Cahokia's emergence and decline coincided with shifts of flood frequency on the Mississippi River

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Here we establish the timing of major flood events of the central Mississippi River over the last 1,800 y, using floodwater sediments deposited in two floodplain lakes. Shifts in the frequency of high-magnitude floods are mediated by moisture availability over midcontinental North America and correspond to the emergence and decline of Cahokia—a major late prehistoric settlement in the Mississippi River floodplain. The absence of large floods from A.D. 600 to A.D. 1200 facilitated agricultural intensification, population growth, and settlement expansion across the floodplain that are associated with the emergence of Cahokia as a regional center around A.D. 1050. The return of large floods after A.D. 1200, driven by waning midcontinental aridity, marks the onset of sociopolitical reorganization and depopulation that culminate in the abandonment of Cahokia and the surrounding region by A.D. 1350. Shifts in the frequency and magnitude of flooding may be an underappreciated but critical factor in the formation and dissolution of social complexity in early agricultural societies.

geoarchaeology | paleohydrology | Mississippi River | flooding | Cahokia

The episodic breakdowns of early agricultural societies, many of which were situated in the floodplains of major rivers, are often attributed to episodes of severe drought (1–3) that correlate with cascading social and environmental feedbacks (4, 5). The causes of the decline and abandonment of Cahokia, a major late prehistoric population center that emerged in the floodplain of the central Mississippi River (6), remain unclear but have also been attributed to drought (7), as well as resource overexploitation (8), intergroup conflict, and sociopolitical factionalism and upheaval (6, 9, 10). Here, we present evidence that Cahokia emerged during a multicentennial period of enhanced midcontinental aridity that inhibited the occurrence of high-magnitude floods on the central Mississippi River, and that Cahokia's decline and abandonment correspond to an increase in the frequency of large floods. These findings imply that the disintegration and dissolution of Cahokia may be, in part, societal responses to enhanced hydrological variability in the form of high-magnitude flooding.

Cahokia's emergence as a regional center can be traced to the population growth and intensified cultivation of native domesticates that began around A.D. 400 in the floodplain of the central Mississippi River near modern-day Saint Louis, MO (6, 11, 12). By A.D. 1050, Cahokia emerged as a hierarchically organized cultural and political center in this region, which was inhabited by tens of thousands of individuals supported in part by the cultivation of native domesticates and maize (6, 13). Settlements affiliated with Cahokia were concentrated on higher-elevation ridges in the floodplain with access to a variety of resources (14), with no evidence that irrigation canals were constructed in this moist and temperate region. Populations in the Cahokia region continued to grow until *ca.* A.D. 1200, when the region's population size and cultural prominence began to decline (6, 9, 15), and, by A.D. 1350, Cahokia and the surrounding region were almost completely abandoned (6).

Archaeologists have previously recognized the possibility that large floods could have affected the sociopolitical stability of Cahokia by disrupting food production and storage, damaging houses, and motivating individuals to relocate (6, 9, 16). Before the establishment of modern flood control infrastructure in the early 20th century (17), large floods like the A.D. 1844 event inundated extensive tracts of the central Mississippi River floodplain (Fig. S1), forcing residents to evacuate and causing widespread destruction (6) (historical accounts of flooding are available in *SI Text*). Past shifts in the locations of house basins and storage pits along elevational gradients in the Mississippi floodplain have been interpreted as indirect evidence for changing hydrological conditions (6, 9, 16), but direct evidence of flooding is rare in archaeological excavations from the Cahokia area (e.g., ref. 18).

Here, we reconstruct the timing of major flood events in the Cahokia area using floodwater sediments deposited in floodplain lakes (19). During flood stages that hydrologically connect the main channel with floodplain lakes, floodplain lakes act as sediment traps that allow the suspended load of floodwaters to fall out of suspension (19, 20). The composition of floodwater sediments usually differs from locally sourced sediment deposited during nonflood conditions, particularly in grain size distribution (19). Across the wide floodplain of a low-gradient river like the Mississippi, overbank floods deposit well-sorted fine silt- and clay-sized sediments in distal floodplain lakes and depressions (21–23). Analysis of sediment records from multiple basins in similar geomorphic settings along the same river ensures that identified flood events are not due to localized erosion or flooding from tributaries (20).

Sediment cores were obtained from two floodplain lakes in the central Mississippi River valley that are abandoned channels of the Mississippi River: Horseshoe Lake (HORM12; Madison

Significance

Our paper evaluates the role that flooding played in the emergence and decline of Cahokia—the largest prehistoric settlement in the Americas north of Mexico that emerged in the floodplain of the Mississippi River around A.D. 1050. We use sediment cores to examine the timing of major Mississippi River floods over the last 1,800 y. These data show that Cahokia emerged during a period of reduced megaflood frequency associated with heightened aridity across midcontinental North America, and that its decline and abandonment followed the return of large floods. We conclude that shifts in flood frequency and magnitude facilitated both the formation and the breakdown of Cahokia and may be important factors in the declines of other early agricultural societies.

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County, IL; 38.704767°N, 90.081279°W), situated 5 km northwest of Cahokia, and Grassy Lake (GRAS13; Union County, IL; 37.431701°N, 89.377466°W), located 190 km downstream from Cahokia (Fig. 1). Both lakes are young features of the high-sinuosity meander belt that formed before the main channel stabilized during the late Holocene into a narrow low-sinuosity meander belt (24). Before the 20th century, Horseshoe Lake attained surficial hydrological connectivity with the Mississippi River only during high-magnitude floods (>10-m stage at Saint Louis) that inundated the majority of the floodplain around Cahokia (Fig. S2). Modern flood control infrastructure now isolates Horseshoe Lake from floods (17, 25), including the A.D. 1993 flood (26).

