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Test Using Sedimentary Records to Quantify Extreme Paleo-flood: A Case Study of an Oxbow Lake in South Carolina

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Abstract

Extreme flooding has become an increasing issue along the coasts for people's health and infrastructure stability. As the effect of climate change continues to persist, the need to prepare for such events becomes imperative. To improve the understanding of climatic forecasting with regards to extreme flooding, there is merit in searching flooding history beyond the instrumental records. There has been some work done in the past to correlate extreme flooding and its sedimentary traces preserved in floodplain depressions, such as oxbow lakes, based on the assumption that the coarser grain sediments in the sediment layers correspond with higher peak discharges brought on by flooding. In this study, we test this correlation using a core sample (1.24 m long) taken from an oxbow lake off the main channel of the Waccamaw River in South Carolina. Grain size of the core sediment was measured for every centimeter to investigate how that might correspond with extreme flooding of the Waccamaw River during the ~60-year life span of the lake. To calculate a reliable range of sediment coarseness, two separate parameters were used, the grain size at 90% cumulative frequency distribution, D90, and the most coarse component through end-member modeling (EMM). The parameters were detrended and normalized to determine the z-scores, or standard scores, for each layer. The z-scores of both parameters depicting coarse sediments corresponded strongly with the peak annual discharge of extreme flooding events (> 9000 cfs) with a correlation coefficient (r^2) of 0.45 for D90 and 0.77 for the EMM analysis. The confidence between these correlations can open up future research opportunities for more articulate paleo-flood records. An analysis of the peak annual discharge of the Waccamaw River over the last ~70 years indicates that the majority of the extreme

discharges are caused by tropical cyclones, suggesting that the history of extreme flooding of this river may reveal how historical tropical cyclones have affected this region.

Introduction

Over the past few decades the frequency and intensity of flooding events, such as those caused by tropical cyclones, has been increasing. As discussed in literature, it was possible to link the increase of storms and associated flooding events in the southeastern US, through the use of satellites, to the increasing temperature of the Earth, otherwise known as global warming (Shepherd et al., 2007). Shepherd et al. (2007) also found that the main contributors of high precipitation were events such as tropical cyclones and hurricanes during the prime of their season from September to October. By simulating storm frequency based on past data, researchers have forecasted a subtle yet noticeable rising trend in the frequency of storms in the next few decades (Wright et al., 2015). The resulting precipitation of such events has led to flooding, property damage, natural habitat damages (Neckles et al., 1990), and human casualties (Diakakis et al., 2012). It has become a pressing need to prepare in advance for these events to minimize the overall damage. However, there is still a lot in the way of research that needs to be done to understand factors affecting the frequency and magnitude of powerful floods. One of the major challenges for this type of research is the need for long-term records of flooding. The present study tests a method to use sedimentary records to study paleoflood in the southeastern US.

There are a number of studies that have been done to analyze paleoflood using sedimentary records in a multitude of environments. In the study by Storen et al. (2010), well-preserved sediments taken from a lake basin in Southern Norway identified sedimentary imprints of paleoflood going back as far as 10,000 years ago. Toonen et al. (2015) was able to record almost five centuries worth of flood data through the use of core sediments taken from an oxbow lake in the Netherlands and the tracing of particle size distribution in correlation to the annual peak discharge. In another paper by Schillereff et al. (2016), they found success from studying lake sediments. The sediments from the English temperate lake had high organic content, especially in their shallower layers, that made it easier to trace ages of each sediment layer within a 4-year range. Schillereff et al. (2016) is not the only one to use the secluded flood-prone qualities, or easily floodable for the transport of sediments, of a lake for the benefit of paleoflood study. The anthropogenic influence from the construction of dams and other man-made structures used to mitigate flooding may have an influence on the sediment distribution. In a paper by Munoz et al. (2018), flood frequency and intensity show a multi-decadal trend in the Mississippi River. These studies demonstrate that the use of lake sediments holds importance in the field of paleoflood studies.

In this study, we want to test the use of oxbow lake sediments as a proxy for paleoflood study in South Carolina. An oxbow lake is a body of water that was originally a part of a main river channel, most commonly a meandering river channel. The lake is cut off over time by sediment build-up, creating its own body of water. Due to oxbow lakes being cut off from the main river channel, the velocity of currents running through them is much lower than it is for the rest of the river. With a lower velocity current, only fine grain sediments like mud and silt will find their way into the lake. During flooding events, however, coarser grained sediments like sand will be washed into the lake where they will settle in with the rest of the sediments, becoming a part of the lake's flood record. The isolated nature of oxbow lakes makes it easier to track and comprehend changes in their sediments from year to year, leaving a more noticeable impact on the flood record.

The lake of choice for our study is an oxbow lake connected to the Waccamaw River in South Carolina. The benefit of the Waccamaw River's oxbow lake is that it does not have any man-made dams that may have affected the flood record in that area. Studies such as Toonen et al. (2015) did include basins like oxbow lakes along their study area of the Rhine River's floodplains, but the area of those riverine systems is affected by a number of man-made dams and embankments put there over the last century. Therefore, although the environments between studies are similar, each one has their own anthropogenic influences to take into account. The oxbow lake chosen for this study is known to have formed in the early 1960s according to historical aerial photos (Figure 1). Therefore, the age of the sediments in this lake is relatively well constrained. This study tests the usefulness of oxbow lake sediments for paleoflood study by correlating past riverine flooding with the varying sediment grain sizes found in the lake sediments to see how accurately they connect.

