HOLOCENE PALEOFLOODS AND THEIR RELEVANCE TO FLOOD MITIGATION, RISK ASSESSMENT, AND POLICY.

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ABSTRACT

Paleofloods are past floods that occurred without being recorded by direct hydrological measurement. Paleoflood evidence can tell us about older, and often much larger historic flooding events than those of the instrumental record. For the past 40 years, paleoflood hydrologists have made the argument that geological or botanical flood evidence can help us better understand the true risks of extreme floods. However, because paleoflood studies are typically presented as individual works for single rivers, it is not known how often this kind of work produces information about floods that are equal or larger than the flood-of-record in conventional hydrological gage records. In my research, I created a new synthesis of all available paleoflood case studies on river systems in the U.S. spanning all available proxy records during the Holocene. My synthesis compared the largest paleoflood event in an area against the flood of record reported by the nearest stream gage, and also evaluated the relevance of paleoflood hydrology to natural hazards research. In order to be included in my analysis, studies had to have taken place on a river system in the continental U.S. during the Holocene, and also had to report a variable of flood magnitude. In the strong majority of cases (70%), Holocene paleoflood events are larger than the largest flood as recorded by instrumental river gages. In the most extreme case, a paleoflood event on Elk Creek, SD had a magnitude 12 times larger than the flood of record. While there is great potential for using data from paleoflood studies in flood frequency analyses, paleoflood hydrologists do not have a standard approach to reporting their results. In my review, I will present a list of suggestions for reporting the location, date, and magnitude in future paleoflood studies to comply with new reporting standards outlined in USGS Bulletin 17C.

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1. INTRODUCTION

In the United States, floods are the most destructive natural hazard in terms of their monetary cost, physical destruction, and loss of life (Baldassarre et al., 2014). On average, floods kill about 140 people each year in the United States and cause $6 billion in collective property damage (USGS, 2016). Seven out of ten of the most expensive natural disasters in U.S. history can be attributed to flooding events (Smith and Katz, 2013). Due to floods being such consequential natural disasters, there is a continuous need to understand flood patterns and flood risk in the United States. As anthropogenic climate change is projected to increase the severity of precipitation-based flood events in hazard-prone areas (Waters et al., 2010), the ability to provide robust and reliable flood risk estimates is becoming increasingly important (Macdonald et al., 2006).

In order to estimate future flood risks, hydrologists commonly conduct a flood frequency analysis (FFA); a method used to predict streamflow values with specific return periods along a river (Saksena, 2017). These analyses use statistical information to calculate estimates of specific return periods, recurrence intervals, and flow values during floods. Estimates from FFAs provide a framework for evaluating the potential peak discharge of a future flood based on past flooding events recorded by instrumental stream gages. Flood frequency analyses are not only useful in flood mitigation, but required for flood insurance, zone planning, and designing safe hydraulic infrastructure. When administering a meaningful FFA, the largest flooding event has a major influence on the FFA estimate range as the peak flood discharge provides an upper bound value used to consider the most extreme flood of record in the analysis (Saksena, 2017).

While FFAs are useful in getting a preliminary, short term estimate of flood return periods, FFA estimates are commonly calculated using instrumental river gage data and do not factor in past flood, or paleoflood, data taken over longer geological time. This can result in underestimating the probable maximum flood (PMF) (Koutsoyiannis, 1999) and the type of infrastructure required to mitigate large flood events in a flood prone area. Instrumental stream gage records provided and monitored by the U.S. Geological Survey (USGS) are often less than 100 years long and usually contain information gaps due to discontinuous measurements (Ruiz-Bellet et al., 2015). This creates a challenge by not having a complete data record at each individual stream gage site where FFAs may be conducted. The instrumental stream gage record can be significantly lengthened by hundreds, sometimes thousands of years by reconstructing discharges of past floods using paleoflood evidence (Kochel and Baker, 1982).

Having an extensive understanding of past, historical flood events is important in flood mitigation, risk assessment, and policy as it allows for the lengthening of the data record and better-informed decision making. In the United States, knowledge of floods before the instrumental record is particularly limited as instrumental stream gage records monitored by the USGS only cover only a relatively short period of time. This can make probability estimates of extreme, rare events poor (Gerard and Karpuk, 1979). Additionally, in some areas, there may be no gage evidence of a past extreme flooding event in the last ≤ 100 years of recorded data. Because instrumental gage records usually extend back a century or so, it is difficult to estimate the risks of high-magnitude floods that may have occurred only one or twice in the past. Therefore, flood frequency estimates could be significantly improved by the inclusion of paleoflood data as a compliment to the standard instrumental data (Gerard and Karpuk, 1979).

Since the field of paleoflood hydrology was first introduced by Kochel and Baker 1982, paleoflood hydrologists have made the argument that geological or botanical flood evidence can help us better understand the true risks of extreme floods. Paleoflood hydrologists have also suggested that a longer perspective of flood history provided by paleoflood evidence can help us understand modern hazards. The first claim of paleoflood hydrology's value came 40 years ago during a time when there was not a lot of evidence available to support the stated significance of the field. Because paleoflood studies are typically presented as individual works for single rivers, it is not known how often this kind of work produces information about floods that are equal or larger than the flood-of-record in conventional hydrological gage records. Affirmations that paleoflood evidence has relevance to risk assessment and policy is based on single paleoflood studies, typically restricted by geographic location and restricted to single river systems. No single paleoflood study has encompassed the entire area of the United States in one comprehensive study. While some paleoflood studies have shown that earlier floods were more severe than modern floods documented by instrumental gauge records, it was not known if those particular examples were representative of the broader field of paleohydrology as a whole. Additionally, it was not known if it is common for earlier floods to be larger than modern floods or if that result is somewhat rare.

In my research, I created a new synthesis of all available paleoflood studies on river systems in the United States spanning all available proxy records during the Holocene. In this study, I present a comprehensive synthesis of paleoflood research done in the U.S. over the last four decades. The purpose of my synthesis is to homogenize the data from paleoflood studies that report magnitude in order to provide information about rare, extreme, past flooding events on U.S. river systems. This synthesis also evaluates the value of paleoflood information in risk assessment, flood mitigation, and policy. In my synthesis, I compare the magnitude of the largest paleoflood event in an area to the flood of record as reported by the nearest instrumental stream gage record. The magnitude of the largest paleoflood event can be a critical variable in risk assessment and policy making, as the instrumental flood record may not be long enough to offer a complete understanding about the most severe history of flooding in an area.

I exclusively reviewed paleoflood studies that report magnitude (m^3/s) and were conducted on river systems in the United States during the Holocene. The peak discharge value reported in each study was reconstructed using various environmental proxies, e.g. slackwater deposits and fluvial sediments (National Climatic Data Center (NCDC). The results of my synthesis will provide information on where paleoflood studies have been conducted in the United States, how often paleoflood studies indicate past floods that are more severe in the past century, how much larger are exceptional paleofloods than the flood-of-record, and the magnitude of these past extreme floods. This synthesis will also provide information on the relevance and value of paleoflood hydrology to natural hazards research.

1.1. Background

Paleofloods are past floods that occurred without being recorded by direct hydrological measurement or without observation or documentation by non-hydrologists (Baker, 2008). While there are older studies that use geologic methods in assessing the risks of outstanding floods (e.g., Costa, 1978), the core concepts of paleoflood hydrology were not formally introduced until Kochel and Baker 1982. Paleoflood hydrology provides a method of estimating recurrence intervals for large floods when return intervals of floods exceed the length of historical data sets (Kochel and Baker, 1982). Since first being introduced in 1982, the field of paleoflood hydrology has been professed as a valuable method of understanding extreme flood events that took place during the mid to late Holocene. Paleoflood data reconstructed from geological or botanical archives can provide a history of flooding events that occurred hundreds to several thousand years ago. Unlike historical flood analysis, paleoflood data are not limited by the locations of past human observations of floods (Kochel and Baker, 1982). Assessing the risk of rare, large magnitude floods is difficult when only the instrumental record and conventional methods of flood frequency analysis are present (Kochel and Baker, 1982).

In order to reconstruct paleoflood data that extends past the instrumental record, paleohydrologists rely on environmental proxies. Proxies are preserved physical characteristics of the past environment that can be used when direct meteorological measurements do not extend far back enough in time to analyze the climate conditions during a specific period of time (Nicholls, 2010). Proxies are useful indicators of past global changes, and enable scientists to understand climatic conditions over a longer fraction of the Earth's history where instrumental records fall short (National Climatic

Data Center (NCDC), 2017). Paleoflood events can be analyzed and reconstructed using proxies such as slackwater deposits (SWD), tree-ring records, historical evidence, and sediment records.

A common proxy used for paleoflood reconstructions is a slackwater deposit. A slackwater deposit is a layer of sediment, usually consisting of sand, silt, and gravel, deposited by a river in flood when its waters decrease in flow velocity. Slackwater deposits are often formed just at the edges of flood waters, when the river rises above its channel and floods onto the surrounding flat area (Ely and Baker, 1985). Slackwater deposits can provide high accuracy information about the discharge, magnitude, and dating of paleoflood events — allowing scientists to extend the temporal record by centuries to millennia (Baker, 1987). The magnitude of a paleoflood event can be reconstructed by slackwater deposits using the sediment texture and amount of energy that was needed to transport the sediment into the deposit. This information is then put into a statistical, hydraulic model (Foulds & Macklin, 2015) allowing for the estimation of a paleoflood's magnitude. Sites of slackwater sediment accumulation can occur in multiple locations, including tributary mouths, abrupt expansions in the channel, and at meander bends (Baker, 1987). Most slackwater deposits are found in arid to semi-arid regions where dry, narrow canyon beds or gorges are resistant to weathering. Slackwater deposits are prevalent in these areas because they are able to be protected and preserved for long periods of time (Baker, 1987). The age of a paleoflood event can also be estimated by slackwater deposits using the method of radiocarbon dating (Bowman, 1990). Radiocarbon dating measures the amount of carbon (^{14}C) in the organic material embedded in a fluvial deposit. The amount of ^{14}C in the deposit is compared against an international reference standard which provides an age estimate of the carbon in the deposit (Knox, 2003).

Tree rings are another proxy used in paleohydrological studies to reconstruct past flooding events, as they can document the occurrence and timing of past floods. Tree-rings record information about flooding events by showing anomalies in their cell vessel anatomy and changes to wood structure (Ballesteros-Cánovas et al., 2015). When trees are struck by debris transported by floods, the tree's bark and underlying tissue layer known as the cambium are damaged resulting in growth deformation referred to as a flood scar (McCord, 1990). The flood scar can be dated, and used to reconstruct information about past fluvial processes. Dating of a flood scar can be used to identify the year of a flooding event, and sometimes the season of a flooding event (Stoffel & Corona, 2014). Additionally, the height of a flood scar on a tree can provide information about flood stage (Ballesteros-Cánovas et al., 2011). Dendrogeomorphic evidence of past flooding events can be seen in the tilting of stems, elimination of branches, root exposure, elimination of neighboring trees (Stoffel & Bollschweiler, 2008).

Another type of proxy that supplies information about paleoflood events are lake sediment records. Lake sediment records are a valuable paleoflood archive, as they are a natural sink for sediments transported during floods (Wilhelm et al., 2018). As sediment accumulates on the floor of a lake, the varying layers provide an extensive data archive of the environmental conditions at the time of deposit. Flood magnitude can be reconstructed using lake sediment deposits, as the grain size may represent the river energy and the discharge needed to transport that sediment (Lapointe et al., 2012). In addition to grain size, sediment layer thickness and a comprehensive understanding of the sedimentary processes of the lake system are also needed to properly reconstruct flood magnitude (Wilhelm et al., 2018). In order to extract lake sediments, scientists drill into the basin floor and retrieve a representative core sample in an aluminum irrigation pipe (Bennington & Farmer, 2015). The materials examined in the extracted core may include detritus, pollen, and chemicals, and diatoms, such as Oxygen 16 (O^{16}) and Oxygen 18 (O^{18}) (National Climatic Data Center, 2017).

