SYNOPSIS

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Title: Impact of Climatic Variations on Flood Magnitude and Frequency in Three Hydroclimatic Regions of the Western U.S.

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Congressional District(s): 4th Washington; 2nd Nevada

Focus Category: Floods, Climatological Processes, Geomorphological and Geochemical Processes

Descriptors: Flood Frequency, Paleofloods, Climate, Geomorphology

Problem and Research Objectives:
Hydroclimatic variability over a wide range of spatial and temporal scales is directly linked to attendant variations in the magnitude and frequency of severe regional flooding events in the western U.S. Understanding this linkage is critical for improving flood-frequency forecasting and water resources management in this region. The spatial and temporal distributions of large floods in the western U.S. are largely controlled by persistent, anomalous patterns in hemispheric to global-scale atmospheric and oceanic circulation that directly influence flood-generating storm systems. Variability in flood frequency over short and long time scales thus provides an insight into variability in related larger-scale climatic phenomena over the same time scales.

This study employed paleoflood analyses to compare the influence of decadal- to millennial-scale climatic variability on the magnitude and frequency of large floods on rivers in three distinct hydroclimatic regions of the western U.S: the Southwest, Northwest, and western Great Basin. This is the first study to construct regional paleoflood chronologies for rivers in the Northwest and Great Basin, and this aspect of the project alone will greatly increase the accuracy of flood-frequency forecasting in these areas. In addition, our comparison of paleoflood chronologies from three areas of the western U.S. will allow us to go one step further and determine whether there are consistent, predictable, long-term similarities or differences in the occurrence of large floods among these distinct hydroclimatic regions and investigate whether the regional differences in the timing and controls on floods in the short-term records hold true for the response of large floods in the three regions to longer-term climatic variations.

Methodology:
The above objectives were accomplished through the following methods:
1) Field and laboratory analyses of paleoflood deposits on multiple rivers in each region, including stratigraphy, sedimentology, and radiocarbon dating;

2) Revised flood-frequency analyses of individual rivers incorporating paleoflood data;

3) Examination of the large-scale climatic factors associated with modern floods as an analog to the paleofloods;

4) Comparison of the long-term variability in paleoflood frequency with regional and global paleoclimatic data covering the last several 100s to 1000s of years to determine the regional effects of climate change on extreme flood events

5) Comparison of the temporal distribution of paleofloods among the three regions to determine whether this pattern is consistent with differences observed at annual time scales in the modern record.

Principal findings and significance:

PALEOFLOOD RESEARCH

The paleoflood analysis of rivers in each of the three hydroclimatic regions extended the records of large floods on these rivers by several thousand years, as shown in Table 1. These data were used in flood frequency estimates and comparisons between the timing of floods and the climatic conditions among the three regions.

Table 1. Length of Paleoflood Records.

- Northwest Rivers
  - John Day River (>9000 year record)
  - Deschutes River (~3000 year record)
  - Grande Ronde River (~ 8000 year record
  - Snake River (~3200 year records
- Western Great Basin Rivers
  - Truckee River (~7000 year record)
  - Carson River (in progress as MS project, UNR)
  - Walker River (1200 year record)
  - Humboldt River (>7000 year record)
- Southwest Rivers
  - Verde River (>10,000 year record)
  - Bill Williams River (800 year record)
  - Other Rivers (previously published) ~5000-yr record

PALEOFLOOD RESEARCH IN THE WESTERN GREAT BASIN

The research on this project in the Great Basin has focused on the Walker, Humboldt, and Truckee Rivers. Research on the Humboldt River has also been supported through the USGS Statemap program.

Humboldt River, Nevada

The Humboldt River is a large, meandering river with a broad floodplain marked by numerous abandoned meander belts and related relict floodplain surfaces. In the area currently being studied, the Humboldt drains more than 8,800 mi^2 of the central Great Basin.

Several abandoned meander belts are characterized by geometry that is strikingly different from the present-day configuration of the river. In some cases, meander amplitude and wavelength are nearly an order of magnitude larger in meander belts that have been tentatively dated to between 2000 and 3000 years old. These patterns in fluvial behavior indicate that the river is clearly sensitive to hydrological changes due to climatic variability in the middle and late Holocene. Detailed mapping, and limited planimetric, and stratigraphic analyses were carried out to establish baseline paleohydrological data to help evaluate changes in regional average hydroclimatological conditions and thus an important point of comparison with the regional paleoflood data set which reflects the occurrence of discrete, extreme events. We performed detailed planimetric analysis of the abandoned meander belts to estimate paleodischarges and performed some excavations of the floodplain to characterize the sedimentology of the relict channels and to ensure that were acquiring samples from the appropriate stratigraphic contexts for age-control for the paleochannel systems.

