The seasonal hydrologic regime of the Willamette River basin in Western Oregon is characterized by winter peaks and summer low flows. Low summer streamflows, in particular, place both aquatic ecosystems and human water demands at risk to changes imposed by either land use or climatic fluctuations. Our studies of the correspondence between geological setting and flow regimes demonstrate that this risk is not uniformly distributed across the landscape. Most of the available water in this region is sourced in the Cascade Mountain range, which includes two distinct volcanic provinces, the High and Western Cascades, which differ in terms of the age and degree of dissection of the landscape. Using empirical analysis of streamflow and temperature variation, we demonstrate how this geologic/geomorphic framework can provide a basis for characterizing and predicting summer baseflow, recession behavior, and timing of response to winter recharge, as well as stream temperature at multiple scales for tributaries of the Willamette River. This analysis illustrates how geologic distinctions between the High and Western Cascades have critical implications for interpreting hydrologic flowpaths mechanisms and modeling the sensitivity of this region to environmental change.

H42I-07 1515h

Integrating spatial watershed and runoff (quantity and quality) data to map and quantify the dominate sources of watershed runoff

Ed Beighley[1] (805-452-0762; beighley@icess.ucsb.edu)

Al Leydecker[1] (al@icess.ucsb.edu)

Tom Dunne[1] (tdunne@bren.ucsb.edu)

John M Melack[1] (melack@lifesci.ucsb.edu)

[1]Donald Bren School of Environmental Science and Management, University of California, Santa Barbara, CA 93106, United States

Basin landscapes possess an identifiable spatial structure, fashioned by climate, geology and land use, that affects their hydrologic response. This structure defines a basin's pattern of runoff and stream chemistry, its hydrogeological signature. In southern California, coastal watersheds are commonly separated into two geologic regions: mountainous uplands with steep, permeable soils over shallow bedrock and mild sloping coastal plains with deeper soils and debris deposits. The region is characterized as having a Mediterranean climate providing long dry periods and a brief winter (Dec-Mar) rainy season with short duration, intense rainfall. Using commonly available GIS data and measured rainfall and runoff data, we present a new approach for interpreting a basin's hydrogeological signature to identify the spatial distribution of dominant runoff mechanisms and pathways. Using spatially distributed high temporal resolution stream (quantity and quality) data, we verify our inferred distribution of runoff sources and quantify their relative importance at the watershed outlet. The benefit of our research is an integrated spatial representation of runoff quantity and pathways, which is useful for interpreting functions of runoff in the recruitment and transport of sediment and other contaminants. Our hydrogeological interpretation method also provides a quantitative approach for partitioning watersheds into similar hydrologic response units appropriate for hydrologic modeling. Our methods are illustrated in a case study focused on two watersheds (24 and 30 km2) draining the southern coast of California for water years 2002 and 2003. Based on our hydrogeological interpretation, we partition streamflow into both surface and subsurface runoff, where surface runoff is from either urban or rural surfaces and subsurface runoff is either interflow from steep shallow soils or groundwater from bedrock and coarse-textured fan deposits.

URL: http://sbc.lternet.edu/

H42J MCC: 3022 Thursday 1340h

Extreme Event Geomorphology II

(joint with T, C, NG)

Presiding: **K X Whipple,** Massachusetts Institute of Technology; **B D Malamud,** Kings College London

H42J-01 1340h

Lessons From the Largest Historic Floods Documented by the U.S. Geological Survey

John E. Costa (503-251-3290; jecosta@usgs.gov)

