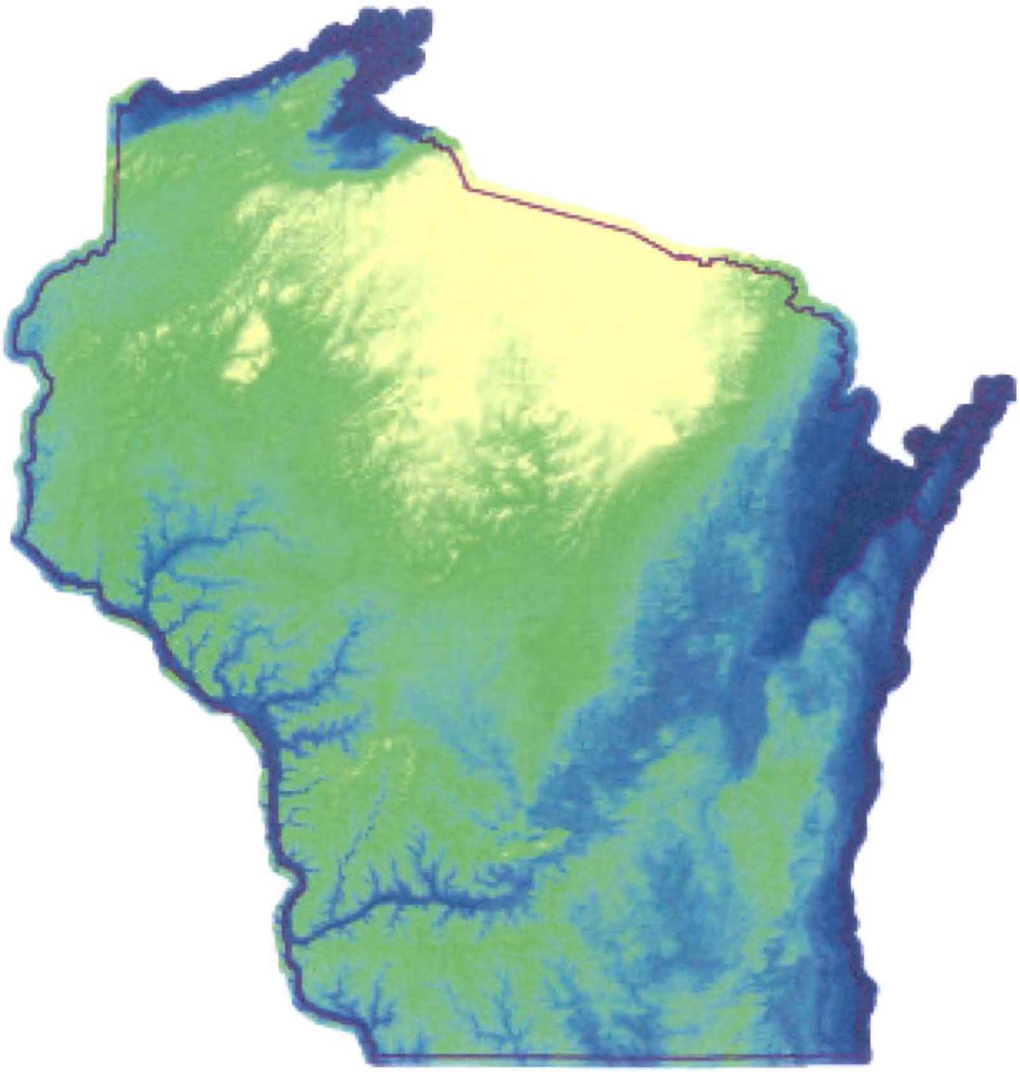
The Catastrophic Flood of Glacial Lake Wisconsin



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Geog 565

Introduction

The formation of Glacial Lake Wisconsin begins during the Wisconsin Glaciation approximately 30,000 years ago (Risjord 2000: 4). As the Laurentide Ice Sheet moved south from Canada into Wisconsin it encountered a high, hard outcropping of rock known as the Niagara Escarpment. It rises 50-200 meters (Attig and Mickelson 1999: 138) and runs from Lake Winnebago all the way to Niagara Falls. This hard escarpment split the Laurentide Ice Sheet into two lobes called the Lake Michigan lobe and the Green Bay lobe. It is the Green Bay lobe that is responsible for shaping much of Eastern Wisconsin and also for forming Glacial Lake Wisconsin.