Results and Discussion

The sediment cores collected from Horseshoe and Grassy Lakes are predominately dark brown massive silts interbedded with distinct light gray to pale brown layers of well-sorted silty clay that we interpret as floodwater sediments deposited by the Mississippi River (Fig. 2). These floodwater sediments are similar in texture to the sediments deposited in floodplain lakes and depressions by historical overbank Mississippi River floods (21–23), and their low organic content and low concentrations of microfossils (12) are consistent with floodwater sediments identified in previous paleohydrological studies (19). At both sites, the first principal component (PC1) of grain size distributions is closely correlated to median grain size and uniformity, and PC1 explains >55% of grain size variance. We define samples with scores in the upper quartile of PC1 as floodwater sediments. These samples have median grain sizes that are significantly lower ($P < 0.005$; paired t tests) and more uniform than nonfloodwater sediments. To establish the timing of flood events, Bayesian age–depth models were constructed for both cores (Fig. S3) based on 17 radiocarbon dates from terrestrial plant macrofossils (Table S1), core tops, and the timing of Anglo-American settlement based on the recent increase of *Ambrosia*-type pollen (12) using bacon v.2.2 (27).

Based on the criteria described above, we identify eight flood events at Horseshoe Lake and five at Grassy Lake (Fig. 2). The five most recent floodwater deposits (flood events I–V) in Horseshoe Lake at A.D. 1810 (A.D. 1780–1880), A.D. 1630 (A.D. 1570–1720), A.D. 1520 (A.D. 1480–1640), A.D. 1400 (A.D. 1340–1510), and A.D. 1200 (A.D. 1080–1250) (ages reported as the mode and 95% confidence interval of probability density functions generated by bacon) temporally coincide with the five flood events recorded in Grassy Lake at A.D. 1800 (A.D. 1760–1880), A.D. 1570 (A.D. 1530–1730), A.D. 1500 (A.D. 1460–1670), A.D. 1390 (AD 1300–1570), and A.D. 1200 (A.D. 1000–1310); assuming that these five deposits represent the same floods, the joint age estimates for these five floods narrow to A.D. 1800 (A.D. 1780–1870), A.D. 1590 (A.D. 1550–1730), A.D. 1510 (A.D. 1470–1590), A.D. 1400 (A.D. 1340–1460), and A.D. 1200 (A.D. 1100–1260) (Fig. S4 and Table S2). The topmost event in both lakes corresponds with the large A.D. 1844 flood that inundated most of the central Mississippi River's floodplain (6, 17) (see also *SI Text*), including the area around Cahokia (Fig. S1), but the other seven identified flood events predate the instrumental record. The three older floodwater deposits (flood events VI–VIII) in Horseshoe Lake at A.D. 580 (A.D. 510–630), A.D. 490 (A.D. 440–560), and A.D. 280 (A.D. 160–320) predate the formation of Grassy Lake. The synchronicity of the five most recent flood events at these two distant sites, and the correspondence of flood event I to a historically documented flood, strongly indicates that these floodwater sediments originated from the Mississippi River during high-magnitude floods.

The frequency of large floods in the central Mississippi River has shifted over the last two millennia (Fig. 3) as a result of atmospheric circulation patterns that promote or suppress precipitation over midcontinental North America (28–30). At Cahokia, large floods are concentrated in two intervals from *ca.* A.D. 300 to A.D. 600 and *ca.* A.D. 1200 to A.D. 1850. These intervals correspond to large flood events on the upper Mississippi River (29) and occur during periods of greater moisture availability over the midcontinent (30, 31). In contrast, no large floods occur between *ca.* A.D. 600 and A.D. 1200, when more arid conditions are documented across central North America (30–34). The close correspondence between midcontinental aridity and Mississippi River flood history implies that decreased moisture availability over the Missouri and Upper Mississippi River basins inhibited the intensive runoff from rainfall and/or snowmelt required to generate large floods (28, 29) that would have inundated Cahokia, neighboring settlements, and croplands in the floodplain of the central Mississippi River.

Shifts in the frequency and magnitude of flood events in the central Mississippi River valley also correspond with changes in settlement patterns, population size, and land use that define Cahokia's emergence and decline (Fig. 3). Intensified cultivation

Fig. 1. Locations of Horseshoe Lake, Grassy Lake, Cahokia, and other Late Prehistoric population centers in the central Mississippi River valley. (*Inset*) Mississippi Basin and major tributaries (blue) in the United States.

