Supplementary material

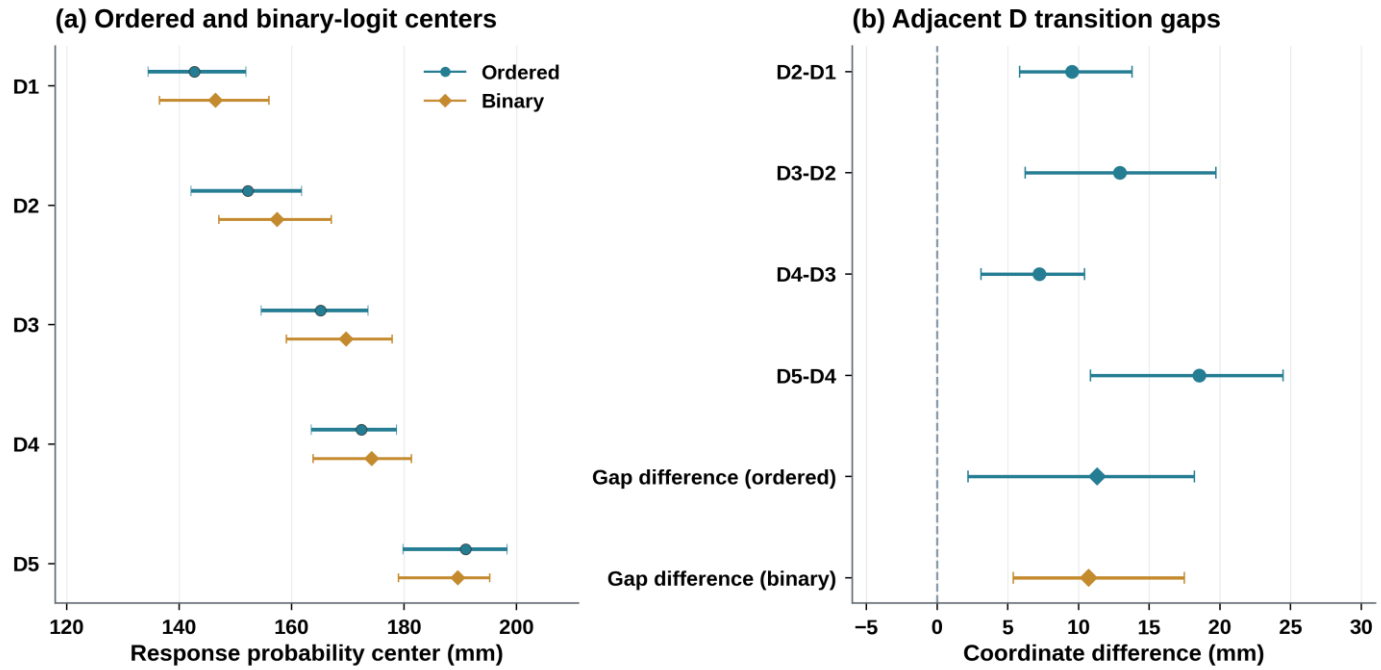

Figure S1. Model-structure sensitivity of deep-soil transition centers and adjacent gaps. Ordered and independent binary-response model probability centers and adjacent gap differences, with existing bootstrap intervals.