The Green Bay Lobe began melting approximately 18,000 years ago (Risjord 2000: 5) and as it began retreating it left behind ridges of sand and rock known as recessional moraines. Its terminal or end moraine on the western margin is called the Johnstown moraine and it crossed the Baraboo Hills at a place called Devil's Lake as in **Figure 1**. As the glacier retreated over the Baraboo Hills, it created a debris-rich ice dam on the Wisconsin River and, as a result, all the meltwater from the retreating glacier began to back-up. This is the beginning of what is called Glacial Lake Wisconsin located on the northern edge of the Driftless Zone. It existed from approximately 18,000 to 14,000 years ago and it covered an area of at least 1,825 square miles, determined from old lake deposits (Risjord 2000: 6). The lake occupied a number of interconnected basins and the dam held back so much meltwater that it is thought to have reached depths of 150 to 160 feet (Clayton and Attig 1989: 3-5).

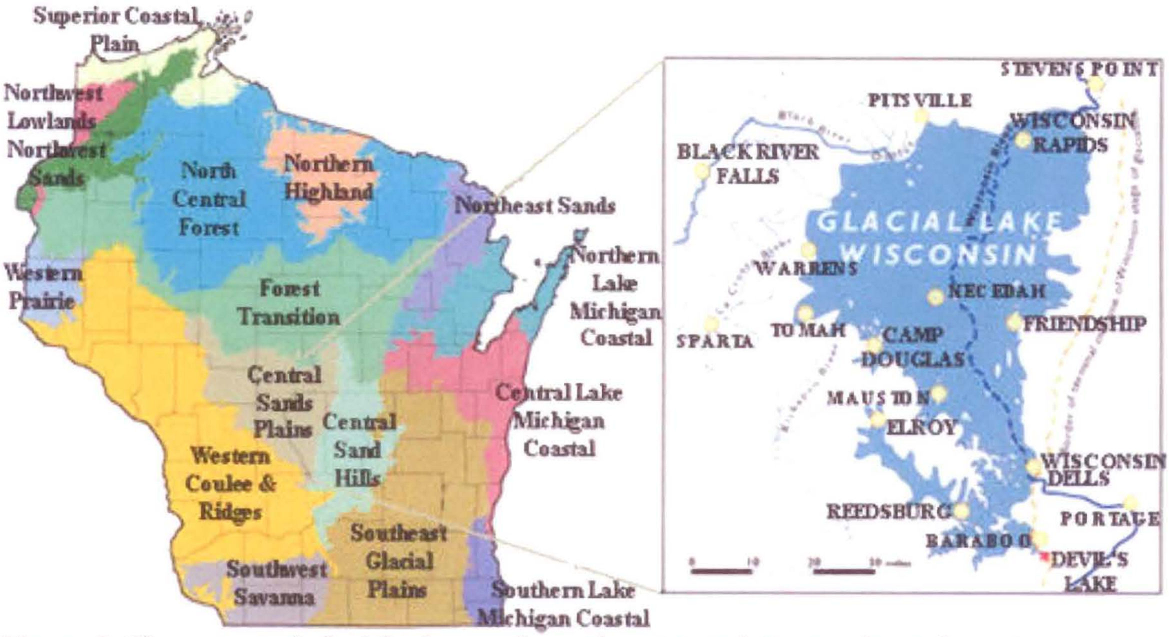

Figure 1. The extent of glacial advance from the east and the resultant damming against the Baraboo Hills. Graphic found at: http://img.geocaching.com/cache/58cfda26-125c-4b68-a96e-d3cccf98d3e0.jpg

The dam though, was a delicate one. While the terrace sequence in southwest Wisconsin suggests that there were many small flooding events of Glacial Lake Wisconsin (Clayton and Knox 2008: 394) at some point around 14,000 years ago the damn breached catastrophically and drained Glacial Lake Wisconsin in less than a week, some speculate in approximately 3 days (Risjord 2000: 6). As a result the lower Wisconsin Riverway was profoundly altered from the high discharge rate. Prior research estimates that peak discharge was between 3.6 and 5.3 x 10^4 m^3/s (Clayton and Knox 2008: 391) with an average velocity of 1.7 to 2.9 m/s (Clayton 2001: 391). Flood magnitude may have been as high as 1.5 x 10^5 m^3/s at the outlet (Clayton and Knox 2008: 393). The force of all this water, sediment, and huge boulders created a new course at a lower elevation for the Wisconsin River, east around the Baraboo Hills, and also carved out what we know today as the Wisconsin Dells, a deep cut 5 mile gorge (see **Figure 2**). The rushing waters carried glacial till through the Wisconsin River and down its tributaries into the Driftless Area and it was as though geologic time was compressed into a few days. The river rose to over a hundred times its normal size and the mass amounts of sediments were deposited on the river's bed, up to 150 feet deep in some places (Lower Wisconsin Riverway Board 2005). Later as the Wisconsin River began eroding all the deposited sediment, sequences of terraces formed.