Historical records, such as journal articles, diary entries, archival documents, epigraphic marks, photographs, newspapers, weather logs, maps, and paintings can also provide scientists with an understanding of past flood events not documented by instrumental gage records (Brázdil et al., 2006). Documentation of historical floods has long been of interest to people and communities for social, cultural, and practical purposes. The earliest accounts of a flooding event are often based in populated urban areas with religious structures, political centers, or in important trading and commerce locations (Pötzsch, 1784). Information about flooding events is documented first hand by witness accounts, or in the markings/etchings on buildings. These etchings record the height or stage of a flood (Benito, 2010). While historical records help to piece together the history of flooding before instrumental records, some of the data may be incomplete or isolated to a single specific extreme flooding event. Some records may also be missing quantitative information about the exact magnitude or discharge of a flood. Despite some gaps in data, historical records are a valuable archive that can help bridge the time between instrumental and paleohydrological data (Benito et al., 2005).

Quantitative data produced from paleoflood studies allows researchers to gain a comprehensive knowledge of how major fluvial systems in North America have behaved in the past. These data also enable the extension of the geological flood record past the human observed instrumental record. Geological or botanical evidence of extraordinary paleofloods provides quantitative information on magnitude and frequency of past floods that increases the reliability of risk analyses for extreme floods (Ely et al., 1991). Using interdisciplinary methods within the field of paleoflood hydrology, scientists can address prevailing problems and difficulties in traditional flood frequency analysis and flood hazard assessment. Some of these problems include not having an extensive instrumental stream gage record, and underestimating the largest flood in an area. Paleoflood studies are valuable because paleoflood data reduces the uncertainty in estimates of long return-period floods and improves scientists general understanding of hydroclimatic effects on flood frequency. Paleoflood hydrological studies also offer new methods for estimating and characterizing flood hazards, which can have societal benefits as engineers can use the results produced by paleoflood studies in the designing or construction of dams or other floodplain structures (Baker et al., 2002).

1.2. New applications of paleoflood hydrology

Traditionally, information from paleoflood studies has not been incorporated into standard FFA or risk assessments by engineers or hydrologists. This is because the USGS Guidelines for Determining Flood Flow Frequency have been in place since the 1960s, and there has never been an avenue for the incorporation of paleoflood data. The USGS guidelines ensure that FFAs are uniform across the nation, and that there is a consistent framework for conducting estimates of flood flow frequency. However, a recent amendment made in 2018 to the USGS *Guidelines for* Determining Flood Flow

Frequency provides a new avenue to incorporate paleoflood data that extends past the instrumental flood record. This new amendment was labeled Bulletin 17C (England Jr. et al., 2019), and is the third major iteration was made to the USGS' Guidelines for Determining Flood Flow Frequency. Bulletin 17C is the first major update to these guidelines in almost four decades and permits the incorporation of paleoflood data derived from geological or botanical field evidence to be used in quantitative flood risk assessments. Bulletin 17C is able to accommodate three types of paleoflood information for flood frequency analyses; discharge estimates of large floods prior to human documentation and gage record, perception thresholds, and paleohydrologic bounds. Discharge estimates provide information about how large an undocumented flood's magnitude was, while perception thresholds allow scientists to generate an expectation about large flooding events based on knowledge of past peak discharges and the number of historical floods documented over time (Paryastre et al., 2011). A paleohydrologic bound is an interval of time during which a specific flood discharge has not been exceeded (Levish, 2002).

In order to satisfy the 17C standards, paleoflood studies in the United States should provide quantitative estimates of flow discharge (and may include the upper and lower range of those estimates), the date of all paleofloods that exceeded some perception threshold, and define explicitly the start and end of the paleoflood period (England Jr. et al., 2019). However, many published paleoflood studies do not report key variables, such as discharge or magnitude, which is needed for FFA estimates. Because there is no uniform way of reporting paleoflood information, some ambiguity still exists in how to use paleoflood data in flood frequency analyses and risk assessment. In order for the field of paleoflood hydrology to move forward, there is a need to standardize reporting in order for paleoflood information to be used in FFA and risk assessment by government agencies.

Because there is a current lack of standards for reviewing and reporting paleoflood information, there has been discussion in the hydrologic community on how to improve the collection of paleoflood data for stakeholders and engineers. May 29-30th, 2019, I attended a public paleoflood workshop at the U.S. Nuclear Regulatory Commission in Rockville, MD hosted by the U.S. Geological Survey. The purpose of this workshop was to collect perspectives and recommendations from a broad range of scientists and stakeholders in order to develop a framework for technical review of paleoflood information. This workshop provided a platform for these leading paleoflood experts to discuss the recent implementation of Bulletin 17C (England Jr. et al., 2019) in the USGS Guidelines for Determining Flood Flow Frequency, as well as developing a framework for technical review of paleoflood study data collection, reporting, and incorporation into probabilistic flood hazard assessments for the U.S. Nuclear Regulatory Commission. The workshop also met to determine what reporting standards and metadata would make paleoflood data most useful to those using paleoflood information in their professions. Since paleoflood hydrology studies are becoming an increasingly important tool used for extending the instrumental flood record, agencies like the U.S. Nuclear Regulatory Commission are interested in using paleoflood information in flood frequency analyses before designing critical infrastructure like nuclear power plants. Creating a consistent framework for paleoflood information will not only be useful to U.S. Nuclear Regulatory Commission, but will be useful to other agencies like the USGS and U.S.

Army Corps of Engineers who may rely on the incorporation of paleoflood information for probabilistic flood-hazard assessments.

Before my synthesis of U.S. paleoflood studies, it was uncertain if the type of paleoflood information reported in studies would meet new reporting standards outlined by the USGS and Bulletin 17C. While at the U.S. Nuclear Regulatory Commission workshop, I spoke to engineers and hydrologists in attendance at the meeting and asked if there was currently any uniform way of reporting paleoflood data. After inquiring with these professionals, it was expressed that while guidelines are in place, standards of practice for conducting and reviewing such studies are lacking (Ryberg, personal communication, 2019). This inhibits paleoflood hydrology's use in regulatory decision making. While speaking to these professionals, it also became clear that there is significant interest in the creation of a uniform paleoflood dataset, as one currently does not exist. Based on the results of my synthesis of paleoflood case studies, I will present a list of suggestions for reporting paleoflood information in order to best serve the interests of those who may use paleoflood data in their professional work.

2. METHODS

I constructed a meta-data table highlighting key aspects of paleoflood studies conducted in the continental United States spanning the Holocene. Sources for the meta-analysis were selected by conducting an initial search of the keyword phrase "paleoflood" on the Google Scholar search engine as well as the University of Minnesota Library website. The first use of the term "paleoflood hydrology" came from Kochel and Baker 1982 as a way to establish recurrence intervals for past, extreme floods where historical records are short or entirely absent. The phrase “paleoflood” brings up approximately 4,000 hits on Google Scholar, however, these listings are not restricted by geographic area or any other parameters, and may contain duplicates or references in citations. I also accessed the Past Global Changes (PAGES) Floods Working Group metadatabase (Wilhelm et al., 2018) for paleoflood archives in the United States. PAGES is an international organization based out of Bern, Switzerland that aims to support research about the Earth’s past environment in order to obtain better predictions of future climate and environment (Newman et al., 2010). The PAGES Floods Working Group is a consortium of international paleoflood researchers that aims to bring together all the scientific communities reconstructing past floods and those studying current and future floods to coordinate, synthesize and promote data and results on the natural variability of floods. The Floods Working Group has packaged a metadatabase of paleoflood studies on their website, grouping paleoflood studies by geographic location, reference citation, archive, time period, and reporting of magnitude. There are currently 390 total entries in the Floods Working Group metadatabase, with 40 entries describing work in the United States (Wilhelm et al., 2018). In addition to this database, I reviewed a 28-page bibliography that was assembled for the USGS Development of a Framework for Technical Review of Paleoflood Information workshop at the U.S. Nuclear Regulatory Commission in Rockville, MD May 2019. This two-day workshop hosted 35 leading paleoflood experts, including members from the USGS, US Army Corps of Engineers, US Bureau of Reclamation, and researchers from academic institutions.

After selecting sources for the synthesis, I applied specific criteria for the variables to be extracted from each paleoflood case study. In order to be considered for my synthesis, studies must have been published, peer-reviewed articles from journals, government reports, or books. Additionally, paleoflood studies for this analysis must have been conducted on a river system (excluding lake flooding) and span some portion of the Holocene. Some entries from the PAGES database were not included for this analysis because they did not meet the criteria of reporting flood magnitude (e.g., Wertz et al., 2013; Mansfield, 1938), or they were not conducted on a river system. Flooding events on lakes (e.g., Oslegger et al., 2009), ponds (e.g., Parris, 2010), caves or caverns (e.g., Dasgupta et al., 2010), and coastal systems (e.g., Hendy et al., 2013) listed in the PAGES database were not included. Once a study was determined to be an eligible candidate for my synthesis, I conducted a preliminary overview of each source to see if the article contained qualitative and quantitative data that could be entered into the meta-analysis spreadsheet. Variables extracted from each paleoflood paper included the defined geographic location of the study site, river basin, proxy type used for paleoflood reconstruction, peak paleoflood discharge value (Q-paleo max; McEwen & Werritty, 1988), and year or range of years for a specific paleoflood event(s) if provided. If a study site's latitude and longitude coordinates were not provided in the article, I approximated the coordinates by cross referencing the river location and estimated location of the study site.

2.1. Paleo and instrumental analysis: I recorded both paleo and instrumental data about past floods for this synthesis. The exact date or range of dates for a paleoflood event inferred from climate proxies was explicitly reported in some studies, but other times was not provided. In my synthesis, the date or range of dates of a paleoflood event were reported in either "Before Common Era (BCE)" and "Common Era (CE)." BCE dates were recorded as negative (-) values while CE dates were recorded as normal values with no + or - before the inserted value. If there was a range of values (for example, ~1,000 yrs ago, +/- 100 years) the central value of 1,000 was recorded. In the cases of radiocarbon dating (American Chemical Society National Historic Chemical Landmarks, n.d.), calibrated radiocarbon dates (BP, before 1950) were converted to calendar dates.

Information about paleoflood magnitude was collected directly from the study. Some studies reported one explicit maximum and/or minimum discharge (Q) values, and others provided a range of Q-max low and Q-max high values. The estimated range of paleoflood discharge values were recorded for the largest extreme paleoflood event at each study site. If only one Q-max value was given, the value was recorded for both Q-paleo max low and Q-paleo max high. The goal of collecting discharge values is to be able to compare the maximum Q-paleo values vs. Q-instrumental values to see how often the magnitude of a paleoflood event exceeds that of the instrumental gage record.

I collected instrumental data for this analysis by referencing the USGS Surface Water Annual Statistics for the Nation (SWASN) website (USGS, 2019). Through SWASN, I was able to collect streamflow data, the approximate drainage area of the study site, instrumental Q-max discharge and the year of the largest recorded instrumental Q-max value. I was also able to view the length of the instrumental stream gage record. Each paleoflood study site in my synthesis was assigned to a corresponding, individual stream gage. This was either estimated by locating the nearest stream gage to the paleoflood study site, or reported in the paleoflood study itself. Information about the drainage area of a study site was taken directly from the site's corresponding stream gage. It is useful to note that the drainage area reported at the nearest USGS stream gage does not account for the drainage area of the entire water body, only the area where the study was conducted. Additionally, the instrumental Q-max reports the maximum annual discharge value recorded on the instrumental gage. This value is found on the SWASN USGS “Surface Water, Peak-streamflow” data table. The “Surface Water, Peak-streamflow” data table also reports the year of the largest flood event on the instrumental record at a single stream gage, which was recorded in my synthesis.

3. RESULTS

Out of 100 studies initially considered, a total of 30 paleoflood studies fit the selection criteria to be included for this synthesis. The 30 studies included in this synthesis fit the outlined criteria of taking place on a river system in the continental United States during the Holocene while also meeting the criteria of reporting a value of flood magnitude. The 70 studies that were considered but not included in the synthesis are documented in **Appendix II,** along with the selection criteria each study does not report resulting in non-inclusion. My synthesis shows that the majority of paleoflood studies are conducted in the Southwestern part of the United States (**Figure 1**). The strong regional trend of paleoflood study site location is illustrated in **Figure 1**. Paleoflood studies are primarily conducted in this area due to the dry and arid climate that protects paleoflood proxies such as slackwater deposits from weathering, deterioration, and erosion. 18 out of 30 paleoflood studies in my synthesis were based on data reconstructed from slackwater deposits. The average time span of the slackwater deposits was between ~500-1,000 years ago, with the longest slackwater deposit record spanning ~10,000 years. Four studies were reconstructed from stratigraphic records, five studies were reconstructed from fluvial sediments, two studies had data reconstructed using slope area computation

(SAC) methods (Kohn et al., 2016), and one study was derived from historical documentation (Fuller, 1987). The SAC method computed peak flood discharges from measurements of high water marks along the stream reaches to estimate paleoflood flow.

