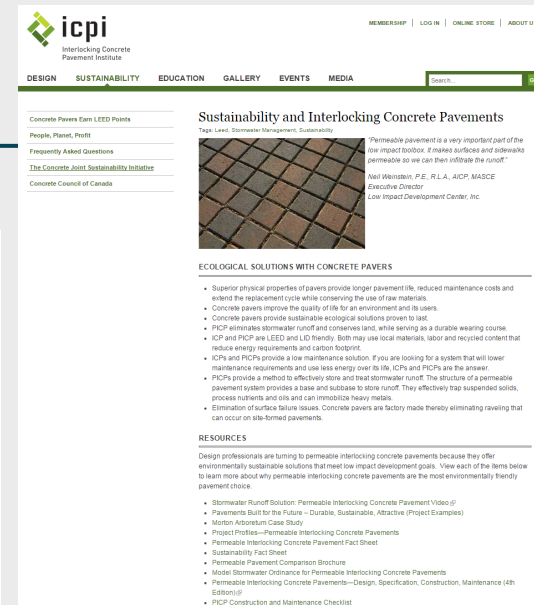
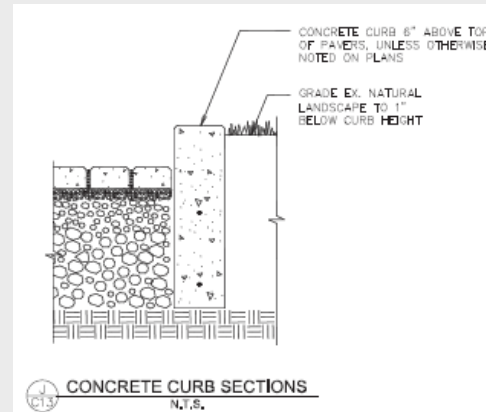
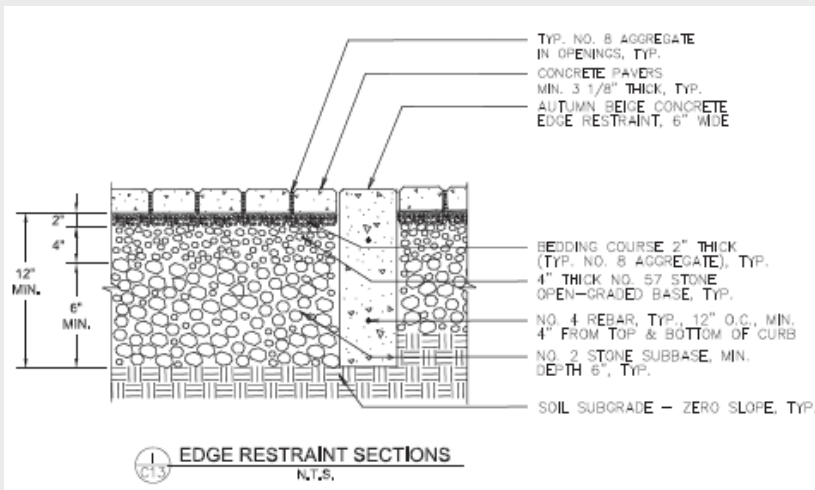
DESIGN AND CONSTRUCTION

A pond with concrete sides and a natural bottom filled with rocks and topped with pavers that allow water to pass through



DESIGN AND CONSTRUCTION

- Design
 - Interlocking Concrete Pavers Institute (ICPI) Specifications
 - Trade Association for the interlocking concrete paving industry
 - Now ASTM has specs matching ICPI
- Honed designs over several years and 11 project sites
 - Lessons Learned



Important Components of a Permeable Paver Project

- Consider Adding Green Space
- Site Suitability
- Level Subgrade
- Seal utility pipes and conduits
- Open graded, crushed aggregate base
- Compaction of base in four to six inch lifts
- Use true Permeable Pavers
- Keep Existing Drainage Pathways in Case Surface Clogs
- Surrounding Area Run-on
- Monitoring Ports

Important Components of a Permeable Paver Project

- Site Suitability
 - Known underground pollutant plumes
 - Groundwater Depth
 - Soil Analysis and Infiltration Rates - tested infiltration rates don't necessarily reflect final project infiltration rates
 - Utility – USA and ground penetrating radar

	Infiltration Rates from Tests (in/hr)			Feb 2014 Storm
	Boring 1	Boring 2	Average	
Stevens Park	0.74	0.255	0.4975	0.296
Westside Neighborhood Center	0.815	0.095	0.455	0.277
Oak Park Tennis	0.05		0.05	0.5
Oak Park Main Lot	0.05	very high	0.05	0.432
Oak Park Stage Area				0.633
Oak Park Main Picnic	1.205	0.165	0.685	very high

Important Components of a Permeable Paver Project

Site Suitability

Subgrade Preparation

Level Subgrade

No Filter Fabric



Important Components of a Permeable Paver Project

Site Suitability

- Subgrade Preparation
 - Avoid over compaction



Important Components of a Permeable Paver Project

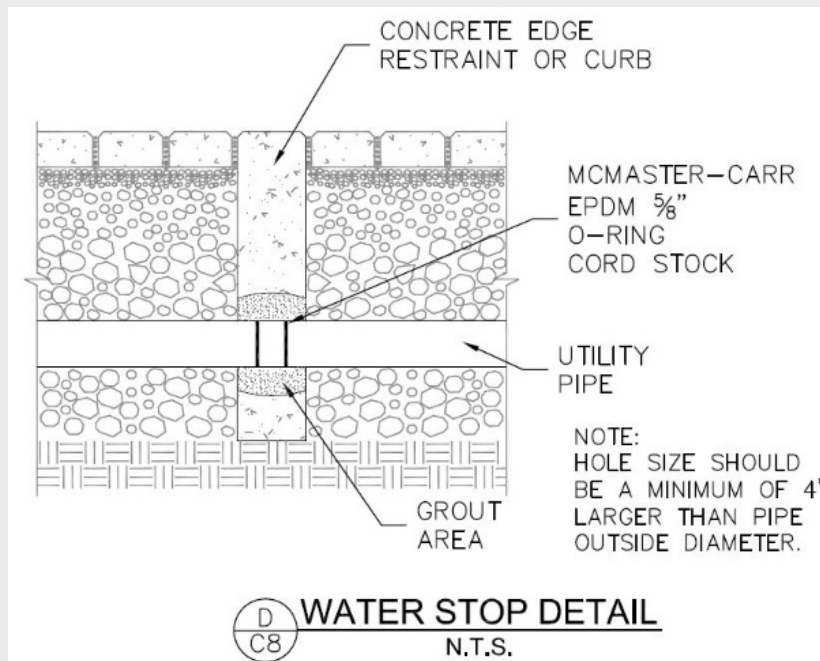
Ensure water doesn't accidentally drain

- Seal utility pipe joints and conduits and DIs



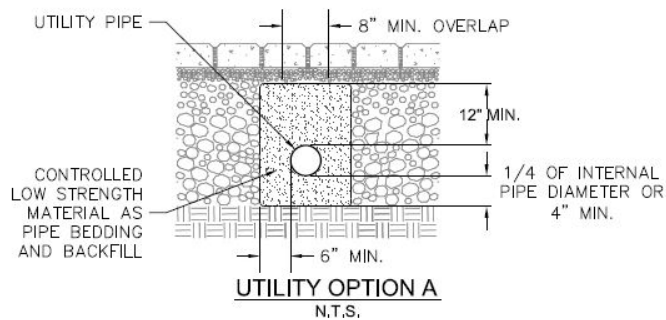
Important Components of a Permeable Paver Project

Seal edge restraint holes

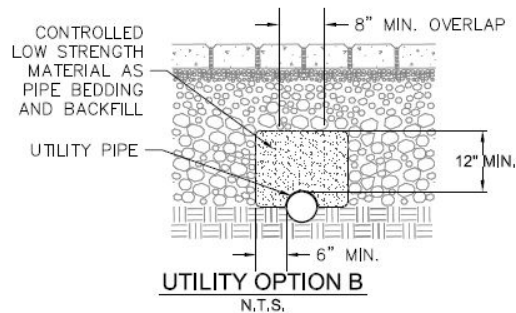


Important Components of a Permeable Paver Project

Bedding sand can let water pass through



NOTE:
UTILITY OPTION A SHALL BE USED WHEN UTILITY PIPE FALLS COMPLETELY WITHIN BASE LAYERS;
UTILITY OPTION B SHALL BE USED WHEN UTILITY PIPE FALLS ONLY PARTIALLY WITHIN BASE LAYERS.



UTILITY DETAIL
N.T.S.