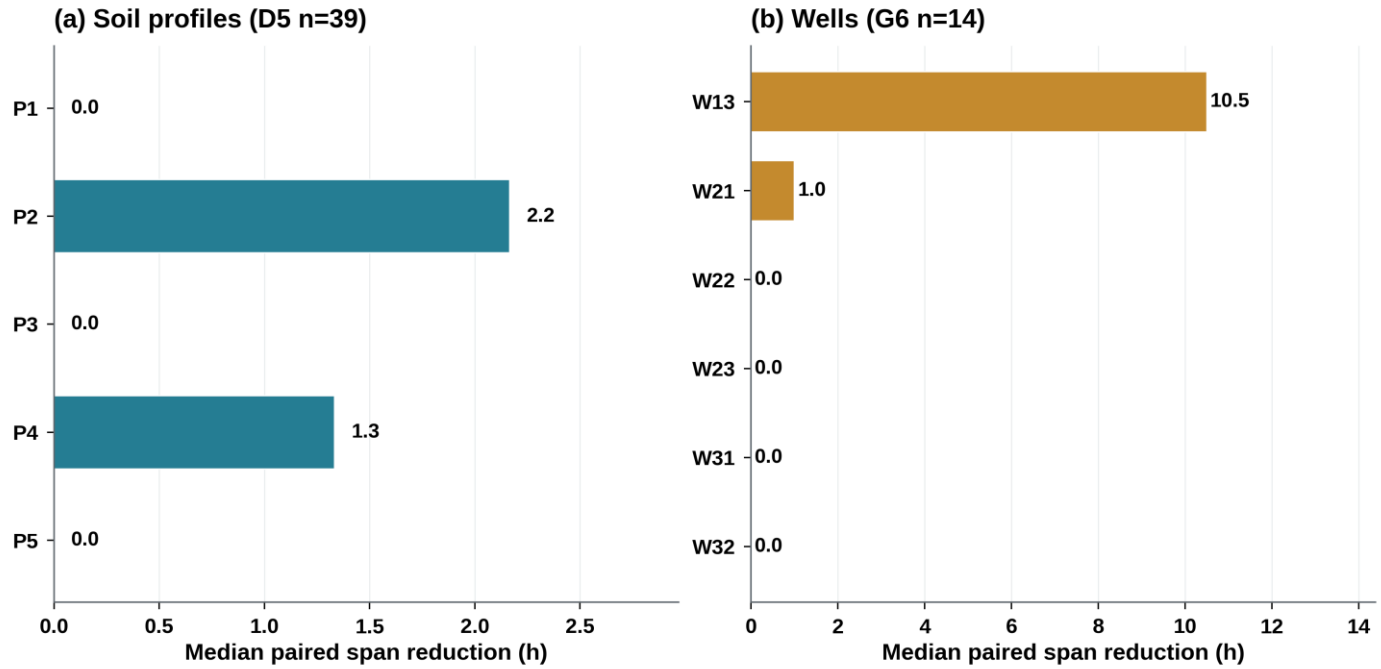

Figure S2. Monitoring-location influence on fixed-extent response timing. Paired per-event reductions in response completion span after removing individual monitoring locations. W13 dominates the six-well final onset gap.

