Project A: Tools for Climate-Informed Flood Mitigation: Integrating Flood Hydroclimatology and Paleodata into Flood Warning and Floodplain Management Applications

As projected global temperatures rise, increases in the intensity of heavy precipitation events and resulting flooding are deemed likely to occur in many areas in response to an intensified hydrologic cycle (Trenberth 1999, IPCC 2001). While some evidence of such increases has been detected in the observed record (e.g., Easterling et al 2000), identifying the explicit influence of climatic variability on local and regional flood frequencies is a complex problem and efforts to detect climate-driven trends in peak streamflow have been mixed (Lins and Slack 1999, IPCC 2001, Jain and Lall 2001, Douglas et al. 2000). At the same time, steady increases in flood *damage* have been observed in the United States and worldwide, a trend that is linked strongly to societal factors, although climate is an important contributor (Pielke and Downton 2000). Indeed, floods rank among the most costly and common natural hazards in the United States, typically causing more fatalities and damage than any other hydrometeorological phenomena (Mileti 1999; NOAA 2002, 2006.) In the Southwest, streams already subject to highly variable flow regimes also experience extreme floods in the form of local flash flooding and large-basin regional flooding accompanied by channel erosion, bank collapse, and/or floodplain inundation. Over the past 100+ years, Arizona has experienced multiple episodes of damaging floods and as rapid population growth and development push the urban-rural interface into ungauged areas, the risk of flood damage increases, even without the exacerbating influence of climate change. Flood hazard mitigation in Arizona, as in other states, is approached through a two-pronged effort aimed at *flood warning* and *floodplain management*. Although united by the common goal of preventing and ameliorating losses from flooding, in practice these two activities involve dramatically different time scales of operation, approach the concept of flood risk in different ways, and have a distinct perspective on the relevance of climate science for their practical operations. **Flood warning** is explicitly focused on *weather* (in combination with short-term antecedent climatic conditions) and involves an integrated multi-agency effort concentrated on rapidly developing hydrometeorological conditions in a watershed, operating in real time and near-real time (see Hartmann et al. 1999). The purpose of a flood warning is to mitigate flood risk by issuing guidance to people who may be immediately vulnerable to danger. Long-term climate information is typically not used in the flood warning operational environment (except to anticipate the snowmelt contribution in expected flooding.) **Floodplain management** on the other hand, reduces flood risk over a much broader time frame through procedures which identify and regulate floodprone areas in order to keep permanent structures out of the likely path of damaging floods of a given size (e.g., the 100-year flood, having a 1% chance of occurring in any given year). The 100-year "design" flood is determined through flood frequency analysis (FFA) of historical records of observed floods, thereby incorporating a climatic perspective indirectly, however, the underlying assumption of stationarity – specifically that individual flood values in a time series represent independent and identically distributed random variables (iid) – in effect assumes that climate's influence is invariant and that probabilities derived from a gauge record will be applicable to future conditions. While the stationarity / iid assumption has been challenged theoretically and empirically by flood and climate researchers on the basis of both land use and climate change (see Hirschboeck 1985, 2003a), in water management practice it has generally proved to be an efficacious and operationally robust assumption and some have argued that it should not be discarded, "at least not until the nonstationarity implied by the empirical evidence has been translated into operational terms of water management." (Matalas 1998, p 66). A recent national flood policy forum asked "is the 1% chance (100-year) flood standard sufficient?"[1] Of 46 short background papers, only one explicitly raised the possibility that climate variability and its "modes of behavior" should be considered as a source of nonstationarity when evaluating this flood frequency standard (see Hirsch et al. 2004). The more common view is that operational systems that are the most resilient in their ability to absorb stresses and limit economic losses are those for which the stationarity assumption has merit and these systems "need not be immediately modified to face the threat of climate change" (Matalas 1998, p 66). In the practical world of flood management operations it is therefore easy to understand the persistence of long-established procedures that assume, via stationarity, that climate's impact on a flood time series is time-invariant– despite the climate research community's sounding alarm over impending increases in heavy precipitation and floods. A qualified exception is seen among managers of large reservoirs who actively use long-range climate forecasts in decisions involving the timing of water releases for downstream flood management. Even so, the flood-management decisions in a reservoir operation are still made in a near-real time environment, albeit one extending from weeks to months in advance, hence there are few compelling reason to integrate IPCC-type future climate change scenarios (e.g., decreased snow cover or projected earlier snowmelt dates) into such decisions. The spatial and temporal scales associated with short-term, extreme rainfall-runoff flood events are not well-represented in such scenarios and downscaling has limitations when dealing with watershed-scale events driven by meteorological processes (see Hirschboeck 2003b). The problems and lack of action in integrating climate information and paleodata into flood management operations stands in stark contrast to the many ways in which water managers are now interacting with climate and tree-ring researchers to address drought mitigation, water supply assessment, and long-range planning of reservoir operations (see Project B below).