Study Area

The Waccamaw river flows through North and South Carolina along the Carolina coastal plain. The coastal plain, a low flatland adjacent to the Atlantic Ocean, is susceptible to flooding and other damages brought on by strong storms. This area of the American southeast reliably receives high annual precipitation and, by proxy, higher threats of flooding. Just in 2018, Hurricane Florence hit the Carolinas with 20-35 inches of precipitation. The severe flooding put schools and businesses out of commission for weeks and displaced thousands of people (Feasters et al., 2018). The oxbow lake studied is found within Horry County of South Carolina, near the border between North Carolina and South Carolina (Figure 2).

Methods

A core (1.24 meters in length) (Figure 3) was taken from an oxbow lake off the Waccamaw River in South Carolina. The core was taken using the method of piston coring with a polycarbonate plastic tube. The upper part of the core was made up of organic mud with some bands of sand at intervals within the sample and the lower part of the core consists of almost exclusively coarse grained sand that would have been common for the lake before it had separated itself from the main river. Therefore, only the top 70 centimeters of the core were used for grain-size analysis.

Taking samples at every 1 cm continuously down the core, their grain-size distribution was measured to examine the coarsest grain-size sediments that are supposed to correlate with flooding of the Waccamaw River. To prepare the samples for grain-size analysis, they were treated with a 30% hydrogen peroxide solution for 1-2 days before the beaker containing the mixture was boiled to remove any excess hydrogen peroxide. Once the organics were removed, the sample was then put through a laser particle size analyzer known as the CILAS 1190 to measure the grain-size distribution of the sediment samples per layer.

Data Analysis

To calculate a reliable range of sediment coarseness, two parameters were used, one of which was the grain size at 90% cumulative frequency distribution, D90. Another method, end-member modeling (EMM) (Yu et al 2014), took the values from the whole grain-size distribution data while corresponding them with the river discharge data from that area. This method correlates that grain size taken at the study area with flooding events that have occurred during the lifetime of the lake, focusing more so on the years with high peak annual discharge in comparison to more moderate years of discharge. The specific form of end-member modeling used exported the relative proportion of each end-member grain-size distribution from the sample, expressing a unit of frequency (%). The coarsest end-member, EM3, was used. To put the measurements into a more unified form, they were calculated into z-scores, or standard scores, for each layer out of the 70 cm of the core used. Using the grain-size data refined into z-score values, we coordinated those values to the years where their size or value would occur, ranging from the oxbow lake's creation (~1960) to present day, spring of 2018 at the time of collection.

Before the z-scores could be calculated, detrending of the data must occur. The creation of the oxbow lake was not a sudden occurrence, more so it was a gradual separation from the main river channel over the course of years. This gradual transformation allowed for a higher concentration of coarser-grained sediments like sand to settle into the lake's paleoflood record during its earlier period. To balance the natural creation of the oxbow lake with its current formation, the data from both the D90 and EMM (specifically EM3) were detrended data before calculating appropriate z-scores for both parameters. Separating the data by the top layer (0-35 cm) and the bottom layer (36-70 cm) of the core, we can represent the past and present formation of the lake. For each section, a figure was produced relating the diameter of the sediments (μm) to the depth of the layer (cm) and found the equation for the graph's trendline. Using the slope and y-intercept of the top layer, the data for the entire core was plugged into the top layer's trendline equation. After getting the values from the new equation, the new "predicted" values were subtracted from the original values to find the residual difference.

To more accurately trace the age of the layers of core sediments with extreme flooding events within the paleoflood record, an age-depth model was created. The linear age-depth model correlated each of the 70 layers from the core to a year within the lake's timeline from 1961 to

2016. Years with high peak discharges brought on by extreme flooding events could take up multiple layers of sediment while years with lower annual discharges culminated in just one layer of sediment.

Results

Peak Discharge

In order to compare grain-size distribution to peak annual discharge, knowing what the annual peak discharge around the area of the oxbow lake and adjacent Waccamaw River is paramount. Data records were taken from the United States Geological Survey (USGS) website from the Longs station going back as far as the 1950s. Data from 1961 to 2018 was applied to the annual peak discharge in cubic feet per second (cfs) (Figure 4). In the figure, noticeable peak discharge events can be found as recently as 2016, pertaining to the recent hurricane Matthew, but also in the late 1990s with hurricane Fran in 1996 and hurricane Floyd in 1999. These recorded events, which were backed up with NOAA's records, showed high precipitation in years that had strong tropical cyclones and hurricanes. Years of high peak annual discharge, specifically those above 9000 cfs, were organized to connect with correlating hurricanes during those years (Table 1).