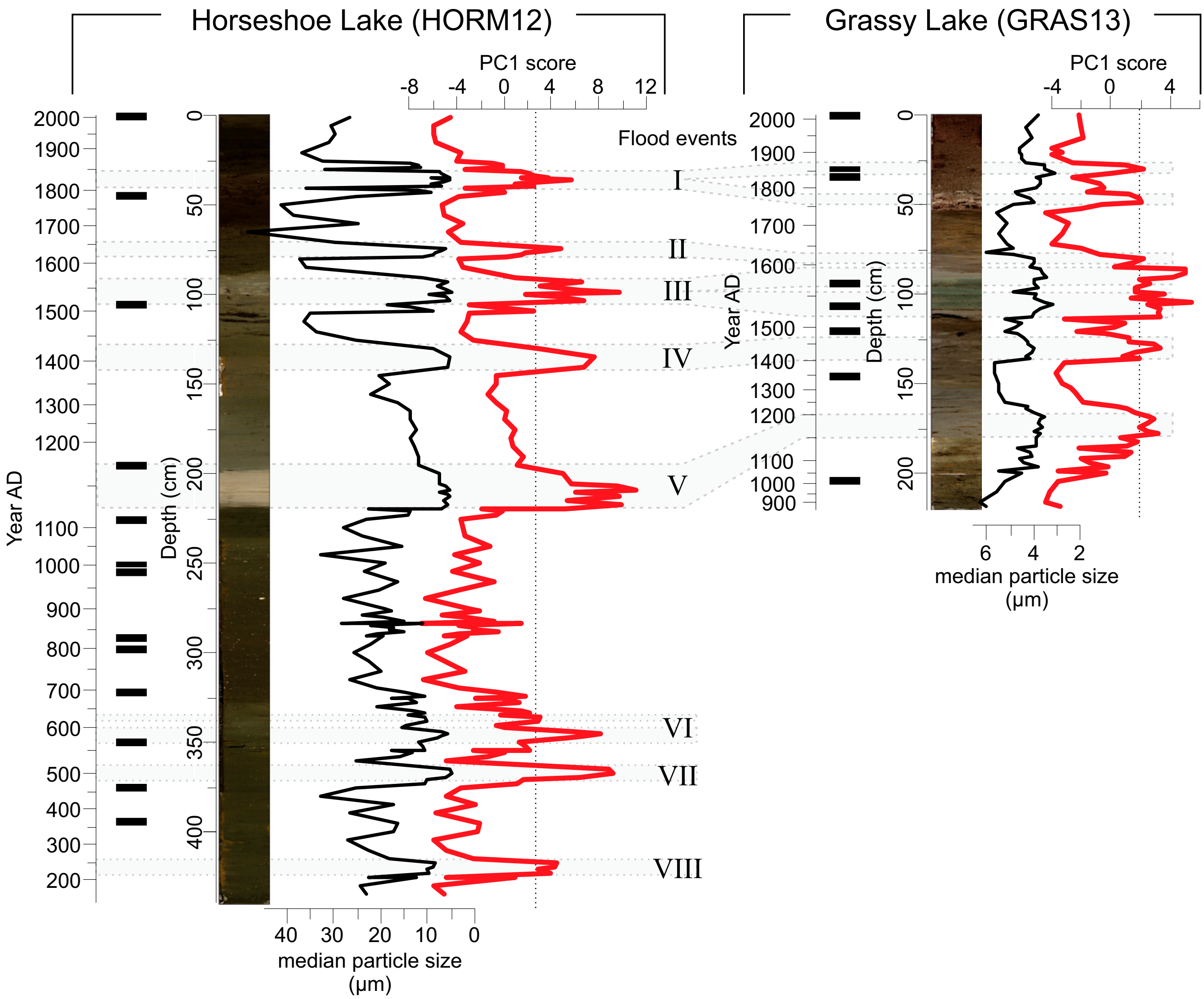

Fig. 2. Median particle size and PC1 scores for Horseshoe Lake (*Left*) and Grassy Lake (*Right*) alongside composite core photographs by depth from surface–water interface. Depths of chronological controls used in age–depth model are marked with black boxes. Flood events (numbered I–VIII) are denoted with gray horizontal bars.

of native domesticates in the central Mississippi River valley began during the early Late Woodland period, around A.D. 400–650 (11, 12, 35), when known settlements were concentrated on higher-elevation alluvial fans and terraces along the edge of the floodplain (16, 36). The absence of large floods from A.D. 600 to A.D. 1200 corresponds to the expansion of settlements to lower-elevation floodplain ridges that are separated by swales, sloughs, and old meander scars (14, 24, 36, 37), an increase in settlement numbers (6, 36), and continued intensification in the cultivation of native domesticates, and, after *ca.* A.D. 900, maize (11, 12). At A.D. 1050, toward the end of this multicentennial period of midcontinental aridity and infrequent large floods, Cahokia emerged as a hierarchically organized regional center that drew thousands of people from across the midcontinent (6, 38).

At the height of Cahokia's size and cultural prominence, flood event V (*ca.* A.D. 1200)—the first large flood event in over 500 y—was of a magnitude sufficient to inundate croplands, food caches, and settlements across most of the floodplain, and would have forced residents to temporarily relocate to the higher elevations available along the edge of the floodplain and adjacent uplands. Floods in the central Mississippi River valley typically occur during the growing season (17, 29); unexpectedly high water levels at this time would have made most of the floodplain uninhabitable, and created serious and persistent agricultural shortfalls for Cahokia's residents by destroying both crops and the agricultural surpluses from previous years stored in underground pits. After floodwaters receded, considerable effort would be required by the region's residents to rebuild in place, clear fields of the sediment and debris that overbank floods deposit unevenly across the floodplain (21–23), and restore food production to preflood levels. Neighboring communities at higher elevations were not directly affected by flooding, but they likely played an important role during the flood by absorbing refugees from Cahokia and other settlements inundated by floodwaters, and providing labor, materials, and food in the flood's aftermath. Maintaining political authority over this dispersed and fragmented population would have posed a significant challenge to a complex nonstate society like Cahokia, as similar societies around the world are typically limited in their ability to exert a strong and persistent hegemony over areas >40 km