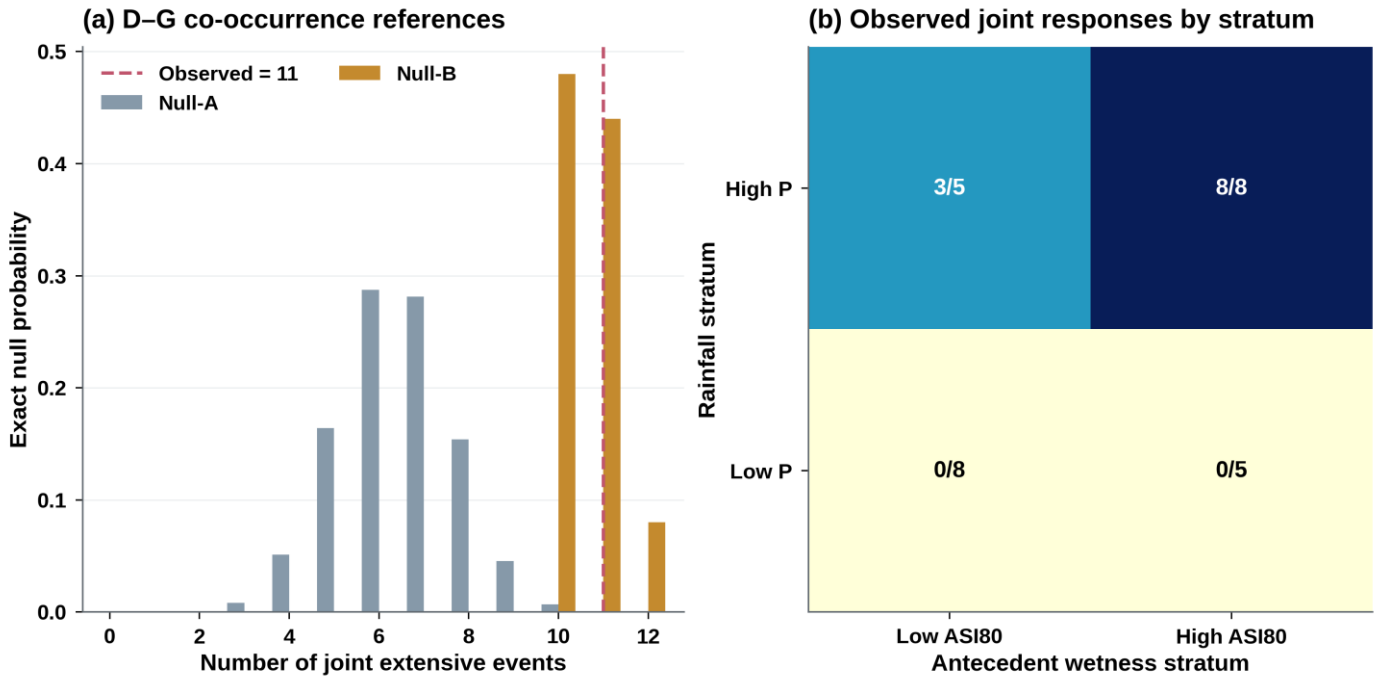

Figure S3. Support and stratification of the soil-groundwater conditional null. Exact Null-A/Null-B distributions and within-stratum co-occurrences; eight high-P/high-ASI80 events are jointly responsive by construction under the stratified null.

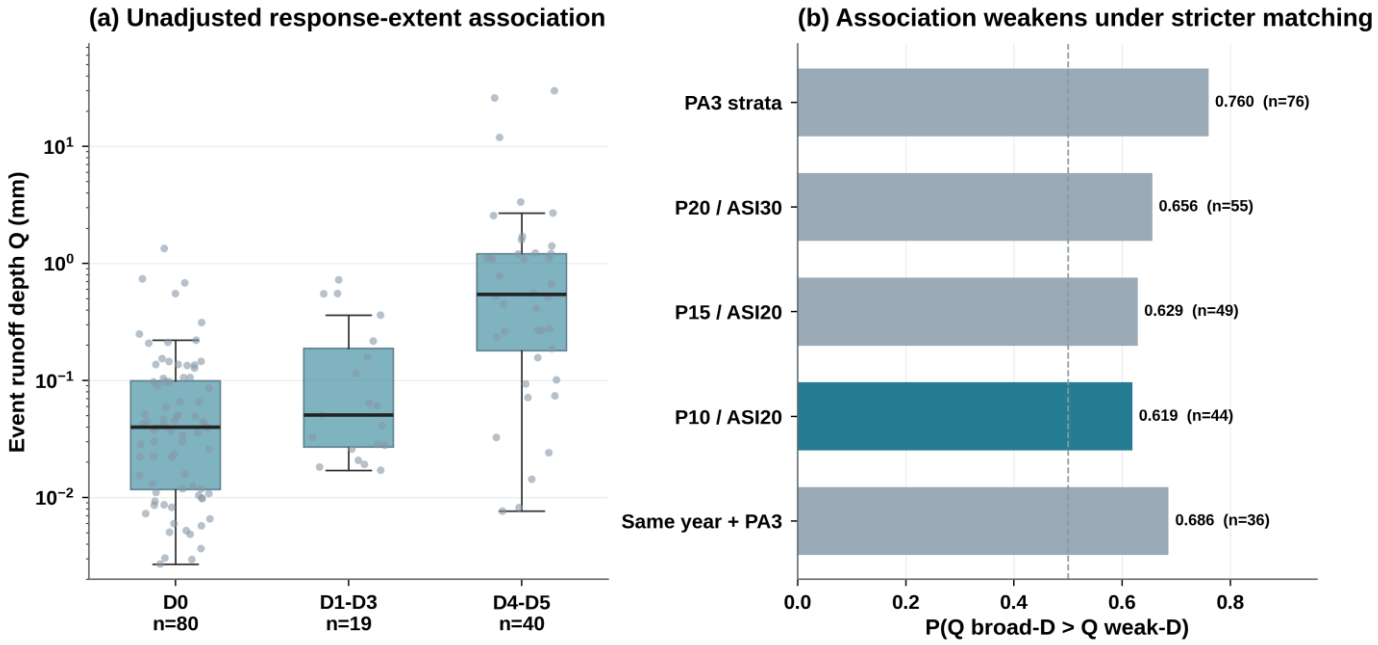

Figure S4. Runoff-depth distributions and continuous forcing-matching sensitivity. (a) Event runoff depth by D response extent in 139 D-Q matched events. (b) Sensitivity of the matched-pair Q ordering to stricter rainfall/ASI80 calipers or same-year conditioning; under P<=10 and ASI<=20, 63 overlapping pairs from 44 events give fraction 0.619 (permutation p=0.1266).