Important Components of a Permeable Paver Project

Ensure proper seating and placement of pipes



Important Components of a Permeable Paver Project

Open graded, crushed,
washed aggregate base



Important Components of a Permeable Paver Project

Compaction of base in four
to six inch lifts

10-ton vibratory roller

Compaction testing



Important Components of a Permeable Paver Project

- Use true Permeable Pavers



Important Components of a Permeable Paver Project

- Keep Existing Surface Drainage Pathways in Case Surface Clogs



Important Components of a Permeable Paver Project

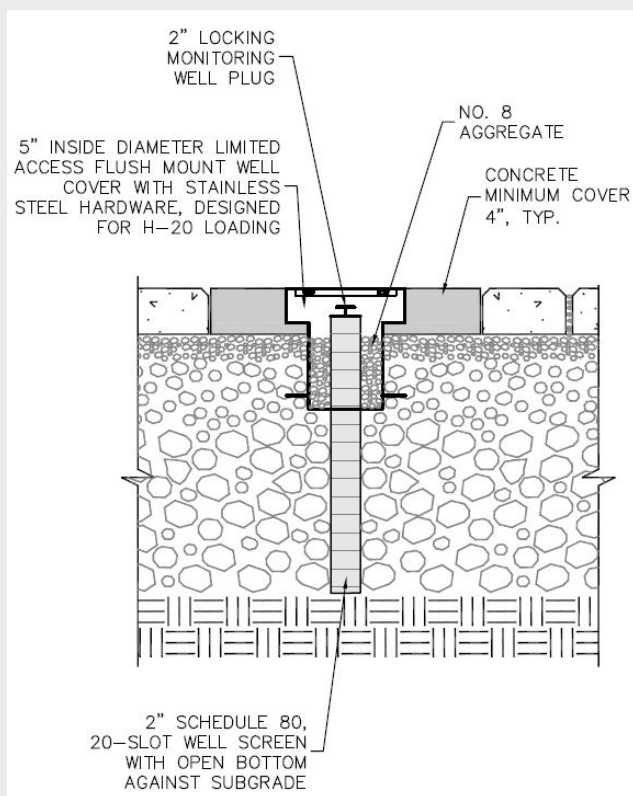
Surrounding Run-on

- Runoff from other paved areas will clog paver surface
- We don't assume 100% capture of storm water from adjacent areas

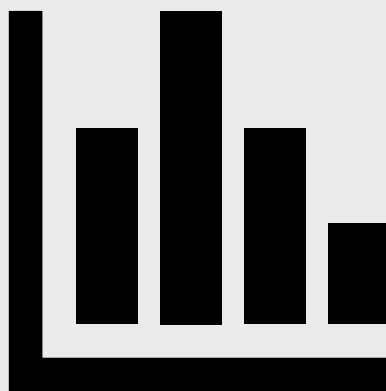


Important Components of a Permeable Paver Project

Monitoring Ports



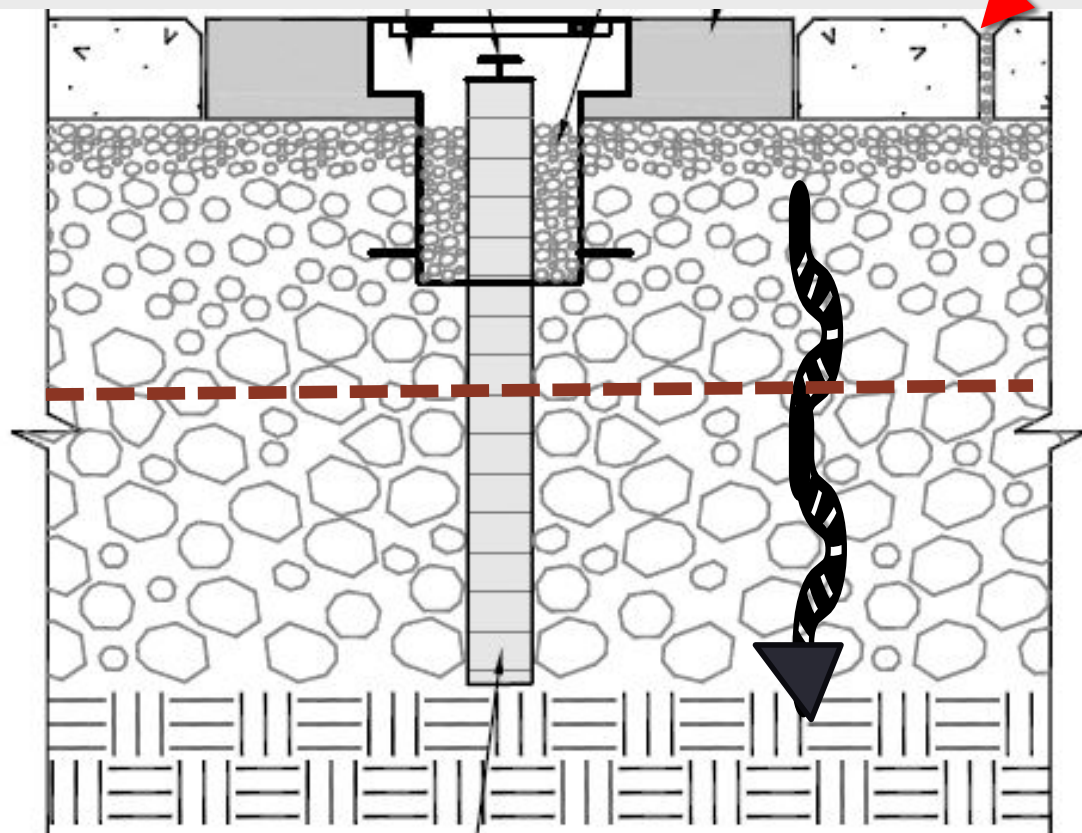
PERFORMANCE TESTING





Surface infiltration

- Infiltration / clogging of paver gaps
- Ring test (ASTM C1781)



Subgrade infiltration

- Infiltration / clogging of subgrade
- Depth loggers in monitoring wells

Surface Infiltration Methods

(ASTM C1781)

Setup

- Cut 5-gallon bucket
- Mark 0.5" line above flat rim
- Putty snake around the flat rim
- Flip and push ring onto ground
- Push putty against ring/ground inside and out, especially in gaps.

Presoak

- Start timer
- Use 1-gallon jug, fill ring 0.5" line
- Keep pouring so that ~1/2" depth is maintained
- If leaking, push putty into gaps, estimate water lost
- When 1 gallon is infiltrated, stop timer.
- Record time





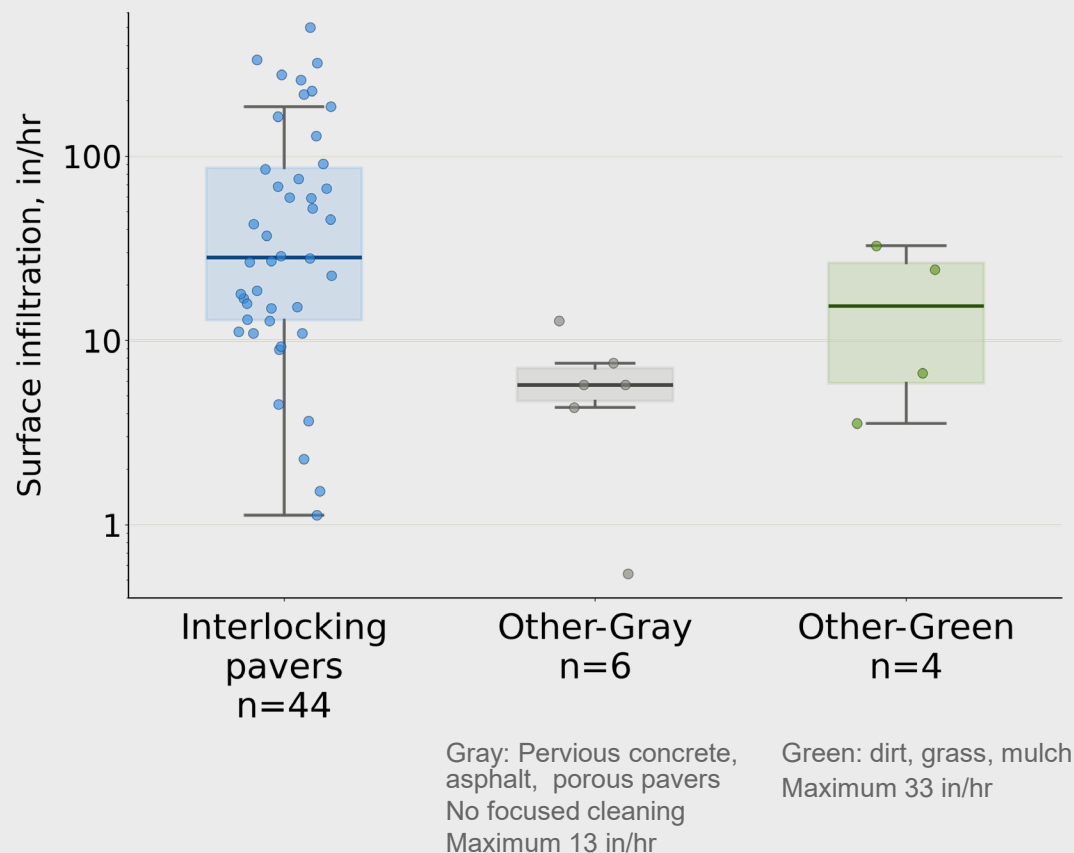
Test

- If presoak time is < 30 sec, use 5 gallons
- If presoak is 30 sec-15 min, use 1 gallon
- If presoak is > 15 min, use 1 L (modification)
- Proceed as above
- Stop at 15 min. Measure water remaining in ring or water jug
- Conduct infiltration calculations

Youtube: Perm Pvmt Infiltration
Training Video FINAL 20210914 (KC
Water)