Grain-Size Distribution

From the grain size distribution data obtained by the Cilas 1190, the grain-size for each layer was compared to find the prevalent coarseness of the sediments. To present representative grain-size distribution of sediments from the oxbow lake, histograms were produced for sediments interpreted as representing major flooding and low to moderate flooding (Figure 5). As an example, looking at the uppermost layer from 0-1 cm, the peak diameter of the sediments was around 300 µm, representing the most recent flood, at the time of collection, in 2016, Hurricane

Matthew (Figure 5). Along with the uppermost layer of the core, five other layers were taken to show the range and consistency of flooding events, whether by a documented event such as a tropical cyclone or simply high precipitation for the year. Although five out of the six figures represent years of high peak discharge, Figure 5f was included to show a year of low to moderate discharge in 1974 as a comparison to the more extreme years of discharge.

Age-Depth Model

For determining the age of each layer to correlate to extreme flooding events, the age of the layers and the depth at which they're found does not automatically fit into a perfect 1:1 ratio. They are connected, but as stated previously, the annual discharge from each year varied in its contribution to the lake's paleoflood record. Comparing the length of the measured core, 70 cm, and the age of the core before 2017, 56 years, an equation was made to connect the two factors. With Age=(0.8)*depth(cm), where the slope was contributed by a trendline equation, it allowed for each layer to accurately correlate to its age in the record before 2017 (Figure 6).

Detrending

One of the main parameters used to find correlation with grain-size and flooding events, D90, had a broad range of sizes (μm) throughout the lake's record (Figure 7). The same could be said for the EMM values (%) (Figure 8). These figures do not take into account that the formation of the oxbow lake was not instantaneous, meaning that more coarse-grained sediments that are more characteristic of the main river channel were able to flow into the lake and settle there. Therefore, although the deeper layers of the core show the largest grained sediments, that does not immediately mean that more recent events were less extreme than those at the beginning of the lake's formation.

To put past layers into a modern perspective, detrending was used to create trendlines for the upper layers and plug older layer data into the resulting equation. This would create a "predicted" value that was then subtracted by the original grain-size value, giving a residual value for D90 (Figure 9) and EMM (Figure 10). Not only does the residual size take into account the lake's formation, but it also set up the values needed to find the standard scores needed for the final comparison. As seen in both Figures 9 and 10, the bottom-most depth of the core has values in a similar range to those at the top, as opposed to more extremes highs and lows seen before the detrending.

Z-scores

With the detrended data for both parameters calculated, their average and standard deviation can be calculated. The values of the detrended size or frequency, mean, and standard deviation calculate the z-scores, or standard scores, used for the final correlation with annual discharge. The equation, which is separate for the top and bottom half of the core, is z = (residual-mean)/STDEV for D90 (Figure 11) and EMM (Figure 12).

Z-score and Annual Peak Discharge

With the use of the age-depth model, it is now possible to connect annual peak discharge with the coarseness of the sediments in the core. Ten peak annual discharges were chosen that exhibited a peak discharge of 9000 cfs or higher. The ten points represented the years of 1961, 1969, 1981, 1983, 1993, 1996, 1998, 1999, 2000, 2016. With the points, their z-scores and peak discharge were compared to find any potential correlations. For the D90 values, the coefficient of determination (R^2) from the trendline was 0.4509 (Figure 13). For the EM3 values, the coefficient of determination (R^2) from the trendline was 0.7691 (Figure 14).

Discussion

The coefficients of determination for D90 and EM3 vary in confidence. Although the D90 value came out to 45% confidence, the EM3 value leaps up to 77% confidence. There was a correlation observed between the z-scores, and by extension grain-size, and the peak annual discharge during years of extreme flooding. Coarser-grained sediments were more prevalent during years of higher precipitation, leading to water from the main river channel flooding into the more removed oxbow lake. The secluded nature of the oxbow lake lent itself to a clearer chain of events to follow, its recorded age along with easy to identify bands of coarser sand gave an immediate hypothesis weight to stand on that was only further proven through data analysis. In conclusion, the oxbow lake proved useful in accurately presenting extreme flooding events in its paleoflood record. The collected data from a 56-year-old oxbow lake was still clear enough to have noticeable bands of coarse-grained sediments correlating with past flood events on a decadal scale.

Similar to papers like Toonen et al. (2015) and Munoz et al. (2018), river channels and basins originally connected to river channels have proven how useful their records on a decade to decade level really are. This begs the question of just how far into the record researchers could go if more attention was given to this particular method of data collection.

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References

Conway, N.W., 2019. A Centennial-scale Extreme Paleoflood History of the Pee Dee River, SC Reconstructed using Oxbow Lake Sediments. Masters Thesis from Coastal Carolina University, 1-59 p.

Diakakis, M., Mavroulis, S., Deligiannakis, G., 2012. Floods in Greece, a statistical and spatial approach. Natural Hazards, **62**, 485-500.

Feaster, T.D., Weaver, J.C., Gotvald, A.J., Kolb, K.R., 2018. Preliminary Peak Stage and Streamflow Data at Selected U.S. Geological Survey Stream gaging Stations in North and South

Carolina for flooding following Hurricane Florence, September 2018: U.S. Geological Survey Open-File Report 2018–1172, **36**.

Munoz, S.E., Giosan, L., Therrell, M.D., Remo, J.W.F., Shen, Z., Sullivan, R.M., Wiman, C., O'Donnell, M., Donnelly, J.P., 2018. Climatic control of Mississippi River flood hazard amplified by river engineering. Nature, **556**, 95-98.