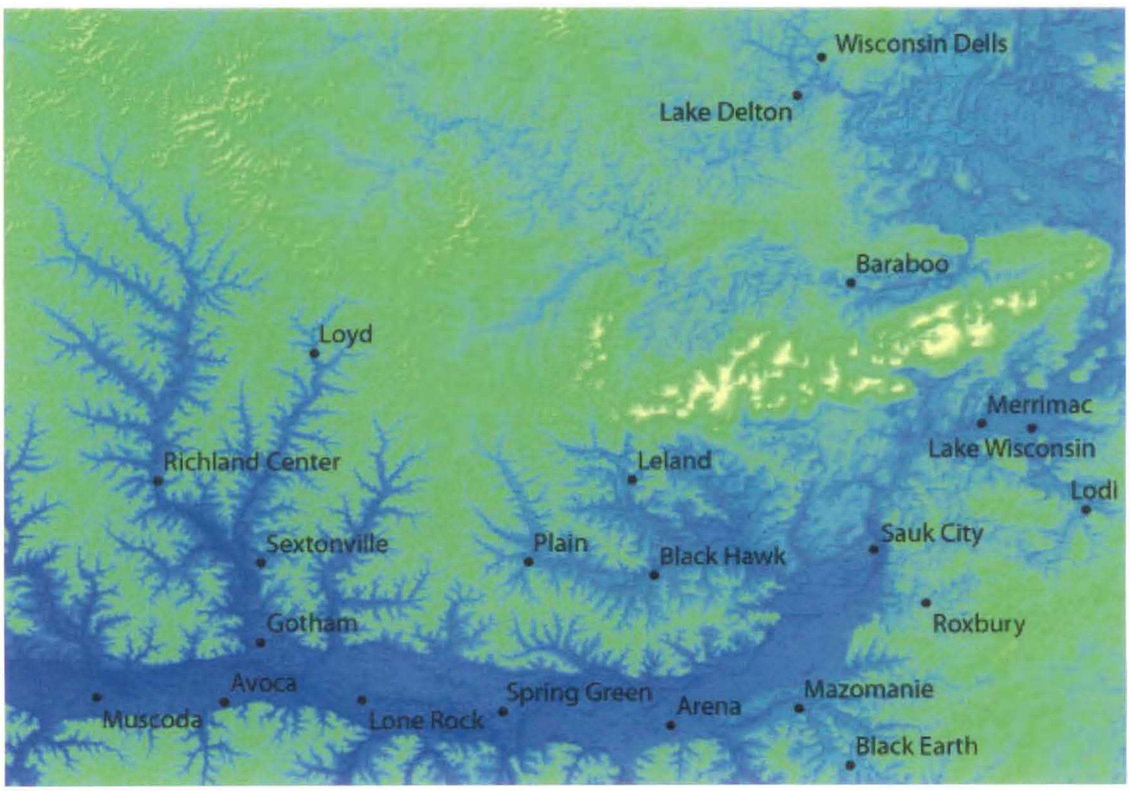

Figure 2. Discharge of Glacial Lake Wisconsin scoured the relatively soft regional sandstone, forming the Wisconsin Dells, then flowed into the Riverway.
The sand presently in the Riverway was deposited by the dam release.

Glacial Lake Wisconsin left behind a sandy plain in central Wisconsin as its legacy, known as the Central Plain, but many of the lake deposits are covered by dune sane, glacial outwash, muck, or peat. It is known that many of the swamps, marshes, and bogs in central Wisconsin were formed by the accumulation of the more impermeable deposits of Glacial Lake Wisconsin. We aim to further understand this catastrophic flood by using this information and conducting our own flood magnitude quantification and examining the flood's effects on the morphology of the Lower Wisconsin River.