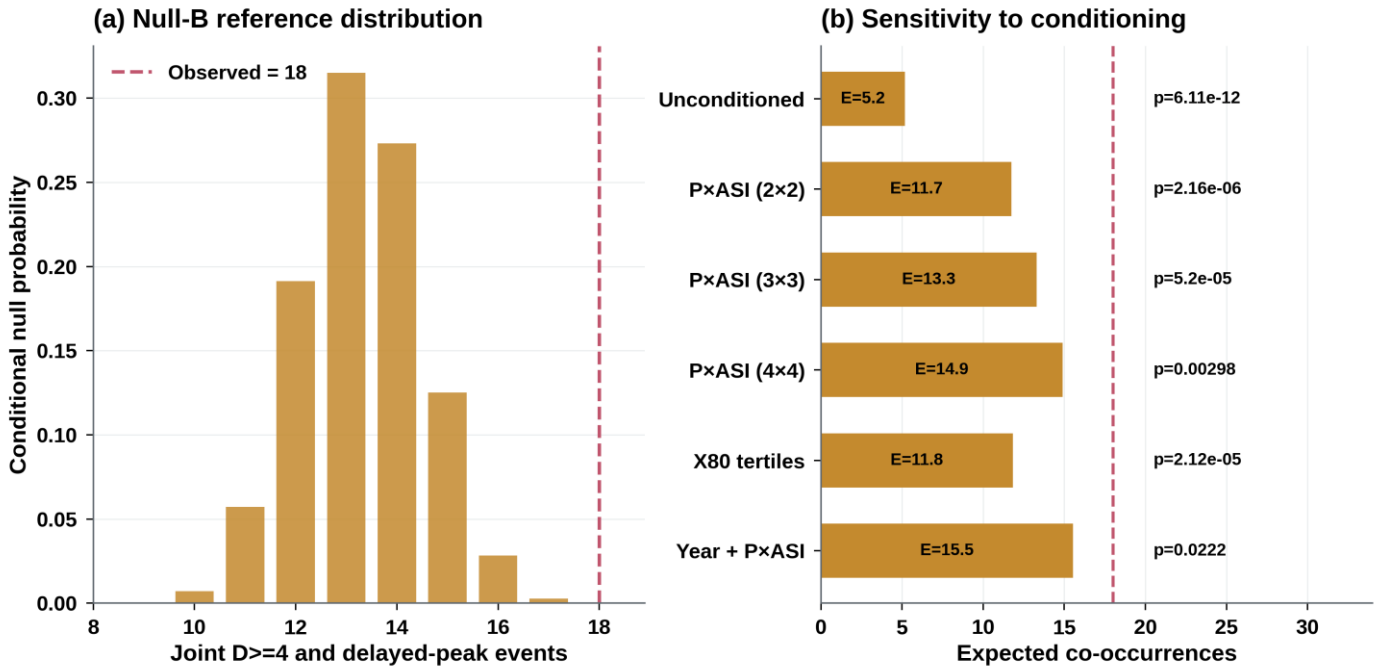

Figure S5. Conditional null references for extensive soil response and delayed runoff. Distribution and sensitivity of D>=4 and confirmed L co-occurrence under alternative forcing and year-stratified nulls (n=139).