Neckles, H.A., Murkin, H.R., Cooper, J.A., 1990. Influences of seasonal flooding on macroinvertebrate abundance in wetland habitats. Freshwater Biology, **23**, 311-322.

Schillereff, D.N., Chiverrell, R.C., Macdonald, N., Hooke, J.M., 2016. Hydrological thresholds and basin control over paleoflood records in lakes. *Geology* ; 44 (1): 43–46.

Shepherd, J.M., Grundstein, A., Mote, T.L., 2007. Quantifying the contribution of tropical cyclones to extreme rainfall along the coastal southeastern United States. Geophysical Research Letters, **34**, 1-5.

Støren, E.N., Dahl, S.O., Nesje, A., Paasche, O., 2010. Identifying the sedimentary imprint of high-frequency Holocene river floods in lake sediments: development and application of a new method. Quaternary Science Reviews, **29**, 3021-3033.

Toonen, W.H.J., Winkels, T.G., Cohen, K.M., Prins, M.A., Middelkoop, H., 2015. Lower Rhine historical flood magnitudes of the last 450 years reproduced from grain-size measurements of flood deposits using End Member Modeling. Catena, **130**, 69-81.

U.S. Geological Survey, 2018, National Water Information System data available on the World Wide Web (USGS Water Data for the Nation), accessed 2018, at URL https://nwis.waterdata.usgs.gov/sc/nwis/uv?cb_00060=on&cb_00065=on&format=html&site_no=02110500&period=&begin_date=1955-03-06&end_date=2018-03-11

Wright, D.B., Knutson, T.R., Smith, J.A., 2015. Regional climate model projections of rainfall from U.S. landfalling tropical cyclones. Springer, **45**, 3365-3379.

Yu, S., Colman, S.M., Li, L., 2014. BEMMA: A Hierarchical Bayesian End-Member Modeling Analysis of Sediment Grain-Size Distributions. Mathematical Geosciences, **48**, 723-741.

Figures and Table

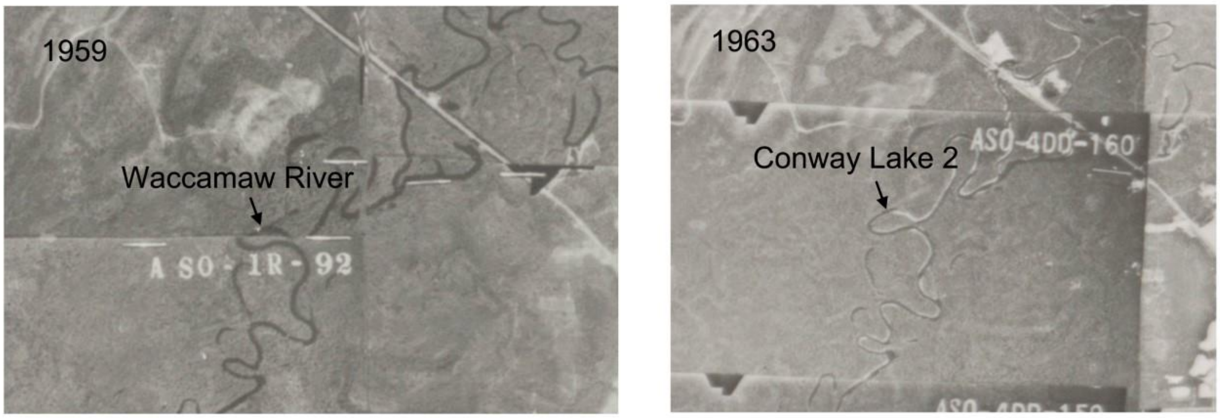

Figure 1 Historical aerial photo taken of the Waccamaw River in Conway, SC before (a) and after (b) the formation of the oxbow lake of this study.