Radiocarbon Dates from the Humboldt River Floodplain

Sample ID	**Material**	**Depth**	**Date (yr. BP)**	**Context**
102797-1A	Organic sediment	0-8 cm	2120 ± 50	Relict floodplain
HR4398-2	Organic sediment	Surface	2500 ± 70	Relict floodplain
HR4398-5	Organic sediment	Surface	2550 ± 60	Relict floodplain
HR21799-2	Gastropod shells	100-140 cm	2910 ± 50	Overlying point bar gravel and thin tephra layer
102797-1C	Gastropod shells	14 cm	3250 ± 50	Relict floodplain
HR21799-3	Organic sediment	125 cm	6720 ± 60	Buried floodplain, beneath Mazama Ash

The Truckee River

The research on the Truckee River focused on evaluating the frequency of large floods on the Truckee in the context of paleoflood information. In particular, we were interested in estimating the exceedence probability of the 1997 flood in the context of a variety of data types. In this analysis we developed a simple hydrological model to remove the influence of flood control reservoirs on peak flood magnitudes on the Truckee. This allows for a more realistic characterization of the natural hydrologic variability in the flood series and a more instructive comparison with paleoflood data. The US Bureau of Reclamation model ***fldfrq3*** is being used for

this analysis. This model allows for the incorporation of paleoflood data and related uncertainties into the statistical analysis. Some of our results are tablulated below.

Flood Frequency Estimates for the 1997 Flood on the Truckee River, Nevada

Scenario	Record Length	1997 Flood Qpk	Est. Recurrence Interval	Q100
1	27 years	14,900	52 years	18,000
2	97 years	34,000	200 years	20,000
3	4000 years	34,000	900 years	29,000

Explanation of modeling scenarios:

1. Period of record with common reservoir system (1970-1997)
2. Systematic record with reservoir influence removed.
3. Same as scenario 3 with the addition of paleoflood information.

West Walker River

The Walker River (California and Nevada) experienced extreme flooding in January 1997. A portion of our research project on paleofloods in the Western Great Basin has focused on this river. Our principal goal was to evaluate the paleohydrological context of the 1997 flood and to evaluate different types of geomorphic criteria that are appropriate for evaluating paleoflood magnitude and frequency in this region. This component of the research was performed by Michael P. Mann for his Masters Degree at the University of Nevada, Reno.

On the Walker River, dendrochronological analysis of trees rooted in fluvial deposits and hillslopes that were undercut by the 1997 flood has proven to be a particularly useful technique. Analysis of 42 trees in 6 study reaches suggests that it is likely that the 1997 event may have been the largest, most erosive flood on the Walker River in the last 330 years. We also identified and described localized slackwater flood deposits that support this interpretation. Our recently completed analyses indicate that it is likely that within the last 300-600 years, the largest floods occurred in 1997 and the 1860s.

The paleoflood information from the west Walker River was incorporated into a Bayesian flood frequency model to evaluate the general frequency of extreme events on this river as well as to place the 1997 event into its appropriate context. Comparisons with conventional analyses based solely on systematic (gage) data are provided in the table below. The estimated "100-year" flood from each analytical method is shown as is the estimated recurrence interval of the January 1997 flood.

FFA Method	**Q100 (cfs)**	**R.I. 1997 (yrs)**
17b (LP-3)	9393	640
Fldfrq3 (GLO)	7945	468

PALEOFLOOD RESEARCH IN THE NORTHWESTERN UNITED STATES

Field studies were completed on the Grande Ronde River (Oregon), upper and lower John Day River (Oregon), Deschutes River (Oregon) and the Snake River (Oregon and Idaho). Reconnaissance field work was conducted on the Powder, Burnt and Malheur Rivers of central

Oregon, and the final results from these rivers will also be included in the final analysis and publications from this project.