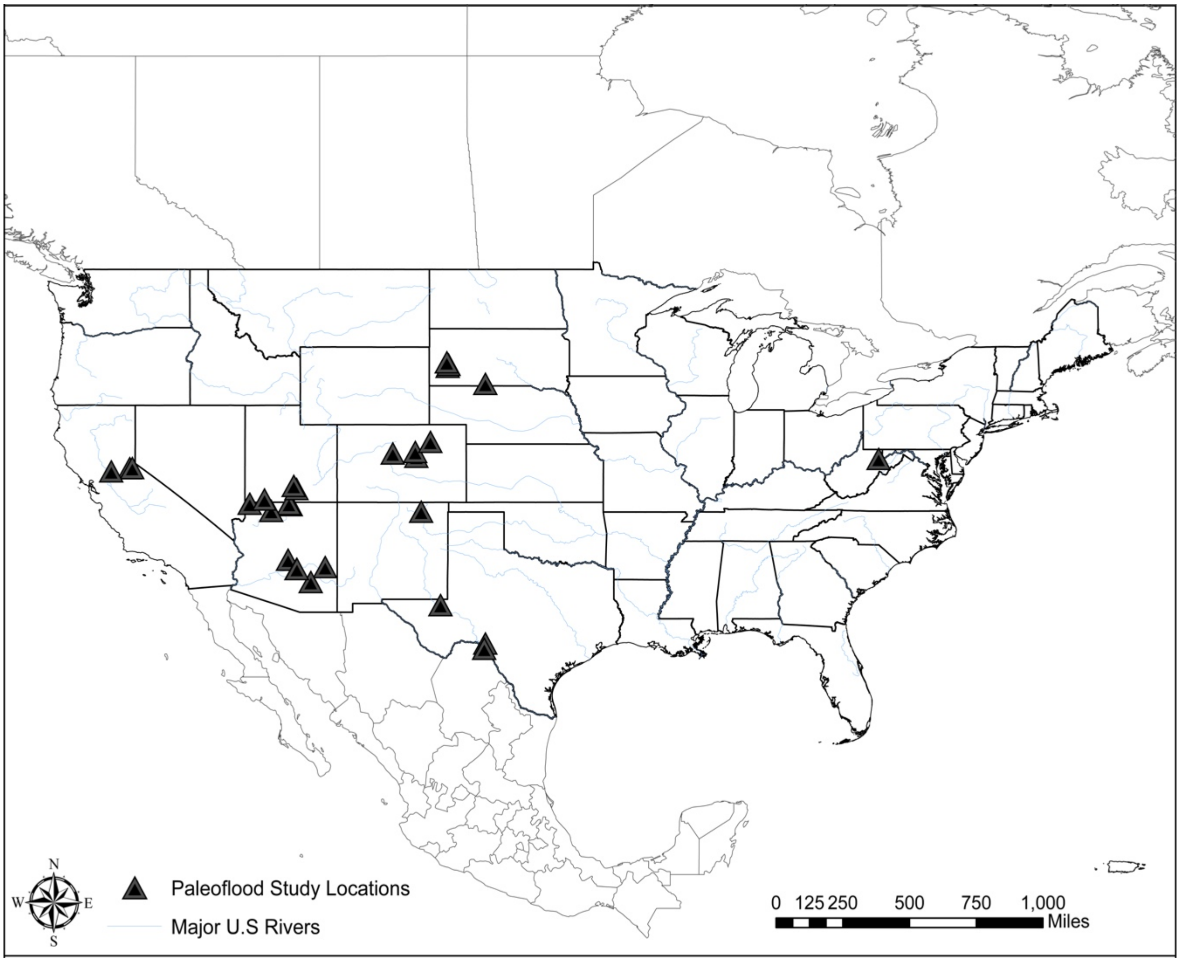

Figure 1. A map illustrating where the paleoflood studies included in my synthesis took place in the United States.

Out of the 30 studies reviewed in this synthesis (**Appendix I**) 21 studies report Holocene paleoflood events that are larger in magnitude than the flood of record reported at the nearest USGS stream gage. Holocene paleoflood events are larger than the largest flood of record reported at the nearest stream gage 70% of the time. In order to obtain information about how much larger paleoflood events are compared to the flood of record, I created a ratio plot (**Figure 2**). The ratio plot shows the maximum paleoflood discharge value divided by the maximum instrumental flood discharge value. The product allows for the maximum paleoflood discharge to be compared against the flood of record at that location. If the product value is over one, it indicates that the paleoflood discharge is larger than the instrumental discharge recorded at the nearest stream gage. If the value is less than one, it indicates that the flood of record was greater than that of the paleoflood record. The range of the ratio plot extends from 0.48 as the minimum value to 12 as the highest value. These results offer a more comprehensive view of the hazards posed by floods. Without knowledge of how often paleoflood events exceed the magnitude of floods on the instrumental gage, our understanding of the relevance of these extreme past events is limited. Estimates of paleoflood discharge are important for safety and natural hazards research because they allow us to understand the worst-case scenario flood. If an extreme paleoflood event were to happen today, we may not be prepared based on estimates from instrumental data.

In 18 out of the 30 cases reviewed in this synthesis, the paleoflood magnitude was between one and four times larger than the flood of record. In the four most extreme cases, the paleoflood magnitude was substantially larger than the flood of record by ratios of 5.6, 5.85, 8.2 and 12. The reconstructed paleoflood event on Elk Creek, South Dakota (Harden et al., 2011) was the most extreme example, with an estimated paleoflood magnitude 12 times larger than the flood of record which occurred in 1972 during the Black Hills flood. Elk Creek is located near Rapid City, SD which has a current population of approximately 75,000 people. Elk Creek has a drainage area of 572km^2 and experienced severe flooding with a peak flow of 294.5 m^3/s during the Black Hills flood. The 1972 flood is considered to be one of the worst flooding events on record in South Dakota, resulting in at least 238 deaths and an estimated $160 million dollars in damage (Schwarz et al, 1975). The 1972 flood produced the highest ever flood levels recorded in South Dakota's history, where 18 of the 27 stream peak flows exceeded the 50-year flood (Schwarz et al, 1975).

Many of the peak flows recorded in 1972 are themselves high outliers by factors of 10 or more in observed gage records that date back to the early 1900s. In order to extend the flood record prior to 1900, Harden et al., 2011 reconstructed the paleoflood magnitude on four small rivers in the Black Hills by extracting paleoflood evidence from stratigraphic sequences of late-Holocene flood deposits primarily in protected slackwater deposits in bedrock canyons. These paleohydrologic reconstruction methods allowed for the determination of the ages and magnitudes of extreme past flooding events on Elk Creek, Rapid Creek, Boxelder Creek, and Spring Creek, SD. The largest paleoflood event on Elk Creek had a magnitude of 3511 m^3/s and occurred ~900 years ago. This value substantially exceeds the flood magnitude value from the 1972 flood (294.5 m^3/s) by a factor of 12. The second most extreme case also was reported by Harden et al., 2011 on Rapid Creek, SD. Rapid Creek is also located near Rapid City, SD with a drainage area of 1164km^2. This reconstructed paleoflood event occurred ~1000 years ago, and had a magnitude 8.2 times larger than the flood of record in 1972.

The third most extreme paleoflood example took place on Salt River, Arizona located in the American Southwest. The Salt River is the largest tributary of the Gila

River and has a drainage area of approximately 35000km^2. Located near Arizona's capital city of Phoenix, it is an important source of water supply and hydropower for residents of the state (Phillips et al., 2009). There is a history of rare, extreme flooding events on the usually dry Salt River, so understanding the river's flood potential is beneficial for flood mitigation and control. The flood of record on the Salt River occurred in 1993, with a peak discharge value of 2169m^3/s reported at USGS stream gage 09497500. The paleoflood study on Salt River (Webb and Rathburn, 1988) reported a reconstructed paleoflood event that occurred ~1000 years ago with a magnitude 5.85 times larger than the flood of record reported at USGS stream gage 09497500. This maximum paleoflood discharge estimate was produced by using slackwater deposits found in the canyon bed near the area of study.

The fourth most extreme paleoflood example took place on Green Mountain Arroyo, NM. Green Mountain Arroyo is a small river with a drainage area of 47km^2 located near Raton, New Mexico. Raton is a small town, with a population size of approximately 6,000 people. The USGS stream gage record for this location (07201450) is relatively short, only extending back to 1971. The flood of record reported at USGS stream gage 07201450 occurred in 1973 with a maximum discharge value of 142m^3/s.

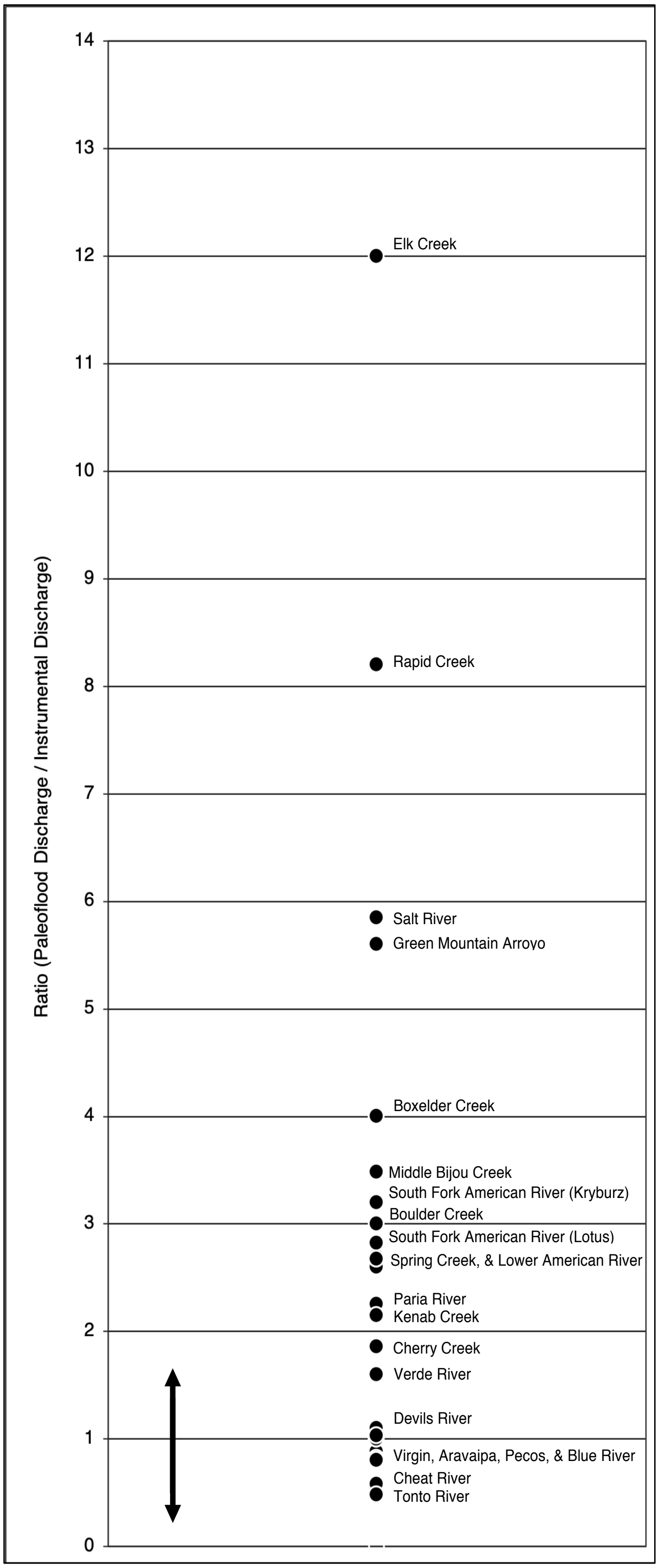

Figure 2. This ratio plot illustrates the maximum paleoflood discharge value divided by the maximum instrumental flood discharge value. Values over one indicate a paleoflood discharge larger than the instrumental discharge recorded at the nearest stream gage.