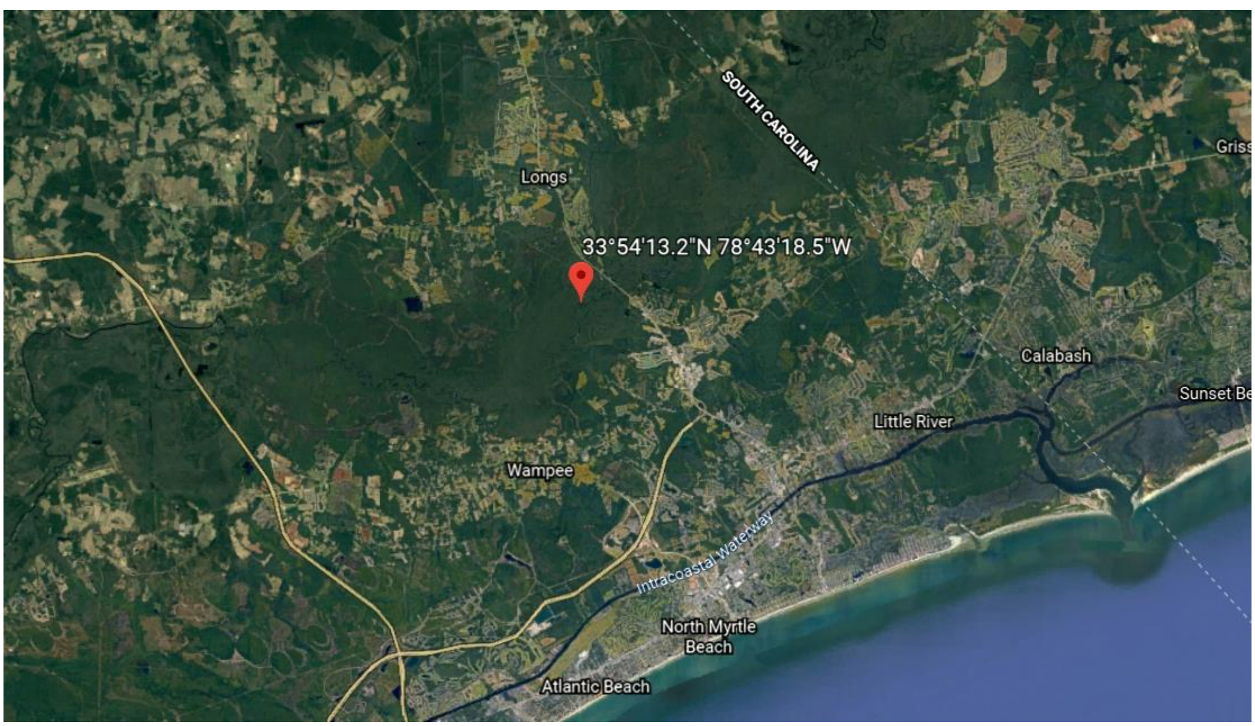

Figure 2 Coordinates and marked location of the studied oxbow lake in regards to the Atlantic Ocean and Carolina state line.

Figure 3 Photo taken of the core that was collected from the oxbow lake of the Waccamaw River in Conway, SC.

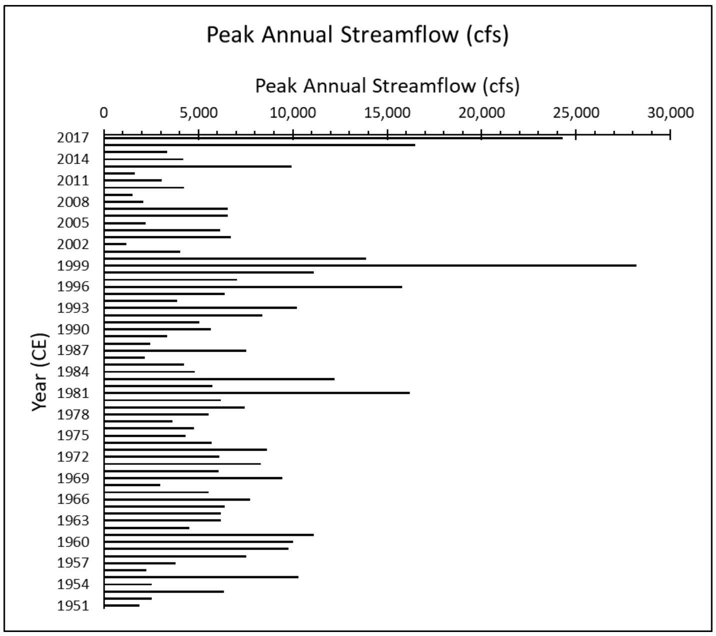

Figure 4 Annual peak discharge of the Waccamaw River over the duration of the oxbow lake's life from 1961-2017.

Table 1 Years of high annual peak discharge correlating to hurricanes of those years.

Year	Peak (cfs)	Hurricane
1961	11100	None
1969	9440	None
1981	16200	Dennis
1983	12200	None
1993	10200	None
1996	15800	Fran
1998	11100	None
1999	28200	Floyd
2016	24300	Matthew

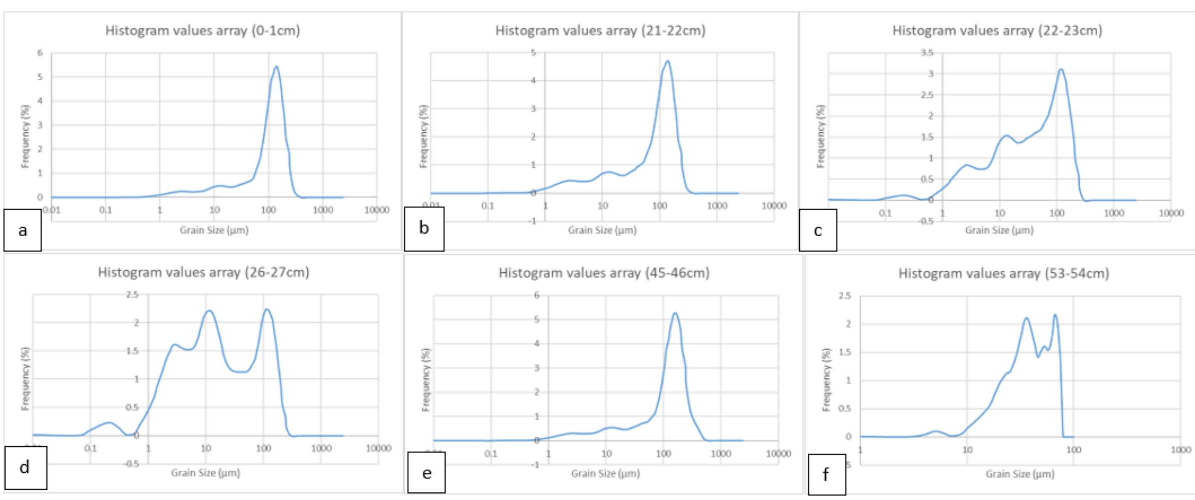

Figure 5 Histogram of six sediment samples from the oxbow lake. 5f represents an average year of flooding, 5a to 5e concern years of flooding where the peak annual discharge was greater than 9000 cfs.