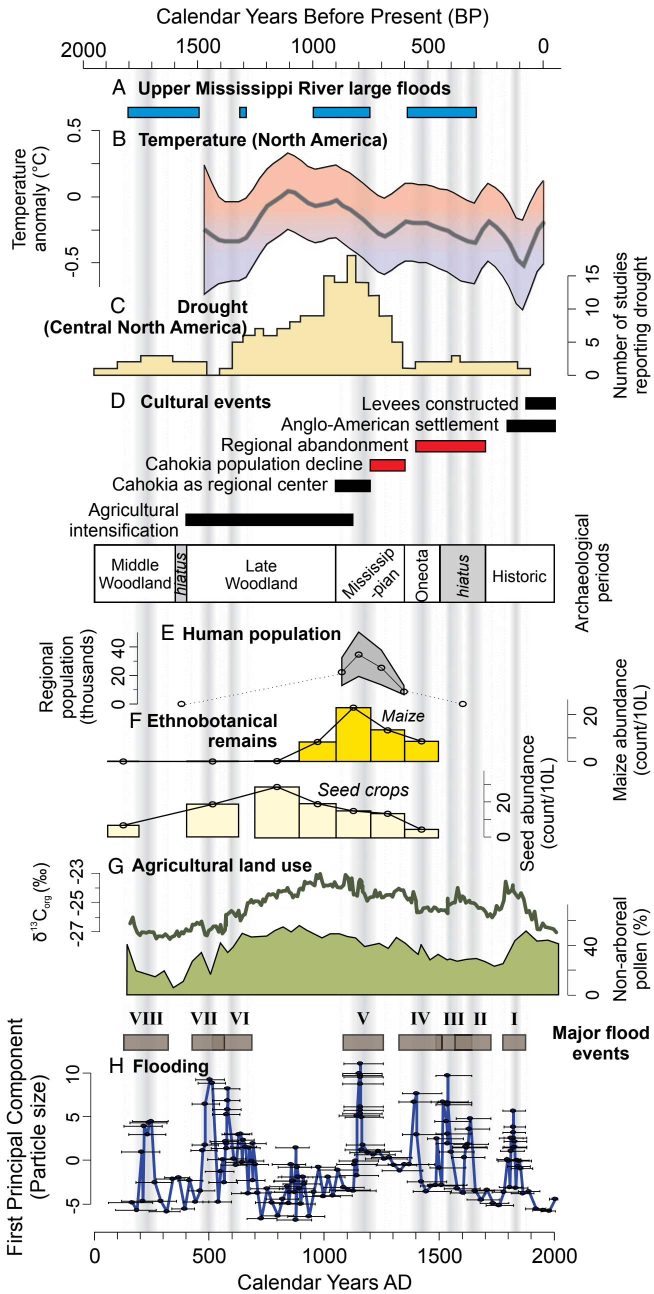

Fig. 3. Record of major flood events from Horseshoe Lake (*H*, this study) plotted against paleoclimatological (*A–C*), archaeological (*D–F*), and paleoecological records (*G*) from Cahokia and midcontinental North America. Proxy evidence of large floods on the upper Mississippi River reconstructed from overbank deposits (*A*, ref. 29), North American temperature (*B*, ref. 34), and histogram of proxy record ($n = 21$) evidence for aridity in central North America (*C*, ref. 31) track environmental changes over midcontinental North America. Archaeological periods and cultural events (*D*, refs. 6 and 35), ethnobotanical data (median abundance of indigenous seed crops and maize by archaeological period; *F*, ref. 11), regional population size (*E*, ref. 6), and nonarboreal pollen and organic carbon isotopic data ($\delta^{13}C_{org}$) from Horseshoe Lake (*G*, ref. 12) track agricultural intensification/contraction and population growth/decline in the central Mississippi River valley.

in diameter (39, 40). Through its direct and indirect impacts on the stability of the Cahokia region's economy and the welfare of its inhabitants, this large and unprecedented flood held the potential to reshape the region's sociopolitical dynamics long after the floodwaters receded.

Environmental perturbations often trigger a societal reorganization that either initiates societal breakdown or fosters resilience, with the outcome mediated by the preparedness and response of established social, political, and ideological institutions (4, 5, 41). Extensive inundation of the floodplain was unprecedented for the sociopolitical system established at Cahokia, and the return of large floods at *ca.* A.D. 1200 at the onset of regional depopulation (6), agricultural contraction (12), political decentralization (15), the construction of defensive palisades (42), destruction of outlying population centers (9, 43), and decline of monumental construction at Cahokia (9) implicate flooding as a factor in the reorganization of Cahokia's sociopolitical structure that initiated its decline. In contrast to the large Mississippi River floods of the 19th century that fostered resilience and motivated legislation aimed at preventing damage from flooding (17), Cahokia's leaders appear to have been unable to maintain the impression of security and stability following the economic upheaval created by the return of large floods. Sociopolitical disintegration progressed over the following century as the residents of the Cahokia area continued to relocate to other regions; by A.D. 1350, the sociopolitical system centered on Cahokia had completely dissolved (6, 10).

The declines of many early agricultural societies in the tropics and subtropics, including those of the ancient Puebloans, Classic Maya, Akkadians, and Harappans, are often attributed to drought and water limitation (1–3). In contrast, our work indicates that Cahokia, a sociopolitical system established in a moist and temperate region, emerged and flourished during a period of heightened midcontinental aridity and was instead vulnerable to flooding mediated by subcontinental-scale shifts in moisture availability. These findings do not preclude the role of additional factors in Cahokia's decline, including more localized high-frequency hydroclimatic variability recorded by dendroclimatological data (7). Instead, our work emphasizes the sensitivity of fluvial systems to climatic variability (28, 29, 44) and shows that variation in flood frequency and magnitude may be an underappreciated but key factor in the development and disintegration of early agricultural societies, even in temperate regions (e.g., refs. 45 and 46). Floodwater deposits may be absent or obscured by postdepositional processes in archaeological contexts (18, 46), but, as demonstrated by this study, can be well preserved in lacustrine sedimentary records. Hydrological variability—both droughts and floods—appears to have profoundly shaped late Holocene ecosystems and societies (1, 3, 7, 33, 47), and, given the increase in the frequency of extreme hydroclimatic events projected for the 21st century (48), more work is needed to understand the coupled responses of sociocultural and hydrological systems to present and past climatic variability.

Methods

Sediment Core Extraction and Sampling. Sediment cores with overlapping 0.5-m offsets were extracted from the in-filled thalwegs of Horseshoe Lake and Grassy Lake in May 2012 and June 2013, respectively, using a modified Livingstone piston corer with a Bolivia adapter for surface sediments. All cores were described, wrapped, and labeled in the field, then taken to the National Lacustrine Core Facility at the University of Minnesota, where they were longitudinally split, scanned for magnetic susceptibility, and photographed at high resolution. Primary core sections, overlapping core sections, and surface sediment sections were used to create continuous composite cores based on stratigraphy and magnetic susceptibility. These composite cores measured 5.5 m and 2.2 m for Horseshoe Lake and Grassy Lake, respectively. Only the top 4.4 m from Horseshoe Lake were used in the present study, because the bottom section of core is characterized by interbedded sands and clays that were deposited before the main channel of the Mississippi River migrated to the low-sinuosity meander belt along the western edge of the floodplain (12, 24). Sediment cores were sampled at 1-cm intervals and refrigerated in labeled Whirl-pak bags for future subsampling.

Radiocarbon Dates. Seventeen wood and charcoal samples from terrestrial plant macrofossils extracted from the Horseshoe and Grassy Lake cores were collected and submitted for Accelerator Mass Spectrometry (AMS) radiocarbon dating (Table S1). Plant macrofossils were rinsed with deionized water obtained from an Academic Milli-Q water purifier with filter for organic carbon, and then dried for 24 h at 60 °C before submission to the Center for Applied Isotope Studies at the University of Georgia, or DirectAMS, for AMS dating.