John Day River

The paleoflood and flood-frequency study of the upper John Day River near Service Creek (Muleshoe site) in central Oregon was completed in Fall, 1998. This study was conducted by Shelly Orth for her Master's degree thesis under the supervision of Dr. Lisa Ely at Central Washington University. Results revealed evidence of 23 individual paleofloods which occurred during the past 2000 years. At least 8 of these floods occurred in the last 1630 years and are comparable in size or larger than the largest historic flood in 1964. Discharge estimates associated with individual paleofloods were calculated using the HEC-2 step-backwater method. The minimum discharge calculated for the highest flood deposit at the study site was 1150cms (40600cfs). By comparison, the largest historical flood of record on the John Day River, which is represented by an inset slackwater deposit, occurred in 1965 and had a discharge of 1138cms (40200cfs). Timing of paleofloods was determined from radiocarbon dating of organic material within the deposits (Table 2). Charcoal from the oldest deposit yielded a radiocarbon age of 1790 +/- 40 B.P., and several of the subsequent floods dated between 1800 and 1600 B.P. This conspicuous clustering of flood events indicates a discharge threshold which was exceeded only by a few extreme floods. The paleoflood data were incorporated into a revised statistical flood-frequency estimate for the John Day River using the U.S. Bureau of Reclamation model ***fldfrq3***. The 100-year flood estimate for this river based solely on the modern gauged data is 1170 cms, and it was lowered substantially to 910 cms when combined with the paleoflood data.

Paleoflood analyses are underway at another site on the lower John Day River near Cottonwood. Field work has been completed, and initial results from radiocarbon dates indicate a record of approximately 30 floods in the last 700 years. The results from this site will supplement the paleoflood record from the upper John Day River by filling in the temporal gap of the last 1000 years.

Grande Ronde River

Three sites of paleoflood deposits were described and dated on the Grande Ronde River in northeastern Oregon. Results indicate a record covering the last 8000 years on this river.

Deschutes River

Field studies and surveys have been completed at three major sites on the Deschutes River in central Oregon by Kurt Hosman as part of his Masters thesis project at Central Washington University. Eighteen samples were submitted for radiocarbon dates, revealing a flood chronology for this river that extends back at least 4000 years. The magnitude and frequency of floods on this river is of critical interest because of the dam relicensing that is presently underway just upstream of the study reach. Cross sections were surveyed in September, 1999 for use in the HEC-RAS modeling of the paleoflood discharges. This flood of record occurred on this river in 1996, and debris left by this flood provides a good reference stage for the paleofloods and a calibration for the discharge calculations. The majority of the paleofloods preserved in the record on the Deschutes River exceed the 1996 discharge. The timing and discharges of the paleofloods will be incorporated into the U.S. Bureau of Reclamation ***fldfrq3*** model to develop revised flood-frequency estimates for this river.

Table 2. Radiocarbon dates from the John Day River paleoflood study

Field Sample Number	Lab Sample Number	Stratigraphic Position	C13/C12 Ratio	Conventional C14 Age	Calibrated Results
MS-A90	DRI	Above Jetty		137 +/- 93 BP	
MS-A300	BETA 121039	Layer 3		1750+/-50 BP	
MS-A102	BETA 112093	Layer 6	-30.2 o/oo	1600 +/- 40 BP	cal AD 395 to 560
MS-A110	BETA 112094	Layer 8	-25.0 o/oo	1630 +/- 50 BP	cal AD 340 to 555
MS-A12	DRI	Layer 12		1675 +/- 60 BP	
MS-A16	DRI	Layer 16		1925 +/- 75 BP	
MS-A17	BETA 112092	Layer 17	-27.4 o/oo	1830 +/- 40 BP	cal AD 100 to 265 and cal AD 290 to 320
MS-B23	BETA 112095	Layer 23	-24.5 o/oo	1790 +/- 40 BP	cal AD 135 to 370

* BETA (BETA Analytic Radiocarbon Laboratory, Florida)
DRI (Desert Research Institute, Water Resource Center Radiocarbon Laboratory, Nevada)

Snake River

Field studies were conducted on the Snake River in western Idaho and eastern Oregon. Flood deposits along the Hell's Canyon reach of the Snake River indicate that at least six late-Holocene extreme floods with stages greater than 5m above bankfull stage have occurred on this section of the river in the last 3800 years.