The paleoflood study on Green Mountain Arroyo conducted by Kohn et al. 2016 reported a reconstructed paleoflood magnitude 5.6 times larger than the flood of record reported at USGS stream gage 07201450. This magnitude was estimated using a slope-area computation model, a technique for estimating the peak discharge of a flood after the water has receded using high-water marks evidence (Bradley, 2012). The paleoflood event on Green Mountain Arroyo occurred an estimated 100 to 140 years ago from the date of data collection in 2014.

In addition to comparing the magnitude of a paleoflood event against the flood of record, I compared other variables such as the length of the instrumental record, peak instrumental discharge, drainage area, and ratio. When comparing the relationship between the peak instrumental discharge value and the length of the instrumental record (**Figure 3**), no distinct relationship can be found after visual assessment of the scatterplot. Similarly, no relationship was found when comparing the ratio (paleoflood discharge value ÷ the instrumental discharge value) to the length of the paleo record (**Figure 4)**. It may have been reasonable to expect that the ratio would increase over time, but that result was not found. A longer record does not always capture the peak flood. In 17 cases, the largest paleoflood event occurred in a record that only goes back 1000 or 2000 years. It is hard to predict how long of a record is needed in order to get the full story. It also does not appear that a longer instrumental record length will affect the amount of extreme flood events seen within that period. Three of the largest instrumental flood events (18400 m^3/s, 17200 m^3/s, 16700 m^3/s) on the Pecos River and Devils River, happened in the past 20 years of instrumental gage data (**Figure 3**).

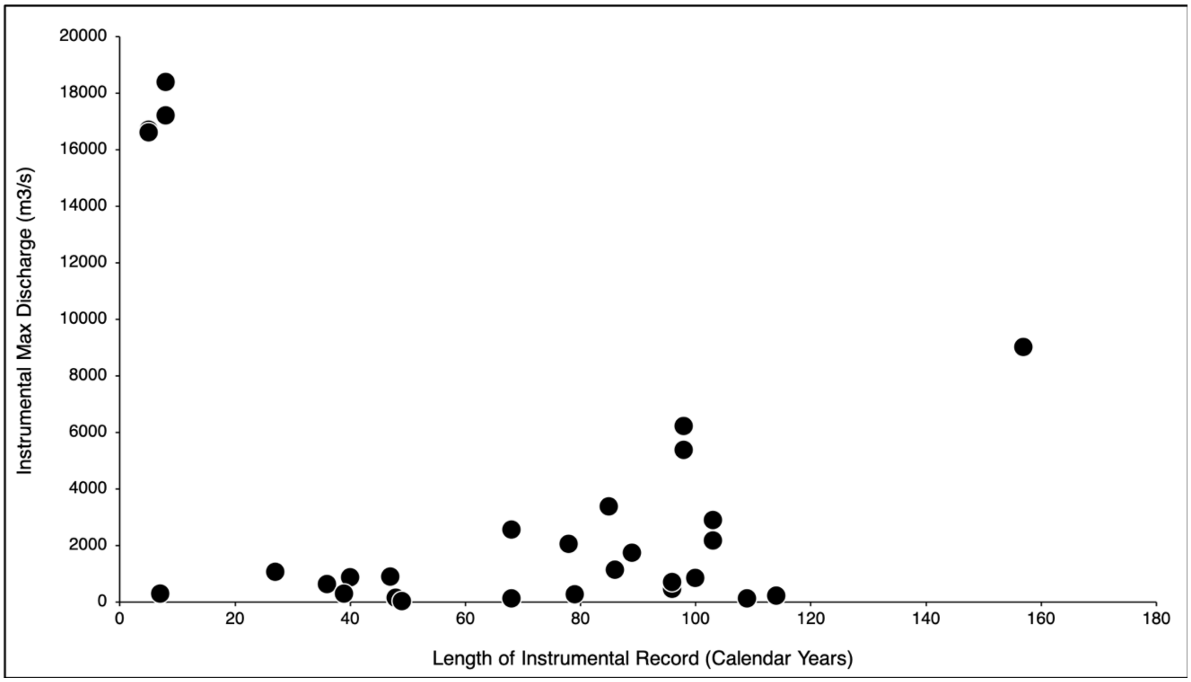

Figure 3. A scatterplot depicting the relationship between the peak instrumental discharge value and the length of the instrumental record.

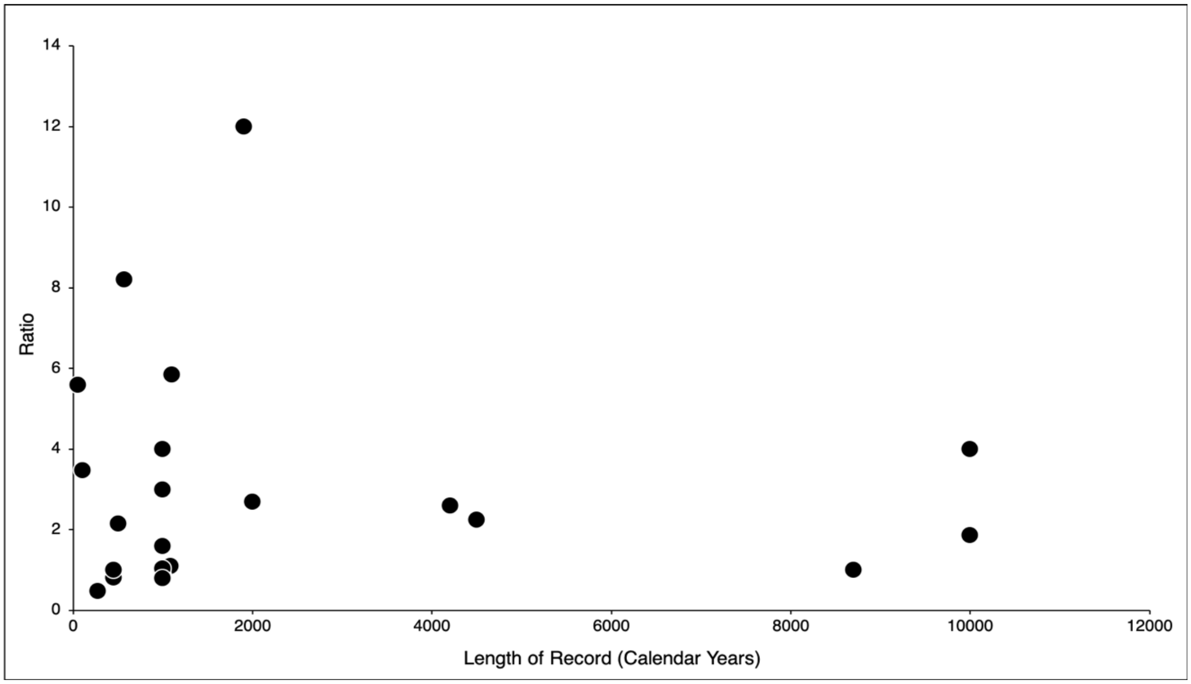

Figure 4: A scatterplot depicting the ratio (paleoflood discharge value ÷ the instrumental discharge value) to the length of the paleo record.

When comparing the drainage area of a river basin to the maximum reconstructed paleoflood discharge (**Figure 5)**, the data shows that a smaller drainage area tends to experience the highest discharge values. Smaller rivers may be susceptible to flooding more frequently because there is less capacity to hold large amounts of water produced in heavy precipitation-based flooding events.

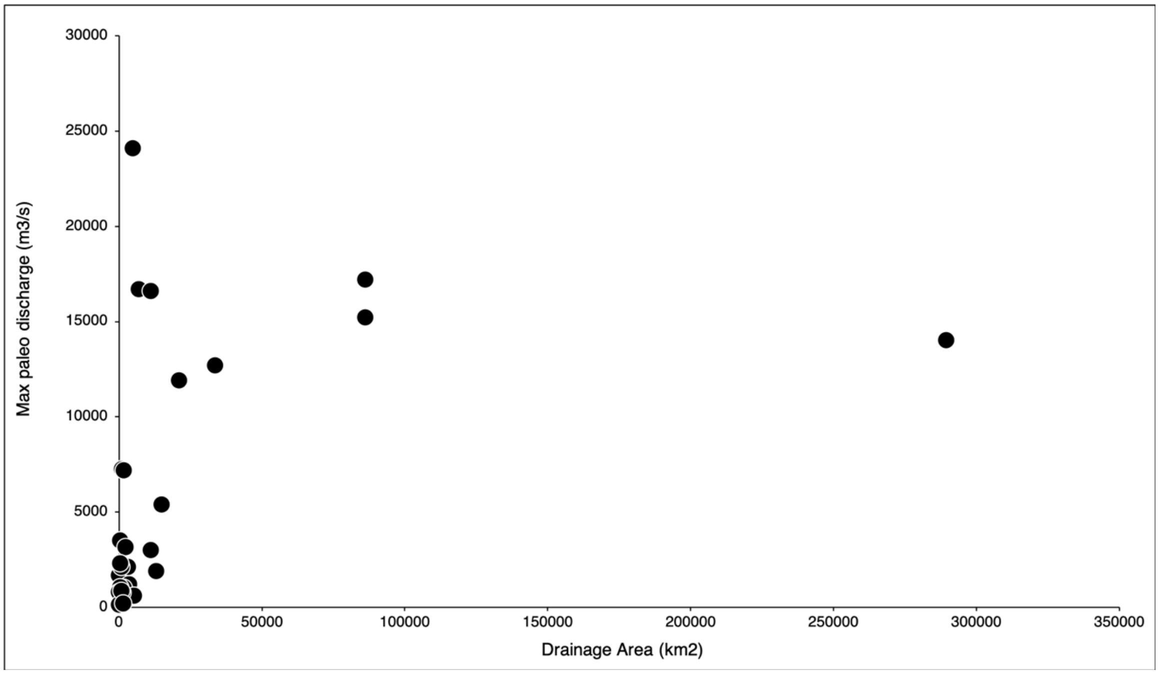

Figure 5: A scatterplot comparing the drainage area of a river basin to the maximum reconstructed paleoflood discharge value.

4. DISCUSSION

My synthesis shows that in order to understand the frequency of extreme floods, hydrologists should study the rare events. Paleoflood evidence can greatly increase the precision of flood frequency estimates by substantially extending the instrumental gage record. In many cases, paleoflood evidence persists for hundreds to thousands of years, allowing the collection of data about the largest floods that occurred during an extended period of time (England Jr. et al., 2019). As part of my synthesis of paleoflood information across multiple studies, I set to understand where paleoflood studies have been conducted in the United States, how often paleoflood studies indicate past floods that are more severe than the flood-of-record, how much larger exceptional paleofloods are than instrumentally gaged floods, and determining if it is common for earlier floods to be larger than modern floods or is that result somewhat rare.

After conducting my analysis, it can be seen that the paleoflood studies I included in my synthesis were most commonly conducted in the southwestern United States, primarily in the states of Texas, Arizona, Colorado and Utah. This region-specific geographical pattern can be explained by the American Southwest's semi-arid climate and its ability to preserve paleoflood proxies. The American southwest is warm, dry, with low annual precipitation due to the quasi-permanent subtropical high-pressure ridge over the region. This warm, arid climate is a strong preserver of paleoflood proxies like slackwater deposits. Slackwater deposits in this region are found in protected channel banks and canyon walls that withstand erosion and weathering, making rivers in the southwest a practical location to extract data for paleoflood reconstruction. It is more challenging to extract proxy data in an environment that is wet and humid, like the southeastern United States where the geological archive is not as strongly preserved and is heavily eroded by frequent precipitation.

When looking at how often past floods are more severe than floods recorded on the instrumental record, paleoflood studies indicate past floods that are more severe than the flood of record 70% of the time. 21 out of 30 paleoflood case studies included in my analysis showed the magnitude of the most severe paleoflood event exceeded that of the largest flood on the instrumental gage record. In the most extreme event, the highest paleoflood discharge estimation was 12x larger than the largest flood of record recorded at the nearest stream gage. After reviewing the data from 30 separate paleoflood studies, it is not atypical to see that earlier floods are more severe than modern floods.