Analogs of Glacial Lake Outburst Floods

Glacial lakes Agassiz and Missoula are important as analogs as they provide continuity of discussion with respect to glacially dammed lakes and subsequent outburst flooding. Glacial Lake Missoula (GLM) provides a respectively popular resource to describe the analogous flood-forced erosion of bed rock (Lopes 2009, 79-82). In a similar manner as the numerous GLM floods eroded the large Scabland region, the GLW flood scoured relatively soft bedrock into the Wisconsin Dells (Clayton and Attig 1989). Similarly, the draining of Glacial Lake Agassiz (GLA), into the Red River Valley is a useful analog for lacustrian sediment deposition (Fisher 2003; 271-276). It should be explicitly stated that the Glacial Lakes Missoula and Agassiz floods are orders of magnitude larger than GLW, but they share erosional characteristics via the concept of uniformitarianism.

Because of the erosional destruction of intermediate shorelines or moraines by the advance of glaciers or filling of lakes, the most reasonable parameters to begin measuring glaciation and lake size are, respectively, the elevations of terminal moraines, shorelines, and outlet channels. Evaluation at maximum extents may not capture the true configuration at the time of flood, but calculations about this specific case of maximums can be used to set upper limits on behavior of the lake, glacier, and valley system. In the case of the GLW, measuring only maximum extents is acceptable and suggested because our narrative is based on calculating the maximum outburst parameters.

Methods

There are many examples of paleoflood studies (Clayton 2000: 21). Previously used techniques include analysis of slackwater sediments (Kochel & Baker, 1988), stratigraphic analysis (Knox 1987: 155-181), and studies dealing with channel morphology after a flood has occurred (Williams and Costa 1988: 65-80).

A practical method for paleoflood reconstruction that has been used by many and that will be employed throughout the course of this paper entails determining paleoflood velocity at a given point by means of using an established relationship between flood transported boulder diameter and the associated velocity required to move such an object. Based off of previous studies we will apply the following relationships (Costa 1983: 991) which were derived empirically from graphing data taken from a variety of previous studies and observing the equation that defines the line of best fit. V_a is the average velocity and d_I is the intermediate axis of the boulder.