Particle Size Analysis. Sediment subsamples of 0.5 cm^3 from the Horseshoe Lake and Grassy Lake cores were pretreated with 1 M HCl, to remove carbonates (i.e., gastropod shells), and rinsed with deionized water. Laser diffraction particle size analysis cannot distinguish coarse organic particles (e.g., roots, wood fragments) from coarse mineral grains, so these organics were removed by ignition at 360 °C for 2 h in a muffle furnace. Pretreated samples were then homogenized with mortar and pestle before their particle size distributions were measured on a Malvern Mastersizer 2000MU laser diffraction particle size analyzer after being dispersed with 10 mL of dispersant (0.5% sodium hexametaphosphate) and sonication for 5–15 min (midrange power, 10-μ tip displacement). To ensure disaggregation and full dispersion, samples were repeatedly sonicated and remeasured until a reproducible grain size distribution was observed. A base sampling resolution of 5–6 cm was initially used, with a higher sampling resolution (1–2 cm) used around core depths with lighter sediment color and/or low organic content that represented potential floodwater deposits. In total, 156 and 87 samples were measured at Horseshoe Lake and Grassy Lake, respectively, for a combined mean sampling resolution of 2.7 cm. A principal components analysis was performed on the full particle size distribution for all samples in each lake in R v. 2.15.1 using the princomp() function; PC1 explains >55% of grain size variance at both sites.

Age–Depth Modeling. Age models were produced for Horseshoe Lake and Grassy Lake (Fig. S3) using bacon v.2.2 (27), calibrating all radiocarbon dates using IntCal13 (26). Additional chronological controls included the core tops (A.D. 2012 and A.D. 2013 for Horseshoe Lake and Grassy Lake, respectively) and the Euro-American settlement horizon (A.D. 1800 $\pm$ 25 y) identified from the abrupt increase in *Ambrosia* pollen (12) at 44 cm in Horseshoe Lake and 36 cm at Grassy Lake. To model the variable sedimentation rate in these floodplain lakes caused by flood events, we set section thickness to 2 cm, then imposed a high sedimentation rate (0.5 y/cm) on floodwater deposits > 5 cm in thickness identified from the particle size analyses, and imposed slower sedimentation rates (10 y/cm) on nonfloodwater sediments. Imposing the Bacon default sedimentation rate of 20 y/cm on nonfloodwater sediments resulted in age models that failed to pass through many calibrated chronological controls, probably because this default sedimentation rate is based primarily on small upland lakes whose geomorphic setting differs substantially from the floodplain lakes used in this study (49). Probability density functions (PDF) were obtained for each floodwater deposit using the Bacon.Age.d() function in bacon, which outputs all ages for a given depth. To develop joint PDFs and more tightly constrained age estimates for flood events I–V, the individual PDFs from Horseshoe and Grassy Lakes were multiplied together and rescaled to sum to a probability of 1 (Table S2).

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Supporting Information

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SI Text

SI Methods

Flood Extent Mapping. Maps delineating the extent of floodwater inundation around Horseshoe Lake were produced using high-resolution lidar imagery of the floodplain obtained from the Illinois State Geological Survey and historic records of flooding from gauging stations along the central Mississippi River (Figs. S1 and S2). The large flood in A.D. 1844 described in newspaper accounts crested at 12.6 m above the datum (115.7 m asl) of the US Geological Survey gauging station at Saint Louis (EADM7). The nearest upstream and downstream gauging stations at Alton, IL (ALNI2), and Chester, IL (CHSI2), with datums of 120.5 m asl and 104.0 m asl, respectively, were used to calculate an average north-to-south slope (0.167 m/km) of the datum around Horseshoe Lake, and elevations below this datum plus flood stage were then delineated as inundated. Recent modifications to the floodplain (e.g., levees, highways, buildings, and landfills) that mostly raised the elevation of the floodplain were not removed from the underlying elevation data, so our analysis likely underestimates the extent of prehistoric floods. These maps thus serve to illustrate that only high-magnitude floods (>10-m stage) inundating the majority of the floodplain will create surficial hydrological connectivity between the Mississippi River and Horseshoe Lake.

SI Historical Accounts of A.D. 1844 Flood

The Ottawa Free Trader (Ottawa, IL), 5 July 1844. The following appeared in The Ottawa Free Trader on 5 July 1844.

Of the Mississippi river, the Belleville Banner of June 25th says, "It is higher by this time, by several feet, than at any previous period, so far as we have any knowledge or history concerning it; and the consequent destruction of life and property is truly appalling. The entire 'American Bottom', with all its towns and villages, is literally inundated from one end to the other; and small steamboats may now pass with facility over the ground which, but a few days since, gave every promise of an ample harvest. The towns of Brooklyn, Illinoistown, Prairie du Pont, Cahokia, Prairie du Roche, and Kaskaskia are entirely abandoned to the remorseless flood. In fact, the inhabitants of nearly the entire bottom have been driven to the hills for refuge; while their fields are laid waste, their stock in many instances drowned, and their valuable improvements destroyed."

New-York Daily Tribune (New York, NY), 4 June 1844. The following appeared in The New-York Daily Tribune on 4 June 1844.

Illinois—Politics—The Great Flood—St. Louis in Danger! – Crops, &c. Correspondence of The Tribune, Alton, Ill. May 17th, 1844.

The Mississippi is now higher than it was ever known to be by the oldest inhabitant of the place, and it is still rising, while the rain pours down in a continuous current. The water reaches within a few inches of the curb stone on Front Street, and although the river is from 15 to 30 miles wide for a long distance above us, it is still rising more than 12 inches a day. At Madison, five miles below, the Mississippi is forming for itself a new channel; crossing the American Bottom, (which is an alluvial deposit and easily worn away) and finding its old bed again below St. Louis. It is said by those who have examined it that there is no doubt it will ere long be the only course of the stream, and that there is every indication it will be accomplished at this time. If this should be the case, St. Louis will be "high and dry," as the junction of the Missouri is 20 miles above it.

The crops are suffering exceedingly from the wet: many large fields of corn that were growing finely, are now, and have been several days, covered with water, and if it does not immediately subside the corn must be destroyed. Wheat that is just ready to "head out" is beaten down by the continued rains flat to the earth, and two large farmers told me to-day they would be glad to sell their crops for one-half of an ordinary one. Fruit promises to be very abundant, and vegetables begin to come into market plentifully.