I narrowed down the number of paleoflood studies included in my synthesis using strict selection criteria and constraints. Relaxing the selection criteria may have allowed the inclusion of more paleoflood studies in my analysis, but doing so would create unique obstacles under the scope of my synthesis. The requirements for a study to be included in my synthesis included taking place on a river system in the continental U.S. spanning some time during the Holocene while also reporting a value of flood magnitude. Without a reported discharge or magnitude value, there is no way to understand how large or extreme a paleoflood event was. Magnitude is also required for flood estimates and statistical analyses so it is a variable that must be included to incorporate paleoflood information in these assessments. Paleoflood events occurring in coastal systems (e.g., Hendy et al., 2013), caves (e.g., Dasgupta et al., 2010), or lakes (e.g., Oslegger et al., 2009), were not included because the processes that create floods in these systems are entirely different from river and stream systems. Additionally, while there have been studies that reconstruct floods before the Holocene (e.g., Hanson et al., 2012), the climatic conditions prior to the Holocene were entirely different from the present and it would be difficult to make an appropriate analysis of the behavior of past extreme floods and their relevance to modern floods. Opening up the selection criteria to include studies outside the continental U.S. would be feasible with more time, however countries outside of the U.S. (e.g., France, The United Kingdom, Spain, Switzerland, Germany) have distinct and differing ways of reporting stream gage information (e.g., Macdonald et al., 2006; Benito et al., 2010), and that data can be difficult to obtain or impossible to access without permission or administrative approval.

4.1. Recommendations for Incorporating Paleoflood Information in Decision Making, Policy, and Flood Frequency Analyses

Even with the recent implementation of Bulletin 17C, a disconnect still exists between those who produce paleoflood data, and those who may utilize information from paleoflood studies in flood estimates. Part of this disconnect may be due to the fact that there currently is no uniform way of reporting or communicating information from paleoflood studies. During the creation of my paleoflood database, I encountered multiple discrepancies in the way that paleoflood data is reported, making the homogenization of the data into one, cohesive table a difficult challenge. Some of the most notable inconsistencies in reporting involved the study location, paleoflood dating, and estimating and/or reporting paleoflood magnitude. While there is a shared understanding of the importance of a paleoflood dataset such as the one created from my synthesis, there currently is no uniform way of reporting paleoflood information. The standards for reporting paleoflood information are also lacking. To combat this, I have constructed a list of recommendations to help ease these obstacles, based on the observations and challenges I encountered while building my own paleoflood dataset.

4.1.1. Dating

While creating my synthesis, I observed multiple different ways of reporting the date of a paleoflood event. Differing methods of reporting paleoflood dates included relative dating (e.g., Harden et al., 2015; Kohn et al., 2016; O'Connor, 1994), radiocarbon dating (e.g. Ely and Baker, 1985; Webb et al., 2002; Chatters and Hoover, 1992), and sometimes, no reported date in the study (e.g., Baker, 1987; Godaire et al, 2012; Kite et al., 2002). In the majority of studies I reviewed, the relative date of a paleoflood event was reported as a range of years (e.g., a paleoflood that took place ~400-1000 years ago) and did not report a precise date for the paleoflood event. I observed this to be a frequently used method of reporting, as it adjusts for any error in estimation and is usually easier to approximate than an absolute date. In other studies, the date of a paleoflood event was presented as a radiocarbon date, which then had to be converted into a calendar date. In other cases, the date of a paleoflood event was not reported or mentioned in the study at all. Based on the criteria needed to satisfy the requirements outlined in Bulletin 17C, the start and end date of the paleoflood period needs to be explicitly reported in a paleoflood study, specifically the number of years before present.

The variance of relative dating made it difficult to determine the exact start and end year of a paleoflood event for my dataset. The main discrepancy I encountered came from determining the start and end date of the paleoflood record. A study may describe a paleoflood event that occurred ~200 and 400 years ago (Harden et al., 2015), making the extraction of a single start date and end date for a paleoflood event challenging. Additionally, when a study described a paleoflood event that occurred ~1,000 years ago

(Wohl, 1989), it was not explicit if the event occurred 1,000 years ago from the year the study was published, or a different year because that information was usually not defined.

Currently, there is no uniform way of reporting the date of a paleoflood event, which can lead to variability and inconsistency from one study to another. To help reduce the ambiguity of paleoflood dating and ease the homogenization of data collection, I would recommend for there to be a standardized way of reporting the date of a paleoflood event — starting with explicitly defining the start and end date of the paleoflood period to satisfy the standards of Bulletin 17C.

4.1.2. Location

The location of a paleoflood study site was another difficult variable to homogenize across my dataset, particularly in relation to determining the appropriate stream gage closest to the study site. In some cases, the exact location of the study site was specifically defined with a specific stream gage that could be attributed to it (e.g. Webb et al., 2002; Godaire, 2012; House et al., 2002). In these instances, a diagram would be shown illustrating where the study site is, including the latitude and longitude of the study site making it clear for comparing the instrumental data to the paleoflood data. However, some studies did not have a specified study site with a specific stream gage that attributed to it (e.g. McQueen et al., 1993; Fuller, 1987) and/or did not report the exact coordinates of the paleoflood site. In the cases where study site location was not explicitly reported, I estimated the latitude and longitude of the study site based on the general diagram or study site description provided in the methodology.

The main challenge I encountered in regards to collecting location data was matching the location of the paleoflood study site to the nearest instrumental stream gage if that information was not provided. If there was not an explicitly given stream gage number or location given in the study, I estimated the closest stream gage to the described paleoflood site and extracted data about the largest instrumental flood from that gage's data. However, I often found that the location of a paleoflood study site did not always match up to the site of the nearest instrumental gage record. This created a problem for making an accurate comparison between paleoflood magnitude and instrumental flood magnitude.

Another complication of this method of comparison was the record length of the closest stream gage. In some cases (e.g., Kohn et al. 2016; Harden et al., 2015; Webb and Rathburn, 1988) the nearest stream gage would have a short record only extending back 10-20 years, or the stream gage would be discontinued, no longer actively recording instrumental discharge measurements. Not having a robust dataset or being able to match the paleoflood site to the appropriate stream gage was a hindrance to being able to extensively compare the stream gage data to the paleoflood data. Since paleoflood information is a complement to gage records, it is preferable to have an active, corresponding stream gage operated by a state or federal agency near the paleoflood site so that paleoflood discharge value can be compared against the instrumental discharge values.

4.1.3. Magnitude

The primary reason for a paleoflood study not being included in my synthesis was because it did not report any estimation of flood magnitude (e.g., Springer and Kite, 1997; Knox, 2000; Ostenaa et al., 2000). One of the main requirements for a study to be included in my synthesis was for the study to have a reported paleoflood magnitude or discharge estimation. It is understandable that the majority of paleoflood articles do not include estimations of magnitude, simply because discharge values can be difficult to estimate or obtain. However, in order to comply with the USGS guidelines for determining Flood Flow Frequency outlined in Bulletin 17C, there must be reported paleoflood discharge estimation values to be incorporated in flood frequency analyses. It is also expected that those discharge estimates can be related to a nearby stream gage.

Including estimations of paleoflood magnitude is critical for flood probability estimates and making decisions about flood mitigation and policy. Without paleoflood magnitude, it is impossible to create a flood frequency analysis using data about the largest, extreme past flood event. Going forward, those conducting paleoflood assessments may consider implementing a standard for reporting past flood discharge and magnitude in order to satisfy the needs and requirements of Bulletin 17C. While it is challenging to reconstruct and report magnitude especially given constraints of uncertainty, having information about paleoflood magnitude is what makes paleoflood data most useful to others doing risk assessments.

5. CONCLUSION

Over the past four decades, there have been claims that data from paleoflood studies has significant relevance in flood mitigation, hazard assessment and policy. Those declarations have been made on a single case basis, without synthesizing the data into one comprehensive case study to test how accurate those claims are. My new synthesis of

Holocene paleoflood studies in the United States shows that paleoflood hydrology is in fact highly beneficial to natural hazards research. Paleoflood hydrology can substantially improve FFAs and flood risk estimates by providing information about the rarest, most extreme flood in an area. Paleoflood studies that report magnitude are valuable for flood mitigation and risk assessment as paleoflood evidence helps us to extend the instrumental record by hundreds, sometimes thousands of years providing information about older, and often much larger historic flooding events than those of the instrumental record. By incorporating paleoflood data into flood frequency analyses and probability estimates, hydrologists and engineers are able to have a more comprehensive understanding of flood behavior and flood potential on river systems in the United States.

While paleofloods are now for the first time being incorporated into the USGS' Guidelines for Determining Flood Flow Frequency as a product of Bulletin 17C, there are some improvements that could be made for reporting paleoflood data. Improving the standards for reporting could help make paleoflood studies more accessible and useful to professionals and stakeholders using paleoflood data in flood frequency analysis, probability estimates, and policy. Having a comprehensive database of paleoflood studies in the United States will significantly help in paleoflood data collection and analysis. With my new synthesis of Holocene paleoflood studies in the United States, the first step towards building a national paleoflood database has been established. This will aid agencies like the USGS Powell Center and U.S. Army Corps of Engineers, who have expressed explicit interest in the creation of a nation-wide paleoflood database. My new database will not only serve as the building block for a nation-wide paleoflood archive, but will endorse the significance and relevance of paleoflood hydrology.

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Waters, D., Watt, W. E., Marsalek, J., & Anderson, B. C. (2003). Adaptation of a Storm Drainage System to Accommodate Increased Rainfall Resulting from Climate Change. *Journal of Environmental Planning and Management*, *46*(5), 755–770.

Webb, R. H., Blainey, J. B., & Hyndman, D. W. (2002). Paleoflood Hydrology of the Paria River, Southern Utah and Northern Arizona, USA. In Ancient Floods, Modern Hazards (pp. 295-310). American Geophysical Union.

Webb, R. H., O'Connor, J. E., & Baker, V. R. (1988). Paleohydrologic reconstruction of flood frequency on the Escalante River, south-central Utah. In V. R. Baker (Ed.), Flood geomorphology (pp. 403-418). Wiley-Interscience.

Webb, R. H., & Rathburn, S. L. (1988.). Paleoflood Hydrolic Research in the Southwestern United States. Transportation Research Record 1201.

Wertz, E.L., St. George, S., Zeleznik, J.D. (2013). Vessel anomalies in Quercus macrocarpa tree rings associated with recent floods along the Red River of the North, United States. *Water Resources Research* 49, 630-634.

Wilhelm, B., Ballesteros-Canovas, J., Corella, J., Kämpf, L., Swierczynski, T., Stoffel, M., Støren, E., Toonen, W. (2018). Recent advances in paleoflood hydrology: From new archives to data compilation and analysis. Water Security. 3. 1-8.

Wilhelm, B., Cánovas, J. A., Macdonald, N., Toonen, W. H., Baker, V., Barriendos, M., Wetter, O. (2018). Interpreting historical, botanical, and geological evidence to aid preparations for future floods. *Wiley Interdisciplinary Reviews: Water, 6*(1).

Appendix I. Studies included in the synthesis.