Examination of slackwater sands and silts along river banks in bedrock canyons such as Hell's Canyon reveal a river's pre-historic record of extreme floods, and analysis of anomalous meso-and synoptic-scale climate activity has proven a useful tool in determining the meteorological cause of floods along rivers. These two methods of flood variability analysis were combined to infer the causes of floods that occurred over the last few thousand years on the Snake River, using the modern flood-climate relationship as an analogue of the climatic conditions associated with past floods.

PALEOFLOOD RESEARCH IN THE SOUTHWESTERN UNITED STATES

Much of the paleoflood research for the southwestern United States was already compiled by the authors before the beginning of this project and is being used for comparison with the new data from the other two hydroclimatic regions in the Northwest and Great Basin. We did collect additional data from the Bill Williams River in western Arizona, and the Verde River in central Arizona. Most paleoflood data from the Verde River was compiled in previous investigations and we only collected supplementary data in this project. More extensive work was performed on the Bill Williams River. Collection of stratigraphic and topographic data was completed on the Bill Williams River in a narrow gorge below Alamo Dam. In the study reach we examined a 6.5 meter thick accumulation of flood slackwater deposits immediately upstream from the constriction. Two samples from the base of the section yielded radiocarbon dates calibrating to about 1400-1520 AD. At this site, the upper 3 meters of flood deposits correspond to extremely large floods in the late 1800s and early 1900s. Hydraulic modeling of the study reach indicates that the magnitude of the floods associated with the slackwater deposits range from 45,000 cfs to 144,300 cfs.

HYDROCLIMATIC ANALYSIS

The flood hydroclimatic analysis of rivers in this study is currently underway. Discharge records have been collected from several rivers throughout the interior northwestern region. An attempt was made to include gauging station records on all rivers on which paleoflood analyses were being conducted, with the addition of other rivers in the region to gain geographically diverse coverage. The dates and magnitudes of floods with discharges greater than the 10-year recurrence interval discharge have been selected from each river for inclusion in the final hydroclimatic analysis. The data were being sorted be region, and the dates of these floods are being combined to create composite anomaly maps of atmospheric pressure and circulation patterns associated with large floods in each sub-region. These maps are begin created using an interactive WEB site run by the National Oceanographic and Atmospheric Administration (NOAA). Given a selection of specific dates, this program calculates the composite departure from mean atmospheric pressure on the combined dates of floods, using a historical data base of daily and monthly mean atmospheric pressure data across a northern-hemisphere grid. If all of the large floods within a region are associated with a similar large-scale atmospheric circulation pattern, then the composite anomaly map of atmospheric pressure for the dates of the floods indicates a single, strong pattern.

The Snake River in Hells Canyon Idaho is the first region for which a hydroclimatic analysis of the modern floods has been conducted, as part of the M.S. thesis by Gwendolyn Rhodes at Central Washington University. The results indicate that a similar large-scale atmospheric circulation anomaly is responsible for the majority of the floods that exceed the 10-year

recurrence interval discharge on this river. This pattern consists of an anomalous low-pressure system in the central-eastern Pacific that moves northeastward over the study area, and a high-pressure system that blocks the system from moving over the hydroclimatic region in the Southwestern U.S. This pattern is in sharp contrast to composite anomaly patterns for floods in the Southwestern U.S., in which the low-pressure system is much farther south along the coast of western California. Detailed examination and characterization of the differences in these circulation patterns is still underway. The results will be used to document the types of climatic conditions conducive to flooding in the different hydroclimatic regions, and will also be compared with the paleoclimatic conditions at the times of past floods in the different regions.

Follow-on Funding

"Comparison of Regional Flood Frequency Responses to Climatic Variability in the Western U.S. during the Late Holocene Using Modern, Historical, and Prehistoric Information." Collaborative Research Project between L.L. Ely, CWU and P.K. House UNR; NSF Hydrologic Sciences Program, Feb. 1, 1998-Jan. 31, 2001; $287,000.

Information Transfer Activities:

Many results from this research were presented at the Second International Paleoflood Conference and Field Trip which was held in Prescott, Arizona, September 27-October 1, 1999. This workshop was mentioned in the original proposal for this project as a major component of the Information Transfer Activities. It was convened by co-PI House and was attended by 34 science and engineering professionals. The conference field trip visited flood study sites on the Verde and Bill Williams Rivers. Presently, the proceedings from the conference are being compiled in a monograph to be published by the American Geophysical Union.

Abstracts, Publications and Theses published and in preparation

We anticipate that additional publications will result from this research as we continue to analyze the relevant data.

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