Surface Infiltration Results

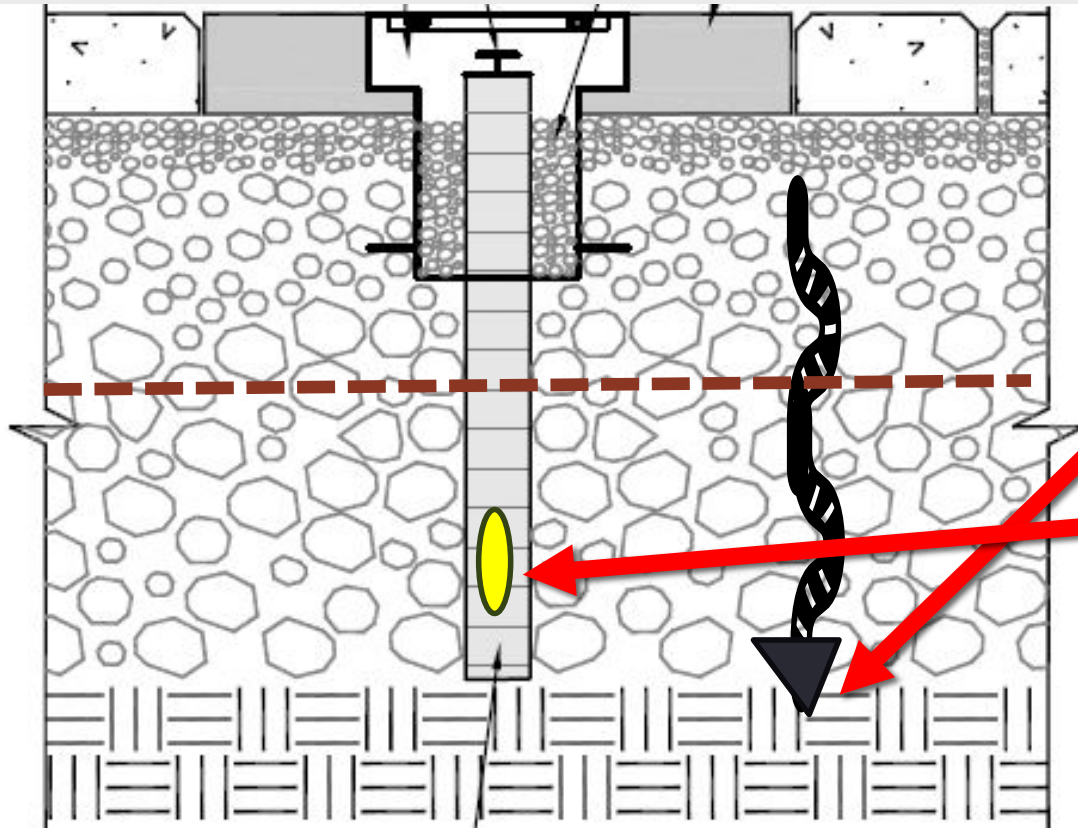
- No focused cleaning in 5+ years: typical street sweeping, leaf blowing
- 10-15 yrs since install
- 84% > 10 in/hr
- Median = 28 in/hr, Mean = 82.2 in/hr
- Problem spots had focused, dirty run-on





Surface infiltration

- Infiltration / clogging of paver gaps
- Ring test (ASTM C1781)

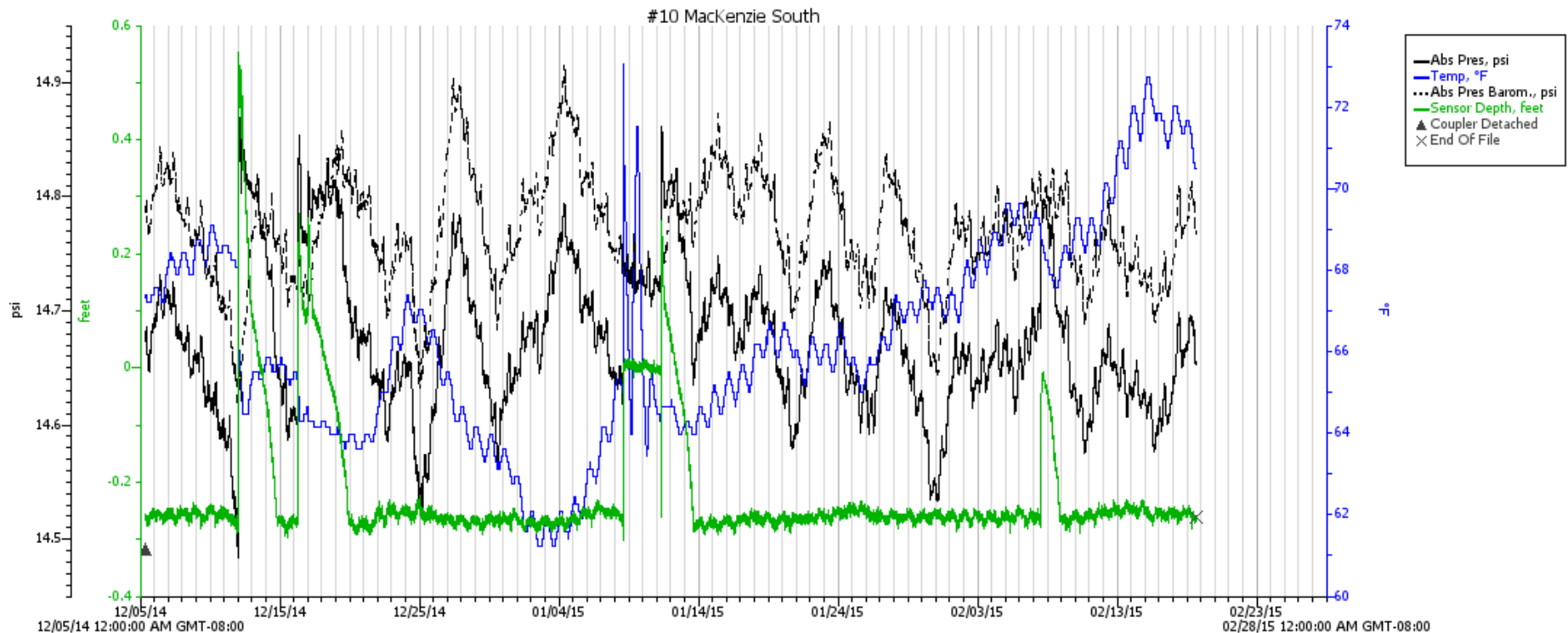


Subgrade infiltration

- Infiltration / clogging of subgrade
- Depth loggers in monitoring wells

Data Collection/Cleaning Methods

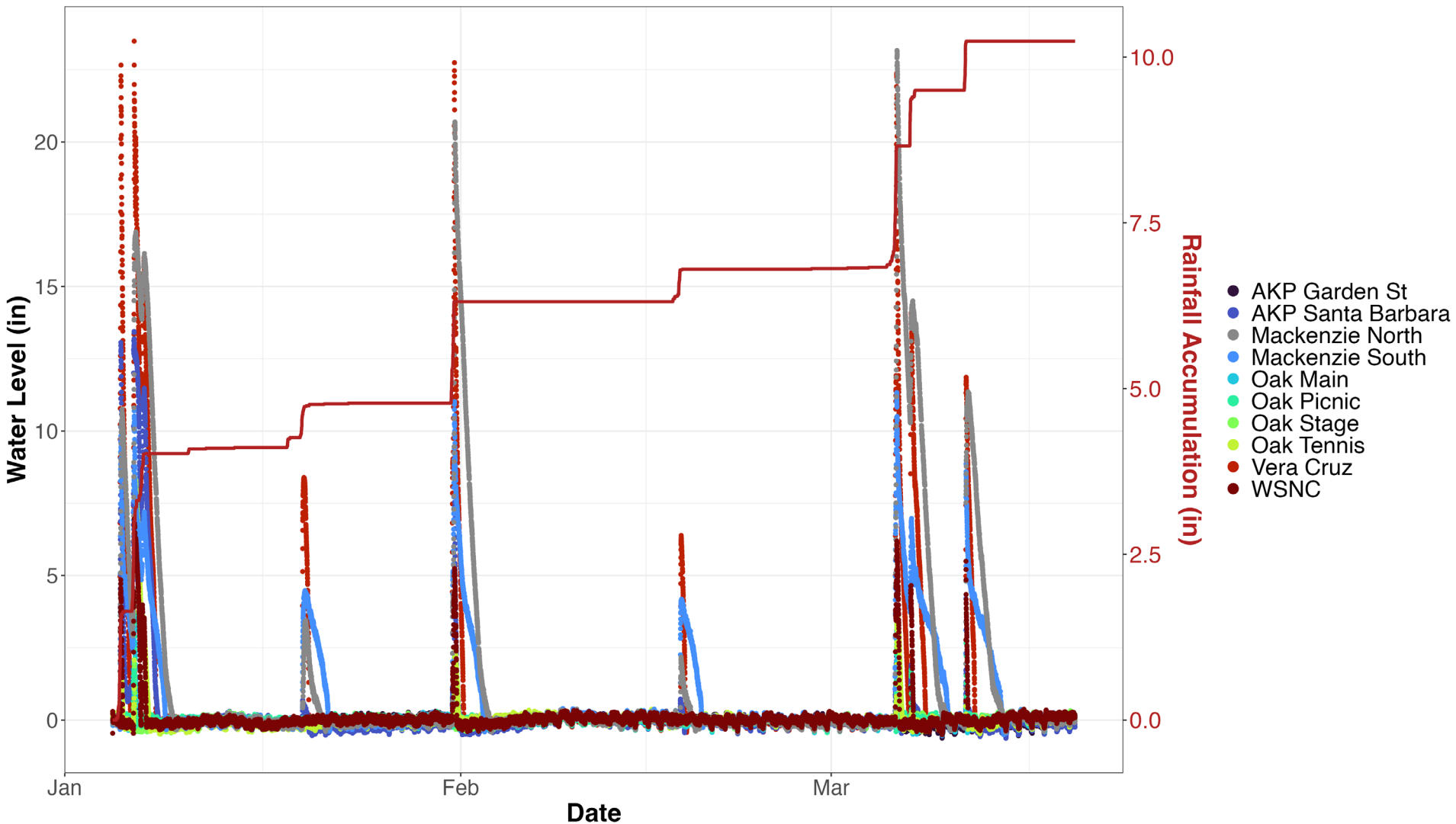
- HOBO Depth Loggers
 - Installed in monitoring wells
 - Ambient monitoring logger stored outside
- HOBOWare Built-In software to translate PSI -> water level