Citation	River Name	Latitude (°N)	Longitude (°W)	USGS Gage Number	Gage Start Year	Drainage Area (km2)	Instrumental Q-Max (m^3/s)	Year of Instrumental Q-Max
O'Connor, J. E., Ely, L. L., Wohl, E. E., Stevens, L. E., Melis, T. S., Kale, V. S., & Baker, V. R. (1994). A 4500-year record of large floods on the Colorado River in the Grand Canyon, Arizona. The Journal of Geology, 1-9	Colorado River	36.87	-111.57	9380000	1921	289561	6230	1921
Harden, T. M., O'Connor, J. E., & D riscoll, D. G. (2015). Late Holocene flood probabilities in the Black Hills, South Dakota with emphasis on the Medieval Climate Anomaly. Catena, 130, 62-68.	Spring Creek	43.12	-101.02	6480400	1983	159	617	1972
Harden, T. M., O'Connor, J. E., & Driscoll, D. G. (2015). Late Holocene flood probabilities in the Black Hills, South Dakota with emphasis on the Medieval Climate Anomaly. Catena, 130, 62-68.	Rapid Creek	44	-103.06	6418800	2017	1164	883.5	1972
Harden, T. M., O'Connor, J. E., & Driscoll, D. G. (2015). Late Holocene flood probabilities in the Black Hills, South Dakota with emphasis on the Medieval Climate Anomaly. Catena, 130, 62-68.	Boxelder Creek	44.1	-103.01	6423010	1979	329	872.2	1972
Harden, T. M., O'Connor, J. E., & Driscoll, D. G. (2015). Late Holocene flood probabilities in the Black Hills, South Dakota with emphasis on the Medieval Climate Anomaly. Catena, 130, 62-68.	Elk Creek	44.23	-103.11	6425100	1980	572	294.5	1972
Enzel, Y., Ely, L., Martinez-Goytre, J., & Gwinn Vivian, R. (1994). Paleofloods and a dam-failure flood on the Virgin River, Utah and Arizona. Journal of Hydrology, 153, 291-315.	Virgin River	36.94	-113.8	9415000	1930	13183	1727	1989
Steven Kite, J., Gebhardt, T., & Springer, G. (2002). Slackwater Deposits As Paleostage Indicators in Canyon Reaches of the Central Appalachians: Reevaluation After the 1996 Cheat River Flood. In Ancient Floods, Modern Hazards (pp. 257-266). American Geophysical Union.	Cheat River	39.25	-79.69	3070000	1921	2432	5380	1986
Lisa L. Ely & Victor R. Baker (1985) Reconstructing Paleoflood Hydrology With Slackwater Deposits; Verde River, Arizona, Physical Geography, 6:2, 103-126	Verde River	34.06	-111.72	9506000	1934	15000	3370	1993

Table 1. Studies included in my synthesis of Holocene paleoflood studies on river systems in the United States. Each entry contains information about instrumental data, as well as paleoflood data from the study site.

Citation	River Name	Latitude (°N)	Longitude (°W)	USGS Gage Number	Gage Start Year	Drainage Area (km2)	Instrumental Q-Max (m^3/s)	Year of Instrumental Q-Max
Webb, R. H., Blainey, J. B., & Hyndman, D. W. (2002). Paleoflood Hydrology of the Paria River, Southern Utah and Northern Arizona, USA. In Ancient Floods, Modern Hazards (pp. 295-310). American Geophysical Union	Paria River	36.93	-111.67	9382000	1923	3670	456	1925
Webb, R. H., O'Connor, J. E., & Baker, V. R. (1988). Paleohydrologic reconstruction of flood frequency on the Escalante River, south-central Utah. In V. R. Baker (Ed.), Flood geomorphology (pp. 403-418). Wiley-Interscience.	Escalante River	37.7	-111.26	9337500	1910	3290	128.8	1998
Fuller, J. E., Kyle House, P., & Pearthree, P. A. (1996). An Assessment of the Paleoflood Hydrology Methodology: Analysis of the 1993 Flood on Tonto Creek, Central Arizona (Rep. No. 96-12). Arizona Geological Survey.	Tonto Creek	33.68	-109.71	9499000	1941	1748	2053	1993
Fuller, J.E., 1987	Salt River	33.58	-111.26	9497500	1916	33650	2169	1993
Kohn, M.S., Stevens, M.R., Harden, T.M., Godaire, J.E., Klinger, R.E., and Mommandi, Amanullah, 2016, Paleoflood investigations to improve peak-streamflow regional-regression equations for natural streamflow in eastern Colorado, 2015: U.S. Geological Survey Scientific Investigations Report 2016–5099.	Cherry Creek near Franktown, CO	39.36	-104.76	6712000	1940	438	259.7	1945
Kohn, M.S., Stevens, M.R., Harden, T.M., Godaire, J.E., Klinger, R.E., and Mommandi, Amanullah, 2016, Paleoflood investigations to improve peak-streamflow regional-regression equations for natural streamflow in eastern Colorado, 2015: U.S. Geological Survey Scientific Investigations Report 2016–5099.	Cherry Creek near Melvin, CO	39.61	-104.82	6712500	1933	932	1130	1965
Webb, R. H., & Rathburn, S. L. (1988.). Paleoflood Hydrolic Research in the Southwestern United States. Transportation Research Record 1201	Devil's River, Texas	29.74	-101.02	8449100	2014	7100	16700	1954

Citation	River Name	Latitude (°N)	Longitude (°W)	USGS Gage Number	Gage Start Year	Drainage Area (km2)	Instrumental Q-Max (m^3/s)	Year of Instrumental Q-Max
Webb, R. H., & Rathburn, S. L. (1988.).	Boulder Cr	37.86	-111.41	9339000	1951	450	131.7	1955
Webb, R. H., & Rathburn, S. L. (1988.). Paleoflood Hydrolic Research in the Southwestern United States. Transportation Research Record 1201	Salt River	33.58	-111.26	9497500	1916	21000	2169	1993
Webb, R. H., & Rathburn, S. L. (1988.). Paleoflood Hydrolic Research in the Southwestern United States. Transportation Research Record 1201	Kanab Cr	36.57	-112.63	9403850	2012	5370	279.2	2013
Webb, R. H., & Rathburn, S. L. (1988.). Paleoflood Hydrolic Research in the Southwestern United States. Transportation Research Record 1201	Aravaipa	32.91	-110.49	9473000	1919	1340	849.5	1984
Kochel, R. C., Baker, V. R., & Patton, P. C. (1982). Paleohydrology of southwestern Texas. Water Resources Research, 18(4), 1165-1183.	Pecos River - Big Fielder	31.72	-103.45	8447300	2011	86335	18400	1954
Kochel, R. C., Baker, V. R., & Patton, P. C. (1982). Paleohydrology of southwestern Texas. Water Resources Research, 18(4), 1165-1183.	Pecos River - Still	31.72	-103.45	8447300	2011	86335	17200	1954
Baker, V. (1987). Paleoflood hydrology and extraordinary flood events. Journal of Hydrology, 96(1-4), 79-99. doi:10.1016/0022-1694(87)90145-4	Devil's River, Texas	29.47	-101.08	8449100	2014	11150	16600	n/d
Baker, V. (1987). Paleoflood hydrology and extraordinary flood events. Journal of Hydrology, 96(1-4), 79-99. doi:10.1016/0022-1694(87)90145-4	Salt River, Arizona	33.58	-111.24	9497500	1916	11153	2900	n/d
Kohn, M.S., Stevens, M.R., Harden, T.M., Godaire, J.E., Klinger, R.E., and Mommandi, Amanullah, 2016, Paleoflood investigations to improve peak-streamflow regional-regression equations for natural streamflow in eastern Colorado, 2015: U.S. Geological Survey Scientific Investigations Report 2016–5099.	Green Mountain Arroyo near Raton, New Mexico	36.53	-104.5	7201450	1971	47	142	1973

Citation	River Name	Latitude (°N)	Longitude (°W)	USGS Gage Number	Gage Start Year	Drainage Area (km2)	Instrumental Q-Max (m^3/s)	Year of Instrumental Q-Max
Kohn, M.S., Stevens, M.R., Harden, T.M., Godaire, J.E., Klinger, R.E., and Mommandi, Amanullah, 2016, Paleoflood investigations to improve peak-streamflow regional-regression equations for natural streamflow in eastern Colorado, 2015: U.S. Geological Survey Scientific Investigations Report 2016–5099.	Middle Bijou Creek Tributary near Deer Trail, CO	40.13	-104	6758700	1970	5	37	1977
Enzel, L. L. Ely, and R. H. Webb (1990.)	Virgin River, East Fork, UT	37.16	-113	9404900	1992	840	1058	2015
Godaire, J. E., Bauer, T. R. & Klinger, R. E. (2012) Paleoflood study, San Joaquin River near Friant Dam, California (Technical Memorandum), 118. Denver, CO: Bureau of Reclamation.	South Fork American River near Kyburz	38.77	-120.31	11439500	1923	500	708	1997
Godaire, J. E., Bauer, T. R. & Klinger, R. E. (2012) Paleoflood study, San Joaquin River near Friant Dam, California (Technical Memorandum), 118. Denver, CO: Bureau of Reclamation.	South Fork American River near Lotus	38.78	-120.17	11445500	1951	1800	2549	1997
Godaire, J. E., Bauer, T. R. & Klinger, R. E. (2012) Paleoflood study, San Joaquin River near Friant Dam, California (Technical Memorandum), 118. Denver, CO: Bureau of Reclamation.	Lower American River	38.61	-121.31	11446500	1862	4890	9005	1862
Godaire, J. E. & Bauer, T. R. (2011) Paleoflood study of Blue River near Green Mountain dam, Colorado (Technical Memorandum), 115. Denver, CO: Bureau of Reclamation.	Blue River nr Kremmling, CO	39.53	-106.04	9056000	1905	1479	221	1906

Citation	River Name	Proxy Type	Paleo Record Start Date (-BCE/CE)	Paleo Record End Date (-BCE/CE)	Q-Paleo Max Low (m^3/s)	Q-Paleo Max High (m^3/s)	Exceed Instrumental Record? Y/N	Year of Most Severe Flood
O'Connor, J. E., Ely, L. L., Wohl, E. E., Stevens, L. E., Melis, T. S., Kale, V. S., & Baker, V. R. (1994). A 4500-year record of large floods on the Colorado River in the Grand Canyon, Arizona. The Journal of Geology, 1-9	Colorado River	FLSED	-282	18	14000	14000	YES	Between 394- 794
Harden, T. M., O'Connor, J. E., & D riscoll, D. G. (2015). Late Holocene flood probabilities in the Black Hills, South Dakota with emphasis on the Medieval Climate Anomaly. Catena, 130, 62-68.	Spring Creek	STRATREC	18	1983	829.7	1659	YES	1311
Harden, T. M., O'Connor, J. E., & Driscoll, D. G. (2015). Late Holocene flood probabilities in the Black Hills, South Dakota with emphasis on the Medieval Climate Anomaly. Catena, 130, 62-68.	Rapid Creek	STRATREC	1011	1578	3625	7249	YES	1571
Harden, T. M., O'Connor, J. E., & Driscoll, D. G. (2015). Late Holocene flood probabilities in the Black Hills, South Dakota with emphasis on the Medieval Climate Anomaly. Catena, 130, 62-68.	Boxelder Creek	STRATREC	1011	1979	1736	3483	YES	n/d
Harden, T. M., O'Connor, J. E., & Driscoll, D. G. (2015). Late Holocene flood probabilities in the Black Hills, South Dakota with emphasis on the Medieval Climate Anomaly. Catena, 130, 62-68.	Elk Creek	STRATREC	118	1980	1175	3511	YES	1111
Enzel, Y., Ely, L., Martinez-Goytre, J., & Gwinn Vivian, R. (1994). Paleofloods and a dam-failure flood on the Virgin River, Utah and Arizona. Journal of Hydrology, 153, 291-315.	Virgin River	SLACK	900	1930	1750	1900	YES	1989

Citation	River Name	Proxy Type	Paleo Record Start Date (-BCE/CE)	Paleo Record End Date (-BCE/CE)	Q-Paleo Max Low (m^3/s)	Q-Paleo Max High (m^3/s)	Exceed Instrumental Record? Y/N	Year of Most Severe Flood
Steven Kite, J., Gebhardt, T., & Springer, G. (2002). Slackwater Deposits As Paleostage Indicators in Canyon Reaches of the Central Appalachians: Reevaluation After the 1996 Cheat River Flood. In Ancient Floods, Modern Hazards (pp. 257-266). American Geophysical Union.	Cheat River	SLACK	n/d	1844	3140	3140	NO	1985
Lisa L. Ely & Victor R. Baker (1985) Reconstructing Paleoflood Hydrology With Slackwater Deposits; Verde River, Arizona, Physical Geography, 6:2, 103-126	Verde River	SLACK	1887	1934	3800	5400	YES	n/d
Webb, R. H., Blainey, J. B., & Hyndman, D. W. (2002). Paleoflood Hydrology of the Paria River, Southern Utah and Northern Arizona, USA. In Ancient Floods, Modern Hazards (pp. 295-310). American Geophysical Union	Paria River	SLACK	-2197	1923	1200	1200	YES	n/d
Webb, R. H., O'Connor, J. E., & Baker, V. R. (1988). Paleohydrologic reconstruction of flood frequency on the Escalante River, south-central Utah. In V. R. Baker (Ed.), Flood geomorphology (pp. 403-418). Wiley-Interscience.	Escalante River	SLACK,TREE	885	1910	1850	2100	YES	988
Fuller, J. E., Kyle House, P., & Pearthree, P. A. (1996). An Assessment of the Paleoflood Hydrology Methodology: Analysis of the 1993 Flood on Tonto Creek, Central Arizona (Rep. No. 96-12). Arizona Geological Survey.	Tonto Creek	SLACK	1670	1941	800	1000	NO	1993
Fuller, J.E., 1987	Salt River	HISTDOC	1887	1916	8500	12700	YES	987