A recent controversy over the flood risk downstream from a USGS streamgaging station in southern California that recorded a large debris flow led to the decision to closely examine a sample of the largest floods documented in the US. Twenty-nine floods that define the envelope curve of the largest rainfall-runoff floods were examined in detail, including field visits. These floods have a profound impact on local, regional, and national interpretations of potential peak discharges and flood risk. These 29 floods occured throughout the US from the northern Chesapeake Bay in Maryland to Kauai, Hawaii, and over time from 1935-1978. Methods used to compute peak discharges were slope-area (21/29), culvert computations (2/29), measurements lost or not available for study (2/29), bridge contraction, culvert flow, and flow over road (1/29), rating curve extension (1/29), current meter measurement (1/29), and rating curve and current meter measurement (1/29). While field methods and tools have improved significantly over the last 70 years (e.g. total stations, GPS, GIS, hydroacoustics, digital plotters and computer programs like SAC and CAP), the primary methods of hydraulic analysis for indirect measurements of outstanding floods has not changed: today flow is still assumed to be 1-D and gradually varied. Unsteady or multi-dimensional flow models are rarely if ever used to determine peak discharges. Problems identified in this sample of 29 floods include debris flows misidentified as water floods, small drainage areas determined from small-scale maps and mislocated sites, high-water marks set by transient hydraulic phenomena, possibility of disconnected flow surfaces, scour assumptions in sand channels, poor site selection, incorrect approach angle for road overflow, and missing or lost records. Each published flood magnitude was checked by applying modern computer models with original field data, or by re-calculating computations. Four of 29 floods in this sample were found to have errors resulting in a change of the peak discharge of more than 10%.

H42J-02 1355h

Determination of Flood Discharges in Rivers as a Prerequisite for Calculating Rates of Geomorphic Change in Drainage Basins During Extreme Events

J. Dungan Smith[1] (303-541-3004; jdsmith@usgs.gov)

Jason W. Kean[2] (303-541-3041; jason.kean@colorado.edu)

[1]U.S. Geological Survey, 3215 Marine St. Suite E127, Boulder, CO 80303, United States

[2]University of Colorado, Campus Box 216, Boulder, CO 80309, United States

Accurate empirical determination of river discharge during an extreme event is very difficult even at a gage site. Moreover, the procurement of extreme flow measurements at many locations in an ungaged drainage basin often is necessary to relate the surface-water flow in the drainage network during a flood to the spatial distribution of intense rainfall. Consequently, paleohydrologic methods have to be employed to estimate peak discharges. These methods, however, require the application of some type of flow model. Often the flow models used with paleo-hydrologic data are over simplified and embody low-flow or extrapolated roughness coefficients that are inappropriate for the high flow of interest and that substantially reduce the reliability of the estimated discharge. Models that permit calculation of flow resistance from measured or calculated pre-flood, post-flood, or evolving channel and floodplain geometries and roughnesses can yield the most accurate results for these extreme situations. We have developed a procedure for directly calculating flow discharge as a function of stage in reaches a few tens of river widths in length. The foundation for this approach is a set of algorithms that permits computation of the form drag on topographic elements and woody vegetation. Its application requires an initial survey of the channel and floodplain topography and roughness. The method can be used either with stage determined from a set of pressure gages distributed throughout a drainage basin to monitor discharge in a drainage network or with paleo-hydrologic data to determine discharge from extreme events. Currently, our method of determining discharge from stage is being tested at various sites in the drainage basin of the Whitewater River, Kansas. Two of these sites are just downstream of USGS gages, and a third is a short distance downstream from the outlet pipe of a man-made lake. These tests are for a full range of hydrologic conditions in order to demonstrate that the model-based method for converting stage to discharge can be employed with confidence (1) in ungaged drainage basins where a large number of discharge measurements are required for hydrologic research, (2) at locations where rated USGS stage gages are too expensive, (3) near the sites of USGS stage gages for floods during which the discharge exceeds those for which the gage has been rated, and (4) for situations where paleo-flood methods have to be used to obtain a peak discharge. Model calculated rating curves are compared to measured ones for one of the USGS gage sites. Model calculations also are used to show that Manning's and other friction coefficients are functions of stage at this site. An approach such as the one described here is essential for the quantitative investigation of fluvial geomorphic processes caused by very large floods.