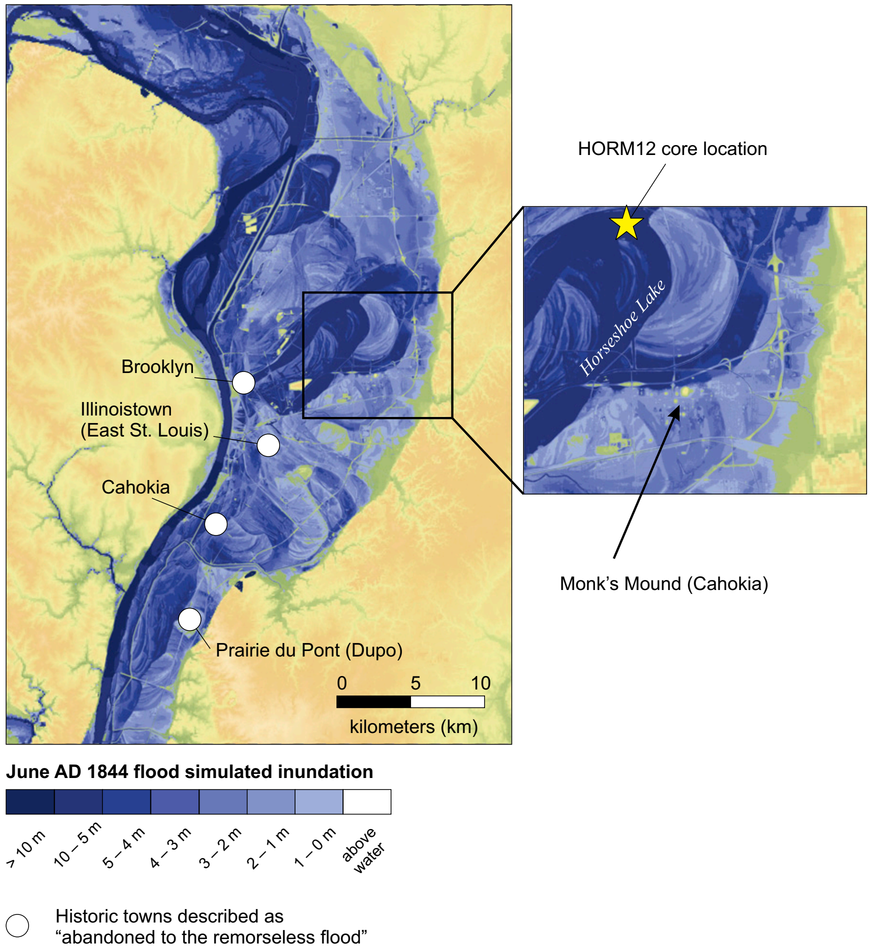

Fig. S1. Modeled flood extent of June A.D. 1844 flood event recorded by the gauging station on the Mississippi River at Saint Louis (EADM7) as 12.6-m stage; areas in blue denote elevations below flood stage. The extensive inundation that covered much of the floodplain and historic towns is consistent with newspaper accounts of the A.D. 1844 flood.