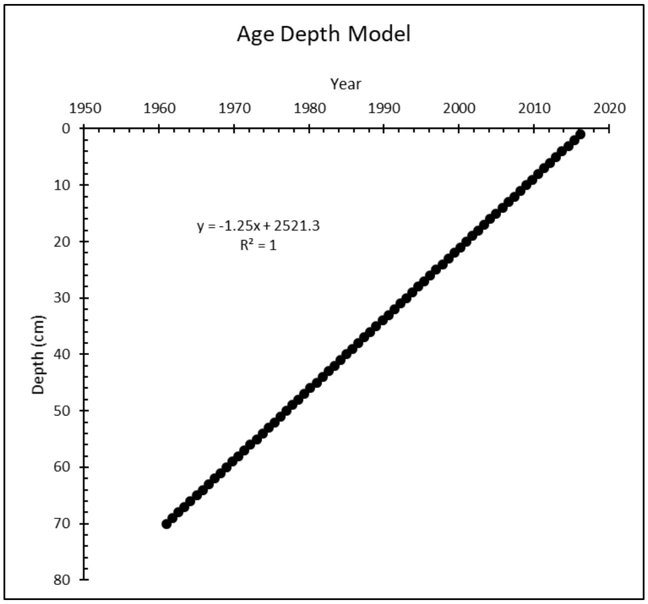

Figure 6 Age-depth model correlating the years before 2017 to 1961 with depth of the core.

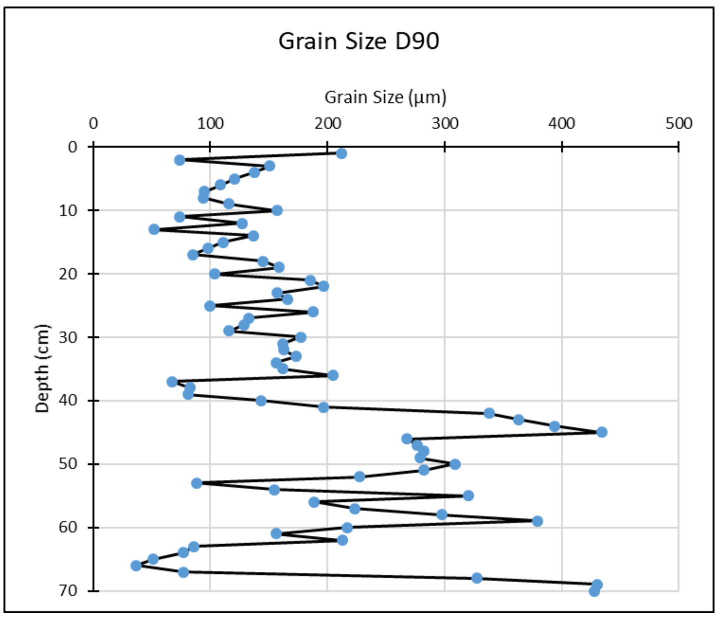

Figure 7 Grain-size of D90 records regarding the depth of the core.

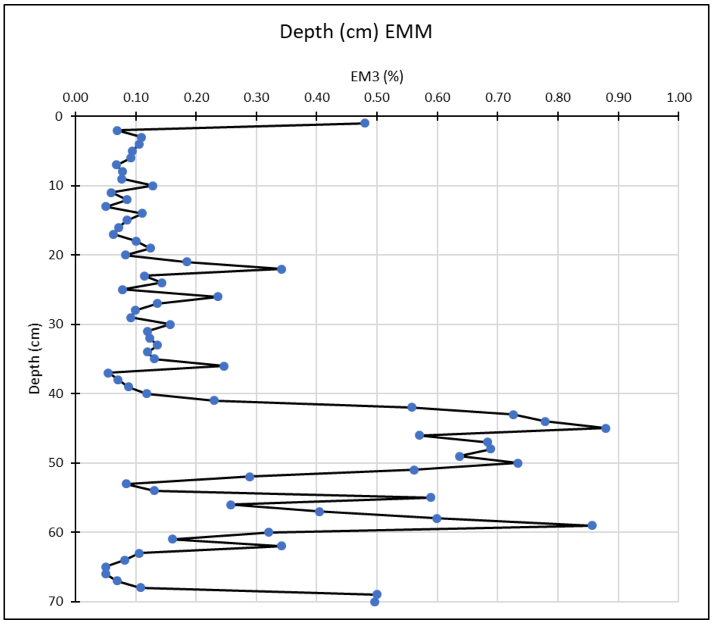

Figure 8 EM3 contribution in regards to the depth of the core.