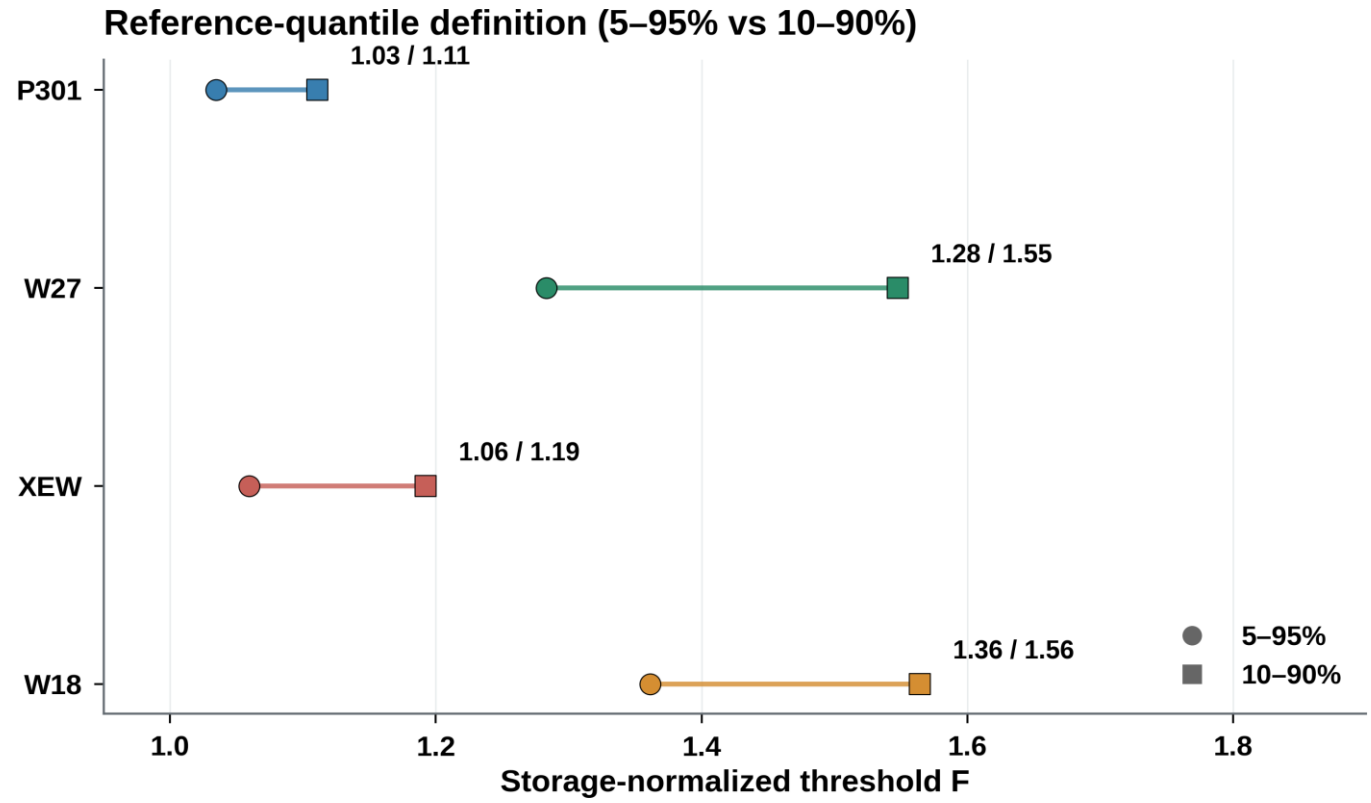

Figure S6. Sensitivity of normalized thresholds to dry-to-wet storage reference quantiles. Alternative 5th–95th versus 10th–90th percentile monitored storage references with fixed site-level thresholds. XEW uses the matched-five mean T=131.18 for both scenarios.

Table S1. Groundwater monitoring-well characteristics and response-rise criteria. Well depths and screened intervals are based on borehole construction records. Minimum-rise thresholds represent the calibrated detection criteria used in the groundwater response-processing workflow. Positive responses additionally had to satisfy the event-window and new-response criteria described in Methods.

Well	Monitoring location	Elevation (m)	Depth (m)	Screen (m)	Minimum rise (m)
W13	Hillslope 1	777.497	10	6-10	0.050
W21	Hillslope 2, lower	724.188	5	2-5	0.020
W22	Hillslope 2, middle	731.473	10	4-10	0.010
W23	Hillslope 2, upper	736.953	26	9-26	0.017
W31	Hillslope 3, lower	689.985	10	4-10	0.060
W32	Hillslope 3, upper	697.596	10	4-10	0.021

Table S2. Published monitoring-position ASI_0+P threshold and sites included in the primary comparison. XEW primary T uses PO1-1 to PO1-5 at MID 60 cm (131.18 mm). WS700, WS900 and WS1100 remain available for the former eight-position sensitivity comparison (135.7625 mm) but are not included in the matched-site primary mean. Other catchments retain all available selected-depth site estimates.