Citation	River Name	Proxy Type	Paleo Record Start Date (-BCE/CE)	Paleo Record End Date (-BCE/CE)	Q-Paleo Max Low (m^3/s)	Q-Paleo Max High (m^3/s)	Exceed Instrumental Record? Y/N	Year of Most Severe Flood
Kohn, M.S., Stevens, M.R., Harden, T.M., Godaire, J.E., Klinger, R.E., and Mommandi, Amanullah, 2016, Paleoflood investigations to improve peak-streamflow regional-regression equations for natural streamflow in eastern Colorado, 2015: U.S. Geological Survey Scientific Investigations Report 2016–5099.	Cherry Creek near Franktown, CO	SLACK	-7984	-2984	1050	1050	YES	n/d
Kohn, M.S., Stevens, M.R., Harden, T.M., Godaire, J.E., Klinger, R.E., and Mommandi, Amanullah, 2016, Paleoflood investigations to improve peak-streamflow regional-regression equations for natural streamflow in eastern Colorado, 2015: U.S. Geological Survey Scientific Investigations Report 2016–5099.	Cherry Creek near Melvin, CO	SLACK	-7984	516	2100	2100	YES	n/d
Webb, R. H., & Rathburn, S. L. (1988.). Paleoflood Hydrolic Research in the Southwestern United States. Transportation Research Record 1201	Devil's River, Texas	SLACK	-6752	1988	16700	16700	NO	1954
Webb, R. H., & Rathburn, S. L. (1988.). Pa	Boulder Cr	SLACK	988	1951	400	400	YES	1650
Webb, R. H., & Rathburn, S. L. (1988.). Paleoflood Hydrolic Research in the Southwestern United States. Transportation Research Record 1201	Salt River	SLACK	888	1916	11900	11900	YES	850
Webb, R. H., & Rathburn, S. L. (1988.). Paleoflood Hydrolic Research in the Southwestern United States. Transportation Research Record 1201	Kanab Cr	SLACK	1488	1988	600	600	YES	1550
Webb, R. H., & Rathburn, S. L. (1988.). Paleoflood Hydrolic Research in the Southwestern United States. Transportation Research Record 1201	Aravaipa	SLACK	888	1919	750	750	NO	n/d
Kochel, R. C., Baker, V. R., & Patton, P. C. (1982). Paleohydrology of southwestern Texas. Water Resources Research, 18(4), 1165-1183.	Pecos River - Big Fielder	SLACK	1450	1900	15200	15200	NO	1954

Citation	River Name	Proxy Type	Paleo Record Start Date (-BCE/CE)	Paleo Record End Date (-BCE/CE)	Q-Paleo Max Low (m^3/s)	Q-Paleo Max High (m^3/s)	Exceed Instrumental Record? Y/N	Year of Most Severe Flood
Kochel, R. C., Baker, V. R., & Patton, P. C. (1982). Paleohydrology of southwestern Texas. Water Resources Research, 18(4), 1165-1183.	Pecos River - Still	SLACK	1450	1900	17200	17200	NO	1954
Baker, V. (1987). Paleoflood hydrology and extraordinary flood events. Journal of Hydrology, 96(1-4), 79-99. doi:10.1016/0022-1694(87)90145-4	Devil's River, Texas	SLACK	n/d	1987	16600	16600	NO	n/d
Baker, V. (1987). Paleoflood hydrology and extraordinary flood events. Journal of Hydrology, 96(1-4), 79-99. doi:10.1016/0022-1694(87)90145-4	Salt River, Arizona	SLACK	1787	1916	3000	3000	YES	n/d
Kohn, M.S., Stevens, M.R., Harden, T.M., Godaire, J.E., Klinger, R.E., and Mommandi, Amanullah, 2016, Paleoflood investigations to improve peak-streamflow regional-regression equations for natural streamflow in eastern Colorado, 2015: U.S. Geological Survey Scientific Investigations Report 2016–5099.	Green Mountain Arroyo near Raton, New Mexico	SAC	1914	1971	289	796	YES	n/d
Kohn, M.S., Stevens, M.R., Harden, T.M., Godaire, J.E., Klinger, R.E., and Mommandi, Amanullah, 2016, Paleoflood investigations to improve peak-streamflow regional-regression equations for natural streamflow in eastern Colorado, 2015: U.S. Geological Survey Scientific Investigations Report 2016–5099.	Middle Bijou Creek Tributary near Deer Trail, CO	SAC	1864	1970	37	129	YES	n/d
Enzel, L. L. Ely, and R. H. Webb (1990.)	Virgin River, East Fork, UT	SLACK	990	1990	800	850	NO	1995
Godaire, J. E., Bauer, T. R. & Klinger, R. E. (2012) Paleoflood study, San Joaquin River near Friant Dam, California (Technical Memorandum), 118. Denver, CO: Bureau of Reclamation.	South Fork American River near Kyburz	FLSED	n/d	n/d	1897	2294	YES	n/d

Citation	River Name	Proxy Type	Paleo Record Start Date (-BCE/CE)	Paleo Record End Date (-BCE/CE)	Q-Paleo Max Low (m^3/s)	Q-Paleo Max High (m^3/s)	Exceed Instrumental Record? Y/N	Year of Most Severe Flood
Godaire, J. E., Bauer, T. R. & Klinger, R. E. (2012) Paleoflood study, San Joaquin River near Friant Dam, California (Technical Memorandum), 118. Denver, CO: Bureau of Reclamation.	South Fork American River near Lotus	FLSED	n/d	n/d	4814	7192	YES	n/d
Godaire, J. E., Bauer, T. R. & Klinger, R. E. (2012) Paleoflood study, San Joaquin River near Friant Dam, California (Technical Memorandum), 118. Denver, CO: Bureau of Reclamation.	Lower American River	FLSED	n/d	n/d	17000	24069	YES	n/d
Godaire, J. E. & Bauer, T. R. (2011) Paleoflood study of Blue River near Green Mountain dam, Colorado (Technical Memorandum), 115. Denver, CO: Bureau of Reclamation.	Blue River nr Kremmling, CO	FLSED	n/d	n/d	104.8	204	NO	n/d

Appendix II. Studies initially considered but not included in the synthesis.

Citation	River/Water Body Name	Explanation For Non-Inclusion
Rannie, W. F. (1999) A survey of hydroclimate, flooding, and runoff in the Red River basin prior to 1870 (Open-File Report No. 3705). Ottawa: Geological Survey of Canada.	Red River	Only uses historic instrumental data.
Speer, P. R. & Gamble, C. R. (1964) Magnitude and frequency of floods in the United States, part 3–B, Cumberland and Tennessee River Basins (Report No. 1676).	Cumberland/Tennessee	Only uses historic instrumental data.
Wang, L. & Leigh, D. S. (2012) Late-Holocene paleofloods in the Upper Little Tennessee River valley, southern Blue Ridge Mountains, USA.	Little Tennessee River	No paleoflood magnitude reported.
Godaire, J. E., Bauer, T. R. & Klinger, R. E. (2012) Paleoflood study, San Joaquin River near Friant Dam, California (Technical Memorandum), 118. Denver, CO: Bureau of Reclamation.	San Joaquin River	Exceedence bounds - no paleoflood info from proxy.
Wohl [1989]	Redfield Creek, AZ	No instrumental data to compare.
Aldridge, B. N. & Eychaner, J. H. (1984) Floods of October 1977 in southern Arizona and March 1978 in central Arizona (Report No. 2223).	San Pedro	Rockville bib — Instrumental analysis. Not a paleoflood study.
Aldridge, B. N. & Hales, T. A. (1984) Floods of November 1978 to March 1979 in Arizona and west-central New Mexico (Report No. 2241).	Little Colorado/Gila River	Rockville bib — Instrumental analysis. Not a paleoflood study.
Alestalo, J. (1971) Dendrochronological interpretation of geomorphic processes. International Journal of Geography 105(1).	N/A	Rockville bib — Application/methods paper - not paleoflood study.
Archer, D. (1999) Practical application of historical flood information to flood estimation.	N/A	Rockville bib — Application/methods paper - not paleoflood study.
Asquith, W. H., Kiang, J. E. & Cohn, T. A. (2017) Application of at-site peak-streamflow frequency analyses for very low annual exceedance probabilities (Report No. 2017–5038).	N/A	Rockville bib — "Does not consider the incorporation of information about historical floods and reconstructed flood events using paleohydrology."
Ballesteros Cánovas, J. ., Stoffel, M., St. George, S. & Hirshboeck, K. (2015) A review of flood records from tree rings.	N/A	Rockville bib — Flood records from tree rings - no paleo discharge value.

Table 2. Studies reviewed for the synthesis of paleoflood studies on river systems in the U.S during the Holocene.

Citation	River/Water Body Name	Explanation For Non-Inclusion
Barnes, H. H. & Golden, H. G. (1966) Magnitude and frequency of floods in the United States, Part 2–B, South Atlantic slope and Eastern Gulf of Mexico basins, Ogeechee River to Pearl River (Report No. 1674).	Multiple Basins	Rockville bib — Instrumental analysis only.
Bauer, T. & Klinger, R. (2010) Evaluation of paleoflood peak discharge estimates in hydrologic hazard studies (No. DSO-11-3). Report, 19. Denver, Colorado: Bureau of Reclamation.	N/A	Rockville bib — Evaluation of discharge estimates.
Bayliss, A. C. & Reed, D. W. (2001) The use of historical data in flood frequency estimation (Report to MAFF), 92.	N/A	Rockville bib — Application/methods paper - not paleoflood study.
Benito, G., Lang, M., Barriendos, M., Llasat, M. C., Francés, F., Ouarda, T., Thorndycraft, V., et al. (2004) Use of systematic, palaeoflood and historical data for the improvement of flood risk estimation.	N/A	Rockville bib — Application/methods paper - not paleoflood study.
Benito, G., Ouarda, T. B. M. J. & Bárdossy, A. (2005) Applications of palaeoflood hydrology and historical data in flood risk analysis.	N/A	Rockville bib — Application/methods paper - not paleoflood study.
Benito, G. & O'Connor, J. E. (2013) 9.24 Quantitative Paleoflood Hydrology. In: Treatise on Geomorphology.	N/A	Rockville bib — Application/methods paper - not paleoflood study.
Benito, G. & Thorndycraft, V. R. (2005) Palaeoflood hydrology and its role in applied hydrological sciences.	N/A	Rockville bib — Application/methods paper - not paleoflood study.
Bureau of Reclamation. (2002) Flood hazard analysis—Folsom Dam Central Valley Project California (Report). Report, 224. Denver, CO: Bureau of Reclamation.	American River	Rockville bib — Paleo information considered in model, no clear discharge values given + maybe some repeat
Cook, J. L. (1987) Quantifying peak discharges for historical floods.	N/A	Rockville bib — Application/methods paper - not paleoflood study.
Costa, J. E. & Jarrett, R. D. (2008) An evaluation of selected extraordinary floods in the United States reported by the U.S. Geological Survey and implications for future advancement of flood science (Report).	Multiple Sites	Rockville bib — Great, organized paper with instrumental peak discharge values for multiple sties. But no paleo discharge.
Dean, D. J., Scott, M. L., Shafroth, P. B. & Schmidt, J. C. (2011) Stratigraphic, sedimentologic, and dendrogeomorphic analyses of rapid floodplain formation along the Rio Grande in Big Bend National Park, Texas.	Rio Grande	Rockville bib — No paleoflood magnitude.