In light of the above, it is unclear if – or exactly how – integrated climate science might provide significant added value to flood risk management operations other than those related to reservoir releases. We propose to partner with flood risk management experts to explore the potential of climate science

[1] *Reducing Flood Losses: Is the 1% Chance (100-year) Flood standard Sufficient* , Background reading for the 2004 Assembly of the Gilbert F. White National Flood Policy Forum, Washington D.C. Sept 21-22 2004. 145 pp. http://www.floods.org/Foundation/Files/2004_Forum_BackgroundPapers.pdf

contributions toward the mitigation of flood risk in Arizona communities, including those regions where development is encroaching along the urban-rural interface. Our research will focus on the following questions: (1) In what ways might a changing climate affect flood risk (defined as the exposure to the probability of a damaging flood) as it is addressed *within the operational environments* of flood warning and floodplain management systems? (2) Can the introduction of a more explicit climatic perspective to flood mitigation operational environments aid in the identification of vulnerable places and people impacted by floods? and (3) Can the integration of climate science into flood risk management operations via transfer of knowledge and tools improve the resilience[2] of Arizona communities to flooding? To address these questions, two research initiatives are planned:

Flood Hydroclimatology Tools for The Arizona Flood Warming System. The Arizona Flood Warning System (AFWS) www.afws.org/ is a state-of-the-art interagency cooperative decision management and information system for the monitoring and display of real time hydrometerological data (Haffer 2006). The system is unique in that it includes information in one place for multiple hazards: floods, droughts, and seismic. Because an openness to the integration of climate information (via appropriate links for drought monitoring) is already part of the system, the AFWS provides an ideal platform for integrating climate science into the real-time flood warning operational process for which the system was developed. The system operates via an interactive GIS-based graphical interface that displays real-time streamflow and precipitation data for a detailed statewide network of stations and gauges operated by multiple agencies. Also, available are NOAA / NWS current weather conditions (text, satellite imagery, radar), daily and monthly climatology summaries, reservoir status, weather and runoff model forecasts, public warnings and advisories, and a communication system for notifications, discussions and posting of reports. As described, the system integrates "current data, future data, and products"[3] but at present there is no integration or display of long-term hydroclimatic data. Through one or more joint CLIMAS-AFWS Committee workshops, we will explore ways in which existing and newly constructed hydroclimate datasets based on past floods might be incorporated into the AFWS. Examples of the type of hydroclimatic information tools that could be added to the system include: (1) historical flood-hydroclimatology overviews for each watershed, (2) time-sequence maps of gauged discharge and precipitation leading up to historical peak flow events for comparison with flood events evolving in real time, (3) long-term records of hydroclimatically separated flood types (winter synoptic, summer convective, tropical storm) for statistical comparison with real time observations during storms of

[2] Resilience in the context of flood risk management has been defined as "the ability of the system to recover easily from floods" http://www.delftcluster.nl/web site/files/files_org/AIO/resilience%20in%20flood%20risk%20management.pdf

[3] See presentation by Tony Haffer for the 2006 Arizona Flood Warning System Symposium at: http://data.afws.org/docs/symposium_2006/AFWS_Feb2006_Haffer.pdf

different types (Hirschboeck 1987, 1988; Webb and Betancourt 1992), (4) synoptic circulation scenarios and teleconnection links for different floods types and historical flood episodes for comparison with evolving model forecasts, and (5) paleoflood-defined upper limits (envelope curves) of expected flood peaks for each watershed, derived from an Arizona Paleoflood Databank.[4] (House and Hirschboeck 1997). The applicability of each type of hydroclimatic tool will be assessed jointly by CLIMAS and an AFMS advisory subcommittee who will then work together to integrate selected tools into the system. Educational and training materials will be developed to accompany the new tools, and their utility will be evaluated through a survey of AFWS participants after flood events.