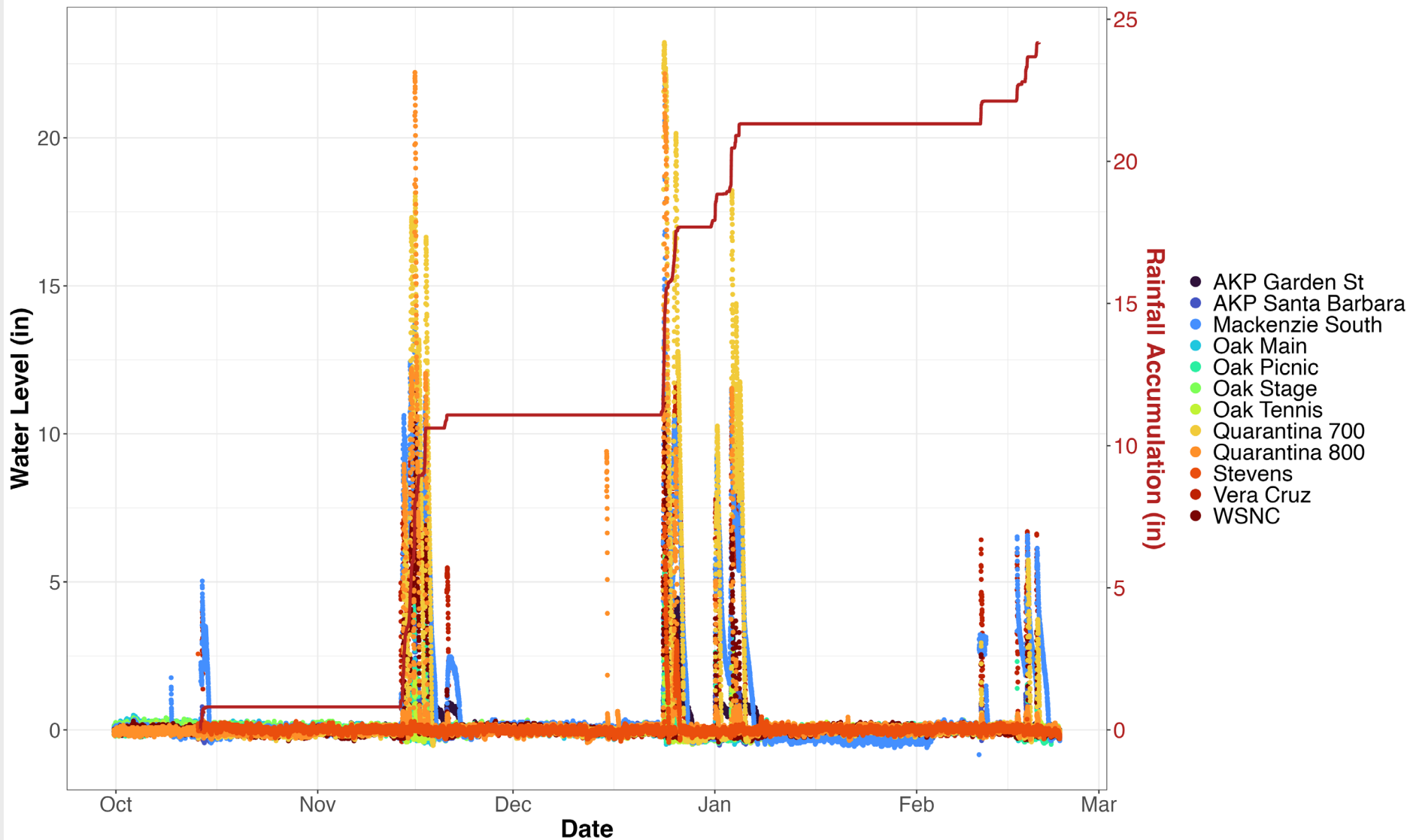
Data Collection/Cleaning Methods

- Calibration needed
 - Use known dry periods to identify when wells should read "0"
 - Find an average value for these dry periods to use as a correction value
 - Apply correction to data
- Rain Data – available in 15min increments from County of Santa Barbara

All Sites (2016)



All Sites (2025-2026)



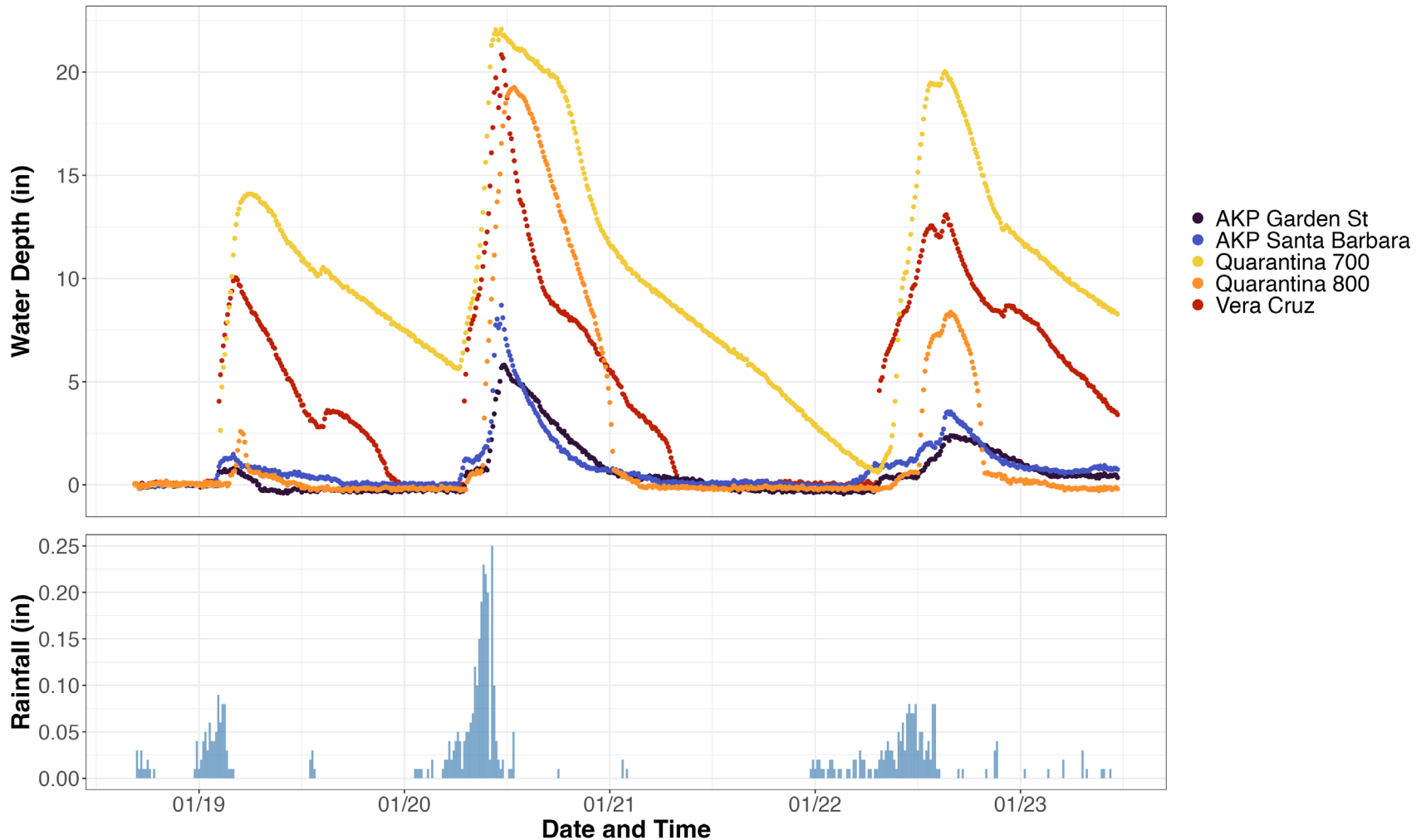
Data Analysis Methods

- Identify comparable storms
 - Total length of storm event
 - Total rain (in)
 - Intensity of rainfall
 - Antecedent dry period
- Manually identify recession periods (periods where water level is dropping) to pick out infiltration rates
- Compare infiltration rates from similar storms across years