Catchment	Published position	MID (cm)	Threshold T (mm)	Used in primary mean?	Selection role
XEW	PO1-1	60	132.6	Yes	Primary matched set
XEW	PO1-2	60	125.3	Yes	Primary matched set
XEW	PO1-3	60	137.0	Yes	Primary matched set
XEW	PO1-4	60	131.2	Yes	Primary matched set
XEW	PO1-5	60	129.8	Yes	Primary matched set
XEW	WS700	60	136.8	No	Sensitivity only (former 8-site XEW mean)
XEW	WS900	60	131.5	No	Sensitivity only (former 8-site XEW mean)
XEW	WS1100	60	161.9	No	Sensitivity only (former 8-site XEW mean)
P301	CZO-4	20	61.2	Yes	Primary matched set
P301	CZO-5	20	56.1	Yes	Primary matched set
P301	CZO-12	20	53.8	Yes	Primary matched set
P301	CZO-16	20	59.2	Yes	Primary matched set
P301	CZO-17	20	48.8	Yes	Primary matched set
P301	CZO-18	20	62.5	Yes	Primary matched set
P301	CZO-19	20	49.6	Yes	Primary matched set
P301	CZO-21	20	57.7	Yes	Primary matched set
P301	CZO-22	20	57.0	Yes	Primary matched set
P301	CZO-29	20	66.6	Yes	Primary matched set
W18	PO1_top	60	183.6	Yes	Primary matched set
W18	PO1_bot	60	187.9	Yes	Primary matched set
W18	PO2_top	60	194.0	Yes	Primary matched set
W18	PO2_bot	60	261.2	Yes	Primary matched set
W18	PO3_top	60	201.3	Yes	Primary matched set
W18	PO3_bot	60	192.3	Yes	Primary matched set
W27	PO1_top	30	92.6	Yes	Primary matched set
W27	PO1_bot	30	81.2	Yes	Primary matched set
W27	PO2_top	30	98.3	Yes	Primary matched set
W27	PO2_bot	30	124.2	Yes	Primary matched set

Table S3. Analysis-specific event support and observation coverage. All counts refer to event IDs drawn from the same 272-event catalogue, but eligible subsets are criterion-specific. The nine-event cross-domain signed-lag set requires G6 and an available deep-soil onset; only eight of those events simultaneously meet D5. The 2026 record ends in August. "Not eligible" (e.g., S2h conditional on D2) is distinguished from missing observations.

Section	Response or analysis cohort	Events, n	Years, n
4.1	Catalogue	272	13
4.1	X80 available	255	13
4.2	D1-D5 response coordinates	208	13
4.2	G1-G6 response coordinates	34	6
4.2	S2h conditional coordinate	77	11
4.2	Q and L response coordinates	161	11
4.2	L-D5 matched coordinate comparison	139	11
4.3	D1-D5 response-order chronology, fixed fully responding cohort	39	10
4.3	G1-G6 response-order chronology, fixed fully responding cohort	14	5
4.3	G6 plus any deep-soil onset, signed-lag cohort	9	4
4.3	D5 and G6 both fully responding, overlap only	8	4
4.4	D-G joint response	26	6
4.4	Deep-soil response and Q/L	139	11
4.4	D-G-Q/L configuration	24	6
4.4	Conditional S2h and Q/L	52	9

Table S4. Response probability centers, transition ranges, and bootstrap support. D endpoints use a proportional-odds model, so their equal p10–p90 widths are imposed by the common-slope assumption rather than independent physical evidence. G4–G6 come from 34 six-well complete events; S2h is conditional on at least two responding profiles. L here uses all 161 eligible events, whereas the separate L−D5 contrast is refitted on the same 139 matched events. The separate Q hinge (140.9 mm for log(1+Q); raw-Q 148.9 mm) is deliberately excluded because it is not a binary-response probability center and is sensitive to transformation.