Integrating Climate Science into the "No Adverse Impact" Floodplain Management Perspective. Key floodplain management decisions "are made sequentially over time, especially after the occurrences of flooding." (Olsen et al. 2000. p 168). By building on the experience and stakeholder partnerships established during the AFWS Tools initiative obtained during real-time flood events, a follow-up CLIMAS initiative will address flood risk mitigation from the perspective of floodplain management. Our goal is to examine the applicability of hydroclimate information and paleodata as potential tools for reducing flood risk and increasing resilience in floodplain management operations. Motivated by increasing trends in flood losses despite decades of federal flood control efforts coupled with the National Flood Insurance Program, a new approach for floodplain management in the United States was recently proposed by the Association of State Floodplain Managers (ASFPM). Titled "No Adverse Impact" (NAI), the approach is explained and promulgated by the ASFPM on their web site www.floods.org/, which includes a "Toolkit for Common Sense Floodplain Management." The essence of the NAI approach is that "the action of one property owner or community [should] not adversely affect the flood risks for other properties or communities . . . unless the impact is mitigated as provided in a community- or watershed-based plan." (Larson and Plasencia 2001, p 171). Noting that existing policies and flood-control projects often encourage at-risk development or foster land use changes that transfer flood risk to other areas, NAI seeks to shift "the focus from the techniques and standards used for floodprone development to how adverse impacts resulting from those land use changes can be planned for and mitigated" (Larson and Plasencia 2001, p 167). Targeted directly at land use impacts on flooding, the NAI approach materials include scarcely any mention of the potential for future climate-related adverse impacts on the flood risk of communities or watersheds or how these might be mitigated.[5] A likely

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[4] The Arizona Paleoflood Databank is a growing repository of information that has been under development for several years as part of a larger Global Paleoflood Databank effort funded through various sources including: NOAA's OGP Paleoclimate Program, the US Bureau of Reclamation, and the UA's TRIF Water Sustainability Program http://www.uawater.arizona.edu/pubs/bulletins/Baker.pdf

[5] The possibility of adverse impacts for coastal communities due to projected global warming-induced sea level rise is mentioned in the *Toolkit for Common Sense Floodplain Management (p. 19)* http://www.floods.org/NoAdverseImpact/NAI_Toolkit_2003.pdf

reason for this omission is the complexity involved in separating out adverse impacts due to land use from adverse impacts due to climate-induced increases in flood magnitudes and/or frequencies. We propose to tackle this complexity by developing a blueprint for integrating climate science into the NAI vision for floodplain management. Our approach will use a watershed-centered, climate-based understanding of the observed distributions of flood peak time series (i.e., "flood hydroclimatology" – see Hirschboeck 1985, Webb and Betancourt 1992) to evaluate past and future probabilistic determinations of the 100-year flood at specific gauges. This understanding will be applied to scenarios of different modes of climatic behavior: such as circulation regime shifts, El Niño / La Niña episodes, and projected changes in the frequency of floods produced by different storm types (synoptic, convective, or tropical). To explore the transferability of this information into floodplain management practice and define ways in which adverse impacts due to climate can be separated from those due to land use, we will first address land use and urban encroachment into rural watersheds via interaction and information exchange with members of The Arizona Floodplain Management Association (AFMA, see azfma.org/) who are already playing a leading role in the NAI approach.[6] Then, through an integrated CLIMAS-stakeholder process that identifies and delineates vulnerabilities on floodplain maps due to changes in traditional NAI factors, we will develop a prototype for incorporating mapped information of estimated adverse impacts during different hydroclimatic scenarios. In tandem with this exercise, we will investigate how data from the Arizona Paleoflood Databank can be used jointly with systematically gauged and historical data to improve flood risk estimation and map floodprone areas for select Arizona watersheds (see House and Hirschboeck 1997, Redmond et al. 2002, Benito et al. 2004, Pelletier et al. 2005). The result will be community-based maps at the floodplain scale of potential and/or evolving flood vulnerability from a suite of adverse impacts ranging from specific types of land use to realistic variations in flood magnitude and frequency driven by explicitly defined modes of climate variability.

Both of these initiatives provide important bridges between current hydrometerological approaches to flood mitigation and a new hydroclimatic approach that more explicitly integrates the added value of climate science information and tools into current flood warning and floodplain management operations. We believe that these initiatives could evolve into the nation's first example of *systematic* integration of long-term climate information into flood risk operations and management. The foundations for the necessary CLIMAS-stakeholder interactions proposed have already been established with the NWS, USGS, USBR, SRP (who hosts the Arizona Flood Warning System platform), and potential collaborators in Arizona flood control districts, along with their affiliated floodplain management associations (AFMA and AFPMA).

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[6] Maricopa County is featured on the ASFPM web site as a community that exemplifies NAI planning: www.floods.org/PDF/NAI_Case_Studies.pdf

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