$$\text{Recession Rate} = \frac{\Delta \text{Water Depth}}{\text{Time}}$$

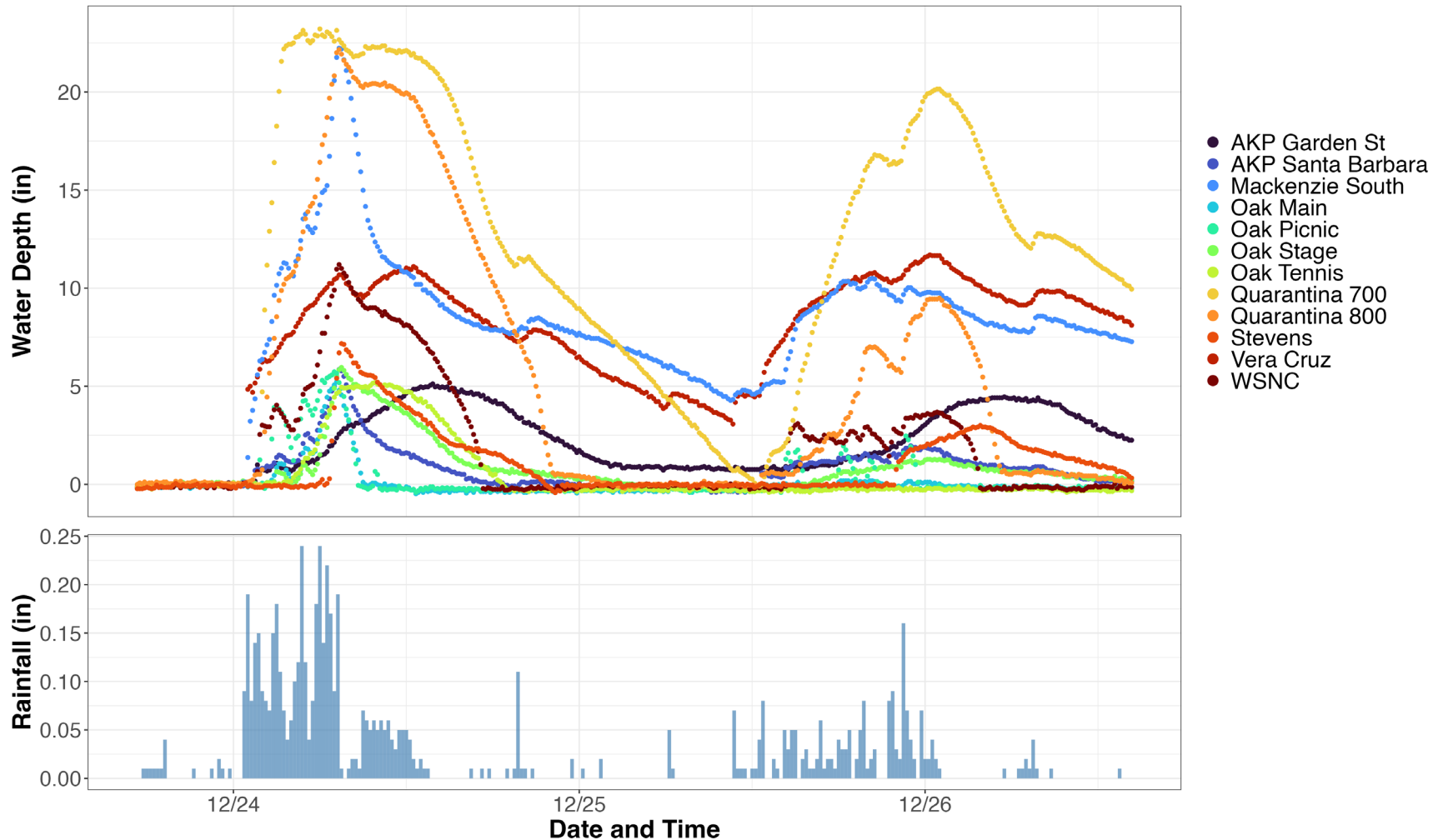
Subgrade Infiltration Monitoring Results

Jan 18-23, 2017 Storm: All Sites



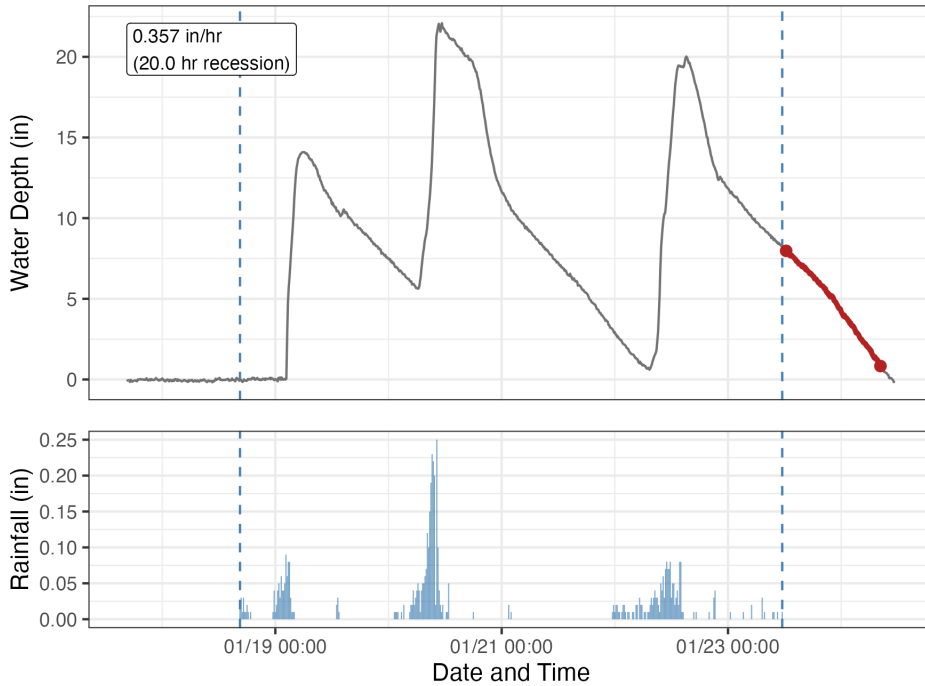
Subgrade Infiltration Monitoring Results

Dec 23-26, 2025 Storm: All Sites



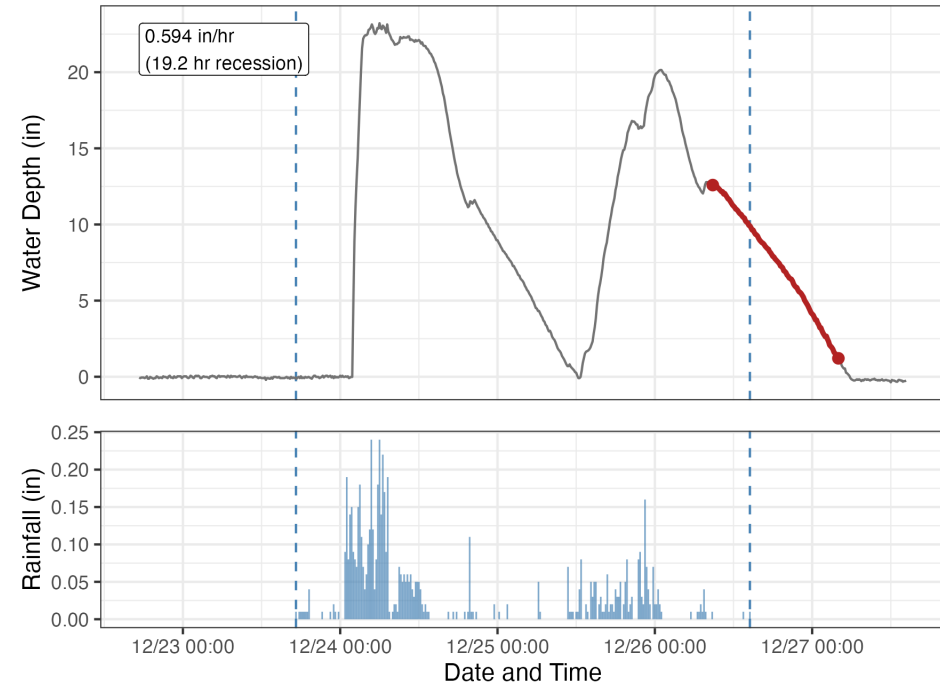
Subgrade Infiltration Monitoring Results