Citation	River/Water Body Name	Explanation For Non-Inclusion
Harden, T.M., and O'Connor, J.E., 2017, Prehistoric floods on the Tennessee River—Assessing the use of stratigraphic records of past floods for improved flood-frequency analysis	Tennessee River, near Chattanooga	No paleoflood magnitude or dates reported, however there is "evidence of three to four other floods similar in size, or larger, than the 1867 flood in the last 3,000 years—one possibly as much or more than 50 percent larger."
Colombaroli, D. and Gavin D.G., 2010. Highly episodic fire and erosion regime over the past 2000 years in the Siskiyou Mountains, Oregon.	Squaw Creek	No reported paleoflood discharge or magnitude.
Oslegger D.A., Heyvaert A.C., Stoner J.S., Verosub K.L., 2009. Lacustrine turbidites as indicators of Holocene storminess and climate: Lake Tahoe, California and Nevada.	Lake Tahoe	No reported paleoflood magnitude and non-river system.
Hendy, I.L., Dunn, L., Schimmelmann, A., Pak, D.K., 2013. Resolving varve and radiocarbon chronology differences during the last 2000 years in the Santa Barbara Basin sedimentary record, California.	Santa Barbara Basin	No reported paleoflood magnitude and non-river system.
E.L. Wertz, S. St. George, J.D. Zeleznik, Vessel anomalies in Quercus macrocarpa tree rings associated with recent floods along the Red River of the North, United States,	Red River	No reported paleoflood discharge or magnitude.
Therrell, M.D., and M.B. Bialecki. 2015. A multi century tree-ring record of spring flooding on the Mississippi River.	Mississippi River	No reported paleoflood discharge or magnitude.
Noren, A., Bierman, P., Steig, E., Lini, A., and Southon, J., (2002) Millennial-scale Storminess Variability in the Northeastern United States during the Holocene Epoch.	Lake Dunmore/Thirteenth Lake	No reported paleoflood magnitude and non-river system.
Mansfield, G.R., 1938. Flood deposits of the Ohio River, January-February, 1937, a study of flood sedimentation.	Ohio River	No reported paleoflood discharge or magnitude.
Springer, G.S., Kite, J.S., 1997. River-derived slackwater sediments in caves along Cheat River, West Virginia.	Cheat River	No reported paleoflood magnitude or date.
Dasgupta, S., Saar, M.O., Edwards, R.L., Shen, C.-C., Cheng, H., Alexander, E.C., 2010. Three thousand years of extreme rainfall events recorded in stalagmites from Spring Valley Caverns, Minnesota.	Spring Valley Caverns	No reported paleoflood magnitude. Dates are included.
Waythomas, C. F., & Jarrett, R. D. (1994). Flood geomorphology of Arthurs Rock Gulch, Colorado.	Arthurs Rock Gulch	No reported discharge/magnitude values. Sediment analysis.

Citation	River/Water Body Name	Explanation For Non-Inclusion
Knox, J.C., 1993. Large increases in flood magnitude in response to modest changes in climate.	Upper Mississippi	Letter to Nature. Dates reported, but no specific magnitude or paleoflood discharge.
Derald G. Smith, Timothy G. Fisher; Glacial Lake Agassiz: The northwestern outlet and paleoflood.	Lake Agassiz	No discharge reported. Not on a river.
Thorson, R. M. (n.d.). Late Quaternary paleofloods along the Porcupine River, Alaska.	Porcupine River	Magnitude values reported. Not in continental US (Alaska).
House, K., Pearthree, P., & Klawon, J. (2002). Historical Flood and Paleoflood Chronology of the Lower Verde River, Arizona: Stratigraphic Evidence and Related Uncertaincies.	Verde River	No reported paleoflood magnitude.
Chatters, J.C., Hoover, K.A., 1986. Changing Late Holocene flooding frequencies on the Columbia River, Washington.	Columbia River	Many dates and ranges reported, no reported flood magnitude.
McQueen, K.C., Vitek, J.D., Carter, B.J.,1993. Paleoflood analysis of an alluvial channel in the south-central Great Plains: Black Bear Creek, Oklahoma.	Black Bear Creek	G-paleo data given, no Q-paleo data.
Ostenaa, D. A., O'Connell, D. R., Walters, R. A., & Creed, R. J. (2002). Holocene paleoflood hydrology of the Big Lost River.	Big Lost River at Howell Ranch near Chilly, Idaho	Could not find Q-paleo discharge value.
Jarrett, R. D., Costa, J. E., & Geological Survey (U.S.). (1988). Evaluation of the Flood Hydrology in the Colorado Front Range Using Precipitation, Streamflow, and Paleoflood Data for the Big Thompson River Basin.	Big Thompson River Estes Park	No reported paleoflood magnitude. Dates are included.
Jarrett, R. D., Costa, J. E., & Geological Survey (U.S.). (1988). Evaluation of the Flood Hydrology in the Colorado Front Range Using Precipitation, Streamflow, and Paleoflood Data for the Big Thompson River Basin.	Big Thompson River at Mouth of Canyon near Drake	No reported paleoflood magnitude. Dates are included.
Knox, J.C., 2000. Sensitivity of modern and Holocene floods to climate change.	Upper Mississippi	No reported flood magnitude.
Patterson, J. L. (1966) Magnitude and frequency of floods in the United States, pt. 6–A, Missouri River Basin above Sioux City, Iowa (Report No. 1679).	Missouri River Basin	No mention of paleofloods.

Citation	River/Water Body Name	Explanation For Non-Inclusion
England, J. F. J. (1998) Assessment of Historical and Paleoflood Information in Flood Frequency Analysis (M.S. Thesis). Colorado State University, Fort Collins, CO.	Multiple	Rockville bib — John England Thesis. Application of paleoflood info in FFA.
England, J. F., Klawon, J. E., Klinger, R. E. & Bauer, T. R. (2006) Flood hazard study Pueblo Dam, Colorado (Final Report). Denver, CO: Bureau of Reclamation.	Arkansas River	Rockville bib — Exceedence bounds and limited paleoflood info from SWD.
Fanok, S. F. & Wohl, E. E. (1997) Assessing the accuracy of paleohydrologic indicators, Harpers Ferry, West Virginia.	Harpers Ferry	Rockville bib — Application/methods paper - paleo stage.
Friedman, J. M., Vincent, K. R. & Shafroth, P. B. (2005) Dating floodplain sediments using tree-ring response to burial.	Rio Puerco	Rockville bib — All about dating, no paleoflood magnitude.
Green, A. R. (1964) Magnitude and frequency of floods in the United States, Part 1–A, North Atlantic Basins, Maine to Connecticut (Report No. 1671).	North Atlantic Basins	Rockville bib — Instrumental analysis, no paleoflood.
Hirshboeck, K. K. (2003, November 18) Floods, Paleofloods, and Drought: Insights from the Upper Tails. Presented at the CLIVAR/PAGES/IPCC Workshop, Tucson, AZ.	N/A	Rockville bib — Presentation, no paleoflood discharge or unique study.
Hosking, J. R. M. & Wallis, J. R. (1986) Paleoflood hydrology and flood frequency analysis.	N/A	Rockville bib- FFA, no discharge.
Hupp, C. R. (1988) Plant ecological aspects of flood geomorphology and paleoflood history.	N/A	Rockville bib — Reconstruction with vegetation, FFA, no discharge.
Jarrett, R. D. (1991) Paleohydrology and its value in analyzing floods and droughts. In: National water summary 1988-89: Hydrologic events and floods and droughts.	N/A	Rockville bib — Application/methods paper - not paleoflood study.
Patterson, J. L. (1966) Magnitude and frequency of floods in the United States, pt. 6–A, Missouri River Basin above Sioux City, Iowa (Report No. 1679). Water-Supply Paper, 471. Washington, D.C.: U. S. Geological Survey.	Mississippi River Basin	Rockville bib — Instrumental analysis. No paleoflood magnitude.
Patterson, J.L. & Gamble, C. R. (1968) Magnitude and frequency of floods in the United States, pt. 5, Hudson Bay and Upper Mississippi River Basins (Report No. 1678). Water-Supply Paper, 546. Washington, D.C.: U.S. Geological Survey.	Mississippi River Basin	Rockville bib — Instrumental analysis. No paleoflood magnitude.

Citation	River/Water Body Name	Explanation For Non-Inclusion
Kelson, K. I., Hall, B. M., Sasaki, R., Leonard, C. M. & Potts, S. (2017) Paleoflood Analysis for Ball Mountain Dam (Report), 82. Lakewood, CO: U.S. Army Corps of Engineers Risk Management Center.	West River	Rockville bib — Modeling frequency analysis and Q-paleo estimation.
Kelson, K. I., Hall, B. M., Walters, G. S., Duren, A. M. & Leonard, C. M. (2018) Paleoflood Analysis for Lookout Point Dam (Report), 80. Lakewood, CO: U.S. Army Corps of Engineers Risk Management Center.	Middle Fork Willamette River	Rockville bib — Modeling frequency analysis and Q-paleo estimation.
McGlashan, H. D. & Briggs, R. C. (1939) Floods of December 1937 in northern California (Report No. 843). Water Supply Paper, 497. Washington, D.C.: U.S. Geological Survey.	Kaweah River	Rockville bib — Instrumental analysis, no paleoflood.
Moftakhari, H. R., Jay, D. A., Talke, S. A. & Schoellhamer, D. H. (2015) Estimation of historic flows and sediment loads to San Francisco Bay,1849–2011.	San Francisco Bay	Rockville bib — Estimation from sediment, no paleoflood info.
Murphy, E. C. (1906) Destructive floods in the United States in 1905, with a discussion of flood discharge and frequency and an index to flood literature (Report No. 162). Water-Supply and Irrigation Paper, 105. Washington, D. C.: U.S. Geological Survey.	Multipe sites	Rockville bib — Instrumental analysis, no paleoflood.
Sanders Jr., C. L., Kubik, H. E., Hoke Jr., J. T. & Kirby, W. H. (1990) Flood frequency of the Savannah River at Augusta, Georgia (Report No. 90–4024). Water-Resources Investigations, 87. Washington, D.C.: U.S. Geological Survey.	Savannah River	No reported paleoflood discharge or magnitude.
Speer, P. R. & Gamble, C. R. (1965) Magnitude and frequency of floods in the United States, part 3–A, Ohio River Basin except Cumberland and Tennessee River Basins (Report No. 1675). Water-Supply Paper, 630. Washington, D.C.: U.S. Geological Survey.	Cumberland/Tennessee	Rockville bib — No reported paleoflood discharge or magnitude.
St. George, S. (2010) Tree rings as paleoflood and paleostage indicators. In: Tree Rings and Natural Hazards.	N/A	Paleostage indicator, no discharge.
Sutcliffe, J. V. (1987) The use of historical records in flood frequency analysis.	N/A	Using historical information, not paleo information derived from proxies.
Wang, L. & Leigh, D. S. (2012) Late-Holocene paleofloods in the Upper Little Tennessee River valley, southern Blue Ridge Mountains, USA.	Tennessee River	No reported paleoflood discharge or magnitude.
O'Connell, D. R. H., Ostenaa, D. A., Levish, D. R. & Klinger, R. E. (2002) Bayesian flood frequency analysis with paleohydrologic bound data.	Santa Ynez/Big Lost River	Rockville bib — Modeling frequency analysis and Q-paleo estimation.

Citation	River/Water Body Name	Explanation For Non-Inclusion
O'Connor, J. E. & Webb, R. H. (1988) Hydraulic modeling for palaeoflood analysis.	N/A	Rockville bib — Application/methods paper - not paleoflood study.
Pickup, G., Marks, A. & Bourke, M. (2013) Paleoflood Reconstruction on Floodplains Using Geophysical Survey Data and Hydraulic Modeling.	Todd River	Modeling, no discharge derived from proxies.
Reis, D. S. & Stedinger, J. R. (2005) Bayesian MCMC flood frequency analysis with historical information.	N/A	Methods paper. No paleoflood information.
Yanosky TM (1983) Evidence of flood on Potomac Riverfrom anatomical abnormalities in the wood of floodplain trees.	Potomic	Tree ring analysis done only during instrumental period.