H42J-03 1410h

Landslides, Earthquakes, and Erosion

Bruce D Malamud[1] (bruce@malamud.com)

Donald L Turcotte[2] (turcotte@geology.ucdavis.edu)

Fausto Guzzetti[3] (fausto.guzzetti@irpi.cnr.it)

Paola Reichenbach[3] (paola.reichenbach@irpi.cnr.it)

[1]Environmental Monitoring and Modeling Research Group, Dept of Geography, King's College London, Strand, London WC2R 2LS, United Kingdom

[2]Department of Geology, University of California at Davis, One Shields Avenue, Davis, CA 95616, United States

[3]CNR-IRPI Perugia, via della Madonna Alta 126, Perugia 06128, Italy

In this paper, we quantify the role of landslides in erosion and in particular, the role of earthquakes to landslides to erosion. A landslide event consists of single to tens of thousands of landslides associated with a trigger, such as an earthquake, sudden snowmelt, or extended precipitation. We have previously introduced a general landslide distribution for landslide events and also a corresponding landslide-event magnitude scale, $M_L = \log(N_{LT})$, with N_{LT} the total number of landslides associated with the landslide event. The magnitude m_L can be determined from both substantially complete' inventories and partial inventories of the largest landslides in the event. Equivalent magnitude values can also be obtained for historical landslide inventories, which represent the sum of many landslide events over periods of one to many thousands of years or more. We believe that our landslide distribution does a rough quantification of the total area (and volume) of landslides that occur for landslide events of different magnitudes, and use this distribution to relate our landslide magnitude to total landslide volume. Using estimated recurrence intervals for three landslide event inventories, we have inferred regional erosion rates due to landslides for the Northridge earthquake-triggered, Umbria (Italy) snowmelt-triggered, and Guatemala heavy-rain triggered events, as 0.1, 0.4, and 2.5 mm yr^{-1}, respectively. Comparing historical inventories to our general landslide event distribution, we have made extrapolations and estimated total landslide volumes associated with two historical inventories in Italy and Japan. Using estimates for time intervals over which these historical landslides accumulated, the associated long-term erosion rates were found to be 1.0 mm yr^{-1} in Umbria, Italy and 2.2 mm yr^{-1} in Japan. We then use an empirical relationship between total landslide volume and earthquake magnitude to determine analytic relationships between earthquake magnitude and the associated landslide event magnitude, area and volume of the largest landslide triggered, and total area of all landslides triggered. Using the Gutenberg–Richter frequency-magnitude relation for regional seismicity, we analytically relate the seismically-induced erosion rate to the regional seismic intensity and the moment magnitude of the largest regional earthquake. We find that typical seismically-induced erosion rates in very active subduction zones is ≈ 0.2–2 mm yr^{-1} and adjacent to plate boundary strike-slip zones ≈ 0.01–0.2 mm yr^{-1}.

H42J-04 1425h

Runoff Variability and Erosional Landscape Evolution: Insights from Numerical Modeling

Dimitri Lague[1] (dlag02@esc.cam.ac.uk)

Philippe Davy[2] (philippe.davy@univ-rennes1.fr)

Niels Hovius[1] (nhovius@esc.cam.ac.uk)

[1]Dpt of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, United Kingdom

[2]Geosciences Rennes, UMR 6118 CNRS, Campus de Beaulieu, Rennes 35042, France

Fluvial incision and sediment transport are driven by variable precipitation, with a common emphasis on rare, large events. The frequency of such events has changed with climate. Records of past runoff and its variability, and associated landscape evolution are scarce, and do rarely permit evaluation of the geomorphic importance of extreme events. This problem can be addressed from a theoretical point of view. Recent studies have shown that in the case of a mechanical threshold for particle detachment and transport, increasing runoff variability gives rise to elevated incision and sediment transport rates, even when the intensity of geomorphic processes depends less than linearly