Quarantina 700 - 2017 - Jan 18-23, 2017 Storm



Dashed blue lines: official storm start/end

Quarantina 700 - 2025 - Dec 23-26, 2025 Storm

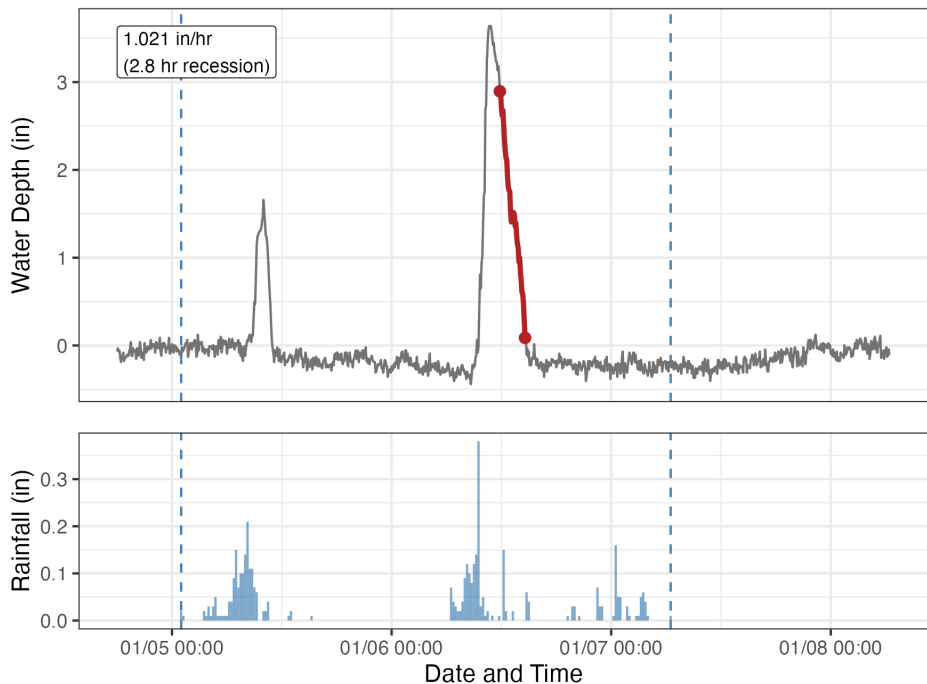


Dashed blue lines: official storm start/end

*This site has
additional run-on

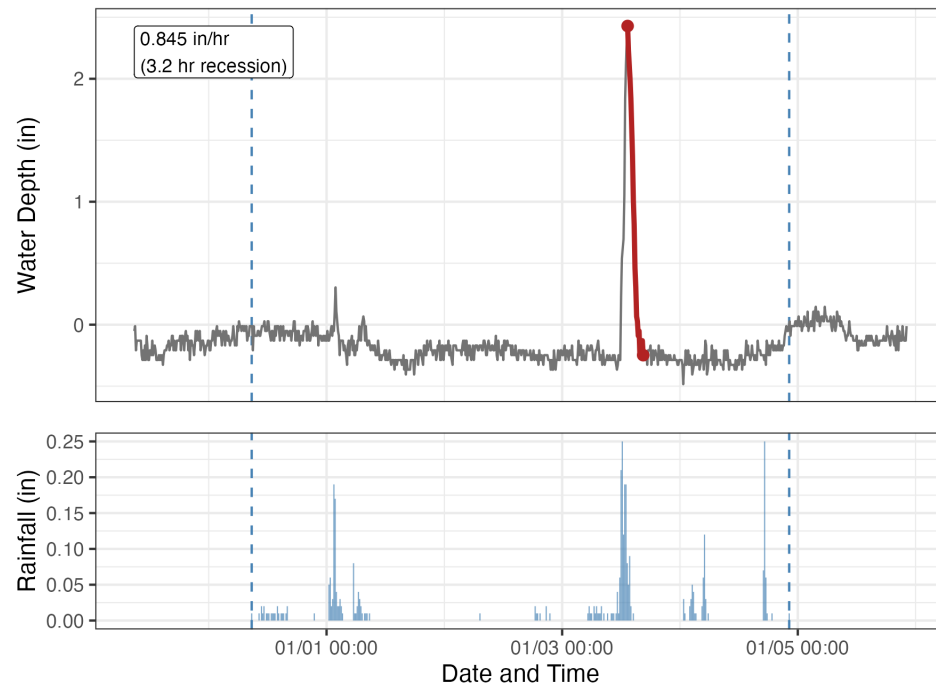
Subgrade Infiltration Monitoring Results

Oak Main - 2016 - Jan 5-7, 2016 Storm



Dashed blue lines: official storm start/end

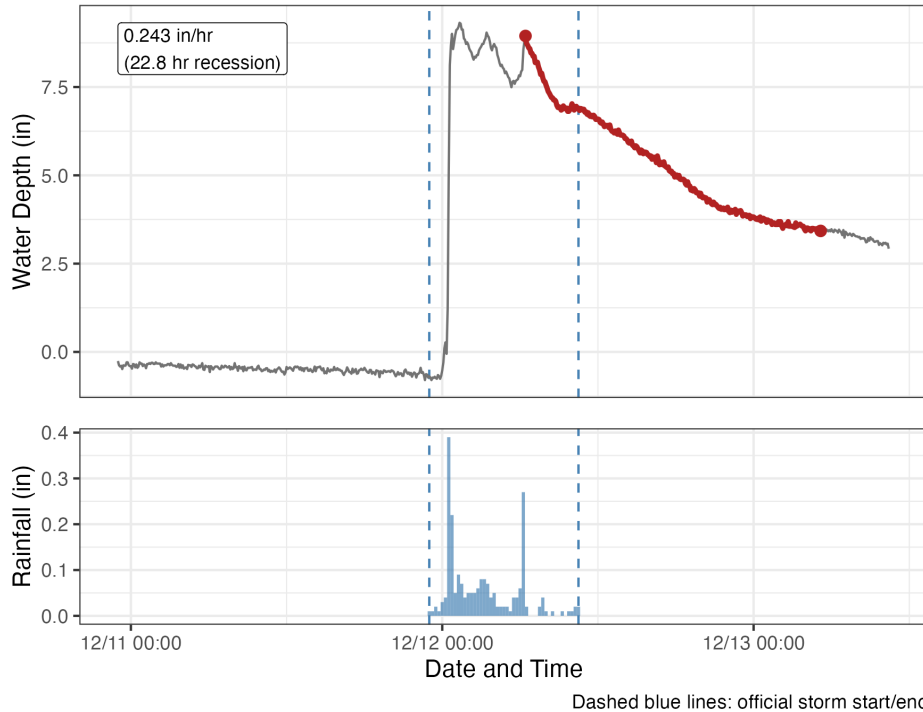
Oak Main - 2025 - Dec 31, 2025 - Jan 4, 2026 Storm



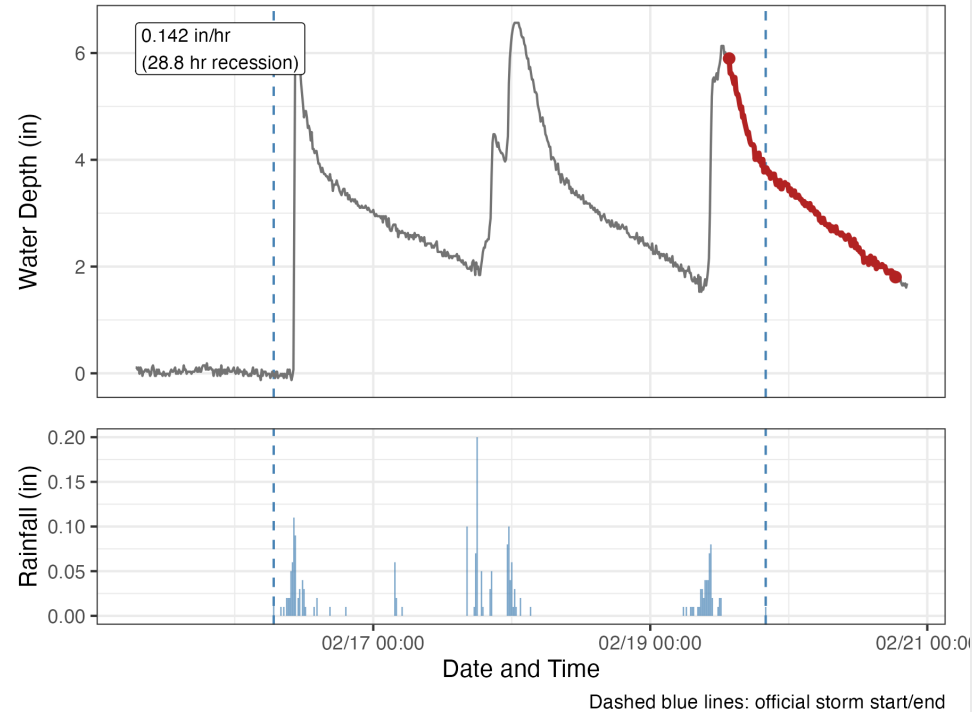
Dashed blue lines: official storm start/end

Subgrade Infiltration Monitoring Results

Mackenzie South - 2015 - Dec 11-12, 2014 Storm



Mackenzie South - 2025 - Feb 16-19, 2026 Storm



*This site has
additional run-on

Subgrade Infiltration Monitoring Results

Infiltration rates per site using only comparable storm data

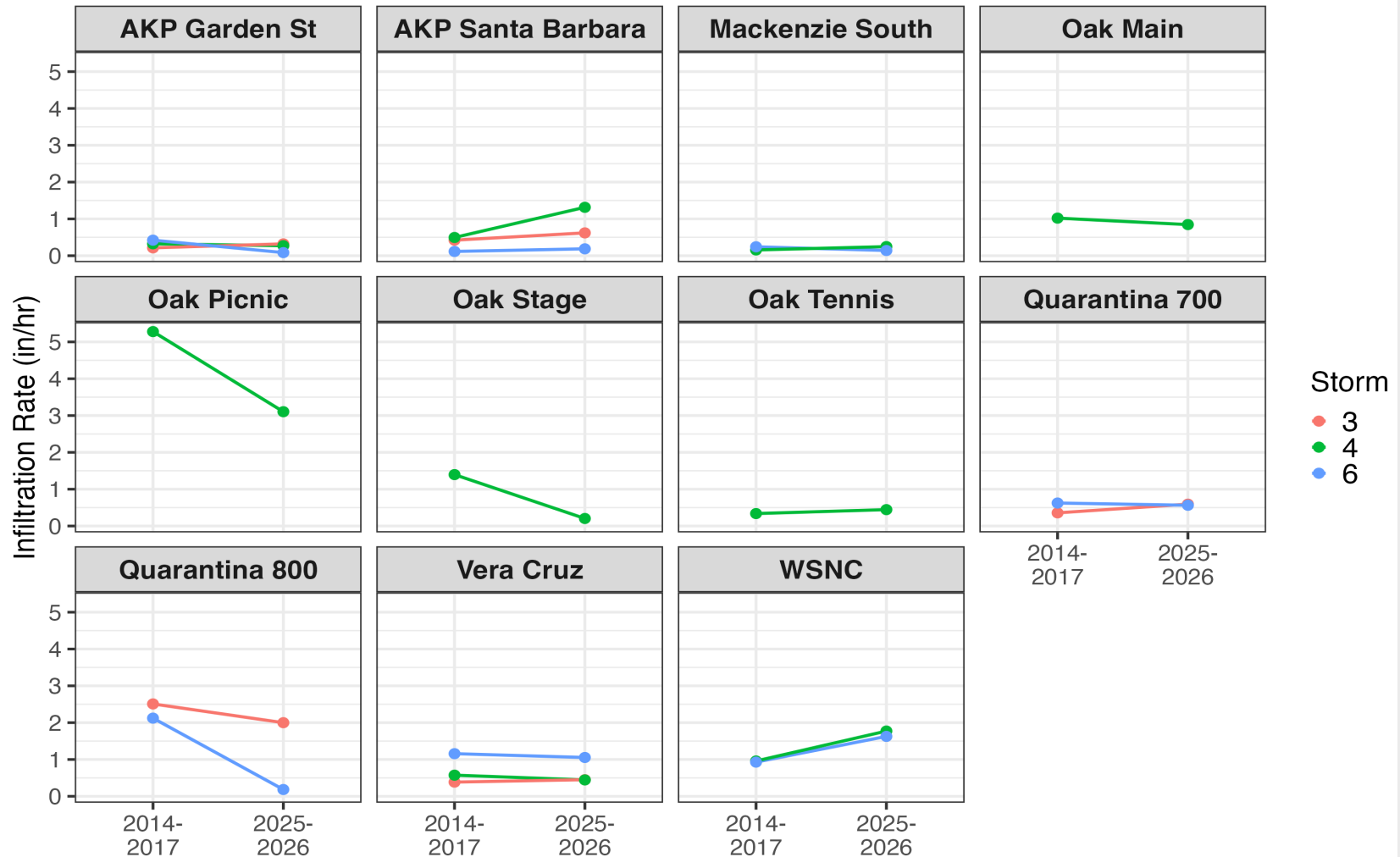
No statistically significant difference, paired t-test: $p = 0.538$

