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Supplemental Material

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Coupling of Atmospheric Rivers and Levee Failure Events in California's Sacramento–San Joaquin Delta, 1980–2021

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Supplemental Material

Of the 57 known events, we categorized the levees into type and characteristics and found that failures were divided between 32 non-project levees (56% of 57 failures), 24 restricted height levees, which include both non-project and unattributed levees (42% of 57 failures), and 1 project levee (Table S1). Project levees are maintained at a higher standard than non-project and unattributed levees. The most common type of levee event was a temporary failure, where a levee failed but was repaired within a couple of months. Of temporary events, the overwhelming majority were non-project or unattributed. There was one project levee temporary failure. Permanent failures were more likely to be restricted height levees, which includes levees in the non-project and unattributed levee categories.

Table S1: Levee events by failure outcome and type.

		Levee Failure Outcome			
		Averted	Temporary	Permanent	Total
Levee Type	Agricultural	15	15	1	31
	Restricted height	4	16	4	24
	“New urban”	0	1	0	1
	Project	0	1	0	1
	Total	19	33	5	57

Figure S1 shows the islands that experienced documented levee events in the study period. Sources for the details of the levee events are in Table S2. Some levees have been breached intentionally for flood control or habitat restoration, such as Prospect and Liberty islands in the Yolo Bypass (Hopf 2011). Similarly, the levees at McCormack-Williamson Tract are intended to relieve flood pressure from the city of Thornton, which is on the border of the Delta. Some other levees, such as those protecting Fay, Rhode, and Little Mandeville islands and Little Franks Tract, are of limited height because there is minimal land fit for agriculture, and, therefore, few financial resources for levee investments (Hopf 2011). Some islands with agricultural or restricted height levees (e.g., Glanville, Dead Horse, Van Sickle, Prospect) experienced temporary floods again and again with repairs in between. These islands are among those that have limited resources for improvements. For instance, “Dead Horse is a 200-acre district that

has little resources. With a 200-acre base, it's tough to raise enough money to maintain the levees. Our district is 8,500 acres and has 23 miles of levees. Dead Horse has two miles. It's tough for them” (Interview 25). On some islands, e.g., Tyler, Twitchell, Bradford, levee failure has been averted multiple times through flood-fighting efforts. Finally, there are levees that only seem to be affected by really strong events. There were clusters of levee events across multiple islands in WY 1983, 1986, 1997, and 1998.

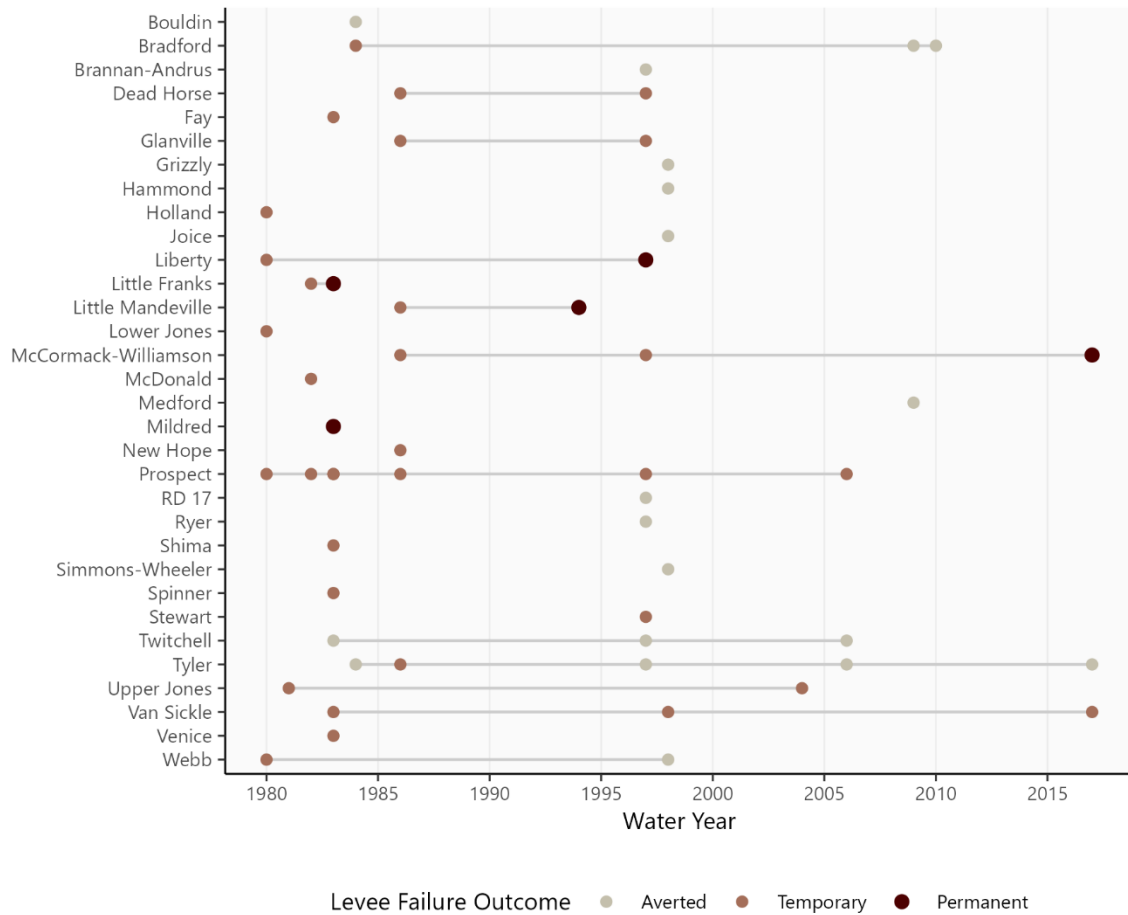


Figure S1: Levee events by island. Points are plotted by the water year of the event and color indicates the failure outcome. Connector lines indicate where multiple levee events occurred on the same island during different water years.