on runoff. Thresholds are a fundamental characteristic of many geomorphic processes. We have studied the effects of runoff variability and changes in runoff variability on incision and sediment transport, and the geomorphic response time, using a numerical surface process model (EROS). This model pairs a stochastic magnitude-frequency distribution of runoff events with deterministic erosion and transport formulations. Computationally inexpensive, the stochastic runoff distribution provides a good description of daily discharge datasets. It can be tuned for various watersheds. Incision and transport laws were calibrated to predict realistic steady-state slope-area relationships. Given the uncertainties on the descriptions of erosion and sediment transport in natural systems, we have explored different cases thought to be characteristic of bedrock or alluvial rivers. Our results imply that the response time of alluvial rivers is more sensitive to change in runoff distribution (mean and variability) than bedrock rivers. In particular, bedrock river response time diminishes as the inverse square root of the mean runoff rate, and decreases with runoff variability, when a mechanical threshold exists. In the case of very variable runoff, alluvial rivers can enter a regime where the mean long-term sediment flux is completely governed by the largest runoff event. This regime is not found for bedrock rivers where each erosive event contributes to the long-term incision rate. This is consistent with field observations of bedrock incision in Taiwan.

H42J-05 1440h

Scaling and pattern of extreme geomorphic events in a mountain basin, Idaho, USA

Charles H Luce[1] (208-373-4382; cluce@fs.fed.us)

Bruce E Rieman[1] (208-373-43; brieman@fs.fed.us)

James A McKean[1] (208-373-4383; jmckean@fs.fed.us)

Jason B Dunham[1] (208-373-4380; @fs.fed.us)

John G King[1] (208-373-4384; jgking@fs.fed.us)

[1]USDA Forest Service, Rocky Mountain Research Station, 316 E. Myrtle St., Boise, ID 83716, United States

While extreme events are rare in individual streams or stream reaches, the occurrence of an extreme event somewhere within an ensemble of streams can be commonplace. The relationship between event frequency and magnitude for large units of analysis depends on the size of area considered and the spatial continuity of events. Some of the more extreme geomorphic events affect only a limited spatial area. Limitations to area relate to spatial extents of event triggers such as fires, thunderstorms, or rain-on-snow. Understanding the size of extreme events is important in approaching the frequency-magnitude relationships for larger analysis frames and clarifying the role of extreme events at different spatial scales. Sequential mapping of channel reorganizing events from aerial photography records dating back 40 years in the Boise River basin reveal important characteristics of severe disturbances in a spatial context. The most relevant to this discussion is that there is little coherence in extreme events beyond 10 km. Patterns of occurrence for fishes occupying these streams may reflect historic patterns of extinction and colonization following catastrophic disturbance. These patterns and recent data on apparent gene flow among streams suggest that scaling of ecological processes is concordant with the patterns of channel disturbance we have identified here. There is evidence that this scale relates more to the scale of driving storm events than to pre-existing land disturbances such as fire, logging, or grazing. One puzzle is that some areas seem more prone to multiple events than others, which may relate to underlying variation in lithology and exposure to weather. Lithology also constrains the temporal signature of extreme events. The spatial extent of events may serve as a valuable metric of event magnitude to gauge their ecological influence.

URL: http://www.fs.fed.us/rm/boise/

H42J-06 1455h

Extreme events and geomorphic resilience-insight from response to the cataclysmic 1980 Mount St. Helens eruption

Jon J. Major (360-993-8927; jjmajor@usgs.gov)