For clasts where 50mm<d<3200mm

$V_a = .2 * d_I^{.455}$

If only clasts >500mm are used

$V_a = .27 * d_I^{.40}$

FLOODS FROM DAM FAILURES

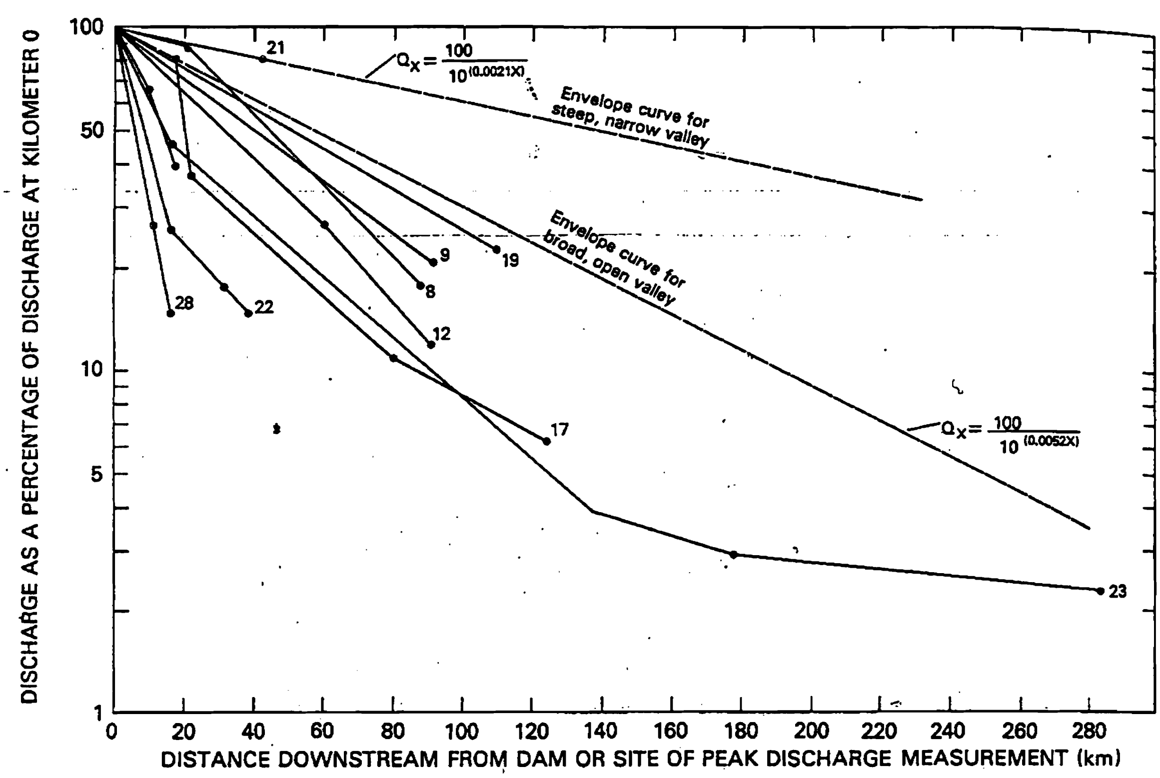

FIGURE 8. Graph showing attenuation rates of floods from selected dam failures, with numbers keyed to Table 4.

Figure 3. Taken from Costa, 1988, page 450 shows the empirical relationship between peak discharge downstream and peak discharge at dam breach. We used this relationship to solve for peak discharge using field measurements. We used intermediate axis measurements to find for velocity, then velocity and cross-sectional area to find for discharge. Lastly, we used the relationship illustrated in the graph to solve for peak discharge at dam breach.

Another relationship is based off of the average of previously documented average velocities determined by differing methods. (Costa 1983: 991) .

For clasts where 50mm<d<3200mm

$V_a = .18 * d_I^{.487}$

Seeing as this method is predicated on the assumption that observed boulders have been moved by the flooding event in question and not by some other means, great care will have to be taken in the field regarding which boulders we choose to measure. Fortunately the mouth of the paleoflood was situated within a distinctly purple quartzite. In this way only quartzite boulders will be measured so that we can be sure that our measurements are applicable to the catastrophic draining of Lake Wisconsin.

By applying local velocity estimates, minimum estimations for attenuation and velocity at the source can be attained by once again relying on previously discovered relationships, this time making use of a previously existing curve (figure 8) (Costa 1988: 450) that compares discharge as a percentage of discharge at the source of the flood or site of peak discharge with distance downstream from this source. The most conservative peak discharge estimate obtained in this way will be the most important result. For we will know with some certainty that the peak discharge of the catastrophic flood associated with the draining of Glacial Lake Wisconsin must have been greater than or equal to this estimate.

Results

Data was gathered at a sand pit run by Kraemer Industries in Iowa county, approximately 43°10'31" north latitude, 90°01'16" west longitude. Samples were near the shore of a quarry lake, in a coarse rock pile and in a large, less sorted rock pile. Thirty-three samples were measured at this site, three of which, due to their location, placed quite intentionally on the side of the road, were suspect and were therefore not used in flood calculations.

The sample that would have required the greatest amount of energy to move was found to have an intermediate axis of approximately .256 meters. A boulder of this size would have required water velocity to be between 2.49 and 2.68 meters per second to move.