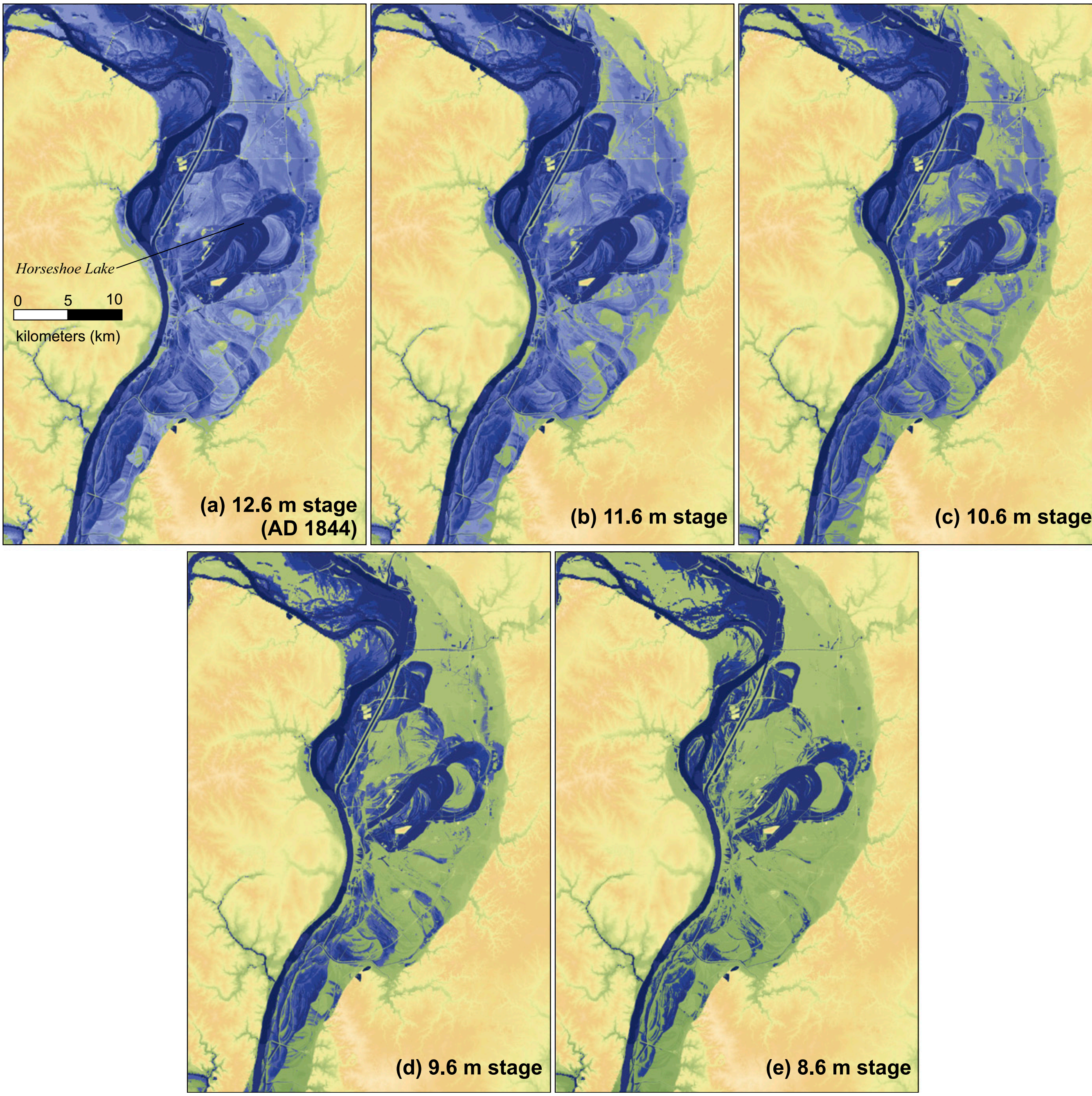

Fig. S2. Sensitivity analyses of flood extent in the Cahokia region used to test the minimum flood stage required to create hydrological connectivity between Horseshoe Lake and the Mississippi River: (*A*) 12.6-m stage, (*B*) 11.6-m stage, (*C*) 10.6-m stage, (*D*) 9.6-m stage, and (*E*) 8.6-m stage. Below 10.6-m stage (2 m below the A.D. 1844 stage), Horseshoe Lake is no longer hydrologically connected to the Mississippi River, implying that only high-magnitude floods (>10-m stage) deposit floodwater sediment in Horseshoe Lake.

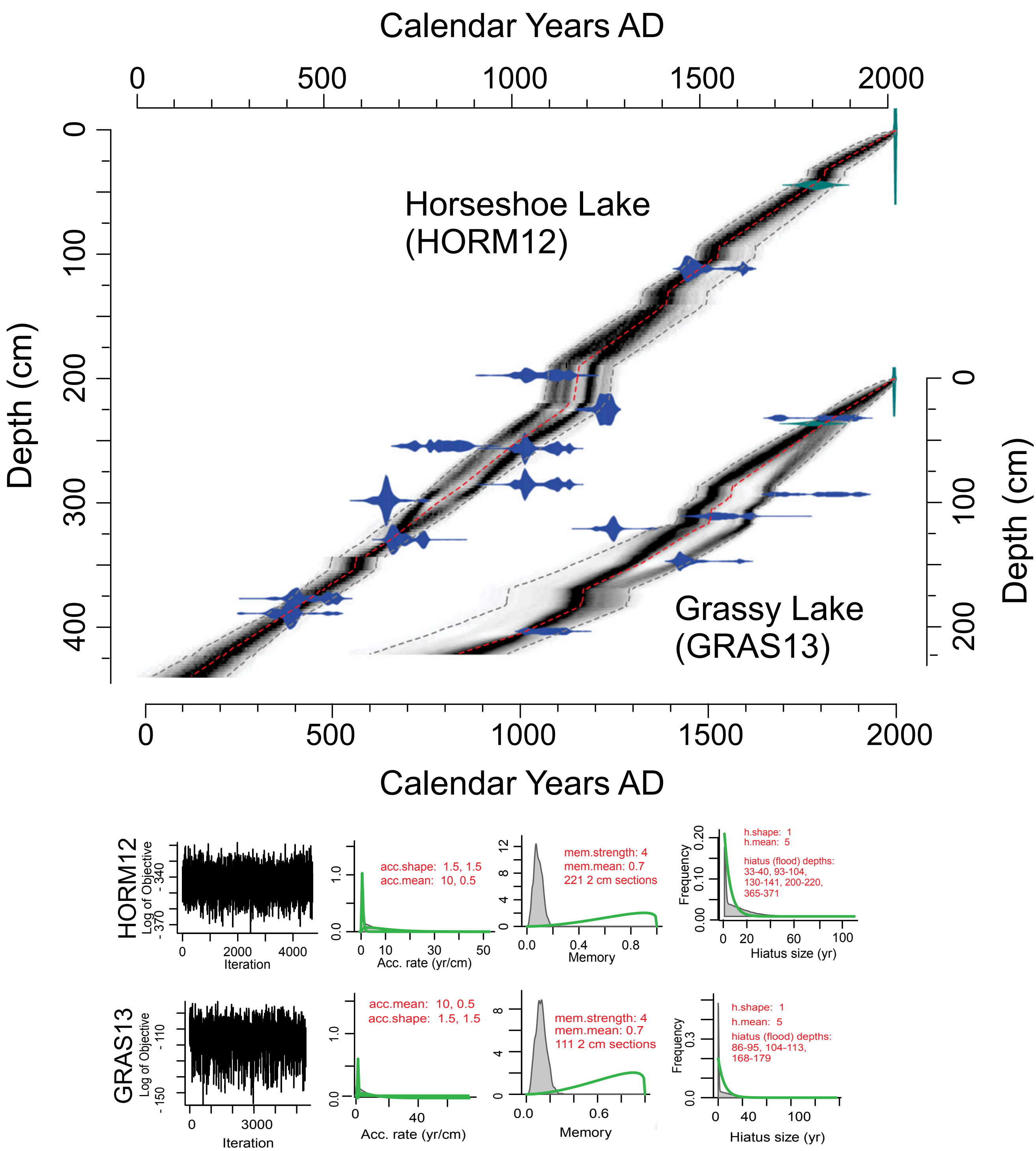

Fig. S3. Age–depth models generated using a Bayesian approach (1) for Horseshoe Lake and Grassy Lake. Rapid sedimentation rates (0.5 y/cm) were imposed as priors on floodwater sediments, with slower sedimentation rates (10 y/cm) on nonfloodwater sediments.