USGS, 1300 SE Cardinal Court, Vancouver, WA 98683, United States

Extreme geomorphic events affect sediment transfer, landform development, and landscape evolution in mountain environments. Less understood are the magnitude and persistence of geomorphic responses to extreme events and the impacts those events have on various geomorphic regimes. Generally, states of geomorphic disequilibrium caused by extreme as well as by lesser events are transient. Periods of geomorphic response to extreme events, however, can range from years to millennia; defining recovery and resilience of geomorphic systems, and thus the long-term impact of an extreme event, depends upon spatial scale and the geomorphic regime (e.g., sediment transport, water discharge, or their associated relationship) examined. Varying geomorphic-regime responses are highlighted by post-eruption responses to the 1980 Mount St. Helens (MSH) eruption. The cataclysmic 1980 MSH eruption altered runoff and abruptly increased sediment supply in several watersheds. In basins ranging in area from 300-1300 km^2, post-eruption peakflow discharges increased by tens of percent for at least 5, and perhaps as long as 20, years. Post-eruption infiltration capacity quickly recovered a substantial proportion of pre-eruption capacity, predominant overland flow diminished rapidly, and runoff conditions approached a pre-eruption state. In comparison, post-eruption suspended-sediment yields increased by a much greater proportion, and have persisted much longer, than increased water discharges. Annual yields as much as 500 times greater than pre-eruption values were measured shortly after the eruption, and yields 10-100 times greater than pre-eruption values persist. Magnitudes and durations of post-eruption sediment delivery have varied chiefly with the nature of volcanic impact. Extraordinary suspended-sediment delivery has been greater and more persistent from zones of channel disturbance than from zones of hillslope disturbance. A classical observation in many "undisturbed" watersheds that moderate discharges do the most work moving sediment also holds true for the MSH basins so dramatically affected by volcanism. Moderate-magnitude discharges (those greater than the mean annual flows but less than 2-year floods) have transported 60% to about 90% of the suspended sediment redistributed during 20 years of post-eruption landscape adjustment. Post-eruption geomorphic responses at MSH suggest that lasting impacts of extreme events are reflected characteristically by long-term sediment delivery from watersheds. Extreme events do not fundamentally alter geomorphic processes or effective-discharge relations; perturbations in runoff and water discharge typically dissipate within several years. Recovery from and resilience to extreme events are therefore defined best by examining locations and magnitudes of long-term sediment transport.

H42J-07 1510h

Network Disturbance Theory: Spatial and Temporal Organization of Physical Heterogeneity in Rivers

Lee Benda[1] (530 926-1066; leebenda@aol.com); LeRoy Poff[2] (970 491-2079; poff@lamar.colostate.edu); Daniel Miller[1] (206 633-1792; danmiller@earthsystems.net); Tom Dunne[3] (805 893-7557; tdunne@bren.ucsb.edu); Gordon Reeves[4] (541 750-7314; greeves@fs.fed.us); George Pess[5] (206 860-3450; George.Pess@noaa.gov); Michael Pollock[5] (206 860-3450; Michael.Pollock@noaa.gov)

[1]Earth Systems Institute, 3040 NW 57th St., Seattle, WA 98107, United States

[2]Department of Biology, Colorado State University, Fort Collins, CO 80523, United States

[3]Donald Bren School of Environmental Science and Management, 3510 Bren Hall University of California, Santa Barbara, CA 93106, United States

[4]U. S. F. S./Forest Sciences Lab, 3200 Jefferson Way, Corvallis, OR 97331, United States

[5]National Marine Fisheries Service, 2725 Montlake Blvd East, Seattle, WA 98112, United States