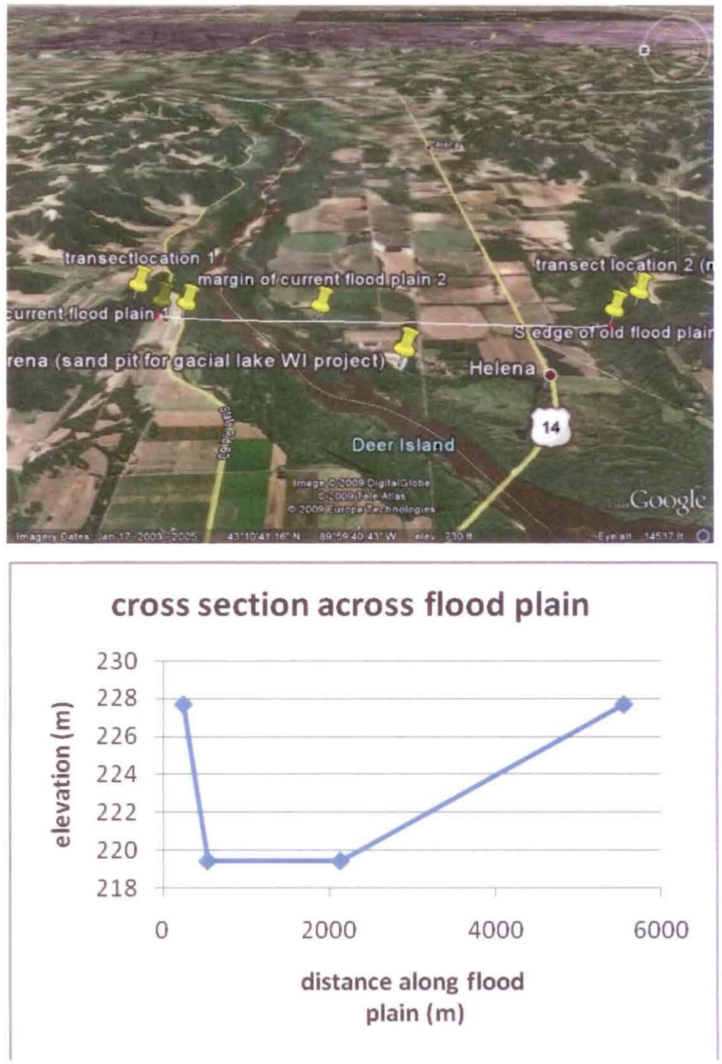

Figure 4. (Top) Transect used to estimate cross-sectional area near sample site. (Bottom) Schematic diagram from which cross section area was calculated.

A primitive cross-section of the Wisconsin River flood plain, illustrated in **Figure 4**, was constructed for an area approximately .30 kilometers upstream from the sample site. From that cross section a minimum estimate of flood height was calculated based only off of the topography of the old flood plain of the Wisconsin River; that is to say that only the lateral limits of the flood plain were taken into account with no additional height assumed (figure 1). This modest approximation of flood height is assumed so that the resultant discharge estimate is a minimum estimate. Area of this cross section was found to be approximately 28,344 square meters.

Figure 5. (Top) Approximate path of the current Wisconsin River, from mouth of flood near Devils Lake to sample site.

(Bottom) Path of least distance across the old floodplain of the Wisconsin River associated with the catastrophic flooding of glacial Lake Wisconsin.

By assuming a maximum velocity that ranges between 2.49 and 2.70 per second and a conservative cross-sectional area of 28,344.1 square meters, simple arithmetic shows that discharge in the area of the Wisconsin River was between 70,675 and 103,003 cubic meters per second at peak discharge during the catastrophic flooding of glacial Lake Wisconsin.

By assuming two possible paths across the old floodplain of the Wisconsin River, a shortest possible path across the flood plain and a path that closely approximates the current course of the river, we found that our sample site would have been between 41.94 and 46.84 km downstream from the mouth of the flood near Devils Lake in Sauk County (Clayton and Knox 2007: 385), approximately 43°24’20” north latitude 89°41’55” west longitude. By applying these estimates for distance downstream and the calculated discharge at the sample site of 64,624 cubic meters per second, and by assuming an envelope curve for a broad, open valley, we can use **Figure 3** to calculate a range of conservative peak discharge estimates, between 113,992 and 130,962 cubic meters per second at the mouth of the flood. The discrepancy between the high and low estimate is due to different possible values with regard to distance down stream from the mouth of the flood at our sample site, as well as the variance in possible velocities depending on which velocity equation we use.