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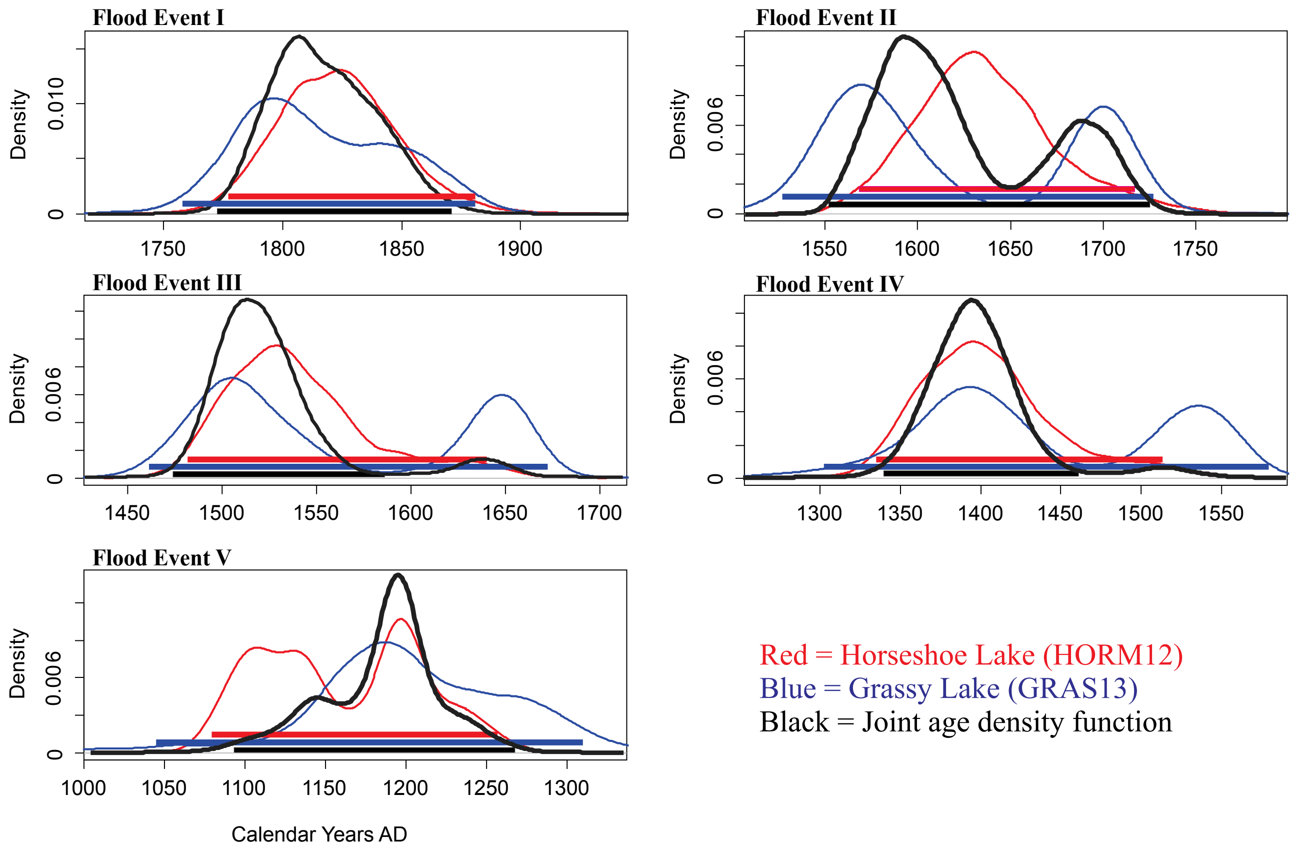

Fig. S4. Probability density functions for the most recent floodwater deposits (flood events I–V) at Horseshoe (red) and Grassy (blue) lakes, with combined density functions (black). Colored bars indicate the 95% confidence interval of each probability density function.

Table S1. The ^{14}C dates from Horseshoe Lake and Grassy Lake sediment cores

Lab number	Sample description	Site	Depth, cm	^{14}C age*
UGAMS-13417	wood	Horseshoe Lake	111.5	400 ± 25
UGAMS-13418	wood	Horseshoe Lake	197.5	980 ± 40
UGAMS-14454	wood	Horseshoe Lake	225	800 ± 20
UGAMS-13419	wood	Horseshoe Lake	254.5	1,220 ± 25
UGAMS-15039	charcoal	Horseshoe Lake	256.5	990 ± 25
UGAMS-15040	charcoal	Horseshoe Lake	285.5	990 ± 25
UGAMS-15041	charcoal	Horseshoe Lake	298.5	1,370 ± 25
DAMS-005563	charcoal	Horseshoe Lake	330	1,316 ± 24
UGAMS-13420	wood	Horseshoe Lake	347.5	3,560 ± 30
UGAMS-14455	wood	Horseshoe Lake	377.5	1,620 ± 25
UGAMS-14456	wood	Horseshoe Lake	389.5	1,650 ± 20
DAMS-005571	wood	Grassy Lake	31.5	91 ± 25
DAMS-005572	wood	Grassy Lake	92.5	120 ± 28
DAMS-005573	wood	Grassy Lake	110	309 ± 25
DAMS-005574	wood	Grassy Lake	120	736 ± 27
DAMS-005575	wood	Grassy Lake	146	423 ± 26
DAMS-005576	wood	Grassy Lake	202	936 ± 24

*Uncalibrated ages provided in radiocarbon years before 1950 (years BP), using the ^{14}C half–life of 5,568 y. The error is quoted as 1 SD and reflects both statistical and experimental errors. Each date has been corrected for isotope fractionation.

Table S2. Summary of probability distribution functions for flood events

Flood event	Peak depth, cm	Mode, year A.D.	Minimum age, year A.D.	Maximum age, year A.D.
HORM12-I	36	1810	1880	1780
HORM12-II	75	1630	1720	1570
HORM12-III	101	1520	1640	1480
HORM12-IV	136	1400	1510	1340
HORM12-V	210	1200	1250	1080
HORM12-VI	346	580	630	510
HORM12-VII	368	490	560	440
HORM12-VIII	418	280	320	160
GRAS13-I	39	1800	1880	1760
GRAS13-II	81	1570	1730	1530
GRAS13-III	101	1500	1670	1460
GRAS13-IV	131	1390	1570	1300
GRAS13-V	171	1200	1310	1000
JOINT-I	—	1800	1870	1780
JOINT-II	—	1590	1730	1550
JOINT-III	—	1510	1590	1470
JOINT-IV	—	1400	1460	1340
JOINT-V	—	1200	1260	1100

Other Supporting Information Files

Dataset S1 (XLSX)