Table S2: Levee events

Year	Month	Day	Island/Tract	Outcome	Type	Source*
1980	1	16	Liberty	Temporary failure	Limited height	Hopf
1980	1	18	Webb	Temporary failure	Agricultural	DeltaRevision, Hopf
1980	1	19	Holland	Temporary failure	Agricultural	DeltaRevision, Hopf
1980	2	12	Prospect	Temporary failure	Limited height	Hopf
1980	9	26	Lower Jones	Temporary failure	Agricultural	DeltaRevision, DPC, Hopf
1980	10	23	Upper Jones	Temporary failure	Agricultural	Hopf
1981	12	23	Prospect	Temporary failure	Limited height	Hopf, USACE
1981	12	24	Little Franks	Temporary failure	Wetland	Hopf, multiple news articles
1982	8	23	McDonald	Temporary failure	Agricultural	DeltaRevision, DPC, Hopf
1982	11	30	Venice	Temporary failure	Agricultural	DeltaRevision, Hopf
1983	7	30	Twitchell	Averted	Agricultural	Hopf
1983	12	3	Bradford	Temporary failure	Agricultural	DeltaRevision, Hopf
1983	12	9	Bouldin	Averted	Agricultural	Hopf
1983	1	16	Van Sickle	Temporary failure	Limited height	Hopf
1983	1	27	Mildred	Permanent failure	Limited height	DeltaRevision, Hopf
1983	1	30	Prospect	Temporary failure	Limited height	Hopf
1983	3	1	Prospect	Temporary failure	Limited height	Hopf
1983	1	27	Shima	Temporary failure	"New urban"	Hopf
1983	1	27	Spinner	Temporary failure	Suisun Marsh	Hopf
1983	1	27	Little Franks	Permanent failure	Wetland	Hopf
1983	1	29	Fay	Temporary failure	Wetland	Hopf
1984	8	21	Tyler	Averted	Agricultural	Hopf
1986	2	19	Tyler	Temporary failure	Agricultural	DeltaRevision, Hopf
1986	2	19	Glanville	Temporary failure	Agricultural	Hopf
1986	2	19	Dead Horse	Temporary failure	Agricultural	Hopf
1986	2	20	New Hope	Temporary failure	Agricultural	DeltaRevision, Hopf
1986	3	20	Little Mandeville	Temporary failure	Agricultural	Hopf
1986	2	18	McCormack-Williamson	Temporary failure	Limited height	Hopf
1986	2	19	Prospect	Temporary failure	Limited height	Hopf, multiple news articles
1994	8	1	Little Mandeville	Permanent failure	Agricultural	Hopf, multiple news articles
1997	1	1	Ryer	Averted	Agricultural	Hopf
1997	1	1	Brannan-Andrus	Averted	Agricultural	Hopf
1997	1	1	Twitchell	Averted	Agricultural	Hopf
1997	1	1	RD 17	Averted	Agricultural	Hopf
1997	1	3	Dead Horse	Temporary failure	Agricultural	Hopf, multiple news articles
1997	1	3	Glanville	Temporary failure	Agricultural	Hopf
1997	1	7	Tyler	Averted	Agricultural	Hopf
1997	1	10	Stewart	Temporary failure	Agricultural	multiple news articles
1997	1	3	McCormack-Williamson	Temporary failure	Limited height	Hopf, multiple news articles

1997	1	5	Prospect	Temporary failure	Limited height	Hopf
1997	1	10	Liberty	Permanent failure	Limited height	Hopf, Hart, USFWS
1998	2	1	Webb	Averted	Agricultural	Hopf
1998	2	1	Van Sickle	Temporary failure	Limited height	Hopf
1998	2	1	Joice	Averted	Suisun Marsh	Hopf
1998	2	1	Grizzly	Averted	Suisun Marsh	Hopf
1998	2	1	Hammond	Averted	Suisun Marsh	Hopf
1998	2	1	Simmons- Wheeler	Averted	Suisun Marsh	Hopf
2004	6	3	Upper Jones	Temporary failure	Project levee	Hopf
2006	1	1	Twitchell	Averted	Agricultural	multiple news articles
2006	1	15	Tyler	Averted	Agricultural	multiple news articles
2006	1	1	Prospect	Temporary failure	Limited height	Hopf
2009	1	24	Medford	Averted	Agricultural	multiple news articles
2009	8	27	Bradford	Averted	Agricultural	Hopf
2009	12	7	Bradford	Averted	Agricultural	multiple news articles
2017	2	12	Tyler	Averted	Agricultural	multiple news articles
2017	2	11	McCormack- Williamson	Permanent failure	Limited height	multiple news articles
2017	1	12	Van Sickle	Temporary failure	Suisun Marsh	multiple news articles

*Protocol for newspaper search is in the Data and Methods of the main text.

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