Mean infiltration rate per site, by period

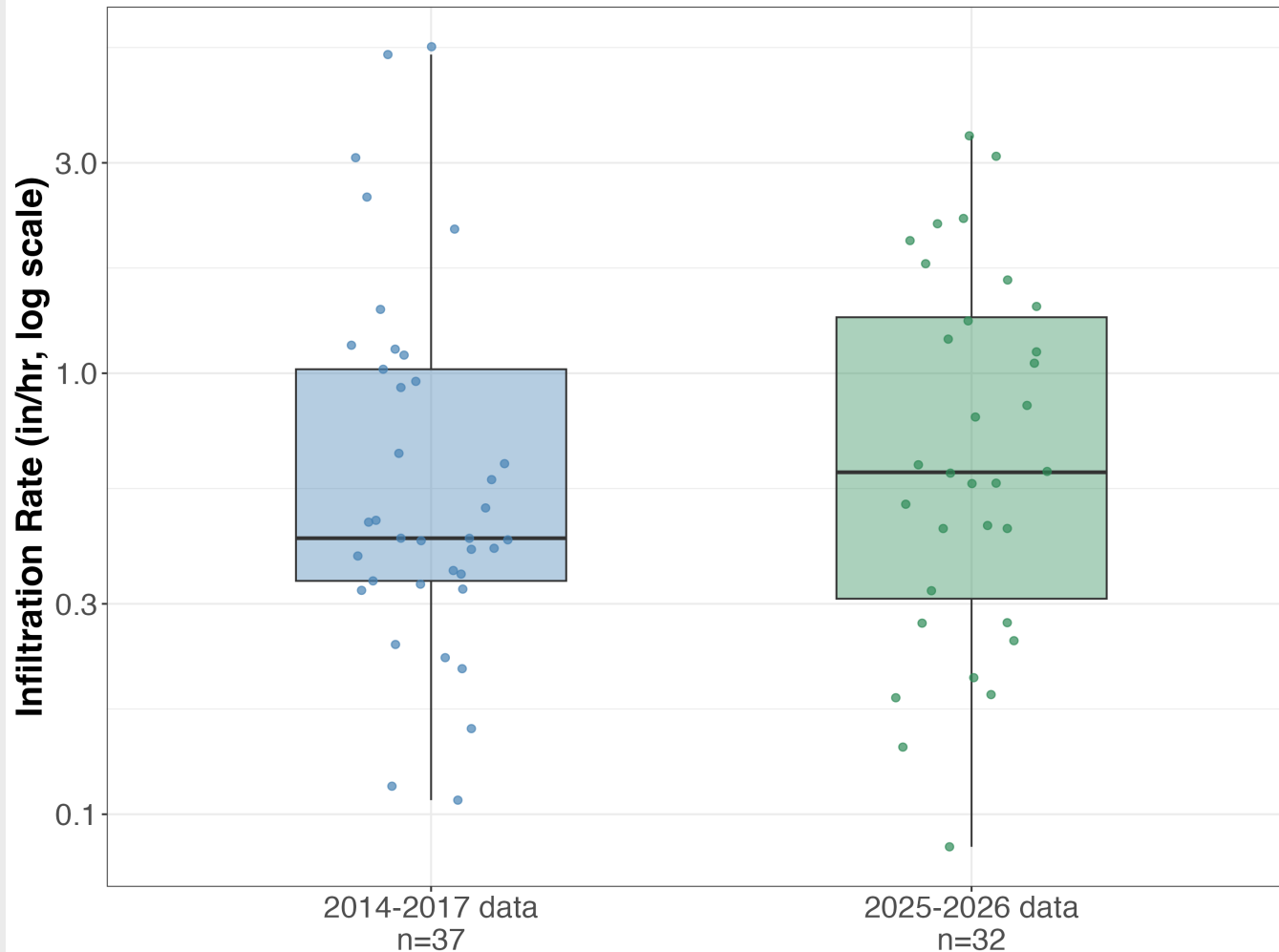
site	2014-2017 data	2025-2026 data
AKP Garden St	0.3	0.2
AKP Santa Barbara	0.3	0.7
Mackenzie South	0.2	0.2
Oak Main	1.1	1.5
Oak Picnic	4.2	3.3
Oak Stage	1.4	0.4
Oak Tennis	0.4	0.6
Quarantina 700	0.5	0.6
Quarantina 800	2.3	1.5
Vera Cruz	0.7	0.7
WSNC	0.9	1.5

Subgrade Infiltration Monitoring Results

Pre-era vs 2025-2026 infiltration rate, by comparable storm (same scale, all sites)



Subgrade Infiltration Monitoring Results



- Every infiltration rate from the time shortly after installation (blue), and recent testing (green)
- No significant difference, t-test on log transformed rates: $p = 0.622$

- **Surface infiltration**

- Seems to have decreased over time, but still functional
- Most of our sites are street swept or leaf blown regularly

- **Subgrade Infiltration**

- No statistically significant change over time, no trend in data
- Still functional

Pollutant Monitoring

Record water quality benefit – measure pollutant loads and toxicity before project

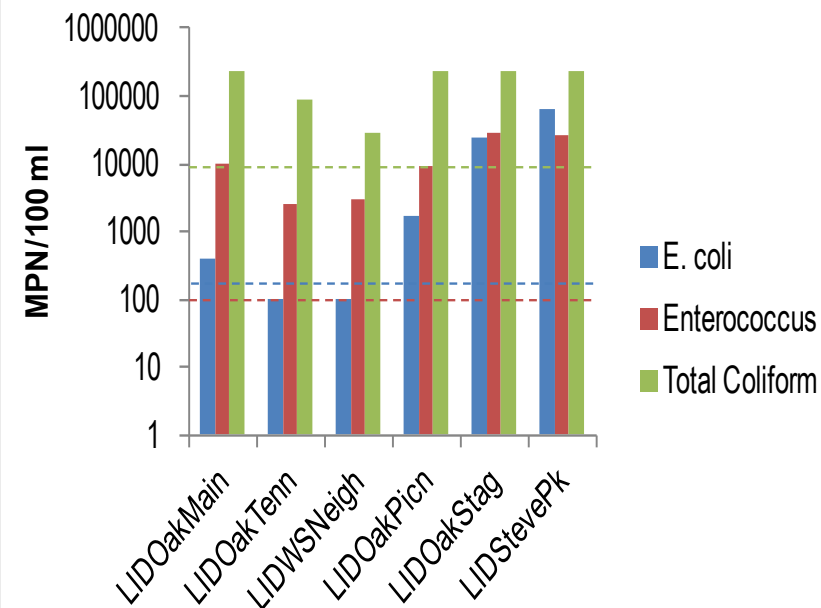
- Use this to calculate the pollutant load reduction after the project is built

Storm Water Capture and Infiltration recorded by water level loggers



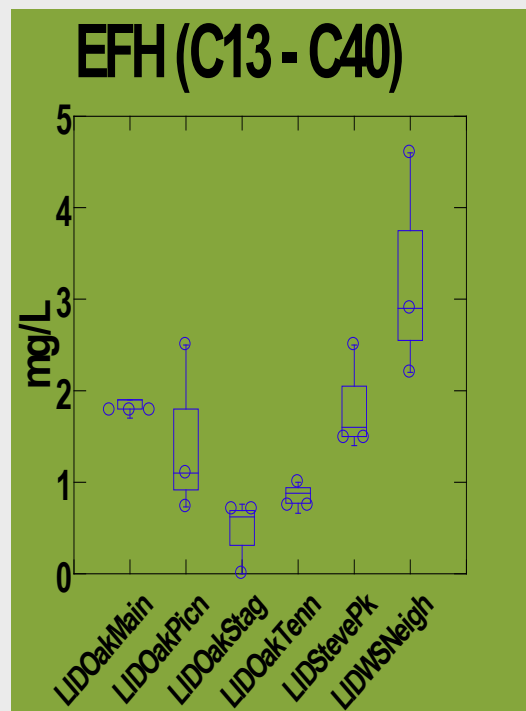
Monitoring Results

Bacteria, TOC, nutrients,
hydrocarbons, TSS, metals,

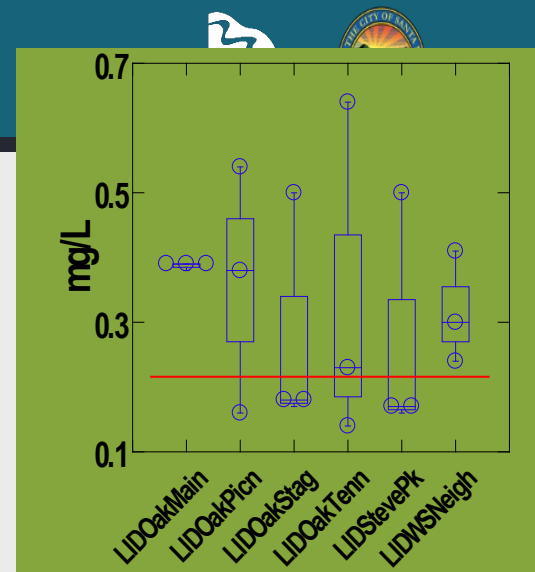


Fecal indicator bacteria results for Storm 1.
Dashed lines represent the AB 411 standards for
each bacterial group.