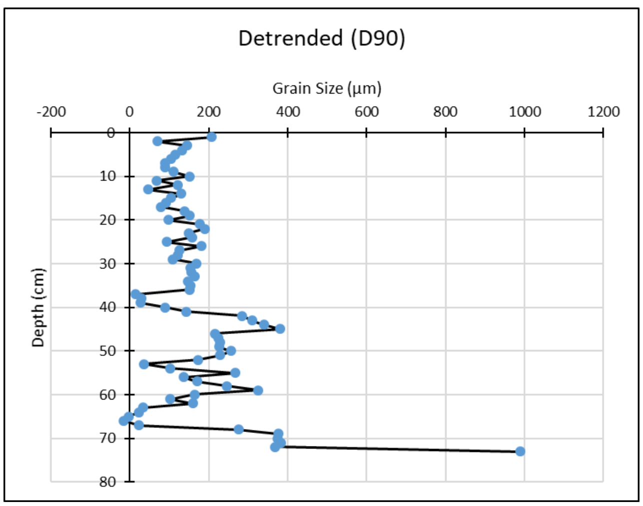

Figure 9 Detrended D90 data in regards to depth of the core.

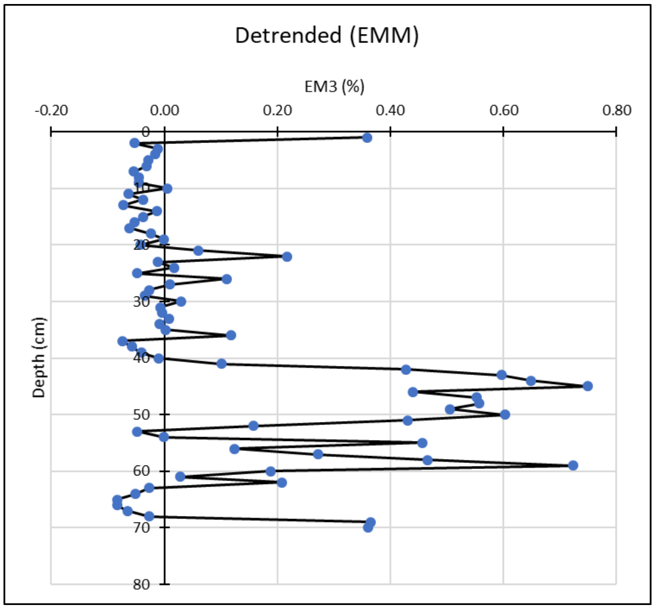

Figure 10 Detrended EM3 data regarding core depth.

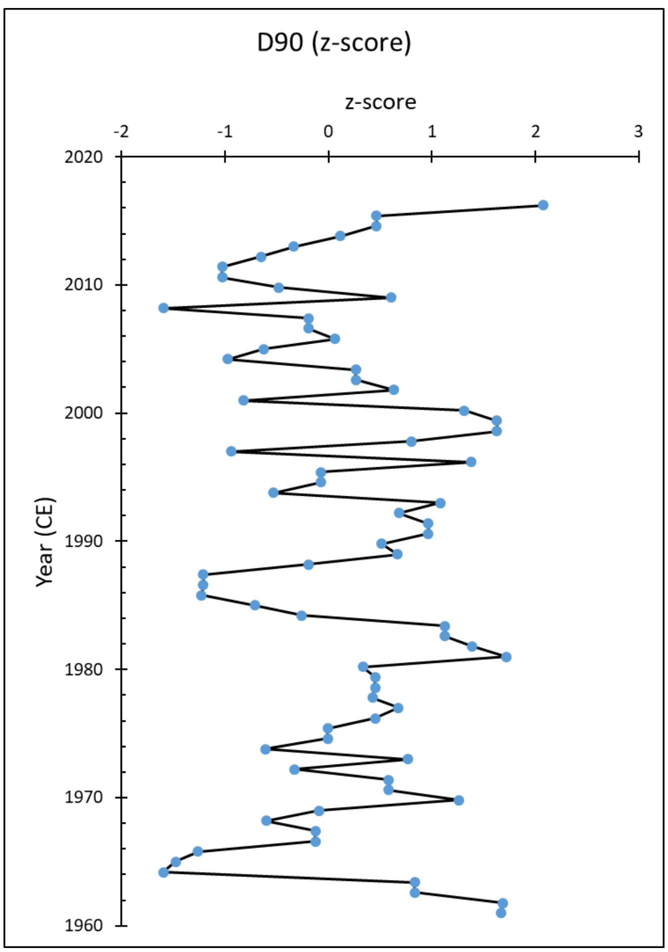

Figure 11 z-score of the core over the duration of the oxbow lake's life using the D90 value of 90% cumulative distribution.