sample name	intermediate axis (m)	minimum velocity (m/sec)	associated discharge (m^3/sec)	estimated discharge at mouth(m^3/sec) short distance estimate	Discharge at mouth long distance estimate	rounding	rock type	area located
AK-1	0.085344	1.51256382	42872.22991	69148.75792	73917.63778	well rounded	sandstone	near lake
AK-2	0.0762	1.436545902	40717.57197	65673.50318	70202.7103	well rounded	sandstone	near lake
AK-3	0.109728	1.69579926	48065.8699	77525.59662	82872.18949	well rounded	quartzite	near lake
AK-4	0.112776	1.717072323	48668.8353	78498.12146	83911.785	rounded	quartzite	near lake
AK-5	0.100584	1.629973885	46200.1102	74516.30677	79655.36241	sub-rounded	sandstone	near lake
AK-6	0.079248	1.462411781	41450.71651	66855.99437	71466.75261	well rounded	sandstone	near lake
AK-7	0.112776	1.717072323	48668.8353	78498.12146	83911.785	well rounded	sandstone	coarse pile
AK-8	0.097536	1.60731147	45557.76488	73480.26594	78547.87048	well rounded	shale/mudstone	coarse pile
AK-9	0.082296	1.487740947	42168.64843	68013.94909	72704.56627	well rounded	sandstone	coarse pile
AK-10	0.073152	1.41010976	39968.26386	64464.9417	68910.79975	well rounded	sandstone	coarse pile
AK-11	0.073152	1.41010976	39968.26386	64464.9417	68910.79975	sub-angular	quartzite	coarse pile
AK-12	0.082296	1.487740947	42168.64843	68013.94909	72704.56627	sub-rounded	sandstone	coarse pile
AK-13	0.082296	1.487740947	42168.64843	68013.94909	72704.56627	rounded	sandstone	coarse pile
AK-14	0.100584	1.629973885	46200.1102	74516.30677	79655.36241	rounded	sandstone	coarse pile
AK-15	0.210312	2.279991038	64624.24839	104232.6587	111421.1179	sub-rounded	limestone	large pile
AK-16	0.176784	2.106767164	59714.37703	96313.51133	102955.8225	sub-angular	quartzite	large pile
AK-17	0.140208	1.89588337	53737.06991	86672.6934	92650.12053	sub-rounded	sandstone	large pile
AK-18	0.195072	2.203274925	62449.80073	100725.4851	107672.0702	rounded	quartzite	large pile
AK-19	0.237744	2.41079259	68331.69803	110212.4162	117813.2725	sub-angular	quartzite	large pile
AK-20	0.256032	2.493468458	70675.06945	113992.0475	121853.568	sub-angular	quartzite	large pile
AK-21	0.204216	2.249680474	63765.12333	102846.9731	109939.8678	sub-rounded	quartzite	large pile
AK-22	0.204216	2.249680474	63765.12333	102846.9731	109939.8678	well rounded	granetoid	large pile
AK-23	0.158496	2.004648923	56819.92945	91645.0475	97965.3956	sub-rounded	quartzite	large pile
AK-24	0.164592	2.039369709	57804.05818	93232.35191	99662.16928	sub-rounded	quartzite	large pile
AK-25	0.1524	1.969192421	55814.94752	90024.10891	96232.66814	sub-rounded	quartzite	large pile
AK-26	0.16764	2.056467391	58288.67625	94013.99395	100497.7177	well rounded	limestone	large pile
AK-27	0.1524	1.969192421	55814.94752	90024.10891	96232.66814	sub-rounded	quartzite	large pile
AK-28	0.1524	1.969192421	55814.94752	90024.10891	96232.66814	sub-angular	quartzite	large pile
AK-29	0.128016	1.819010604	51558.18208	83158.35819	88893.41738	well rounded	quartzite	large pile
AK-30	0.188976	2.171675953	61554.15694	99280.89829	106127.8568	rounded	limestone	large pile
AK-31	0.478536	3.314294877	93940.63914	151517.1599	161966.6192	sub-angular	gniess	roadside (on site)
AK-32	0.62484	3.742008851	106063.7982	171070.6423	182868.6177	rounded	granetoid	roadside (on site)
AK-33	0.48768	3.34296166	94753.17274	152827.698	163367.5392	rounded	basalt	roadside (on site)

Table 1. Sample data used to reconstruct the catastrophic flooding of glacial Lake Wisconsin. Samples AK-31, AK-32 & AK-33 are suspect due to the location that they were found. Therefore these three samples were not used in this study.

Discussion

Our calculated flood discharge values agree with previously existing literature (Clayton and Knox 2007: 385). Our discharge estimate is slightly lower than previously documented literature, but this is most likely due to the conservative nature of the estimation presented in this paper; minimum water heights were assumed. The primary equation relied upon yields a conservative estimate. A minimum distance along the flood plain from the site of dam breach was assumed to yield the estimate for peak discharge at the mouth of the flood of 104,232 cubic meters per second. Furthermore, larger boulders that may have indicated a larger peak discharge estimate were found at the site, but due to suspect locations, unusually large dimensions and inconsistencies regarding rounding, these samples were assumed to be ice rafted relics or, in one case, a piece of country rock.

This study, however, is far from comprehensive. The data, however consistent, is based off of a sample set taken from one area. Boulder analysis from other areas in the Wisconsin River flood plain would help to add further confidence to the flood estimates presented above.

Conclusion

This study serves to re-affirm previous expert flood estimates to the correct order of magnitude (Clayton and Knox 2008: 393). The methods by which this reconstruction was undertaken are different from the methods used in previously existing literature, but the results are similar. This consistency helps add further credence to our understanding of the catastrophic flooding of glacial Lake Wisconsin.

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