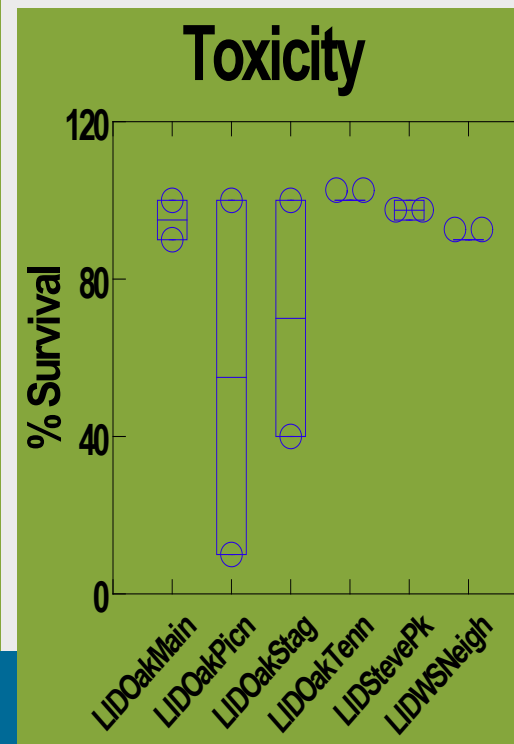
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Hydrocarbon results for
Storms 1-3.



Methylene Blue Active
Substances



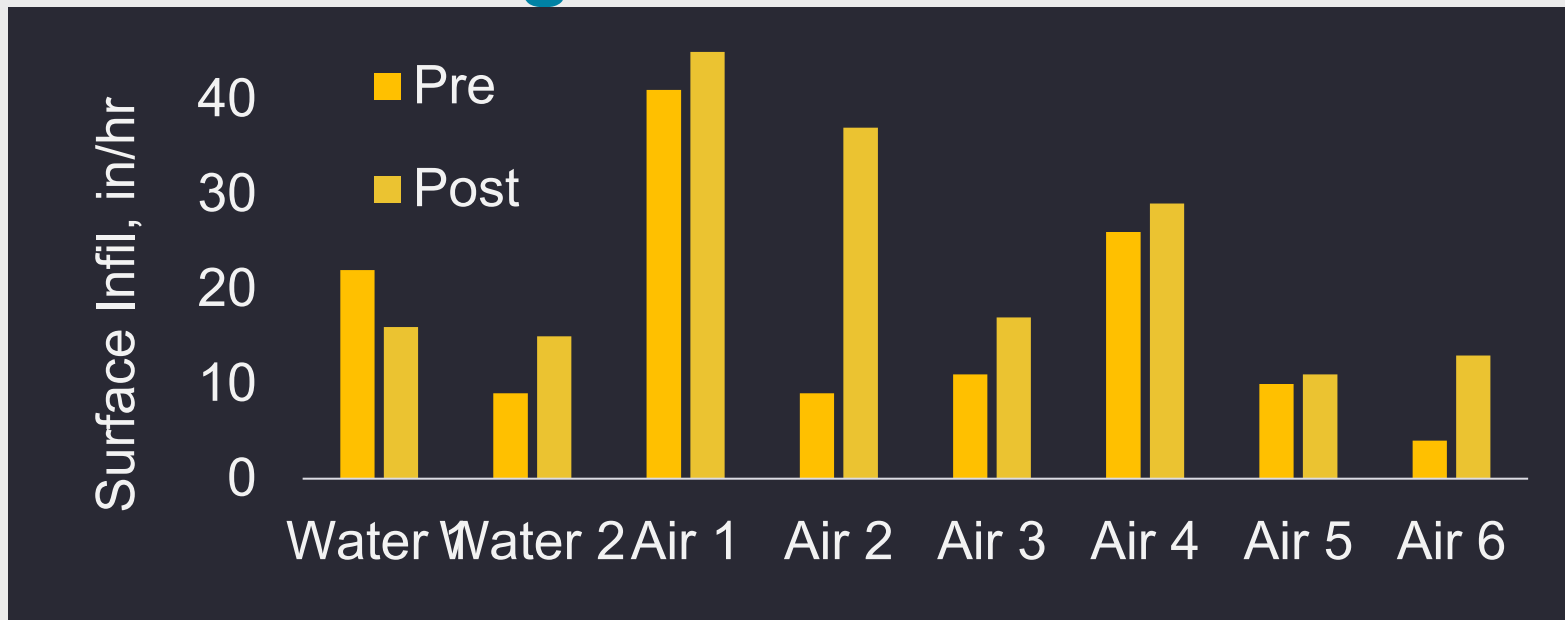
Cleaning Permeable Pavers

Gaps between pavers accumulate debris

- From overhanging trees – low impact on permeability
- Run-on from other surfaces pavement carries sediment and reduces permeability
- Run-on from landscape areas will clog pavers quickly and reduce permeability



Pre & Post Cleaning Surface Infiltration



Cleaning

- Pressure washing and vacuum recovery
- Compressed air cleaning with vacuum recovery
- Hand Vacuuming
- None restore to 100 in/hr (MN design standard)
- Replacing pea gravel >100 "/hr

-Intensive cleaning pavers over a large scale reduces cost benefit, and has limited success

-Impacted sites that accept stormwater runoff from other surface areas will clog right back after a few storms, so cleaning them is not cost effective

-Good news – intensive cleaning may not be necessary for typical rain that falls on a site

-Regular leaf blowing or street sweeping can reduce organic matter buildup

Cost Comparisons to other paving

2014	Price Per square foot	Square footage of lots	Cost for entire lot	Maintenance over 30 years (reslurry every 10 years for \$1.14/sq.ft. x 2)	Total Cost	SWMP Compliance Cost Included?	Re-asphalt after 30 years	Maintenance over 30 years (reslurry every 10 years for \$1.14/sq.ft. x 2)	Total cost over 80 years (avg concrete life span)	Need to add SWMP Cost?
Permeable Pavers	\$17.03	85,000	\$1,447,550		\$1,447,550	Yes			\$1,447,550	No
Asphalt (30 yr life span)	\$8.42	85,000	\$715,581	\$193,800	\$909,381	No	\$715,581	\$193,800	\$1,818,763	Yes
Concrete (50-80 yr life span)	\$20.00	85,000	\$1,700,000		\$1,700,000	No			\$1,700,000	Yes
Over 30 YEAR?					Over 65 YEARS?					
2026	Price Per square foot	Square footage of lots	Cost for entire lot	Maintenance over 30 years (reslurry every 10 years for \$1.14/sq.ft. x 2)	Total Cost	SWMP Compliance Cost Included?	Re-asphalt after 30 years	Maintenance over 30 years (reslurry every 10 years for \$1.14/sq.ft. x 2)	Total cost over 80 years (avg concrete life span)	Need to add SWMP Cost?
Permeable Pavers	\$40.00	85,000	\$3,400,000		\$3,400,000	Yes			\$3,400,000	No
Asphalt (30 yr life span)	\$18.25	85,000	\$1,551,250	\$193,800	\$1,745,050	No	\$1,551,250	\$193,800	\$3,490,100	Yes
Concrete (50-80 yr life span)	\$45.00	85,000	\$3,825,000		\$3,825,000	No			\$3,825,000	Yes

2026 Asphalt: \$16.50-\$20/sq. ft. (This is a range from a few recent projects.)

Concrete cost varies

2026 Permeable Pavers cost derived from a City project (\$30/ft.), but I increased the estimate to \$40 since it varies based on project.

Regulatory Requirements

- City has a Stormwater Management Program through the RWQCB that requires development and redevelopment to treat stormwater on-site
- Pavers considered a permeable surface in City SWMP Manual
- Treated the same for permeability as a natural surface (oak woodland, coastal sage scrub, landscape, lawn, etc.)
- Increase in percent of projects with PICP over time
- This has resulted in permeable pavers replacing natural areas to expand the built-out footprint on parcels, or to stay within certain stormwater tiers.

Effects of use of pavers as a permeable surface

City-Wide

- Might create a false sense of permeability or infiltration from surrounding sites where pavers are clogged
- Allows added permeability to replace existing impermeable hardscape
- Can be used to replace natural/landscaped areas with hardscape (show diagram)
- May lead to grey LID infrastructure replacing green infrastructure
- We are thinking more about ways to balance the incentives better to avoid the elimination of green space

Lessons Learned

- Permeable Interlocking Concrete Pavers continue to infiltrate at a rate sufficient to accept rain falling onto the surface
- If installed with exfiltration (intentional or unintentional), much of the reported infiltration will not occur.
- Performance Depends on where it built and run-on from surrounding areas (landscape, hardscape)
- Surrounding run-on areas can clog pavers so that can't be relied on for accepting run-on
- Stick to specs, consider testing for permeability before inspection sign-off to get SW credit
- Cleaning the pavers is expensive
- Avoid permeable grey infrastructure replacing green spaces, when structuring requirements (policy)
- Monitoring can confirm functionality (mention above) inform maintenance, help troubleshoot issues.



SUSTAINABILITY & RESILIENCE DEPARTMENT
CREEKS DIVISION

Questions?

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Time Lapse of Project Construction

- https://www.youtube.com/watch?v=4CH_X8oVlk0