Beginning with the premise that extreme events, or "disturbances" in the parlance of ecologists (i.e., storms, fires, floods, and punctuated erosion and sediment transport), are intrinsic to many landscapes and river systems across the world, we develop new theory on the interaction between disturbances and branching river networks. The interaction of disturbances with network geometry is central to the question of how habitat heterogeneity forms within riverine corridors, a principle underlying the emerging ecosystem concept of "riverscapes". We explore that interaction by examining how tributary confluences interrupt gradual downstream changes in channel morphology leading to locally increased physical heterogeneity. Punctuated erosion during storms and following fires and episodic floods leads to discontinuous inputs of water, sediment, and organic material at confluences that modify channel and valley-floor morphology for tens of meters to kilometers, including substrate sizes, channel hydraulic geometry, floodplain widths, fans, terraces, and log jams. Based on 14 studies that documented these confluence effects at 168 junctions spanning 6 orders of magnitude in drainage area, it appears that the probability of confluence effects increases with increasing size ratio of tributary to mainstem river. This simple scaling relationship indicates that the downstream increase in tributary basin size found in many watersheds results in a downstream increase in the spacing between confluences that have morphological effects, identifying a control on the spatial scale of confluence-related heterogeneity in rivers. Therefore, when a river network is viewed as a population of tributaries and confluences, the extent to which a network interrupts downstream continua of physical and biological processes (and the degree of habitat heterogeneity) should depend on network geometry, basin shape, drainage density, and basin size. For example, oval-shaped basins (containing dendritic networks) should favor confluence effects and therefore increased heterogeneity while rectilinear basins (containing trellis networks) should not. Moreover, basins with higher drainage (and junction) density should lead to a higher degree of network-generated morphological heterogeneity. The frequency and magnitude of floods and accelerated sediment supply that maintain confluence effects - in probability distributions containing extreme events - should also scale with basin size, leading to an age distribution of confluence-related landforms (i.e., fans, terraces, bars) that is predicted to be dominated by older features in headwaters. Additionally, the age distribution of confluence-related features should become younger with increasing distance downstream. These new theoretical insights yield testable hypotheses that should motivate and support studies on the role of extreme events, or disturbances, in river systems.

H42J-08 1525h

Extreme events and alluvial-fan flood hazards: An assessment using hydrological modeling, field mapping, and remote sensing in Arizona

Jon D Pelletier[1] (jon@geo.arizona.edu)

Philip A Pearthree[2] (phil.pearthree@azgs.az.gov)

Larry Mayer[1] (lmayer@geo.arizona.edu)

[1]Geosciences Dept., University of Arizona, 1040 E. Fourth St., Tucson, AZ 85721, United States

[2]Arizona Geological Survey, 416 W. Congress St., Tucson, AZ 85701, United States

Alluvial fans pose a significant challenge to flood-hazard assessment because of their complex and dynamic topography. The complexity of fan topography renders many standard flood-routing methods inapplicable. As a result, there is currently no widely-used analytical method for predicting flood-inundation extents on alluvial fans. To fill this gap, we propose and test a new flood-hazard methodology based on a 2D hydrological model capable of modeling flows over complex topography. The model solves the continuity equation and Manning's equation simultaneously using an implicit numerical method. A high-resolution DEM and peak flood stage are required inputs. The model can be used to reconstruct inundation extents and flow regimes of historical floods for comparison with field- and satellite-based flood-inundation maps or to predict the inundation extents for a range of peak discharges in order to construct a probability-of-inundation map. This map can then be compared with a surficial-geologic map to determine flood-prone areas. To test the accuracy of the model for reconstructing historical floods, we compared model predictions for inundation extent against field- and satellite-based flood-inundation maps for two extreme historical floods on the southern Tortolita and Harquahala piedmonts in Arizona. Predicted inundation extents match field- and satellite-based maps for the Tortolita and Harquahala floods by 83% and 86%, respectively. Probability-of-inundation maps predict a spatially-complex flood hazard that strongly reflects small-scale topography and surficial geology. These results provide further evidence that alluvial-fan flood hazards are not well resolved and generally overpredicted in FEMA Flood Insurance Rate Maps (FIRMs). The hydrological model is particularly useful for identifying the thresholds in input flood stage required to "activate" flood hazards on different segments of the fan. The model also enables the impact of extreme events on the flood hazard to be assessed. In some areas, uncertainty in the probability of extreme events does not greatly impact flood hazards because incised channels convey all of the flow within a broad range of extreme flood sizes.