Endpoint	Eligible n	Positive n	p50 (mm)	95% CI year-block interval for p50 (mm)	p10–p90 (mm)	Valid / attempted
D1	208	91	142.7	134.5–151.9	100.6–184.8	2000/2000
D2	208	77	152.2	142.1–161.8	110.1–194.4	2000/2000
D3	208	61	165.2	154.6–173.6	123.0–207.3	2000/2000
D4	208	54	172.4	163.5–178.7	130.3–214.5	2000/2000
D5	208	39	190.9	179.8–198.3	148.8–233.0	2000/2000
G4	34	19	149.0	135.4–167.2	105.7–192.4	1783/2000
G5	34	17	159.3	143.6–174.4	124.5–194.1	1741/2000
G6	34	14	179.2	151.6–202.0	134.4–224.0	1741/2000
S2h	77	36	185.0	165.3–203.4	115.2–254.7	1999/2000
L	161	19	211.9	188.7–242.5	167.4–256.3	2000/2000

Table S5. Cumulative response-onset times within fixed full-response event cohorts. D response times use the same 39 D5 events; groundwater times use the same 14 G6 events. Rank 1 is zero elapsed time by definition and is omitted. The IQR describes event-to-event variation, while the 95% interval describes uncertainty in the estimated median.

Responding rank	Events, n	Median elapsed time (h)	Event IQR (h)	95% CI year-block interval for median (h)
D2	39	1.50	0.33-2.50	0.33-1.67
D3	39	2.17	1.25-3.25	1.67-2.83
D4	39	2.83	1.75-5.17	2.17-3.67
D5	39	6.83	4.42-11.33	4.50-10.33
G2	14	1.00	0.00-1.75	0.00-1.00
G3	14	2.00	1.00-3.75	1.00-3.00
G4	14	2.50	1.00-6.25	1.00-3.00
G5	14	4.50	2.25-9.00	2.50-9.00
G6	14	17.00	12.25-19.75	12.00-30.00

Table S6. Sensitivity of runoff-depth associations to rainfall and antecedent-wetness matching criteria. The fraction compares runoff depth for extensive (D≥4) and less-extensive soil-response events within driver-matched strata/pairs. Event pairs reuse observations and are not independent event replicates. The p values were obtained from 5,000 conditional permutations. ΔP denotes the residual mean rainfall difference between paired groups; narrower matching also decreases the number of eligible comparisons.

Matching condition	Pairs	Distinct events	Fraction Q higher for D≥4	Permutation p	Mean ΔP (mm)
PA3, no caliper	179	76	0.760	0.0016	19.23
P≤20, ASI≤30	93	55	0.656	0.0452	3.25
P≤15, ASI≤20	70	49	0.629	0.1044	2.95
P≤10, ASI≤20	63	44	0.619	0.1266	1.97
Same year + PA3	35	36	0.686	0.0890	14.07

Table S7. Adjacent response-onset intervals within fixed full-response cohorts. D intervals use the same 39 D5 events; G intervals use the same 14 G6 events. Rank k denotes the k-th responding location within each event, not a fixed geographic order. Year-block intervals quantify resampling variability across the observed years and do not resolve the small number of independent years or site-specific limitations.

Domain	Transition	n	Years	Median interval (h)	Event IQR (h)	95% year-block interval for median (h)
D	1→2	39	10	1.50	0.33–2.50	0.33–1.67
D	2→3	39	10	0.67	0.25–1.58	0.33–1.33
D	3→4	39	10	0.50	0.00–1.08	0.00–0.83
D	4→5	39	10	2.83	1.83–7.67	2.17–6.51
G	1→2	14	5	1.00	0.00–1.75	0.00–1.00
G	2→3	14	5	1.00	1.00–2.00	0.00–2.00
G	3→4	14	5	0.00	0.00–1.00	0.00–1.00
G	4→5	14	5	1.00	0.25–1.00	0.50–3.00
G	5→6	14	5	10.50	7.25–13.50	8.00–25.00

Note: For the D5 cohort, the preceding-interval summary was calculated by first taking the median of the first three adjacent intervals within each event and then taking the median across the 39 events.