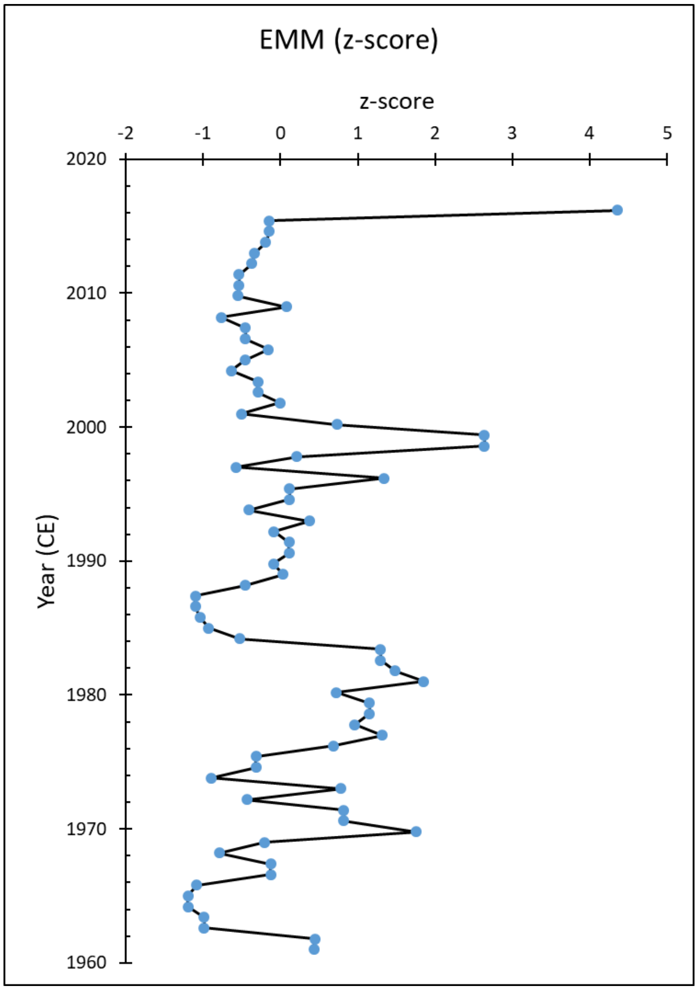

Figure 12 z-score of the core over the duration of the oxbow lake's life using the coarsest components of grain size distribution with end member modeling (EMM).

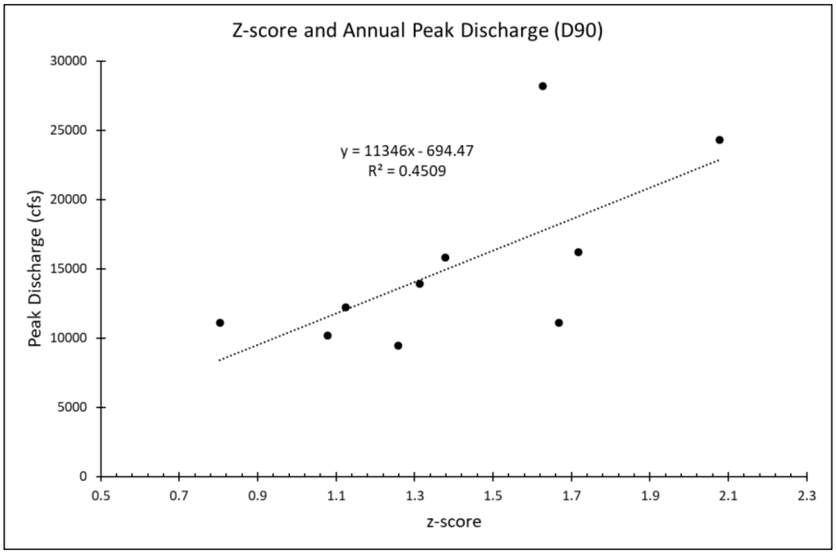

Figure 13 Linear regression between the z-score and annual peak discharge using the D90 measurements.

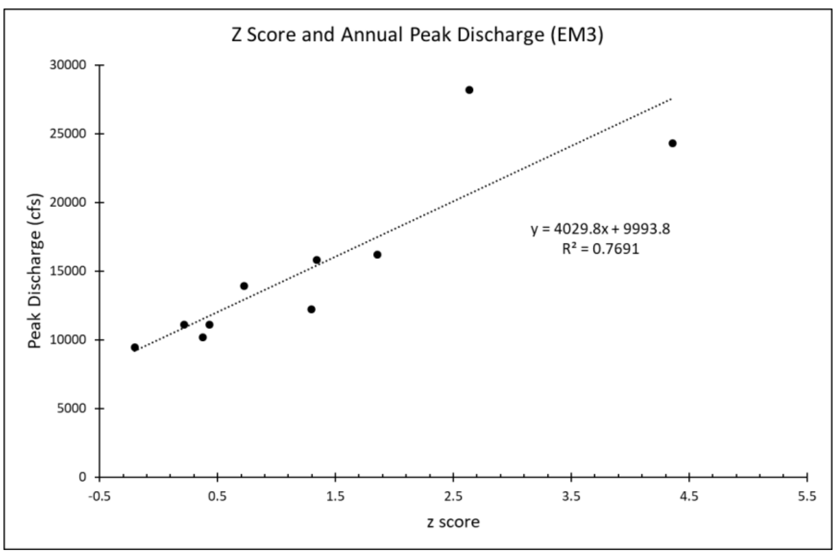

Figure 14 Linear regression between the z-score and annual peak discharge using the EMM measurements.